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# Technical Aptitude

# ELECTROMAGNETIC THEORY

**Electromagnetic theory** is a discipline concerned with the study of charges at rest and in motion. Electromagnetic principles are fundamental to the study of electrical engineering and physics. Electromagnetic theory is also indispensable to the understanding, analysis and design of various electrical, electromechanical and electronic systems. Some of the branches of study where electromagnetic principles find application are:

RF communication
Microwave Engineering
Antennas
Electrical Machines
Satellite Communication
Atomic and nuclear research
Radar Technology
Remote sensing
EMI EMC
Quantum Electronics
VLSI

Electromagnetic theory is a prerequisite for a wide spectrum of studies in the field of Electrical Sciences and Physics. Electromagnetic theory can be thought of as generalization of circuit theory. There are certain situations that can be handled exclusively in terms of field theory. In electromagnetic theory, the quantities involved can be categorized as **source quantities** and **field quantities**. Source of electromagnetic field is electric charges: either at rest or in motion. However an electromagnetic field may cause a redistribution of charges that in turn change the field and hence the separation of cause and effect is not always visible.

Electric charge is a fundamental property of matter. Charge exist only in positive or negative integral multiple of **electronic charge**, -e, $e = 1.60 \times 10^{-19}$ coulombs. [It may be noted here that in 1962, Murray Gell-Mann hypothesized **Quarks** as the basic building blocks of matters. Quarks were predicted to carry a fraction of electronic charge and the existence of Quarks have been experimentally verified.] Principle of conservation of charge states that the total charge (algebraic sum of positive and negative charges) of an isolated system remains unchanged, though the charges may redistribute under the influence of electric field. Kirchhoff's Current Law (**KCL**) is an assertion of the conservative property of charges under the implicit assumption that there is no accumulation of charge at the junction.

Electromagnetic theory deals directly with the electric and magnetic field vectors where as circuit theory deals with the voltages and currents. Voltages and currents are integrated effects of electric and magnetic fields respectively. Electromagnetic field problems involve three space variables along with the time variable and hence the solution tends to become correspondingly complex. Vector analysis is a mathematical tool with which electromagnetic concepts are more conveniently expressed and best comprehended. Since use of vector analysis in the study of electromagnetic field theory results in real economy of time and thought, we first introduce the concept of vector analysis.

### 2. Vector Analysis

The quantities that we deal in electromagnetic theory may be either **scalar** or **vectors** [There are other class of physical quantities called **Tensors**: scalars and vectors are special cases]. Scalars are quantities characterized by magnitude only and algebraic sign. A quantity that has direction as well as magnitude is called a vector. Both scalar and vector quantities are function of *time* and *position*. A field is a function that specifies a particular quantity everywhere in a region. Depending upon the nature of the quantity under consideration, the field may be a vector or a scalar field. Example of scalar field is the electric potential in a region while electric or magnetic fields at any point is the example of vector field.

**Fundamentals Vector Algebra:**

A vector is represented by a directed line segment: length of the line is proportional to magnitude and the orientation of the directed line segment with respect to some reference gives the vector.

A vector $\vec{A}$ can be written as $\vec{A} = \hat{a}A$, where $A = \left|\vec{A}\right|$ is the magnitude and $\hat{a} = \frac{\vec{A}}{|A|}$ is the unit vector which has unit magnitude and direction same as that of $\vec{A}$.

Two vectors $\vec{A}$ and $\vec{B}$ are added together to give another vector $\vec{C}$. We have:

$$\vec{C} = \vec{A} + \vec{B}$$

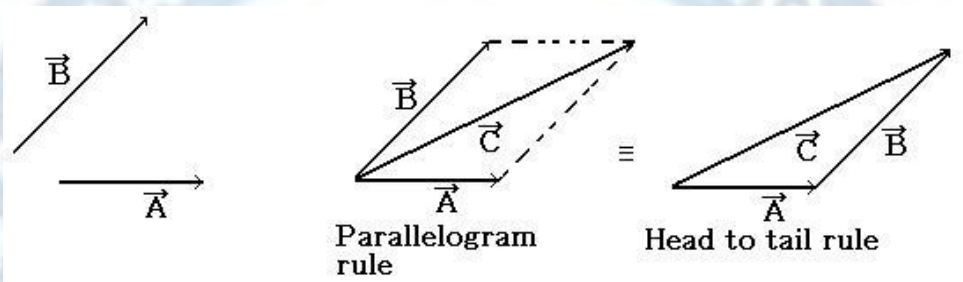



Figure 1: Vector addition

Vector subtraction is similarly carried out as:

$$\vec{D} = \vec{A} - \vec{B} = \vec{A} + (-\vec{B})$$

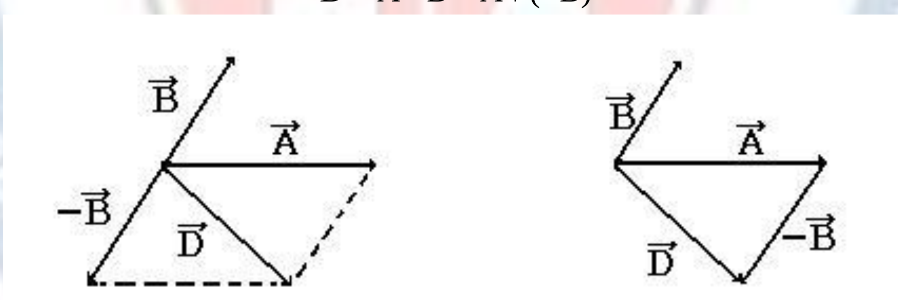



Figure 2: Vector subtraction

Scaling of a vector is defined as $\vec{C} = \alpha\vec{B}$, where $\vec{C}$ is a scaled version of vector $\vec{B}$ and $\alpha$ is a scalar.

Some important laws of vector algebra are:

| | |
|---|---|
| $\vec{A} + \vec{B} = \vec{B} + \vec{A}$ | Commutative law |
| $\vec{A} + (\vec{B} + \vec{C}) = (\vec{A} + \vec{B}) + \vec{C}$ | Associative law |
| $\alpha(\vec{A} + \vec{B}) = \alpha\vec{A} + \alpha\vec{B}$ | Distributive law |

The position vector $\vec{r}_P$ of a point $P$ is the directed distance from the origin ($O$) to $P$ i.e. $\vec{r}_P = \overrightarrow{OP}$.

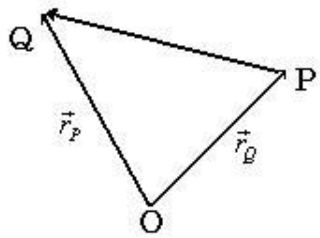



Figure 3: Distant vector

If $\vec{r}_P = \overrightarrow{OP}$ and $\vec{r}_Q = \overrightarrow{OQ}$ are the position vectors of the points $P$ and $Q$ then the distance vector $\overrightarrow{PQ} = \overrightarrow{OQ} - \overrightarrow{OP} = \vec{r}_Q - \vec{r}_P$

## Product of Vectors

When two vectors $\vec{A}$ and $\vec{B}$ are multiplied, the result is either a scalar or a vector depending how the two vectors were multiplied. The two types of vector multiplication are:

Scalar product (or dot product) $\vec{A} \cdot \vec{B}$ gives a scalar
Vector product (or cross product) $\vec{A} \times \vec{B}$ gives a vector

The dot product between two vectors is defined as $\vec{A} \cdot \vec{B} = AB\cos\theta_{AB}$.

Figure: Dot product

The dot product is commutative i.e. $\vec{A} \cdot \vec{B} = \vec{B} \cdot \vec{A}$ and distributive i.e. $\vec{A} \cdot (\vec{B} + \vec{C}) = \vec{A} \cdot \vec{B} + \vec{A} \cdot \vec{C}$. Associative law does not apply to scalar product.

The vector or cross product of two vectors $\vec{A}$ and $\vec{B}$ is denoted by $\vec{A} \times \vec{B}$. $\vec{A} \times \vec{B}$ is a vector perpendicular to the plane containing $\vec{A}$ and $\vec{B}$, the magnitude is given by $ABSin\theta_{AB}$ and direction is given by right hand rule as explained in Figure.

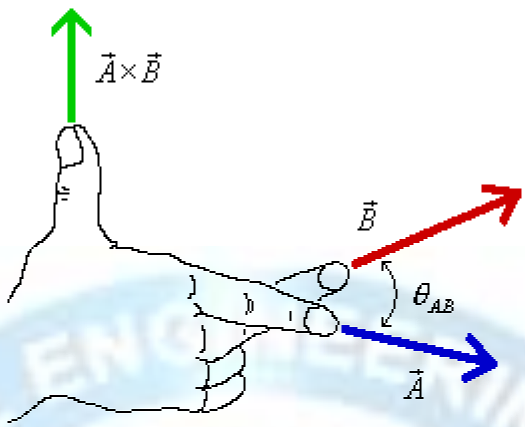



Figure: Vector cross product

$\vec{A}\times\vec{B} = \hat{a}_n ABSin\theta_{AB}$, where $\hat{a}_n$ is the unit vector given by

$$\hat{a}_n = \frac{\vec{A}\times\vec{B}}{\left|\vec{A}\times\vec{B}\right|}$$

The following relations hold for vector product.

$\vec{A}\times\vec{B} = -\vec{B}\times\vec{A}$ i.e. cross product is non commutative

$\vec{A}\times(\vec{B}+\vec{C}) = \vec{A}\times\vec{B}+\vec{A}\times\vec{C}$ i.e. cross product is distributive

$\vec{A}\times(\vec{B}\times\vec{C}) \neq (\vec{A}\times\vec{B})\times\vec{C}$ i.e. cross product is non associative

**Scalar and vector triple product**

Scalar triple product $\vec{A}\cdot(\vec{B}\times\vec{C}) = \vec{B}\cdot(\vec{C}\times\vec{A}) = \vec{C}\cdot(\vec{A}\times\vec{B})$

Vector triple product $\vec{A}\times(\vec{B}\times\vec{C}) = \vec{B}(\vec{A}\cdot\vec{C}) - \vec{C}(\vec{A}\cdot\vec{B})$

## 3. COORDINATE SYSTEMS

In order to describe the spatial variations of the quantities, we require using appropriate co-ordinate system. A point or vector can be represented in a **curvilinear** coordinate system that may be **orthogonal** or **non-orthogonal**. An orthogonal system is one in which the co-ordinates are mutually perpendicular. Non-orthogonal co-ordinate systems are also possible, but their usage is very limited in practice.

Let $u$ =constant, $v$ =constant and $w$ =constant represent surfaces in a co-ordinate system, the surfaces may be curved surfaces in general. Further, let $\hat{a}_u$ , $\hat{a}_v$ and $\hat{a}_w$ be the unit vectors in the three co-ordinate directions (base vectors). In a general right-handed orthogonal curvilinear system, the vectors satisfy the following relations.

$$\hat{a}_u \times \hat{a}_v = \hat{a}_w$$
$$\hat{a}_v \times \hat{a}_w = \hat{a}_u$$
$$\hat{a}_w \times \hat{a}_u = \hat{a}_v$$

These equations are not independent and specification of one will automatically imply the other two.

Furthermore, the following relations hold

$$\hat{a}_u.\hat{a}_v = \hat{a}_v.\hat{a}_w = \hat{a}_w.\hat{a}_u = 0$$
$$\hat{a}_u.\hat{a}_u = \hat{a}_v.\hat{a}_v = \hat{a}_w.\hat{a}_w = 1$$

A vector can be represented as sum of its orthogonal components

$$\vec{A} = A_u\hat{a}_u + A_v\hat{a}_v + A_w\hat{a}_w$$

In general $u$ , $v$ and $w$ may not represent length. We multiply $u$ , $v$ and $w$ by conversion factors $h_1$ , $h_2$ and $h_3$ respectively to convert differential changes $du$ , $dv$ and $dw$ to corresponding changes in length $dl_1$ , $dl_2$ and $dl_3$ . Therefore

$$\begin{aligned} d\vec{l} &= \hat{a}_u dl_1 + \hat{a}_v dl_2 + \hat{a}_w dl_3 \\ &= h_1 du\hat{a}_u + h_2 dv\hat{a}_v + h_3 dw\hat{a}_w \end{aligned}$$

In the same manner, differential volume $dv$ can be written as $dv = h_1h_2h_3dudvdw$ and differential area $ds_1$ normal to $\hat{a}_u$ is given by $ds_1 = dl_2dl_3 = h_2h_3dvdw$ and $d\vec{s}_1 = h_2h_3dvdw\hat{a}_u$ . In the same manner, differential areas normal to unit vectors $\hat{a}_v$ and $\hat{a}_w$ can be defined.

In the following sections we discuss three most commonly used orthogonal co-ordinate systems, viz:

1. Cartesian (or rectangular) co-ordinate system
2. Cylindrical co-ordinate system
3. Spherical polar co-ordinate system

**Cartesian Co-ordinate System**

In Cartesian co-ordinate system, we have, $(u, v, w) = (x, y, z)$. A point $P(x_0, y_0, z_0)$ in Cartesian co-ordinate system is represented as intersection of three planes $x = x_0$, $y = y_0$ and $z = z_0$. The unit vectors satisfies the following relation:

$$\hat{a}_x \times \hat{a}_y = \hat{a}_z$$

$$\hat{a}_y \times \hat{a}_z = \hat{a}_x$$

$$\hat{a}_z \times \hat{a}_x = \hat{a}_y$$

$$\hat{a}_x . \hat{a}_y = \hat{a}_y . \hat{a}_z = \hat{a}_z . \hat{a}_x = 0$$

$$\hat{a}_x . \hat{a}_x = \hat{a}_y . \hat{a}_y = \hat{a}_z . \hat{a}_z = 1$$

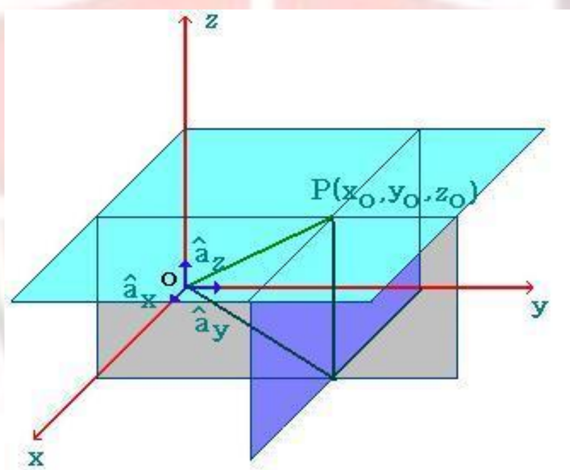



Figure: Cartesian coordinate system

$$\vec{OP} = \hat{a}_x x_0 + \hat{a}_y y_0 + \hat{a}_z z_0$$

In cartesian coordinate system, a vector $\vec{A}$ can be written as $\vec{A} = \hat{a}_x A_x + \hat{a}_y A_y + \hat{a}_z A_z$. The dot and cross product of two vectors $\vec{A}$ and $\vec{B}$ can be written as follows:

$$\vec{A}\cdot\vec{B} = A_x B_x + A_y B_y + A_z B_z$$

$$\vec{A}\times\vec{B} = \hat{a}_x (A_y B_z - A_z B_y) + \hat{a}_y (A_z B_x - A_x B_z) + \hat{a}_z (A_x B_y - A_y B_x)$$

$$= \begin{vmatrix} \hat{a}_x & \hat{a}_y & \hat{a}_z \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

Since $x$, $y$ and $z$ all represent lengths, $h_1 = h_2 = h_3 = 1$. The differential length, are and volume are defined respectively as

$$\overrightarrow{dl} = dx\hat{a}_x + dy\hat{a}_y + dz\hat{a}_z$$

$$\overrightarrow{ds}_x = dydz\hat{a}_x$$

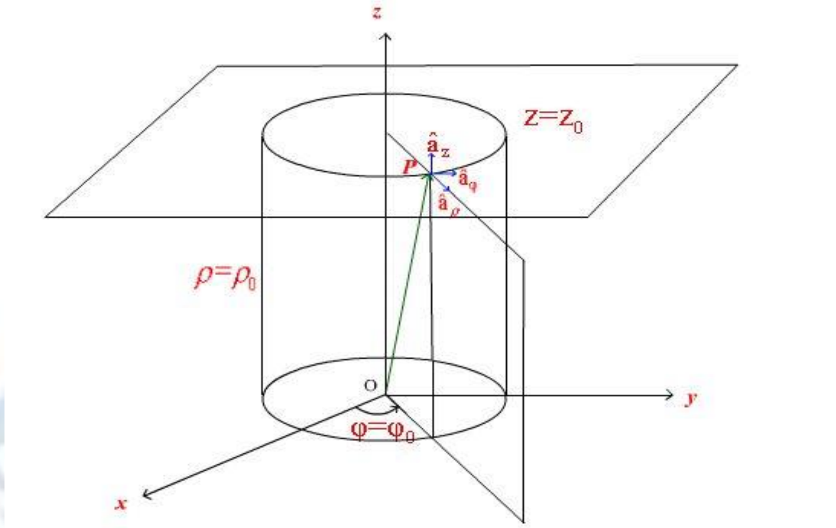
$$\overrightarrow{ds}_y = dxdz\hat{a}_y$$

$$\overrightarrow{ds}_z = dxdy\hat{a}_x$$

$$dv = dxdydz$$

## Cylindrical Co-ordinate System

For cylindrical coordinate systems we have $(u, v, w) = (\rho, \phi, z)$ and a point $P(\rho_{0,} \phi_0, z_0)$ is determined as the point of intersection of a cylindrical surface $\rho = \rho_0$, half plane containing the z-axis and making an angle $\phi = \phi_0$ with the $xz$ plane and a plane parallel to $xy$ plane located at $z = z_0$ as shown in figure.




In cylindrical coordinate system, the unit vectors satisfy the following relations:

$$\hat{a}_\rho \times \hat{a}_\phi = \hat{a}_z$$

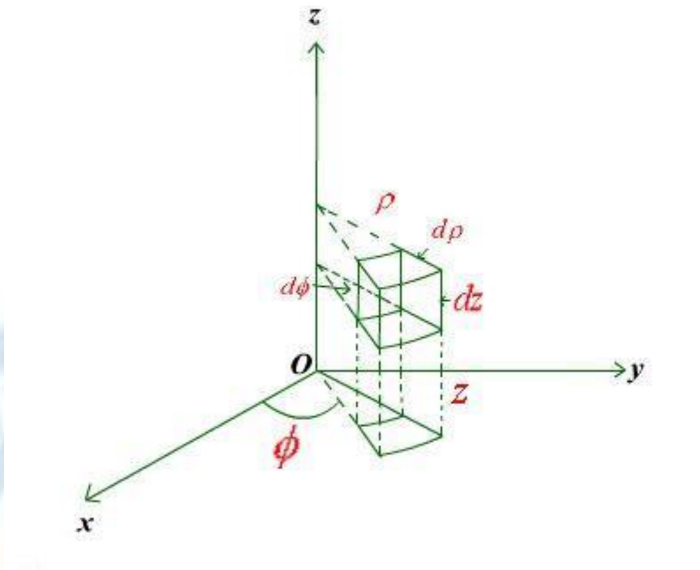
$$\hat{a}_\phi \times \hat{a}_z = \hat{a}_\rho$$

$$\hat{a}_z \times \hat{a}_\rho = \hat{a}_\phi$$

A vector $\vec{A}$ can be written as $\vec{A} = A_\rho \hat{a}_\rho + A_\phi \hat{a}_\phi + A_z \hat{a}_z$ .

The differential length is defined as

$$dl = \hat{a}_\rho d\rho + \rho d_\phi \hat{a}_\phi + dz\hat{a}_z \qquad h_1 = 1, \ h_2 = \rho \ h_3 = 1$$




Differential volume element in cylindrical coordinates

Differential areas are

$$\overrightarrow{ds_\rho} = \rho d\phi dz \hat{a}_\rho$$

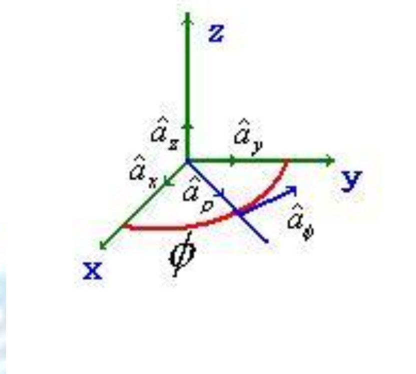
$$\overrightarrow{ds_\phi} = d\rho dz \hat{a}_\phi$$

$$\overrightarrow{ds_z} = \rho d\phi d\rho \hat{a}_z$$

Differential volume $dv = \rho d\rho d\phi dz$

**Transformation between Cartesian and Cylindrical coordinates**

Let us consider a vector $\vec{A} = \hat{a}_\rho A_\rho + \hat{a}_\phi A_\phi + \hat{a}_z A_z$ is to be expressed in Cartesian coordinates as $\vec{A} = \hat{a}_x A_x + \hat{a}_y A_y + \hat{a}_z A_z$. In doing so we note that $A_x = \vec{A} \cdot \hat{a}_x = (\hat{a}_\rho A_\rho + \hat{a}_\phi A_\phi + \hat{a}_z A_z) \cdot \hat{a}_x$ and it applies for other components as well.




Unit vectors in Cartesian and Cylindrical coordinates

From the figure we note that:

$$\hat{a}_\rho \cdot \hat{a}_x = \cos\phi$$
$$\hat{a}_\rho \cdot \hat{a}_y = \sin\phi$$

$$\hat{a}_\phi \cdot \hat{a}_x = \cos(\phi + \frac{\pi}{2}) = -\sin\phi$$
$$\hat{a}_\phi \cdot \hat{a}_y = \cos\phi$$

Therefore we can write

$$A_x = \vec{A} \cdot \hat{a}_x = A_\rho \cos\phi - A_\phi \sin\phi$$
$$A_y = \vec{A} \cdot \hat{a}_x = A_\rho \sin\phi + A_\phi \cos\phi$$
$$A_z = \vec{A} \cdot \hat{a}_z = A_z$$

These relations can be put conveniently in the matrix form as:

$$\begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix} = \begin{bmatrix} \cos\phi & -\sin\phi & 0 \\ \sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} A_\rho \\ A_\phi \\ A_z \end{bmatrix}$$

$A_\rho$, $A_z$ and $A_z$ themselves may be functions of $\rho$, $\phi$ and $z$. These variables are transformed in terms of $x$, $y$ and $z$ as:

$$x = \rho \cos \phi$$
$$y = \rho \sin \phi$$
$$z = z$$

The inverse relation ships are:

$$\rho = \sqrt{x^2 + y^2}$$
$$\phi = \tan^{-1} \frac{y}{x}$$
$$z = z$$

Thus we see that a vector in one coordinate system is transformed to another coordinate system through two-step process: Finding the component vectors and then variable transformation.

**Spherical polar coordinate**

For spherical polar coordinate system, we have, $(u, v, w) = (r, \theta, \phi)$. A point $P(r_0, \theta_0, \phi_0)$ is represented as the intersection of

(i) Spherical surface $r = r_0$
(ii) Conical surface $\theta = \theta_0$, and
(iii) Half plane containing $z$-axis making angle $\phi = \phi_0$ with the $xz$ plane as shown in the figure.

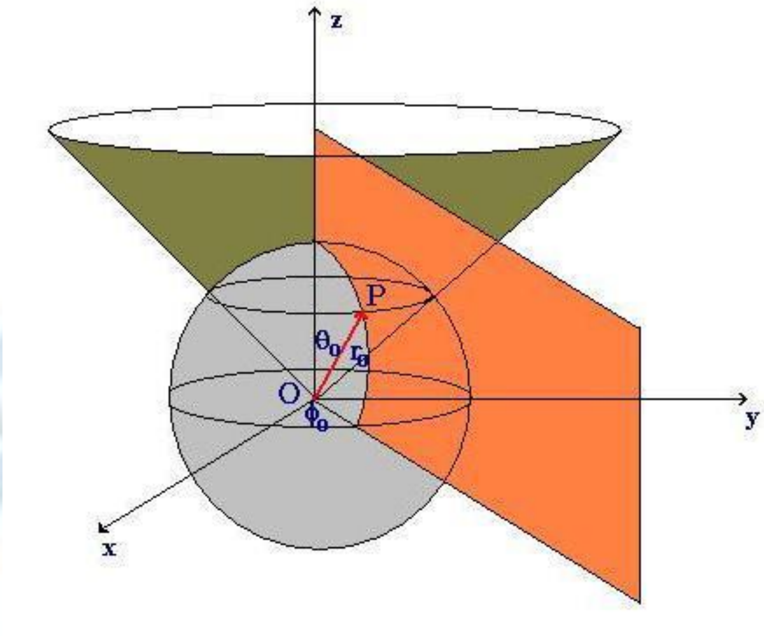



Figure:

The unit vectors satisfy the following relations

$$\hat{a}_r \times \hat{a}_\theta = \hat{a}_\phi$$

$$\hat{a}_\theta \times \hat{a}_\phi = \hat{a}_\phi$$

$$\hat{a}_\phi \times \hat{a}_r = \hat{a}_\theta$$

The orientation of the unit vectors are shown in the figure

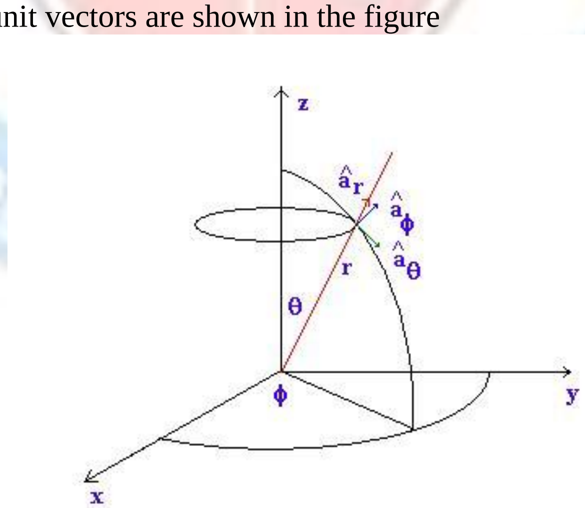



Figure:

A vector in spherical polar co-ordinate is written as: $\vec{A} = A_r\hat{a}_r + A_\theta\hat{a}_\theta + A_\phi\hat{a}_\phi$ and $\overrightarrow{dl} = \hat{a}_r dr + \hat{a}_\theta r d\theta + \hat{a}_\phi r\sin\theta d\phi$. For spherical polar coordinate system we have $h_1 = 1, h_2 = r\sin\theta$ and $h_3 = r$.

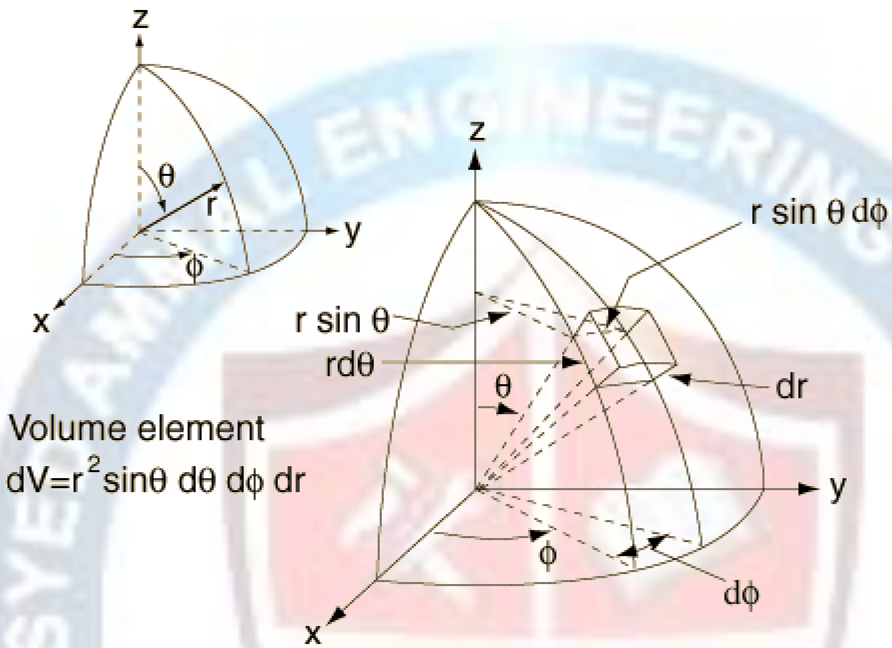



Figure:

With reference to the Figure, the elemental areas are:

$$\overrightarrow{ds_r} = r^2\sin\theta d\theta d\phi\hat{a}_r$$
$$\overrightarrow{ds_\theta} = r\sin\theta dr d\phi\hat{a}_\theta$$
$$\overrightarrow{ds_\phi} = r dr d\theta\hat{a}_\phi$$

and elemental volume is given by $dv = r^2\sin\theta dr d\theta d\phi$

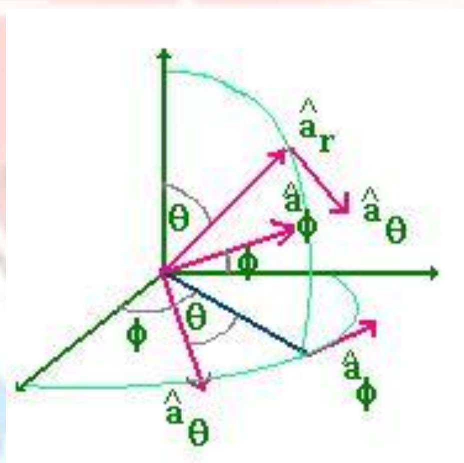
**Coordinate transformation between rectangular and spherical polar**

With reference to the Figure we can write the following:

$$\hat{a}_r \cdot \hat{a}_x = \sin\theta\cos\phi$$
$$\hat{a}_r \cdot \hat{a}_y = \sin\theta\sin\phi$$
$$\hat{a}_r \cdot \hat{a}_z = \cos\theta$$

$$\hat{a}_\theta \cdot \hat{a}_x = \cos\theta\cos\phi$$
$$\hat{a}_\theta \cdot \hat{a}_y = \cos\theta\sin\phi$$
$$\hat{a}_\theta \cdot \hat{a}_z = \cos(\theta + \frac{\pi}{2}) = -\sin\theta$$

$$\hat{a}_\phi \cdot \hat{a}_x = \cos(\phi + \frac{\pi}{2}) = -\sin\phi$$
$$\hat{a}_\phi \cdot \hat{a}_y = \cos\phi$$
$$\hat{a}_\phi \cdot \hat{a}_z = 0$$




Figure

Given a vector $\vec{A} = A_r\hat{a}_r + A_\theta\hat{a}_\theta + A_\phi\hat{a}_\phi$ in the Spherical Polar coordinate system, its component in the Cartesian coordinate system can be found out as follows:

$$A_x = \vec{A}.\hat{a}_x = A_r \sin\theta\cos\phi + A_\theta \cos\theta\cos\phi - A_\phi \sin\phi$$

Similarly,

$$A_y = \vec{A}.\hat{a}_y = A_r \sin\theta \sin\phi + A_\theta \cos\theta \sin\phi + A_\phi \cos\phi$$

$$A_z = \vec{A}.\hat{a}_z = A_r \cos\theta - A_\theta \sin\theta$$

The above expressions may be put in a compact form:

$$\begin{bmatrix} Ax \\ Ay \\ Az \end{bmatrix} = \begin{bmatrix} \sin\theta\cos\phi & \cos\theta\cos\phi & -\sin\phi \\ \sin\theta\sin\phi & \cos\theta\sin\phi & \cos\phi \\ \cos\theta & -\sin\theta & 0 \end{bmatrix} \begin{bmatrix} Ar \\ A\theta \\ A\phi \end{bmatrix}$$

The components $A_r, A_\theta$ and $A_\phi$ themselves will be function of $r, \theta$ and $\phi$. $r, \theta$ and $\phi$ are related to $x, y$ and $z$ as

$$x = r\sin\theta\cos\phi$$

$$y = r\sin\theta\sin\phi$$

$$z = r\cos\theta$$

and conversely,

$$r = \sqrt{x^2 + y^2 + z^2}$$

$$\theta = \cos^{-1}\frac{z}{\sqrt{x^2 + y^2 + z^2}}$$

$$\phi = \tan^{-1}\frac{y}{x}$$

Using the variable transformation listed above, the vector components, which are functions of variables of one coordinate system, can be transformed to functions of variables of other coordinate system and a total transformation can be done.

**Line, surface and volume integrals**

In electromagnetic theory we come across integrals, which contain vector functions. Some representative integrals are listed below:

$\int_V \vec{F} dv \qquad \int_C \phi \vec{dl} \quad \int_C \vec{F}.\vec{dl} \qquad \int_S \vec{F}.\vec{ds}$ etc.

In the above integrals, $\vec{F}$ and $\phi$ respectively represent vector and scalar function of space coordinates. $C, S \,\&\, V$ represent path, surface and volume of integration. All these integrals are evaluated using extension of the usual one-dimensional integral as the limit of a sum, i.e., if a function $f(x)$ is defined over arrange $a$ to $b$ of values of x, then the integral is given by

$$\int_a^b f(x)dx = \lim_{n \to \infty} \sum_{i=1}^{n} f_i \delta x_i$$

where the interval $(a,b)$ is subdivided into $n$ continuous interval of lengths $\delta x_1 ..........\delta x_n$.

**Line integral**

Line integral $\int_C \vec{E}.\vec{dl}$ is the dot product of a vector with a specified path $C$; in other words it is the integral of the tangential component of $\vec{E}$ along the curve $C$.

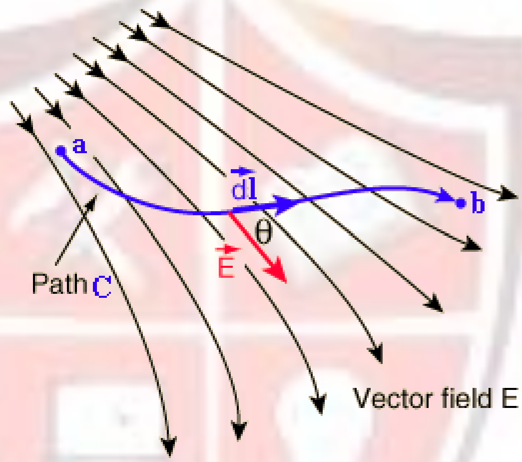



Figure: Line integral

As shown in the figure, given a vector field $\vec{E}$ around $C$, we define the integral $\int_C \vec{E} \cdot \vec{dl} = \int_a^b E\cos\theta dl$ as the line integral of $\vec{E}$ along the curve $C$. If the path of integration is a closed path as shown in Figure, the line integral becomes a closed line integral and is called the circulation of $\vec{E}$ around $C$ and denoted as $\oint_C \vec{E} \cdot \vec{dl}$

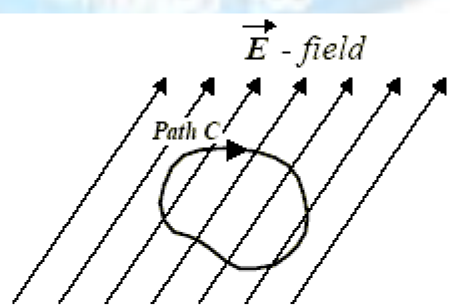



Figure: Closed line integral

**Surface integral**

Given a vector field $\vec{A}$, continuous in a region containing the smooth surface $S$, we define the surface integral or the flux of $\vec{A}$ through $S$ as

$$\psi = \int_S A\cos\theta ds = \int_S \vec{A}\cdot\hat{a}_n ds = \int_S \vec{A}\cdot\overrightarrow{ds}$$

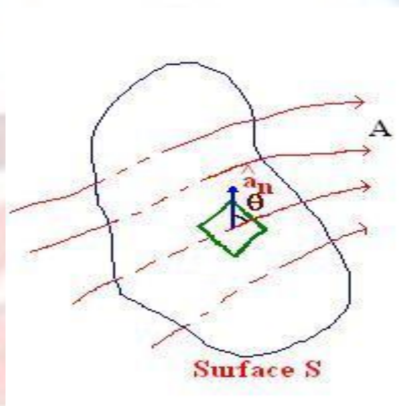



Figure: Computation of surface integral

If the surface integral is carried out over a closed surface, then we write: $\psi = \oint_S \vec{A}\cdot\overrightarrow{ds}$ which gives the net outward flux of $\vec{A}$ from $S$.

**Volume integrals**

We define $\int_V f dv$ or $\iiint_v f dv$ as the volume integral of the scalar function $f$ (function of spatial coordinates) over the volume $V$. Evaluation of integral of the form $\int_V \vec{F} dv$ can be carried out as a sum of three scalar volume integrals, where each scalar volume integral is a component of the vector $\vec{F}$.

**The Del Operator**

The vector differential operator $\nabla$ was introduced by Sir W. R. Hamilton and later on developed by P. G. Tait.

Mathematically the vector differential operator can be written in the general form as:

$$\nabla = \frac{1}{h_1}\frac{\partial}{\partial u}\hat{a}_u + \frac{1}{h_2}\frac{\partial}{\partial v}\hat{a}_v + \frac{1}{h_3}\frac{\partial}{\partial w}\hat{a}_w$$

In Cartesian coordinates:

$$\nabla = \frac{\partial}{\partial x}\hat{a}_x + \frac{\partial}{\partial y}\hat{a}_y + \frac{\partial}{\partial z}\hat{a}_z$$

In cylindrical coordinates:

$$\nabla = \frac{\partial}{\partial \rho}\hat{a}_\rho + \frac{1}{\rho}\frac{\partial}{\partial \phi}\hat{a}_\phi + \frac{\partial}{\partial z}\hat{a}_z$$

and in spherical polar coordinates:

$$\nabla = \frac{\partial}{\partial r}\hat{a}_r + \frac{1}{r}\frac{\partial}{\partial \theta}\hat{a}_\theta + \frac{1}{r\sin\theta}\frac{\partial}{\partial \phi}\hat{a}_\phi$$

# ELECTROMAGNETIC THEORY

1. The force between two charges is 120 N. If the distance between the charges is doubled, the force will be
(a) 60 N
(b) 30 N
(c) 40 N
(d) 15 N

Ans: b

2. The electric field intensity at a point situated 4 metres from a point charge is 200 N/C. If the distance is reduced to 2 metres, the field intensity will be
(a) 400 N/C
(b) 600 N/C
(c) 800 N/C
(d) 1200 N/C

Ans: c

3. The lines of force due to charged particles are
(a) always straight
(b) always curved
(c) sometimes curved
(d) none of the above

Ans: b

4. The electric field at a point situated at a distance d from straight charged conductor is
(a) proportional to d
(b) inversely proportional to d
(c) inversely proportional to d
(d) none of the above

Ans: b

5. The direction of electric field due +0 positive charge is .
(a) away from the charge
(b) towards the charge
(c) both (a) and (6)

Ans:(d)nonea of the above

6. A field line and an equipotential surface are
(a) always parallel
(b) always at 90°
(c) inclined at any angle 0

Ans:(d)noneb of the above

7. The ability of charged bodies to exert force on 6ne another is attributed to the existence of
(a) electrons
(b) protons
(c) neutrons

Ans:(d)electricd field

8. If the sheet of a bakelite is inserted between the plates of an air capacitor, the capacitance will
(a) decrease
(b) increase
(c) remains unchanged

Ans:(d)becomeb zero

9. A capacitor stores 0.24 coulombs at 10 volts. Its capacitance is
(a) 0.024 F
(b) 0.12 F
(c) 0.6 F

Ans:(d)0.8a F

10. For making a capacitor, it is better to select a dielectric having
(a) low permittivity
(b) high permittivity
(c) permittivity same as that of air

Ans:(d)permittivityb slightly more than that of air

11. The units of capacitance are

(a) volts/coulomb
(b) coulombs/volt
(c) ohms

(d)Ans:henry/Wbb

12. If three 15 uF capacitors are connected in series, the net capacitance is
(a) 5 uF
(6) 30 uF
(c) 45 uF

Ans:(d)50a uF

13. If three 10 uF capacitors are connected in parallel, the net cararitance is
(a) 20 uF
(b) 30 uE
(c) 40 uF

Ans:(d)50b uF

14. A dielectric material must be
(a) resistor
(b) insulator
(c) good conductor

Ans:(d)semib conductor

15. An electrolytic capacitor can be used for
(a) D.C. only
(b) AC. only

Ans:(c)botha D.C. as well as A.C.

16. The capacitance of a capacitor is not affected by
(a) distance between plates
(6) area of plates
(c) thickness of plates

Ans:(d)allc of the above

17. Which of the following is not a vector ?
(a) Linear momentum
(b) Angular momentum
(c) Electric field

Ans:(d)Electricb potential

18. Two plates of a parallel plate capacitor after being charged from a constant voltage source are separated apart by means of insulated handles, then the
(a) Voltage across the plates increases
(b) voltage across the plates decreases
(c) charge on the capacitor decreases

Ans:(d)chargeb on the capacitor increases

19. If A.C. voltage is applied to capacitive circuit, the alternating current can flow in the circuit because
(a) varying voltage produces the charg¬ing and dicharging currents
(b) of high peak value
(c) charging current can flow

Ans:(d) adischarge current can flow

20. Voltage applied across a ceramic dielectric produces an electrolytic field 100 times greater than air. What will be the value of dielectric constant ?
(a) 50
(6) 100
(c) 150

Ans:(d)200b

21. Which of the following statements is correct ?
(a) Air capacitors have a blackband to indicate the outside foil
(6) Electrolytic capacitor must be con¬nected in the correct polarity
(c) Ceramic capacitors must be con¬nected in the correct polarity
(d) Mica capacitors are available in capacitance value of 1 to 10 pF

Ans: b

22. The dissipation factor of a good dielectric is of the order of
(a) 0.0002
(b) 0.002
(c) 0.02

Ans:(d)0.2a

23. "The total electric flux through any closed surface surrounding charges is equal to the amount oflcharge enclosed".
The above statement is associated with
(a) Coulomb's square law
(b) Gauss's law
(c) Maxwell's first law
(d) Maxwell's second law

Ans: b

24. Three capacitors each of the capacity C are given. The resultant capacity 2/3 C can be obtained by using them
(a) all in series
(b) all in parallel
(c) two in parallel and third in series with this combination
(d) two in series and third in parallel across this combination

Ans: c

25. For which of the following parameter variation, the capacitance of the capacitor remains unaffected ?
(a) Distance between plates
(b) Area of the plates
(c) Nature of dielectric

Ans:(d)Thicknessd of the plates

26. Which of the following statement is true ?
(a) The current in the discharging capacitor grows linearly
(b) The current in the dicharging capacitor grows exponentially
(c) The current in the discharging capacitor decays exponentially
(d) The current in the discharging capacitor decreases constantly

Ans: b

27. Which of the following expression is correct for electric field strength ?
(a) E = D/E
(b) E = D2/t
(c) E = jtD

Ans:(d)E=a nD2

28. In a capacitor the electric charge is stored in
(a) metal plates
(b) dielectric
(c) both (a) and (6)

(d)Ans:noneb of the above

29. Which of the following materials has the highest value of dielectric constant?
(a) Glass
(b) Vacuum
(c) Ceramics
(d) Oil
Ans: c

30. Which of the following capacitors will have the least variation ?
(a) Paper capacitor
(b) Ceramic capacitor
(c) Silver plated mica capacitor

Ans:(d)Nonec of the above

31. Which of the following statements is incorrect ?
(a) The leakage resistance of ceramic capacitors is generally high
(b) The stored energy in a capacitor decreases with reduction in value of capacitance
(c) The stored energy in a capacitor increases with applied voltage
(d) A wire cable has distributed capacitance between the conductors

Ans: b

32. Which of the following capacitors has relatively shorter shelf life ?
(a) Mica capacitor
(b) Electrolytic capacitor
(c) Ceramic capacitor

Ans:(d)Paperb capacitor

33. The sparking between two electrical contacts can be reduced by inserting a
(a) capacitor in parallel with contacts
(6) capacitor in series with each contact
(c) resistance in line

Ans:(d)nonea of the above

34. In the case of a lossy capacitor, its series equivalent resistance value will be
(a) small
(b) very small
(c) large

Ans:(d)zeroc

35. The power dissipated in a pure capacitor is
(a) zero
(6) proportional to applied voltage
(c) proportional to value of capacitance

Ans:(d)botha (b) and (c) above

36. In a capacitive circuit
(a) a steady value of applied voltage causes discharge
(b) an increase in applied voltage makes a capacitor charge
(c) decrease in applied voltage makes a capacitor charge

Ans:(d)noneb of the above

37. When a dielectric slab is introduced in a parallel plate capacitor, the potential difference between plates will
(a) remain uncharged
(b) decrease
(c) increase

Ans:(d)becomeb zero

38. Capacitance increases with
(a) increase in plate area and decrease in distance between the plates
(b) increase in plate area and distance between the plates
(c) decrease in plate area and value of applied voltage
(d) reduction in plate area and distance between the plates

Ans: a

39. The self-inductance of the coil may be defined as equal to the e.m.f. induced in volts when the current in the circuit changes at the rate of unit weber turns.
(a) Yes
(b) No
Ans: b

40. A gang condenser is a
(a) polarised capacitor
(6) variable capacitor
(c) ceramic capacitor

Ans:(d)none of the above

41. A paper capacitor is usually available in the form of
(a) tubes
(b) rolled foil
(c) disc

Ans:(d)meshedb plates

42. Air capacitors are generally available in the range
(a) 10 to 400 pF
(b) 1 to 20 pF
(c) 100 to 900 pF

Ans:(d)20a to 100 pF

43. The unit of capacitance is
(a) henry
(b) ohm
(c) farad

Ans:(d)farad/mc

44. A capacitor charged to 200 V has 2000 (iC of charge. The value of capacitance will be
(a) 10 F
(6) 10 uF
(c) 100 nF

Ans:(d)1000b uF

45. A capacitor in a circuit became hot and ultimately exploded due to wrong con¬nections, which type of capacitor it could be ?
(a) Paper capacitor
(b) Ceramic capacitor
(c) Electrolytic capacitor

Ans:(d)Anyc-of the above

46. Energy stored in the electric field of a capacitor C when charged from a D.C source of voltage V is equal to joules
(a) CV2
(b) C2V
(c) CV2
(d) CV
Ans: a

47. The absolute permittivity of free space is given by
(a) 8.854 x 1(T9 F/m)
(6) 8.854 x 1(T10 F/m)
(c) 8.854 x KT11 F/m

Ans:(d)8.854b x 10"12 F/m

48. The relative permittivity of free space is given by
(a) 1
(b) 10
(c) 100

Ans:(d)1000a

49. Electric field intensity is a quantity
(a) scalar

(b) vector
(c) both (a) and (6)

Ans:(d)noneb of the above

50. When 4 volts e.m.f. is applied across a 1 farad capacitor, it will store energy of
(a) 2 joules
(b) 4 joules
(c) 6 joules

Ans:(d)8 djoules

51. The capacitor preferred for high frequency circuits is
(a) air capacitor
(b) mica capacitor
(c) electrolytic capacitor

Ans:(d)noneb of the above

52. The capacity of capacitor bank used in power factor correction is expressed in terms of
(a) kW
(b) kVA
(c) kVAR

Ans:(d)voltsc

53. While testing a capacitor with ohm-metre, if the capacitor shows charging, but the final resistance reading is appreciably less than normal, it can be concluded that the capacitor is
(a) short-circuited
(b) open circuited
(c) alright

Ans:(d)leakyd

54. If a 6 (iF capacitor is charged to 200 V, the charge in coulombs will be
(a) 800 uC
(b) 900 uC
(c) 1200 uC

Ans:(d)1600c uC

55. Which capacitor will be physically smaller for the same ratings ?
(a) Ceramic capacitor
(b) Paper capacitor
(c) Both will be of equal size
(d) None of the above

Ans: a

56. What is the value of capacitance that must be connected in parallel with 50 pF condenser to make an equivalent capacitance of 150 pF ?
(a) 50 pF
(b) 100 pF
(c) 150 pF

Ans:(d)200b pF

57. A mica capacitor and a ceramic capacitor both have the same physical dimensions. Which will have more value of capacitance ?
(a) Ceramic capacitor
(b) Mica capacitor
(c) Both will have identical value of capacitance

Ans:(d)Itadepends on applied voltage

58. Which of the following material has least value of dielectric constant ?
(a) Ceramics
(b) Oil
(c) Glass

Ans:(d)Paperb

59. Which of the following capacitors will have the least value of breakdown voltage ?
(a) Mica
(b) Paper
(c) Ceramic

Ans:(d)Electrolyticd

3.73. The breakdown voltage for paper capacitors is usually
(a) 20 to 60 volts
(b) 200 to 1600 volts
(c) 2000 to 3000 volts

Ans:(d)more than 10000 volts

60. Dielectric constant for mica is nearly
(a) 200
(b) 100
(c) 3 to 8

(d)Ans:1 toc 2

61. The value of dielectric constant for vacuum is taken as
(a) zero
(b) 1
(c) 4

Ans:(d)10b

62. Which of the following capacitors is marked for polarity ?
(a) Air
(b) Paper
(c) Mica

Ans:(d)Electrolyticd

63. Which of the following capacitors can be used for temperature compensation ?
(a) Air capacitor
(b) Ceramic capacitor
(c) Paper capacitor

Ans:(d)Noneb of the above

64. Which of the following statements is incorrect ?
(a) The thinner the dielectric, the more the capacitance and the lower the voltage breakdown rating for a capacitor .
(b) A six dot mica capacitor colour coded white, green, black, red and yellow has the capacitance value of 500 pF
(c) Capacitors in series provide less capacitance but a higher voltage breakdown rating for the combina¬tion
(d) A capacitor can store charge be¬cause it has a dielectric between two conductors

Ans: b

65. Paper capacitors usually have a tolerance of
(a) ± 5%
(b) ± 10%
(c) ± 15%

Ans:(d)± b20%

66. For closer tolerances which of the following capacitors is usually preferred ?
(a) Paper capacitor
(b) Mica capacitor
(c) Ceramic disc capacitor

Ans:(d)Noneb of the above

67. The electrostatic force between two charges of one coulomb each and placed at a

distance of 0.5 m will be
(a) 36 x 10fa
(b) 36 x 107 N
(c) 36 x 108 N

Ans:(d)36d x 109 N

68. The units of volume charge density are
(a) Coulomb/metre
(b) Coulomb/metre
(c) Coulomb/metre

Ans:(d)Coulomb/metrec

69. "The surface integral of the normal component of the electric displacement D over any closed surface equals the charge enclosed by the surface".
The above statement is associated with
(a) Gauss's law
(b) Kirchhoff s law
(c) Faraday's law

Ans:(d)Lenz'sa law

70. Dielectric strength of mica is
(a) 10 to 20 kV/mm
(6) 30 to 50 kV/mm
(c) 50 to 200 kV/mm

Ans:(d)300c to 500 kV/mm

71. The dielectric constant (relative permittivity) of glass is given by
(a) 0.1 to 0.4
(b) 0.5 to 1.0
(c) 2.0 to 4.0

Ans:(d)5 dto 100

72 capacitors are mainly used for radio frequency tuning.
(a) Paper
(b) Air
(c) Mica

Ans:(d)Electrolyticb

73. capacitors can be used only for D.C.
(a) Air

(b) Paper
(e) Mica

Ans:(d)Electrolyticd

74. capacitors are used in transistor circuits.
(a) Ceramic
(b) Paper
(c) Air

Ans:(d)Electrolytica

75. capacitors are used for audio frequency and radio frequency coupling and tuning.
(a) Air
(b) Mica
(c) Plastic film

Ans:(d)Ceramicb

76. The inverse of capacitance is called
(a) reluctance
(b) conductance
(c) susceptance

Ans:(d)elastanced

77. When the dielectric is homogeneous,the potential gradient is
(a) uniform
(b) non-uniform
(c) zero

Ans:(d)anya of the above

78. The potential gradient across the material of low permittivity is than across the material of high permittivity.
(a) smaller
(b) greater
(c) both (a) and (b)

Ans:(d)noneb of the above

79. ________field is associated with the capacitor.
(a) Electric
(b) Magnetic
(c) Both (a) and (b)
(d) None of the above

Ans: a

80. A capacitor having capacitance of 5 uF is charged to a potential difference of 10,000 V. The energy stored in the capacitor is
(a) 50 joules
(b) 150 joules
(c) 200 joules

Ans:(d)250d joules

81. A single core cable used on 33000 V has conductor diameter 10 mm and the in¬ternal diameter of sheath 25 mm. The maximum electrostatic stress in the cable is
(a) 62 x 105 V/m
(b) 72 x 105 V/m
(c) 82 x 105 V/m

Ans:(d)92b x 105 V/m

82. Two infinite parallel plates 10 mm apart have maintained between them a potential difference of 100 V. The acceleration of an electron placed between them is
(a) 0.56 x 1015 m/s2
(b) 1.5 x 1015 m/s2
(c) 1.6 x 1015 m/s2

Ans:(d)1.76d x 1015 m/s2

83. The total deficiency or excess of electrons in a body is known as
(a) current
(b) voltage
(c) potential gradient

Ans:(d)charged

84. The relative permittivity has the following units
(a) F/m
(b) m/F
(c) Wb/m

Ans:(d)noc units

85. The phenomenon of an uncharged body getting charged merely by the nearness of a charged body is known as
(a) pholoelectric effect
(b) chemical effect
(c) magnetic effect
(d) induction

Ans: d

86. A unit tube of flux is known as tube
(a) Newton
(b) Faraday
(c) Michale

Ans:(d)Noneb of the above

87. The number of Faraday tubes of flux passing through a surface in an electric field is called
(a) electric flux
(6) electric flux density
(c) magnetic flux density

Ans:(d)electrica charge density

88. The unit of electric instensity is
(a) N/C2
(b) Wb/m2
(c) N/C

Ans:(d)N2/C

89. The value of E within the field due to a point charge can be found with the help of
(a) Faraday's laws
(b) Kirchhoff s laws
(c) Coulomb's laws

Ans:(d)nonec of the above

90. at a point may be defined as equal to the lines of force passing normally through a unit cross section at that point.
(a) Electric intensity
(6) Magnetic flux density
(c) Electric flux

Ans:(d)Nonea of the above

91. Electric intensity at any point in an electric field is equal to the at that point.
(a) electric flux
(b) magnetic flux density
(c) potential gradient

Ans:(d)nonec of the above

92. Electric displacement is a______quantity.
(a) scalar
(b) vector
(c) both of the above

Ans:(d)noneb of the above

93. at a point is equal to the negative potential gradient at that point.
(a) Electric intensity
(6) Electric flux
(c) Magnetic flux

Ans:(d)Magnetica flux density

94. The unit of dielectric strength is given by
(a) V/m
(b) V2/m
(c) m/V

Ans:(d)m/V2a

95. Dielectric strength ______ with increasing thickness
(a) increases
(b) decreases
(c) remains unaltered

Ans:(d)noneb of the above

96. The property of a capacitor to store electricity is called its
(a) capacitance
(b) charge
(c) energy

Ans:(d)nonea of the above

97. is that property of a capacitor which delays any change of voltage across it.
(a) Inductance
(b) Capacitance
(c) Potential gradient

Ans:(d)Noneb of the above

98. A capacitance of 100 fiF is connected in series with a resistance of 8000 £2. The time constant of the circuit is
(a) 0.2 s
(b) 0.4 s

(c) 0.6 s

(d)Ans:0.8d s

99. In a cable capacitor, voltage gradient ismaximum at the surface of the
(a) earth
(b) conduction
(c) sheath

Ans:(d)insulatorb

100. The time constant of an R -C circuit is defined as the time during which capacitor charging voltage actually rises to ______ percent of its______value.
(a) 37, initial
(b) 63.2, initial
(c) 63.2, final

Ans:(d)37,c final

101. The time constant and R-C circuit may also be defined as the time during which the charging current falls to ______ percent of its initial maximum value,
(a) 37
(b) 42
(c) 63

Ans:(d)73a

102. The capacitance of a capacitor is influenced by
(a) plate area
(b) plate separation
(c) nature of dielectric
(d) none of the above

Ans:(e)all of the above

103. A capacitor consists of two
(a) ceramic plates and one mica disc
(b) insulators separated by a dielectric
(c) silver-coated insulators

Ans:(d)conductorsd separated by an insulator

104. Permittivity is expressed in
(a) Farad/sq-m
(b) Farad/metre
(c) Weber/metre

Ans:(d)Weber/sqb-m

105. Dielectric strength of a material depends on
(a) moisture content
(b) temperature
(c) thickness
(d) all of the above

Ans:(e)noned of the above

106. What will happen to an insulating medium if voltage more than the breakdown voltage is applied on it ?
(a) It will become magnetic
(b) It will melt
(c) It will get punctured or cracked

Ans:(d)Itsc molecular structure will get changed

107. Which medium has the least dielectric strength ?
(a) Paraffin wax
(b) Quartz
(c) Glass
(d) Air
Ans: d

108. 1 volt/metre is same as
(a) 1 metre/coulomb
(6) 1 newton metre
(c) 1 newton/metre

Ans:(d)1 cjoule/coulomb

109. One volt is the same as
(a) one joule/coulomb
(b) one coulomb/joule
(c) one coulomb

Ans:(d)onea joule

110. The capacitance between two plates increases with
(a) shorter plate area and higher ap¬plied voltage
(6) shorter plate area and shorter dis¬tance between them
(c) larger plate area, longer distance between plates and higher,applied voltage
(d) larger plate area and shorter distance between plates

Ans: d

111. The capacitance C is charged through a resistance R. The time constant of the charging circuit is given by
(a) CIR
(b) 1/RC
(c) RC
(d) RIC
Ans: c

112. The bridge used for the measurement of the value of the capacitance is
(a) Wien's bridge
(b) Wheatstone bridge
(c) Schering bridge

Ans:(d)Hay'sc bridge

113. If an ohmmeter reading immediately goes practically to zero and stays there, capacitor is
(a) charged
(b) short-circuited
(c) lossy

Ans:(d)satisfactoryb

114. Out of the following capacitors of identical rating which one will have the smallest dimensions ?
(a) Aluminium foil capacitor
(b) Mica capacitor
(c) Ceramic capacitor

Ans:(d)Paperc capacitor

115. An uncharged conductor is placed near a charged conductor, then (a)
the uncharged conductor gets charged by conduction
(6) the uncharged conductor gets charged by induction and then attracted towards the charging body
(c) the uncharged conductor is attracted first and then charged by induction

Ans:(d)itbremains as such

116. The presence of an uncharged conductor near a charged one increases the
(a) charge of the charged conductor
(6) capacity of the charged conductor
(c) potential of the charged conductor

Ans:(d)allb of the above

117. Paper condenser is
(a) always polarised
(6) usually of fixed value
(c) electrolytic condenser

Ans:(d)a bvariable condenser

118. Mica capacitors are characterised by all of thte following except
(a) stable operation
(b) accurate value
(c) low leakage reactance

Ans:(d)lowc losses

119. A potential of 400 V is applied to a capacitor, the plates of which are 4 mm apart. The strength of electric field is
(a) 100 kV/m
(b) 10 kV/m
(c) 5 kV/m

Ans:(d)2 akV/m

120. For a good 0.05 uF capacitor ohmmeter reading should
(a) show low resistance momentarily and back off to a very high resis¬tance
(6) show high resistance momentarily and then a very low resistance
(c) go quickly to 50 ohm approximately and remain there

Ans:(d)nota move at all

121. The ohmmeter reading for a short circuited capacitor is
(a) infinity
(b) few kilo ohms
(c) few megaahms

Ans:(d)zerod

122. Which of the following statements is correct ?
(a) Mica capacitors are available in capacitance values of 5 to 20 \iF
(b) Air capapitors have a black band to indicate the outside foil
(c) Electrolytic capacitors must be connected in correct polarity
(d) Ceramic capacitors must be con¬nected in correct polarity

Ans: c

123. Which of the following capacitors preferred for high frequency circuits ? (a)

Air capacitor

(b) Electrolytic capacitor
(c) Mica capacitor

(d)Ans:nonec of the above

124. An electrolytic capacitor is generally made to provide
(a) low capacitance
(b) fixed capacitance
(c) variable capacitance

Ans:(d)larged value of capacitance

125. In order to remove static electricity from machinery
(a) construct insulated cabins
(b) insulate the machinery
(c) ground the framework

Ans:(d)humidifyc the surroundings

126. If a third equal and similar charge is placed between two equal and similar charges, then this third charge will
(a) move out of the field of influence of the two charges
(b) remain in stable equilibrium (c) not be in equilibrium
Ans:(d)beb in unstable equilibrium

127. A region around a stationary electric charge has
(a) an electric field
(b) a magnetic field
(c) both (a) and (b)

Ans:(d)nonea of the above

128. The minimum value of potential gradient in a cable occurs in
(a) insulation
(b) conductor
(c) outer sheath

Ans:(d)uniformlya all over

129. Dielectric strength of medium
(a) increases with rise in temperature
(b) increases with moisture content
(c) is same for all insulating materials
(d) none of the above

Ans: d

130. Acharge which when placed in vacuum from an equal and similar charge repels with a force of 9 x 10 N, is known as
(a) milli -coulomb
(b) micro -coulomb
(c) pico-coulomb

Ans:(d)coulombb

131. Dielectric strength of a medium is usually expressed in
(a) J/mm
(b) C/m2
(c) kV/mm

Ans:(d)N/mmc

132. A positive and a negative charge are initially 50 mm apart. When they are moved close together so that they are now only 10 mm apart, the force between them will be
(a) 5 times smaller than before
(b) 5 times greater than before
(c) 10 times greater than before

Ans:(d)25d times larger than before

133. Which is the most superior dielectric out of the following ?
(a) Air
(b) Glass
(c) Bakelite

Ans:(d)Paperc

134. When a dielectric is placed in an electric field the field strength
(a) decreases
(b) increases
(c) reduces to zero

Ans:(d)remaina unchanged

135. To prevent the generation of static charges on rubber or flat leather
(a) surface is moistened
(b) conductive dressing is done
(c) oil compound dressing is done

Ans:(d)talcumb powder is sprayed on the surface

136. Which of the following capacitor is preferred in case of single phase motor ?
(a) Mica capacitor
(b) Paper capacitor
(c) Electrolytic capacitor

Ans:(d)Ceramicc capacitor

137. A capacitance is a circuit component that opposes the change in circuit
(a) current
(b) voltage
(c) impedance

Ans:(d)nonea of the above

138. A condenser suitable for D.C. only is
(a) metallic plate variable gang condenser
(b) metallic paper capacitor
(c) oil impregrated paper condenser

Ans:(d)poledd aluminium electrolytic condenser

139. In a capacitor, the electric charge is stored in
(a) metal plates
(b) dielectric
(c) dielectric as well as metal plates

Ans:(d)noneb of the above

**MAGNETISM AND ELECTROMAGNETISM**

1. Tesla is a unit of
(a) field strength
(b) inductance
(c) flux density
(d) flux

Ans: c

2. A permeable substance is one
(a) which is a good conductor
(6) which is a bad conductor
(c) which is a strong magnet
(d) through which the magnetic lines of force can pass very easily

Ans: d

3. The materials having low retentivity are suitable for making
(a) weak magnets
(b) temporary magnets
(c) permanent magnets
(d) none of the above

Ans: b

4. A magnetic field exists around
(a) iron
(b) copper
(c) aluminium

Ans:(d)movingd charges

7. Ferrites are materials.
(a) paramagnetic
(b) diamagnetic
(c) ferromagnetic

Ans:(d)nonec of the above

8. Air gap has_______eluctance as compared to iron or steel path
(a) little
(b) lower
(c) higher

Ans:(d)zerob

9. The direction of magnetic lines of force is
(a) from south pole to north pole
(b) from north pole to south pole
(c) from one end of the magnet to another

Ans:(d)noneb of the above

10. Which of the following is a vector quantity ?

(a) Relative permeability (b) Magnetic field

intensity (c) Flux density

Ans:(d)Magneticb potential

11. The two conductors of a transmission line carry equal current I in opposite directions. The force on each conductor is
(a) proportional to 7
(b) proportional to X
(c) proportional to distance between the conductors

Ans:(d)inverselyb proportional to I

12. A material which is slightly repelled by a magnetic field is known as
(a) ferromagnetic material
(b) diamagnetic material
(c) paramag>etic material

Ans:(d)conductingb material

13. When an iron piece is placed in a magnetic field
(a) the magnetic lines of force will bend away from their usual paths in order to go away from the piece
(b) the magnetic lines of force will bend away from their usual paths in order to pass through the piece
(c) the magnetic field will not be affected

Ans:(d)theb iron piece will break

14. Fleming's left hand rule is used to find
(a) direction of magnetic field due to current carrying conductor
(b) direction of flux in a solenoid
(c) direction of force on a current car¬rying conductor in a magnetic field

Ans:(d)polarityc of a magnetic pole

15. The ratio of intensity of magnetisation to the magnetisation force is known as
(a) flux density
(b) susceptibility
(c) relative permeability

(d)Ans:noneb of the above

16. Magnetising steel is normals difficult because
(a) it corrodes easily
(6) it has high permeability
(c) it has high specific gravity

Ans:(d)itdhas low permeability

17. The left hand rule correlates to
(a) current, induced e.m.f. and direc¬tion of force on a conductor
(b) magnetic field, electric field and direction of force on a conductor
(c) self induction, mutual induction and direction of force on a conductor
(d) current, magnetic field and direc¬tion of force on a conductor

Ans: d

18. The unit of relative permeability is
(a) henry/metre
(b) henry
(c) henry/sq. m

Ans:(d)itdis dimensionless

19. A conductor of length L has current I passing through it, when it is placed parallel to a magnetic field. The force experienced by the conductor will be
(a) zero
(b) BLI
(c) B2LI
(d) BLI2
Ans: a

20. The force between two long parallel conductors is inversely proportional to
(a) radius of conductors
(b) current in one conductor
(c) product of current in two conduc¬tors

Ans:(d)distanced between the conductors

21. Materials subjected to rapid reversal of magnetism should have
(a) large area oiB-H loop
(b) high permeability and low hysteresis loss
(c) high co-ercivity and high reten-tivity

Ans:(d)highb co-ercivity and low density

22. Indicate which of the following material does not retain magnetism permanently.
(a) Soft iron
(b) Stainless steel
(e) Hardened steel

Ans:(d)Nonea of the above

23. The main constituent of permalloy is
(a) cobalt
(b) chromium

(c) nickel

Ans:(d)tungstenc

24. The use of permanent magnets is. not made in
(a) magnetoes
(6) energy meters
(c) transformers

Ans:(d)loudc-speakers

25. Paramagnetic materials have relative permeability
(a) slightly less than uuity
(b) equal to unity
(c) slightly more than unity

Ans:(d)equalc to that ferromagnetic mate rials

26. Degaussing is the process of
(a) removal of magnetic impurities
(b) removing gases from the materials
(c) remagnetising metallic parts

Ans:(d)demagnetising metallic parts

27. Substances which have permeability less than the permeability of free space are known as
(a) ferromagnetic
(b) paramagnetic
(c) diamagnetic

Ans:(d)bipolarc

28. Two infinitely long parallel conductors in vacuum anf' separated 1 metre between centres >rhen a current of 1 ampere flows thn. ugh each conductor, produce on each otLer a force of
(a) 2 x 1(T2 N/m)
(b) 2 x KT3 N/m
(c) 2 x 10"5 N/m

Ans:(d)2xd 1(T7 N/m)

29. In the left hand rule, forefinger always represents
(a) voltage
(b) current
(c) magnetic field

Ans:(d)directionc of force on the conductor

30. Which of the following is a ferromagnetic material ?
(a) Tungsten
(b) Aluminium
(c) Copper

Ans:(d)Nickeld

31. Ferrites are a sub-group of
(a) non-magnetic materials
(b) ferro-magnetic materials
(c) paramagnetic materials

Ans:(d)ferrid-magnetic materials

32. Gilbert is a unit of
(a) electromotive force
(b) magnetomotive force
(c) conductance

Ans:(d)permittivityb

33. The working of a meter is based on the use of a permanent magnet. In order to protect the meter functioning from stray magnetic fields
(a) meter is surrounded by strong magnetic fields (b) a soft iron shielding is used (c) a plastic shielding is provided
(d) a shielding of anon-magnetic material is used

Ans: b

34. Reciprocal of permeability is
(a) reluctivity
(b) susceptibility
(c) permittivity

Ans:(d)conductancea

35. The relative permeability is less than unity is case of
(a) ferromagnetic materials
(b) ferrites
(c) non-ferrous materials

Ans:(d)diamagneticd materials

36. Which of the following is the unit of magnetic flux density ?
(a) weber
(b) lumens
(c) tesla

Ans:(d)nonec of the above

37. The magnetism left in the iron after exciting field has been removed is known as
(a) permeance
(b) residual magnetism
(c) susceptance

Ans:(d) breluctance

38. Which of the following is not a unit of flux?
(a) Maxwell
(b) Telsa
(c) Weber

Ans:(d)Allb of the above

39. Which of the following is expected to have the maximum permeability ?
(a) Brass
(b) Copper
(c) Zinc

Ans:(d)Ebonited

40. One telsa is equal to
(a) 1 Wb/mm2
(b) 1 Wb/m
(c) 1 Wb/m2

Ans:(d)1 cmWb/m2

42. Out of the following statements, concerning an electric field, which statement is not true ?
(a) The electric intensity is a vector quantity
(b) The electric field intensity at a point is numerically equal to the force exerted upon a charge placed at that point
(c) An electric field is defined as a point in space at which an electric charge would experienc* a force
(d) Unit field intensity in the exertion of a force of one newton on a charge of one coulomb
Ans: b

43. When a magnet is in motion relative to a coil the induced e.m.f. does not depend upon
(a) resistance of the coil
(b) motion of the magnet
(c) number of turns of the coil

Ans:(d)polea strength of the magnet

44. One maxwell is equal to
(a) 10 webers
(b) 10 webers
(c) 10 webers

Ans:(d)10d webers

46. When two ends of a circular uniform wire are joined to the terminals of a battery, the field at the centre of the circle
(a) will be zero
(b) will be infinite
(c) will depend on the amount of e.m.f. applied

Ans:(d)willd depend on the radius of the circle

47. Susceptibility is positive for
(a) non-magnetic substances
(b) diamagnetic substances
(c) ferromagnetic substances

Ans:(d) cnone of the above

48. Two long parallel conductors carry 100 A. If the conductors are separated by 20 mm, the force per metre of length of each conductor will be
(a) 100 N
(b) 10 N
(c) 1 N

Ans:(d)0.1d N

49. A 300 mm long conductor is carrying a current of 10 A and is situated at right angles to a magnetic field having a flux density of 0.8 T ; the force on the conductor will be
(a) 240 N
(6) 24 N
(c) 2.4 N

Ans:(d)0.24c N

50. A 200 turn coil having an axial length of 30 mm and a radius of 10 mm is pivoted in a

magnetic field having a flux density of 0.8 T. If the coil carries a current of 0.5 A, the torque acting on the coil will be
(a) 4.8 N-m
(b) 0.48 N-m
(e) 0.048 N-m
(d) 0.0048 N-m

Ans:[Hint.c Torque = 2BIlNr N-m]

51. The electromagnet has 50 turns and a current of 1A flows through the coil. If the length of the magnet circuit is 200 mm, what is the magnetic field strength ?
(a) 2500 AT/m
(b) 250 AT/m
(c) 25 AT/m

Ans:(d)2.5b AT/m

52. What is the magnitude and the direction of force per 1.1m length of a pair of conductors of a direct current linecarrying 10 amperes and spaced 100 mm apart ?
(a) 22 x 10"8 N
(b) 22 x 10"7 N
(c) 22 x 10-6 N

Ans:(d)22d x 10"5 N

53. A square cross-sectional magnet has a pole strength of 1 x 10 Wb and cross sectional area of 20 mm x 20 mm. What is the strength at a distance of 100 mm from the unit pole in air ?
(a) 63.38 N/Wb
(b) 633.8 N/Wb
(c) 6338 N/Wb

Ans:(d)63380c N/Wb

56. The unit of flux is the same as that of
(a) reluctance
(b) resistance
(c) permeance

Ans:(d)poled strength

57. Unit for quantity of electricity is
(a) ampere-hour
(b) watt
(c) joule
(d) coulomb

Ans: d

58. The Biot-savart's law is a general modification of
(a) Kirchhoffs law
(b) Lenz's law
(c) Ampere's law

Ans:(d)Faraday'sc laws

61. The most effective and quickest may of making a magnet from soft iron is by
(a) placing it inside a coil carrying current
(b) induction
(c) the use of permanent magnet

Ans:(d)rubbinga with another magnet

62. The commonly used material for shielding or screening magnetism is
(a) copper
(b) aluminium
(c) soft iron

Ans:(d)brassc

63. If a copper disc is rotated rapidly below a freely suspended magnetic needle, the magnetic needle shall start rotating with a velocity
(a) less than that of disc but in opposite direction
(b) equal to that of disc and in the same direction
(c) equal to that of disc and in the opposite direction
(d) less than that of disc and in the same direction

Ans: d

64. A permanent magnet
(a) attracts some substances and repels others
(b) attracts all paramagnetic substan¬ces and repels others
(c) attracts only ferromagnetic sub¬stances
(d) attracts ferromagnetic substances and repels all others

Ans: a

65. The retentivity (a property) of material is useful for the construction of
(a) permanent magnets
(b) transformers
(c) non-magnetic substances

Ans:(d)electromagnetsa

66. The relative permeability of materials is not constant.

(a) diamagnetic
(b) paramagnetic
(c) ferromagnetic

Ans:(d)insulatingc

67. The materials are a bit inferior conductors of magnetic flux than air.
(a) ferromagnetic
(b) paramagnetic
(c) diamagnetic

Ans:(d)dielectricc

68. Hysteresis loop in case of magnetically hard materials is more in shape as compared to magnetically soft materials.
(a) circular
(b) triangular
(c) rectangular

Ans:(d)nonec of the above

69. A rectangular magnet of magnetic moment M is cut into two piece of same length, the magnetic moment of each piece will be
(a) M
(6) M/2
(c) 2 M
(d) M/4
Ans: b

70. A keeper is used to
(a) change the direction of magnetic lines
(b) amplify flux
(c) restore lost flux

Ans:(d)provided a closed path for flux

71. Magnetic moment is a
(a) pole strength
(6) universal constant
(c) scalar quantity

Ans:(d)vectord quantity

72. The change of cross-sectional area of conductor in magnetic field will affect
(a) reluctance of conductor
(b) resistance of conductor

(c) (a) and (b) b >th in the same way

Ans:(d)nonec of the above

73. The uniform magnetic field is
(a) the field of a set of parallel conductors
(b) the field of a single conductor
(c) the field in which all lines of mag¬netic flux are parallel and equidis¬tant

Ans:(d)nonec of the above

74. The magneto-motive force is
(a) the voltage across the two ends of exciting coil
(b) the flow of an electric current
(c) the sum of all currents embraced by one line of magnetic field
(d) the passage of magnetic field through an exciting coil

Ans: c

75. What will be the current passing through the ring shaped air cored coil when number of turns is 800 and ampere turns are 3200 ?
(a) 2
(b) 4
(c) 6

(d)Ans:8 b

76. What will be the magnetic potential difference across the air gap of 2 cm length in magnetic field of 200 AT/m ?
(a) 2 AT
(b) 4 AT
(c) 6 AT

Ans:(d)10b AT

77. Which of the following statements is correct ?
(a) The magnetic flux inside an exciting coil is lower than its outside surface
(6) The magnetic flux inside an exciting coil is zero
(e) The magnetic flux inside the exciting coil is greater than its outside surface
(d) The magnetic flux inside the exciting coil is same as on its outside surface

Ans: d

78. A certain amount of current flows through a ring-shaped coil with fixed number of turns. How does the mag
netic induction B varies inside the coil if an iron core is threaded into coil without dimensional change of coil ?
(a) Decreases

(b) Increases
(c) Remains same
(d) First increases and then decreases depending on the depth of iron in¬sertion Ans:

b

79. The magnetic reluctance of a material
(a) decreases with increasing cross sectional area of material
(6) increases with increasing cross-sec-tional area of material
(c) does not vary with increasing cross-sectional area of material

Ans:(d)anya of the above

80. The initial permeability of an iron rod is
(a) the highest permeability of the iron rod
(b) the lowest permeability of the iron rod
(c) the permeability at the end of the iron rod
(d) the permeability almost in non-magnetised state

Ans: d

82. How does the magnetic compass needle behave in a magnetic field ?
(a) It assures a position right angle to magnetic field
(b) It starts rotating
(c) It assures a position which follows a line of magnetic flux

Ans:(d)Nonec of the above

83. In a simple magnetic field the strength of magnet flux
(a) is constant and has same value in energy part of the magnetic field
(6) increases continuously from initial value to final value
(c) decreases continuously from initial value to final value
(d) first increases and then decreases till it becomes zero

Ans: d

84. The stray line of magnetic flux is defined as
(a) a line vertical to the flux lines
(b) the mean length of a ring shaped coil
(c) a line of magnetic flux in a non-uniform field
(d) a line of magnetic flux which does not follow the designed path

Ans: d

85. The bar magnet has
(a) the dipole moment
(b) monopole moment
(c) (a) and (b) both

Ans:(d)nonea of the above

86. Which of the following materials are dia-magnetic ?
(a) Silver
(b) Copper
(c) Silver and copper
(d) Iron
Ans: c

87. Which of the following type of materials are not very important for engineering applications ?
(a) Ferromagnetic
(b) Paramagnetic
(c) Diamagnetic

(d)Ans:Nonec of the above

88. The susceptibility of paramagnetic materials generally lies between
(a) KT3 and 1CT6
(b) 1CT3 and 1CT7
(c) KT4 and KT8

Ans:(d)10"2a and KT5

89. For which of the following materials the saturation value is the highest ?
(a) Ferromagnetic materials
(6) Paramagnetic materials
(c) Diamagnetic materials

Ans:(d)Ferritesd

90. The magnetic materials exhibit the property of magnetisation because of
(a) orbital motion of electrons
(b) spin of electrons
(c) spin of nucleus
(d) either of these

Ans:(e)allc of the above

91. For which of the following materials the net magnetic moment should be zero ?
(a) Diamagnetic materials
(b) Ferrimagnetic materials
(c) Antiferromagnetic materials

Ans:(d)Antiferrimagneticc materials

92. The attraction capacity of electromagnet will increase if the

(a) core length increases i
(b) core area increases
(c) flux density decreases

Ans:(d)fluxd density increases

93. Which of the following statements is correct ?
(a) The conductivity of ferrites is better than ferromagnetic materials
(b) The conductivity of ferromagnetic materials is better than ferrites
(c) The conductivity of ferrites is very high
(d) The conductivity of ferrites is same as that of ferromagnetic materials

Ans: a

96. Temporary magnets are used in
(a) loud-speakers
(b) generators
(c) motors

Ans:(d)alld of the above

97. Main causes of noisy solenoid are
(a) strong tendency of fan out of lami-nations at the end caused by repul¬sion among magnetic lines of force
(b) uneven bearing surface, caused by dirt or uneven wear between moving and stationary parts
(c) both of above

Ans:(d)nonec of the above

99. Strength of an electromagnet can be increased by (a) increasing the cross-sectional area (b) increasing the number of turns (c) increasing current supply

Ans:(d)all above methods

100. Core of an electromagnet should have
(a) low coercivity
(6) high susceptibility
(c) both of the above

Ans:(d)nonec of the above

101. Magnetism of a magnet can be destroyed by
(a) heating
(b) hammering

(c) by inductive action of another magnet

Ans:(d)byd all above methods

## MAGNETIC CIRCUIT

1. An air gap is usually inserted in magnetic circuits to
(a) increase m.m.f.
(b) increase the flux
(c) prevent saturation
(d) none of the above

Ans: c

2. The relative permeability of a ferromagnetic material is
(a) less than one
(b) more than one
(c) more than 10
(d) more than 100 or 1000

Ans: d

3. The unit of magnetic flux is
(a) henry
(b) weber
(c) ampereturn/weber

Ans:(d)ampere/metreb

4. Permeability in a magnetic circuit corresponds to______ in an electric circuit.
(a) resistance
(b) resistivity
(c) conductivity

Ans:(d)conductancec

5. Point out the wrong statement.
Magnetic leakage is undesirable in electric machines because it
(a) lowers their power efficiency
(b) increases their cost of manufacture
(c) leads to their increased weight
(d) produces fringing

Ans: a

6. Relative permeability of vacuum is
(a) 1
(b) 1 H/m
(c) 1/4JI

Ans:(d)4na x 10-' H/m

7. Permanent magnets are normally made of
(a) alnico alloys
(b) aluminium
(c) cast iron

Ans:(d)wroughta iron

8. Energy stored by a coil is doubled when its current is increased by percent. (a)

25

(c)41.4(b)50

Ans:(d)100c

9. Those magnetic materials are best suited for making armature and transformer cores which have____permeability and_______hystersis loss.
(a) high, high
(b) low, high
(c) high, low

Ans:(d)low,c low

10. The rate of rise of current through an inductive coil is maximum (a)

at 63.2% of its maximum steady value (b) at the start of the current

flow (c) after one time constant

Ans:(d)nearb the final maximum value of current

11. When both the inductance and resistance of a coil are doubled the value of
(a) time constant remains unchanged
(b) initial rate of rise of current is doubled
(c) final steady current is doubled

Ans:(d)timea constant is halved

12. The initial rate of rise of current through a coil of inductance 10 H when suddenly

connected to a D.C. supply of 200 V is_______Vs
(a) 50
(b) 20
(c) 0.05

Ans:(d)500b

13. A material for good magnetic memory should have
(a) low hysteresis loss
(b) high permeability
(c) low retentivity

Ans:(d)highd retentivity

14. Conductivity is analogous to
(a) retentivity
(b) resistivity
(c) permeability

Ans:(d)inductancec

15. In a magnetic material hysteresis loss takes place primarily due to
(a) rapid reversals of its magnetisation
(b) flux density lagging behind magnetising force
(c) molecular friction

Ans:(d)itdhigh retentivity

16. Those materials are well suited for making permanent magnets which have______retentivity and _______coercivity.
(a) low, high
(b) high, high
(c) high, low

(d)Ans:low,b low

17. If the area of hysteresis loop of a material is large, the hysteresis loss in this material will be
(a) zero
(b) small
(c) large

Ans:(d)nonec of the above

18. Hard steel is suitable for making permanent magnets because (a)

it has good residual magnetism

(b) its hysteresis loop has large area
(c) its mechanical strength is high

Ans:(d)itsa mechanical strength is low

19. Silicon steel is used in electrical machines because it has
(a) low co-ercivity
(b) low retentivity
(c) low hysteresis loss

Ans:(d)highc co-ercivity

20. Conductance is analogous to
(a) permeance
(b) reluctance
(c) flux

Ans:(d)inductancea

21. The property of a material which opposes the creation of magnetic flux in it is known as
(a) reluctivity
(b) magnetomotive force
(c) permeance

Ans:(d) dreluctance

22. The unit of retentivity is
(a) weber
(b) weber/sq. m
(c) ampere turn/metre

Ans:(d)ampereb turn

23. Reciprocal of reluctance is
(a) reluctivity
(b) permeance
(c) permeability

Ans:(d)susceptibilityb

24. While comparing magnetic and electric circuits, the flux of magnetic circuit is compared with which parameter of electrical circuit ?
(a) E.m.f.
(b) Current
(c) Current density
(d) Conductivity

Ans: b

25. The unit of reluctance is
(a) metre/henry
(b) henry/metre
(c) henry

Ans:(d)1/henryd

26. A ferrite core has less eddy current loss than an iron core because
(a) ferrites have high resistance
(b) ferrites are magnetic
(c) ferrites have low permeability

Ans:(d)ferritesd have high hysteresis

27. Hysteresis loss least depends on
(a) volume of material
(b) frequency
(c) steinmetz co-efficient of material

Ans:(d)ambientd temperature

28. Laminated cores, in electrical machines, are used to reduce
(a) copper loss
(b) eddy current loss
(c) hysteresis loss

Ans:(d)allb of the above

## ELECTROMAGNETIC INDUCTION

1. The property of coil by which a counter e.m.f. is induced in it when the current through the coil changes is known as
(a) self-inductance
(b) mutual inductance
(c) series aiding inductance
(d) capacitance

Ans: a

2. As per Faraday's laws of electromagnetic induction, an e.m.f. is induced in a conductor

whenever it

(a) lies perpendicular to the magnetic flux
(b) lies in a magnetic field
(e) cuts magnetic flux
(d) moves parallel to the direction of the magnetic field

Ans: c

3. Which of the following circuit element stores energy in the electromagnetic field ?
(a) Inductance
(b) Condenser
(c) Variable resistor
(d) Resistance

Ans: a

4. The inductance of a coil will increase under all the following conditions except (a) when more length for the same number of turns is provided (6) when the number of turns of the coil increase (c) when more area for each turn is provided
(d) when permeability of the core increases

Ans: a

5. Higher the self-inductance of a coil,
(a) lesser its weber-turns
(b) lower the e.m.f. induced
(c) greater the flux produced by it
(d) longer the delay in establishing steady current through it

Ans: d

6. In an iron cored coil the iron core is removed so that the coil becomes an air cored coil. The inductance of the coil will
(a) increase
(b) decrease
(c) remain the same

Ans:(d)initiallyb increase and then decrease

7. An open coil has
(a) zero resistance and inductance
(b) infinite resistance and zero inductance
(c) infinite resistance and normal inductance
(d) zero resistance and high inductance

Ans: b

8. Both the number of turns and the core length of an inductive coil are doubled. Its self-inductance will be
(a) unaffected
(b) doubled
(c) halved

Ans:(d)quadrupledb

9. If current in a conductor increases then according to Lenz's law self-induced voltage will
(a) aid the increasing current
(b) tend to decrease the amount of cur-rent
(c) produce current opposite to the in-creasing current

Ans:(d)aidc the applied voltage

10. The direction of incViced e.m.f. can be found by
(a) Laplace's law
(b) Lenz's law
(c) Fleming's right hand rule

Ans:(d)Kirchhoffb s voltage law

11. Air-core coils are practically free from
(a) hysteresis losses
(b) eddy current losses
(c) both (a) and (b)

Ans:(d)nonec of the above

12. The magnitude of the induced e.m.f. in a conductor depends on the
(a) flux density of the magnetic field
(b) amount of flux cut
(c) amount of flux linkages

Ans:(d)rated of change of flux-linkages

13. Mutually inductance between two magnetically-coupled coils depends on
(a) permeability of the core
(b) the number of their turns
(c) cross -sectional area of their com-mon core

Ans:(d)alld of the above

14. A laminated iron core has reduced eddy-current losses because

(a) more wire can be used with less D.C. resistance in coil
(b) the laminations are insulated from each other
(c) the magnetic flux is concentrated in the air gap of the core

Ans:(d)theb laminations are stacked vertf -cally

15. The law that the induced e.m.f. and current always oppose the cause producing them is due to
(a) Faraday
(b) Lenz
(c) Newton

Ans:(d)Coulombb

16. Which of the following is not a unit of inductance ?
(a) Henry
(b) Coulomb/volt ampere
(c) Volt second per ampere

Ans:(d)Allb of the above

17. In case of an inductance, current is proportional to
(a) voltage across the inductance
(b) magnetic field
(c) both (a) and (b)

Ans:(d)neitherb (a) nor (b)

18. Which of the following circuit elements will oppose the change in circuit current ?
(a) Capacitance
(b) Inductance
(c) Resistance

Ans:(d)Allb of the above

19. For a purely inductive circuit which of the following is true ?
(a) Apparent power is zero
(b) Relative power is.zero
(c) Actual power of the circuit is zero
(d) Any capacitance even if present in the circuit will not be charged

Ans: c

20. Which of the following is unit of inductance ?
(a) Ohm
(b) Henry
(c) Ampere turns

Ans:(d)Webers/metreb

21. An e.m.f. of 16 volts is induced in a coil of inductance 4H. The rate of change of current must be
(a) 64 A/s
(b) 32 A/s
(c) 16 A/s

Ans:(d)4 dA/s

22. The core of a coil has a length of 200 mm. The inductance of coil is 6 mH. If the core length is doubled, all other quantities, remaining the same, the in ductance will be
(a) 3 mH
(b) 12 mH
(c) 24mH

Ans:(d)48mHa

0.23.5, Thethe mutualselfinductancesinductanceof twoofthecoilscoilsareis 8 mH and 18 mH. If the co-efficients of coupling is
(a) 4 mH
(b) 5 mH
(c) 6 mH

(d)Ans:12c mH

24. Two coils have inductances of 8 mH and 18 mH and a co-efficient of coupling of 0.5. If the two coils are connected in series aiding, the total inductance will be
(a) 32 mH
(b) 38 mH
(c) 40 mH

Ans:(d)48b mH

25. A 200 turn coil has an inductance of 12 mH. If the number of turns is increased to 400 turns, all other quantities (area, length etc.) remaining the same, the inductance will be
(a) 6 mH
(b) 14 mH
(c) 24 mH

Ans:(d)48d mH

26. Two coils have self-inductances of 10 H and 2 H, the mutual inductance being zero. If the two coils are connected in series, the total inductance will be
(a) 6 H

(b) 8 H
(c) 12 H

Ans:(d)24c H

27. In case all the flux from the current in coil 1 links with coil 2, the co-efficient of coupling will be
(a) 2.0
(b) 1.0
(c) 0.5

Ans:(d)zerob

28. A coil with negligible resistance has 50V across it with 10 mA. The inductive reactance is
(a) 50 ohms
(b) 500 ohms
(c) 1000 ohms

Ans:(d)5000d ohms

29. A conductor 2 metres long moves at right angles to a magnetic field of flux density 1 tesla with a velocity of 12.5 m/s. The induced e.m.f. in the conductor will be
(a) 10 V
(6) 15 V
(c) 25V

Ans:(d)50Vc

30. Lenz's law is a consequence of the law of conservation of
(a) induced current
(b) charge
(c) energy

Ans:(d)inducedc e.m.f.

31. A conductor carries 125 amperes of current under 60° to a magnetic field of 1.1 tesla. The force on the conductor will be
nearly
(a) 50 N
(b) 120 N
(c) 240 N

Ans:(d)480b N

32. Find the force acting on a conductor 3m long carrying a current of 50 amperes at right

angles to a magnetic field having a flux density of 0.67 tesla.
(a) 100 N
(b) 400 N
(c) 600 N

Ans:(d)1000a N

33. The co-efficient of coupling between two air core coils depends on
(a) self-inductance of two coils only
(b) mutual inductance between two coils only
(c) mutual inductance and self inductance of two coils

Ans:(d)nonec of the above

34. An average voltage of 10 V is induced in a 250 turns solenoid as a result of a change in flux which occurs in 0.5 second. The total flux change is
(a) 20 Wb
(b) 2 Wb
(c) 0.2 Wb

Ans:(d)0.02d Wb

35. A 500 turns solenoid develops an average induced voltage of 60 V. Over what time interval must a flux change of 0.06 Wb occur to produce such a voltage ?
(a) 0.01 s
(b) 0.1 s
(c) 0.5 s

Ans:(d)5 cs

36. Which of the fpllowing inductor will have the least eddy current losses ?
(a) Air core
(b) Laminated iron core
(c) Iron core

Ans:(d)Powdereda iron core

37. A coil induces 350 mV when the current changes at the rate of 1 A/s. The value of inductance is
(a) 3500 mH
(b) 350 mH
(c) 250 mH

Ans:(d)150b mH

38. Two 300 uH coils in series without mutual coupling have a total inductance of

(a) 300 uH
(b) 600 uH
(c) 150 uH

Ans:(d)75b uH

39. Current changing from 8 A to 12 A in one second induced 20 volts in a coil. The value of inductance is
(a) 5 mH
(b) 10 mH
(c) 5 H

Ans:(d)10c H

40. Which circuit element(s) will oppose the change in circuit current ?
(a) Resistance only
(b) Inductance only
(c) Capacitance only

Ans:(d)Inductanceb and capacitance

41. A crack in the magnetic path of an inductor will result in
(a) unchanged inductance
(b) increased inductance
(c) zero inductance

Ans:(d)reducedd inductance

42. A coil is wound on iron core which carries current I. The self-induced voltage in the coil is not affected by
(a) variation in coil current
(b) variation in voltage to the coil
(c) change of number of turns of coil

Ans:(d)theb resistance of magnetic path

43. A moving magnetic field will produce the same effect as a conductor that is moving.
(a) Yes
(b) No
Ans:

44. The polarity of the induced voltage can be determined by using the left-hand generator rule.
(a) Yes
(b) No
Ans: a

45. Increasing the field or increasing the current will decrease the force on the conductor.
(a) Yes
(b) No
Ans: b

46. Reversing the field or the current will reverse the force on the conductor.
(a) Yes
(b) No
Ans: a

47. When a conductor moves in the field, so that it makes an angle 8 with the lines of flux, the force F is given as : F = Bl sin2 0.
(a) Yes
(b) No
Ans: b

## *Combinational Logic and Systems Design*

So far we have been discussing the generation, transmission and processing of signals whose amplitude (voltage, current) varies continuously in time and can in principle take any value.
At a certain instant of time we may represent a signal by displaying its amplitude in an analog form or in a digital format. The graphics below demonstrate the familiar representation of the two forms. Both displays are asked to display the number 4.7.


In this case the digital display on the left has the required resolution to represent the number exactly. If we try to display the number 4.76, this digital display, with its ability to display only 2 digits will have to round off the number, representing it either as 4.7 or 4.8, depending on how the system processes the numerics.

Our reading of the number off the analog display requires some interpolation of the value but in principle the resolution is only limited by our ability to identify the position of the measuring needle.

In general the characteristics of the digital display correspond to the digital signal which is required to generate the digital display in the first place.

If we now consider an analog signal which varies continuously in time, see Figure 2a, then if we sample the signal at discrete times (τ, 2τ, 3τ, κλπ) we will obtain the values indicated by the solid circles on Figure 2b. Furthermore, if we consider the **quantization** of the signal at these **discrete** sampling times we obtain the signal indicated on Figure 2c which is a **digital signal**. The analog signal is also shown on Figure 2c to emphasize the relationship between it and its digital representation.

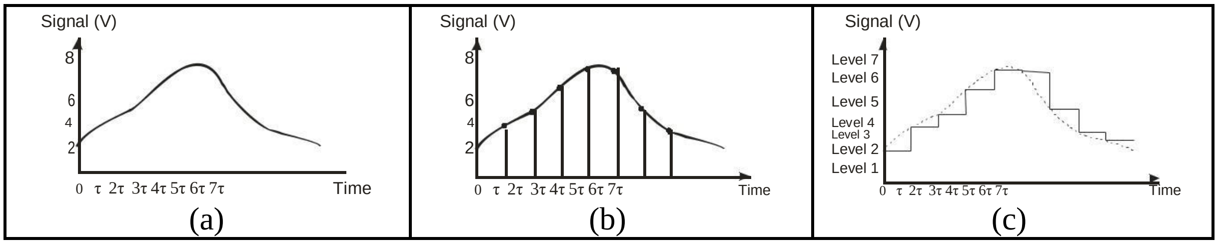



Figure 2. Schematic representation of analog and digital signals.

This review should have motivated us to ask a few questions about these signals and in particular about the digital signal shown on Figure 2c.

Some of these questions are:

3. How is the information embodied by the digital signal represented?
4. How is the signal generated?
    - How is the sampling frequency selected and how is it related to the "quality" of signal representation?
    - How is the amplitude quantization achieved?
5. What are the advantages and disadvantages of generating the digital signal? For example, how does it perform in
    - Accuracy
    - Transmission
    - Noise immunity
    - Information storage
    - Computation

In the next few classes we will answer these questions and explore the fundamental issues associated with the design of digital circuits.

## *Numbering Systems*

### Binary Code.

In digital electronics the signals are formed with only two voltage values, HI and LOW, or level **1** and level **0** and it is called binary digital signal.[1] Therefore, the information contained in the digital signal is represented by the numbers **1** and **0**. In most digital systems the state **1** corresponds to a voltage range from 2V to 5V while the state **0** corresponds to a voltage range from a fraction of a volt to 1 volts.

Digital operations are performed by creating and operating on binary numbers. Binary numbers are comprised of the digits 0 and 1 and are based on powers of 2.

Each digit of a binary number, 0 or 1, is called a bit, an abbreviation for **bi**nary digi**t**. Four bits together is a nibble, 8 bits is called a byte. (8, 16, 32, 64 bit arrangements are also called words) The rightmost bit is called the Least Significant Bit (LSB) while the leftmost bit is called the Most Significant Bit (MSB). The schematic below illustrates the general structure of a binary number and the associated labels.

### Binary to Decimal Conversion.

The conversion of a binary number to a decimal number may be accomplished by taking the successive powers of 2 and summing for the result.

For example let's consider the four bit binary number 0101. The conversion to a decimal number (base 10) is illustrated below.

$$\begin{array}{ccccccccc} 0 & & 1 & & 0 & & 1 & & \\ \downarrow & & \downarrow & & \downarrow & & \downarrow & & \\ 0\text{x}2^3 & + & 1\text{x}2^2 & + & 0\text{x}2^1 & + & 1\text{x}2^0 & & \\ \Downarrow & & \Downarrow & & \Downarrow & & \Downarrow & & \\ 0 & + & 4 & + & 0 & + & 1 & = & 5_{10} \end{array}$$

For this four bit binary number the range of powers of 2 goes from 0, corresponding to the LSB, to 3, corresponding to the MSB. The number 5 is shown as $5_{10}$ to indicate that it is a decimal number (power of 10).

The signal represented on Figure 2c has a value of 5 V at time=6τ. The binary representation of that value is 0101 and it is shown on Figure 3 replacing Level 4. We will see more of this later when we consider the fundamentals of the device which converts the analog signal to a digital signal.

Examples:

Verify the Binary to Decimal conversion

$1111_2 = 15_{10}$

$1111\ 0000_2 = 240_{10}$

$1111\ 1111_2 = 255_{10}$

$1101\ 1011_2 = 219_{10}$

$0001\ 0101\ 1011_2 = 347_{10}$

$1001\ 0101\ 1011_2 = 2395_{10}$

## Decimal to Binary Conversion.

The conversion of a decimal number to a binary number is accomplished by successively dividing the decimal number by 2 and recording the remainder as 0 or 1. Here is an example of the conversion of decimal number 125 to binary.

$$\frac{125}{2} = 62 + 1 \text{ LSB}$$

$$\frac{62}{2} = 31 + 0$$

$$\frac{31}{2} = 15 + 1$$

$$\frac{15}{2} = 7 + 1 \quad \Rightarrow 0111\ 1101$$

$$\frac{7}{2} = 3 + 1$$

$$\frac{3}{2} = 1 + 1$$

$$\frac{1}{2} = 0 + 1 \text{ MSB}$$

Practice number conversion by verifying the conversions from decimal to binary:

| Decimal | Binary |
|---|---|
| 69 | 0100 0101 |
| 299 | 0001 0010 1011 |
| 756 | 0010 1111 0100 |

Representation of fractions and signed numbers.

A fractional number may be represented as a binary fraction by simply extending the procedure used in representing integer numbers. For example,

$13.75_{10} = 1101.1100_2$

The procedure is clearly visualized by considering the following mapping

| $2^3$ | $2^2$ | $2^1$ | $2^0$ | | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ |
|---|---|---|---|---|---|---|---|---|
| 8 | 4 | 2 | 1 | | 0.5 | 0.25 | 0.125 | 0.0625 |
| 1 | 1 | 0 | 1 | . | 1 | 1 | 0 | 0 |
| | | | 13 | . | 75 | | | |

Signed binary numbers may be represented by assigning the MSB to indicate the sign. A 0 is used to indicate a positive number and a 1 is used to indicate a negative number.

For example, an 8 bit signed binary number represents the decimal numbers from -128 to +127.

Two's complement is used to represent negative numbers. The use of 2's complement simplifies the operation of subtraction since the circuit is only required to perform the operation of addition since X – Y = X + (-Y).

The 2's complement of a binary number is obtained by subtracting each digit of the binary number from digit 1. This is equivalent to replacing all 1's by 0's and all 0's by 1's. Negative numbers of 2's compliment can then be found by adding 1 to the complement of a positive number.

For example, the 2's complement of the 8 bit binary number 0000 1110 is 1111 0001 = $10_{10}$

The negative number of this 2's complement representation is 1111 0110 = $-10_{10}$

The procedure is outlined in the following

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | | 1 | 0 | 1 | 0 | binary number ($10_{10}$ ) |
| 1 | 1 | 1 | 1 | | 0 | 1 | 0 | 1 | 2's complement |
| | | | | + | | | | 1 | |
| 1 | 1 | 1 | 1 | | 0 | 1 | 1 | 0 | $-10_{10}$ |

By adding the two numbers the result is zero as shown below.

0000 1110 (+10)
Q. 1111 0110 (-10)
0000 0000 (0)

The table below shows the 2's complement representation of a few numbers. Fill in the empty spaces.

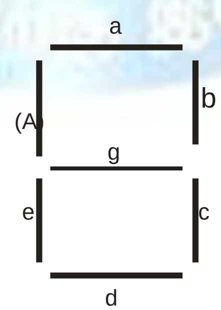
| Decimal | 2's complement |
|---|---|
| 0 | 0000 0000 |
| -1 | 1111 1111 |
| -2 | 1111 1110 |
| -3 | 1111 1101 |
| -4 | 1111 1100 |
| -10 | 1111 0110 |
| -15 | |
| -27 | |
| -80 | |
| -110 | |

## Binary Coded Decimal. BCD Code

BCD is a code used to represent each digit of a decimal number (0 to 9) as a 4 bit binary. For example, the decimal number 260 corresponds to the BDC number 0010 0110 0000.

2N 6N 0N Decimal
⇓ ⇓ ⇓
0010 0110 0000 BDC

This code is used to drive the 7 segment led displays.




For example, the BCD number 0010 corresponds to decimal 2 and is used to drive the segments a,b,d,e,g of the display. Similarly the number 0110 corresponds to number 6 and it is used to drive segments a,c,d,e,f,g. BCD 0000 corresponds to decimal 0 and it drives segments a,b,c,d,e,f. Special logic ICs are available for driving the led segments from a BCD number.

## Numbers with other bases.

The octal system, with base 8 and digits 0,1,2,3,4,5,6,7, and the hexadecimal system with base 16 and digits 0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F are also used in digital electronics. Octal and Hex representation is more compact, consider the conversion of the decimal number 1132 in binary, Octal and Hex shown below, and it is used in assembly language programming of microcontrollers.

$1132_{10}$ = $0100\ 0110\ 1100_2$ = $2154_8$ = $46C_{16}$

## *Fundamental Digital Devices: The inverter.*

The fundamental digital circuit for performing binary operations is the one which will convert from a logic **1** to a logic **0** and vise-versa. In our discussions we will use the positive logic convention which implies that the logic level 1 will correspond to the higher voltage level and the logic level 0 will correspond to the lower voltage level. Such a fundamental is shown on Figure 4.

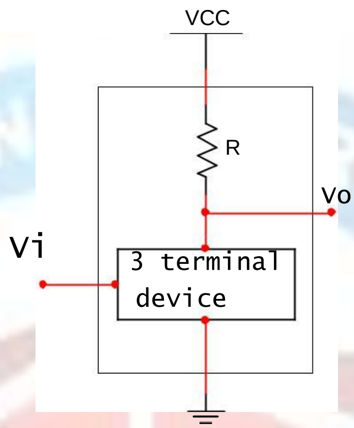



Figure 4. Fundamental inverter circuit.

The ideal voltage transfer characteristic of this circuit is shown on Figure 5.

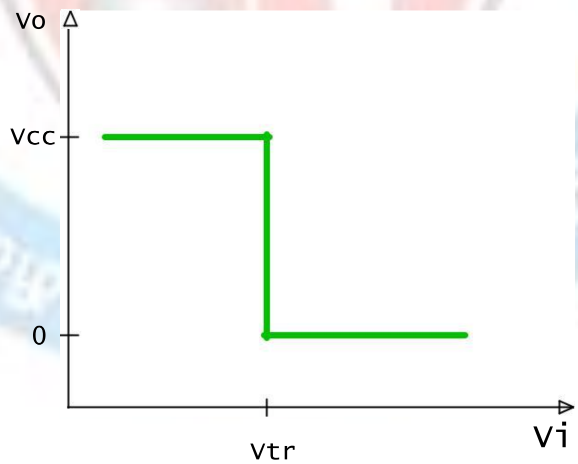



Figure 5. Ideal inverter voltage transfer characteristic

When the input voltage exceeds the transition value Vtr, the output switches.

It will become useful to familiarize ourselves with time evolution of digital signals. Such representation is called **timing diagram** which is used extensively in representing the operation of digital circuits. For our idealized inverter circuit, also called “inverter gate” a timing diagram would look like

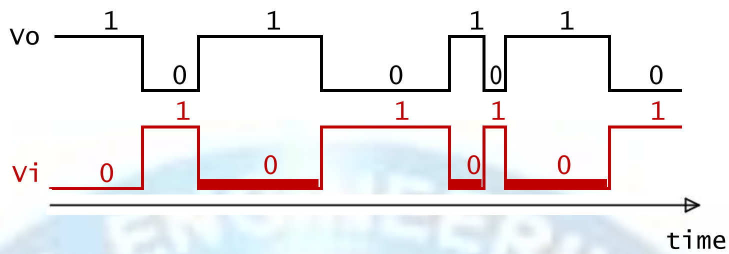



Figure 6. Ideal inverter timing diagram.

We thus see that the inverter is a voltage controlled digital switch. In practice the behavior of the inverter is not ideal. The output could assume a low value which will be in a range of voltages and a high value which also encompasses a range of voltage values. In addition the transition occurs with a time delay.

The inverter circuit may be constructed with active devices such as the Field Effect Transistor (FET) or the Bipolar Junction Transistor (BJT). The inverter circuit arrangements for these fundamental devices are shown on Figure 7.

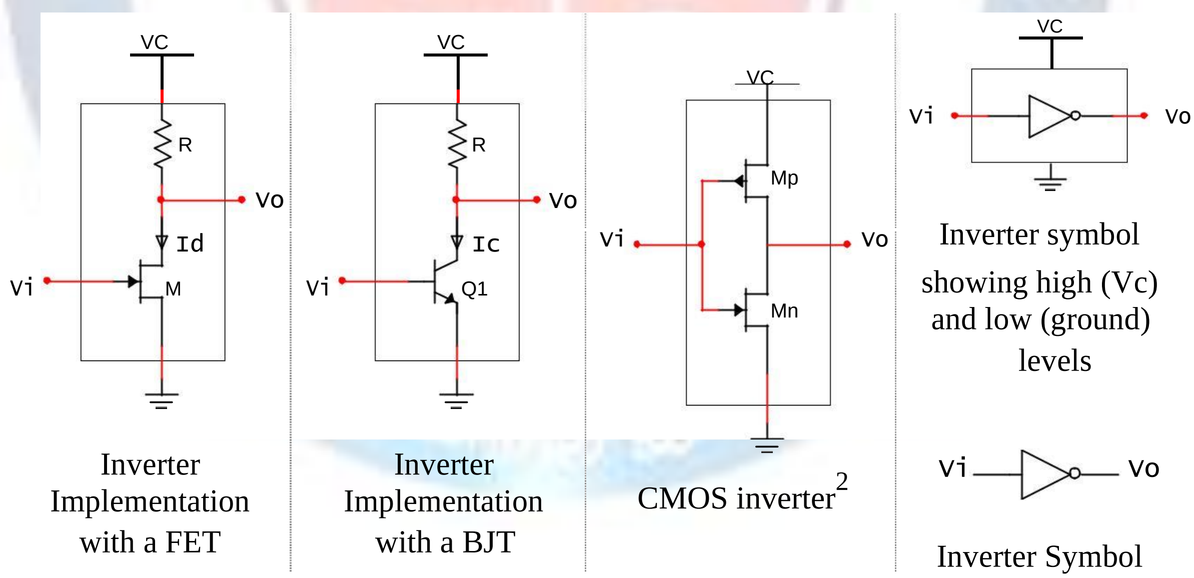
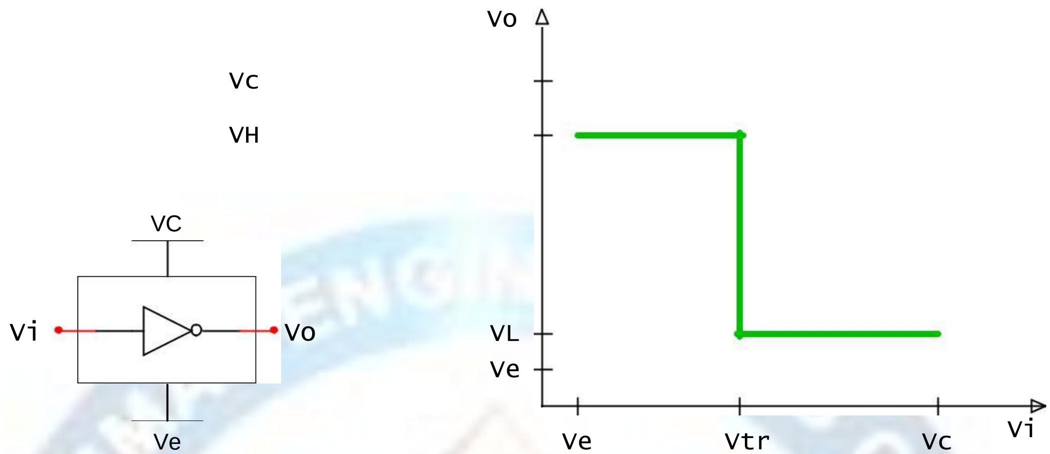


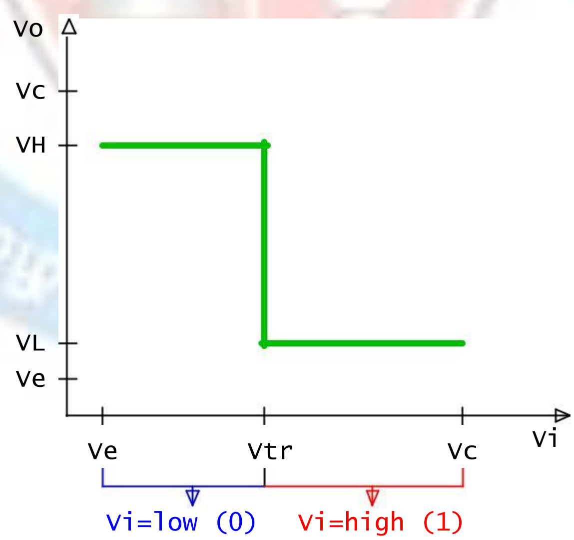

Figure 7. Inverter circuits and inverter symbol

The output voltage is the inverse of the input and the switching from one state to another state happens when the input voltage crosses a certain value Vtr. An inverter with supply voltages Vc and Ve and the corresponding voltage transfer characteristic is,




When Vi is less than the voltage Vtr (i.e when Vi is low) the output is VH (high). As the input voltage exceeds Vtr, (Vi is now high) the output switches to VL (low). Note that the values for VH and VL are not the same as the supply rails of the device. The actual values of VH and VL depend on the particular technology used in the construction of the inverter circuit.

For each design and for the particular semiconductor technology used the supply voltages Vc and Ve are well defined. A familiar power supply for digital systems is the Vc=+5V and Ve=0V. Supply systems with, Vc, voltage levels ranging from 1.5V to 5V are available.




In practical circuits the transition from one state to another does not happen abruptly. The transition is gradual and there is not a single value at which the transitions happen but rather a range of values that correspond to the transition as well as to the high and low states. This is a desirable situation since it allows for the design of robust systems with considerable noise immunity.

In addition there is a range of values which correspond to a certain logic level. Figure 8 shows a generic representation of the logic levels.

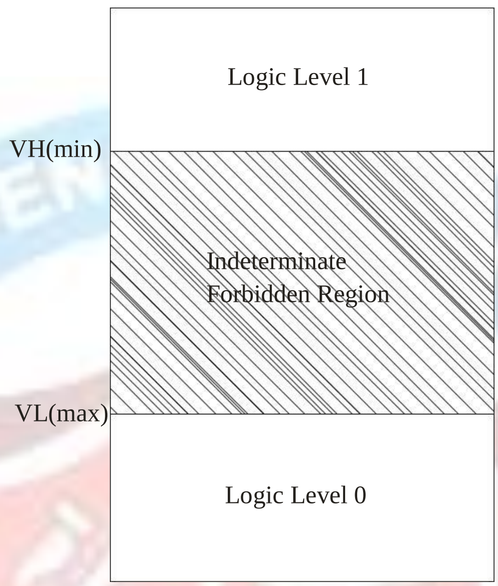



Figure 8. Logic gate levels

Any value less than VH(min) and greater than VL(max) falls in the forbidden region and its state is indeterminate. The values for VH(min) and VL(max) are different for the input and output of a gate. It is important to pay particular attention to these voltage levels since when one gate drives another, the input and output of each should fall within the specified level values.

When one gate drives another as in the graphic shown on Figure 9, the various voltage levels are defined as follows:

VHin(min): The minimum voltage level required for a logic level 1 at the input of a gate.

VLin(max): The maximum voltage level required for a logic 0 at the input of a gate.

VHout(min): The minimum voltage level required for a logic level 1 at the output of a gate.

VLout(max): The maximum voltage level required for a logic 0 at the output of a gate.

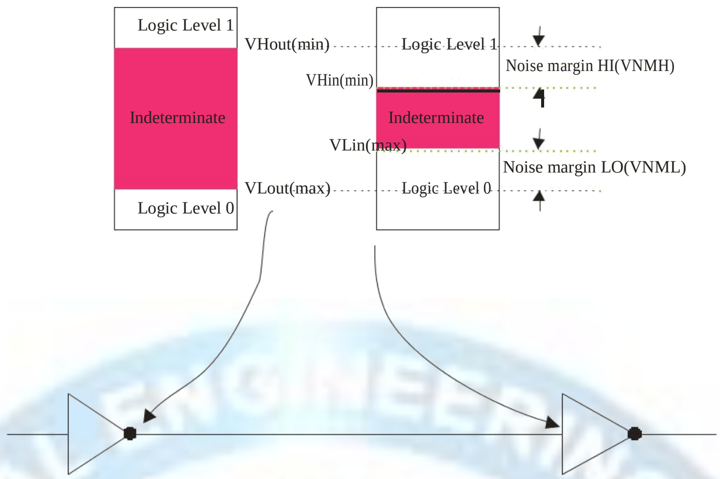



Figure 9. Logic gate input and output voltage levels

As can be seen from Figure 9, the presence of noise at the output of a certain gate may result in a voltage level which may be recognized as an appropriate state at the input of the following gate. The maximum voltage deviations due to noise that can be accepted by the logic gate inputs are defined as the HI and LO voltage noise margins,

$$VNMH = V1out(min) – V1in(min)$$

$$VNML = V0in(max) – V0out(max)$$

These voltage levels are summarized on Figure 10.

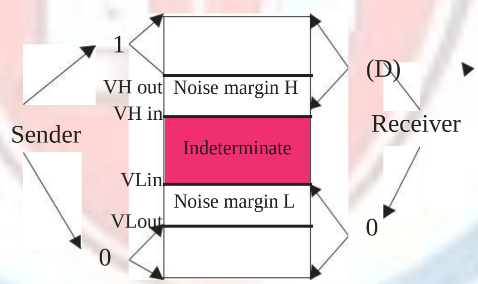



Figure 10. Voltage levels for sender and receiver.

The actual values of the minimum and maximum voltage values at the input and output of the logic gates depend on the type of device used to construct the logic gate. Currently there are two dominant logic families. They are the Transistor to Transistor Logic (TTL) based on the BJT inverter shown on Figure 7 and the Complementary Metal-Oxide Semiconductor (CMOS), based on the MOS families. Besides differences in speed and power consumption, these logic families are also different in the acceptable logic voltage levels for the gates. These differences should be taken into consideration when the design involves interfacing between TTL and CMOS circuits.

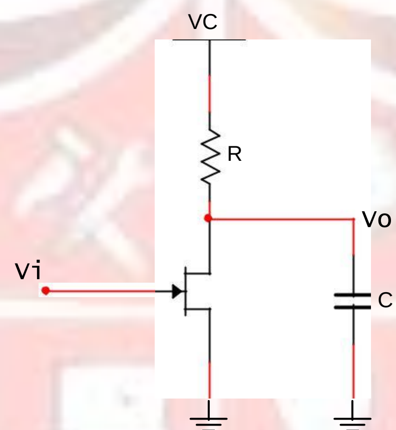
Table I provides a general comparison of the two families.

| | TTL | CMOS |
|---|---|---|
| Supply voltage (V) | 5 | 5 |
| V1in(min) | 2 | 3.5 |
| V0in(max) | 0.8 | 1.5 |
| V1out(min) | 2.4 | 4.5 |
| V0out(max) | 0.4 | 0.1 |
| VNMH | 0.4 | 1.0 |
| VNML | 0.4 | 1.4 |

Table I. Comparison of TTL and CMOS logic family parameters.

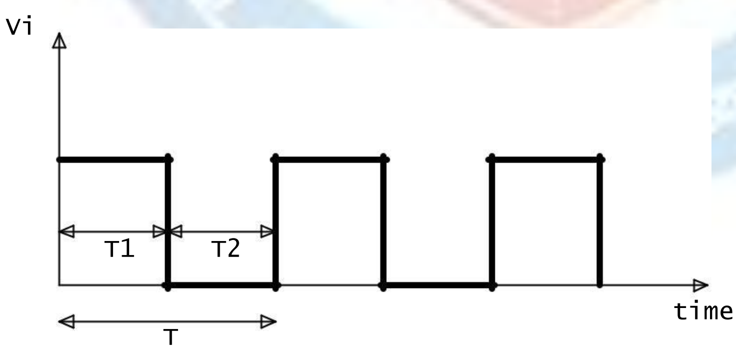
**A few words on power consumption.**

Let's consider the inverting gate,

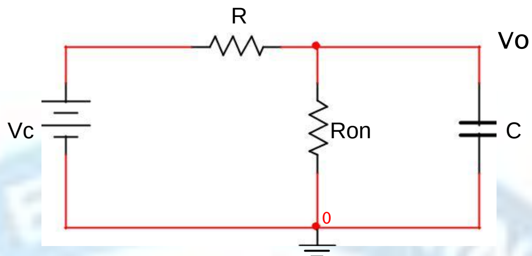



The capacitor C represents the wiring capacitance as well as the capacitance of the gate-source junction of the following gate.

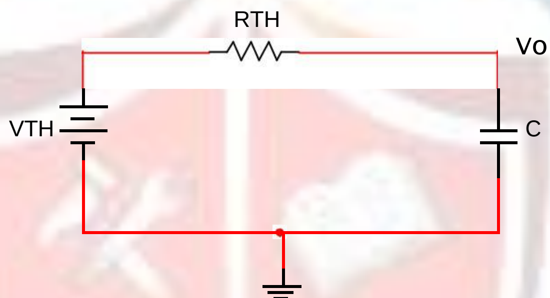
Let's calculate the average power for an input signal Vi has the form



During time T1 the FET is on and the equivalent circuit is



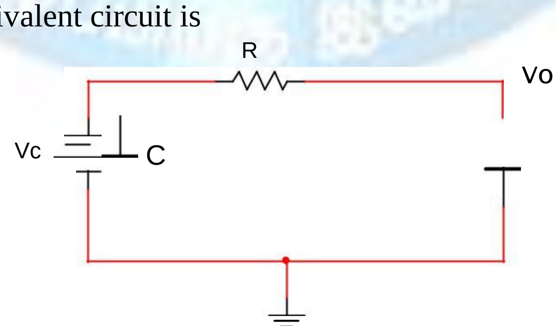

Where Ron is the on resistance of the FET. The Thevenin equivalent circuit is




Where $VTH = Vc \frac{Ron}{R+Ron}$ and $RTH = \frac{R(Ron)}{R+Ron}$. By assuming that time T1>> (RTH C) the energy dissipated during T1 is (The details of the calculation are left as an exercise for the student)

$$E1 = \underbrace{\frac{Vc^2\ T1}{R+Ron}}_{\text{Static}} + \underbrace{\frac{VTH^2C}{2}}_{\text{Dynamic}} = \underbrace{\frac{Vc^2\ T1}{R+Ron}}_{\text{Static}} + \underbrace{\frac{Vc^2R^2C}{2(R+Ron)^2}}_{\text{Dynamic}}$$

During time T2 the equivalent circuit is




During this time interval the capacitor will discharge starting from the voltage VTH reached during time T1. The energy dissipated during T2 is then (assuming T2>>RC)

$$E2 = \frac{Vc^2 R^2 C}{2(R+Ron)^2}$$

Dynamic

The total power dissipated during one period (T), assuming that T1 = T2 is

$$P = \frac{Vc^2}{2(R+Ron)} + \frac{Vc^2 R^2 C}{(R+Ron)^2 T}$$

Static Dynamic

Since R>>Ron (usually) the total power is

$$P = \frac{Vc^2}{N2R} + \frac{Vc^2 C}{NT} = \frac{Vc^2}{N2R} \text{ (A)} \quad Vc^2 \ f\ C$$

Static Dynamic Static

Dynamic

The static power is independent of frequency (f=1/T). The dynamic power is proportional to frequency and the supply voltage Vc.

Aw an example lets consider a digital device (chip) which incorporates $10^9$ gates operating at a frequency of 1GHz. Typical values are:
R = 10 kΩ
C = 0.1 fF
Vc = 5V

Total power is,

$$Pt = 10^{9} \frac{25}{20000} + 25 \times 10^{-16} \times 10^{9}$$

= 1250 kW + 2.5 kW

Static power Dynamic power

Well… something has to be done.

Indeed the static power can be practically reduced to zero by the CMOS design which basically eliminates the path to ground through resistor Ron.

The Dynamic power can be reduced by decreasing Vc. By going from Vc=5 V to Vc=1 V the dynamic power is reduced from 2500 W to 100 W. Not bad.

**Signal Conversion.**

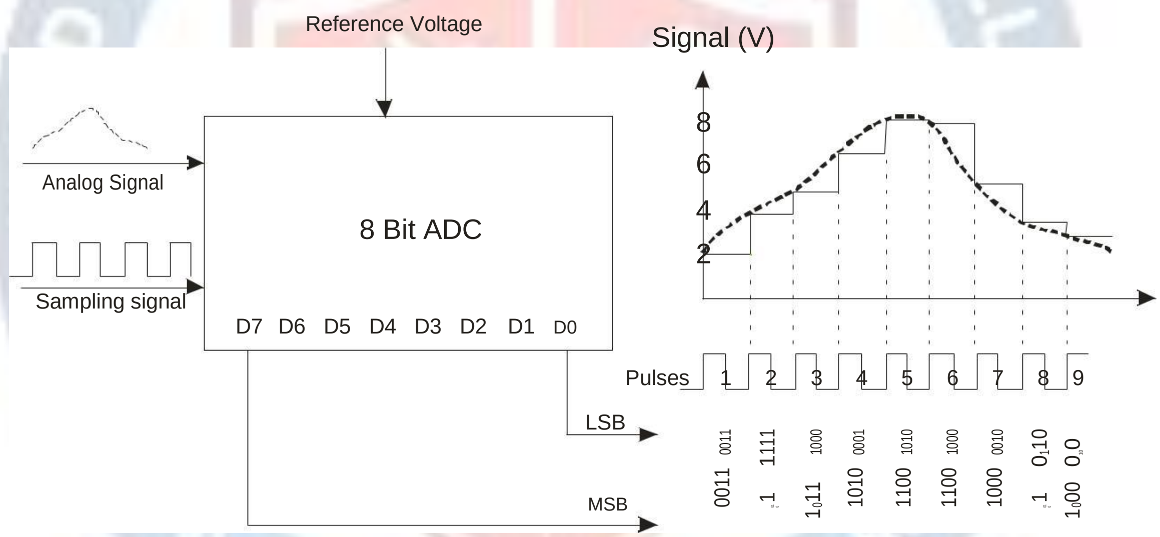
Analog to Digital Conversion

The electrical signals (voltage or current) generated by a transducer is an analog signal. The amplitude of the signal corresponds to the value of the physical phenomenon that the transducer detects. The signal values are continuous in time.

The processing of the signal by a digital system requires the conversion of the analog signal to a digital signal. The analog to digital conversion is not a continuous process but it happens at discrete time intervals. Furthermore the magnitude of the digital signal at the time of conversion should correspond to the magnitude of the analog signal.

The analog to digital converter (ADC) is a device that receives as its input the analog signal along with instructions regarding the sampling rate (how often is a conversion going to be performed) and scaling parameters corresponding to the desired resolution of the system. The output of the ADC is a binary number at each sampling time.

The following schematic shows the basic structure of an 8 bit ADC.




The selection of an 8 bit ADC sets the resolution of our conversion and the selection of the scale for the analog signal determines the measurement resolution for our ADC. In our example the 8 bit ADC implies $2^8$ = 256 different levels within the maximum signal range.

Since we are measuring a voltage with possible values between 0V and 10V, our 8 bit ADC is not able to resolve voltages smaller than $\frac{10}{2^8}$ mV = 39mV.

If this ADC has a resolution of 16 bits, like the one that you have in your laboratory, the resolution, for the same measurement range, would be $\frac{10}{2^{16}}$ mV=0.15mV.

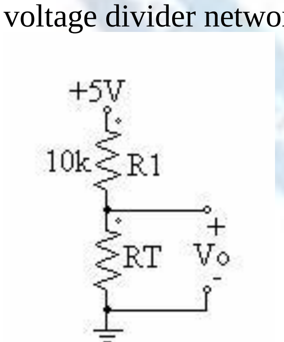
The table below summarizes the conversion process

| Pulse | Signal Value | Level | Binary number |
|---|---|---|---|
| 1 | 2 | $\frac{2}{10}256 = 51$ | 0011 0011 |
| 2 | 3.7 | $\frac{3.7}{10}256 = 95$ | 0101 1111 |
| 3 | 4.7 | $\frac{4.7}{10}256 = 120$ | 0111 1000 |
| 4 | 6.3 | $\frac{6.3}{10}256 = 161$ | 1010 0001 |
| 5 | 7.9 | $\frac{7.9}{10}256 = 202$ | 1100 1010 |
| 6 | 7.8 | $\frac{7.8}{10}256 = 200$ | 1100 1000 |
| 7 | 5.1 | $\frac{5.1}{10}256 = 130$ | 1000 0010 |
| 8 | 3.5 | $\frac{3.5}{10}256 = 90$ | 0101 1010 |

The sampling frequency must be larger than the highest frequency of the analog signal to be converted. In fact as stated by the "Sampling Theorem" ***The sampling frequency must be at greater than 2 times the bandwidth of the input signal***.

Problem:

You would like to design a thermistor based thermometer with a resolution of $0.1^{o}$ Celcius in the range of 0 to 100 degrees Celsius. Let's assume that your thermistor (RT) has an accuracy of 0.001 Degrees Celsius and that the analog signal is generated by the standard voltage divider network,




Design your instrument by appropriately selecting resistor R1 and the resolution of the ADC.

## Digital Logic: Boolean Algebra

Boolean algebra is a special symbolic mathematical language used to carry out logic operations. Boolean algebra was developed in the mid 1800s by George Boole (1815-1864) an English mathematician, for the purpose of performing "Logic and Probability Calculations". In Boolean algebra variables have only two possible values, 1 or 0 and it is the language used for performing binary logic operations.

The basic logic operations and their corresponding Boolean representation and associated symbols are given on Table II. The variables A and B are the inputs to the functions (Gates) and can assume the value 0 or 1. The variable Y represents the output of the logic operation or equivalently the output of the logic gate and its value is also either 0 or 1.

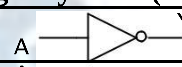
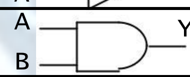
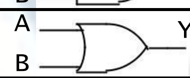
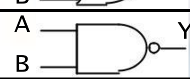
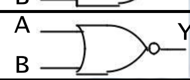
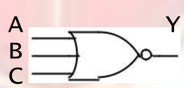
| Logic Operation | Boolean Representation | Logic Symbol (Gates) |
|---|---|---|
| NOT | $Y = \overline{A}$ |   |
| AND | $Y = A \bullet B = AB$ |   |
| OR | $Y = A + B$ |   |
| NAND | $Y = \overline{A \bullet B} = \overline{AB}$ |   |
| NOR | $Y = \overline{A + B}$ |   |

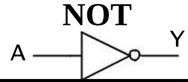
Table II. Basic logic operations and their Boolean representation

The NOT operation (inversion) is performed by the inverter discussed earlier and it has one input and one output. The number of inputs to the AND, OR, NOR, NAND logic gates can be greater than two. For example the Boolean representation of the 3 input NOR gate is $Y = \overline{A + B + C}$ and the corresponding logic gate is,



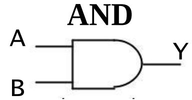
The rules associated with each logic operation (function) may be represented in a useful tabular form by the Truth Table. The Truth Tables for the basic logic operations listed on Table II are:

**NOT**



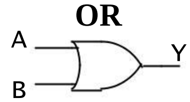

| A | Y |
|---|---|
| 0 | 1 |
| 1 | 0 |

**AND**



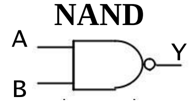

| A | B | Y |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

**OR**



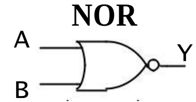

| A | B | Y |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

**NAND**




| A | B | Y |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

**NOR**




| A | B | Y |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 0 |

The designer of logic circuits and systems must optimize the design for maximum performance (i.e low power, speed, etc) and for the lowest cost. The simplification of logic expressions results in a simplified digital logic circuit. Logic expressions may be simplified by making use of the following Boolean identities.

| **Boolean Identities** | |
|---|---|
| A + 0 = A | A •1=A |
| A + B = B + A | AB=BA |
| A + (B + C) = (A + B) + C | A(BC) = (AB)C |
| A + BC = (A +B)(A + C) | A(B+C) = AB + AC |
| A + A = A | A • $\overline{A}$ = 0 |
| A + 1 = 1 | A • A = A |
| A + $\overline{A}$ = 1 | A • 0=0 |
| A + AB = A | A(A +B)=A |
| A + $\overline{A}$ B = A+B | (A + B) (A + C) = A + B C |
| $\overline{AB} = \overline{A} + \overline{B}$ | $\overline{A+B} = \overline{A} \bullet \overline{B}$ |

The identities $\overline{AB} = \overline{A} + \overline{B}$ and $\overline{A+B} = \overline{A} \bullet \overline{B}$ are also called DeMorgan's Theorems and are of particular importance in logic analysis and design. The fundamental consequence of DeMorgan's theorems is that:

**Any logic function may be implemented by using only OR and NOT gates or only AND and NOT gates.**

A very important consequence of Boolean algebra is the **sum of products** or the **product of sums** representation of any Boolean expression. To illustrate the usefulness of the procedure let's consider the logic function represented by the following truth table,

| A | B | Y |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

The information in this truth table might represent the logic associated with a certain digital process that we would like to model, or it might represent the operational characteristics of a certain digital circuit that we would like to construct. The Boolean representation of the logic function is the first step in achieving a robust and efficient design.

In order to construct the **sum of products** we proceed as follows.

(I) Identify the rows for which the result (Y in our case) is 1 (TRUE). For our example these are rows 2 and 3.

| A | B | Y |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

(II) Use these cases to construct the sum of products by using the uncomplemented representation of the variable that has the value of 1 and the complemented representation of the variable that has the value of 0

| A | B | Y | |
|---|---|---|---|
| 0 | 0 | 0 | |
| 0 | 1 | 1 | $\overline{A} \bullet B$ |
| 1 | 0 | 1 | $A \bullet \overline{B}$ |
| 1 | 1 | 0 | |

And by taking the "sum of the products" we obtain: $Y = \left(\overline{A} \bullet B\right) + \left(A \bullet \overline{B}\right)$

(III) The resulting Boolean function represents the entire logic sequence as can be verified by constructing the corresponding truth table.

The **product of sums** method may also be used in order to realize the Boolean representation of the logic presented by the previous truth table.

The construction of **products of sums** proceeds as follows.

(V) Identify the rows for which the result (Y in our case) is 0 (FALSE). For our example these are rows 1 and 4.

| A | B | Y |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

A Use these cases to construct the products of sums by using the uncomplemented representation of the variable that is 0 and the complemented representation of the variable that is 1

| A | B | Y | |
|---|---|---|---|
| 0 | 0 | 0 | A + B |
| 0 | 1 | 1 | |
| 1 | 0 | 1 | |
| 1 | 1 | 0 | $\bar{A}+\bar{B}$ |

$$Y = (\bar{A}+\bar{B})\cdot(A+B)$$

**3.** The resulting Boolean function represents the entire logic sequence as can be verified by constructing the corresponding truth table. Also by manipulating the expression obtained from the application of the product of sums we obtain:

$(\bar{A}+\bar{B})\cdot(A+B)=$ ← (product of sums)

(A)— AB )•( A + B)=

(B)— AB )•A + ( AB )•B=

A — A+B)•A + ( A+B)•B=

Q. — A+B)•A + ( A+B)•B=

(A) A•A+B•A) + ( A•B+B•B)=

(A)— 0+B•A) + ( A•B+0)=

$(\bar{B}\cdot A)+(\bar{A}\cdot B)=(A\cdot\bar{B})+(\bar{A}\cdot B)$ ← sum of products

The two methods are equivalent. The choice of which method to use is based on the details of the logic function to be implemented. For example, is we are considering a 3 input logic sequence for which the result is true (1) for 2 out of the eight ($2^3$) possible cases then the reduced algebraic complexity associated with the use of the sum of products approach will be advantageous.

| A | B | C | Y1 | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | |
| 0 | 0 | 1 | 1 | $\overline{A}\bullet\overline{B}\bullet C$ |
| 0 | 1 | 0 | 0 | |
| 0 | 1 | 1 | 0 | |
| 1 | 0 | 0 | 0 | |
| 1 | 0 | 1 | 1 | $A\bullet\overline{B}\bullet C$ |
| 1 | 1 | 0 | 0 | |
| 1 | 1 | 1 | 0 | |

Work with Sum of Products

$$Y1=(\overline{A}\bullet\overline{B}\bullet C)+(A\bullet\overline{B}\bullet C)$$

| A | B | C | Y2 | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | $A+B+C$ |
| 0 | 0 | 1 | 1 | |
| 0 | 1 | 0 | 1 | |
| 0 | 1 | 1 | 1 | |
| 1 | 0 | 0 | 0 | $\overline{A}+B+C$ |
| 1 | 0 | 1 | 1 | |
| 1 | 1 | 0 | 1 | |
| 1 | 1 | 1 | 1 | |

Work with Products of Sums

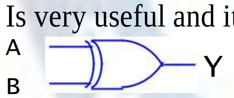
$$Y2=(A+B+C)\bullet(\overline{A}+B+C)$$

**Two additional useful gates: XOR and XNOR**

The gate represented by the truth table

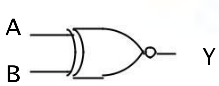
| A | B | Y |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

Is very useful and it is called Exclusive OR (XOR). The symbol of this gate is




Another useful gate is the Exclusive NOR gate (XNOR). The truth table and the symbol for this gate are

| A | B | Y |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |



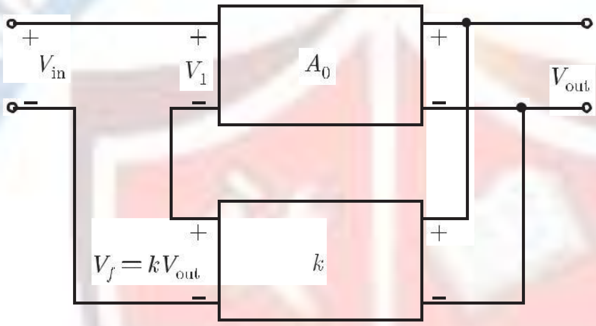
# ANALOG & DIGITAL ELECTRONICS

Q. 1 A bulb in a staircase has two switches, one switch being at the ground floor and the other one at the first floor. The bulb can be turned ON and also can be turned OFF by any one of the switches irrespective of the state of the other switch. The logic of switching of the bulb resembles

(A) and AND gate (B) an OR gate

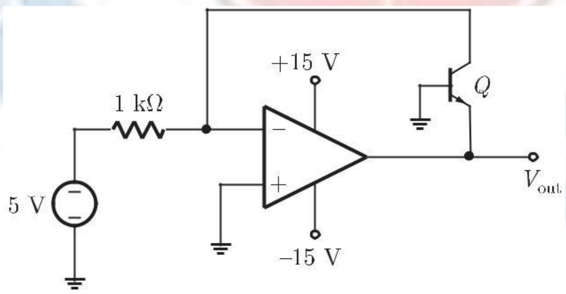
(C) an XOR gate (D) a NAND gate

Q. 2 In a voltage-voltage feedback as shown below, which one of the following statements is TRUE if the gain $k$ is increased?




6. The input impedance increases and output impedance decreases
7. The input impedance increases and output impedance also increases
8. The input impedance decreases and output impedance also decreases
9. The input impedance decreases and output impedance increases

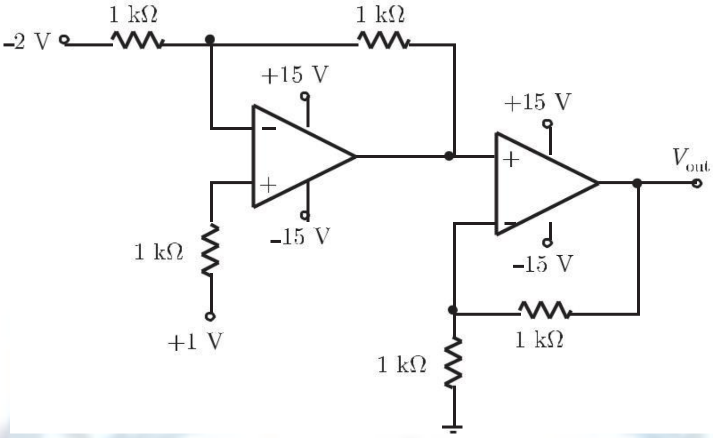
Q. 3 In the circuit shown below what is the output voltage $V_{out}$ if a silicon transistor $Q$ and an ideal op-amp are used?




(A) -15 V (B) -0.7 V

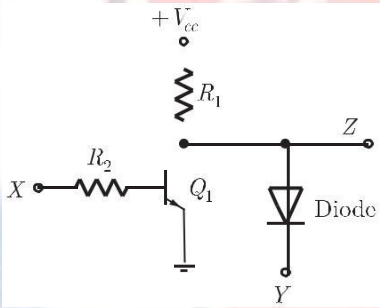
(C) +0.7 V (D) +15 V

Q. 4 In the circuit shown below the op-amps are ideal. Then, $V_{out}$ in Volts is



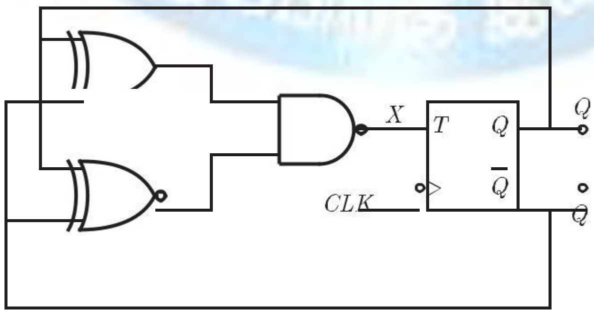

(A) 4 (B) 6
(C) 8 (D) 10

Q. 5 In the circuit shown below, $Q_1$ has negligible collector-to-emitter saturation voltage and the diode drops negligible voltage across it under forward bias. If $V_{cc}$ is +5 V, $X$ and $Y$ are digital signals with 0 V as logic 0 and $V_{cc}$ as logic 1, then the Boolean expression for $Z$ is



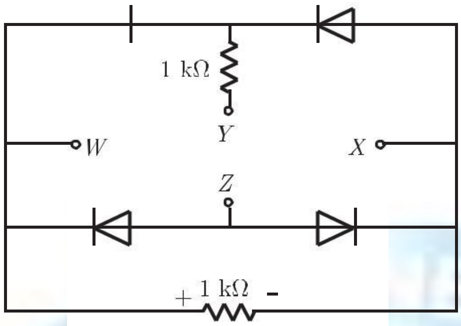

(A) $XY$ (B) $\overline{X}Y$
(C) $X\overline{Y}$ (D) $\overline{XY}$

Q. 6 The clock frequency applied to the digital circuit shown in the figure below is 1 kHz. If the initial state of the output of the flip-flop is 0, then the frequency of the output waveform $Q$ in kHz is




(A) 0.25 (B) 0.5
(C) 1 (D) 2

Q. 7 A voltage 1000 sin *wt* Volts is applied across *YZ* . Assuming ideal diodes, the voltage measured across *WX* in Volts, is



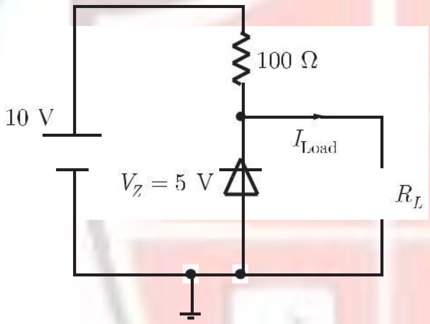

(A) sin *wt*

(B) _ sin *wt* + |sin *wt* |i/2

(C) ^sin *wt* - sin *wt* h/2

(D) 0 for all *t*

Q. 8 In the circuit shown below, the knee current of the ideal Zener dioide is 10 mA . To maintain 5 V across $R_L$ , the minimum value of $R_L$ in W and the minimum power rating of the Zener diode in mW, respectively, are




(A) 125 and 125

(B) 125 and 250

(C) 250 and 125

(D) 250 and 250

Q. 9 In the sum of products function *f* (*X*, *Y*, *Z*) = /(2,3,4,5), the prime implicants are

(A) $\overline{X}Y, X\overline{Y}$

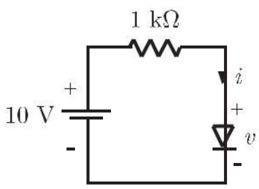
(B) $\overline{X}Y, X\overline{Y}\,\overline{Z}, X\overline{Y}Z$

(C) $\overline{X}Y\overline{Z}, \overline{X}YZ, X\overline{Y}$

(D) $\overline{X}Y\overline{Z}, \overline{X}YZ, X\overline{Y}\,\overline{Z}, X\overline{Y}Z$

R. 10 The *i* -*v* characteristics of the diode in the circuit given below are

$$i = * \begin{matrix} \frac{v - 0.7}{500} \text{ A}, & v \$ 0.7 \text{ V} \\ 0 \text{ A} & v < 0.7 \text{ V} \end{matrix}$$




The current in the circuit is

(A) 10 mA (B) 9.3 mA

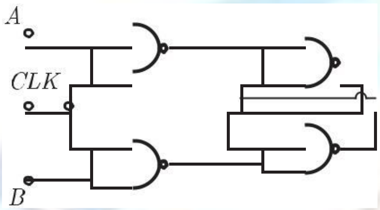
(C) 6.67 mA (D) 6.2 mA

Q. 11 The output $Y$ of a 2-bit comparator is logic 1 whenever the 2-bit input $A$ is greater than the 2-bit input $B$ . The number of combinations for which the output is logic 1, is

(A) 4 (B) 6

(C) 8 (D) 10

Q. 12 Consider the given circuit




In this circuit, the race around

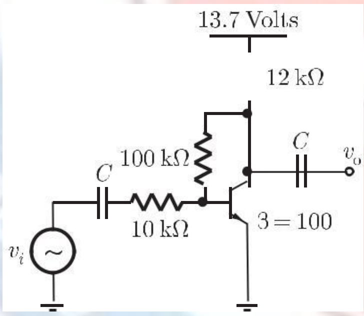
(A) does not occur

(B) occur when $CLK$ = 0

(C) occur when $CLK$ = 1 and $A$ = $B$ = 1

(D) occur when $CLK$ = 1 and $A$ = $B$ = 0

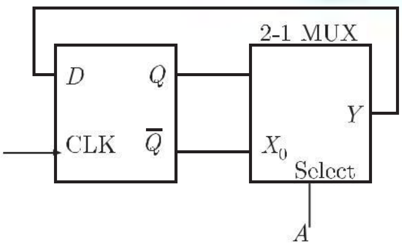
Q. 13 The voltage gain $A_v$ of the circuit shown below is

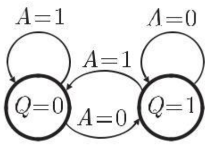


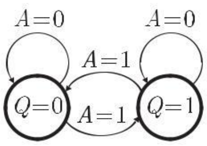

(A) $|A_v|$. 200 (B) $|A_v|$. 100

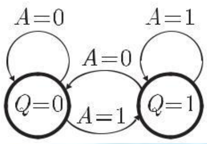
(C) $|A_v|$. 20 (D) $|A_v|$. 10

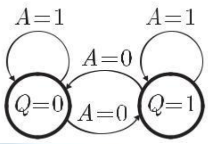
Q. 14 The state transition diagram for the logic circuit shown is



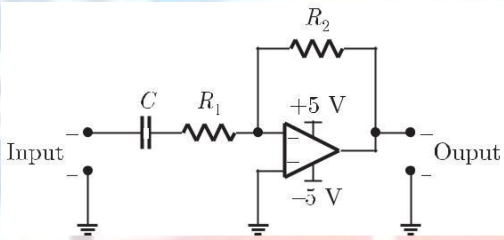
(A) 


(B) 


(C) 


(B) 


Q. 15 The circuit shown is a



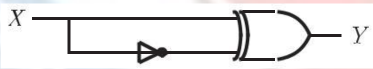

(A) low pass filter with $f_{3dB} = \dfrac{1}{(R_1 + R_2)C}$ rad/s

(B) high pass filter with $f_{3dB} = \dfrac{1}{R_1 C}$ rad/s

(C) low pass filter with $f_{3dB} = \dfrac{1}{R_1 C}$ rad/s

(D) high pass filter with $f_{3dB} = \dfrac{1}{(R_1 + R_2)C}$ rad/s

Q. 16 The output $Y$ of the logic circuit given below is




(A) 1

(B) 0

(C) $X$

(D) $\overline{X}$

Q. 17 A low-pass filter with a cut-off frequency of 30 Hz is cascaded with a high pass filter with a cut-off frequency of 20 Hz. The resultant system of filters will function as

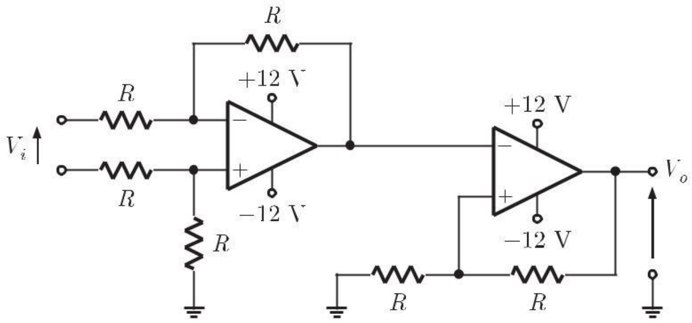
(A) an all – pass filter

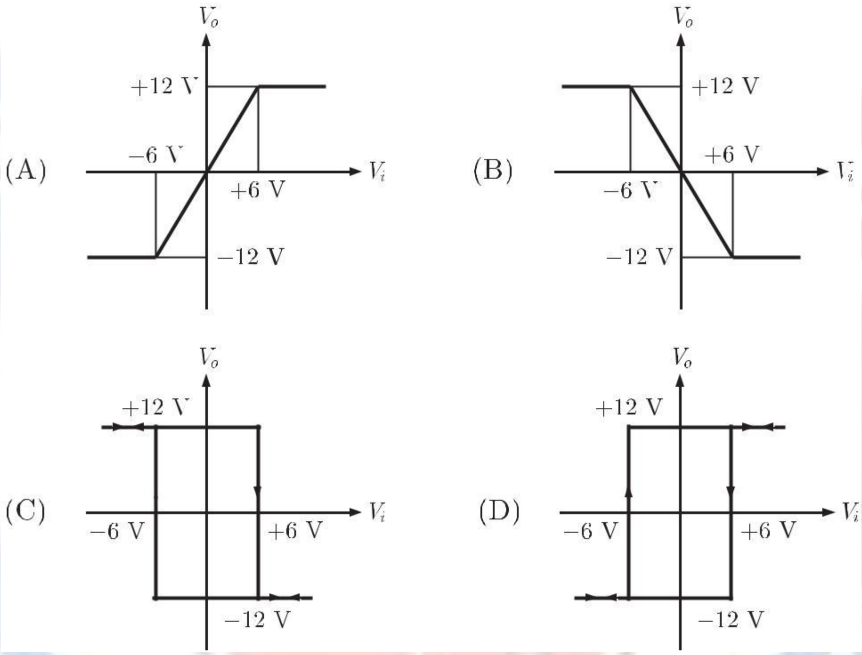
(B) an all – stop filter

(C) an band stop (band-reject) filter

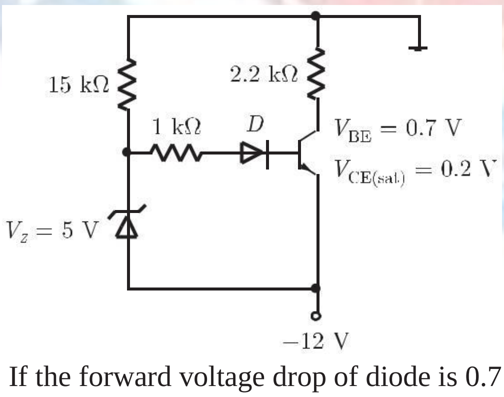
(D) a band – pass filter

**Q. 18** The CORRECT transfer characteristic is




**Q. 19** The transistor used in the circuit shown below has a *b* of 30 and $I_{CBO}$ is negligible




If the forward voltage drop of diode is 0.7 V, then the current through collector will be

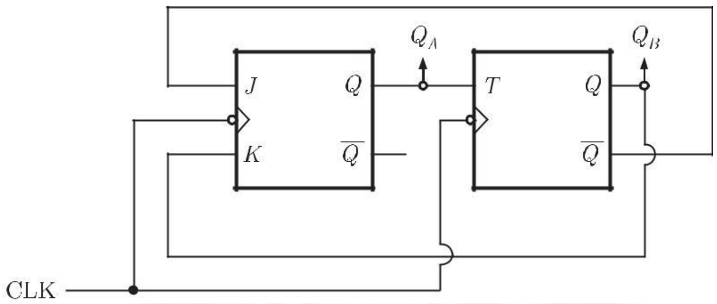
(A) 168 mA

(B) 108 mA

(C) 20.54 mA

(D) 5.36 mA

Q. 20 A two bit counter circuit is shown below




It the state $Q_A Q_B$ of the counter at the clock time $t_n$ is '10' then the state $Q_A Q_B$ of the counter at $t_n + 3$ (after three clock cycles) will be

(A) 00 (B) 01

(C) 10 (D) 11

Q. 21 A portion of the main program to call a subroutine SUB in an 8085 environment is given below.

h
LXI D, DISP
LP : CALL SUB
LP+3
h

It is desired that control be returned to LP+DISP+3 when the RET instruction is executed in the subroutine. The set of instructions that precede the RET instruction in the subroutine are

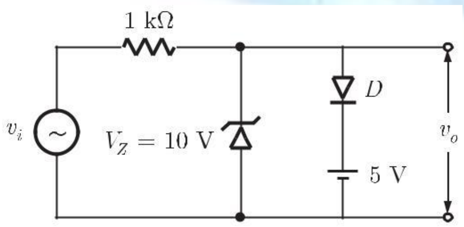
(B) POP D
DAD H
PUSH D

(B) POP H
DAD D
INX H
INX H
INX H
PUSH H

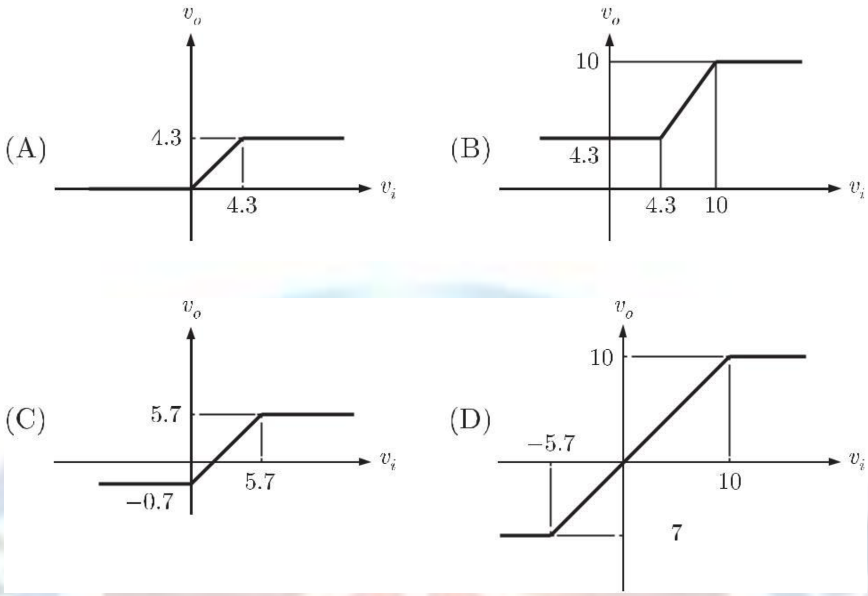
(C) POP H
DAD D
PUSH H

(E) XTHL
INX D
INX D
INX D
XTHL

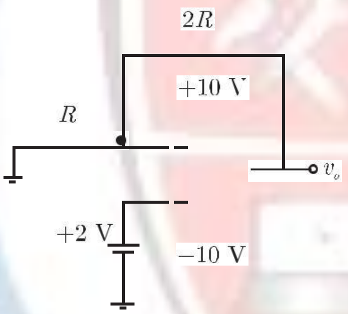
Q. 22 A clipper circuit is shown below.




Assuming forward voltage drops of the diodes to be 0.7 V, the input-output transfer characteristics of the circuit is

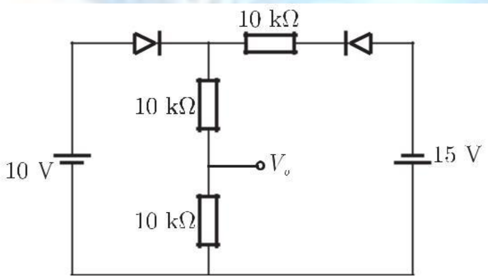



Q. 23 Given that the op-amp is ideal, the output voltage $v_o$ is



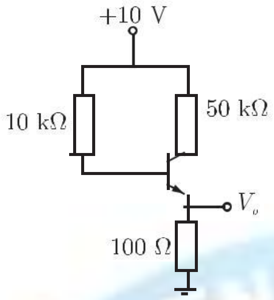

(B) 4 V
(C) 6 V
(D) 7.5 V
(E) 12.12 V

Q. 24 Assuming that the diodes in the given circuit are ideal, the voltage $V_0$ is



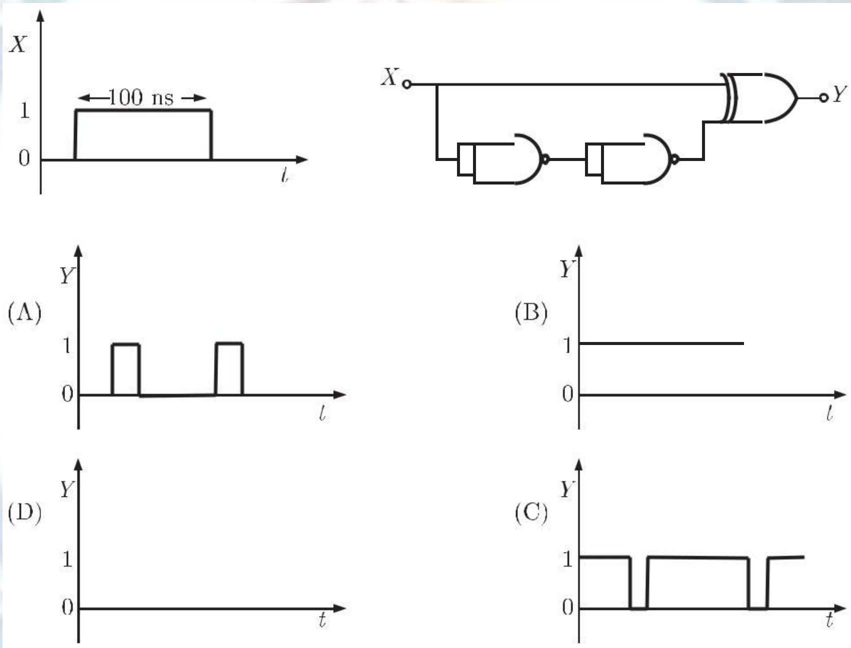

(A) 4 V
(B) 5 V
(C) 7.5 V
(D) 12.12 V

Q. 25 The transistor circuit shown uses a silicon transistor with $V_{BE} = 0.7$, $I_C \, . \, I_E$ and a dc current gain of 100. The value of $V_0$ is




(A) 4.65 V (B) 5 V
(C) 6.3 V (D) 7.23 V

Q. 26 The TTL circuit shown in the figure is fed with the waveform $X$ (also shown). All gates have equal propagation delay of 10 ns. The output $Y$ of the circuit is




**Statement For Linked Answer Questions: 27 and 28**

The following Karnaugh map represents a function $F$ .

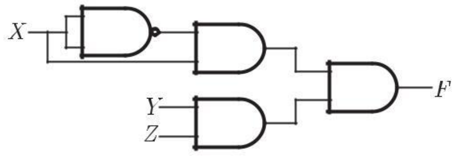
| F: X \ YZ | 00 | 01 | 11 | 10 |
|---|---|---|---|---|
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 1 | 0 |

Q. 27 A minimized form of the function $F$ is

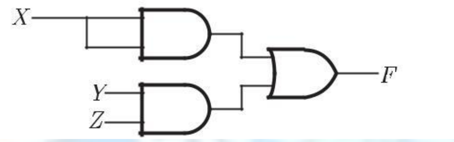
(A) $F = \overline{X} Y + YZ$ (B) $F = \overline{X}\,\overline{Y} + YZ$
(C) $F = \overline{X}\,\overline{Y} + Y\overline{Z}$ (D) $F = X\overline{Y} + Y\overline{Z}$

Q. 28 Which of the following circuits is a realization of the above function $F$ ?

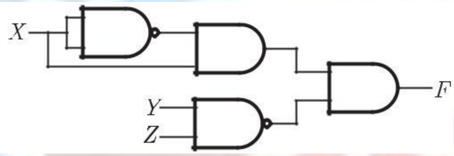
(A)



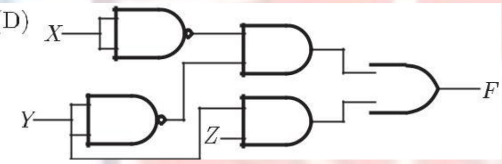

(B)




(C)




(D)




Q. 29 When a "CALL Addr" instruction is executed, the CPU carries out the following sequential operations internally :

Note: (R) means content of register R
((R)) means content of memory location pointed to by R.
PC means Program Counter
SP means Stack Pointer

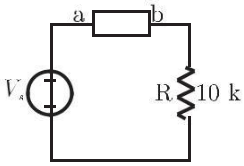
(A) (SP) incremented
(PC)!Addr
((SP))!(PC)

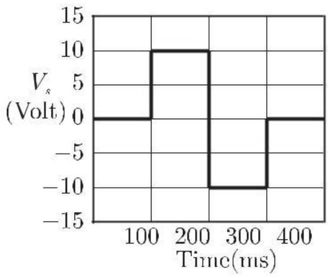
(B) (PC)!Addr
((SP))!(PC)
(SP) incremented

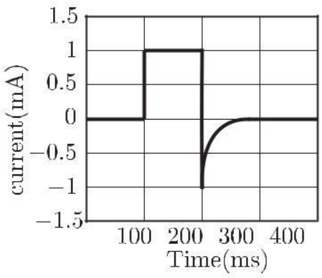
(C) (PC)!Addr
(SP) incremented
((SP))!(PC)

(D) ((SP))!(PC)
(SP) incremented
(PC)!Addr

Q. 30 The following circuit has a source voltage $V_S$ as shown in the graph. The current through the circuit is also shown.





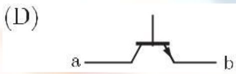

The element connected between *a* and *b* could be

(A)


(B)


(C)


(D)




Q. 31 The increasing order of speed of data access for the following device is

(J) Cache Memory

(JJ) CD-ROM

(JJJ) Dynamic RAM (IV)

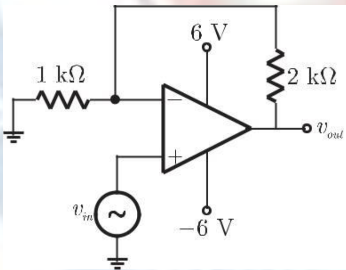
Processor Registers

(W) Magnetic Tape

(A) (V), (II), (III), (IV), (I) (B) (V), (II), (III), (I), (IV)

(C) (II), (I), (III), (IV), (V) (D) (V), (II), (I), (III), (IV)

Q. 32 The nature of feedback in the op-amp circuit shown is




(A) Current-Current feedback (B) Voltage-Voltage feedback

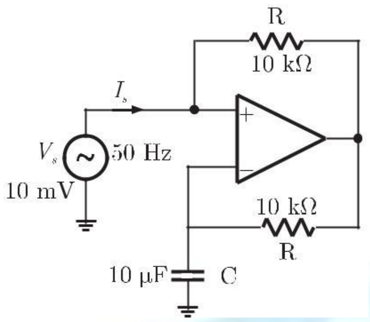
(C) Current-Voltage feedback (D) Voltage-Current feedback

Q. 33 The complete set of only those Logic Gates designated as Universal Gates is

(A) NOT, OR and AND Gates (B) XNOR, NOR and NAND Gates

(C) NOR and NAND Gates (D) XOR, NOR and NAND Gates

Q. 34 The following circuit has $R$ = 10 kW,$C$ = 10 $m$F. The input voltage is a sinusoidal at 50 Hz with an rms value of 10 V. Under ideal conditions, the current $I_s$ from the source is




(A) $10p$ mA leading by 90%
(B) $20p$ mA leading by 90%
(C) $10p$ mA leading by 90%
(D) $10p$ mA lagging by 90%

Q. 35 Transformer and emitter follower can both be used for impedance matching at the output of an audio amplifier. The basic relationship between the input power $P_{in}$ and output power $P_{out}$ in both the cases is

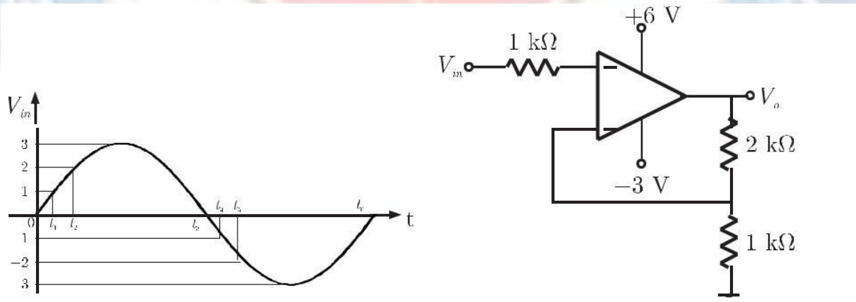
(A) $P_{in} = P_{out}$ for both transformer and emitter follower
(B) $P_{in} > P_{out}$ for both transformer and emitter follower
(C) $P_{in} < P_{out}$ for transformer and $P_{in} = P_{out}$ for emitter follower
(D) $P_{in} = P_{out}$ for transformer and $P_{in} < P_{out}$ for emitter follower

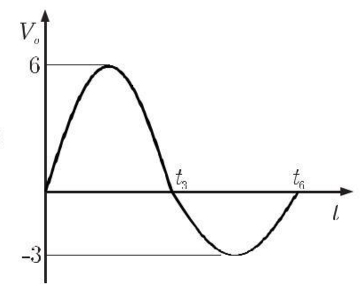
Q. 36 In an 8085 microprocessor, the contents of the Accumulator, after the following instructions are executed will become

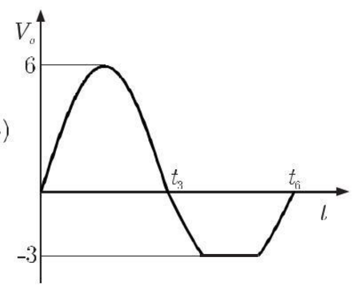
```
XRA   A
MVI   B, F0 H
SUB   B
```

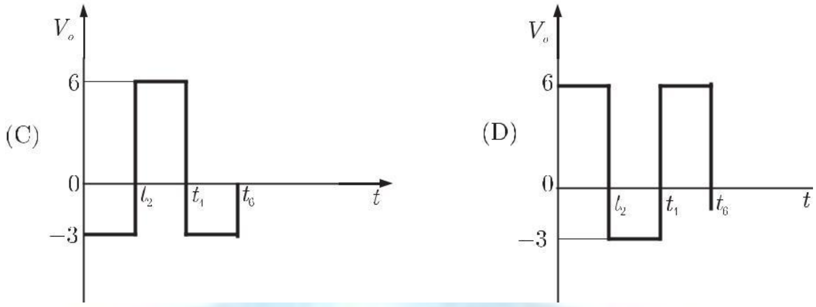
(A) 01 H
(B) 0F H
(C) F0 H
(D) 10 H

Q. 37 An ideal op-amp circuit and its input wave form as shown in the figures. The output waveform of this circuit will be




(A)


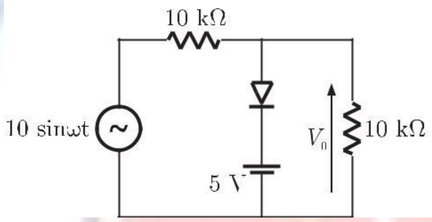

(B)




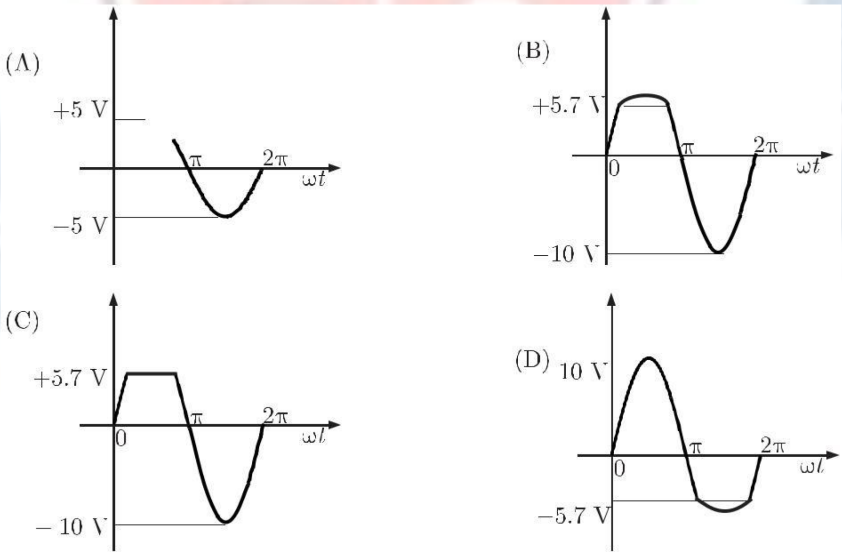

**Q. 38** The equivalent circuits of a diode, during forward biased and reverse biased conditions, are shown in the figure.

(I) ≡ 

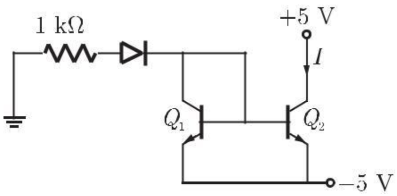

(II) ≡ 




If such a diode is used in clipper circuit of figure given above, the output voltage $V_0$ of the circuit will be




**Q. 39** Two perfectly matched silicon transistor are connected as shown in the figure assuming the *b* of the transistors to be very high and the forward voltage drop in diodes to be 0.7 V, the value of current *I* is



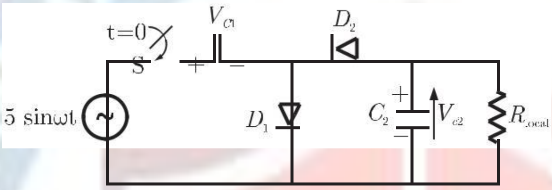

(A) 0 mA

(B) 3.6 mA

(C) 4.3 mA

(D) 5.7 mA

Q. 40 In the voltage doubler circuit shown in the figure, the switch '$S$' is closed at $t = 0$. Assuming diodes $D_1$ and $D_2$ to be ideal, load resistance to be infinite and initial capacitor voltages to be zero. The steady state voltage across capacitor $C_1$ and $C_2$ will be



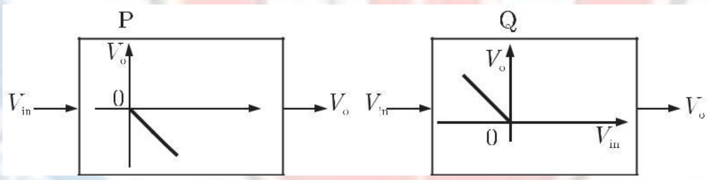

(A) $V_{c1} = 10$ V, $V_{c2} = 5$ V

(B) $V_{c1} = 10$ V, $V_{c2} = -5$ V

(C) $V_{c1} = 5$ V, $V_{c2} = 10$ V

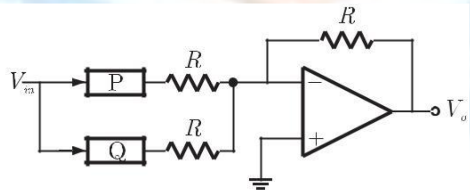
(D) $V_{c1} = 5$ V, $V_{c2} = -10$ V

Q. 41 The block diagrams of two of half wave rectifiers are shown in the figure. The transfer characteristics of the rectifiers are also shown within the block.

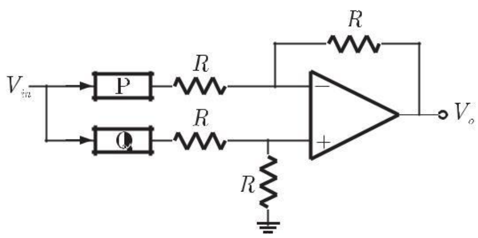



It is desired to make full wave rectifier using above two half-wave rectifiers. The resultants circuit will be

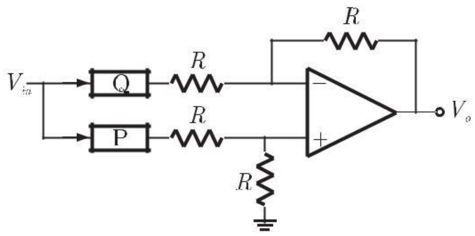
(A)



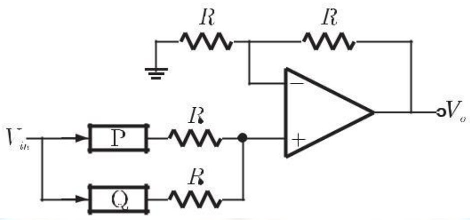

(B)



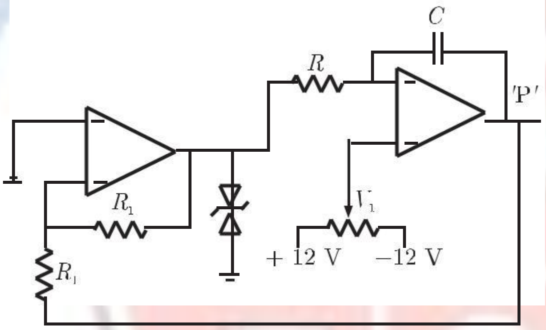
(C)




(D)

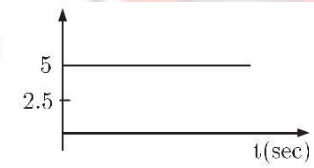



Q. 42 A waveform generator circuit using OPAMPs is shown in the figure. It produces a triangular wave at point 'P' with a peak to peak voltage of 5 V for $V_i = 0$ V.

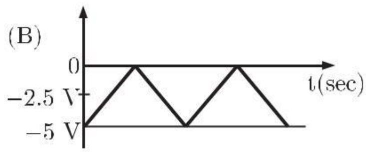



If the voltage $V_i$ is made +2.5 V, the voltage waveform at point 'P' will become

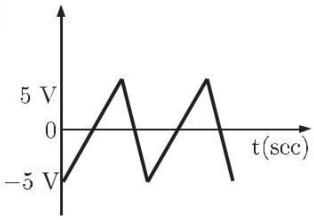
(A)



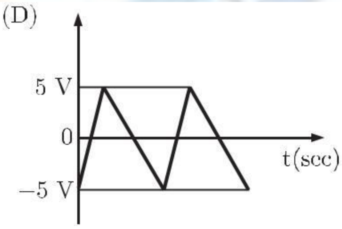

(B)




(C)

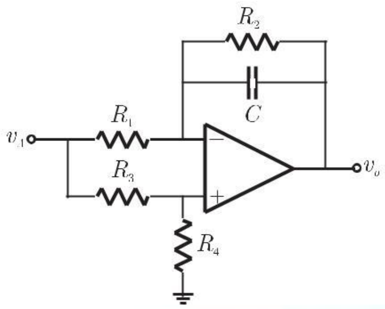



(D)




**Statement for Linked Answer Questions 43 and 44**

A general filter circuit is shown in the figure :




**Q. 43** If $R_1 = R_2 = R_A$ and $R_3 = R_4 = R_B$ , the circuit acts as a

(A) all pass filter

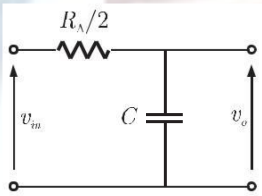
(B) band pass filter

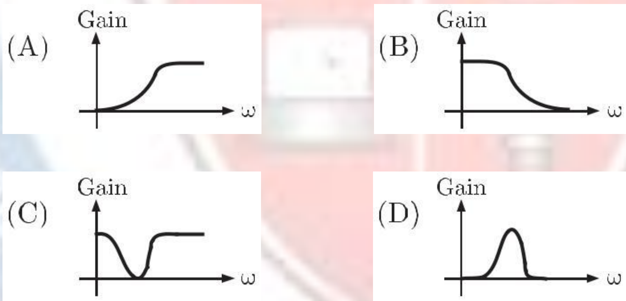
(C) high pass filter

(D) low pass filter

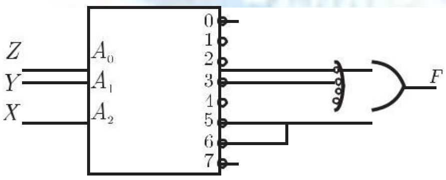
**Q. 44** The output of the this filter is given to the circuit in figure :

The gain v/s frequency characteristic of the output ($v_o$) will be




**Q. 45** A 3-line to 8-line decoder, with active low outputs, is used to implement a 3-variable Boolean function as shown in the figure




The simplified form of Boolean function $F$ ($A$, $B$, $C$) implemented in 'Product of Sum' form will be

(B) $(X + Z)(\overline{X} + Y + \overline{Z})(\overline{Y} + Z)$

(C) $(\overline{X} + \overline{Z})(X + Y + Z)(Y + \overline{Z})$

(D) $(\overline{X} + \overline{Y} + Z)(X + \overline{Y} + Z)(X + Y + \overline{Z})(X + Y + Z)$

(E) $(\overline{X} + \overline{Y} + Z)(X + \overline{Y} + Z)(\overline{X} + Y + \overline{Z})(X + Y + Z)$

Q. 46 The content of some of the memory location in an 8085 accumulator based system are given below

| Address | Content |
|---|---|
| g | g |
| 26FE | 00 |
| 26FF | 01 |
| 2700 | 02 |
| 2701 | 03 |
| 2702 | 04 |
| g | g |

The content of stack (SP), program counter (PC) and (H,L) are 2700 H, 2100 H and 0000 H respectively. When the following sequence of instruction are executed.

2100 H: DAD SP

2101 H: PCHL

the content of (SP) and (PC) at the end of execution will be

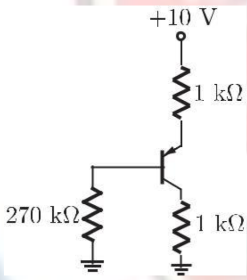
(A) PC = 2102 H, SP = 2700 H

(B) PC = 2700 H,SP = 2700 H

(C) PC = 2800 H,SP = 26FE H

(D) PC = 2A02 H,SP = 2702 H

Q. 47 The common emitter forward current gain of the transistor shown is $b_F = 100$




The transistor is operating in

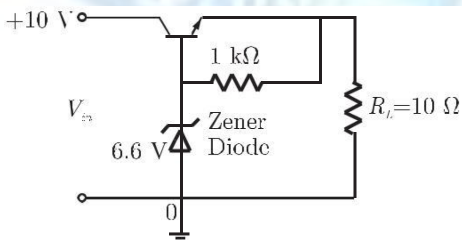
(A) Saturation region

(B) Cutoff region

(C) Reverse active region

(D) Forward active region

Q. 48 The three-terminal linear voltage regulator is connected to a 10 W load resistor as shown in the figure. If $V_{in}$ is 10 V, what is the power dissipated in the transistor ?



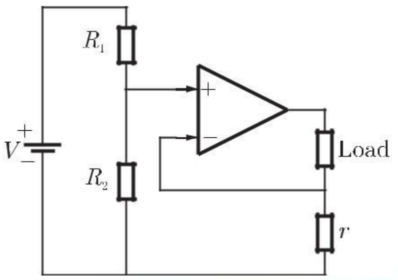

(A) 0.6 W

(B) 2.4 W

(C) 4.2 W

(D) 5.4 W

Q. 49 The circuit shown in the figure is



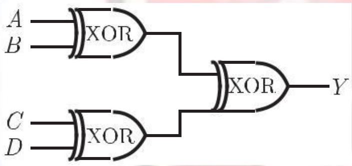

(A) a voltage source with voltage $\frac{rV}{R_1 < R_2}$

(C) a voltage source with voltage $\frac{r < R_2}{V R_1}$

(D) a current source with current c $\frac{r < R_2}{R_1 + R_2}$ m $\frac{V}{r}$

(E) a current source with current c $\frac{R_2}{R_1 + R_2}$ m $\frac{V}{r}$

Q. 50 *A*, *B*, *C* and *D* are input, and *Y* is the output bit in the XOR gate circuit of the figure below. Which of the following statements about the sum *S* of *A*, *B*, *C*, *D* and *Y* is correct ?



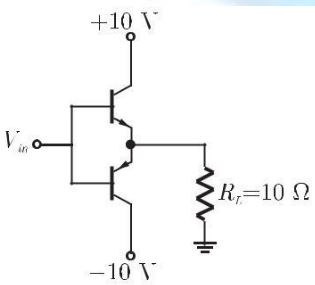

(A) *S* is always with zero or odd

(B) *S* is always either zero or even

(C) *S* = 1 only if the sum of *A*, *B*, *C* and *D* is even

(D) *S* = 1 only if the sum of *A*, *B*, *C* and *D* is odd

Q. 51 The input signal $V_{in}$ shown in the figure is a 1 kHz square wave voltage that alternates between +7 V and -7 V with a 50% duty cycle. Both transistor have the same current gain which is large. The circuit delivers power to the load resistor $R_L$ . What is the efficiency of this circuit for the given input ? choose the closest answer.



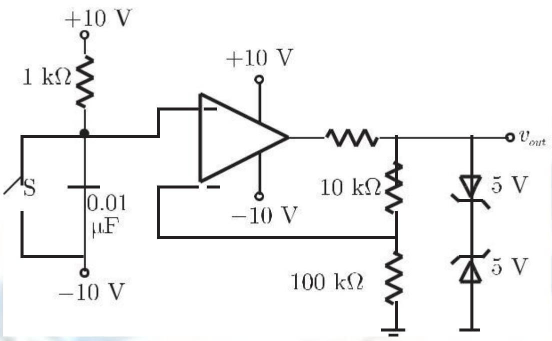

(A) 46%

(B) 55%

(C) 63%

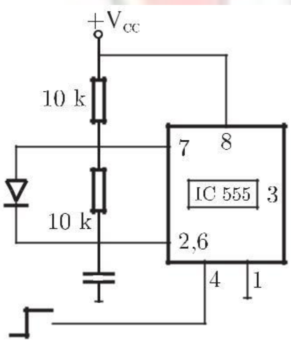
(D) 92%

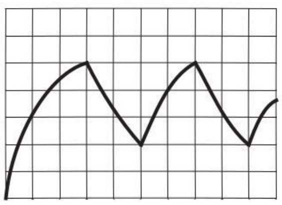
Q. 52 The switch S in the circuit of the figure is initially closed, it is opened at time $t = 0$ . You may neglect the zener diode forward voltage drops. What is the behavior of $v_{out}$ for $t > 0$ ?

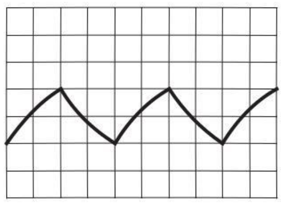


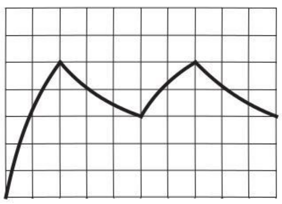

(A) It makes a transition from -5 V to +5 V at $t = 12.98$ *ms*
(B) It makes a transition from -5 V to +5 V at $t = 2.57$ *ms*
(C) It makes a transition from +5 V to -5 V at $t = 12.98$ *ms*
(D) It makes a transition from +5 V to -5 V at $t = 2.57$ *ms*

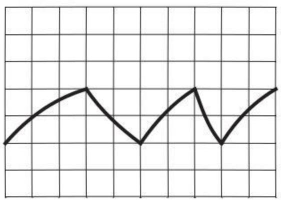
Q. 53 IC 555 in the adjacent figure is configured as an astable multi-vibrator. It is enabled to to oscillate at $t = 0$ by applying a high input to pin 4. The pin description is : 1 and 8-supply; 2-trigger; 4-reset; 6-threshold 7-discharge. The waveform appearing across the capacitor starting from $t = 0$, as observed on a storage CRO is




(A)


(B)


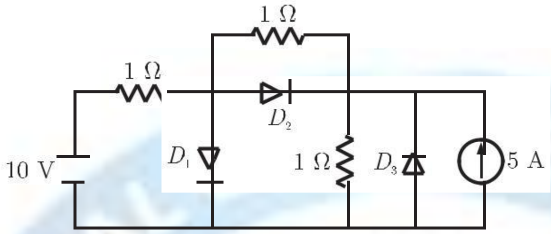
(C)


(D)


**Q. 54** The Octal equivalent of HEX and number AB.CD is

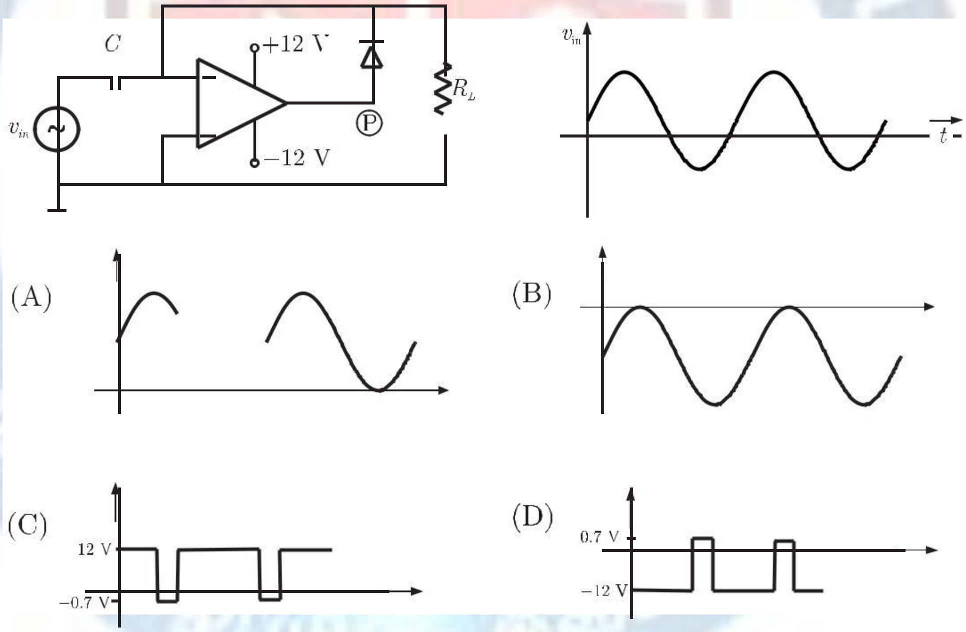
(A) 253.314
(B) 253.632
(C) 526.314
(D) 526.632

**Q. 55** What are the states of the three ideal diodes of the circuit shown in figure ?

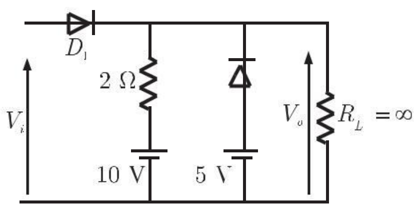


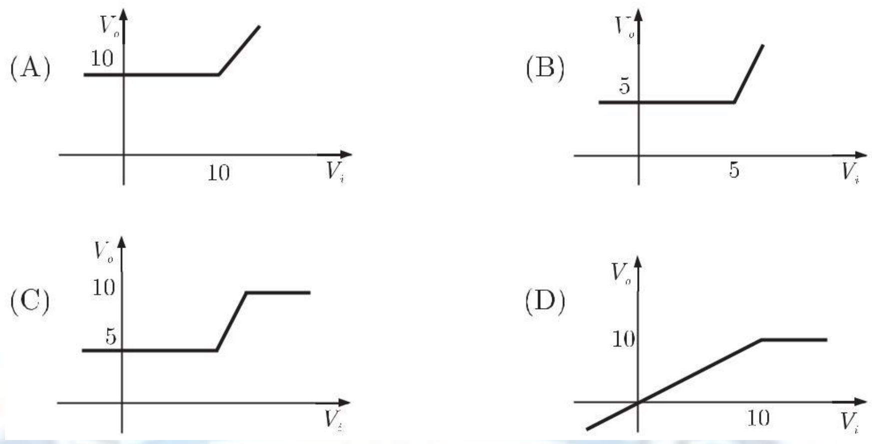

(A) $D_1$ ON, $D_2$ OFF, $D_3$ OFF
(B) $D_1$ OFF, $D_2$ ON, $D_3$ OFF
(C) $D_1$ ON, $D_2$ OFF, $D_3$ ON
(D) $D_1$ OFF, $D_2$ ON, $D_3$ ON

**Q. 56** For a given sinusoidal input voltage, the voltage waveform at point P of the clamper circuit shown in figure will be

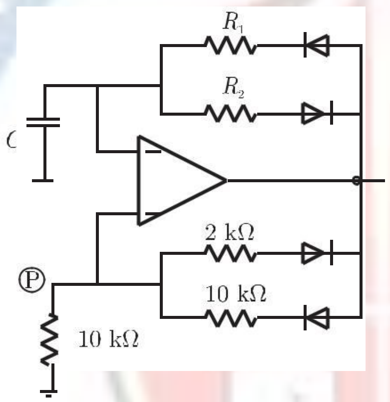


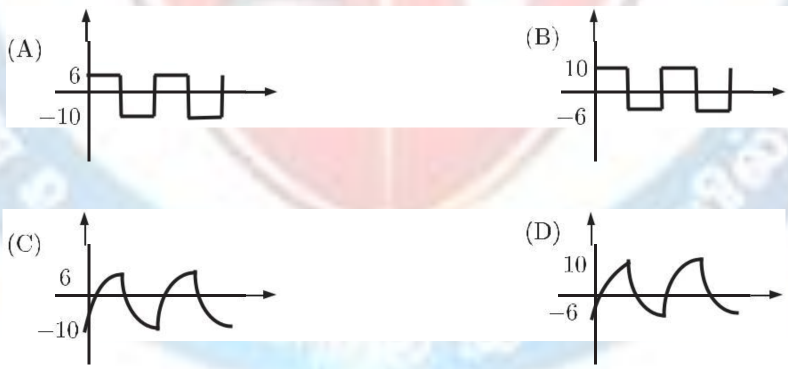

**Q. 57** Assuming the diodes $D_1$ and $D_2$ of the circuit shown in figure to be ideal ones, the transfer characteristics of the circuit will be



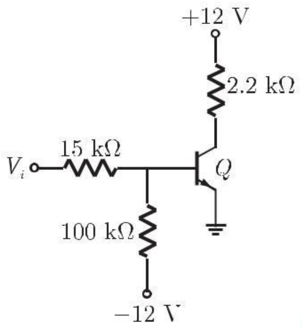



**Q. 58** A relaxation oscillator is made using OPAMP as shown in figure. The supply voltages of the OPAMP are !12 V. The voltage waveform at point P will be



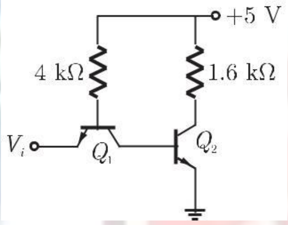




**Q. 59** Consider the circuit shown in figure. If the *b* of the transistor is 30 and $I_{CBO}$ is 20 mA and the input voltage is +5 V, the transistor would be operating in



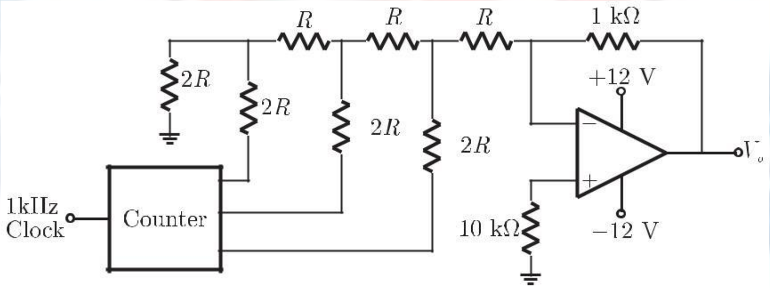

(A) saturation region (B) active region
(C) breakdown region (D) cut-off region

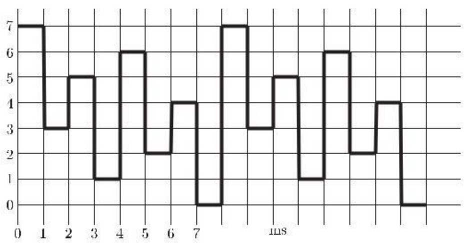
Q. 60 A TTL NOT gate circuit is shown in figure. Assuming $V_{BE}$ = 0.7 V of both the transistors, if $V_i$ = 3.0 V, then the states of the two transistors will be




(A) $Q_1$ ON and $Q_2$ OFF (B) $Q_1$ reverse ON and $Q_2$ OFF
(C) $Q_1$ reverse ON and $Q_2$ ON(D) $Q_1$ OFF and $Q_2$ reverse ON

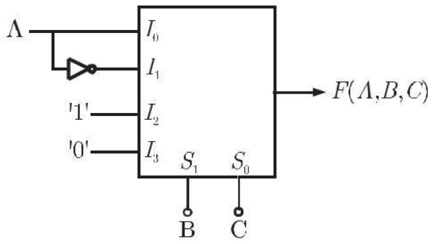
R. 61A student has made a 3-bit binary down counter and connected to the $R$-2$R$ ladder type DAC, [Gain = (- 1 kW/2$R$)] as shown in figure to generate a staircase waveform. The output achieved is different as shown in figure. What could be the possible cause of this error ?




(B) The resistance values are incorrect option.
(C) The counter is not working properly
(D) The connection from the counter of DAC is not proper
(E) The R and 2R resistance are interchanged

Q. 62 A 4 # 1 MUX is used to implement a 3-input Boolean function as shown in figure. The Boolean function *F* (*A*, *B*, *C*) implemented is




(A) *F* (*A*, *B*, *C*) = S(1,2,4,6)

(B) *F* (*A*, *B*, *C*) = S(1,2,6)

(C) *F* (*A*, *B*, *C*) = S(2,4,5,6)

(D) *F* (*A*, *B*, *C*) = S(1,5,6)

Q. 63 A software delay subroutine is written as given below :

```
DELAY :   MVI    H, 255D
          MVI    L, 255D
LOOP :    DCR    L
          JNZ    LOOP
          DCR    H
          JNZ    LOOP
```

How many times DCR L instruction will be executed ?

(A) 255

(B) 510

(C) 65025

(D) 65279

Q. 64 In an 8085 A microprocessor based system, it is desired to increment the contents of memory location whose address is available in (D,E) register pair and store the result in same location. The sequence of instruction is

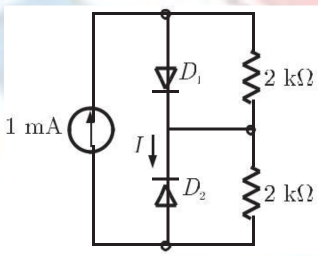
(A) XCHG
INR M

(B) XCHG
INX H

(C) INX D
XCHG

(D) INR M
XCHG

Q. 65 Assume that $D_1$ and $D_2$ in figure are ideal diodes. The value of current is




(A) 0 mA

(B) 0.5 mA

(C) 1 mA

(D) 2 mA

Q. 66 The 8085 assembly language instruction that stores the content of H and L register into the memory locations $2050_H$ and $2051_H$, respectively is

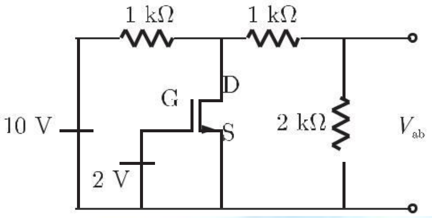
(A) SPHL $2050_H$

(B) SPHL $2051_H$

(C) SHLD $2050_H$

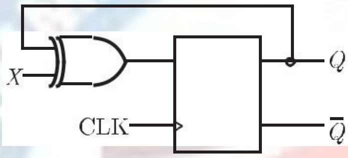
(D) STAX $2050_H$

Q. 67 Assume that the N-channel MOSFET shown in the figure is ideal, and that its threshold voltage is +1.0 V the voltage $V_{ab}$ between nodes *a* and *b* is



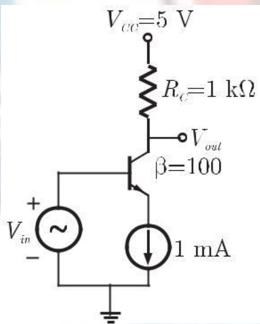

(A) 5 V
(B) 2 V
(C) 1 V
(D) 0 V

Q. 68 The digital circuit shown in the figure works as



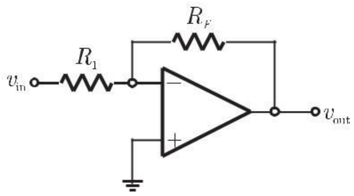

(A) JK flip-flop
(B) Clocked RS flip-flop
(C) T flip-flop
(D) Ring counter

Q. 69 The common emitter amplifier shown in the figure is biased using a 1 mA ideal current source. The approximate base current value is



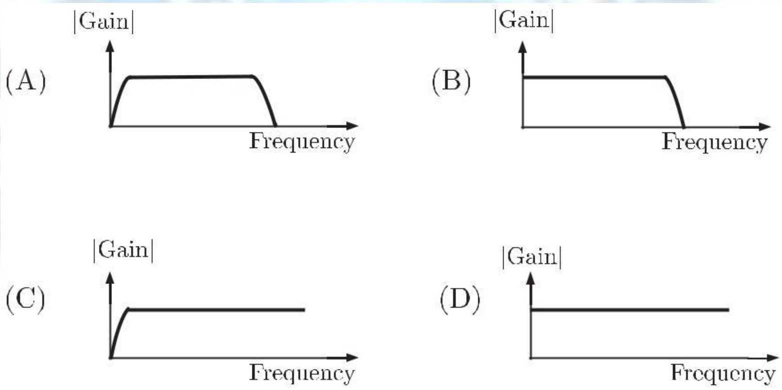

(A) 0 *m*A
(B) 10 *m*A
(C) 100 *m*A
(D) 1000 *m*A

Q. 70 Consider the inverting amplifier, using an ideal operational amplifier shown in the figure. The designer wishes to realize the input resistance seen by the small-signal source to be as large as possible, while keeping the voltage gain between -10 and -25. The upper limit on $R_F$ is 1 MW. The value of $R_1$ should be

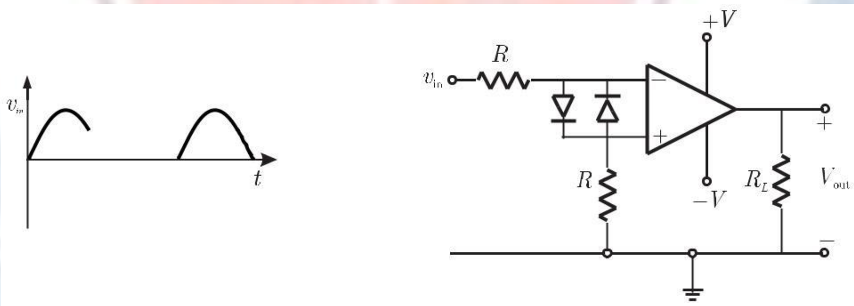


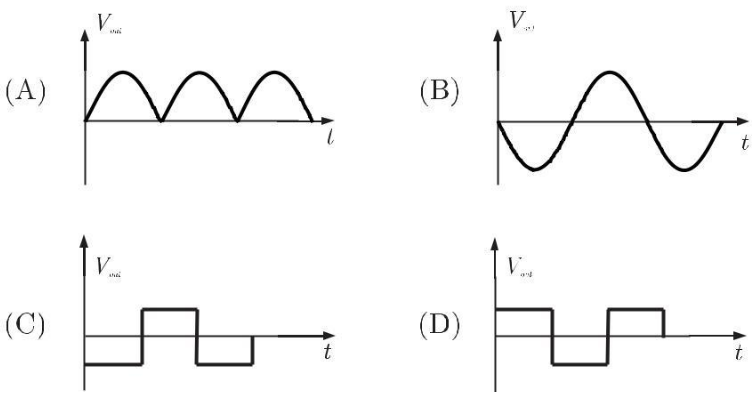

(A) Infinity
(B) 1 MW
(C) 100 kW
(D) 40 kW

Q. 71 The typical frequency response of a two-stage direct coupled voltage amplifier is as shown in figure

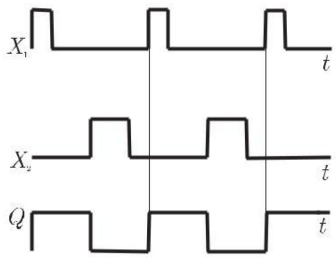


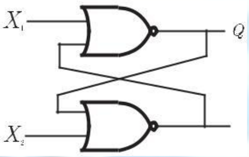

Q. 72 In the given figure, if the input is a sinusoidal signal, the output will appear as shown

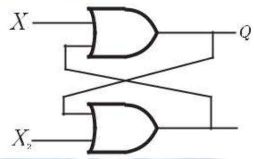


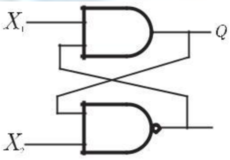



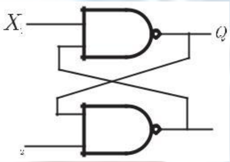

Q. 73 Select the circuit which will produce the given output $Q$ for the input signals $X_1$ and $X_2$ given in the figure



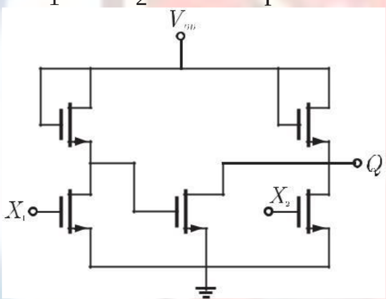

(A) 


(B) 


(C) 


(D) 


Q. 74 If $X_1$ and $X_2$ are the inputs to the circuit shown in the figure, the output $Q$ is




(A) $\overline{\underline{X_1} + X_2}$

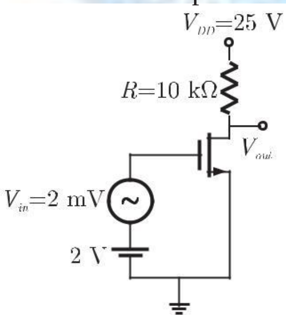
(B) $\overline{X_1 : \underline{X_2}}$

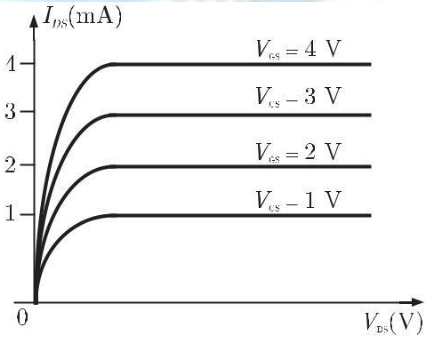
(C) $X_1 : X_2$

(D) $X_1 : X_2$

**Common Data For Q. 75 and 76**

Assume that the threshold voltage of the N-channel MOSFET shown in figure is + 0.75 V. The output characteristics of the MOSFET are also shown




Q. 75 The transconductance of the MOSFET is

(A) 0.75 ms

(B) 1 ms

(C) 2 ms

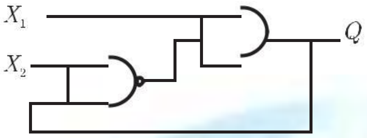
(D) 10 ms

Q. 76 The voltage gain of the amplifier is

(A) +5 (B) -7.5

(C) +10 (D) -10

Q. 77 In the figure, as long as $X_1 = 1$ and $X_2 = 1$, the output $Q$ remains



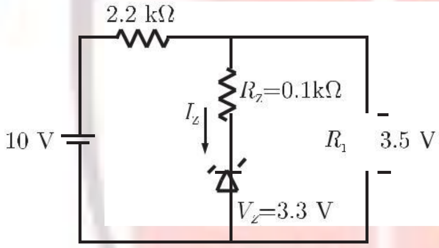

(B) at 1

(C) at 0

(D) at its initial value

(E) unstable

Q. 78 The current through the Zener diode in figure is



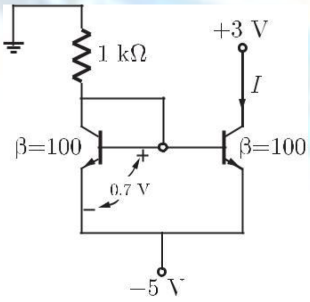

(A) 33 mA

(B) 3.3 mA

(C) 2 mA

(D) 0 mA

Q. 79 Two perfectly matched silicon transistor are connected as shown in figure. The value of the current $I$ is



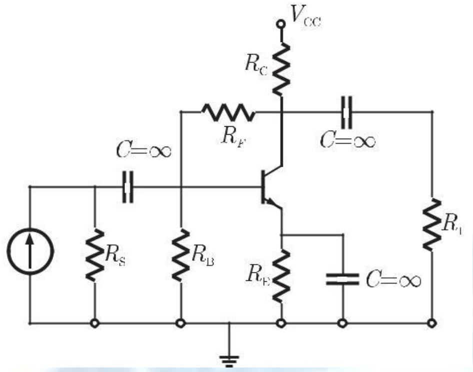

(A) 0 mA

(B) 2.3 mA

(C) 4.3 mA

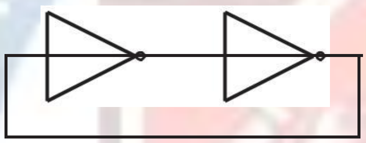
(D) 7.3 mA

Q. 80 The feedback used in the circuit shown in figure can be classified as



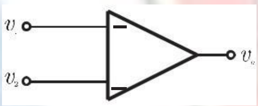

(A) shunt-series feedback
(B) shunt-shunt feedback
(C) series-shunt feedback
(D) series-series feedback

Q. 81 The digital circuit using two inverters shown in figure will act as



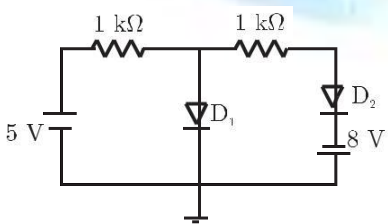
(A) a bistable multi-vibrator
(B) an astable multi-vibrator
(C) a monostable multi-vibrator
(D) an oscillator

Q. 82 The voltage comparator shown in figure can be used in the analog-to-digital conversion as



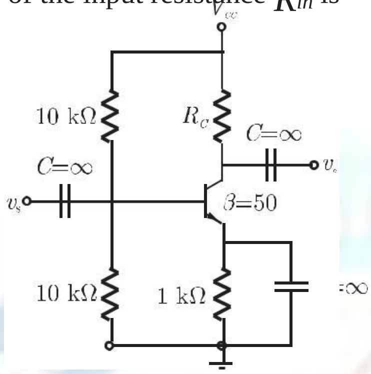
(A) a 1-bit quantizer
(B) a 2-bit quantizer
(C) a 4-bit quantizer
(D) a 8-bit quantizer

Q. 83 Assuming that the diodes are ideal in figure, the current in diode $D_1$ is



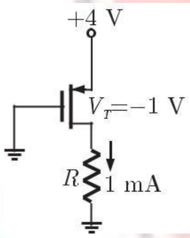

(A) 9 mA
(B) 5 mA
(C) 0 mA
(D) -3 mA

Q. 84 The trans-conductance $g_m$ of the transistor shown in figure is 10 mS. The value of the input resistance $R_{in}$ is



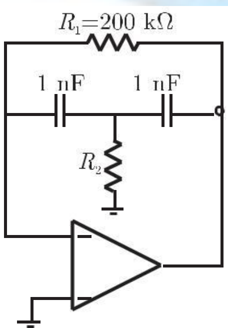

(A) 10.0 kW
(B) 8.3 kW
(C) 5.0 kW
(D) 2.5 kW

Q. 85 The value of *R* for which the PMOS transistor in figure will be biased in linear region is



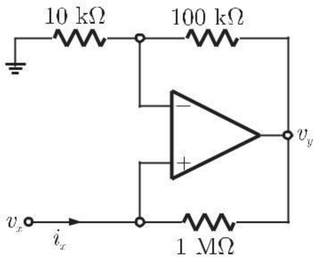

(A) 220 W
(B) 470 W
(C) 680 W
(D) 1200 W

Q. 86 In the active filter circuit shown in figure, if Q = 1, a pair of poles will be realized with $w_0$ equal to




(A) 1000 rad/s
(B) 100 rad/s
(C) 10 rad/s
(D) 1 rad/s

Q. 87 The input resistance $R_{in} = v_x / i_x$ of the circuit in figure is




(A) +100 kW (B) -100 kW

(C) +1 MW (D) -1 MW

Q. 88 The simplified form of the Boolean expression $Y = (A \$ B\overline{C} + D)(A \$ D + \overline{B \$ C})$ can be written as

(A) $\overline{A} \$ D + \overline{B} \, {}_{\$} \overline{C} \ \$ D$ (B) $AD + B \$ \ \overline{C}\, D$

(C) $(\overline{A} + D)(\overline{B} \$ C + \overline{D})$ (D) $A \$ \overline{D} + BC \$ \overline{D}$

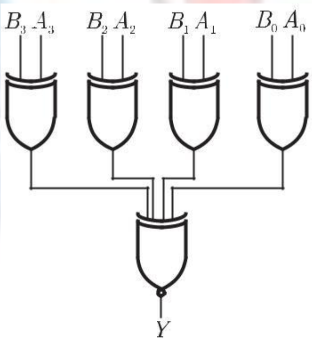
Q. 89 If the following program is executed in a microprocessor, the number of instruction cycle it will take from START to HALT is

| | | | |
|---|---|---|---|
| START | MVI A, 14H ; | | Move 14 H to register A |
| SHIFT | RLC | ; | Rotate left without carry |
| | JNZ SHIFT | ; | Jump on non-zero to SHIFT |
| | HALT | | |

(A) 4 (B) 8

(C) 13 (D) 16

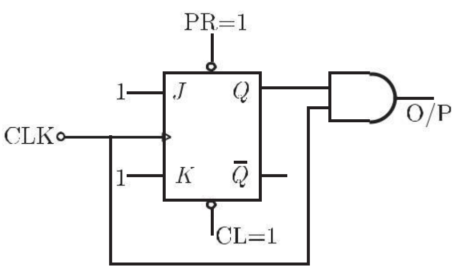
Q. 90 A digit circuit which compares two numbers $A_3\, A_2\, A_1\, A_0$ and $B_3\, B_2\, B_1\, B_0$ is shown in figure. To get output $Y = 0$, choose one pair of correct input numbers.

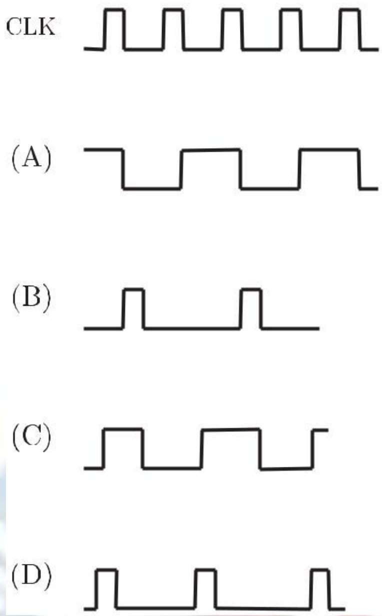



(A) 1010, 1010 (B) 0101, 0101

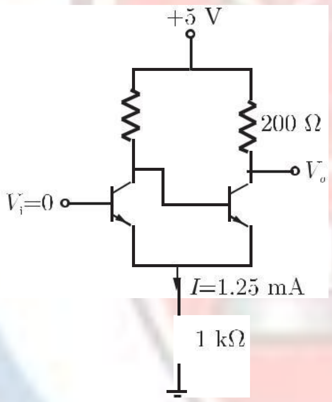
(C) 0010, 0010 (D) 1010, 1011

Q. 91 The digital circuit shown in figure generates a modified clock pulse at the output. Choose the correct output waveform from the options given below.



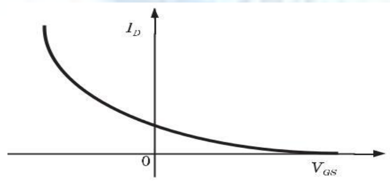



Q. 92 In the Schmitt trigger circuit shown in figure, if $V_{CE(sat)}$ = 0.1 V, the output logic low level ($V_{OL}$) is




(A) 1.25 V
(B) 1.35 V
(C) 2.50 V
(D) 5.00 V

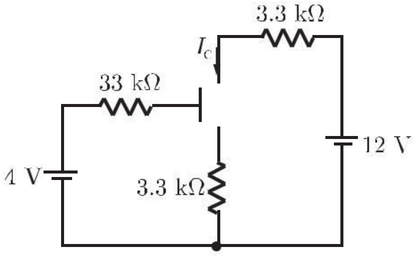
Q. 93 The variation of drain current with gate-to-source voltage ($I_D$ - $V_{GS}$ characteristic) of a MOSFET is shown in figure. The MOSFET is




(A) an n-channel depletion mode device
(B) an n-channel enhancement mode device
(C) an p-channel depletion mode device

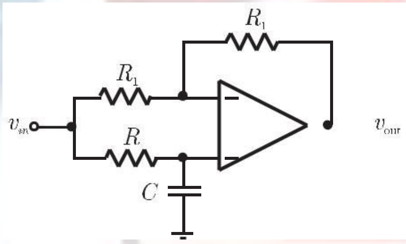
(D) an p-channel enhancement mode device

Q. 94 In the circuit of figure, assume that the transistor has $h_{fe} = 99$ and $V_{BE} = 0.7$ V. The value of collector current $I_C$ of the transistor is approximately



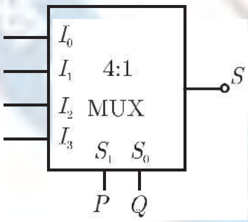

(A) [3.3/3.3] mA
(B) [3.3/(3.3+3.3)] mA
(C) [3.3/.33] mA
(D) [3.3(33+3.3)] mA

Q. 95 For the circuit of figure with an ideal operational amplifier, the maximum phase shift of the output $v_{out}$ with reference to the input $v_{in}$ is




(A) 0c
(B) -90c
(C) +90c
(D) !180c

Q. 96 Figure shows a 4 to 1 MUX to be used to implement the sum $S$ of a 1-bit full adder with input bits $P$ and $Q$ and the carry input $C_{in}$. Which of the following combinations of inputs to $I_0, I_1, I_2$ and $I_3$ of the MUX will realize the sum $S$ ?

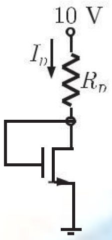



(A) $I_0 = I_1 = C_{in}; I_2 = I_3 = \overline{C_{in}}$
(B) $I_0 = I_1 = \overline{C_{in}}; I_2 = I_3 = C_{in}$
(C) $I_0 = I_3 = C_{in}; I_1 = I_2 = \overline{C_{in}}$
(D) $I_0 = I_3 = \overline{C_{in}}; I_1 = I_2 = C_{in}$

Q. 97 When a program is being executed in an 8085 microprocessor, its Program

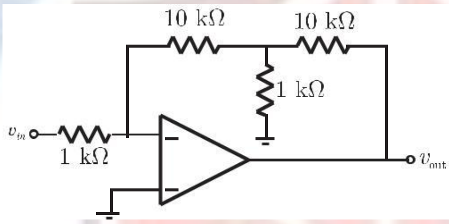
(A) the number of instructions in the current program that have already been executed
(B) the total number of instructions in the program being executed.
(C) the memory address of the instruction that is being currently executed
(D) the memory address of the instruction that is to be executed next

Q. 98 For the n-channel enhancement MOSFET shown in figure, the threshold voltage $V_{th}$ = 2 V. The drain current $I_D$ of the MOSFET is 4 mA when the drain resistance $R_D$ is 1 kW.If the value of $R_D$ is increased to 4 kW, drain current $I_D$ will become



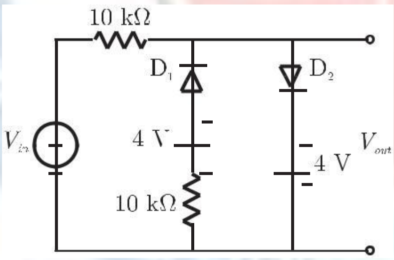

(A) 2.8 mA
(B) 2.0 mA
(C) 1.4 mA
(D) 1.0 mA

Q. 99 Assuming the operational amplifier to be ideal, the gain $v_{out}/v_{in}$ for the circuit shown in figure is



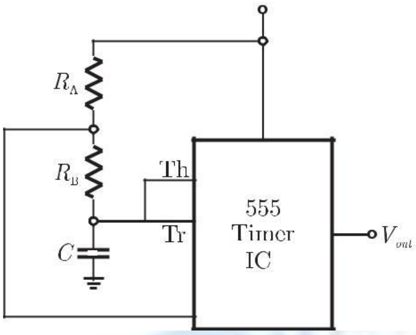

(A) -1
(B) -20
(C) -100
(D) -120

Q. 100 A voltage signal 10 sin *wt* is applied to the circuit with ideal diodes, as shown in figure, The maximum, and minimum values of the output waveform $V_{out}$ of the circuit are respectively




(A) +10 V and -10 V
(B) +4 V and -4 V
(C) +7 V and -4 V
(D) +4 V and -7 V

Q. 101 The circuit of figure shows a 555 Timer IC connected as an astable multi-vibrator. The value of the capacitor $C$ is 10 nF. The values of the resistors $R_A$ and $R_B$ for a frequency of 10 kHz and a duty cycle of 0.75 for the output voltage waveform are

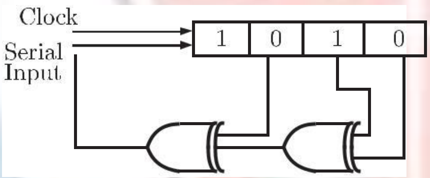



(A) $R_A = 3.62$ kW, $R_B = 3.62$ kW
(B) $R_A = 3.62$ kW, $R_B = 7.25$ kW
(C) $R_A = 7.25$ kW, $R_B = 3.62$ kW
(D) $R_A = 7.25$ kW, $R_B = 7.25$ kW

Q. 102 The boolean expression $\overline{X}Y\overline{Z} + \overline{XY}Z + XY\overline{Z} + XY\overline{Z} + XYZ$ can be simplified to

(A) $X\overline{Z} + \overline{X}Z + YZ$
(B) $XY + Y\overline{Z} + YZ$
(C) $\overline{X}Y + YZ + XZ$
(D) $\overline{XY} + \overline{YZ} + \overline{X}Z$

Q. 103 The shift register shown in figure is initially loaded with the bit pattern 1010. Subsequently the shift register is clocked, and with each clock pulse the pattern gets shifted by one bit position to the right. With each shift, the bit at the serial input is pushed to the left most position (msb). After how many clock pulses will the content of the shift register become 1010 again ?




(A) 3
(B) 7
(C) 11
(D) 15

Q. 104 A memory system has a total of 8 memory chips each with 12 address lines and 4 data lines, The total size of the memory system is

(A) 16 kbytes
(B) 32 kbytes
(C) 48 kbytes
(D) 64 kbytes

Q. 105

The following program is written for an 8085 microprocessor to add two bytes located at memory addresses 1FFE and 1FFF

```
LXI   H, 1FFE
MOV   B, M
INR   L
MOV   A, M
ADD   B
INR   L
MOV   M, A
XOR   A
```

On completion of the execution of the program, the result of addition is found (A) in the register A

(B) at the memory address 1000

(C) at the memory address 1F00

(D) at the memory address 2000

# SOLUTION

**Sol. 1** Option (C) is correct.

Let $A$ denotes the position of switch at ground floor and $B$ denotes the position of switch at upper floor. The switch can be either in up position or down position. Following are the truth table given for different combinations of $A$ and $B$

| A | B | Y(Bulb) |
|---|---|---|
| up(1) | up(1) | OFF(0) |
| Down(0) | Down(0) | OFF(0) |
| up(1) | Down(0) | ON(1) |
| Down(0) | up(1) | ON(1) |

When the switches $A$ and $B$ are both up or both down, output will be zero (i.e. Bulb will be OFF). Any of the switch changes its position leads to the ON state of bulb. Hence, from the truth table, we get

$$Y = A \oplus B$$

i.e., the XOR gate

**Sol. 2** Option (A) is correct.

The i/p voltage of the system is given as

$$V_{in} = V_1 + V_f = V_1 + k\,V_{out}$$
$$= V_1 + k A_0 V_1 \qquad (V_{out} = A_0 V_1)$$
$$= V_1 (1 + k A_0)$$

Therefore, if $k$ is increased then input voltage is also increased so, the input impedance increases. Now, we have

$$V_{out} = A_0 V_1$$
$$= A_0 \left(\frac{V_{in}}{1 + k A_0}\right) = \frac{A_0 V_{in}}{1 + k A_0}$$

Since, $V_{in}$ is independent of $k$ when seen from output mode, the output voltage decreases with increase in $k$ that leads to the decrease of output impedance. Thus, input impedance increases and output impedance decreases.

**Sol. 3** Option (B) is correct.

For the given ideal op-amp, negative terminal will be also ground (at zero voltage) and so, the collector terminal of the $BJT$ will be at zero voltage.

i.e., $V_C = 0$ volt

The current in 1 kΩ resistor is given by

$$I = \frac{5 - 0}{1\ \text{k}\Omega} = 5\ \text{mA}$$

This current will flow completely through the $BJT$ since, no current will flow into the ideal op-amp (I/P resistance of ideal op-amp is infinity). So, for $BJT$ we have

$$V_C = 0$$

$V_B = 0$

$I_C = 5$ mA

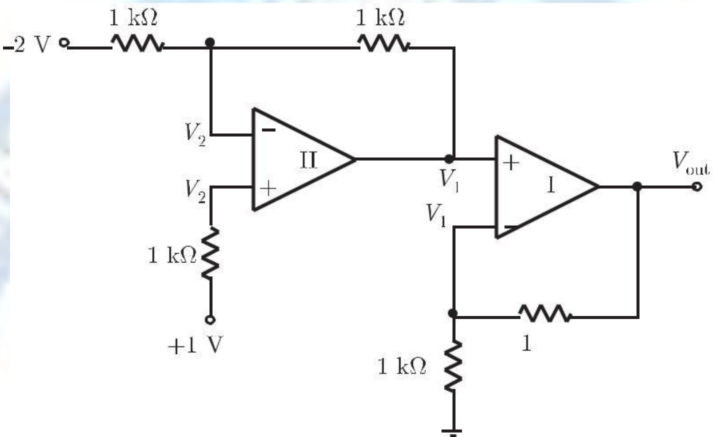
i.e.,the base collector junction is reverse biased (zero voltage) therefore, the collector current ($I_C$) can have a value only if base-emitter is forward biased. Hence,

$V_{BE} = 0.7$ volts

& $V_B - V_E = 0.7$

& $0 - V_{out} = 0.7$ & $V_{out} = -0.7$ volt

Sol. 4 Option (C) is correct.




For the given ideal op-Amps we can assume

$V_2^- = V_2^+ = V_2$ (ideal)

$V_1^+ = V_1^- = V_1$ (ideal)

So, by voltage division

$$V_1 = \frac{V_{out} \# 1}{2}$$

$$V_{out} = 2V_1$$

and, as the I/P current in Op-amp is always zero therefore, there will be no voltage drop across 1 KW in II op-amp

i.e., $V_2 = 1$ V

Therefore, $\frac{V_1 - V_2}{1} = \frac{V_2 - -2}{1}$

or, $V_1 - 1 = 1 + 2$

or, $V_1 = 4$

So,

$$V_{out} = 2V_1 = 8 \text{ volt}$$

Sol. 5 Option (B) is correct.

For the given circuit, we can make the truth table as below

| $X$ | $Y$ | $Z$ |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 0 |
| 1 | 1 | 0 |

Logic 0 means voltage is $v = 0$ volt and logic 1 means voltage is 5 volt

For $x = 0$, $y = 0$, Transistor is at cut off mode and diode is forward biased. Since, there is no drop across forward biased diode.

So, $Z = Y = 0$

For $x = 0$, $y = 1$, Again Transistor is in cutoff mode, and diode is forward biased. with no current flowing through resistor.

So, $Z = Y = 1$

For $x = 1$, $y = 0$, Transistor is in saturation mode and so, $z$ directly connected to ground irrespective of any value of $Y$ .

i.e., $Z = 0$ (ground)

Similarly for $X = Y = 1$

$Z = 0$ (ground)

Hence, from the obtained truth table, we get

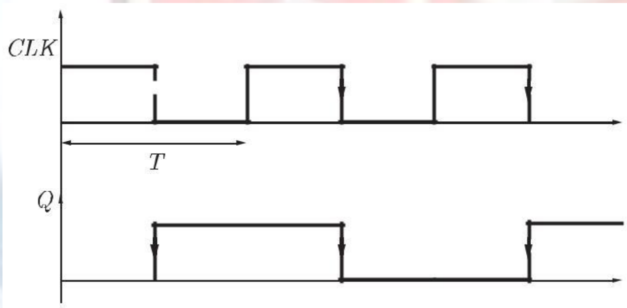
$$Z = \overline{X}\,Y$$

Sol. 6 Option (B) is correct.

From the given logic diagram, we obtain

$$X = Q\,5\,\overline{Q}_h\,\$\,\overline{Q}\,5\overline{Q}_h = \overline{0} = 1$$

So, the input is always ‘1’ at $T$ , since, clock is -ve edge trigged therefore, at the negative edge $Q$ changes its state as shown in waveform below



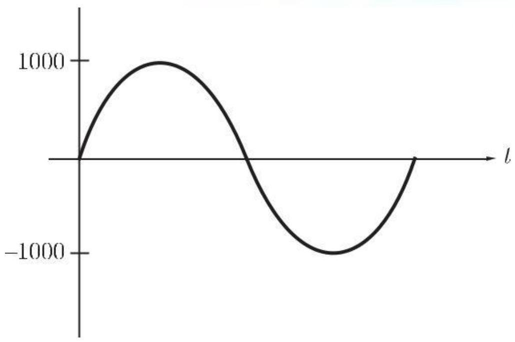

Hence, as obtained from the waveform, time period of $Q$ is double to that of $CLK$ I/p and so, frequency is $\frac{1}{2}$ of clock frequency

Thus, $f_Q = \frac{F_{CLK}}{2} = \frac{1}{2} = 0.5$ kHz

Sol. 7 Option (D) is correct.

Given, the input voltage

$$V_{YZ} = 100 \sin wt$$



For +ve half cycle

$$V_{YZ} > 0$$

i.e., $V_Y$ is a higher voltage than $V_Z$

So, the diode will be in cutoff region. Therefore, there will no voltage difference between $X$ and $W$ node.

i.e., $V_{WX} = 0$

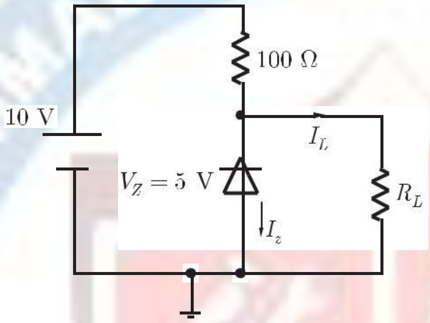
Now, for -ve half cycle all the four diodes will active and so, $X$ and $W$ terminal is short circuited

i.e., $V_{WX} = 0$

Hence, $V_{WX} = 0$ for all $t$

Option (B) is correct.

Sol. 8




From the circuit, we have

$$I_s = I_Z + I_L$$

or, $I_Z = I_s - I_L$ (1)

Since, voltage across zener diode is 5 V so, current through 100 W resistor is obtained as

$$I_s = \frac{10 - 5}{100} = 0.05 \text{ A}$$

Therefore, the load current is given by

$$I_L = \frac{5}{R_L}$$

Since, for proper operation, we must have

$$I_Z \$ I_{knes}$$

So, from Eq. (1), we write

$$0.05 \text{ A} - \frac{5}{R_L} \$ 10 \text{ mA}$$

$$50 \text{ mA} - \frac{5}{R_L} \$ 10 \text{ mA}$$

$$40 \text{ mA} \$ \frac{5}{R_L}$$

$$40 \# 10^{-3} \$ \frac{5}{R_L}$$

$$\frac{1}{40 \# 10^{-3}} \# \frac{R_L}{5}$$

$$\frac{5}{40 \# 10^{-3}} \# R_L$$

or, $125\ \text{W} \# R_L$

Therefore, minimum value of $R_L = 125$ W

Now, we know that power rating of Zener diode is given by

$$P_R = V_Z I_{Z^\wedge \max h}$$

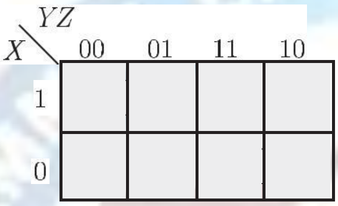
$I_{Z^\wedge \max h}$ is maximum current through zener diode in reverse bias. Maximum currrent through zener diode flows when load current is zero. i.e.,

$$I_{Z \max ^\wedge h} = I_s = \frac{10 - 5}{100} = 0.05$$

Therefore, $P_R = 5 \# 0.05\ \text{W} = 250\ \text{mW}$

Sol. 9 Option (A) is correct.

Prime implicants are the terms that we get by solving K-map




$$F = \underbrace{XY + XY}_{\text{prime implicants}}$$

1 44 2 443

Sol. 10 Option (D) is correct.

Let $v > 0.7$ V and diode is forward biased. Applying Kirchoff's voltage law

$$10 - i \# 1\text{k} - v = 0$$

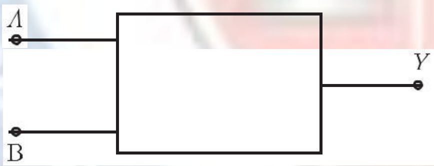
$$10 - :\frac{v - 0.7}{500} D(1000) - v = 0$$

$$10 - (v - 0.7) \# 2 - v = 0$$

$$v = \frac{11.4}{3} = 3.8\ \text{V} > 0.7 \quad \text{(Assumption is true)}$$

So, $i = \frac{v - 0.7}{500} = \frac{3.8 - 0.7}{500} = 6.2$ mA

Sol. 11 Option (B) is correct.




$Y = 1$, when $A > B$

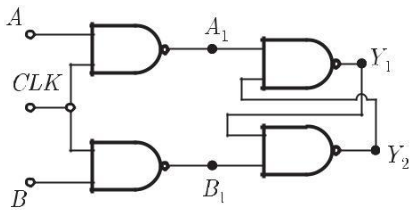
$$A = a_1 a_0, B = b_1 b_0$$

| $a_1$ | $a_0$ | $b_1$ | $b_0$ | $Y$ |
|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 1 |
| 1 | 0 | 0 | 0 | 1 |
| 1 | 0 | 0 | 1 | 1 |
| 1 | 1 | 0 | 0 | 1 |
| 1 | 1 | 0 | 1 | 1 |
| 1 | 1 | 1 | 0 | 1 |

Total combination = 6

Sol. 12 Option (A) is correct.

The given circuit is




Condition for the race-around

It occurs when the output of the circuit ($Y_1$, $Y_2$) oscillates between '0' and '1' checking it from the options.

**1.** Option (A): When $CLK = 0$

Output of the NAND gate will be $A_1 = B_1 = \overline{0} = 1$. Due to these input to the next NAND gate, $Y_2 = \overline{Y_1 : 1} = \overline{Y_1}$ and $Y_1 = \overline{Y_2 : 1} = \overline{Y_2}$.

If $Y_1 = 0$, $\quad Y_2 = \overline{Y_1} = 1$ and it will remain the same and doesn't oscillate.

If $Y_2 = 0$, $Y_1 = \overline{Y_2} = 1$ and it will also remain the same for the clock period. So, it won't oscillate for $CLK = 0$.

So, here race around doesn't occur for the condition $CLK = 0$.

**2.** Option (C): When $CLK = 1$, $A = B = 1$

$$A_1 = B_1 = 0 \text{ and so } Y_1 = Y_2 = 1$$

And it will remain same for the clock period. So race around doesn't occur for the condition.

**3.** Option (D): When $CLK = 1$, $A = B = 0$

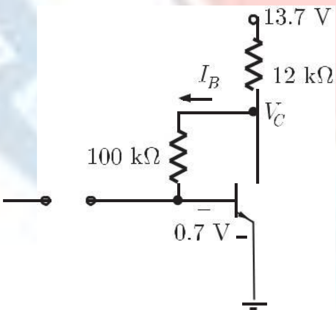
So, $\quad A_1 = B_1 = 1$

And again as described for Option (B) race around doesn't occur for the condition.

So, Option (A) will be correct.

Sol. 13 Option (D) is correct.

**DC Analysis :**




Using KVL in input loop,

$$V_C - 100I_B - 0.7 = 0$$

$$V_C = 100I_B + 0.7 \qquad \text{...(i)}$$

$$I_C - I_E = \frac{13.7 - V_C}{12k} = (b+1)I_B$$

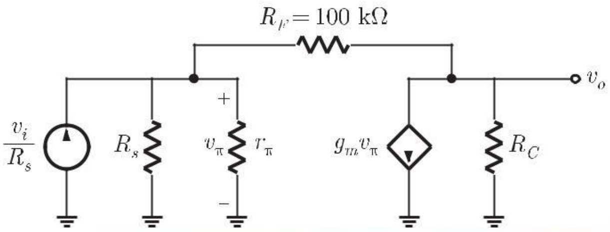
$$\frac{13.7 - V_C}{12 \# 10^3} = 100I_B \qquad \text{...(ii)}$$

Solving equation (i) and (ii),

$$I_B = 0.01 \text{ mA}$$

**Small Signal Analysis :**

Transforming given input voltage source into equivalent current source.




This is a shunt-shunt feedback amplifier.

Given parameters,

$$r_p = \frac{V_T}{I_B} = \frac{25 \text{ mV}}{0.01 \text{ mA}} = 2.5 \text{ kW}$$

$$g_m = \frac{b}{r_p} = \frac{100}{2.5 \# 1000} = 0.04 \text{ s}$$

Writing KCL at output node

$$\frac{v_0}{R_C} + g_m v_p + \frac{v_0 - v_p}{R_F} = 0$$

$$v_0 : \frac{1}{R_C} + \frac{1}{R_F} D + v_p : g_m - \frac{1}{R_F} D = 0$$

Substituting $R_C = 12$ kW, $R_F = 100$ kW, $g_m = 0.04$ s

$$v_0 (9.33 \# 10^{-5}) + v_p (0.04) = 0$$

$$v_0 =- 428.72 V_p \qquad \text{...(i)}$$

Writing KCL at input node

$$\frac{v_i}{R_s} = \frac{v_p}{R_s} + \frac{v_p}{r_p} + \frac{v_p - v_o}{R_F}$$

$$= v_p : \frac{1}{R_s} + \frac{1}{r_p} + \frac{1}{R_F} D - \frac{v_0}{R_F}$$

$$= v_p (5.1 \# 10^{-4}) - \frac{v_0}{R_F}$$

Substituting $V_p$ from equation (i)

$$\frac{v_i}{R_s} = \frac{-5.1 \# 10^{-4}}{428.72} v_0 - \frac{v_0}{R_F}$$

$$\frac{v_i}{10 \# 10^3} =- 1.16 \# 10^{-6} v_0 - 1 \# 10^{-5} v_0 \quad R_s = 10 \text{ kW}$$

$$\frac{v_i}{10 \# 10^3} =- 1.116 \# 10^{-5}$$

$$|A_v| = \left|\frac{v_0}{v_i}\right| = \frac{1}{10 \# 10^3 \# 1.116 \# 10^{-5}} - 8.96$$

Option (D) is correct.

Sol. 14 Let $Q_{n+1}$ is next state and $Q_n$ is the present state. From the given below figure.

$$D = Y = A\overline{X}_0 + AX_1$$

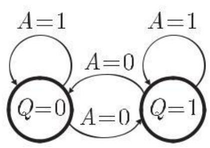
$$Q_{n+1} = D = A\overline{X}_0 + AX_1$$

$$Q_{n+1} = \overline{A}\,\overline{Q}_n + AQ_n \qquad X_0 = \overline{Q}, X_1 = Q$$

If $A = 0$, $Q_{n+1} = \overline{Q}_n$ (toggle of previous state)

If $A = 1$, $Q_{n+1} = Q_n$

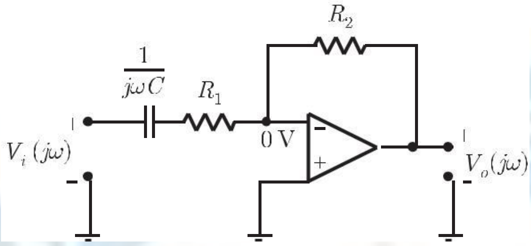
So state diagram is




**Sol. 15**

Option (B) is correct.

First we obtain the transfer function.




$$\frac{0 - V_i(jw)}{\frac{1}{jwC} + R_1} + \frac{0 - V_o(jw)}{R_2} = 0$$

$$\frac{V_o(jw)}{R_2} = \frac{-V_i(jw)}{\frac{1}{jwC} + R_1}$$

$$V_o(jw) = -\frac{V_i(jw)R_2}{R_1 - j\frac{1}{wC}}$$

At $w \to 0$ (Low frequencies), $\frac{1}{wC} \to \infty$, so $V_o = 0$

At $w \to \infty$ (higher frequencies), $\frac{1}{wC} \to 0$, so $V_o(jw) = -\frac{R_2}{R_1} V_i(jw)$

The filter passes high frequencies so it is a high pass filter.

$$H(jw) = \frac{V_o}{V_i} = \frac{-R_2}{R_1 - j\frac{1}{wC}}$$

$$|H(\infty)| = \left|\frac{-R_2}{R_1}\right| = \frac{R_2}{R_1}$$

At 3 dB frequency, gain will be $\frac{1}{\sqrt{2}}$ times of maximum gain $[H(\infty)]$

$$|H(jw_0)| = \frac{1}{\sqrt{2}}|H(\infty)|$$

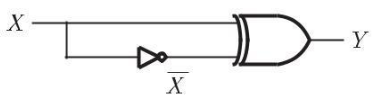
So,
$$\frac{R_2}{\sqrt{R_1^2 + \frac{1}{w_0^2 C^2}}} = \frac{1}{\sqrt{2}}\left(\frac{R_2}{R_1}\right)$$

$$2R_1^2 = R_1^2 + \frac{1}{w_0^2 C^2} \Rightarrow R_1^2 = \frac{1}{w^2 C^2}$$

$$w_0 = \frac{1}{R_1 C}$$

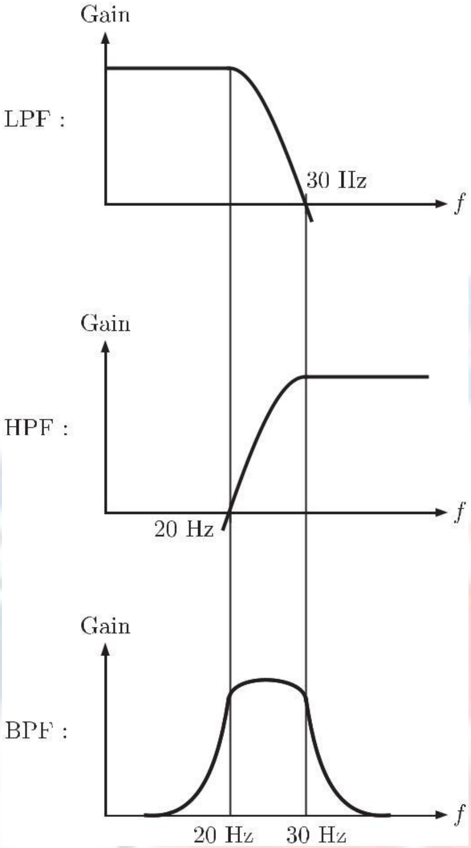
**Sol. 16**

Option (A) is correct.



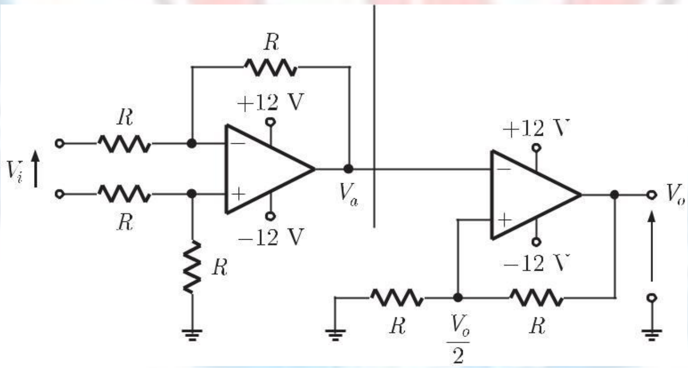

$$Y = X \oplus \overline{X} = X\overline{\overline{X}} + \overline{X}\,\overline{X}$$
$$= XX + \overline{X}\,\overline{X} = X + \overline{X} = 1$$

Sol. 17 Option (D) is correct.




So, it will act as a Band pass filter.

Sol. 18 Option (D) is correct.




The first half of the circuit is a differential amplifier (negative feedback)

$$V_a = -(V_i)$$

Second op-amp has a positive feedback, so it acts as an schmitt trigger.

Since

$V_a = -V_i$ this is a non-inverting schmitt trigger.

Threshold value

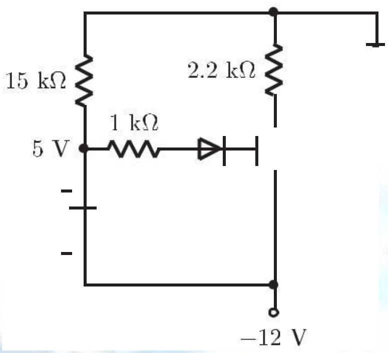
$$V_{TH} = \frac{12}{2} = 6 \text{ V}$$

$$V_{TL} = -6 \text{ V}$$

Sol. 19 Option (D) is correct.

Zener Diode is used as stabilizer.

The circuit is assumed to be as




We can see that both BE and BC Junction are forwarded biased. So the BJT is operating in saturation.

Collector current $I_C = \frac{12 - 0.2}{2.2k} = 5.36 \text{ mA}$

*Note*:- In saturation mode $I_C$ - $bI_B$

Y

Sol. 20 Option (C) is correct.

The characteristics equation of the JK flip-flop is

$Q_{n+1} = J\overline{Q}_n + \overline{K}Q_n$ $Q_{n+1}$ is the next state From figure it is clear that

$$J = \overline{Q}_B \,;\; K = Q_B$$

The output of JK flip flop

$$Q_{A(n+1)} = \overline{Q}_B \overline{Q}_A + \overline{Q}_B Q_A = \overline{Q}_B(\overline{Q}_A + Q_A) = \overline{Q}_B$$

Output of T flip-flop

$$Q_{B(n+1)} = \overline{Q}_A$$

| Clock pulse | $Q_A$ | $Q_B$ | $Q_{A(n+1)}$ | $Q_{B(n+1)}$ |
|---|---|---|---|---|
| Initially($t_n$) | 1 | 0 | 1 | 0 |
| $t_n + 1$ | 1 | 0 | 1 | 0 |
| $t_n + 2$ | 1 | 0 | 1 | 0 |
| $t_n + 3$ | 1 | 0 | 1 | 0 |

Sol. 21 Option (C) is correct.

LXI D, DISP

LP : CALL SUB

LP + 3

When CALL SUB is executed LP+3 value is pushed(inserted) in the stack.

POP H & $HL = LP + 3$

DAD D & $HL = HL + DE$

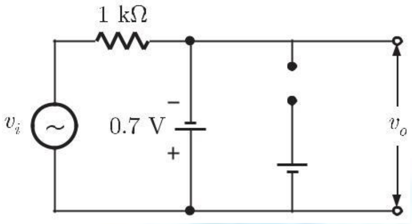
$= LP + 3 + DE$

PUSH H & The last two value of the stack will be HL value i.e, $LP + DISP + 3$

Sol. 22 Option (C) is correct.

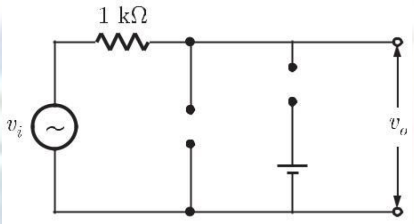
We can obtain three operating regions depending on whether the Zener and PN diodes are forward biased or reversed biased.

1. $v_i$ #- 0.7 V, zener diode becomes forward biased and diode $D$ will be off so the equivalent circuit looks like




The output $v_o$ =- 0.7 V

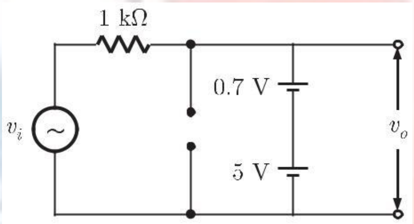
2. When -0.7 1 $v_i$ # 5.7, both zener and diode $D$ will be off. The circuit is




Output follows input i.e $v_o = v_i$

*Note* that zener goes in reverse breakdown(i.e acts as a constant battery) only when difference between its p-n junction voltages exceeds 10 V.

3. When $v_i > 5.7$ V, the diode $D$ will be forward biased and zener remains off, the equivalent circuit is




$$v_o = 5 + 0.7 = 5.7 \text{ V}$$

**Sol. 23** Option (B) is correct.

Since the op-amp is ideal

$$v_+ = v_- = +2 \text{ volt}$$

By writing node equation

$$\frac{v_- - 0}{R} + \frac{v_- - v_o}{2R} = 0$$

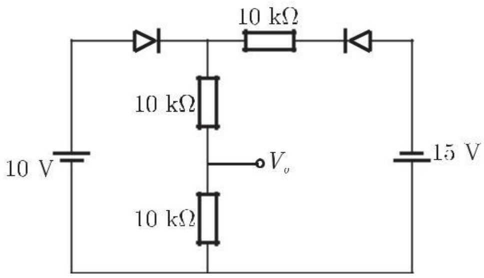
$$\frac{2}{R} + \frac{(2 - v_o)}{2R} = 0$$

$$4 + 2 - v_o = 0$$

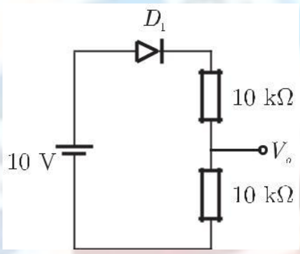
$$v_o = 6 \text{ volt}$$

**Sol. 24** Option (B) is correct.

Given circuit is,




We can observe that diode $D_2$ is always off, whether $D_1$,is on or off. So equivalent circuit is.




$D_1$ is ON in this condition and

$$V_0 = \frac{10}{10+10} \# 10$$
$$= 5 \text{ volt}$$

Sol. 25 Option (A) is correct.

By writing KVL equation for input loop (Base emitter loop)

$$10 - (10 \text{ kW}) I_B - V_{BE} - V_0 = 0 \qquad ...(1)$$

Emitter current $I_E = \dfrac{V_0}{100}$

$$I_C - I_E = \text{b} I_B$$

So,
$$\frac{V_0}{100} = 100 I_B$$
$$I_B = \frac{V_0}{10 \# 10^3}$$

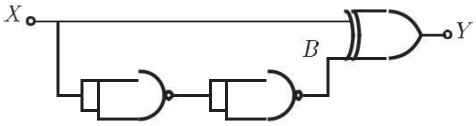
Put $I_B$ into equation (1)

$$10 - (10 \# 10^3) \frac{V_0}{10 \# 10^3} - 0.7 - V_0 = 0$$
$$9.3 - 2V_0 = 0$$

& $$V_0 = \frac{9.3}{2} = 4.65 \text{ A}$$

Sol. 26 Option (A) is correct.

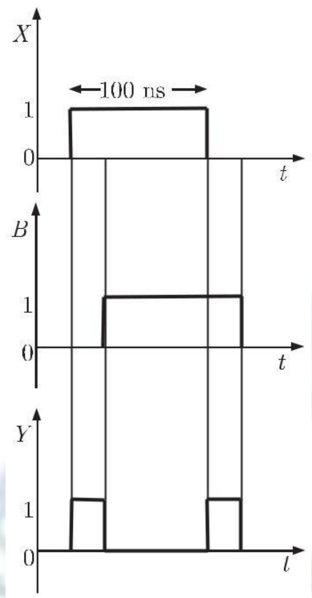
The circuit is




Output $Y$ is written as

$$Y = X 5 B$$

Since each gate has a propagation delay of 10 ns.




Sol. 27

Option (B) is correct.

Function $F$ can be minimized by grouping of all 1's in K-map as following.

| X \ YZ | 00 | 01 | 11 | 10 |
|---|---|---|---|---|
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 1 | 0 |

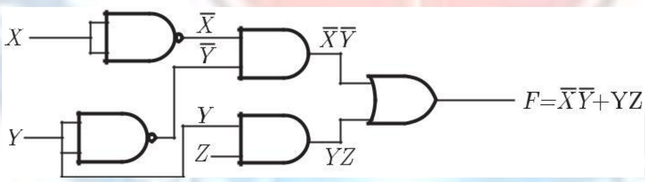
$$F = \overline{X}\,\overline{Y} + YZ$$

Sol. 28

Option (D) is correct.

Since $F = \overline{X}\,\overline{Y} + YZ$

In option (D)




Sol. 29

Option (D) is correct.

CALL, Address performs two operations

(1) PUSH PC & Save the contents of PC (Program Counter) into stack.

SP = SP - 2 (decrement)

((SP)) ! (PC)

(2) Addr stored in PC.

(PC) ! Addr

Sol. 30

Option (A) is correct.

Figure shows current characteristic of diode during switching.

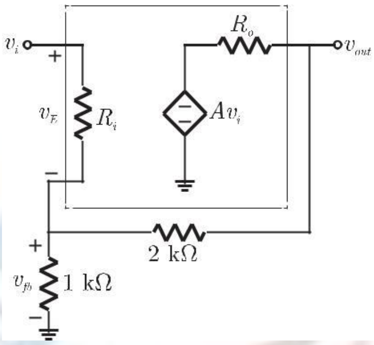
Sol. 31 Option (B) is correct.

The increasing order of speed is as following

Magnetic tape> CD-ROM> Dynamic RAM>Cache Memory>Processor register

Sol. 32 Option (B) is correct.

Equivalent circuit of given amplifier




Feedback samples output voltage and adds a negative feedback voltage ($v_{fb}$) to input.

So, it is a voltage-voltage feedback.

Sol. 33 Option () is correct.

NOR and NAND gates considered as universal gates.

Sol. 34 Option (A) is correct.

Let voltages at positive and negative terminals of op-amp are $V_+$ and $V_-$ respectively, then

$$V_+ = V_- = V_s \text{ (ideal op-amp)}$$

In the circuit we have,

$$\frac{V_- - 0}{`\frac{1}{Cs}j} + \frac{V_- - V_0(s)}{R} = 0$$

$$(RCs)\,V_- + V_- - V_0(s) = 0$$

$$(1 + RCs)\,V_s = V_0(s)$$

Similarly current $I_s$ is, $I_s = \frac{V_s - V_0}{R}$

$$I_s = \frac{RCs}{R} V_s$$

$$I_s = jw\,CV_s$$

$$I_s = |wCV_s| + +90^{\%}$$

$$|I_s| = 2pf \# 10 \# 10^{-6} \# 10$$

$$|I_s| = 2 \# p \# 50 \# 10 \# 10^{-6} \# 10$$

$|I_s| = 10p$ mA, leading by 90%

Sol. 35 Option (D) is correct.

Input and output power of a transformer is same

$$P_{in} = P_{out}$$

for emitter follower, voltage gain($A_v$) = 1 current gain($A_i$) > 1

$$\text{Power}(P_{out}) = A_v A_i P_{in}$$

Since emitter follower has a high current gain so $P_{out} > P_{in}$

Sol. 36 Option (D) is correct.

For the given instruction set,

$$\text{XRA } A \; \& \; \text{XOR } A \text{ with } A \; \& \; \text{A} = 0$$

$$\text{MVI } B, \text{F0 H} \& B = \text{F0 H}$$

$$\text{SUB } B \; \& A = A - B$$

$$A = 0\,0\,0\,0\,0\,0\,0\,0$$

$$B = 1111\,0\,0\,0\,0$$

$$\text{2's complement of } (-B) = 0\,0\,0\,1\,0\,0\,0\,0$$

$$A + (-B) = A - B = 0\,0\,0\,1\,0\,0\,0\,0 = 10 \text{ H}$$

Sol. 37 Option (D) is correct.

This is a schmitt trigger circuit, output can takes two states only.

$$V_{OH} = +6 \text{ volt}$$

$$V_{OL} = -3 \text{ volt}$$

Threshold voltages at non-inverting terminals of op-amp is given as

$$\frac{V_{TH} - 6}{2} + \frac{V_{TH} - 0}{1} = 0$$

$$3V_{TH} - 6 = 0$$

$$V_{TH} = 2 \text{ V (Upper threshold)}$$

Similarly $$\frac{V_{TL} - (-3)}{2} + \frac{V_{TL}}{1} = 0$$

$$3V_{TL} + 3 = 0$$

$$V_{TL} = -1 \text{ V (Lower threshold)}$$

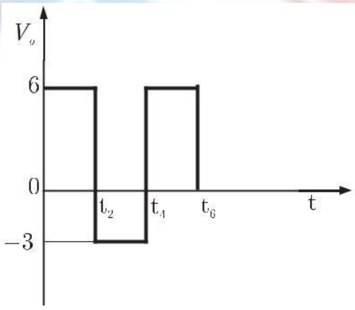
For $$V_{in} < 2 \text{ Volt}, V_0 = +6 \text{ Volt}$$

$$V_{in} > 2 \text{ Volt}, V_0 = -3 \text{ Volt}$$

$$V_{in} < -1 \text{ Volt } V_0 = +6 \text{ Volt}$$

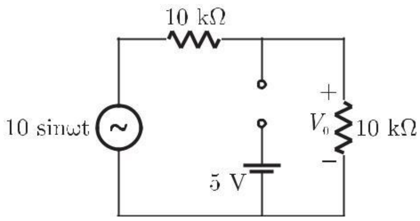
$$V_{in} > -1 \text{ Volt } V_0 = -3 \text{ Volt}$$

Output waveform




Sol. 38 Option (A) is correct.

Assume the diode is in reverse bias so equivalent circuit is

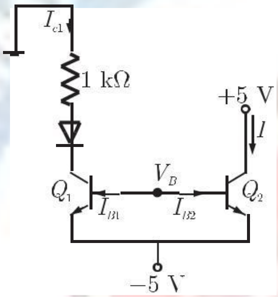



Output voltage $V_0 = \frac{10 \sin wt}{10 + 10} \# 10 = 5\sin wt$

Due to resistor divider, voltage across diode $V_D < 0$ (always). So it in reverse bias for given input.

Output, $V_0 = 5\sin wt$

Sol. 39 Option (C) is correct.




This is a current mirror circuit. Since $b$ is high so $I_{C1} = I_{C2}, I_{B1} = I_{B2}$

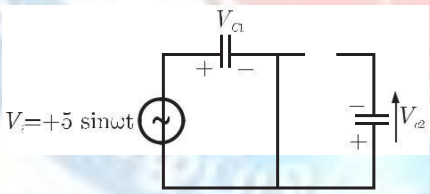
$$V_B = (-5 + 0.7) = -4.3 \text{ volt}$$

Diode $D_1$ is forward biased.

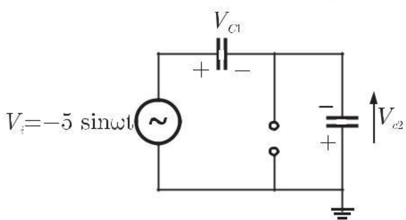
So, current $I$ is, $I = I_{C2} = I_{C1} = \frac{0 - (-4.3)}{1} = 4.3$ mA

Sol. 40 Option (D) is correct.

In positive half cycle of input, diode $D_1$ is in forward bias and $D_2$ is off, the equivalent circuit is



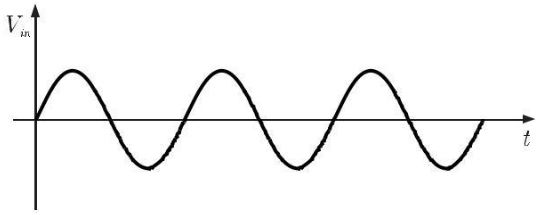

Capacitor $C_1$ will charge upto +5 volt. $V_{C1} = +5$ volt In negative halt cycle diode $D_1$ is off and $D_2$ is on.



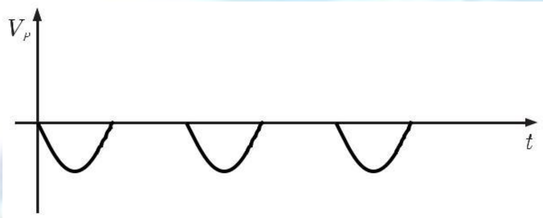

Now capacitor $V_{C2}$ will charge upto -10 volt in opposite direction.

Sol. 41 Option () is correct.

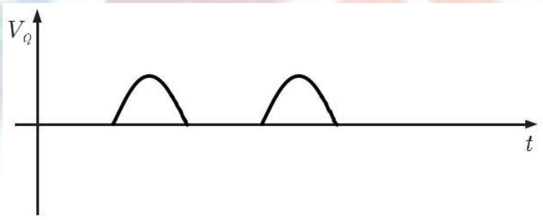
Let input $V_{in}$ is a sine wave shown below



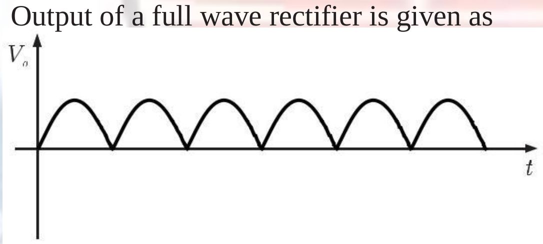

According to given transfer characteristics of rectifiers output of rectifier P is.




Similarly output of rectifier Q is




Output of a full wave rectifier is given as




To get output $V_0$

$V_0 = K(- V_P + V_Q)$ K - gain of op-amp

So, P should connected at inverting terminal of op-amp and Q with non-inverting terminal.

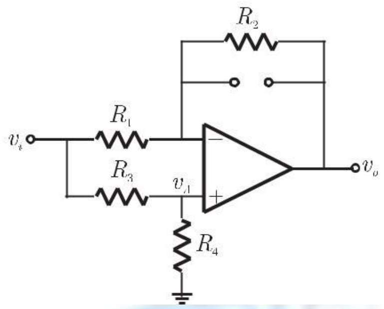
Sol. 42 Option () is correct.

Sol. 43 Option (C) is correct.

For low frequencies,

$w$ " 0, so $\frac{1}{wC}$ " 3

Equivalent circuit is,




Applying node equation at positive and negative input terminals of op-amp.

$$\frac{v_A - v_i}{R_1} + \frac{v_A - v_o}{R_2} = 0$$

$$2v_A = v_i + v_o, \qquad \because R_1 = R_2 = R_A$$

Similarly,

$$\frac{v_A - v_i}{R_3} + \frac{v_A - 0}{R_4} = 0$$

$$2v_A = v_{in}, \qquad \because R_3 = R_4 = R_B$$

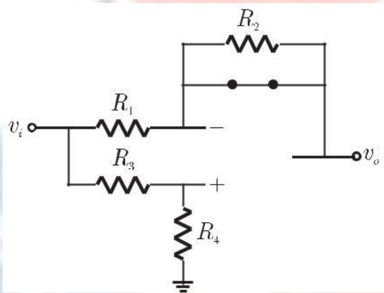
So, $v_o = 0$

It will stop low frequency signals.

For high frequencies,

$$\omega \to \infty, \text{ then } \frac{1}{\omega C} \to 0$$

Equivalent circuit is,




Output, $v_o = v_i$

So it will pass high frequency signal.

This is a high pass filter.

Sol. 44 Option (D) is correct.

In previous solution cutoff frequency of high pass filter is given by,

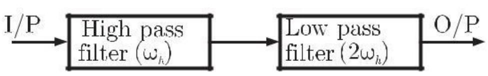
$$\omega_h = \frac{1}{2\pi R_A C}$$

Here given circuit is a low pass filter with cutoff frequency,

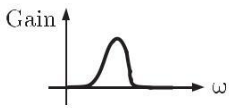
$$\omega_L = \frac{1}{2\pi \frac{R_A}{2} C} = \frac{2}{2\pi R_A C}$$

$$\omega_L = 2\omega_h$$

When both the circuits are connected together, equivalent circuit is,




So this is is Band pass filter, amplitude response is given by.




Sol. 45 Option (B) is correct.

In SOP form, $F$ is written as

$$F = \Sigma m(1, 3, 5, 6) = \overline{X}\,\overline{Y}Z + \overline{X}YZ + X\overline{Y}Z + XY\overline{Z}$$

Solving from K- map

| $X \backslash YZ$ | $\overline{Y}\,\overline{Z}$ | $\overline{Y}Z$ | $YZ$ | $Y\overline{Z}$ |
|---|---|---|---|---|
| $\overline{X}$ | | 1 | 1 | |
| $X$ | | 1 | | 1 |

$$F = \overline{X}Z + \overline{Y}Z + XY\overline{Z}$$

In POS form $\quad F = (Y + Z)(X + Z)(\overline{X} + \overline{Y} + \overline{Z})$

Since all outputs are active low so each input in above expression is complemented

$$F = (\overline{Y} + \overline{Z})(\overline{X} + \overline{Z})(X + Y + Z)$$

Sol. 46 Option (B) is correct.

Given that $\quad$ SP = 2700 H

PC = 2100 H

HL = 0000 H

Executing given instruction set in following steps,

DAD SP & Add register pair (SP) to HL register

HL = HL + SP

HL = 0000 H + 2700 H

HL = 2700 H

PCHL & Load program counter with HL contents

PC = HL = 2700 H

So after execution contents are,

PC = 2700 H, HL = 2700 H

Sol. 47 Option (D) is correct.

If transistor is in normal active region, base current can be calculated as following,

By applying KVL for input loop,

$$10 - I_C(1 \times 10^3) - 0.7 - 270 \times 10^3 I_B = 0$$

$$\beta I_B + 270\, I_B = 9.3 \text{ mA}, \qquad \because I_C = \beta I_B$$

$$I_B(\beta + 270) = 9.3 \text{ mA}$$

$$I_B = \frac{9.3 \text{ mA}}{270 + 100} = 0.025 \text{ mA}$$

In saturation, base current is given by,

$$10 - I_C(1) - V_{CE} - I_E(1) = 0$$

$$\frac{10}{2} = I_{C\,(sat)} \qquad I_C \approx I_E,\ V_{CE} \approx 0$$

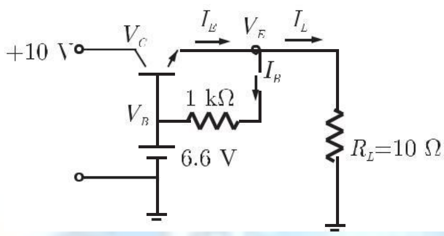
$$I_{C\,(sat)} = 5 \text{ mA}$$

$$I_{B(sat)} = \frac{I_{C\,(sat)}}{b} = \frac{5}{100} = .050 \text{ mA}$$

$I_B$ 1 $I_{B(sat)}$, so transistor is in forward active region.

Sol. 48 Option (B) is correct.

In the circuit




We can analyze that the transistor is operating in active region.

$$V_{BE(ON)} = 0.6 \text{ volt}$$

$$V_B - V_E = 0.6$$

$$6.6 - V_E = 0.6$$

$$V_E = 6.6 - 0.6 = 6 \text{ volt}$$

At emitter (by applying KCL),

$$I_E = I_B + I_L$$

$$I_E = \frac{6 - 6.6}{1 \text{ kW}} + \frac{6}{10 \text{ W}} \quad - 0.6 \text{ amp}$$

$V_{CE} = V_C - V_E = 10 - 6 = 4$ volt

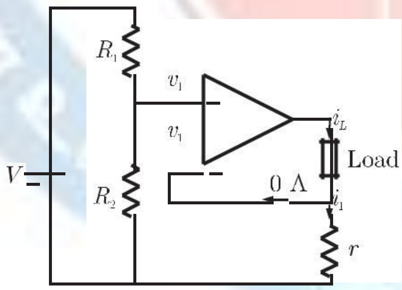
Power dissipated in transistor is given by.

$$P_T = V_{CE} \# I_C = 4 \# 0.6 \qquad ` I_C - I_E = 0.6 \text{ amp}$$

$$= 2.4 \text{ W}$$

Sol. 49 Option (D) is correct.

This is a voltage-to-current converter circuit. Output current depends on input voltage.




Since op-amp is ideal $v_+ = v_- = v_1$

Writing node equation.

$$\frac{v_1 - V}{R_1} + \frac{v_1 - 0}{R_2} = 0$$

$$v_1\left(\frac{R_1 + R_2}{R_1 R_2}\right) = \frac{V}{R_1}$$

$$v_1 = V\left(\frac{R_2}{R_1 + R_2}\right)$$

Since the op-amp is ideal therefore

$$i_L = i_1 = \frac{v_1}{r} = \frac{V}{r}\left(\frac{R_2}{R_1 + R_2}\right)$$

**Sol. 50** Option (D) is correct.

In the circuit output $Y$ is given as

$$Y = [A \oplus B] \oplus [C \oplus D]$$

Output $Y$ will be 1 if no. of 1's in the input is odd.

**Sol. 51** Option () is correct.

This is a class-B amplifier whose efficiency is given as

$$\eta = \frac{\pi V_P}{4V_{CC}}$$

where $V_P \approx$ peak value of input signal

$V_{CC} \approx$ supply voltage

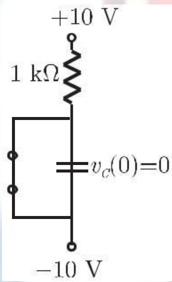
here $V_P = 7$ volt, $V_{CC} = 10$ volt

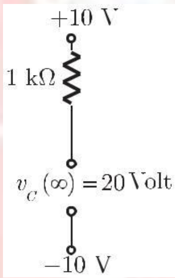
so,
$$\eta = \frac{\pi}{4} \times \frac{7}{10} \times 100 = 54.95\% \approx 55\%$$

**Sol. 52** Option (B) is correct.

In the circuit the capacitor starts charging from 0 V (as switch was initially closed) towards a steady state value of 20 V.

for $t < 0$ (initial) for $t \to \infty$ (steady state)




So at any time $t$, voltage across capacitor (i.e. at inverting terminal of op-amp) is given by

$$v_c(t) = v_c(\infty) + [v_c(0) - v_c(\infty)]e^{\frac{-t}{RC}}$$

$$v_c(t) = 20(1 - e^{\frac{-t}{RC}})$$

Voltage at positive terminal of op-amp

$$\frac{v_+ - v_{out}}{10} + \frac{v_+ - 0}{100} = 0$$

$$v_+ = \frac{10}{11} v_{out}$$

Due to zener diodes, $-5 \le v_{out} \le +5$

So,
$$v_+ = \frac{10}{11}(5)\text{ V}$$

Transistor form -5 V to +5 V occurs when capacitor charges upto $v_+$.

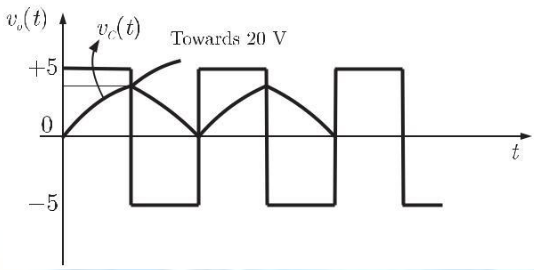
So
$$20(1 - e^{-t/RC}) = \frac{10 \times 5}{11}$$

$$1 - e^{-t/RC} = \frac{5}{22}$$

$$\frac{17}{22} = e^{-t/RC}$$

$$t = RC \ln`\frac{22}{17}j = 1 \# 10^3 \# .01 \# 10^{-6} \# 0.257 = 2.57$$

*m*sec Voltage waveforms in the circuit is shown below




Sol. 53 Option (B) is correct.

In a 555 astable multi vibrator circuit, charging of capacitor occurs through resistor ($R_A + R_B$) and discharging through resistor $R_B$ only. Time for charging and discharging is given as.

$$T_C = 0.693(R_A + R_B)C = 0.693\, R_B\, C$$

But in the given circuit the diode will go in the forward bias during charging, so the capacitor will charge through resistor $R_A$ only and discharge through $R_B$ only.

a $R_A = R_B$

So $T_C = T_D$

Sol. 54 Option (B) is correct.

First convert the given number from hexadecimal to its binary equivalent, then binary to octal.

Hexadecimal no. AB. CD

Binary equivalent $^S1010\ ^S1011\ 11\ 0\ 0\ ^S110\ 1$ $ A B **B** C

*A* *B* *C* *D*

To convert in octal group three binary digits together as shown

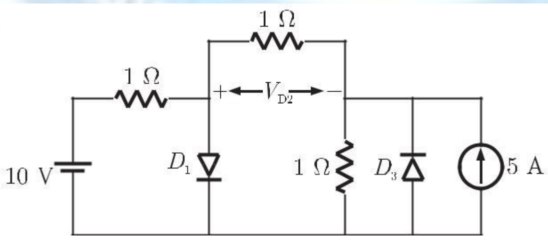
S010 S101 S011 $S110 S011 S010

2 5 3 6 3 2

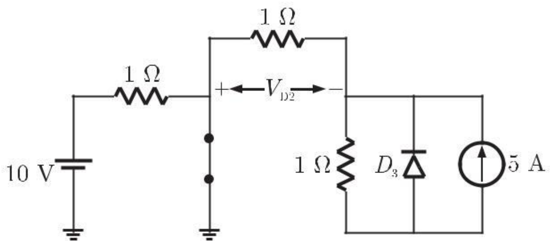
So, $(AB.\ CD)_H = (253.632)_8$

Sol. 55 Option (A) is correct.

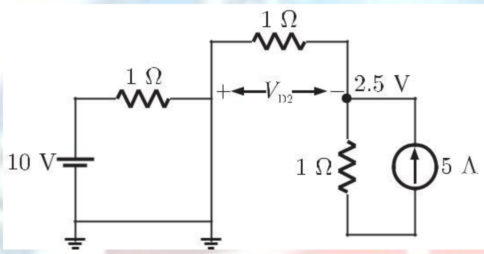
First we can check for diode $D_2$. Let diode $D_2$ is OFF then the circuit is




In the above circuit diode $D_1$ must be ON, as it is connected with 10 V battery now the circuit is



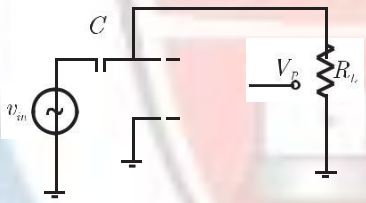

Because we assumed diode $D_2$ OFF so voltage across it $V_{D2}$ # 0 and it is possible only when $D_3$ is off.




So, all assumptions are true.

**Sol. 56** Option (D) is correct.

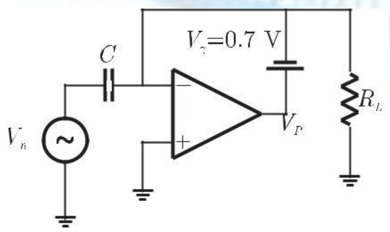
In the positive half cycle of input, Diode $D_1$ will be reverse biased and equivalent circuit is.




Since there is no feed back to the op-amp and op-amp has a high open loop gain so it goes in saturation. Input is applied at inverting terminal so.

$$V_P = -V_{CC} = -12\text{ V}$$

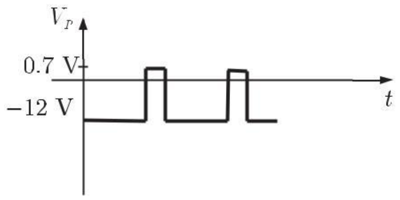
In negative half cycle of input, diode $D_1$ is in forward bias and equivalent circuit is shown below.




Output $V_P = V_g + V_-$

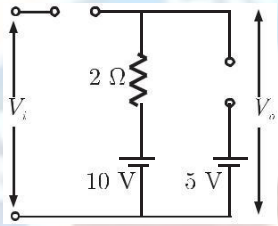
Op-amp is at virtual ground so $V_+ = V_- = 0$ and $V_P = V_g = 0.7$ V

Voltage wave form at point P is



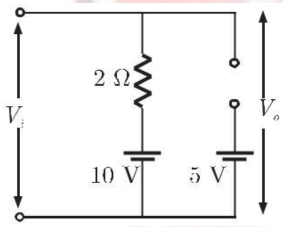

Sol. 57 Option (A) is correct.

In the circuit when $V_i < 10$ V, both $D_1$ and $D_2$ are off.
So equivalent circuit is,



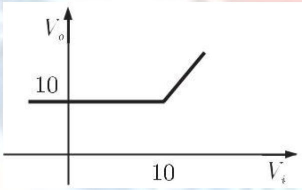

Output, $V_o = 10$ volt

When $V_i > 10$ V ($D_1$ is in forward bias and $D_2$ is off So the equivalent circuit is,




Output, $V_o = V_i$

Transfer characteristic of the circuit is



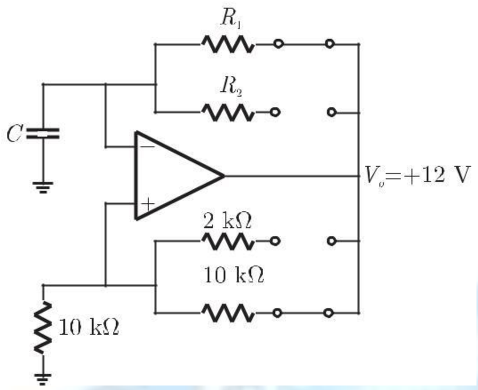

Sol. 58 Option (C) is correct.

Here output of the multi vibrator is

$$V_0 =! 12 \text{ volt}$$

Threshold voltage at positive terminal of op-amp can be obtained as following

When output $V_0 =+ 12$ V, equivalent circuit is,



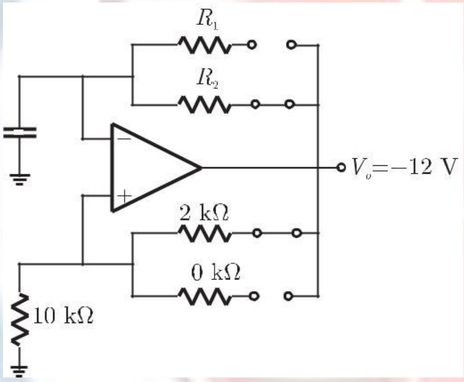

writing node equation at positive terminal of op-amp

$$\frac{V_{th}-12}{10}+\frac{V_{th}-0}{10}=0$$

$$V_{th} = 6 \text{ volt (Positive threshold)}$$

So, the capacitor will charge upto 6 volt.

When output $V_0$ =- 12 V, the equivalent circuit is.




node equation

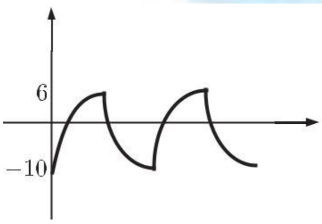
$$\frac{V_{th}+12}{2}+\frac{V_{th}-0}{10}=0$$

$$5\,V_{th} + 60 + V_{th} = 0$$

$$V_{th} = -10 \text{ volt (negative threshold)}$$

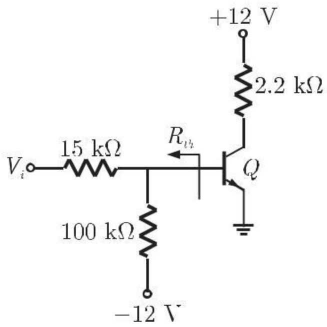
So the capacitor will discharge upto -10 volt.

At terminal P voltage waveform is.




Sol. 59 Option (B) is correct.

Assume that BJT is in active region, thevenin equivalent of input circuit is obtained as




$$\frac{V_{th} - V_i}{15} + \frac{V_{th} - (-12)}{100} = 0$$

$$20V_{th} - 20V_i + 3V_{th} + 36 = 0$$

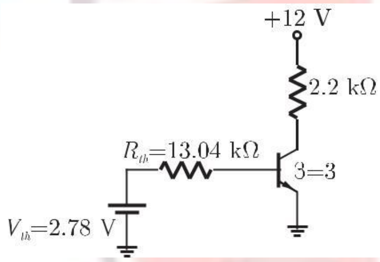
$$23V_{th} = 20 \# 5 - 36, \; V_i = 5 \text{ V}$$

$$V_{th} = 2.78 \text{ V}$$

Thevenin resistance $R_{th} = 15 \text{ KW} \| 100 \text{ KW}$

$$= 13.04 \text{ KW}$$

So the circuit is




Writing KVL for input loop

$$2.78 - R_{th} I_B - 0.7 = 0$$

$$I_B = 0.157 \text{ mA}$$

Current in saturation is given as,

$$I_{B(sat)} = \frac{I_{C(sat)}}{b}$$

$$I_{C(sat)} = \frac{12.2}{2.2} = 5.4 \text{ mA}$$

So, $I_{B(sat)} = \dfrac{5.45 \text{ mA}}{30} = 0.181 \text{ mA}$

Since $I_{B\,(sat)} > I_B$, therefore assumption is true.

Sol. 60 Option () is correct.

Sol. 61 Option () is correct.

Sol. 62 Option (A) is correct.

Function $F$ can be obtain as,

$$F = I_0 \overline{S_1}\,\overline{S_0} + \overline{I_1} S_1 S_0 + I_2 \overline{S_1} S_0 + I_3 S_1 S_0$$

$$= A\overline{B}\,\overline{C} + \overline{A}\,\overline{B}\,\overline{C} + 1 \$ B\overline{C} + 0 \$ BC$$

$$= A\overline{B}\,\overline{C} + \overline{A}\,\overline{BC} + BC$$

$$= A\overline{B}\,\overline{C} + \overline{A}\,\overline{BC} + BC\,(\overline{A} + A)$$

$$= A\overline{B}\,\overline{C} + \overline{A}\,\overline{B}\,\overline{C} + ABC + \overline{A}\,\overline{B}C$$
$$= S(1, 2, 4, 6)$$

**Sol. 63** Option (A) is correct.

MVI H and MVI L stores the value 255 in H and L registers. DCR L decrements L by 1 and JNZ checks whether the value of L is zero or not. So DCR L executed 255 times till value of L becomes ‘0’.

Then DCR H will be executed and it goes to ‘Loop’ again, since L is of 8 bit so no more decrement possible and it terminates.

**Sol. 64** Option (A) is correct.

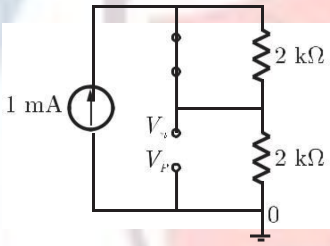
XCHG & Exchange the contain of DE register pair with HL pair So now addresses of memory locations are stored in HL pair.

INR M & Increment the contents of memory whose address is stored in HL pair.

**Sol. 65** Option (A) is correct.

From the circuit we can observe that Diode $D_1$ must be in forward bias (since current is flowing through diode).

Let assume that $D_2$ is in reverse bias, so equivalent circuit is.




Voltage $V_n$ is given by

$$V_n = 1 \# 2 = 2 \text{ Volt}$$
$$V_p = 0$$

$V_n > V_p$ (so diode is in reverse bias, assumption is true)

Current through $D_2$ is $I_{D2} = 0$

**Sol. 66** Option (C) is correct.

SHLD transfers contain of HL pair to memory location.

SHLD 2050 & L " M[2050H]

H " M[2051H]

**Sol. 67** Option (D) is correct.

This is a N-channel MOSFET with $V_{GS} = 2$ V

$$V_{TH} = +1 \text{ V}$$
$$V_{DS(sat)} = V_{GS} - V_{TH}$$
$$V_{DS(sat)} = 2 - 1 = 1 \text{ V}$$

Due to 10 V source $V_{DS} > V_{DS(sat)}$ so the NMOS goes in saturation, channel conductivity is high and a high current flows through drain to source and it acts as a short circuit.

So, $V_{ab} = 0$

**Sol. 68** Option (C) is correct.

Let the present state is Q(t), so input to D-flip flop is given by,

$$D = Q(t) \, 5 \, X$$

Next state can be obtained as,

$$Q(t+1) = D$$
$$= Q(t) \oplus X$$
$$= Q(t)\overline{X} + \overline{Q}(t)X$$
$$= \overline{Q}(t), \text{ if } X = 1$$

and $Q(t+1) = Q(t), \quad \text{if } X = 0$

So the circuit behaves as a T flip flop.

**Sol. 69** Option (B) is correct.

Since the transistor is operating in active region.

$$I_E \approx \beta I_B$$
$$I_B = \frac{I_E}{\beta} = \frac{1 \text{ mA}}{100} = 10 \ \mu\text{A}$$

**Sol. 70** Option (C) is correct.

Gain of the inverting amplifier is given by,

$$A_v = -\frac{R_F}{R_1} = -\frac{1 \times 10^6}{R_1}, \quad R_F = 1 \ \text{M}\Omega$$
$$R_1 = -\frac{1 \times 10^6}{A_v}$$

$A_v = -10$ to $-25$ so value of $R_1$

$$R_1 = \frac{10^6}{10} = 100 \ \text{k}\Omega \qquad \text{for } A_v = -10$$
$$R_1' = \frac{10^6}{25} = 40 \ \text{k}\Omega \qquad \text{for } A_v = -25$$

$R_1$ should be as large as possible so $R_1 = 100 \ \text{k}\Omega$

**Sol. 71** Option (B) is correct.

Direct coupled amplifiers or DC-coupled amplifiers provides gain at dc or very low frequency also.

**Sol. 72** Option (C) is correct.

Since there is no feedback in the circuit and ideally op-amp has a very high value of open loop gain, so it goes into saturation (ouput is either $+V$ or $-V$ ) for small values of input.

The input is applied to negative terminal of op-amp, so in positive half cycle it saturates to $-V$ and in negative half cycle it goes to $+V$ .

**Sol. 73** Option (B) is correct.

From the given input output waveforms truth table for the circuit is drawn as

| $X_1$ | $X_2$ | Q |
|---|---|---|
| 1 | 0 | 1 |
| 0 | 0 | 1 |
| 0 | 1 | 0 |

In option (A), for $X_1 = 1, Q = 0$ so it is eliminated.

In option (C), for $X_1 = 0, Q = 0$ (always), so it is also eliminated.

In option (D), for $X_1 = 0, Q = 1$, which does not match the truth table.

Only option (B) satisfies the truth table.

**Sol. 74** Option (D) is correct.

In the given circuit NMOS $Q_1$ and $Q_3$ makes an inverter circuit. $Q_4$ and $Q_5$ are in

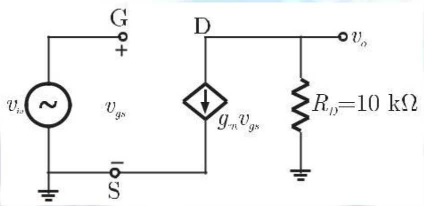
parallel works as an OR circuit and $Q_2$ is an output inverter.
So output is

$$Q = \overline{\overline{X_1} + X_2} = X_1 . \overline{X_2}$$

Sol. 75 Option (B) is correct.
Trans-conductance of MOSFET is given by

$$g_m = \frac{2i_D}{2V_{GS}} = \frac{(2 - 1)\text{ mA}}{(2 - 1)\text{ V}} = 1\text{ mS}$$

Sol. 76 Option (D) is correct.
Voltage gain can be obtain by small signal equivalent circuit of given amplifier.



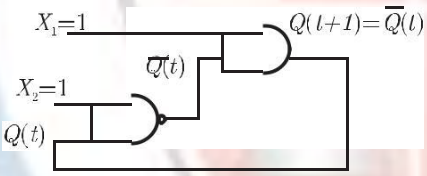

$$v_o = - g_m v_{gs} R_D$$

$$v_{gs} = v_{in}$$

So, $$v_o = - g_m R_D v_{in}$$

Voltage gain $$A_v = \frac{v_o}{v_i} = - g_m R_D = - (1\text{ mS})(10\text{ kW}) = - 10$$

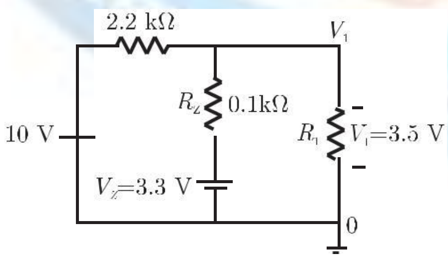
Sol. 77 Option (D) is correct.
Let $Q(t)$ is the present state then from the circuit,




So, the next state is given by

$$Q(t + 1) = \overline{Q}(t)\text{ (unstable)}$$

Sol. 78 Option (C) is correct.
Given circuit,




In the circuit

$$V_1 = 3.5\text{ V (given)}$$

Current in zener is.

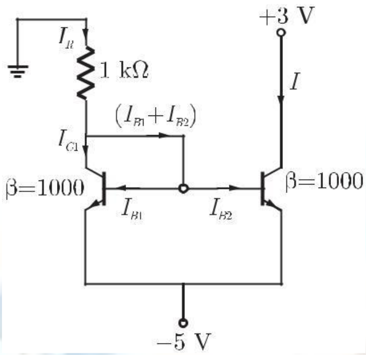
$$I_Z = \frac{V_1 - V_Z}{R_Z} = \frac{3.5 - 3.3}{0.1 \# 10^3} = 2\text{ mA}$$

Sol. 79 Option (C) is correct.

This is a current mirror circuit. Since $V_{BE}$ is the same in both devices, and transistors are perfectly matched, then

$$I_{B1} = I_{B2} \text{ and } I_{C1} = I_{C2}$$

From the circuit we have,




$$I_R = I_{C1} + I_{B1} + I_{B2} = I_{C1} + 2I_{B2} \qquad \because I_{B1} = I_{B2}$$

$$= I_{C2} + \frac{2I_{C2}}{\beta} \qquad \because I_{C1} = I_{C2},\ I_{C2} = \beta I_{B2}$$

$$I_R = I_{C2}\left(1 + \frac{2}{\beta}\right)$$

$$I_{C2} = I = \frac{I_R}{\left(1 + \frac{2}{\beta}\right)}$$

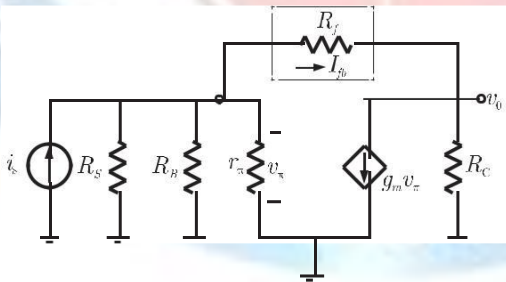
$I_R$ can be calculate as

$$I_R = \frac{-5 + 0.7}{1 \times 10^3} = -4.3 \text{ mA}$$

So,
$$I = \frac{4.3}{\left(1 + \frac{2}{100}\right)} \simeq 4.3 \text{ mA}$$

Sol. 80 Option (B) is correct.

The small signal equivalent circuit of given amplifier




Here the feedback circuit samples the output voltage and produces a feed back current $I_{fb}$ which is in shunt with input signal. So this is a shunt-shunt feedback configuration.

Sol. 81 Option (A) is correct.

In the given circuit output is stable for both 1 or 0. So it is a bistable multi-vibrator.

Sol. 82 Option (A) is correct.

Since there are two levels ($+V_{CC}$ *or* $-V_{CC}$) of output in the given comparator circuit.

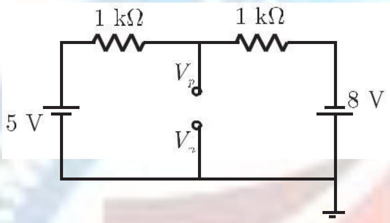
For an $n$ -bit Quantizer

$$2^n = \text{No. of levels}$$
$$2^n = 2$$
$$n = 1$$

Sol. 83 Option (C) is correct.

From the circuit, we can see the that diode $D_2$ must be in forward Bias.
For $D_1$ let assume it is in reverse bias.
Voltages at $p$ and $n$ terminal of $D_1$ is given by $V_p$ and $V_n$

$V_p < V_n$ ($D_1$ is reverse biased)




Applying node equation

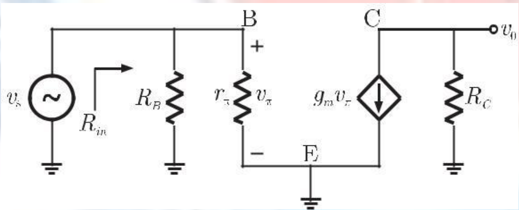
$$\frac{V_p - 5}{1} + \frac{V_p + 8}{1} = 0$$
$$2V_p = - 3$$
$$V_p = - 1.5$$
$$V_n = 0$$

$V_p < V_n$ (so the assumption is true and $D_1$ is in reverse bias) and current in $D_1$

$$I_{D1} = 0 \text{ mA}$$

Sol. 84 Option (D) is correct.

The small signal ac equivalent circuit of given amplifier is as following.




Here $$R_B = (10 \text{ kW} < 10 \text{ kW}) = 5 \text{ kW}$$
$$g_m = 10 \text{ ms}$$

Input resistance $$a\, g_m r_p = b \ \& \ r_p = \frac{50}{10 \# 10^{-3}} = 5 \text{ kW}$$
$$R_{in} = R_B < r_p = 5 \text{ kW} < 5 \text{ kW} = 2.5 \text{ kW}$$

Sol. 85 Option (D) is correct.

For PMOS to be biased in non-saturation region.

$$V_{SD} < V_{SD(\text{sat})}$$

and

$$V_{SD(\text{sat})} = V_{SG} + V_T$$

$V_{SD(sat)} = 4 - 1$ "a $V_{SG} = 4 - 0 = 4$ volt

$= 3$ Volt

So, $V_{SD} < 3$

$V_S - V_D < 3$

$4 - I_D R < 3$

$1 < I_D R$

$I_D R > 1,$ $I_D = 1$ mA

$R > 1000$ W

Sol. 86 Option () is correct.

Sol. 87 Option (B is correct.

If op-amp is ideal, no current will enter in op-amp. So current $i_x$ is

$$i_x = \frac{v_x - v_y}{1 \# 10^6} \quad ...(1)$$

$$v_+ = v_- = v_x \quad \text{(ideal op-amp)}$$

$$\frac{v_x - v_y}{100 \# 10^3} + \frac{v_x - 0}{10 \# 10^3} = 0$$

$$v_x - v_y + 10v_x = 0$$

$$11v_x = v_y \quad ...(2)$$

For equation (1) & (2)

$$i_x = \frac{v_x - 11v_x}{1 \# 10^6} = -\frac{10v_x}{10^6}$$

Input impedance of the circuit.

$$R_{in} = \frac{v_x}{i_x} = -\frac{10^6}{10} = -100 \text{ kW}$$

Sol. 88 Option (A) is correct.

Given Boolean expression,

$$Y = (\overline{A} \$ BC + D)(\overline{A} \$ D + \overline{B}\,\overline{C})$$

$$= (\overline{A} \$ BCD) + (\overline{A}BC \$ \overline{B} \$ \overline{C}) + (\overline{A}D) + \overline{B}\,\overline{C}\,D$$

$$= \overline{A}BCD + \overline{A}D + \overline{B}\,\overline{C}\,D$$

$$= \overline{A}D(BC + 1) + \overline{B}\,\overline{C}\,\overline{D} = \overline{A}D + \overline{B}\,\overline{C}\,\overline{D}$$

Sol. 89 Option (C) is correct.

The program is executed in following steps.

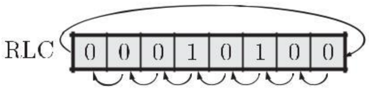
START MVI A, 14H " one instruction cycle.

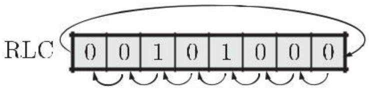
RLC & rotate accumulator left without carry

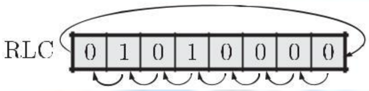
RLC is executed 6 times till value of accumulator becomes zero.

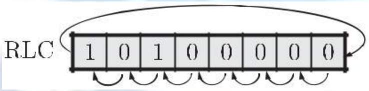
JNZ, JNZ checks whether accumulator value is zero or not, it is executed 5 times.

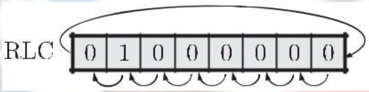
HALT " 1-instruction cycle.

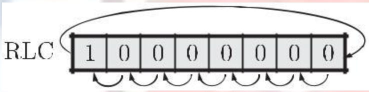


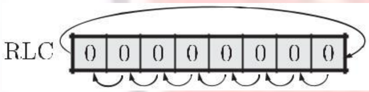




So total no. of instruction cycles are

$$n = 1 + 6 + 5 + 1 = 13$$

**Sol. 90** Option (D) is correct.

In the given circuit, output is given as.

$$Y = (A_0 \; 5 \; B_0) \; 9 \; (A_1 \; 5 \; B_1) \; 9 \; (A_2 \; 5 \; B_2) \; 9 \; (A_3 \; 5 \; B_3)$$

For option (A)

$$Y = (1\;5\;1)\;9\;(0\;5\;0)\;9\;(1\;5\;1)\;9\;(0\;5\;0)$$
$$= 0\;9\;0\;9\;0\;9\;0 = 1$$

For option (B)

$$Y = (0\;5\;0)\;9\;(1\;5\;1)\;9\;(0\;5\;0)\;9\;(1\;5\;1)$$
$$= 0\;9\;0\;9\;0\;9\;0 = 1$$

For option (C)

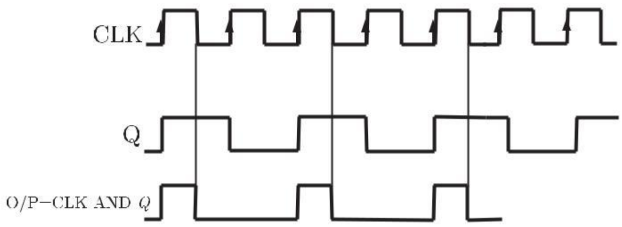
$$Y = (0\;5\;0)\;9\;(0\;5\;0)\;9\;(1\;5\;1)\;9\;(0\;5\;0)$$
$$= 0\;9\;0\;9\;0\;9\;0 = 1$$

For option (D)

$$Y = (1\;5\;1)\;9\;(0\;5\;0)\;9\;(1\;5\;1)\;9\;(0\;5\;1)$$
$$= 0\;9\;0\;9\;0\;9\;1 = 0$$

**Sol. 91** Option (B) is correct.

In the given circuit, waveforms are given as,




**Sol. 92** Option (B) is correct.

In the given circuit

$$V_i = 0 \text{ V}$$

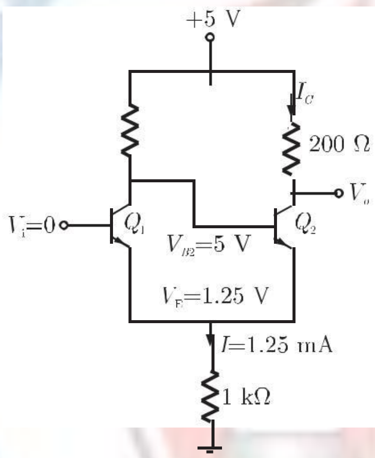
So, transistor $Q_1$ is in cut-off region and $Q_2$ is in saturation.

$$5 - I_C R_C - V_{CE(sat)} - 1.25 = 0$$

$$5 - I_C R_C - 0.1 - 1.25 = 0$$

$$5 - I_C R_C = 1.35$$

$$V_0 = 1.35 \qquad \text{"a } V_0 = 5 - I_C R_C$$




**Sol. 93** Option (C) is correct.

Since there exists a drain current for zero gate voltage ($V_{GS} = 0$), so it is a depletion mode device.

$I_D$ increases for negative values of gate voltages so it is a *p*-type depletion mode device.

**Sol. 94** Option (B) is correct.

Applying KVL in input loop,

$$4 - (33 \# 10^3) I_B - V_{BE} - (3.3 \# 10^3) I_E = 0 \qquad \text{a } I_E = (h_{fe} + 1) I_B$$

$$4 - (33 \# 10^3) I_B - 0.7 - (3.3 \# 10^3)(h_{fe} + 1) I_B = 0$$

$$@ \quad 3.3 = \quad (33 \# 10^3) + (3.3 \# 10^3)(99 + 1) \, I_B$$

$$I_B = \frac{3.3}{33 \# 10^3 + 3.3 \# 10^3 \# 100}$$

$$I_C = h_{fe} I_B$$

$$= \frac{99 \# 3.3}{[0.33 + 3.3] \# 100} \text{ mA} = \frac{3.3}{0.33 + 3.3} \text{ mA}$$

**Sol. 95** Option (D) is correct.

Let the voltages at positive and negative terminals of op-amp are $v_+$ and $v_-$ respectively. Then by applying nodal equations.

$$\frac{v_- - v_{in}}{R_1} + \frac{v_- - v_{out}}{R_1} = 0$$

$$2v_{--} = v_{in} + v_{out} \quad ..(1)$$

Similarly,

$$\frac{v_+ - v_{in}}{R} + \frac{v_+ - 0}{\frac{1}{jwC}} = 0$$

$$v_+ - v_{in} + v_+(jwCR) = 0$$

$$v_+(1 + jwCR) = V_{in} \quad ..(2)$$

By equation (1) & (2)

$$\frac{2v_{in}}{1 + jw\,CR} = v_{in} + v_{out} \qquad \text{"a } v_+ = v_- \text{ (ideal op-amp)}$$

$$v_{in}\left(\frac{2}{1 + j\,w\,CR} - 1\right) = v_{out}$$

$$v_{out} = v_{in}\frac{(1 - jwCR)}{1 + j\,w\,CR}$$

Phase shift in output is given by

$$q = \tan^{-1}(-w\,CR) - \tan^{-1}(wCR)$$

$$= p - \tan^{-1}(w\,CR) - \tan^{-1}(wCR)$$

$$= p - 2\tan^{-1}(wCR)$$

Maximum phase shift $\quad q = p$

Sol. 96 Option (C) is correct.

In given circuit MUX implements a 1-bit full adder, so output of MUX is given by.

$$F = \text{Sum} = A \oplus Q \oplus C_{in}$$

Truth table can be obtain as.

| P | Q | $C_{in}$ | Sum |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 1 |
| 0 | 1 | 1 | 0 |
| 1 | 0 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 0 |
| 1 | 1 | 1 | 1 |

$$\text{Sum} = \overline{P}\,\overline{Q}\,C_{in} + \overline{P}Q\,\overline{C_{in}} + P\,\overline{Q}\,\overline{C_{in}} + P\,Q\,C_{in}$$

Output of MUX can be written as

$$F = \overline{P}\,\overline{Q}\,\$\,I_0 + \overline{P}Q\,\$\,I_1 + P\overline{Q}\,\$\,I_2 + PQ\,\$\,I_3$$

Inputs are, $\quad I_0 = C_{in},\ I_1 = \overline{C_{in}},\ I_2 = \overline{C_{in}},\ I_3 = C_{in}$

Sol. 97 Option (D) is correct.

Program counter contains address of the instruction that is to be executed next.

Sol. 98 Option (A) is correct.

For a $n$ -channel enhancement mode MOSFET transition point is given by,

$$V_{DS(sat)} = V_{GS} - V_{TH} \qquad \text{a } V_{TH} = 2 \text{ volt}$$

$$V_{DS(sat)} = V_{GS} - 2$$

From the circuit,

$$V_{DS} = V_{GS}$$

So $$V_{DS(sat)} = V_{DS} - 2 \;\&\; V_{DS} = V_{DS(sat)} + 2 \; V_{DS} > V_{DS(sat)}$$

Therefore transistor is in saturation region and current equation is given by.

$$I_D = K\,(V_{GS} - V_{TH})^2$$
$$4 = K\,(V_{GS} - 2)^2$$

$V_{GS}$ is given by

$$V_{GS} = V_{DS} = 10 - I_D R_D = 10 - 4 \# 1 = 6 \text{ Volt}$$

So, $$4 = K(6 - 2)^2$$

$$K = \frac{1}{4}$$

Now $R_D$ is increased to 4 kW, Let current is $I_D'$ and voltages are $V_{DS}' = V_{GS}'$

Applying current equation.

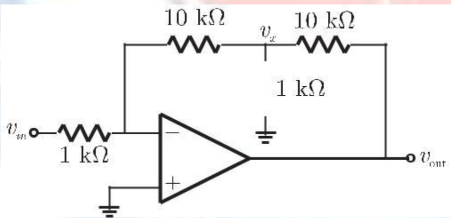
$$I_D' = K\,(V_{GS}' - V_{TH})^2$$
$$I_D' = \frac{1}{4}(V_{GS}' - 2)^2$$
$$V_{GS}' = V_{DS}' = 10 - I_D' \# R_D' = 10 - 4I_D'$$

So, $$4I_D' = (10 - 4I_D' - 2)^2 = (8 - 4I_D')^2$$
$$= 16(2 - I_D')^2$$
$$I_D' = 4(4 + I'^2_D - 4I_D')$$
$$4I'^2_D - 17 + 16 = 0$$
$$I'^2_D = 2.84 \text{ mA}$$

Option (D) is correct.

**Sol. 99** Let the voltages at input terminals of op-amp are $v_-$ and $v_+$ respectively.

So, $v_+ = v_- = 0$ (ideal op-amp)




Applying node equation at negative terminal of op-amp,

$$\frac{0 - v_{in}}{1} + \frac{0 - v_x}{10} = 0 \qquad \text{...(1)}$$

At node $x$ $$\frac{v_x - 0}{10} + \frac{v_x - v_{out}}{10} + \frac{v_x - 0}{1} = 0$$

$$v_x + v_x - v_{out} + 10v_x = 0$$
$$12\,v_x = v_{out}$$
$$v_x = \frac{v_{out}}{12}$$

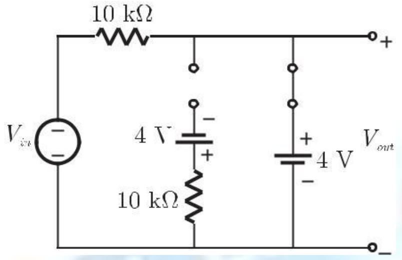
From equation (1), $$\frac{v_{in}}{1} + \frac{v_x}{10} = 0$$

$$v_{in} = -\frac{v_{out}}{120}$$

$$\frac{v_{out}}{v_{in}} = -120$$

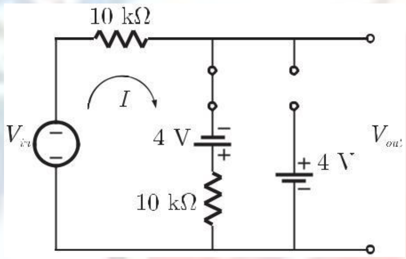
**Sol. 100** Option (D) is correct.

In the positive half cycle (when $V_{in} > 4$ V) diode $D_2$ conducts and $D_1$ will be off so the equivalent circuit is,




$$V_{out} = +4 \text{ Volt}$$

In the negative half cycle diode $D_1$ conducts and $D_2$ will be off so the circuit is,




Applying KVL

$$V_{in} - 10I + 4 - 10I = 0$$

$$\frac{V_{in} + 4}{20} = I$$

$V_{in} = -10$ V (Maximum value in negative half cycle)

So, $$I = \frac{-10 + 4}{20} = -\frac{3}{10} \text{ mA}$$

$$\frac{V_{in} - V_{out}}{10} = I$$

$$\frac{-10 - V_{out}}{10} = -\frac{3}{10}$$

$$V_{out} = -(10 - 3)$$

$$V_{out} = -7 \text{ volt}$$

**Sol. 101** Option (C) is correct.

In the circuit, the capacitor charges through resistor $(R_A + R_B)$ and discharges through $R_B$. Charging and discharging time is given as.

$$T_C = 0.693(R_A + R_B)C$$

$$T_D = 0.693\, R_B\, C$$

Frequency $$f = \frac{1}{T} = \frac{1}{T_D + T_C} = \frac{1}{0.693(R_A + 2R_B)C}$$

$$\frac{1}{0.693(R_A + 2R_B) \# 10 \# 10^{-9}} = 10 \# 10^3$$

$$14.4 \# 10^3 = R_A + 2R_B \qquad ...(1)$$

$$\text{duty cycle} = \frac{T_C}{T} = 0.75$$

$$\frac{0.693(R_A + R_B)C}{0.693(R_A + 2R_B)C} = \frac{3}{4}$$

$$4R_A + 4R_B = 3R_A + 6R_B$$

$$R_A = 2R_B \qquad \text{...(2)}$$

From (1) and (2) $\quad 2R_A = 14.4 \# 10^3$

$$R_A = 7.21 \text{ kW}$$

and $\quad R_B = 3.60 \text{ kW}$

Sol. 102 Option (B) is correct.

Given boolean expression can be written as,

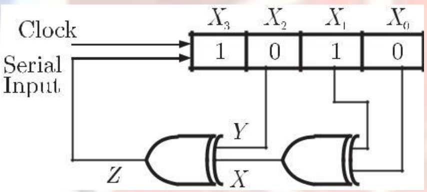
$$F = \overline{X}Y\overline{Z} + X\overline{Y}\,\overline{Z} + XY\overline{Z} + XYZ + \overline{X}YZ$$

$$= \overline{X}Y\overline{Z} + \overline{Y}\,\overline{Z}(X + \overline{X}) + XY(Z + \overline{Z}) = \overline{X}Y\overline{Z} + \overline{Y}\,\overline{Z} + XY$$

$$= \overline{Y}\,\overline{Z} + Y(X + \overline{X}\,\overline{Z}) \quad \text{a} \quad A + BC = (A + B)(A + C)$$

$$= \overline{Y}\,\overline{Z} + Y(X + \overline{X})(X + \overline{Z}) = \overline{Y}\,\overline{Z} + Y(X + \overline{Z}) = \overline{Y}\,\overline{Z} + YX + Y\overline{Z}$$

Sol. 103 Option (B) is correct.




$$X = X_1 5 X_0, \; Y = X_2$$

Serial Input $Z = X 5 Y = [X_1 5 X_0] 5 X_2$

Truth table for the circuit can be obtain as.

| Clock pulse | Serial Input | Shift register |
|---|---|---|
| Initially | 1 | 1010 |
| 1 | 0 | 1101 |
| 2 | 0 | 0110 |
| 3 | 0 | 0011 |
| 4 | 1 | 0001 |
| 5 | 0 | 1000 |
| 6 | 1 | 0100 |
| 7 | 1 | 1010 |

So after 7 clock pulses contents of the shift register is 1010 again.

**Sol. 104** Option (A) is correct.

Total size of the memory system is given by.

= ($2^{12}$ # 4) # 8 bits

= $2^{14}$ # 8 bits = $2^{14}$ Bytes = 16 K bytes

**Sol. 105** Option (C) is correct.

Executing all the instructions one by one.

LXI H,1FFE &H = $(1F)_H$, L = $(FE)_H$

MOV B,M & B = Memory [HL] = Memory [1FFE]

INR L & L = L + $(1)_H$ = $(FF)_H$

MOV A,M & A = Memory [HL] = Memory [1FFF]

ADD B & A = A + B

INR L & L = L + $(1)_H$ = $(FF)_H$ + $(1)_H$ = 00

MOV M,A & Memory [HL] = A

Memory [1F00] = A

XOR A & A = A XOR A = 0

So the result of addition is stored at memory address 1F00.

# CONTROL SYSTEMS

## What is a system?

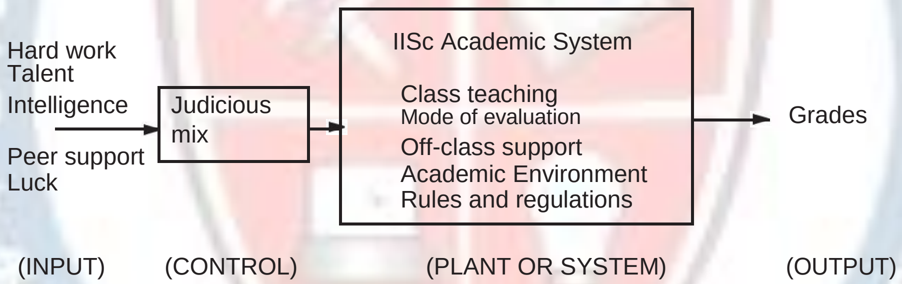
A collection of components that interact with one another and with their environment.

*Some examples of systems.* Human beings, mechanical devices, an electrical switch, plants, animals, the atmosphere, the stock market, the political system, etc. As aerospace engineers we may consider some aerospace systems like aircraft, helicopters, missiles, avionics, rocket engines, and so on.

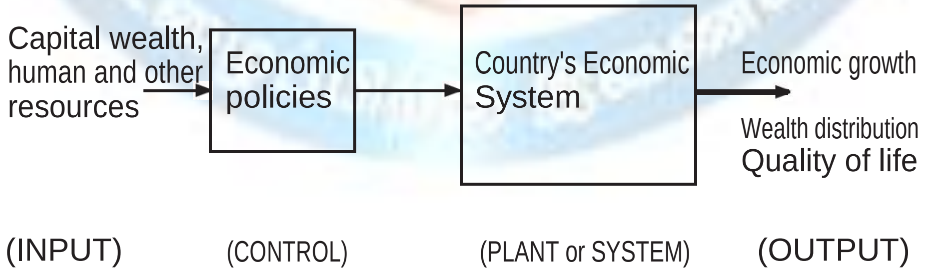
## What is a control system?

A control system is a collection of components that is designed to drive a given system (plant) with a given input to a desired output.

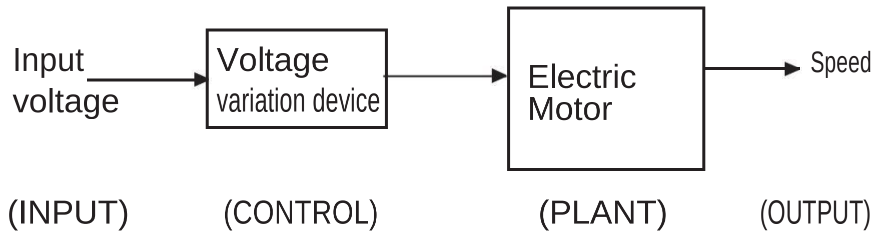
*Examples.*



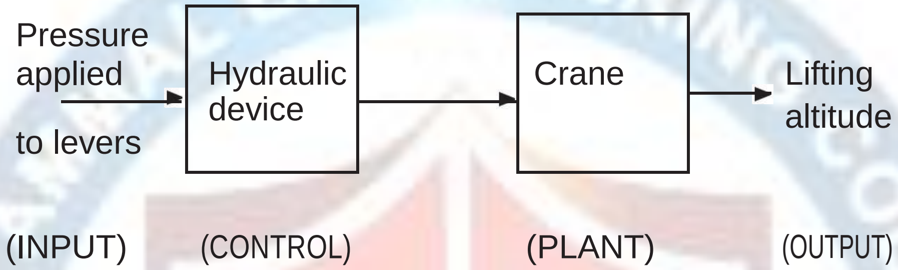

*The IISc academic system*



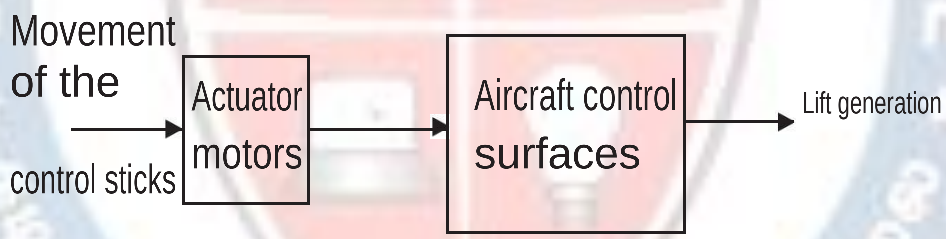

: *The economic system of a country*




*Speed control of an electric motor*




*Control of a hydraulic crane*




*Lift generation in an aircraft*

## Control Problem

Let us be a little more specific about what constitutes a control problem and what are the different types of control problems. In Table 8.1 we consider an aircraft control problem as an example.

| *Different aspects of the control problem* | *Example* |
|---|---|
| The Plant | Aircraft |
| Control Inputs | Control surface deflections |
| Disturbance Inputs | Wind gusts |
| Outputs | Vehicle Translation and rotation, position and velocities |
| Goals of Control – Performance criteria, design criteria, control specifications | Speed of achieving commanded output, handling qualities, stability |

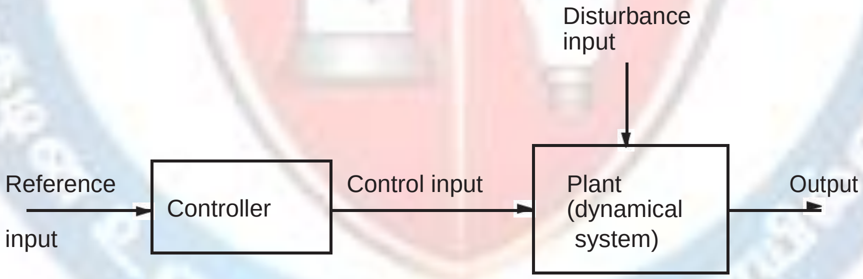
*Constituents of a control problem (aircraft example)*

.

| | |
|---|---|
| Open loop | Closed loop |
| Dynamic | Static |
| Linear | Non-linear |
| Time-variant | Time-invariant |
| Continuous | Discrete-time |
| Stochastic | Deterministic |

*Classification of control problems*

## What is an open loop control system?




*A general open-loop control system*

Example. Electronic Fan Switch

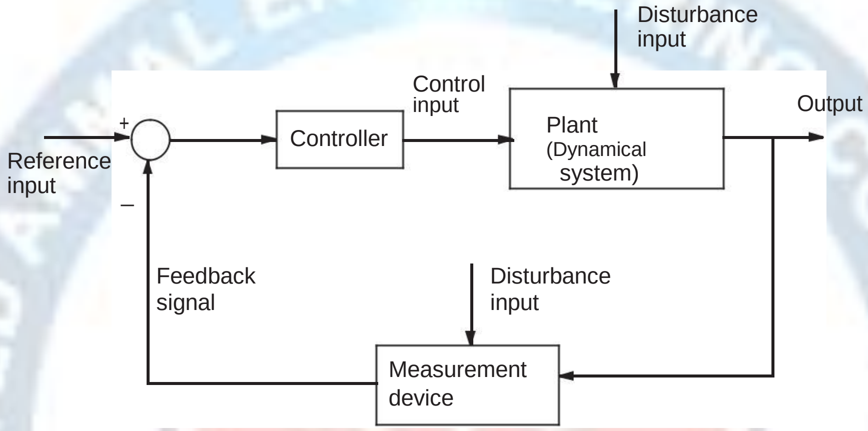
*Reference input:* Switch on the fan (that is, press the switch and 230 V is applied). So, the reference input is the 230 V signal.

*Controller:* The electronic voltage controller (that is, turn the knob to the desired position). The elect is to reduce/change the voltage to the appropriate value. We may have approximately 230 V (= full speed) and 115 V (half-speed), and so on.

Once the speed is set there is nothing else that needs to be done. But suppose you have three fans. Even if you give their knobs the same amount of turn, the speeds are likely to be slightly different. This may happen due to inaccuracy in the settings, inconsistency in ball bearings performance, imperfect setting of the fan blades causing different amount of drag on the blades, or maybe due to non-standard performance of the electronic components.

So, essentially an open loop system is one where there is no way to correct the error between the desired output and the actual output.

## What is a closed loop control system?




*A general closed-loop control system*

Consider the same electronic fan control switch. Assume that you are looking at the fan blades to make sure that the speed is right. If it isn't, then you turn the knob continuously till the desired speed is achieved. The block diagram in Figure 8.7 is not an exact representation of this, but it conveys the idea in a broad sense.

*Closed loop systems have different characteristics when compared to open-loop systems.*

They are more accurate.

They are less sensitive to disturbances.

They are less sensitive to system characteristics/parameter variations.

However, they have a tendency to oscillate.

## What are the objectives of controller design?

The main objective is to meet system specifications in the presence of large input disturbances and plant variations. Generally controller design goals are characterized by,

- Speed
- Accuracy
- Stability

## General input-output relationships

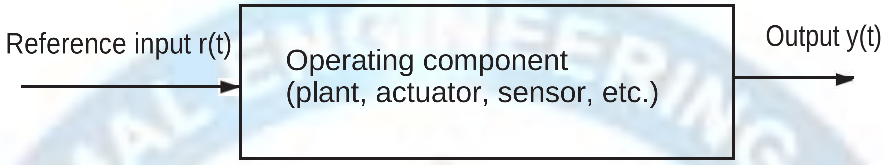


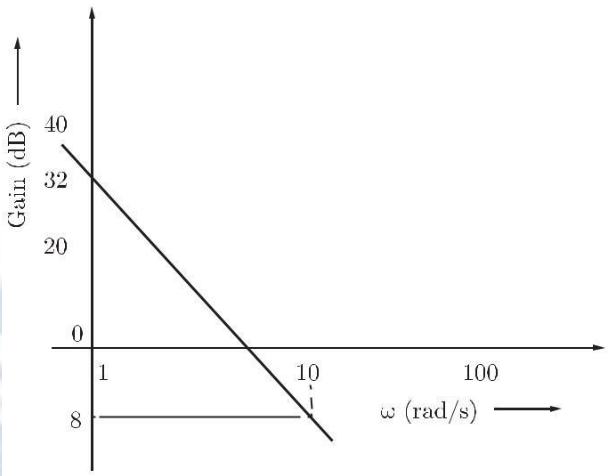

Figure 8.8: *An input-output model of a system*

A *model* is a mathematical relationship between the input and the output of a system. It is an approximation of the physical system.

A model may be described by differential equations (continuous-time systems) or difference equations (discrete-time systems), or a combination of both (hybrid systems).

# CONTROL SYSTEMS

Q. 1 The Bode plot of a transfer function $G(s)$ is shown in the figure below.

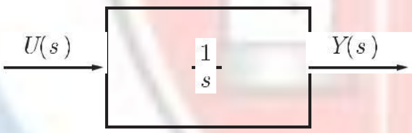



The gain $20\log|G(s)|$ is 32 dB and -8 dB at 1 rad/s and 10 rad/s respectively. The phase is negative for all $\omega$. Then $G(s)$ is

(A) $\frac{39.8}{s}$ (B) $\frac{39.8}{s^2}$

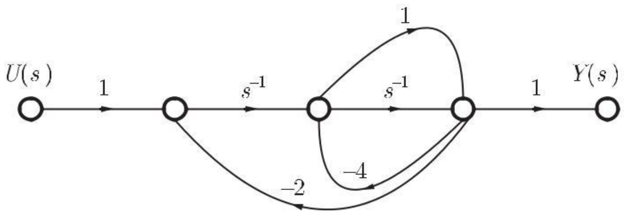
(C) $\frac{32}{s}$ (D) $\frac{32}{s^2}$

Q. 2 Assuming zero initial condition, the response $y(t)$ of the system given below to a unit step input $u(t)$ is




1. $u(t)$
2. $tu(t)$
3. $\frac{t^2}{2}u(t)$
4. $e^{-t}u(t)$

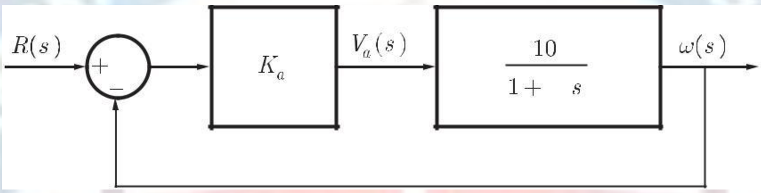
Q. 3 The signal flow graph for a system is given below. The transfer function $\frac{Y(s)}{U(s)}$ for this system is




(A) $\frac{s+1}{5s^2+6s+2}$ (B) $\frac{s+1}{s^2+6s+2}$

(C) $\frac{s+1}{s^2+4s+2}$ (D) $\frac{1}{5s^2+6s+2}$

**Q. 4** The open-loop transfer function of a dc motor is given as $\frac{\omega(s)}{V_a(s)} = \frac{10}{1+10s}$. When connected in feedback as shown below, the approximate value of $K_a$ that will reduce the time constant of the closed loop system by one hundred times as compared to that of the open-loop system is




A. 1 (B) 5

C. 10 (D) 100

**Common Data For Q. 5 and 6**

The state variable formulation of a system is given as

$$\begin{bmatrix}\dot x_1\\ \dot x_2\end{bmatrix} = \begin{bmatrix}-2 & 0\\ 0 & -1\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}1\\ 1\end{bmatrix}u,\ x_1(0) = 0,\ x_2(0) = 0 \text{ and } y = \begin{bmatrix}1 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}$$

**Q. 5** The response $y(t)$ to the unit step input is

(A) $\frac{1}{2} - \frac{1}{2}e^{-2t}$ (B) $1 - \frac{1}{2}e^{-2t} - \frac{1}{2}e^{-t}$

(C) $e^{-2t} - e^{-t}$ (D) $1 - e^{-t}$

**Q. 6** The system is

(A) controllable but not observable

(B) not controllable but observable

(C) both controllable and observable

(D) both not controllable and not observable

**Q. 7** The state variable description of an LTI system is given by

$$\begin{bmatrix}\dot x_1\\ \dot x_2\\ \dot x_3\end{bmatrix} = \begin{bmatrix}0 & a_1 & 0\\ 0 & 0 & a_2\\ a_3 & 0 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix} + \begin{bmatrix}0\\ 0\\ 1\end{bmatrix}u$$

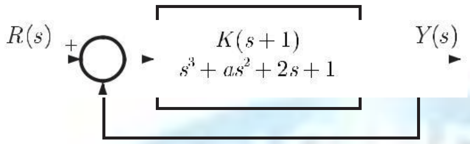
$$y = \begin{bmatrix}1 & 0 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix}$$

where $y$ is the output and $u$ is the input. The system is controllable for

(A) $a_1$ ! 0,$a_2$ = 0,$a_3$ ! 0 (B) $a_1$ = 0,$a_2$ ! 0,$a_3$ ! 0

(C) $a_1$ = 0,$a_3$ ! 0,$a_3$ = 0 (D) $a_1$ ! 0,$a_2$ ! 0,$a_3$ = 0

Q. 8 The feedback system shown below oscillates at 2 rad/s when




(A) $K$ = 2 and $a$ = 0.75 (B) $K$ = 3 and $a$ = 0.75

(C) $K$ = 4 and $a$ = 0.5 (D) $K$ = 2 and $a$ = 0.5

**Statement for Linked Answer Questions 9 and 10 :**

The transfer function of a compensator is given as

$$G_c(s) = \frac{s+a}{s+b}$$

Q. 9 $G_c(s)$ is a lead compensator if

(A) $a$ = 1, $b$ = 2 (B) $a$ = 3, $b$ = 2

(C) $a$ √ 3, $b$ =- 1 (D) $a$ √ 3, $b$ = 1

Q. 10 The phase of the above lead compensator is maximum at

(A) 2 rad/s (B) 3 rad/s

(C) 6 rad/s (D) 1/ 3 rad/s

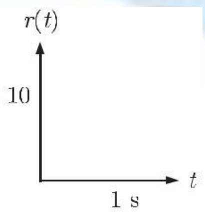
Q. 11 The frequency response of a linear system $G(jw)$ is provided in the tubular form below

| | | | | | | |
|---|---|---|---|---|---|---|
| $\lvert G(jw)\rvert$ | 1.3 | 1.2 | 1.0 | 0.8 | 0.5 | 0.3 |
| +$G(jw)$ | -130c | -140c | -150c | -160c | -180c | -200c |

(A) 6 dB and 30c (B) 6 dB and -30c

(C) -6 dB and 30c (D) -6 dB and -30c

Q. 12 The steady state error of a unity feedback linear system for a unit step input is 0.1. The steady state error of the same system, for a pulse input $r(t)$ having a magnitude of 10 and a duration of one second, as shown in the figure is




(A) 0 (B) 0.1

(C) 1 (D) 10

Q. 13 An open loop system represented by the transfer function

$$G(s) = \frac{(s - 1)}{(s + 2)(s + 3)} \text{ is}$$

(A) Stable and of the minimum phase type

(B) Stable and of the non–minimum phase type

(C) Unstable and of the minimum phase type

(D) Unstable and of non–minimum phase type

Q. 14 The open loop transfer function $G(s)$ of a unity feedback control system is given as

$$\frac{K bs + \frac{2}{} l}{3}$$

From the root locus, at can be inferred that when $K$ tends to positive infinity,

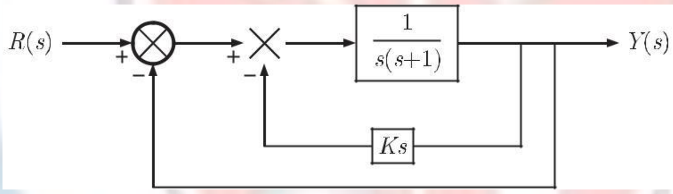
(A) Three roots with nearly equal real parts exist on the left half of the $s$ -plane

(B) One real root is found on the right half of the $s$ -plane

(C) The root loci cross the $j$w axis for a finite value of $K$; $K$ ! 0

(D) Three real roots are found on the right half of the $s$ -plane

Q. 15 A two loop position control system is shown below




The gain $K$ of the Tacho-generator influences mainly the

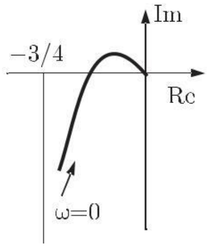
(A) Peak overshoot

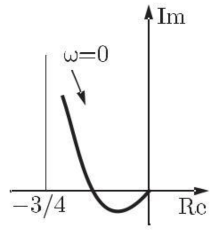
(B) Natural frequency of oscillation

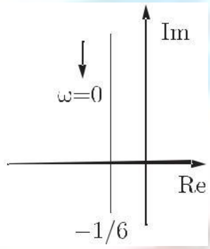
(C) Phase shift of the closed loop transfer function at very low frequencies (w " 0)

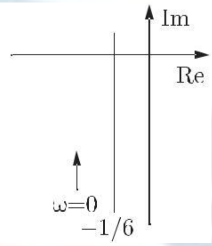
(D) Phase shift of the closed loop transfer function at very high frequencies (w " 3)

Q. 16 The frequency response of $G(s) = \frac{1}{s(s + 1)(s + 2)}$ plotted in the complex $G(j$w$)$ plane (for 0 < w < 3) is

(A) 


(B) 


(C) 


(D) 


Q. 17 The system $\dot{X} = AX + Bu$ with $A = \begin{bmatrix} -1 & 2 \\ 0 & 2 \end{bmatrix}$, $B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$ is

(A) Stable and controllable

(B) Stable but uncontrollable

(C) Unstable but controllable

(D) Unstable and uncontrollable

Q. 18 The characteristic equation of a closed-loop system is $s(s + 1)(s + 3)k(s + 2) = 0$, $k > 0$.Which of the following statements is true ?

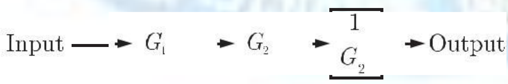
A Its root are always real

B It cannot have a breakaway point in the range $-1 < Re[s] < 0$

C Two of its roots tend to infinity along the asymptotes $Re[s] =- 1$

D It may have complex roots in the right half plane.

Q. 19 The measurement system shown in the figure uses three sub-systems in cascade whose gains are specified as $G_1, G_2, 1/G_3$. The relative small errors associated with each respective subsystem $G_1, G_2$ and $G_3$ are $e_1$, $e_2$ and $e_3$. The error associated with the output is :



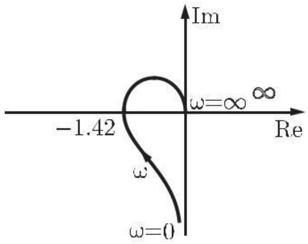

(A) $e_1 + e_2 + \frac{1}{e_3}$

(B) $\frac{e_1 e_2}{e_3}$

(C) $e_1 + e_2 - e_3$

(D) $e_1 + e_2 + e_3$

Q. 20 The polar plot of an open loop stable system is shown below. The closed loop system is




(A) always stable

(B) marginally stable

(C) un-stable with one pole on the RH $s$ -plane

(D) un-stable with two poles on the RH $s$ -plane

Q. 21 The first two rows of Routh's tabulation of a third order equation are as follows.

$s^3$ 2 2

$s^2$ 4 4

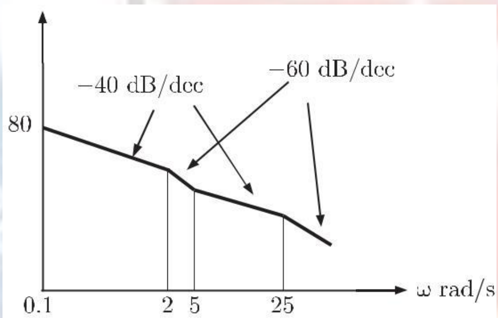
Two roots at $s$ =! $j$ and one root in right half $s$ -plane

Two roots at $s$ =! $j$2 and one root in left half $s$ -plane

Two roots at $s$ =! $j$2 and one root in right half $s$ -plane

Two roots at $s$ =! $j$ and one root in left half $s$ -plane

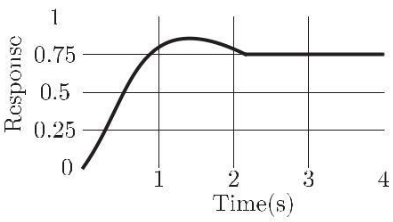
Q. 22 The asymptotic approximation of the log-magnitude v/s frequency plot of a system containing only real poles and zeros is shown. Its transfer function is




(A) $\frac{10(s+5)}{s(s+2)(s+25)}$ (B) $\frac{1000(s+5)}{s^2(s+2)(s+25)}$

(C) $\frac{100(s+5)}{s(s+2)(s+25)}$ (D) $\frac{80(s+5)}{s^2(s+2)(s+25)}$

Q. 23 The unit-step response of a unity feed back system with open loop transfer function $G(s) = K/((s+1)(s+2))$ is shown in the figure. The value of $K$ is



(A) 0.5 (B) 2

(C) 4 (D) 6

Q. 24 The open loop transfer function of a unity feed back system is given by $G(s) = (e^{-0.1s})/s$. The gain margin of the is system is

(A) 11.95 dB (B) 17.67 dB

(C) 21.33 dB (D) 23.9 dB

**Common Data for Question 25 and 26 :**

A system is described by the following state and output equations

$$\frac{dx_1(t)}{dt} = -3x_1(t) + x_2(t) + 2u(t)$$

$$\frac{dx_2(t)}{dt} = -2x_2(t) + u(t)$$

$$y(t) = x_1(t)$$

when $u(t)$ is the input and $y(t)$ is the output

Q. 25 The system transfer function is

(A) $\frac{s+2}{s^2+5s-6}$ (B) $\frac{s+3}{s^2+5s+6}$

(C) $\frac{2s+5}{s^2+5s+6}$ (D) $\frac{2s-5}{s^2+5s-6}$

Q. 26 The state-transition matrix of the above system is

(A) $e^{-3t}$ 0 $= e^{-2t} + e^{-3t}$ $e^{-2t}$ G $e^{-3t}$ $e^{-2t} + e^{-3t}$

(B) $e^{-3t}$ $e^{-2t} - e^{-3t}$ = 0 $e^{-2t}$ G $e^{3t}$ $e^{-2t} - e^{-3t}$

(C) = 0 $e^{-2t}$ G

(D) = 0 $e^{-2t}$ G

Q. 27 A function $y(t)$ satisfies the following differential equation :

$$\frac{dy(t)}{dt} + y(t) = d(t)$$

where $d(t)$ is the delta function. Assuming zero initial condition, and denoting the unit step function by $u(t)$, $y(t)$ can be of the form

(A) $e^{t}$ (B) $e^{-t}$

(C) $e^{t}u(t)$ (D) $e^{-t}u(t)$

Q. 28 The transfer function of a linear time invariant system is given as

$$G(s) = \frac{1}{s^2+3s+2}$$

The steady state value of the output of the system for a unit impulse input applied at time instant $t = 1$ will be

(A) 0 (B) 0.5

(C) 1 (D) 2

Q. 29 The transfer functions of two compensators are given below :

$$C_1 = \frac{10(s+1)}{(s+10)},\ C_2 = \frac{s+10}{10(s+1)}$$

Which one of the following statements is correct ?

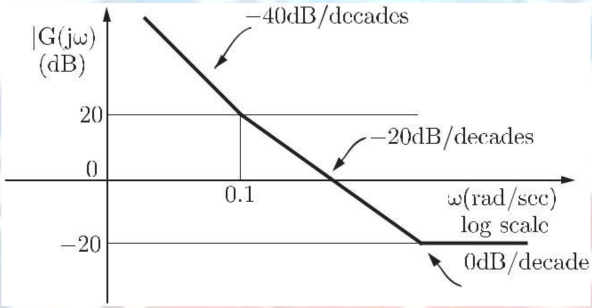
$C_1$ is lead compensator and $C_2$ is a lag compensator

$C_1$ is a lag compensator and $C_2$ is a lead compensator

Both $C_1$ and $C_2$ are lead compensator

Both $C_1$ and $C_2$ are lag compensator

Q. 30 The asymptotic Bode magnitude plot of a minimum phase transfer function is shown in the figure :

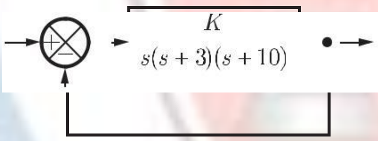



This transfer function has

(A) Three poles and one zero (B) Two poles and one zero

(C) Two poles and two zero (D) One pole and two zeros

Q. 31 Figure shows a feedback system where $K > 0$




The range of $K$ for which the system is stable will be given by

(A) $0 < K < 30$ (B) $0 < K < 39$

(C) $0 < K < 390$ (D) $K > 390$

Q. 32 The transfer function of a system is given as

$$\frac{100}{s^2 + 20s + 100}$$

The system is

(A) An over damped system (B) An under damped system

(C) A critically damped system (D) An unstable system

**Statement for Linked Answer Question 33 and 34.**

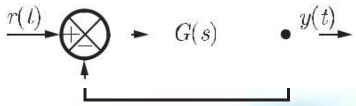
The state space equation of a system is described by $\dot{X} = AX + Bu$, $Y = CX$ where $X$ is state vector, $u$ is input, $Y$ is output and $A = \begin{bmatrix} 0 & 1 \\ 0 & -2 \end{bmatrix}$, $B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$, $C = [1\ 0]$

Q. 33 The transfer function G(s) of this system will be

(A) $\frac{s}{(s+2)}$ (B) $\frac{s+1}{s(s-2)}$

(C) $\frac{s}{(s - 2)}$ (D) $\frac{1}{s\,(s + 2)}$

Q. 34 A unity feedback is provided to the above system $G\,(s)$ to make it a closed loop system as shown in figure.

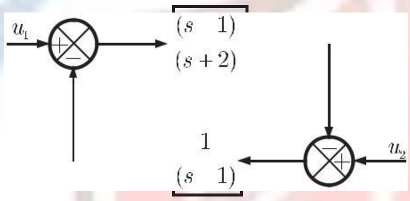



For a unit step input $r\,(t)$, the steady state error in the input will be

(A) 0 (B) 1

(C) 2 (D) 3

Q. 35 The system shown in the figure is




(A) Stable

(B) Unstable

(C) Conditionally stable

(D) Stable for input $u_1$, but unstable for input $u_2$

Q. 36 If $x$ = Re[$G\,(jw)$], and $y$ = Im[$G\,(jw)$] then for $w$ " $0^+$, the Nyquist plot for $G\,(s\,) = 1/s\,(s + 1)(s + 2)$ is

(A) $x = 0$ (B) $x =- 3/4$

(C) $x = y - 1/6$ (D) $x = y/$ 3√

Q. 37 The system $900/s\,(s + 1)(s + 9)$ is to be such that its gain-crossover frequency becomes same as its uncompensated phase crossover frequency and provides a 45c phase margin. To achieve this, one may use

(A) a lag compensator that provides an attenuation of 20 dB and a phase lag of 45c at the frequency of 3 3√ rad/s

(B) a lead compensator that provides an amplification of 20 dB and a phase lead of 45c at the frequency of 3 rad/s

(C) a lag-lead compensator that provides an amplification of 20 dB and a phase lag of 45c at the frequency of √ rad/s

(D) a lag-lead compensator that provides an attenuation of 20 dB and phase lead of 45c at the frequency of 3 rad/s

Q. 38 If the loop gain $K$ of a negative feed back system having a loop transfer function $K(s+3)/(s+8)^2$ is to be adjusted to induce a sustained oscillation then

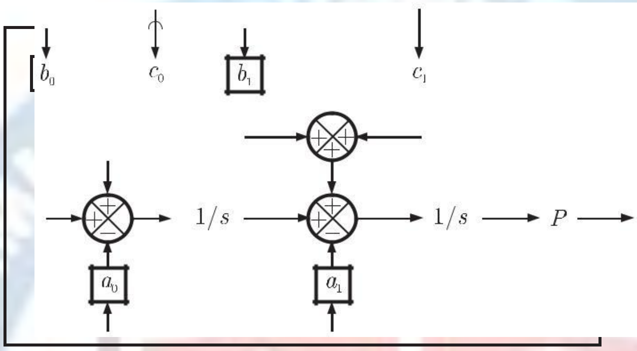
(A) The frequency of this oscillation must be $4\sqrt{3}$ rad/s

(B) The frequency of this oscillation must be 4 rad/s

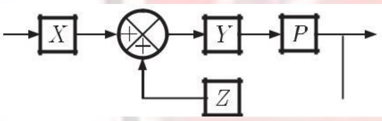
(C) The frequency of this oscillation must be 4 or $4\sqrt{3}$ rad/s

(D) Such a $K$ does not exist

Q. 39 The system shown in figure below




can be reduced to the form




with

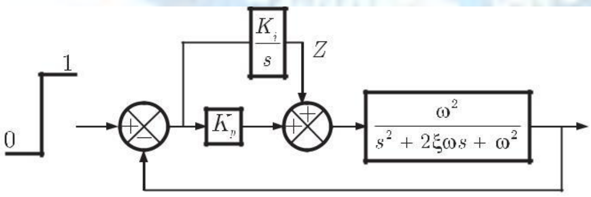
(A) $X = c_0 s + c_1, Y = 1/(s^2 + a_0 s + a_1), Z = b_0 s + b_1$

(B) $X = 1, Y = (c_0 s + c_1)/(s^2 + a_0 s + a_1), Z = b_0 s + b_1$

(C) $X = c_1 s + c_0, Y = (b_1 s + b_0)/(s^2 + a_1 s + a_0), Z = 1$

(D) $X = c_1 s + c_0, Y = 1/(s^2 + a_1 s + a), Z = b_1 s + b_0$

Q. 40 Consider the feedback system shown below which is subjected to a unit step input. The system is stable and has following parameters $K_p = 4, K_i = 10, w = 500$ and $x = 0.7$. The steady state value of $Z$ is




1

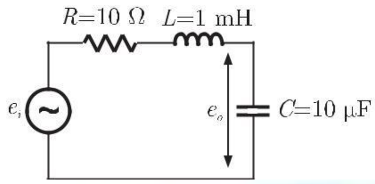
0.25

0.1

0

**Common Data For Q. 41 and 42**

R-L-C circuit shown in figure




Q. 41 For a step-input $e_i$ , the overshoot in the output $e_0$ will be

(A) 0, since the system is not under damped

(B) 5 %

(C) 16 %

(D) 48 %

Q. 42 If the above step response is to be observed on a non-storage CRO, then it would be best have the $e_i$ as a

(A) Step function

(B) Square wave of 50 Hz

(C) Square wave of 300 Hz

(D) Square wave of 2.0 KHz

Q. 43 For a system with the transfer function $H(s) = \frac{3(s-2)}{4s^2 - 2s + 1}$,

the matrix $A$ in the state space form $\dot{\boldsymbol{X}} = A\boldsymbol{X} + B\boldsymbol{u}$ is equal to

(A) $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -1 & 2 & -4 \end{bmatrix}$

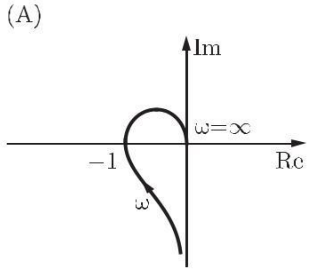
(B) $\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -1 & 2 & -4 \end{bmatrix}$

(C) $\begin{bmatrix} & 1 & 0 \\ 3 & -2 & 1 \\ 1 & -2 & 4 \end{bmatrix}$

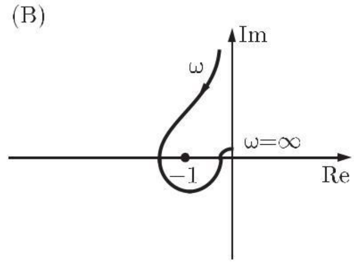
(D) $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ -1 & 2 & -4 \end{bmatrix}$

Q. 44 Consider the following Nyquist plots of loop transfer functions over $w = 0$ to $w = 3$. Which of these plots represent a stable closed loop system ?

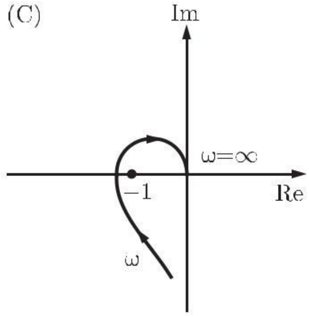
(A)



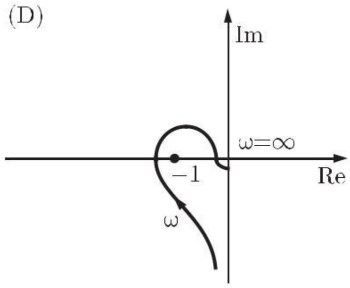

(B)



(C)




(D)




(A) (1) only

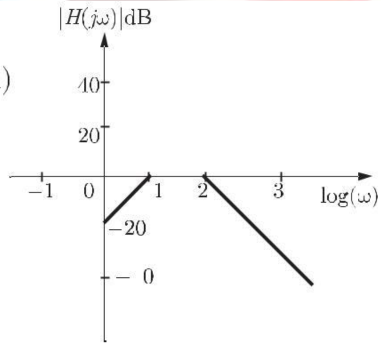
(B) all, except (1)

(C) all, except (3)

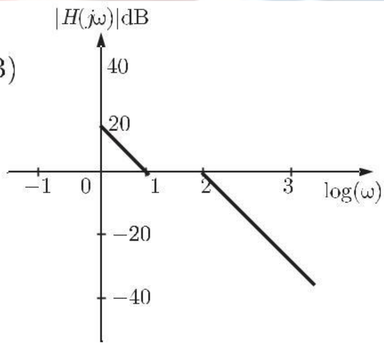
(D) (1) and (2) only

Q. 45 The Bode magnitude plot $H(jw) = \dfrac{10^4(1 + jw)}{\phantom{xxxxxxxx}}$ is

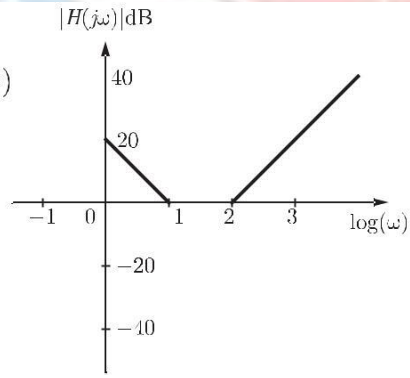
(A)



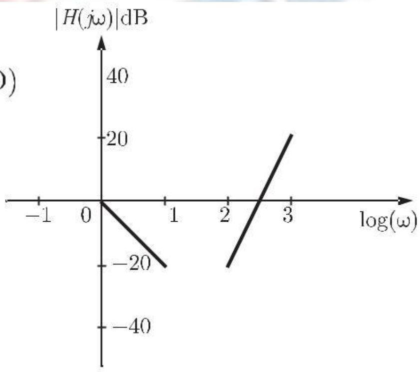

(B)



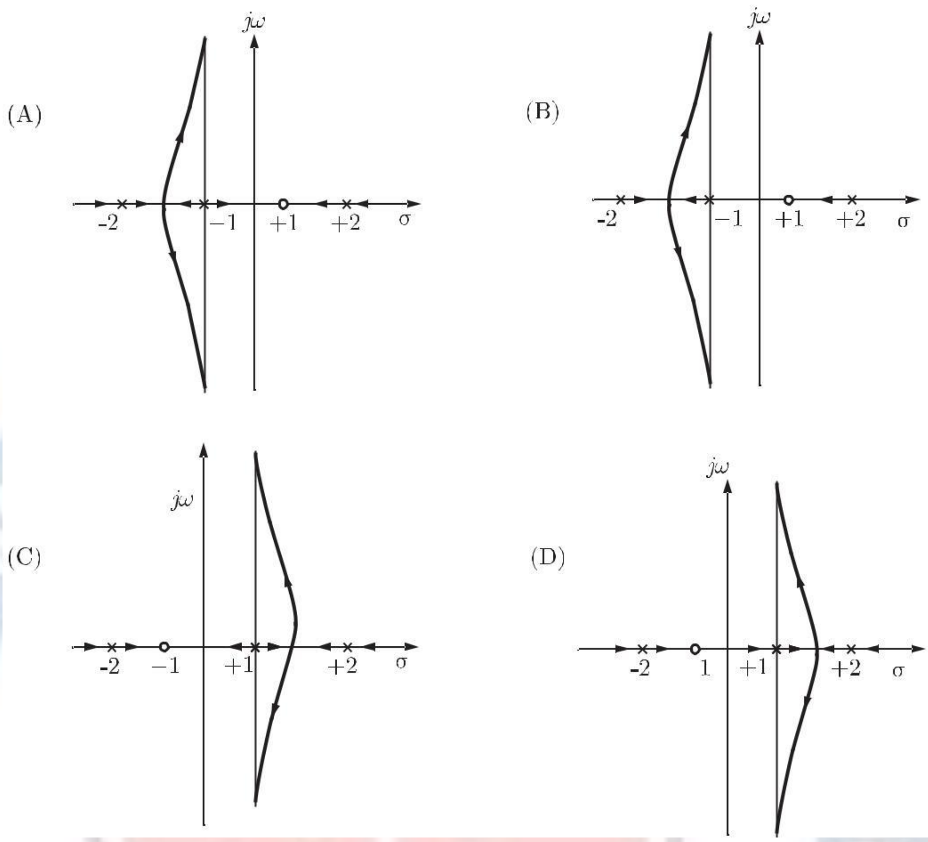

(C)




(D)




Q. 46 A closed-loop system has the characteristic function $(s^2 - 4)(s + 1) + K(s - 1) = 0$. Its root locus plot against $K$ is




Q. 47 A system with zero initial conditions has the closed loop transfer function.

$$T(s) = \frac{s^2 + 4}{(s+1)(s+4)}$$

The system output is zero at the frequency

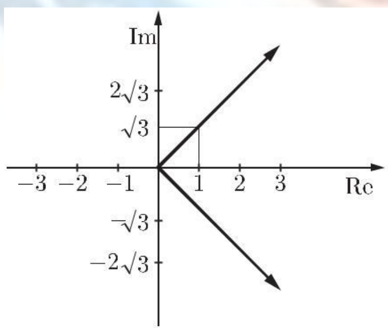
(A) 0.5 rad/sec

(B) 1 rad/sec

(C) 2 rad/sec

(D) 4 rad/sec

Q. 48 Figure shows the root locus plot (location of poles not given) of a third order system whose open loop transfer function is




A $\frac{K}{s^3}$

(B) $\frac{K}{s^2(s+1)}$

(C) $\frac{K}{s(s^2+1)}$

(D) $\frac{K}{s(s^2-1)}$

Q. 49 The gain margin of a unity feed back control system with the open loop transfer function $G(s) = \frac{(s+1)}{s^2}$ is

(A) 0 (B) $\frac{\sqrt{\ }}{2}$

(C) $\sqrt{2}$ (D) 3

Q. 50 A unity feedback system, having an open loop gain

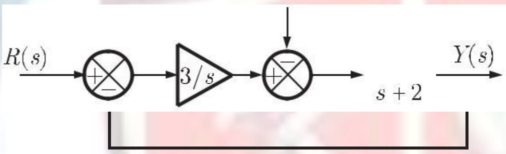
$$G(s)H(s) = \frac{K(1-s)}{(1+s)},$$

becomes stable when

(A) $|K| > 1$ (B) $K > 1$

(C) $|K| < 1$ (D) $K < -1$

Q. 51 When subject to a unit step input, the closed loop control system shown in the figure will have a steady state error of




(A) -1.0 (B) -0.5

(C) 0 (D) 0.5

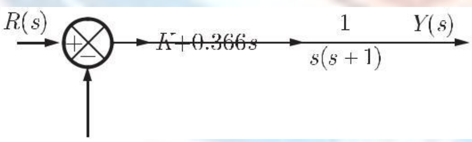
Q. 52 In the $G(s)H(s)$-plane, the Nyquist plot of the loop transfer function

$-0.25s$

(A) $(-0.25, j0)$ (B) $(-0.5, j0)$

(C) 0 (D) 0.5

Q. 53 If the compensated system shown in the figure has a phase margin of 60c at the crossover frequency of 1 rad/sec, then value of the gain $K$ is




(A) 0.366 (B) 0.732

(C) 1.366 (D) 2.738

**Common Data For Q. 54 and 55**

A state variable system $\dot{X}(t) = \begin{bmatrix} 0 & 1 \\ 0 & -3 \end{bmatrix} X(t) + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u(t)$ with the initial condition $X(0) = [-1, 3]^T$ and the unit step input $u(t)$ has

Q. 54 The state transition matrix

(A) $\begin{bmatrix} 1 & \frac{1}{3}(1 - e^{-3t}) \\ 0 & e^{-3t} \end{bmatrix}$

(B) $\begin{bmatrix} 1 & \frac{1}{3}(e^{-t} - e^{-3t}) \\ 0 & e^{-t} \end{bmatrix}$

(C) $\begin{bmatrix} 1 & \frac{1}{3}(e^{3-t} - e^{-3t}) \\ 0 & e^{-3t} \end{bmatrix}$

(D) $\begin{bmatrix} 1 & (1 - e^{-t}) \\ 0 & e^{-t} \end{bmatrix}$

Q. 55 The state transition equation

(A) $X(t) = \begin{bmatrix} t - e^{-t} \\ e^{-t} \end{bmatrix}$

(B) $X(t) = \begin{bmatrix} 1 - e^{-t} \\ 3e^{-3t} \end{bmatrix}$

(C) $X(t) = \begin{bmatrix} t - e^{3t} \\ 3e^{-3t} \end{bmatrix}$

(D) $X(t) = \begin{bmatrix} t - e^{-3t} \\ e^{-t} \end{bmatrix}$

Q. 56 The Nyquist plot of loop transfer function $G(s)H(s)$ of a closed loop control system passes through the point $(-1, j\,0)$ in the $G(s)H(s)$ plane. The phase margin of the system is

(A) 0c

(B) 45c

(C) 90c

(D) 180c

Q. 57 Consider the function, $F(s) = \frac{5}{\quad}$

where $F(s)$ is the Laplace transform of the of the function $f(t)$. The initial value of $f(t)$ is equal to

(A) 5

(B) $\frac{5}{2}$

(C) $\frac{5}{3}$

(D) 0

Q. 58 For a tachometer, if $q(t)$ is the rotor displacement in radians, $e(t)$ is the output voltage and $K_t$ is the tachometer constant in V/rad/sec, then the transfer function, $\frac{E(s)}{Q(s)}$ will be

(A) $K_t s^2$

(B) $K_t\ s$

(C) $K_t s$

(D) $K_t$

Q. 59 For the equation, $s^3 - 4s^2 + s + 6 = 0$ the number of roots in the left half of $s$-plane will be

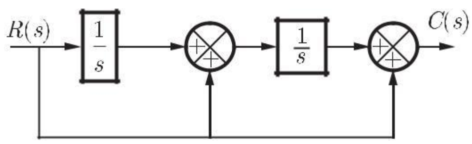
(A) Zero

(B) One

(C) Two

(D) Three

Q. 60 For the block diagram shown, the transfer function $\frac{C(s)}{R(s)}$ is equal to




(A) $\frac{s^2 + 1}{s^2}$

(B) $\frac{s^2 + s + 1}{s^2}$

(C) $\frac{s^2 + s + 1}{s}$

(D) $\frac{1}{s^2 + s + 1}$

o

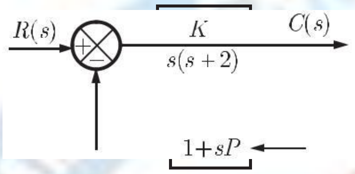
Q. 61 The state variable description of a linear autonomous system is, $\boldsymbol{X} = A\boldsymbol{X}$ where

**24** is the two dimensional state vector and $A$ is the system matrix given by

(A) -2 and +2 (B) $-j2$ and $+j2$

(C) -2 and -2 (D) +2 and +2

Q. 62 The block diagram of a closed loop control system is given by figure. The values of $K$ and $P$ such that the system has a damping ratio of 0.7 and an undamped natural frequency $w_n$ of 5 rad/sec, are respectively equal to




(A) 20 and 0.3 (B) 20 and 0.2

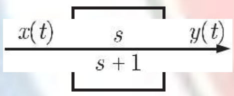
(C) 25 and 0.3 (D) 25 and 0.2

Q. 63 The unit impulse response of a second order under-damped system starting from rest is given by $c(t) = 12.5e^{-6t} \sin 8t$, $t \$ 0$. The steady-state value of the unit step response of the system is equal to

(A) 0 (B) 0.25

(C) 0.5 (D) 1.0

Q. 64 In the system shown in figure, the input $x(t) = \sin t$. In the steady-state, the response $y(t)$ will be




(A) $\frac{\sqrt{\ }}{2} \sin(t - 45c)$ (B) $\frac{\sqrt{\ }}{2} \sin(t + 45c)$

(C) $\sin(t - 45c)$ (D) $\sin(t + 45c)$

Q. 65 The open loop transfer function of a unity feedback control system is given as

$$G(s) = \frac{as + 1}{s^2}.$$

The value of '$a$' to give a phase margin of 45c is equal to

(A) 0.141 (B) 0.441

(C) 0.841 (D) 1.141

Q. 66 A control system is defined by the following mathematical relationship

$$\frac{d^2x}{dt^2} + 6\frac{dx}{dt} + 5x = 12(1 - e^{-2t})$$

The response of the system as $t$ " 3 is

(A) $x = 6$ (B) $x = 2$

(C) $x = 2.4$ (D) $x = -2$

Q. 67 A lead compensator used for a closed loop controller has the following transfer function $\frac{K\left(1+\frac{s}{a}\right)}{\left(1+\frac{s}{b}\right)}$ For such a lead compensator

(A) $a < b$  (B) $b < a$

(C) $a > Kb$  (D) $a < Kb$

Q. 68 A second order system starts with an initial condition of $\begin{bmatrix} 2 \\ 3 \end{bmatrix}$ without any external input. The state transition matrix for the system is given by $\begin{bmatrix} e^{-2t} & 0 \\ 0 & e^{-t} \end{bmatrix}$. The state of the system at the end of 1 second is given by

(A) $\begin{bmatrix} 0.271 \\ 1.100 \end{bmatrix}$  (B) $\begin{bmatrix} 0.135 \\ 0.368 \end{bmatrix}$

(C) $\begin{bmatrix} 0.271 \\ 0.736 \end{bmatrix}$  (D) $\begin{bmatrix} 0.135 \\ 1.100 \end{bmatrix}$

Q. 69 A control system with certain excitation is governed by the following mathematical equation

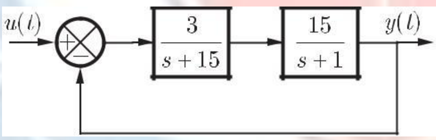
$$\frac{d^2x}{dt^2} + \frac{1}{2}\frac{dx}{dt} + \frac{1}{18}x = 10 + 5e^{-4t} + 2e^{-5t}$$

The natural time constant of the response of the system are

(A) 2 sec and 5 sec  (B) 3 sec and 6 sec

(C) 4 sec and 5 sec  (D) 1/3 sec and 1/6 sec

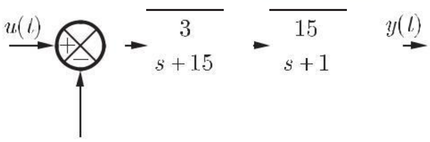
Q. 70 The block diagram shown in figure gives a unity feedback closed loop control system. The steady state error in the response of the above system to unit step input is




(A) 25%  (B) 0.75 %

(C) 6%  (D) 33%

Q. 71 The roots of the closed loop characteristic equation of the system shown above (Q-5.55)




(A) -1 and -15  (B) 6 and 10

(C) -4 and -15  (D)-6 and -10

Q. 72 The following equation defines a separately excited dc motor in the form of a differential equation

$$\frac{d^2 w}{dt^2} + \frac{B}{J}\frac{dw}{dt} + \frac{K^2}{LJ} w = \frac{K}{LJ} V_a$$

The above equation may be organized in the state-space form as follows

$$\begin{bmatrix} \frac{d^2 w}{dt^2} \\ \frac{dw}{dt} \end{bmatrix} = P \begin{bmatrix} \frac{dw}{dt} \\ w \end{bmatrix} + QV_a$$

Where the $P$ matrix is given by

(A) $\begin{bmatrix} -\frac{B}{J} & -\frac{K^2}{LJ} \\ 0 & 1 \end{bmatrix}$ (B) $\begin{bmatrix} -\frac{K^2}{LJ} & -\frac{B}{J} \\ 1 & 0 \end{bmatrix}$

(C) $\begin{bmatrix} -\frac{K^2}{LJ} & -\frac{B}{J} \end{bmatrix}$ (D) $\begin{bmatrix} -\frac{B}{J} & -\frac{K^2}{LJ} \end{bmatrix}$

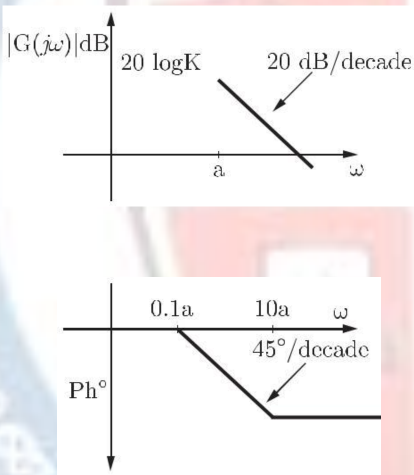
Q. 73 The loop gain $GH$ of a closed loop system is given by the following expression

$\frac{K}{s(s+2)(s+4)}$ The value of K for which the system just becomes unstable is

(A) $K = 6$ (B) $K = 8$

(C) $K = 48$ (D) $K = 96$

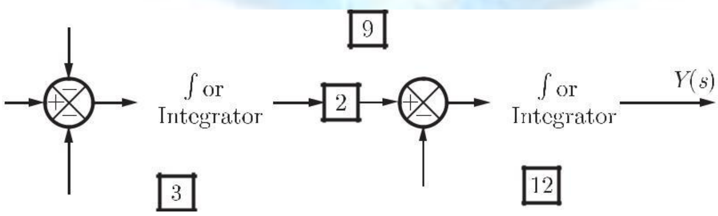
Q. 74 The asymptotic Bode plot of the transfer function $K/[1 + (s/a)]$ is given in figure. The error in phase angle and dB gain at a frequency of $w = 0.5a$ are respectively




(A) 4.9c, 0.97 dB (B) 5.7c, 3 dB

(C) 4.9c, 3 dB (D) 5.7c, 0.97 dB

Q. 75 The block diagram of a control system is shown in figure. The transfer function $G(s) = Y(s)/U(s)$ of the system is




(A) $\frac{1}{18\left(1+\frac{s}{12}\right)\left(1+\frac{s}{3}\right)}$ (B) $\frac{1}{27\left(1+\frac{s}{6}\right)\left(1+\frac{s}{9}\right)}$

(C) $\frac{1}{27\left(1+\frac{s}{12}\right)\left(1+\frac{s}{9}\right)}$ (D) $\frac{1}{27\left(1+\frac{s}{9}\right)\left(1+\frac{s}{3}\right)}$

# SOLUTION

**Sol. 1** Option (B) is correct.

From the given plot, we obtain the slope as

$$\text{Slope} = \frac{20\log G_2 - 20\log G_1}{\log \omega_2 - \log \omega_1}$$

From the figure

$$20\log G_2 = -8 \text{ dB}$$
$$20\log G_1 = 32 \text{ dB}$$

and $\omega_1 = 1$ rad/s

$\omega_2 = 10$ rad/s

So, the slope is

$$\text{Slope} = \frac{-8-32}{\log 10 - \log 1}$$

2. $- 40$ dB/decade

Therefore, the transfer function can be given as

at $\omega = 1$ $\quad G(s) = \frac{k}{S^2}$

$$|G(j\omega)| = \frac{k}{|\omega|^2} = k$$

In decibel,

$$20\log|G(j\omega)| = 20\log k = 32$$

or, $k = 10^{32/20} = 39.8$

Hence, the Transfer function is

$$G(s) = \frac{k}{s^2} = \frac{39.8}{s^2}$$

**Sol. 2** Option (B) is correct.

The Laplace transform of unit step fun$^n$ is

$$U(s) = \frac{1}{s}$$

So, the O/P of the system is given as

$$Y(s) = \left(\frac{1}{s}\right)\left(\frac{1}{s}\right) = \frac{1}{s^2}$$

For zero initial condition, we check

$$u(t) = \frac{dy(t)}{dt}$$

3. $U(s) = sY(s) - y(0)$

4. $U(s) = s\left(\frac{1}{s^2}\right) - y(0)$

or, $U(s) = \frac{1}{s}$ $\qquad (y(0) = 0)$

25. $Y(s) = \frac{1}{s^2}$

its inverse Laplace transform is given by

$$y(t) = tu(t)$$

**Sol. 3** Option (A) is correct.

For the given SFG, we have two forward paths

$$P_{k1} = (1)(s^{-1})(s^{-1})(1) = s^{-2}$$

$$P_{k2} = (1)(s^{-1})(1)(1) = s^{-1}$$

since, all the loops are touching to both the paths $P_{k1}$ and $P_{k2}$ so,

$$\Delta k_1 = \Delta k_2 = 1$$

Now, we have

= $\Delta$ = 1 - (sum of individual loops)

(sum of product of nontouching loops)

Here, the loops are

$$L_1 = (-4)(1) = -4$$

$$L_2 = (-4)(s^{-1})(1) = 4s^{-1}$$

$$L_3 = (-2)(s^{-1})(s^{-1})(1) = -2s^{-2}$$

$$L_4 = (-2)(s^{-1})(1) = -2s^{-1}$$

As all the loop $L_1$, $L_2$, $L_3$ and $L_4$

11 $\Delta = 1 - (L_1 + L_2 + L_3 + L_4)$

$$1 - (-4 - 4s^{-1} - 2s^{-2} - 2s^{-1})$$

$$5 + 6s^{-1} + 2s^{-2}$$

From Mason's gain formulae

$$\frac{Y(s)}{U(s)} = \frac{\Sigma P \Delta}{\Delta} = \frac{s^{-2} + s^{-1}}{5 + 6s^{-1} + 2s^{-2}} = \frac{s + 1}{5s^2 + 6s + 2}$$

**Sol. 4** Option (C) is correct.

Given, open loop transfer function

$$G(s) = \frac{10K_a}{1 + 10s} = \frac{K_a}{s + \frac{1}{10}}$$

By taking inverse Laplace transform, we have

$$g(t) = e^{-\frac{1}{10}t}$$

Comparing with standard form of transfer function, $Ae^{-t/\tau}$, we get the open loop time constant,

$$\tau_{ol} = 10$$

Now, we obtain the closed loop transfer function for the given system as

$$H(s) = \frac{G(s)}{1 + G(s)} = \frac{10K_a}{1 + 10s + 10K_a}$$

11 $= \frac{K_a}{s + \left(K_a + \frac{1}{10}\right)}$

By taking inverse laplace transform, we get

$$h(t) = k_a . e^{-\left(k_a + \frac{1}{10}\right)t}$$

So, the time constant of closed loop system is obtained as

$$\tau_{cl} = \frac{1}{k_a + \frac{1}{10}}$$

or, $\tau_{cl} = \frac{1}{k_a}$ (approximately)

Now, given that $k_a$ reduces open loop time constant by a factor of 100. i.e.,

$$\tau_{cl} = \frac{\tau_{ol}}{100}$$

or, $\frac{1}{k_a} = \frac{10}{100}$

or, $k_a = 10$

Sol. 5 Option (A) is correct.

Given, the state variable formulation,

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -2 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1 \\ 1 \end{bmatrix} u \qquad \text{....(1)}$$

and

$$y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \qquad \text{....(2)}$$

From Eq. (1) we get

$$\dot{x}_1 = 2x_1 + u$$

Taking Laplace transform

$$sX_1 - x_1(0) = -2X_1 + \frac{1}{s} \quad \text{(Here, } X_1 \text{ denotes Laplace transform of } x_1\text{)}$$

So,

$$(s + 2)X_1 = \frac{1}{s} \qquad (x_1(0) = 0)$$

or,

$$X_1 = \frac{1}{s(s+2)} \qquad \text{....(3)}$$

Now, from Eq. (2) we have

$$y = x_1$$

Taking Laplace transform both the sides,

$$Y = X_L$$

or,

$$Y = \frac{1}{s(s+2)} \qquad \text{(from eq. (3))}$$

or,

$$Y = \frac{1}{2}\left[\frac{1}{s} - \frac{1}{s+2}\right]$$

Taking inverse Laplace transform

$$y = \frac{1}{2}\left(u(t) - e^{-2t}u(t)\right)$$

$$= \frac{1}{2} - \frac{1}{2}e^{-2t} \qquad (\text{for } t > 0)$$

Sol. 6 Option (A) is correct.

From the given state variable system, we have

$$A = \begin{bmatrix} -2 & 0 \\ 0 & 1 \end{bmatrix}$$

and

$$B = \begin{bmatrix} 1 \\ 1 \end{bmatrix}; \quad C = \begin{bmatrix} 1 & 0 \end{bmatrix}$$

Now, we obtain the controllability matrix

$$C_M = [B \;\vdots\; AB]$$

$$= \begin{bmatrix} 1 & -2 \\ 2 & 1 \end{bmatrix}$$

E

and the observability matrix is obtained as

$$O_M = \begin{bmatrix} C \\ CA \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -2 & 0 \end{bmatrix}$$

So, we get

Rank of the controllability matrix " Rank $(C_M) = 2$

Rank of the observability matrix " Rank $(O_M) = 1$

Since, the order of state variable is 2 $(x_1$ and $x_2)$. Therefore, we have

Rank $(C_M)$ = order of state variables

but, Rank $(O_M)$ < order of state variables

Thus, system is controllable but not observable

Sol. 7 Option (D) is correct.

General form of state equations are given as

$$\dot{x} = \boldsymbol{A}x + \boldsymbol{B}u$$
$$\dot{y} = \boldsymbol{C}x + \boldsymbol{D}u$$

For the given problem

$$\boldsymbol{A} = \begin{bmatrix} 0 & a_1 & 0 \\ 0 & 0 & a_2 \\ a_3 & 0 & 0 \end{bmatrix}, \quad \boldsymbol{B} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$\boldsymbol{AB} = \begin{bmatrix} 0 & a_1 & 0 \\ 0 & 0 & a_2 \\ a_3 & 0 & 0 \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ a_2 \\ 0 \end{bmatrix}$$

$$\boldsymbol{A}^2\boldsymbol{B} = \begin{bmatrix} 0 & 0 & a_1 a_2 \\ a_2 a_3 & 0 & 0 \\ 0 & a_3 a_1 & 0 \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} a_1 a_2 \\ 0 \\ 0 \end{bmatrix}$$

For controllability it is necessary that following matrix has a tank of $n = 3$.

$$\boldsymbol{U} = [\boldsymbol{B} : \boldsymbol{AB} : \boldsymbol{A}^2\boldsymbol{B}] = \begin{bmatrix} 0 & 0 & a_1 a_2 \\ 0 & a_2 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

So,

$$a_2 \neq 0$$
$$a_1 a_2 \neq 0 \;\&\; a_1 \neq 0$$

$a_3$ may be zero or not.

Sol. 8 Option (A) is correct.

$$Y(s) = \frac{K(s+1)}{s^3 + as^2 + 2s + 1}[R(s) - Y(s)]$$

$$Y(s)\left[1 + \frac{K(s+1)}{s^3 + as^2 + 2s + 1}\right] = \frac{K(s+1)}{s^3 + as^2 + 2s + 1}R(s)$$

$$Y(s)[s^3 + as^2 + s(2+k) + (1+k)] = K(s+1)R(s)$$

Transfer Function,

$$H(s) = \frac{Y(s)}{R(s)} = \frac{K(s+1)}{s^3 + as^2 + s(2+k) + (1+k)}$$

**Routh Table :**

| | | |
|---|---|---|
| | $1$ | $2+K$ |
| | $a$ | $1+K$ |
| $s^1$ | $\frac{a(2+K)-(1+K)}{a}$ | $0$ |

For oscillation,

$$\frac{a(2+K) - (1+K)}{a} = 0$$

$$a = \frac{K+1}{K+2}$$

Auxiliary equation

$$A(s) = as^2 + (k+1) = 0$$

$$s^2 = -\frac{k+1}{a}$$

$$s^2 = \frac{-k+1}{(k+1)}(k+2) = -(k+2)$$

$$s = j\sqrt{k+2}$$
$$j\omega = j\sqrt{2}$$
$$\omega = \sqrt{2} \qquad \text{(Oscillation frequency)}$$
$$k = 2$$

and $$a = \frac{2+1}{2+2} = \frac{3}{4} = 0.75$$

Sol. 9 Option (A) is correct.

$$G_C(s) = \frac{s+a}{s+b} = \frac{j\omega + a}{j\omega + b}$$

Phase lead angle, $$\phi = \tan^{-1}\left(\frac{\omega}{a}\right) - \tan^{-1}\left(\frac{\omega}{b}\right)$$
$$= \tan^{-1}\left[\frac{\frac{\omega}{a} - \frac{\omega}{b}}{1 + \frac{\omega^2}{ab}}\right] = \tan^{-1}\left(\frac{\omega(b-a)}{ab+\omega^2}\right)$$

For phase-lead compensation $\phi > 0$

$$b - a > 0$$
$$b > a$$

**Note:** For phase lead compensator zero is nearer to the origin as compared to pole, so option (C) can not be true.

Sol. 10 Option (A) is correct.

$$\phi = \tan^{-1}\left(\frac{\omega}{a}\right) - \tan^{-1}\left(\frac{\omega}{b}\right)$$
$$\frac{d\phi}{d\omega} = \frac{1/a}{1+\left(\frac{\omega}{a}\right)^2} - \frac{1/b}{1+\left(\frac{\omega}{b}\right)^2} = 0$$
$$\frac{1}{a} + \frac{\omega^2}{ab^2} = \frac{1}{b} + \frac{1}{b}\frac{\omega^2}{a^2}$$
$$\frac{1}{a} - \frac{1}{b} = \frac{\omega^2}{ab}\left(\frac{1}{a} - \frac{1}{b}\right)$$

$I$ $$= \sqrt{\quad} \text{ l/sec}$$

Sol. 11 Option (A) is correct.

Gain margin is simply equal to the gain at phase cross over frequency ($\omega_p$). Phase cross over frequency is the frequency at which phase angle is equal to -180c.

From the table we can see that $\angle G(j\omega_p) = -180°$, at which gain is 0.5.

$$GM = 20\log_{10}\left(\frac{1}{|G(j\omega_p)|}\right) = 20\log\left(\frac{1}{0.5}\right) = 6 \text{ dB}$$

Phase Margin is equal to 180c plus the phase angle $\phi_g$ at the gain cross over frequency ($\omega_g$). Gain cross over frequency is the frequency at which gain is unity.

From the table it is clear that $|G(j\omega_g)| = 1$, at which phase angle is -150c

$$\phi_{PM} = 180° + \angle G(j\omega_g) = 180 - 150 = 30°$$

Sol. 12 Option (A) is correct.

We know that steady state error is given by

$$e_{ss} = \lim_{s \to 0} \frac{sR(s)}{1 + G(s)}$$

where $R(s) \to$ input

$G(s) \to$ open loop transfer function

For unit step input

$$R(s) = \frac{1}{s}$$

So $$e_{ss} = \lim_{s " 0} \frac{s\,b\frac{1}{s}l}{1 + G(s)} = 0.1$$

$$1 + G(0) = 10$$

$$G(0) = 9$$

Given input $r(t) = 10[\mathrm{m}(t) - \mathrm{m}(t-1)]$

or $$R(s) = 10:\frac{1}{s} - \frac{1}{s}e^{-s}D = 10:\frac{1 - e^{-s}}{s}D$$

So steady state error

$$e_{ss}l = \lim_{s " 0} \frac{s \# 10 \frac{(1 - e^{-s})}{s}}{1 + G(s)} = \frac{10(1 - e^{0})}{1 + 9} = 0$$

**Sol. 13** Option (B) is correct.

Transfer function having at least one zero or pole in RHS of $s$-plane is called non-minimum phase transfer function.

$$G(s) = \frac{s - 1}{(s + 2)(s + 3)}$$

Z In the given transfer function one zero is located at $s = 1$ (RHS), so this is a non-minimum phase system.

AA Poles - 2, - 3, are in left side of the complex plane, So the system is stable

**Sol. 14** Option (A) is correct.

$$G(s) = \frac{K\,b s + \frac{2}{3}l}{s^2(s+2)}$$

Steps for plotting the root-locus

A Root loci starts at $s = 0, s = 0$ and $s = -2$

B $n > m$, therefore, number of branches of root locus $b = 3$

C Angle of asymptotes is given by

$$\frac{(2q + 1)180c}{n - m}, \; q = 0, 1$$

(I) $$\frac{(2 \# 0 + 1)180c}{(3 - 1)} = 90c$$

(II) $$\frac{(2 \# 1 + 1)180c}{(3 - 1)} = 270c$$

(4) The two asymptotes intersect on real axis at centroid

$$x = \frac{/\text{Poles} - /\text{Zeroes}}{n - m} = \frac{-2 - b - \frac{2}{3}l}{3 - 1} = -\frac{2}{3}$$

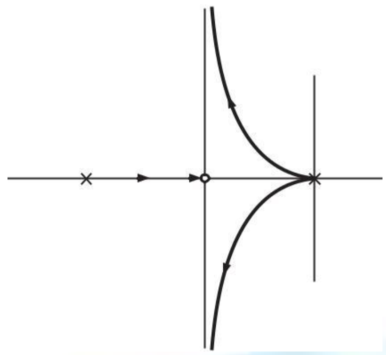
(5) Between two open-loop poles $s = 0$ and $s = -2$ there exist a break away point.

$$K = -\frac{s^2(s + 2)}{b s + \frac{2}{3}l}$$

$$\frac{dK}{ds} = 0$$

= 0

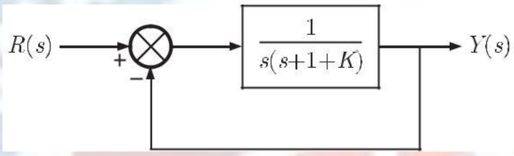
Root locus is shown in the figure



Three roots with nearly equal parts exist on the left half of $s$ -plane.

**Sol. 15** Option (A) is correct.

The system may be reduced as shown below




$$\frac{Y(s)}{R(s)} = \frac{\frac{1}{s(s+1+K)}}{1+\frac{1}{s(s+1+K)}} = \frac{1}{s^2 + s(1+K) + 1}$$

This is a second order system transfer function, characteristic equation is

$$s^2 + s(1+K) + 1 = 0$$

Comparing with standard form

$$s^2 + 2\xi\omega_n s + \omega_n^2 = 0$$

We get $\xi = \frac{1+K}{2}$

Peak overshoot

$$M_p = e^{-\pi\xi/\sqrt{1-\xi^2}}$$

So the Peak overshoot is effected by $K$.

**Sol. 16** Option (A) is correct.

Given $G(s) = \frac{1}{s(s+1)(s+2)}$

$$G(j\omega) = \frac{1}{j\omega(j\omega+1)(j\omega+2)}$$

$$|G(j\omega)| = \frac{1}{\omega\sqrt{\ }\sqrt{\ }}$$

$$\angle G(j\omega) = -90° - \tan^{-1}(\omega) - \tan^{-1}(\omega/2)$$

In nyquist plot

For $\omega = 0$, $|G(j\omega)| = 3$

$$\angle G(j\omega) = -90°$$

For $\omega = 3$, $|G(j\omega)| = 0$

$$\angle G(j\omega) = -90° - 90° - 90° = -270°$$

Intersection at real axis

$$G(j\omega) = \frac{1}{j\omega(j\omega+1)(j\omega+2)} = \frac{1}{j\omega(-\omega^2 + j3\omega + 2)}$$

$$= \frac{1}{-3\omega^2 + j\omega(2-\omega^2)} \# \frac{-3\omega^2 - j\omega(2-\omega^2)}{-3\omega^2 - j\omega(2-\omega^2)}$$

$$= \frac{-3\omega^2 - j\omega(2-\omega^2)}{9\omega^4 + \omega^2(2-\omega^2)^2}$$

$$= \frac{-3\omega^2}{9\omega^4 + \omega^2(2-\omega^2)^2} - \frac{j\omega(2-\omega^2)}{9\omega^4 + \omega^2(2-\omega^2)^2}$$

At real axis $\quad \text{Im}[G(j\omega)] = 0$

So, $\quad \frac{\omega(2-\omega^2)}{9\omega^4 + \omega^2(2-\omega^2)^2} = 0$

$$2 - \omega^2 = 0 \;\&\; \omega = \sqrt{2} \text{ rad/sec}$$

At $\omega = \sqrt{2}$ rad/sec, magnitude response is

$$|G(j\omega)| \ldots = \frac{1}{6} < \frac{3}{4}$$

Sol. 17 Option (C) is correct.

Stability :

Eigen value of the system are calculated as

$$|A - \lambda I| = 0$$

$$A - \lambda I = \begin{bmatrix} -1 & 2 \\ 0 & 2 \end{bmatrix} - \lambda \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} -1-\lambda & 2 \\ 0 & 2-\lambda \end{bmatrix}$$

$$|A - \lambda I| = (-1-\lambda)(2-\lambda) - 2 \# 0 = 0$$

& $\quad \lambda_1, \lambda_2 = -1, 2$

Since eigen values of the system are of opposite signs, so it is unstable

Controllability :

$$A = \begin{bmatrix} -1 & 2 \\ 0 & 2 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$AB = \begin{bmatrix} 2 \\ 2 \end{bmatrix}$$

$$[B : AB] = \begin{bmatrix} 0 & 2 \\ 1 & 2 \end{bmatrix}$$

$$|[B : AB]| \neq 0$$

So it is controllable.

Sol. 18 Option (C) is correct.

Given characteristic equation

$$s(s+1)(s+3) + K(s+2) = 0; \qquad K > 0$$

$$s(s^2 + 4s + 3) + K(s+2) = 0$$

$$s^3 + 4s^2 + (3+K)s + 2K = 0$$

From Routh's tabulation method

| | | |
|---|---|---|
| $s^3$ | 1 | $3+K$ |
| $s^2$ | 4 | $2K$ |
| $s^1$ | $\frac{4(3+K) - 2K(1)}{4} = \frac{12+2K}{4} > 0$ | |
| $s^0$ | $2K$ | |

There is no sign change in the first column of routh table, so no root is lying in right half of $s$ -plane.

For plotting root locus, the equation can be written as

$$1 + \frac{K(s+2)}{s(s+1)(s+3)} = 0$$

Open loop transfer function

$$G(s) = \frac{K(s+2)}{s(s+1)(s+3)}$$

Root locus is obtained in following steps:

1. No. of poles $n = 3$, at $s = 0$, $s =- 1$ and $s =- 3$
2. No. of Zeroes $m = 1$, at $s =- 2$
3. The root locus on real axis lies between $s = 0$ and $s =- 1$, between $s =- 3$ and $s =- 2$.
4. Breakaway point lies between open loop poles of the system. Here breakaway point lies in the range $-1 < \mathrm{Re}[s] < 0$.
5. Asymptotes meet on real axis at a point $C$, given by

$$C = \frac{\sum \text{real part of poles} - \sum \text{real parts of zeroes}}{n - m}$$

$$= \frac{(0 - 1 - 3) - (-2)}{3 - 1}$$

$$=- 1$$

As no. of poles is 3, so two root loci branches terminates at infinity along asymptotes $\mathrm{Re}(s) =- 1$

Sol. 19 Option (D) is correct.

Overall gain of the system is written as

$$G = G_1 G_2 \frac{1}{G_3}$$

We know that for a quantity that is product of two or more quantities total percentage error is some of the percentage error in each quantity. so error in overall gain $G$ is

$$3G = e_1 + e_2 + \frac{1}{e_3}$$

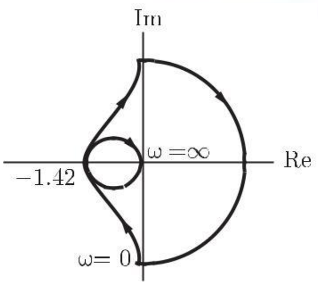
Sol. 20 Option (D) is correct.

From Nyquist stability criteria, no. of closed loop poles in right half of $s$ -plane is given as

$$Z = P - N$$

$P$ " No. of open loop poles in right half $s$ -plane

$N$ " No. of encirclement of $(-1, j0)$




Here $N =- 2$ (` encirclement is in clockwise direction)

$P = 0$ (` system is stable)

So, $Z = 0 - (-2)$

$Z = 2$, System is unstable with 2-poles on RH of $s$ -plane.

Sol. 21 Option (D) is correct.

Given Routh's tabulation.

| | | |
|---|---|---|
| $s^3$ | 2 | 2 |
| $s^2$ | 4 | 4 |
| $s^1$ | 0 | 0 |

So the auxiliary equation is given by,

$$4s^2 + 4 = 0$$

$$s^2 =- 1$$

# $=! j$

From table we have characteristic equation as

$$2s^3 + 2s + 4s^2 + 4 = 0$$

$$s^3 + s + 2s^2 + 2 = 0$$

$$s(s^2 + 1) + 2(s^2 + 1) = 0$$

$$(s + 2)(s^2 + 1) = 0$$

$$s =- 2, s =! j$$

Sol. 22 Option (B) is correct.

Since initial slope of the bode plot is -40 dB/decade, so no. of poles at origin is 2.

Transfer function can be written in following steps:

w Slope changes from -40 dB/dec. to -60 dB/dec. at $w_1 = 2$ rad/sec., so at $w_1$ there is a pole in the transfer function.

w Slope changes from -60 dB/dec to -40 dB/dec at $w_2 = 5$ rad/sec., so at this frequency there is a zero lying in the system function.

w The slope changes from -40 dB/dec to -60 dB/dec at $w_3 = 25$ rad/sec, so there is a pole in the system at this frequency.

Transfer function

$$T(s) = \frac{K(s + 5)}{s^2 (s + 2)(s + 25)}$$

Constant term can be obtained as.

$$T(jw)\Big|_{at\ w = 0.1} = 80$$

So, $80 = 20 \log \frac{K(5)}{(0.1)^2 \# 50}$

- $= 1000$

therefore, the transfer function is

$$T(s) \quad \frac{1000(s + 5)}{s^2 (s + 2)(s + 25)}$$

Sol. 23 Option (D) is correct.

From the figure we can see that steady state error for given system is

$$e_{ss} = 1 - 0.75 = 0.25$$

Steady state error for unity feed back system is given by

$$e_{ss} = \lim \frac{sR(s)}{}$$

$$= \quad G$$

$$_{s "0} \quad 1 + G(s)$$

$$= \lim_{s \to 0} \frac{s\left(\frac{1}{s}\right)}{1 + \frac{K}{(s+1)(s+2)}} \; ; R(s) = \frac{1}{s} \text{ (unit step input)}$$

$$= \frac{1}{1 + \frac{K}{2}} = \frac{2}{2 + K}$$

So,

$$e_{ss} = \frac{2}{2 + K} = 0.25$$

$$2 = 0.5 + 0.25K$$

$$K = \frac{1.5}{0.25} = 6$$

**Sol. 24** Option (D) is correct.

Open loop transfer function of the figure is given by,

$$G(s) = \frac{e^{-0.1s}}{s}$$

$$G(j\omega) = \frac{e^{-j0.1\omega}}{j\omega}$$

Phase cross over frequency can be calculated as,

$$\angle G(j\omega_p) = -180°$$

$$\left(-0.1\omega_p \times \frac{180}{\pi}\right) - 90° = -180°$$

$$0.1\omega_p \times \frac{180°}{\pi} = 90°$$

$$0.1\omega_p = \frac{90° \times \pi}{180°}$$

$$\omega_p = 15.7 \text{ rad/sec}$$

So the gain margin (dB)

$$= 20 \log \left( \frac{1}{|G(j\omega_p)|} \right) = 20 \log \left( \frac{1}{\frac{1}{15.7}} \right)$$

$$= 20 \log 15.7 = 23.9 \text{ dB}$$

**Sol. 25** Option (C) is correct.

Given system equations

$$\frac{dx_1(t)}{dt} = -3x_1(t) + x_2(t) + 2u(t)$$

$$\frac{dx_2(t)}{dt} = -2x_2(t) + u(t)$$

$$y(t) = x_1(t)$$

Taking Laplace transform on both sides of equations.

$$sX_1(s) = -3X_1(s) + X_2(s) + 2U(s)$$

$$(s+3)X_1(s) = X_2(s) + 2U(s) \qquad \text{...(1)}$$

Similarly

$$sX_2(s) = -2X_2(s) + U(s)$$

$$(s+2)X_2(s) = U(s) \qquad \text{...(2)}$$

From equation (1) & (2)

$$(s+3)X_1(s) = \frac{U(s)}{s+2} + 2U(s)$$

$$X_1(s) = \frac{U(s)}{s+3}\left[\frac{1 + 2(s+2)}{s+2}\right] = U(s)\frac{(2s+5)}{(s+2)(s+3)}$$

From output equation,

$$Y(s) = X_1(s)$$

So, $$Y(s) = U(s)\frac{(2s+5)}{(s+2)(s+3)}$$

System transfer function

$$\text{T.F} = \frac{Y(s)}{U(s)} = \frac{(2s+5)}{(s+2)(s+3)} = \frac{(2s+5)}{s^2+5s+6}$$

**Sol. 26** Option (B) is correct.

Given state equations in matrix form can be written as,

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -3 & 1 \\ 0 & -2 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 2 \\ 1 \end{bmatrix}\boldsymbol{u}(t)$$

$$\frac{d\boldsymbol{X}(t)}{dt} = A\boldsymbol{X}(t) + B\boldsymbol{u}(t)$$

State transition matrix is given by

$$\phi(t) = \mathcal{L}^{-1}[\boldsymbol{\Phi}(s)]$$

$$\boldsymbol{\Phi}(s) = (sI - A)^{-1}$$

$$(sI - A) = \begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix} - \begin{bmatrix} -3 & 1 \\ 0 & -2 \end{bmatrix}$$

$$(sI - A) = \begin{bmatrix} s+3 & -1 \\ 0 & s+2 \end{bmatrix}$$

$$(sI - A)^{-1} = \frac{1}{(s+3)(s+2)}\begin{bmatrix} s+2 & 1 \\ 0 & s+3 \end{bmatrix}$$

So $$\boldsymbol{\Phi}(s) = (sI - A)^{-1} = \begin{bmatrix} \frac{1}{(s+3)} & \frac{1}{(s+3)(s+2)} \\ 0 & \frac{1}{(s+2)} \end{bmatrix}$$

$$\boldsymbol{\phi}(t) = \mathcal{L}^{-1}[\boldsymbol{\Phi}(s)] = \begin{bmatrix} e^{-3t} & e^{-2t} - e^{-3t} \\ 0 & e^{-2t} \end{bmatrix}$$

**Sol. 27** Option (D) is correct.

Given differential equation for the function

$$\frac{dy(t)}{dt} + y(t) = \delta(t)$$

Taking Laplace on both the sides we have,

$$sY(s) + Y(s) = 1$$

$$(s+1)Y(s) = 1$$

$$Y(s) = \frac{1}{s+1}$$

Taking inverse Laplace of $Y(s)$

$$y(t) = e^{-t}u(t),\ t > 0$$

**Sol. 28** Option (A) is correct.

Given transfer function

$$G(s) = \frac{1}{s^2+3s+2}$$

Input $$r(t) = \delta(t-1)$$

$$R(s) = \mathcal{L}[\delta(t-1)] = e^{-s}$$

Output is given by

$$Y(s) = R(s)G(s) = \frac{e^{-s}}{s^2+3s+2}$$

Steady state value of output

$$\lim_{t \to \infty} y(t) = \lim_{s \to 0} sY(s) = \lim_{s \to 0} \frac{se^{-s}}{s^2 + 3s + 2} = 0$$

**Sol. 29** Option (A) is correct.

For $C_1$ Phase is given by

$$\theta_{C1} = \tan^{-1}(\omega) - \tan^{-1}\left(\frac{\omega}{10}\right)$$

$$= \tan^{-1}\left(\frac{\omega - \frac{\omega}{10}}{1 + \frac{\omega^2}{10}}\right)$$

$$= \tan^{-1}\left(\frac{9\omega}{10 + \omega^2}\right) > 0 \quad \text{(Phase lead)}$$

Similarly for $C_2$, phase is

$$\theta_{C2} = \tan^{-1}\left(\frac{\omega}{10}\right) - \tan^{-1}(\omega)$$

$$= \tan^{-1}\left(\frac{\frac{\omega}{10} - \omega}{1 + \frac{\omega^2}{10}}\right)$$

$$= \tan^{-1}\left(\frac{-9\omega}{10 + \omega^2}\right) < 0 \quad \text{(Phase lag)}$$

**Sol. 30** Option (C) is correct.

= Slope -40 dB/decade $\Rightarrow$ 2 poles

= Slope -20 dB/decade (Slope changes by +20 dB/decade) $\Rightarrow$ 1 Zero

= Slope 0 dB/decade (Slope changes by +20 dB/decade) $\Rightarrow$ 1 Zero So there are 2 poles and 2 zeroes in the transfer function.

**Sol. 31** Option (C) is correct.

Characteristic equation for the system

$$1 + \frac{K}{s(s+3)(s+10)} = 0$$

$$s(s+3)(s+10) + K = 0$$

$$s^3 + 13s^2 + 30s + K = 0$$

Applying Routh's stability criteria

| | | |
|---|---|---|
| $s^3$ | 1 | 30 |
| $s^2$ | 13 | $K$ |
| $s^1$ | $\frac{(13 \times 30) - K}{13}$ | |
| $s^0$ | $K$ | |

For stability there should be no sign change in first column

So, $390 - K > 0 \;\; \& \; K < 390$

$K > 0$

$0 < K < 90$

**Sol. 32** Option (C) is correct.

Given transfer function is

$$H(s) = \frac{100}{s^2 + 20s + 100}$$

Characteristic equation of the system is given by

$$s^2 + 20s + 100 = 0$$

$$\omega_n^2 = 100 \quad \& \quad \omega_n = 10 \text{ rad/sec.}$$

$$2\xi\omega_n = 20$$

or $$\xi = \frac{20}{2 \times 10} = 1$$

($\xi = 1$) so system is critically damped.

Sol. 33 Option (D) is correct.

State space equation of the system is given by,

$$\dot{\boldsymbol{X}} = A\boldsymbol{X} + B\boldsymbol{u}$$

$$\boldsymbol{Y} = C\boldsymbol{X}$$

Taking Laplace transform on both sides of the equations.

$$s\boldsymbol{X}(s) = A\boldsymbol{X}(s) + B\boldsymbol{U}(s)$$

$$(sI - A)\boldsymbol{X}(s) = B\boldsymbol{U}(s)$$

$$\boldsymbol{X}(s) = (sI - A)^{-1}B\boldsymbol{U}(s)$$

$$\because \boldsymbol{Y}(s) = C\,\boldsymbol{X}(s)$$

So $$\boldsymbol{Y}(s) = C\,(sI - A)^{-1}B\boldsymbol{U}(s)$$

$$\text{T.F} = \frac{\boldsymbol{Y}(s)}{\boldsymbol{U}(s)} = C\,(sI - A)^{-1}B$$

$$(sI - A) = \begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix} - \begin{bmatrix} 0 & 1 \\ 0 & -2 \end{bmatrix} = \begin{bmatrix} s & -1 \\ 0 & s+2 \end{bmatrix}$$

$$(sI - A)^{-1} = \frac{1}{s(s+2)}\begin{bmatrix} s+2 & 1 \\ 0 & s \end{bmatrix} = \begin{bmatrix} \frac{1}{s} & \frac{1}{s(s+2)} \\ 0 & \frac{1}{(s+2)} \end{bmatrix}$$

Transfer function

$$G(s) = C\,[sI - A]^{-1}B = \begin{bmatrix} 1 & 0 \end{bmatrix}\begin{bmatrix} \frac{1}{s} & \frac{1}{s(s+2)} \\ 0 & \frac{1}{(s+2)} \end{bmatrix}\begin{bmatrix} 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \end{bmatrix}\begin{bmatrix} \frac{1}{s(s+2)} \\ \frac{1}{(s+2)} \end{bmatrix} = \frac{1}{s(s+2)}$$

Sol. 34 Option (A) is correct.

Steady state error is given by,

$$e_{ss} = \lim_{s \to 0} \frac{sR(s)}{1 + G(s)H(s)}$$

Here

$$R(s) = \mathcal{L}[r(t)] = \frac{1}{s} \text{ (Unit step input)}$$

$$G(s) = \frac{1}{s(s+2)}$$

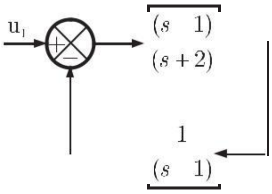
$$H(s) = 1 \text{ (Unity feed back)}$$

So, $$e_{ss} = \lim_{s \to 0} \frac{s\left(\frac{1}{s}\right)}{1 + \frac{1}{s(s+2)}} = \lim_{s \to 0} \frac{s(s+2)}{s(s+2) + 1} = 0$$

Sol. 35

Option (D) is correct.

For input $u_1$, the system is ($u_2 = 0$)

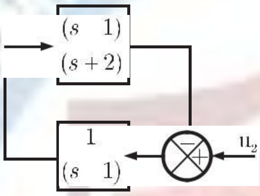



System response is

$$H_1(s) = \frac{\dfrac{(s-1)}{(s+2)}}{1 + \dfrac{(s-1)}{(s+2)}\dfrac{1}{(s-1)}} = \frac{(s-1)}{(s+3)}$$

Poles of the system is lying at $s = -3$ (negative $s$-plane) so this is stable.

For input $u_2$ the system is ($u_1 = 0$)




System response is

$$H_2(s) = \frac{\dfrac{1}{(s-1)}}{1 + \dfrac{1}{(s-1)}\dfrac{(s-1)}{(s+2)}} = \frac{(s+2)}{(s-1)(s+3)}$$

One pole of the system is lying in right half of $s$-plane, so the system is unstable.

Sol. 36

Option (B) is correct.

Given function is.

$$G(s) = \frac{1}{s(s+1)(s+2)}$$

$$G(j\omega) = \frac{1}{j\omega(1+j\omega)(2+j\omega)}$$

By simplifying

$$G(j\omega) = \left(\frac{1}{j\omega} \times \frac{-j\omega}{-j\omega}\right)\left(\frac{1}{1+j\omega} \times \frac{1-j\omega}{1-j\omega}\right)\left(\frac{1}{2+j\omega} \times \frac{2-j\omega}{2-j\omega}\right)$$

$$G = \left(\frac{-j\omega}{\omega^2}\right)\left(\frac{1-j\omega}{1+\omega^2}\right)\left(\frac{2-j\omega}{4+\omega^2}\right) = \frac{-j\omega(2-\omega^2-j3\omega)}{\omega^2(1+\omega^2)(4+\omega^2)}$$

$$= \frac{-3\omega^2}{\omega^2(1+\omega^2)(4+\omega^2)} + \frac{j\omega(\omega^2-2)}{\omega^2(1+\omega^2)(4+\omega^2)}$$

$$G(j\omega) = x + iy$$

$$x = \mathrm{Re}[G(j\omega)]\Big|_{\omega \to 0} = \frac{-3}{1 \times 4} = -\frac{3}{4}$$

Sol. 37

Option (D) is correct.

Let response of the un-compensated system is

$$H_{UC}(s) = \frac{900}{s(s+1)(s+9)}$$

Response of compensated system.

$$H_C(s) = \frac{900}{s(s+1)(s+9)} G_c(s)$$

Where $G_C(s)$ " Response of compensator

Given that gain-crossover frequency of compensated system is same as phase crossover frequency of un-compensated system So,

$$(\omega_g)_{compensated} = (\omega_p)_{uncompensated}$$

$$-180^\circ = \angle H_{UC}(j\omega_p)$$

$$-180^\circ = -90^\circ - \tan^{-1}(\omega_p) - \tan^{-1}\left(\frac{\omega_p}{9}\right)$$

$$90^\circ = \tan^{-1}\left(\frac{\omega_p + \frac{\omega_p}{9}}{1 - \frac{\omega_p^2}{9}}\right)$$

$$1 - \frac{\omega_p^2}{9} = 0$$

$$\omega_p = 3 \text{ rad/sec.}$$

So,

$$(\omega_g)_{compensated} = 3 \text{ rad/sec.}$$

At this frequency phase margin of compensated system is

$$\phi_{PM} = 180^\circ + \angle H_C(j\omega_g)$$

$$45^\circ = 180^\circ - 90^\circ - \tan^{-1}(\omega_g) - \tan^{-1}(\omega_g/9) + \angle G_C(j\omega_g)$$

$$45^\circ = 180^\circ - 90^\circ - \tan^{-1}(3) - \tan^{-1}(1/3) + \angle G_C(j\omega_g)$$

$$45^\circ = 90^\circ - \tan^{-1}\left(\frac{3 + \frac{1}{3}}{1 - 3\left(\frac{1}{3}\right)}\right) + \angle G_C(j\omega_g)$$

$$45^\circ = 90^\circ - 90^\circ + \angle G_C(j\omega_g)$$

$$\angle G_C(j\omega_g) = 45^\circ$$

The gain cross over frequency of compensated system is lower than un-compensated system, so we may use lag-lead compensator.

At gain cross over frequency gain of compensated system is unity so.

$$|H_C(j\omega_g)| = 1$$

$$\frac{900|G_C(j\omega_g)|}{\omega_g\sqrt{\omega_g^2+1}\sqrt{\omega_g^2+81}} = 1$$

$$|G_C(j\omega_g)| = \frac{3\sqrt{10}\sqrt{90}}{900} = \frac{3 \# 30}{900} = \frac{1}{10}$$

$$|G_C(\omega_g)|_{\text{in dB}} = 20\log\left(\frac{1}{10}\right)$$

$$= -20 \text{ dB (attenuation)}$$

**Sol. 38** Option (B) is correct.

Characteristic equation for the given system,

$$1 + \frac{K(s+3)}{(s+8)^2} = 0$$

$$(s+8)^2 + K(s+3) = 0$$

$$s^2 + (16+K)s + (64+3K) = 0$$

By applying Routh's criteria.

| | | |
|---|---|---|
| $s^2$ | 1 | $64 + 3K$ |
| $s^1$ | $16 + K$ | 0 |
| $s^0$ | $64 + 3K$ | |

For system to be oscillatory

$$16 + K = 0 \& K =- 16$$

$$\text{Auxiliary equation } A(s) = s^2 + (64 + 3K) = 0$$

& $$s^2 + 64 + 3 \# (- 16) = 0\ s^2$$

$$+ 64 - 48 = 0$$

$$s^2 =- 16 \& j\,w = 4j\,w$$

$$= 4 \text{ rad/sec}$$

**Sol. 39** Option (D) is correct.

From the given block diagram we can obtain signal flow graph of the system.

Transfer function from the signal flow graph is written as

$$\text{T.F} = \frac{\frac{c_0 P}{s^2} + \frac{c_1 P}{s}}{1 + \frac{a_1}{s} + \frac{a_0}{s^2} - \frac{Pb_0}{s^2} - \frac{Pb_1}{s}}$$

$$= \frac{(c_0 + c_1 s)P}{(s^2 + a_1 s + a_0) - P(b_0 + sb_1)}$$

$$= \frac{\dfrac{(c_0 + c_1 s)P}{(s^2 + a_1 s + a_0)}}{1 - \dfrac{P(b_0 + sb_1)}{s^2 + a_1 s + a_0}}$$

from the given reduced form transfer function is given by

$$\text{T.F} = \frac{XYP}{1 - YPZ}$$

by comparing above two we have

$$X = (c_0 + c_1 s)$$

$$Y = \frac{1}{s^2 + a_1 s + a_0}$$

$$Z = (b_0 + sb_1)$$

**Sol. 40** Option (A) is correct.

For the given system $Z$ is given by

$$Z = E(s)\,\frac{K_i}{s}$$

Where $E(s)$ " steady state error of the system

Here $$E(s) = \lim_{s " 0} \frac{sR(s)}{1 + G(s)H(s)}$$

Input $$R(s) = \frac{1}{s} \text{ (Unit step)}$$

$$G(s) = \text{b}\ \frac{K_i}{s} + K_p \text{ le } \frac{\text{w}^2}{s^2 + 2\text{xw}\, s + \text{w}^2} \text{ o}$$

$$H(s) = 1 \text{ (Unity feed back)}$$

So,

$$= \lim_{s\to 0} s\,\frac{s\left(\frac{1}{s}\right)\frac{K_i}{s}}{s\left[1+\left(\frac{K_i}{s}+K_p\right)\left(\frac{\omega^2}{s^2+2\xi\omega s+\omega^2}\right)\right]}$$

$$= \lim_{s\to 0} \frac{K_i}{s+(K_i+K_p s)\left(\frac{\omega^2}{s^2+2\xi\omega s+\omega^2}\right)} = \frac{K_i}{K_i} = 1$$

**Sol. 41** Option (C) is correct.

System response of the given circuit can be obtained as.

$$H(s) = \frac{e_0(s)}{e_i(s)} = \frac{\left(\frac{1}{Cs}\right)}{\left(R+Ls+\frac{1}{Cs}\right)}$$

$$H(s) = \frac{1}{LCs^2+RCs+1} = \frac{\left(\frac{1}{LC}\right)}{s^2+\frac{R}{L}s+\frac{1}{LC}}$$

Characteristic equation is given by,

$$s^2+\frac{R}{L}s+\frac{1}{LC} = 0$$

Here natural frequency $\omega_n = \frac{1}{\sqrt{LC}}$

$$2\xi\omega_n = \frac{R}{L}$$

Damping ratio $\xi = \frac{R}{2L}\sqrt{LC} = \frac{R}{2}\sqrt{\frac{C}{L}}$

Here $\xi = \frac{10}{2}\sqrt{\frac{1\times 10^{-3}}{10\times 10^{-3}}}$ = 0.5 (under damped)

So peak overshoot is given by

$$\%\text{ peak overshoot} = e^{\frac{-\pi\xi}{\sqrt{1-\xi^2}}}\times 100 = e^{\frac{-\pi\times 0.5}{\sqrt{1-(0.5)^2}}}\times 100 = 16\%$$

**Sol. 42** Option ( ) is correct.

**Sol. 43** Option (B) is correct.

In standard form for a characteristic equation give as

$$s^n + a_{n-1}s^{n-1} + \dots + a_1 s + a_0 = 0$$

in its state variable representation matrix $A$ is given as

$$A = \begin{bmatrix} 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & & \vdots \\ -a_0 & -a_1 & -a_2 & \cdots & -a_{n-1} \end{bmatrix}$$

Characteristic equation of the system is

$$4s^2 - 2s + 1 = 0$$

So, $a_2 = 4, a_1 = -2, a_0 = 1$

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -a_0 & -a_1 & -a_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -1 & 2 & -4 \end{bmatrix}$$

**Sol. 44** Option (A) is correct.

In the given options only in option (A) the nyquist plot does not enclose the unit circle $(-1, j0)$, So this is stable.

**Sol. 45** Option (A) is correct.

Given function is,

$$H(j\omega) = \frac{10^4(1 + j\omega)}{(10 + j\omega)(100 + j\omega)^2}$$

Function can be rewritten as,

$$H(j\omega) = \frac{10^4(1 + j\omega)}{10\left(1 + j\frac{\omega}{10}\right)10^4\left(1 + j\frac{\omega}{100}\right)^2}$$

$$= \frac{0.1(1 + j\omega)}{\left(1 + j\frac{\omega}{10}\right)\left(1 + j\frac{\omega}{100}\right)^2}$$

The system is type 0, So, initial slope of the bode plot is 0 dB/decade.

Corner frequencies are

$$\omega_1 = 1 \text{ rad/sec}$$
$$\omega_2 = 10 \text{ rad/sec}$$
$$\omega_3 = 100 \text{ rad/sec}$$

As the initial slope of bode plot is 0 dB/decade and corner frequency $\omega_1 = 1$ rad/ sec, the Slope after $\omega = 1$ rad/sec or $\log\omega = 0$ is$(0 + 20) = +20$ dB/dec.

After corner frequency $\omega_2 = 10$ rad/sec or $\log \omega_2 = 1$, the Slope is $(+20 - 20) = 0$ dB/dec.

Similarly after $\omega_3 = 100$ rad/sec or $\log \omega = 2$, the slope of plot is $(0 - 20 \times 2) = -40$ dB/dec.

Hence (A) is correct option.

**Sol. 46** Option (B) is correct.

Given characteristic equation.

$$(s^2 - 4)(s + 1) + K(s - 1) = 0$$

or $$1 + \frac{K(s - 1)}{(s^2 - 4)(s + 1)} = 0$$

So, the open loop transfer function for the system.

$$G(s) = \frac{K(s - 1)}{(s - 2)(s + 2)(s + 1)}, \qquad \text{no. of poles } n = 3$$

no of zeroes $m = 1$

Steps for plotting the root-locus

(1) Root loci starts at $s = 2, s = -1, s = -2$

(2) $n > m$ , therefore, number of branches of root locus $b = 3$

(3) Angle of asymptotes is given by

$$\frac{(2q + 1)180^\circ}{n - m}, q = 0, 1$$

(I) $$\frac{(2 \times 0 + 1)180^\circ}{(3 - 1)} = 90^\circ$$

(II) $$\frac{(2 \times 1 + 1)180^\circ}{(3 - 1)} = 270^\circ$$

(4) The two asymptotes intersect on real axis at

$$x = \frac{\Sigma\text{Poles} - \Sigma\text{Zeroes}}{n - m} = \frac{(-1 - 2 + 2) - (1)}{3 - 1} = -1$$

(5) Between two open-loop poles $s = -1$ and $s = -2$ there exist a break away point.

$$K = -\frac{(s^2 - 4)(s + 1)}{(s - 1)}$$

$$\frac{dK}{ds} = 0$$

$$s = -1.5$$

Sol. 47 Option (C) is correct.

Closed loop transfer function of the given system is,

$$T(s) = \frac{s^2 + 4}{(s + 1)(s + 4)}$$

$$T(j\omega) = \frac{(j\omega)^2 + 4}{(j\omega + 1)(j\omega + 4)}$$

If system output is zero

$$|T(j\omega)| = \frac{|4 - \omega^2|}{|(j\omega + 1)(j\omega + 4)|} = 0$$

$$4 - \omega^2 = 0$$

$$\omega^2 = 4$$

$$\Rightarrow \omega = 2 \text{ rad/sec}$$

Sol. 48 Option (A) is correct.

From the given plot we can see that centroid $C$ (point of intersection) where asymptotes intersect on real axis) is 0

So for option (a)

$$G(s) = \frac{K}{s^3}$$

$$\text{Centroid} = \frac{\Sigma \text{Poles} - \Sigma \text{Zeros}}{n - m} = \frac{0 - 0}{3 - 0} = 0$$

Sol. 49 Option (A) is correct.

Open loop transfer function is.

$$G(s) = \frac{(s + 1)}{s^2}$$

$$G(j\omega) = \frac{j\omega + 1}{-\omega^2}$$

Phase crossover frequency can be calculated as.

$$\angle G(j\omega_p) = -180^\circ$$

$$\tan^{-1}(\omega_p) = -180^\circ$$

$$\omega_p = 0$$

Gain margin of the system is.

$$G.M = \frac{1}{|G(j\omega_p)|} = \frac{1}{\frac{\sqrt{\omega_p^2 + 1}}{\omega_p^2}} = \frac{\omega_p^2}{\sqrt{\omega_p^2 + 1}} = 0$$

Sol. 50 Option (C) is correct.

Characteristic equation for the given system

$$1 + G(s)H(s) = 0$$

$$1 + K\frac{(1 - s)}{(1 + s)} = 0$$

$$s(1-K) + (1+K) = 0$$

For the system to be stable, coefficient of characteristic equation should be of same sign.

$$1 - K > 0,\ K + 1 > 0$$

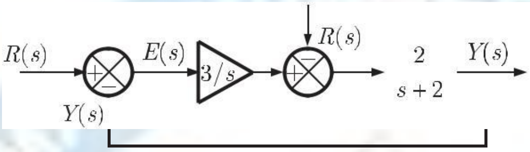
$$K < 1,\ K > -1$$

$$-1 < K < 1$$

$$|K| < 1$$

Sol. 51 Option (C) is correct.

In the given block diagram




Steady state error is given as

$$e_{ss} = \lim_{s \to 0} sE(s)$$

$$E(s) = R(s) - Y(s)$$

$Y(s)$ can be written as

$$Y(s) = \left[\{R(s) - Y(s)\}\frac{3}{s} - R(s)\right]\frac{2}{s+2}$$

$$= R(s)\left[\frac{6}{s(s+2)} - \frac{2}{s+2}\right] - Y(s)\left[\frac{6}{s(s+2)}\right]$$

$$Y(s)\left[1 + \frac{6}{s(s+2)}\right] = R(s)\left[\frac{6-2s}{s(s+2)}\right]$$

$$Y(s) = R(s)\frac{(6-2s)}{(s^2+2s+6)}$$

So, $$E(s) = R(s) - \frac{(6-2s)}{(s^2+2s+6)}R(s)$$

$$= R(s)\left[\frac{s^2+4s}{s^2+2s+6}\right]$$

For unit step input $R(s) = \frac{1}{s}$

Steady state error $e_{ss} = \lim_{s \to 0} sE(s)$

$$e_{ss} = \lim_{s \to 0} s\left[\frac{1}{s}\frac{(s^2+4s)}{(s^2+2s+6)}\right] = 0$$

Sol. 52 Option (B) is correct.

When it passes through negative real axis at that point phase angle is $-180°$ So

$$\angle G(j\omega)H(j\omega) = -180°$$

$$-0.25j\omega - \frac{\pi}{2} = -\pi$$

$$-0.25j\omega = -\frac{\pi}{2}$$

$$j0.25\omega = \frac{\pi}{2}$$

$$j\omega = \frac{\pi}{2 \times 0.25}$$

$$s = j\omega = 2\pi$$

Put $s = 2\pi$ in given open loop transfer function we get

$$G(s)H(s)\Big|_{s=2\pi} = \frac{\pi e^{-0.25 \times 2\pi}}{2\pi} = -0.5$$

So it passes through $(-0.5, j0)$

**Sol. 53** Option (C) is correct.

Open loop transfer function of the system is given by.

$$G(s)H(s) = \frac{K + 0.366s}{s(s+1)}$$

$$G(j\omega)H(j\omega) = \frac{K + j0.366\omega}{j\omega(j\omega + 1)}$$

Phase margin of the system is given as

$$\phi_{PM} = 60^\circ = 180^\circ + \angle G(j\omega_g)H(j\omega_g)$$

Where $\omega_g \rightarrow$ gain cross over frequency = 1 rad/sec

So,
$$60^\circ = 180^\circ + \tan^{-1}\left(\frac{0.366\omega_g}{K}\right) - 90^\circ - \tan^{-1}(\omega_g)$$

$$= 90^\circ + \tan^{-1}\left(\frac{0.366}{K}\right) - \tan^{-1}(1)$$

$$= 90^\circ - 45^\circ + \tan^{-1}\left(\frac{0.366}{K}\right)$$

$$15^\circ = \tan^{-1}\left(\frac{0.366}{K}\right)$$

$$\frac{0.366}{K} = \tan 15^\circ$$

$$K = \frac{0.366}{0.267} = 1.366$$

**Sol. 54** Option (A) is correct.

Given state equation.

$$\dot{X}(t) = \begin{bmatrix} 0 & 1 \\ 0 & -3 \end{bmatrix} X(t) + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u(t)$$

Here $A = \begin{bmatrix} 0 & 1 \\ 0 & -3 \end{bmatrix}$, $B = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$

State transition matrix is given by,

$$\phi(t) = \mathcal{L}^{-1}[(sI - A)^{-1}]$$

$$[sI - A] = \begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix} - \begin{bmatrix} 0 & 1 \\ 0 & -3 \end{bmatrix} = \begin{bmatrix} s & -1 \\ 0 & s+3 \end{bmatrix}$$

$$[sI - A]^{-1} = \frac{1}{s(s+3)}\begin{bmatrix} s+3 & 1 \\ 0 & s \end{bmatrix} = \begin{bmatrix} \frac{1}{s} & \frac{1}{s(s+3)} \\ 0 & \frac{1}{(s+3)} \end{bmatrix}$$

$$\phi(t) = \mathcal{L}^{-1}[(sI - A)^{-1}]$$

$$= \begin{bmatrix} 1 & \frac{1}{3}(1 - e^{-3t}) \\ 0 & e^{-3t} \end{bmatrix}$$

**Sol. 55** Option (C) is correct.

State transition equation is given by

$$\boldsymbol{X}(s) = \mathbf{\Phi}(s)\boldsymbol{X}(0) + \mathbf{\Phi}(s)B\boldsymbol{U}(s)$$

Here $\mathbf{\Phi}(s)$ " state transition matrix

$$\mathbf{\Phi}(s) = \begin{bmatrix} \frac{1}{s} & \frac{1}{s(s+3)} \\ 0 & \frac{1}{(s+3)} \end{bmatrix}$$

$\boldsymbol{X}(0)$ " initial condition

$$\boldsymbol{X}(0) = \begin{bmatrix} -1 \\ 3 \end{bmatrix}$$

$$B = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

So

$$\boldsymbol{X}(s) = \begin{bmatrix} \frac{1}{s} & \frac{1}{s(s+3)} \\ 0 & \frac{1}{(s+3)} \end{bmatrix}\begin{bmatrix} -1 \\ 3 \end{bmatrix} + \begin{bmatrix} \frac{1}{s} & \frac{1}{(s+3)s} \\ 0 & \frac{1}{s+3} \end{bmatrix}\begin{bmatrix} 1 \\ 0 \end{bmatrix}\frac{1}{s}$$

$$= \begin{bmatrix} -\frac{1}{s} + \frac{3}{s(s+3)} \\ 0 + \frac{3}{s+3} \end{bmatrix} + \frac{1}{s}\begin{bmatrix} \frac{1}{s} \\ 0 \end{bmatrix} = \begin{bmatrix} -\frac{1}{s+3} \\ \frac{3}{s+3} \end{bmatrix} + \begin{bmatrix} \frac{1}{s^2} \\ 0 \end{bmatrix}$$

$$\boldsymbol{X}(s) = \begin{bmatrix} \frac{1}{s^2} - \frac{1}{s+3} \\ \frac{3}{s+3} \end{bmatrix}$$

Taking inverse Laplace transform, we get state transition equation as,

$$\boldsymbol{X}(t) = \begin{bmatrix} t - e^{-3t} \\ 3e^{-3t} \end{bmatrix}$$

**Sol. 56** Option () is correct

Phase margin of a system is the amount of additional phase lag required to bring the system to the point of instability or $(-1, j0)$

So here phase margin = 0c

**Sol. 57** Option (D) is correct.

Given transfer function is

$$F(s) = \frac{5}{s(s^2 + 3s + 2)}$$

$$F(s) = \frac{5}{s(s+1)(s+2)}$$

By partial fraction, we get

$$F(s) = \frac{5}{2s} - \frac{5}{s+1} + \frac{5}{2(s+2)}$$

Taking inverse Laplace of $F(s)$ we have

$$f(t) = \frac{5}{2}u(t) - 5e^{-t} + \frac{5}{2}e^{-2t}$$

So, the initial value of $f(t)$ is given by

$$\lim_{t \to 0} f(t) = \frac{5}{2} - 5 + \frac{5}{2}(1) = 0$$

Sol. 58 Option (C) is correct.

In A.C techo-meter output voltage is directly proportional to differentiation of rotor displacement.

$$e(t) \propto \frac{d}{dt}[\theta(t)]$$

$$e(t) = K_t \frac{d\theta(t)}{dt}$$

Taking Laplace tranformation on both sides of above equation

$$E(s) = K_t s\theta(s)$$

So transfer function

$$\text{T.F} = \frac{E(s)}{\theta(s)} = (K_t)s$$

Sol. 59 Option (B) is correct.

Given characteristic equation,

$$s^3 - 4s^2 + s + 6 = 0$$

Applying Routh's method,

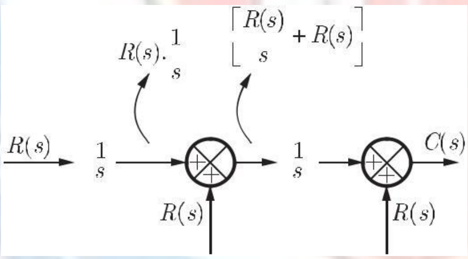
| | | |
|---|---|---|
| $s^3$ | 1 | 1 |
| $s^2$ | -4 | 6 |
| $s^1$ | $\frac{-4-6}{-4} = 2.5$ | 0 |
| $s^0$ | 6 | |

There are two sign changes in the first column, so no. of right half poles is 2.

No. of roots in left half of $s$-plane $= (3 - 2) = 1$

Sol. 60 Option (B) is correct.

Block diagram of the system is given as.




From the figure we can see that

$$C(s) = \left[R(s)\frac{1}{s} + R(s)\right]\frac{1}{s} + R(s)$$

$$C(s) = R(s)\left[\frac{1}{s^2} + \frac{1}{s} + 1\right]$$

$$\frac{C(s)}{R(s)} = \frac{1 + s + s^2}{s^2}$$

Sol. 61 Option (A) is correct.

Characteristic equation is given by,

$$|sI - A| = 0$$

$$(sI - A) = \begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix} - \begin{bmatrix} 0 & 2 \\ 2 & 0 \end{bmatrix} = \begin{bmatrix} s & -2 \\ -2 & s \end{bmatrix} = s^2 - 4 = 0$$

$$s_1, s_2 = \pm 2$$

Sol. 62 Option (D) is correct.

For the given system, characteristic equation can be written as,

$$1 + \frac{K}{s(s+2)}(1+sP) = 0$$

$$s(s+2) + K(1+sP) = 0$$

$$s^2 + s(2+KP) + K = 0$$

From the equation.

$$w_n \sqrt{\;\;} \text{ = 5 rad/sec (given)}$$

So, $K = 25$

and $2xw_n = 2 + KP$

$$2 \# 0.7 \# 5 = 2 + 25P$$

or $P = 0.2$

so $K = 25$, $P = 0.2$

Sol. 63 Option (D) is correct.

Unit - impulse response of the system is given as,

$$c(t) = 12.5e^{-6t} \sin 8t\ ,\ t \$ 0$$

So transfer function of the system.

$$H(s) = L[c(t)] = \frac{12.5 \# 8}{(s+6)^2 + (8)^2}$$

$$H(s) = \frac{100}{s^2 + 12s + 100}$$

Steady state value of output for unit step input,

$$\lim_{t "3} y(t) = \lim_{s " 0} sY(s) = \lim_{s " 0} sH(s)R(s)$$

$$= \lim_{s "0} s \left[\frac{100}{s^2 + 12s + 100}\right] \frac{1}{s} = 1.0$$

Sol. 64 Option (A) is correct.

System response is.

$$H(s) = \frac{s}{s+1}$$

$$H(jw) = \frac{jw}{jw+1}$$

Amplitude response

$$|H(jw)| = \frac{w}{\sqrt{\;\;}}$$

Given input frequency w = 1 rad/sec.

So $|H(jw)|_{w = 1\ \text{rad/sec}} = \frac{1}{\sqrt{\;\;}} = \frac{1}{\sqrt{2}}$

Phase response

$$q_h(w) = 90c - \tan^{-1}(w)$$

$$q_h(w)\big|_{w=1} = 90c - \tan^{-1}(1) = 45c$$

So the output of the system is

$$y(t) = |H(jw)|\, x(t - q_h) = \frac{1}{\sqrt{\;}} \sin(t - 45c)$$

Sol. 65 Option (C) is correct.

Given open loop transfer function

$$G(jw) = \frac{jaw + 1}{(jw)^2}$$

Gain crossover frequency ($\omega_g$) for the system.

$$|G(j\omega_g)| = 1$$

$$\frac{\sqrt{a^2\omega_g^2+1}}{\omega_g^2} = 1$$

$$a^2\omega_g^2 + 1 = \omega_g^4$$

$$\omega_g^4 - a^2\omega_g^2 - 1 = 0 \qquad \text{...(1)}$$

Phase margin of the system is

$$\phi_{PM} = 45^\circ = 180^\circ + \angle G(j\omega_g)$$

$$45^\circ = 180^\circ + \tan^{-1}(\omega_g a) - 180^\circ$$

$$\tan^{-1}(\omega_g a) = 45^\circ$$

$$\omega_g a = 1 \qquad (2)$$

From equation (1) and (2)

$$\frac{1}{a^4} - 1 - 1 = 0$$

$$a^4 = \frac{1}{2} \;\&\; a = 0.841$$

Sol. 66 Option (C) is correct.

Given system equation is.

$$\frac{d^2x}{dt^2} + 6\frac{dx}{dt} + 5x = 12(1 - e^{-2t})$$

Taking Laplace transform on both side.

$$s^2X(s) + 6sX(s) + 5X(s) = 12\left(\frac{1}{s} - \frac{1}{s+2}\right)$$

$$(s^2 + 6s + 5)X(s) = 12\left(\frac{2}{s(s+2)}\right)$$

System transfer function is

$$X(s) = \frac{24}{s(s+2)(s+5)(s+1)}$$

Response of the system as $t \to \infty$ is given by

$$\lim_{t\to\infty} f(t) = \lim_{s\to 0} sF(s) \qquad \text{(final value theorem)}$$

$$= \lim_{s\to 0} s\left[\frac{24}{s(s+2)(s+5)(s+1)}\right]$$

$$= \frac{24}{2\times 5} = 2.4$$

Sol. 67 Option (A) is correct.

Transfer function of lead compensator is given by.

$$H(s) = \frac{K\left(1 + \frac{s}{a}\right)}{\left(1 + \frac{s}{b}\right)}$$

$$H(j\omega) = K\left[\frac{1 + j\frac{\omega}{a}}{1 + j\frac{\omega}{b}}\right]$$

So, phase response of the compensator is.

$$\theta_h(\omega) = \tan^{-1}\left(\frac{\omega}{a}\right) - \tan^{-1}\left(\frac{\omega}{b}\right)$$

$$= \tan^{-1}\left[\frac{\frac{\omega}{a} - \frac{\omega}{b}}{1 + \frac{\omega^2}{ab}}\right] = \tan^{-1}\left[\frac{\omega(b-a)}{ab + \omega^2}\right]$$

$q_h$ should be positive for phase lead compensation

So,
$$q_h(\omega) = \tan^{-1}\left[\frac{\omega(b-a)}{ab+\omega^2}\right] > 0$$
$$b > a$$

**Sol. 68** Option (A) is correct.

Since there is no external input, so state is given by

$$\boldsymbol{X}(t) = \boldsymbol{\phi}(t)\boldsymbol{X}(0)$$

$\boldsymbol{\phi}(t)$ "state transition matrix

$\boldsymbol{X}[0]$ "initial condition

So
$$x(t) = \begin{bmatrix} e^{-2t} & 0 \\ 0 & e^{-t} \end{bmatrix} \begin{bmatrix} 2 \\ 3 \end{bmatrix}$$

$$x(t) = \begin{bmatrix} 2e^{-2t} \\ 3e^{-t} \end{bmatrix}$$

At $t = 1$, state of the system

$$x(t)\Big|_{t=1} = \begin{bmatrix} 2e^{-2} \\ 2e^{-1} \end{bmatrix} = \begin{bmatrix} 0.271 \\ 1.100 \end{bmatrix}$$

**Sol. 69** Option (B) is correct.

Given equation

$$\frac{d^2x}{dt^2} + \frac{1}{2}\frac{dx}{dt} + \frac{1}{18}x = 10 + 5e^{-4t} + 2e^{-5t}$$

Taking Laplace on both sides we have

$$s^2X(s) + \frac{1}{2}sX(s) + \frac{1}{18}X(s) = \frac{10}{s} + \frac{5}{s+4} + \frac{2}{s+5}$$

$$\left(s^2 + \frac{1}{2}s + \frac{1}{18}\right)X(s) = \frac{10(s+4)(s+5) + 5s(s+5) + 2s(s+4)}{s(s+4)(s+5)}$$

System response is,

$$X(s) = \frac{10(s+4)(s+5) + 5s(s+5) + 2s(s+4)}{s(s+4)(s+5)\left(s^2 + \frac{1}{2}s + \frac{1}{18}\right)}$$

$$= \frac{10(s+4)(s+5) + 5s(s+5) + 2s(s+4)}{s(s+4)(s+5)\left(s + \frac{1}{3}\right)\left(s + \frac{1}{6}\right)}$$

We know that for a system having many poles, nearness of the poles towards imaginary axis in $s$ -plane dominates the nature of time response. So here time constant given by two poles which are nearest to imaginary axis. Poles nearest to imaginary axis

$$s_1 = -\frac{1}{3},\ s_2 = -\frac{1}{6}$$

So, time constants
$$\tau_1 = 3 \text{ sec}$$
$$\tau_2 = 6 \text{ sec}$$

Sol. 70 Option (A) is correct.

Steady state error for a system is given by

$$e_{ss} = \lim_{s \to 0} \frac{sR(s)}{1 + G(s)H(s)}$$

Where input $R(s) = \frac{1}{s}$ (unit step)

$$G(s) = \left(\frac{3}{s+15}\right)\left(\frac{15}{s+1}\right)$$

$$H(s) = 1 \quad \text{(unity feedback)}$$

So

$$e_{ss} = \lim_{s \to 0} \frac{s\left(\frac{1}{s}\right)}{1 + \frac{45}{(s+15)(s+1)}} = \frac{15}{15+45} = \frac{15}{60}$$

$$\%e_{ss} = \frac{15}{60} \times 100 = 25\%$$

Sol. 71 Option (C) is correct.

Characteristic equation is given by

$$1 + G(s)H(s) = 0$$

Here

$$H(s) = 1 \quad \text{(unity feedback)}$$

$$G(s) = \left(\frac{3}{s+15}\right)\left(\frac{15}{s+1}\right)$$

So,

$$1 + \left(\frac{3}{s+15}\right)\left(\frac{15}{s+1}\right) = 0$$

$$(s+15)(s+1) + 45 = 0$$

$$s^2 + 16s + 60 = 0$$

$$(s+6)(s+10) = 0$$

$$s = -6, -10$$

Sol. 72 Option (A) is correct.

Given equation can be written as,

$$\frac{d^2\omega}{dt^2} = -\frac{B}{J}\frac{d\omega}{dt} - \frac{K^2}{LJ}\omega + \frac{K}{LJ}V_a$$

Here state variables are defined as,

$$\frac{d\omega}{dt} = x_1$$

$$\omega = x_2$$

So state equation is

$$\dot{x}_1 = -\frac{B}{J}x_1 - \frac{K^2}{LJ}x_2 + \frac{K}{LJ}V_a$$

$$\dot{x}_2 = \frac{d\omega}{dt} = x_1$$

In matrix form

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -B/J & -K^2/LJ \\ 1 & 0 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} K/LJ \\ 0 \end{bmatrix}V_a$$

$$\begin{bmatrix} \frac{d^2\omega}{dt^2} \\ \frac{d\omega}{dt} \end{bmatrix} = P\begin{bmatrix} \frac{d\omega}{dt} \\ \omega \end{bmatrix} + QV_a$$

So matrix P is

$$-B/J \quad -K^2/LJ$$

$$> 1 \qquad 0 \quad H$$

**Sol. 73** Option (C) is correct.

Characteristic equation of the system is given by

$$1 + GH = 0$$

$$1 + \frac{K}{s(s+2)(s+4)} = 0$$

$$s(s+2)(s+4) + K = 0$$

$$s^3 + 6s^2 + 8s + K = 0$$

Applying routh's criteria for stability

| | | |
|---|---|---|
| $s^3$ | 1 | 8 |
| $s^2$ | 6 | K |
| $s^1$ | $\frac{K-48}{6}$ | |
| $s^0$ | K | |

System becomes unstable if $\frac{K-48}{6} = 0$ & $K = 48$

**Sol. 74** Option (A) is correct.

The maximum error between the exact and asymptotic plot occurs at corner frequency.

Here exact gain(dB) at $\omega = 0.5a$ is given by

$$\text{gain(dB)}\Big|_{\omega=0.5a} = 20\log K - 20\log\sqrt{1+\frac{(0.5a)^2}{a^2}}$$

$$= 20\log K - 20\log\left[1+\frac{(0.5a)^2}{a^2}\right]^{1/2}$$

$$= 20\log K - 0.96$$

Gain(dB) calculated from asymptotic plot at $\omega = 0.5a$ is

$$= 20\log K$$

Error in gain (dB) $= 20\log K - (20\log K - 0.96)$ dB $= 0.96$ dB

Similarly exact phase angle at $\omega = 0.5a$ is.

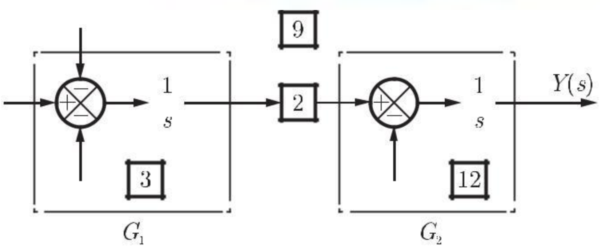
$$\theta_h(\omega)\Big|_{\omega=0.5a} = -\tan^{-1}\left(\frac{\omega}{a}\right) = -\tan^{-1}\left(\frac{0.5a}{a}\right) = -26.56^\circ$$

Phase angle calculated from asymptotic plot at ($\omega = 0.5a$) is $-22.5^\circ$

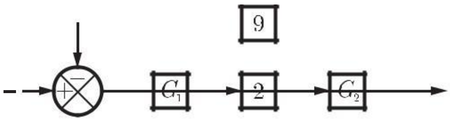
Error in phase angle $= -22.5 - (-26.56^\circ) = 4.9^\circ$

**Sol. 75** Option (B) is correct.

Given block diagram



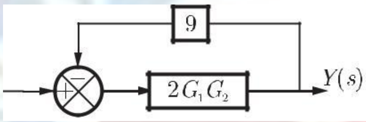

Given block diagram can be reduced as




Where $G_1 = \dfrac{\left(\frac{1}{s}\right)}{1 + \left(\frac{1}{s}\right)3} = \dfrac{1}{s+3}$

$$G_2 = \frac{\left(\frac{1}{s}\right)}{1 + \left(\frac{1}{s}\right)12} = \frac{1}{s+12}$$

Further reducing the block diagram.




$$Y(s) = \frac{2G_1 G_2}{1 + (2G_1 G_2)9}$$

$$= \frac{(2)\left(\frac{1}{s+3}\right)\left(\frac{1}{s+12}\right)}{1 + (2)\left(\frac{1}{s+3}\right)\left(\frac{1}{s+12}\right)(9)}$$

$$= \frac{2}{(s+3)(s+12)+18} = \frac{2}{s^2 + 15s + 54}$$

$$= \frac{2}{(s+9)(s+6)} = \frac{1}{27\left(1 + \frac{s}{9}\right)\left(1 + \frac{s}{6}\right)}$$

# ELECTRICAL & ELECTRONIC MEASUREMENTS

One of the most frequent tasks that an Engineer involved in the design, commissioning, testing, purchasing, operation or maintenance related to industrial processes, is to interpret manufacturer's specifications for their own purpose. It is therefore of paramount importance that one understands the basic form of an instrument specification and at least the generic elements in it that appear in almost all instrument specifications.

Different blocks of a measurement system have been discussed in lesson-2. The combined performance of all the blocks is described in the specifications. Specifications of an instrument are provided by different manufacturers in different wrap and quoting different terms, which sometimes may cause confusion. Moreover, there are several application specific issues. Still, broadly speaking, these specifications can be classified into three categories: (i) *static characteristics*, (b) *dynamic characteristics* and (iii) *random characteristics*

## Static Characteristics

Static characteristics refer to the characteristics of the system when the input is either held constant or varying very slowly. The items that can be classified under the heading static characteristics are mainly:

## Range (or span)

It defines the maximum and minimum values of the inputs or the outputs for which the instrument is recommended to use. For example, for a temperature measuring instrument the input range may be 100-500 $^{o}$C and the output range may be 4-20 mA.

## Sensitivity

It can be defined as the ratio of the *incremental output* and the *incremental input*. While defining the sensitivity, we assume that the input-output characteristic of the instrument is approximately linear in that range. Thus if the sensitivity of a thermocouple is denoted as 10 $\mu V / {}^{0}C$ , it indicates the sensitivity in the linear range of the thermocouple voltage vs. temperature characteristics. Similarly sensitivity of a spring balance can be expressed as 25 mm/kg (say), indicating additional load of 1 kg will cause additional displacement of the spring by 25mm.

Again sensitivity of an instrument may also vary with temperature or other external factors. This is known as *sensitivity drift*. Suppose the sensitivity of the spring balance mentioned above is 25 mm/kg at 20 $^{o}$C and 27 mm/kg at 30$^{o}$C. Then the sensitivity drift/$^{o}$C is 0.2 (mm/kg)/$^{o}$C. In order to avoid such sensitivity drift, sophisticated instruments are either kept at controlled temperature, or suitable in-built temperature compensation schemes are provided inside the instrument.

## Linearity

Linearity is actually a measure of nonlinearity of the instrument. When we talk about sensitivity, we assume that the input/output characteristic of the instrument to be approximately linear. But in practice, it is normally nonlinear, as shown in Fig.1. The *linearity* is defined as the maximum deviation from the linear characteristics as a percentage of the full scale output. Thus,

$$Linearity = \frac{O}{O_{max} - O_{min}} \qquad (1)$$

where, $O = \max(O_1, O_2)$.

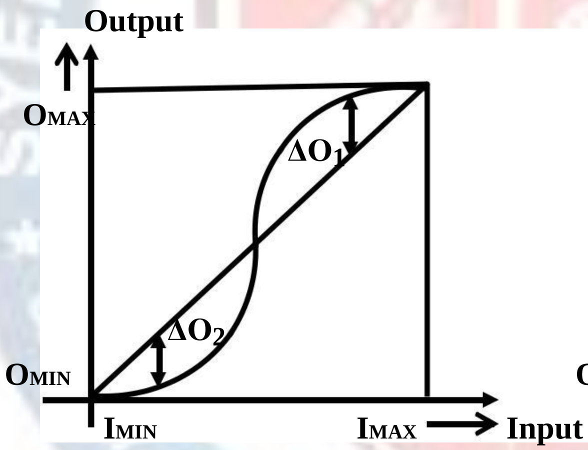



**Fig. 1 Linearity**

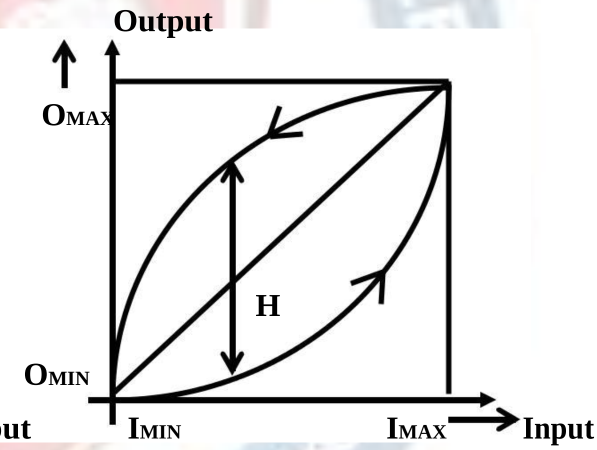



**Fig. 2 Hysteresis**

## Hysteresis

Hysteresis exists not only in magnetic circuits, but in instruments also. For example, the deflection of a diaphragm type pressure gage may be different for the same pressure, but one for increasing and other for decreasing, as shown in Fig.2. The *hysteresis* is expressed as the maximum hysteresis as a full scale reading, i.e., referring fig.2,

$$Hysteresis = \frac{H}{O_{max} - O_{min}} X100. \qquad (2)$$

## Resolution

In some instruments, the output increases in discrete steps, for continuous increase in the input, as shown in Fig.3. It may be because of the finite graduations in the meter scale; or the instrument has a digital display, as a result the output indication changes discretely. A $3\frac{1}{2}$ - digit voltmeter, operating in 0-2V range, can have maximum reading of 1.999V, and it cannot measure any change in voltage below 0.001V. *Resolution* indicates the minimum change in input variable that is detectable. For example, an eight-bit A/D converter with +5*V* input can measure

the minimum voltage of $\frac{5}{2^8 - 1}$ or 19.6 *mv*. Referring to fig.3, *resolution* is also defined in terms of percentage as:

$$Resolution = \frac{I}{I_{max} - I_{min}} X100 \qquad (3)$$

The quotient between the measuring range and resolution is often expressed as *dynamic range* and is defined as:

$$\text{Dynamic range} = \frac{measurement\ range}{resolution} \qquad (4)$$

And is expressed in terms of dB. The dynamic range of an *n*-bit ADC, comes out to be approximately 6*n* dB.

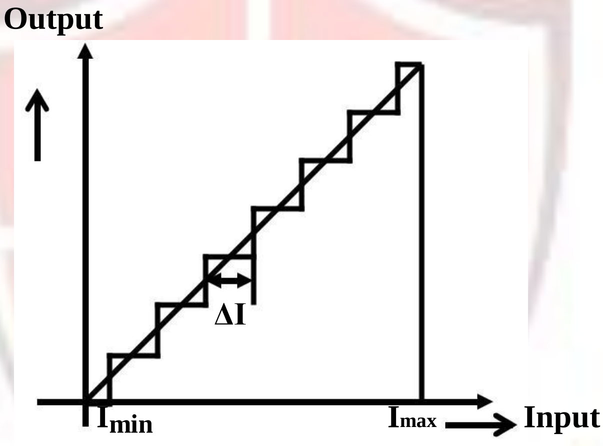



**Fig. 3 Resolution**

## Accuracy

Accuracy indicates the closeness of the measured value with the actual or true value, and is expressed in the form of the *maximum error (= measured value – true value)* as a percentage of full scale reading. Thus, if the accuracy of a temperature indicator, with a full scale range of 0-500 $^{o}$C is specified as ± 0.5%, it indicates that the measured value will always be within ± 2.5 $^{o}$C of the true value, if measured through a standard instrument during the process of calibration. But if it indicates a reading of 250 $^{o}$C, the error will also be ± 2.5 $^{o}$C, i.e. ± 1% of the reading. Thus it is always better to choose a scale of measurement where the input is near full-scale value. But the true value is always difficult to get. We use standard calibrated instruments in the laboratory for measuring true value if the variable.

## Precision

Precision indicates the repeatability or reproducibility of an instrument (but does not indicate accuracy). If an instrument is used to measure the same input, but at different instants, spread

over the whole day, successive measurements may vary randomly. The random fluctuations of readings, (mostly with a Gaussian distribution) is often due to random variations of several other factors which have not been taken into account, while measuring the variable. A precision instrument indicates that the successive reading would be very close, or in other words, the standard deviation $\sigma_e$ of the set of measurements would be very small. Quantitatively, the
precision can be expressed as:

$$Precision = \frac{measured\ range}{\sigma_e} \tag{5}$$

The difference between precision and accuracy needs to be understood carefully. Precision means repetition of successive readings, but it does not guarantee accuracy; successive readings may be close to each other, but far from the true value. On the other hand, an accurate instrument has to be precise also, since successive readings must be close to the true value (that is unique).

## Dynamic Characteristics

Dynamic characteristics refer to the performance of the instrument when the input variable is changing rapidly with time. For example, human eye cannot detect any event whose duration is more than one-tenth of a second; thus the dynamic performance of human eye cannot be said to be very satisfactory. The dynamic performance of an instrument is normally expressed by a differential equation relating the input and output quantities. It is always convenient to express the input-output dynamic characteristics in form of a linear differential equation. So, often a nonlinear mathematical model is linearised and expressed in the form:

$$a_n \frac{d^n x_0}{dt^n} + a_{n-1} \frac{d^{n-1} x_0}{dt^{n-1}} + \cdots + a_1 \frac{dx_0}{dt} + a_0 x_0 = b_m \frac{d^m x_i}{dt^m} + b_{m-1} \frac{d^{m-1} x_i}{dt^{m-1}} + \cdots + b_1 \frac{dx_i}{dt} + b_0 x_i \tag{6}$$

where $x_i$ and $x_0$ are the input and the output variables respectively. The above expression can also be expressed in terms of a transfer function, as:

$$G(s) = \frac{x_0(s)}{x_i(s)} = \frac{b_m s^m + b_{m-1} s^{m-1} \cdots + b_1 s + b_0}{a_n s^n + b_{n-1} s^{n-1} \cdots + a_1 s + a_0} \tag{7}$$

Normally $m<n$ an $n$ is called the order of the system. Commonly available sensor characteristics can usually be approximated as either *zero-th order*, *first order* or *second order* dynamics. Here are few such examples:

## Potentiometer

Displacement sensors using potentiometric principle (Fig.4) have no energy storing elements. The output voltage $e_o$ can be related with the input displacement $x_i$ by an algebraic equation:

$$e_o(t)x_t = Ex_i(t); \;\; or, \;\; \frac{e_o(s)}{x_i(s)} = \frac{E}{x_t} = constant \tag{8}$$

where $x_t$ is the total length of the potentiometer and $E$ is the excitation voltage.. So, it can be termed as a *zeroth order system*.

## Thermocouple

A bare thermocouple (Fig.5) has a mass ($m$) of the junction. If it is immersed in a fluid at a temperature $T_f$ , then its dynamic performance relating the output voltage $e_o$ and the input temperature $T_f$ , can be expressed by the transfer function:

$$\frac{e_o(s)}{T_f(s)} = \frac{K_v}{1 + s\tau} \qquad (9)$$

where, $K_v$ = steady state voltage sensitivity of the thermocouple in V/ $^oC$.

(C) = time constant of the thermocouple = $\frac{mC}{hA}$

(M) = mass of the junction
$C$ = specific heat
$h$ = heat transfer co-efficient
$A$ = surface area of the hot junction.

Hence, the bare thermocouple is a first order sensor. But if the bare thermocouple is put inside a metallic protective well (as it is normally done for industrial thermocouples) the order of the system increases due to the additional energy storing element (thermal mass of the well) and it becomes a second order system.

## Seismic Sensor

Seismic sensors (Fig.6.) are commonly used for vibration or acceleration measurement of foundations. The transfer function between the input displacement $x_i$ and output displacement $x_o$ can be expressed as:

$$\frac{x_o(s)}{x_i(s)} = \frac{Ms^2}{Ms^2 + Bs + K} \qquad (10)$$

where: $M$ = mass of the seismic body
$B$ = damping constant
$K$= spring constant

From the above transfer function, it can be easily concluded that the seismic sensor is a *second order system*.

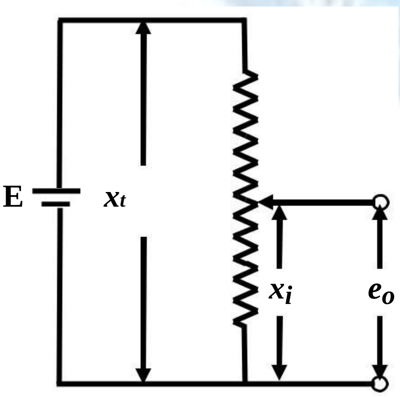


**Fig. 4 Potentiometer**

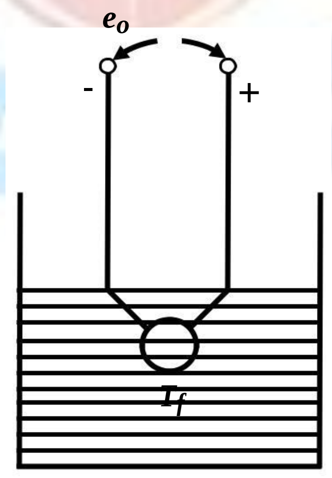


**Fig. 5 Thermocouple**

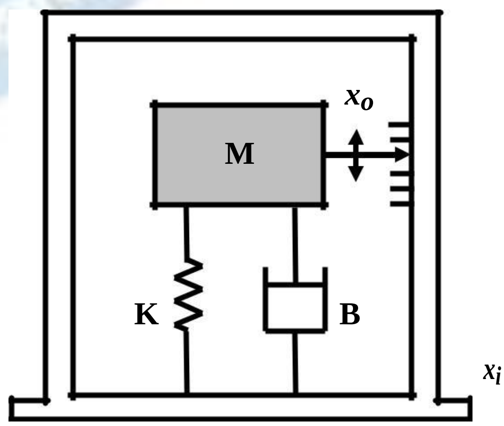
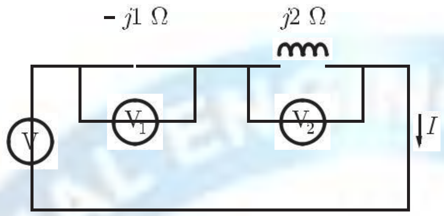


**Fig. 6 Seismic sensor**

## ELECTRICAL & ELECTRONIC MEASUREMENTS

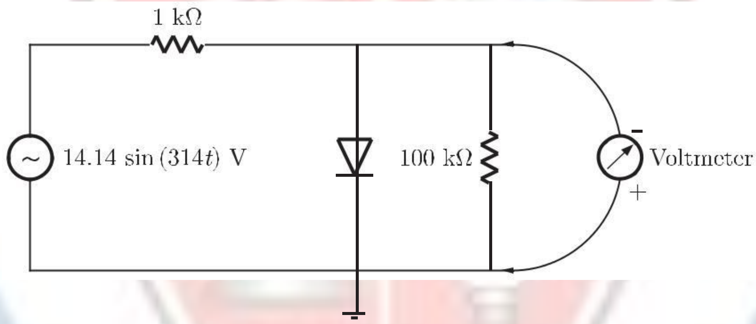
Q. 1 Three moving iron type voltmeters are connected as shown below. Voltmeter readings are $V$, $V_1$ and $V_2$ as indicated. The correct relation among the voltmeter readings is




(A) $V = \frac{V_1}{\sqrt{2}} + \frac{V_2}{\sqrt{2}}$ (B) $V = V_1 + V_2$

(C) $V = V_1 V_2$ (D) $V = V_2 - V_1$

Q. 2 The input impedance of the permanent magnet moving coil (PMMC) voltmeter is infinite. Assuming that the diode shown in the figure below is ideal, the reading of the voltmeter in Volts is




(A) 4.46 (B) 3.15

(C) 2.23 (D) 0

Q. 3 Two magnetically uncoupled inductive coils have $Q$ factors $q_1$ and $q_2$ at the chosen operating frequency. Their respective resistances are $R_1$ and $R_2$. When connected in series, their effective $Q$ factor at the same operating frequency is

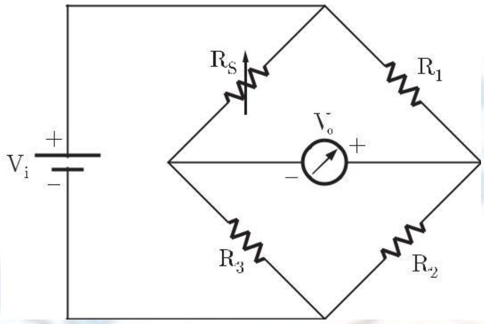
(A) $q_1 + q_2$

(B) $(1/q_1) + (1/q_2)$

(C) $(q_1 R_1 + q_2 R_2) / (R_1 + R_2)$

(D) $(q_1 R_2 + q_2 R_1) / (R_1 + R_2)$

Q. 4 A strain gauge forms one arm of the bridge shown in the figure below and has 5. nominal resistance without any load as $R_s$ = 300 W. Other bridge resistances are $R_1$ = $R_2$ = $R_3$ = 300 W. The maximum permissible current through the strain gauge is 20 mA. During certain measurement when the bridge is excited by maximum permissible voltage and the strain gauge resistance is increased by 1% over the nominal value, the output voltage $V_0$ in mV is



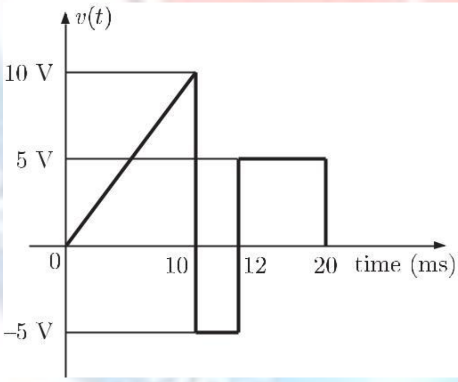

B. 56.02

C. 40.83

D. 29.85

E. 10.02

Q. 5 A periodic voltage waveform observed on an oscilloscope across a load is shown. A permanent magnet moving coil (PMMC) meter connected across the same load reads




D. 4 V

E. 5 V

F. 8 V

G. 10 V

Q. 6 The bridge method commonly used for finding mutual inductance is

(D) Heaviside Campbell bridge

(E) Schering bridge

(F) De Sauty bridge

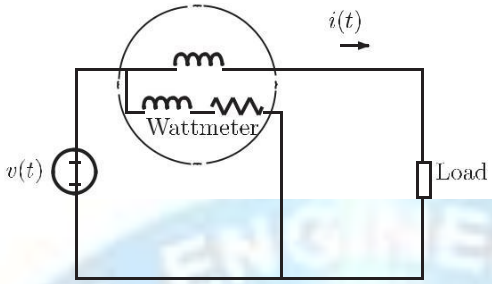
(G) Wien bridge

Q. 7 For the circuit shown in the figure, the voltage and current expressions are

$v(t) = E_1 \sin(wt) + E_3 \sin(3wt)$ and

$i(t) = I_1 \sin(wt - f_1) + I_3 \sin(3wt - f_3) + I_5 \sin(5wt)$

The average power measured by the wattmeter is




(A) $\frac{1}{2} E_1 I_1 \cos f_1$

(B) $\frac{1}{2} [E_1 I_1 \cos f_1 + E_1 I_3 \cos f_3 + E_1 I_5]$

(C) $\frac{1}{2} [E_1 I_1 \cos f_1 + E_3 I_3 \cos f_3]$

(D) $\frac{1}{2} [E_1 I_1 \cos f_1 + E_3 I_1 \cos f_1]$

Q. 8 An analog voltmeter uses external multiplier settings. With a multiplier setting of 20 kW, it reads 440 V and with a multiplier setting of 80 kW, it reads 352 V. For a multiplier setting of 40 kW, the voltmeter reads

(A) 371 V

(B) 383 V

(C) 394 V

(D) 406 V

Q. 9 A dual trace oscilloscope is set to operate in the ALTernate mode. The control input of the multiplexer used in the *y* -circuit is fed with a signal having a frequency equal to

(A) the highest frequency that the multiplexer can operate properly

(B) twice the frequency of the time base (sweep) oscillator

(C) the frequency of the time base (sweep) oscillator

(D) haif the frequency of the time base (sweep) oscillator

Consider the following statement

(1) The compensating coil of a low power factor wattmeter compensates the effect of the impedance of the current coil.

(2) The compensating coil of a low power factor wattmeter compensates the effect of the impedance of the voltage coil circuit.

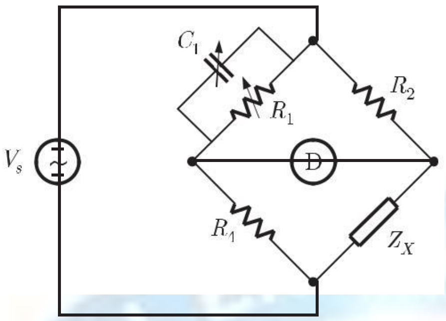
(A) (1) is true but (2) is false

(B) (1) is false but (2) is true

(C) both (1) and (2) are true

(D) both (1) and (2) are false

Q. 10 The bridge circuit shown in the figure below is used for the measurement of an unknown element $Z_X$ . The bridge circuit is best suited when $Z_X$ is a




(A) low resistance
(B) high resistance
(C) low $Q$ inductor
(D) lossy capacitor

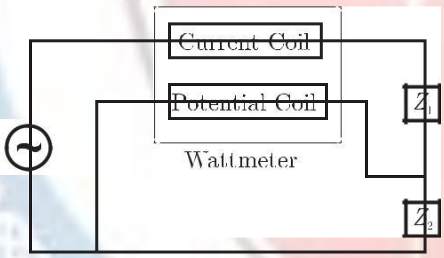
---

Q. 11 A $4\frac{1}{2}$ digit DMM has the error specification as: 0.2% of reading + 10 counts. If a dc voltage of 100 V is read on its 200 V full scale, the maximum error that can be expected in the reading is

(A) !0.1%
(B) !0.2%
(C) !0.3%
(D) !0.4%

---

Q. 12 A wattmeter is connected as shown in figure. The wattmeter reads.

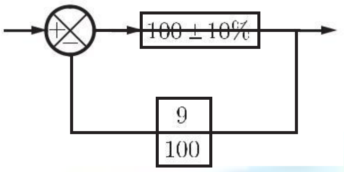



(A) Zero always
(B) Total power consumed by $Z_1$ and $Z_2$
(C) Power consumed by $Z_1$
(D) Power consumed by $Z_2$

Q. 13 An ammeter has a current range of 0-5 A, and its internal resistance is 0.2 W. In order to change the range to 0-25 A, we need to add a resistance of

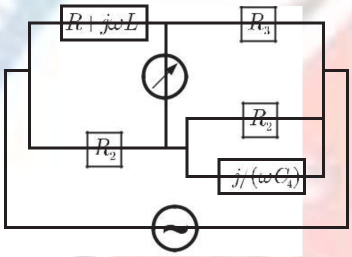
(A) 0.8 W in series with the meter
(B) 1.0 W in series with the meter
(C) 0.04 W in parallel with the meter
(D) 0.05 W in parallel with the meter

Q. 14 As shown in the figure, a negative feedback system has an amplifier of gain 100 with !10% tolerance in the forward path, and an attenuator of value 9/100 in the feedback path. The overall system gain is approximately :




(A) 10 ! 1%
(B) 10 ! 2%
(C) 10 ! 5%
(D) 10 ! 10%

Q. 15 The Maxwell's bridge shown in the figure is at balance. The parameters of the inductive coil are.



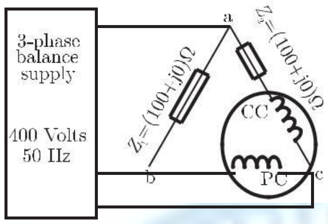

(A) $R = R_2 R_3 / R_4$, $L = C_4 R_2 R_3$
(B) $L = R_2 R_3 / R_4$, $R = C_4 R_2 R_3$
(C) $R = R_4 / R_2 R_3$, $L = 1/(C_4 R_2 R_3)$
(D) $L = R_4 / R_2 R_3$, $R = 1/(C_4 R_2 R_3)$

---

Q. 16 The pressure coil of a dynamometer type wattmeter is
(A) Highly inductive
(B) Highly resistive
(C) Purely resistive
(D) Purely inductive

Q. 17 The two inputs of a CRO are fed with two stationary periodic signals. In the X-Y mode, the screen shows a figure which changes from ellipse to circle and back to ellipse with its major axis changing orientation slowly and repeatedly. The following inference can be made from this.
(A) The signals are not sinusoidal
(B) The amplitudes of the signals are very close but not equal
(C) The signals are sinusoidal with their frequencies very close but not equal
(D) There is a constant but small phase difference between the signals

Q. 18 The figure shows a three-phase delta connected load supplied from a 400V, 50 Hz, 3-phase balanced source. The pressure coil (PC) and current coil (CC) of a wattmeter are connected to the load as shown, with the coil polarities suitably selected to ensure a positive deflection. The wattmeter reading will be




(A) 0
(B) 1600 Watt
(C) 800 Watt
(D) 400 Watt

Q. 19 An average-reading digital multi-meter reads 10 V when fed with a triangular wave, symmetric about the time-axis. For the same input an rms-reading meter will read

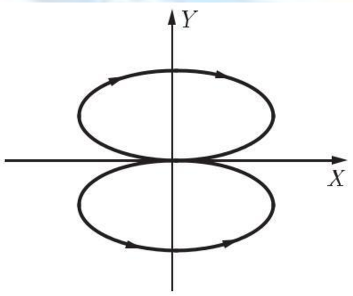
(A) $\frac{\sqrt{20}}{\sqrt{3}}$
(B) $\frac{\sqrt{10}}{\sqrt{3}}$
(C) 20 3
(D) 10 3

---

Q. 20 Two 8-bit ADCs, one of single slope integrating type and other of successive approximate type, take $T_A$ and $T_B$ times to convert 5 V analog input signal to equivalent digital output. If the input analog signal is reduced to 2.5 V, the approximate time taken by the two ADCs will respectively, be

(A) $T_A$, $T_B$
(B) $T_A/2$, $T_B$
(C) $T_A$, $T_B/2$
(D) $T_A/2$, $T_B/2$

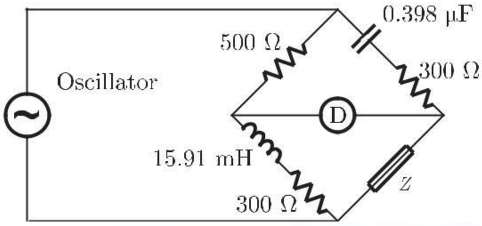
Q. 21 Two sinusoidal signals $p(w_1, t) = A \sin w_1 t$ and $q(w_2 t)$ are applied to X and Y inputs of a dual channel CRO. The Lissajous figure displayed on the screen shown below :
The signal $q(w_2 t)$ will be represented as




(A) $q(w_2 t) = A \sin w_2 t$, $w_2 = 2w_1$
(B) $q(w_2 t) = A \sin w_2 t$, $w_2 = w_1/2$
(C) $q(w_2 t) = A \cos w_2 t$, $w_2 = 2w_1$
(D) $q(w_2 t) = A \cos w_2 t$, $w_2 = w_1/2$

Q. 22

The ac bridge shown in the figure is used to measure the impedance $Z$ .



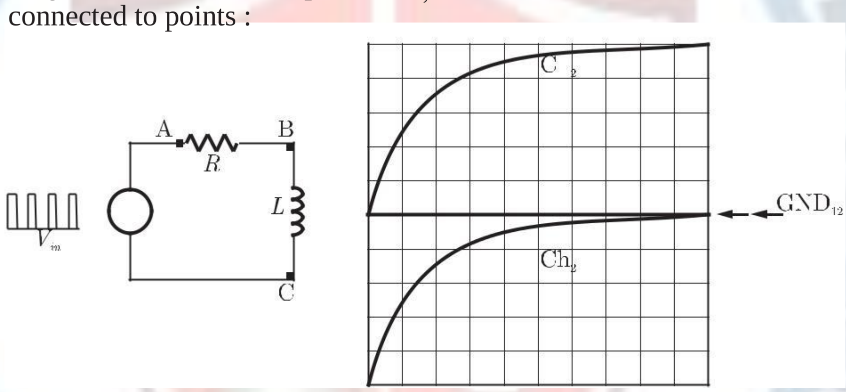

If the bridge is balanced for oscillator frequency $f$ = 2 kHz, then the impedance $Z$ will be

(A) (260 + $j$0) W (B) (0 + $j$200) W

(C) (260 - $j$200) W (D) (260 + $j$200) W

Q. 23

The probes of a non-isolated, two channel oscillocope are clipped to points A, B and C in the circuit of the adjacent figure. $V_{in}$ is a square wave of a suitable low frequency. The display on $Ch_1$ and $Ch_2$ are as shown on the right. Then the "Signal" and "Ground" probes $S_1$, $G_1$ and $S_2$, $G_2$ of $Ch_1$ and $Ch_2$ respectively are connected to points :




(A) A, B, C, A

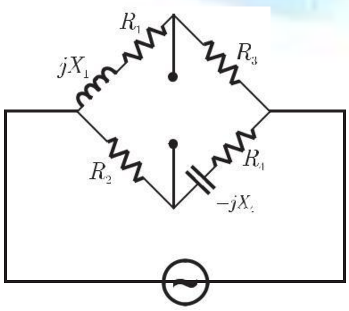
(B) A, B, C, B

(C) C, B, A, B

(D) B, A, B, C

Q. 24

A bridge circuit is shown in the figure below. Which one of the sequence given below is most suitable for balancing the bridge ?



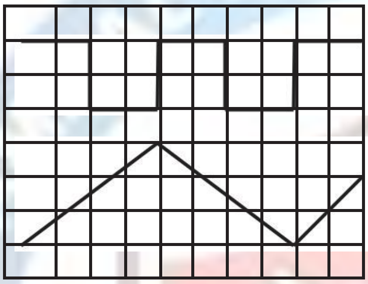
(A) First adjust $R_4$ , and then adjust $R_1$

(B) First adjust $R_2$, and then adjust $R_3$

(C) First adjust $R_2$, and then adjust $R_4$

(D) First adjust $R_4$ , and then adjust $R_2$

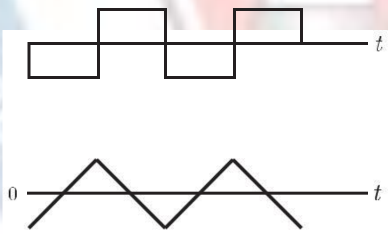
Q. 25 The time/div and voltage/div axes of an oscilloscope have been erased. A student connects a 1 kHz, 5 V p-p square wave calibration pulse to channel-1 of the scope and observes the screen to be as shown in the upper trace of the figure. An unknown signal is connected to channel-2(lower trace) of the scope. It the time/ div and V/div on both channels are the same, the amplitude (p-p) and period of the unknown signal are respectively



(N) 5 V, 1 ms  (H) 5 V, 2 ms

(E) 7.5 V, 2 ms  (E) 10 V, 1 ms

Q. 26 A sampling wattmeter (that computes power from simultaneously sampled values of voltage and current) is used to measure the average power of a load. The peak to peak voltage of the square wave is 10 V and the current is a triangular wave of 5 A p-p as shown in the figure. The period is 20 ms. The reading in W will be




(A) 0 W  (B) 25 W

(C) 50 W  (D) 100 W

Q. 27 A current of - 8 + 6 $\sqrt{2}$ (sin *wt* + 30%) A is passed through three meters. They are a centre zero PMMC meter, a true rms meter and a moving iron instrument. The respective reading (in A) will be

(A) 8, 6, 10  (B) 8, 6, 8

(C) -8,10,10  (D) -8,2,2

Q. 28 A variable $w$ is related to three other variables $x$ ,$y$ ,$z$ as $w = xy/z$ . The variables are measured with meters of accuracy !0.5% reading, !1% of full scale value and !1.5% reading. The actual readings of the three meters are 80, 20 and 50 with 100 being the full scale value for all three. The maximum uncertainty in the measurement of $w$ will be

(A) !0.5% rdg (B) !5.5% rdg

(C) !6.7 rdg (D) !7.0 rdg

Q. 29 A 200/1 Current transformer (CT) is wound with 200 turns on the secondary on a toroidal core. When it carries a current of 160 A on the primary, the ratio and phase errors of the CT are found to be -0.5% and 30 minutes respectively. If the number of secondary turns is reduced by 1 new ratio-error(%) and phase-error(min) will be respectively

(A) 0.0,30 (B) -0.5,35

(C) -1.0,30 (D) -1.0,25

Q. 30 $R_1$ and $R_4$ are the opposite arms of a Wheatstone bridge as are $R_3$ and $R_2$. The source voltage is applied across $R_1$ and $R_3$. Under balanced conditions which one of the following is true

(A) $R_1 = R_3 R_4 /R_2$ (B) $R_1 = R_2 R_3 /R_4$

(C) $R_1 = R_2 R_4 /R_3$ (D) $R_1 = R_2 + R_3 + R_4$

---

Q. 31 The Q-meter works on the principle of

(A) mutual inductance

(B) self inductance

(C) series resonance

(D) parallel resonance

Q. 32 A PMMC voltmeter is connected across a series combination of DC voltage source $V_1 = 2$ V and AC voltage source $V_2(t) = 3\sin(4t)$ V. The meter reads

(A) 2 V (B) 5 V

(C) (2 + 3 /2) V (D) ( 17 /2)$V$

Q. 33 A digital-to-analog converter with a full-scale output voltage of 3.5 V has a resolution close to 14 mV. Its bit size is

(A) 4 (B) 8

(C) 16 (D) 32

Q. 34 The simultaneous application of signals $x(t)$ and $y(t)$ to the horizontal and vertical plates, respectively, of an oscilloscope, produces a vertical figure-of-8 display. If P and Q are constants and $x(t)$ = P sin(4$t$ + 30c), then $y(t)$ is equal to

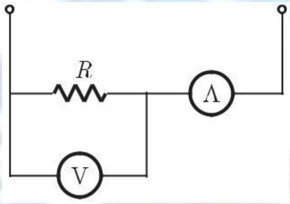
(A) Q sin(4$t$ - 30c) (B) Q sin(2$t$ + 15c)

(C) Q sin(8$t$ + 60c) (D) Q sin(4$t$ + 30c)

(E) 35 A DC ammeter has a resistance of 0.1 W and its current range is 0-100 A. If the range is to be extended to 0-500 A, then meter required the following shunt resistance

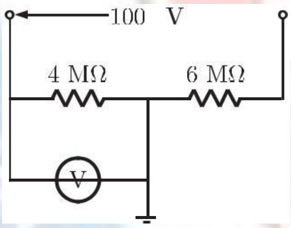
(A) 0.010 W
(B) 0.011 W
(C) 0.025 W
(D) 1.0 W

(E) 36 The set-up in the figure is used to measure resistance *R* .The ammeter and voltmeter resistances are 0.01W and 2000 W, respectively. Their readings are 2 A and 180 V, respectively, giving a measured resistances of 90 W The percentage error in the measurement is




(A) 2.25%
(B) 2.35%
(C) 4.5%
(D) 4.71%

Q. 37 A 1000 V DC supply has two 1-core cables as its positive and negative leads : their insulation resistances to earth are 4 MW and 6 MW, respectively, as shown in the figure. A voltmeter with resistance 50 kW is used to measure the insulation of the cable. When connected between the positive core and earth, then voltmeter reads




(A) 8 V
(B) 16 V
(C) 24 V
(D) 40 V

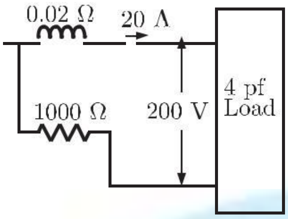
Q. 38 Two wattmeters, which are connected to measure the total power on a three-phase system supplying a balanced load, read 10.5 kW and -2.5 kW, respectively. The total power and the power factor, respectively, are

(A) 13.0 kW, 0.334
(B) 13.0 kW, 0.684
(C) 8.0 kW, 0.52
(D) 8.0 kW, 0.334

Q. 39 A dc potentiometer is designed to measure up to about 2 V with a slide wire of 800 mm. A standard cell of emf 1.18 V obtains balance at 600 mm. A test cell is seen to obtain balance at 680 mm. The emf of the test cell is

(A) 1.00 V
(B) 1.34 V
(C) 1.50 V
(D) 1.70 V

Q. 40 The circuit in figure is used to measure the power consumed by the load. The current coil and the voltage coil of the wattmeter have 0.02 W and 1000W resistances respectively. The measured power compared to the load power will be

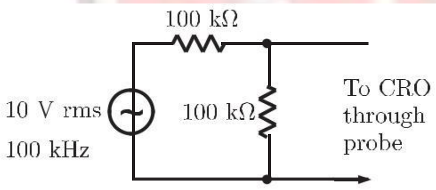



(A) 0.4 % less | (B) 0.2% less
(C) 0.2% more | (D) 0.4% more

Q. 41 A galvanometer with a full scale current of 10 mA has a resistance of 1000 W. The multiplying power (the ratio of measured current to galvanometer current) of 100 W shunt with this galvanometer is

(A) 110 | (B) 100
(C) 11 | (D) 10

Q. 42 A CRO probe has an impedance of 500 kW in parallel with a capacitance of 10 pF. The probe is used to measure the voltage between P and Q as shown in figure. The measured voltage will be




(A) 3.53 V | (B) 4.37 V
(C) 4.54 V | (D) 5.00 V

(E) 43 A moving coil of a meter has 100 turns, and a length and depth of 10 mm and 20 (F) respectively. It is positioned in a uniform radial flux density of 200 mT. The coil carries a current of 50 mA. The torque on the coil is

(A) 200 *m*Nm | (B) 100 *m*Nm
(C) 2 *m*Nm | (D) 1 *m*Nm

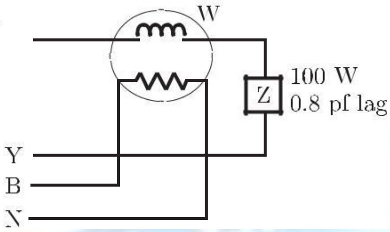
E 44 A dc A-h meter is rated for 15 A, 250 V. The meter constant is 14.4 A-sec/rev. The meter constant at rated voltage may be expressed as

(A) 3750 rev/kWh | (B) 3600 rev/kWh
(C) 1000 rev/kWh | (D) 960 rev/kWh

(F) 45 A moving iron ammeter produces a full scale torque of 240 *m*Nm with a deflection of 120c at a current of 10 A . The rate of change of self induction (*m*H/radian) of the instrument at full scale is

(A) 2.0 *m*H/radian | (B) 4.8 *m*H/radian
(C) 12.0 *m*H/radian | (D) 114.6 *m*H/radian

Q. 46 A single-phase load is connected between R and Y terminals of a 415 V, symmetrical, 3-phase, 4-wire system with phase sequence RYB. A wattmeter is connected in the system as shown in figure. The power factor of the load is 0.8 lagging. The wattmeter will read




(A) -795 W (B) -597 W

(C) +597 W (D) +795 W

B 47 A 50 Hz, bar primary CT has a secondary with 500 turns. The secondary supplies 5 A current into a purely resistive burden of 1 W. The magnetizing ampere-turns is 200. The phase angle between the primary and second current is

(A) 4.6c (B) 85.4c

(C) 94.6c (D) 175.4c

S. 48 The core flux in the CT of Prob Q.44, under the given operating conditions is

(A) 0 (B) 45.0 *m*Wb

(C) 22.5 mWb (D) 100.0 mWb

consisting of a milli-ammeter and a suitable shunt in order to

(A) minimise the effect of temperature variation

(B) obtain large deflecting torque

(C) reduce the size of the meter

(D) minimise the effect of stray magnetic fields

Q. 50 The effect of stray magnetic field on the actuating torque of a portable instrument is maximum when the operating field of the instrument and the stray fields are

(A) perpendicular

(B) parallel

(C) inclined at 60%

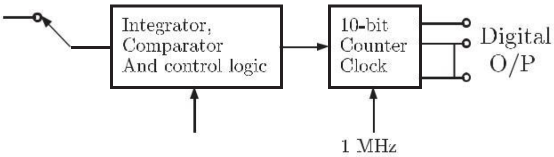
(D) inclined at 30%

Q. 51 A reading of 120 is obtained when standard inductor was connected in the circuit of a Q-meter and the variable capacitor is adjusted to value of 300 pF. A lossless capacitor of unknown value $C_x$ is then connected in parallel with the variable capacitor and the same reading was obtained when the variable capacitor is readjusted to a value of 200 pF. The value of $C_x$ in pF is

(A) 100 (B) 200

(C) 300 (D) 500

Q. 52 The simplified block diagram of a 10-bit A/D converter of dual slope integrator type is shown in figure. The 10-bit counter at the output is clocked by a 1 MHz clock. Assuming negligible timing overhead for the control logic, the maximum frequency of the analog signal that can be converted using this A/D converter is approximately




(A) 2 kHz
(B) 1 kHz
(C) 500 Hz
(D) 250 Hz

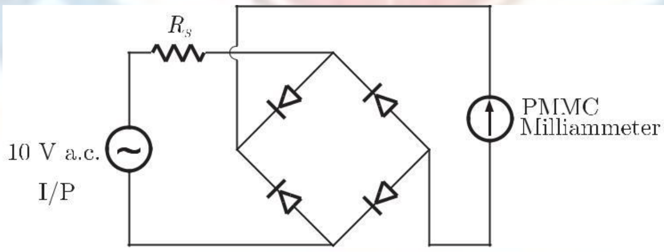
Q. 53 The items in Group-I represent the various types of measurements to be made with a reasonable accuracy using a suitable bridge. The items in Group-II represent the various bridges available for this purpose. Select the correct choice of the item in Group-II for the corresponding item in Group-I from the following

| | List-I | | List-II |
|---|---|---|---|
| **P.** | Resistance in the milli-ohm range | **1.** | Wheatstone Bridge |
| **Q.** | Low values of Capacitance | **2.** | Kelvin Double Bridge |
| **(C)** | Comparison of resistance which are nearly equal | **3.** | Schering Bridge |
| **S.** | Inductance of a coil with a large time-constant | **4.** | Wien's Bridge |
| | | **5.** | Hay's Bridge |
| | | **6.** | Carey-Foster Bridge |

**Codes :**

(A) P=2, Q=3, R=6, S=5
(B) P=2, Q=6, R=4, S=5
(C) P=2, Q= 3, R=5, S=4
(D) P=1, Q=3, R=2, S=6

Q. 54 A rectifier type ac voltmeter of a series resistance $R_S$ , an ideal full-wave rectifier bridge and a PMMC instrument as shown in figure. The internal. resistance of the instrument is 100 W and a full scale deflection is produced by a dc current of 1 mA. The value of $R_S$ required to obtain full scale deflection with an ac voltage of 100 V (rms) applied to the input terminals is




(A) 63.56 W
(B) 69.93 W
(C) 89.93 W
(D) 141.3 kW

Q. 55 A wattmeter reads 400 W when its current coil is connected in the R-phase and its pressure coil is connected between this phase and the neutral of a symmetrical 3-phase system supplying a balanced star connected 0.8 p.f. inductive load. This phase sequence is RYB. What will be the reading of this wattmeter if its pressure coil alone is reconnected between the B and Y phases, all other connections remaining as before ?

(A) 400.0 (B) 519.6

(C) 300.0 (D) 692.8

Q. 56 The inductance of a certain moving-iron ammeter is expressed as $L = 10 + 3q - (q^2/4)\ mH$, where $q$ is the deflection in radians from the zero position. The control spring torque is 25 # $10^{-6}$ Nm/radian. The deflection of the pointer in radian when the meter carries a current of 5 A, is

(A) 2.4 (B) 2.0

(C) 1.2 (D) 1.0

Q. 57 A 500A/5A, 50 Hz transformer has a bar primary. The secondary burden is a pure resistance of 1 W and it draws a current of 5 A. If the magnetic core requires 250 AT for magnetization, the percentage ratio error is

(A) 10.56 (B) -10.56

(C) 11.80 (D) -11.80

Q. 58 The voltage-flux adjustment of a certain 1-phase 220 V induction watt-hour meter is altered so that the phase angle between the applied voltage and the flux due to it is 85c(instead of 90c). The errors introduced in the reading of this meter when the current is 5 A at power factor of unity and 0.5 lagging are respectively

(A) 3.8 mW, 77.4 mW (B) -3.8 mW, -77.4 mW

(C) -4.2 W, -85.1 W (D) 4.2 W, 85.1 W

Q. 59 Group-II represents the figures obtained on a CRO screen when the voltage signals $V_x = V_{xm} \sin wt$ and $V_y = V_{ym} \sin(wt + F)$ are given to its X and Y plates respectively and F is changed. Choose the correct value of F from Group-I to match with the corresponding figure of Group-II. Group-II

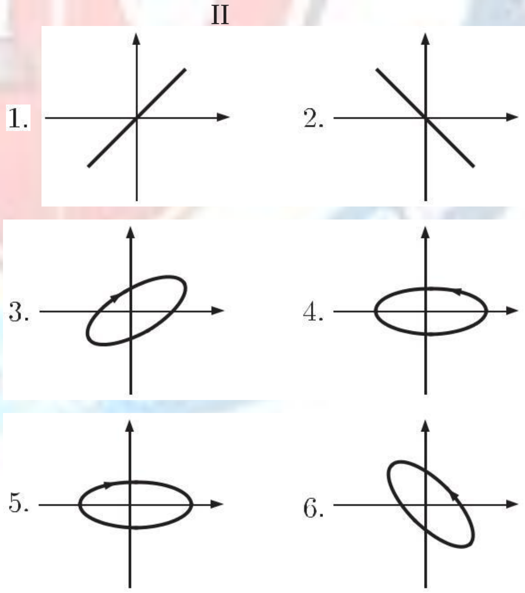
Group-I

P. F = 0

Q. F = $p/2$

R. $p$ < F < $3p/2$

S. F = $3p/2$




**Codes :**

(A) P=1, Q= 3, R=6, S=5 (B) P=2, Q= 6, R=4, S=5

(C) P=2, Q= 3, R=5, S=4 (D) P=1, Q=5, R=6, S=4

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# SOLUTIONS

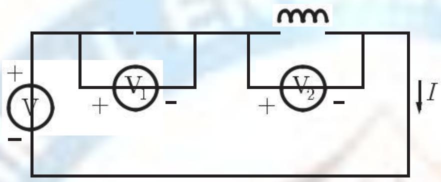
**Sol. 1** Option (B) is correct.

For an ideal voltmeter interval resistance is always zero. So we can apply the KVL along the two voltmeters as

$$V - V_1 - V_2 = 0$$

or

$$V = V_1 + V_2$$




**Sol. 2** Option (A) is correct.

For the +ve half cycle of I/p voltage, diode will be forward biased ($V_q = 0$, ideal diode) Therefore, the voltmeter will be short circuited and reads

$$V_1 = 0 \text{ volt} \qquad \text{(for +ve half cycle)}$$

Now, for -ve half cycle, diode will be reverse biased and treated as open circuit. So, the voltmeter reads the voltage across 100 kW. Which is given by

$$V_2 = 100 \# \frac{14.14\angle 0c}{100 + 1}$$

So,

$$V_{2,rms} = \frac{14}{\sqrt{2}} \text{volt}$$

Therefore, the average voltage for the whole time period is obtained as

$$V_{ave} = \frac{V_1 + V_{2,\,rms}}{2} = \frac{0 + 14/\sqrt{2}}{2} = \frac{14}{2\sqrt{2}}$$

$$\text{(F)} \qquad 4.94 \,.\, 4.46 \text{ volt}$$

**Sol. 3** Option (C) is correct.

The quality factor of the inductances are given by

$$q_1 = \frac{wL_1}{R_1}$$

and

$$q_2 = \frac{wL_2}{R_2}$$

So, in series circuit, the effective quality factor is given by

$$Q = \frac{\lfloor X_{Leq} \rfloor}{R_{eq}} = \frac{wL_1 + wL_2}{R_1 + R_2}$$

$$= \frac{\frac{wL_1}{R_1 R_2} + \frac{wL_2}{R_1 R_2}}{\frac{1}{R_2} + \frac{1}{R_1}} = \frac{\frac{q_1}{R_2} + \frac{q_2}{R_1}}{\frac{1}{R_2} + \frac{1}{R_1}} \;\text{E}\; \frac{q_1 R_1 + q_2 R_2}{R_1 + R_2}$$

**Sol. 4** Option (C) is correct.

**Sol. 5** Option (A) is correct.

PMMC instrument reads average (dc) value.

$$V_{avg} = \frac{1}{T}\int_0^T v(t)\,dt = \frac{1}{20\times 10^{-3}}\int_0^{20} v(t)\,dt$$

$$= \frac{1}{20}\left[\int_0^{10} t\,dt + \int_{10}^{12}(-5)\,dt + \int_{12}^{20} 5\,dt\right]$$

$$= \frac{1}{20}\left[\frac{t^2}{2}\Big|_0^{10} - 5t\Big|_{10}^{12} + 5t\Big|_{12}^{20}\right]$$

$$= \frac{1}{20}[50 - 5(2) + 5(8)] = \frac{80}{20} = 4\text{ V}$$

**Sol. 6** Option (A) is correct.

Heaviside mutual inductance bridge measures mutual inductance is terms known self-inductance.

**Sol. 7** Option (C) is correct.

Let $\omega t = \theta$, we have instaneous voltage and current as follows.

$$v(t) = E_1 \sin\theta + E_3 \sin 3\theta$$

$$i(t) = I_1 \sin(\theta - \phi_1) + I_3 \sin(3\theta - \phi_3) + I_5 \sin(5\theta)$$

We know that wattmeter reads the average power, which is gives as

$$P = \frac{1}{2\pi}\int_0^{2\pi} v(t)\, i(t)\, d\theta$$

We can solve this integration using following results.

(i) $\frac{1}{2\pi}\int_0^{2\pi} A\sin(\theta + \alpha)\cdot B\sin(\theta + \beta)\, d\theta = \frac{1}{2} AB\cos(\alpha - \beta)$

(ii) $\frac{1}{2\pi}\int_0^{2\pi} A\sin(\theta + \alpha)\cdot B\cos(\theta + \alpha)\, d\theta = \frac{1}{2} AB\sin(\alpha - \beta)$

(iii) $\frac{1}{2\pi}\int_0^{2\pi} A\sin(m\theta + \alpha)\cdot B\cos(n\theta + \beta)\, d\theta = 0$

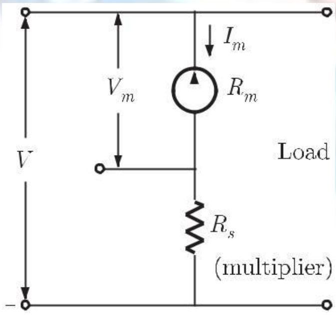
(iv) $\frac{1}{2\pi}\int_0^{2\pi} A\sin(m\theta + \alpha)\cdot B\cos(n\theta + \beta)\, d\theta = 0$

Result (iii) and (iv) implies that power is transferred between same harm voltages and currents. Thus integration of equation (i) gives.

$$P = \frac{1}{2}E_1 I_1 \cos\phi + \frac{1}{2}E_3 I_3 \cos\phi_3$$

**Sol. 8** Option (D) is correct.

A voltmeter with a multiplier is shown in figure below.




Here $I_m$ = Fully scale deflection current of meter.

$R_m$ = Internal resistance of meter

$R_s$ = Voltage across the meter

$(U)$ = Full range voltage of instrument $V_m = I_m R_m$

$$V = I_m (R_m + R_s)$$

$$\frac{V}{V_m} = \frac{R_m + R_s}{R_m} = 1 + \frac{R_s}{R_m}$$

Here when, $R_{s1} = 20$ kW, $V_{m1} = 440$ V

So, $\frac{V}{440} = 1 + \frac{20k}{R_m}$ ...(i)

When, $R_{s2} = 80$ kW, $V_{m2} = 352$ V

So, $\frac{V}{352} = 1 + \frac{80\text{ k}}{R_m}$ ...(ii)

Solving equation (i) and (ii), we get

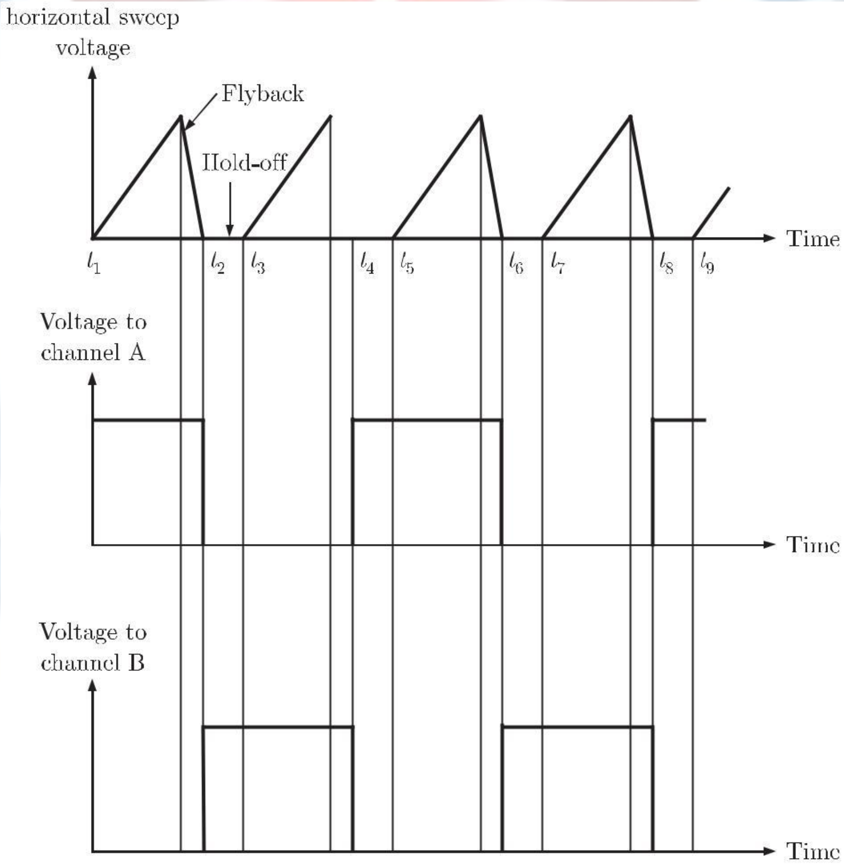
$V = 480$ V, $R_m = 220$ kW

So when $R_{s3} = 40$ kW, $V_{m3} = ?$

$\frac{480}{V_{m3}} = 1 + \frac{40k}{220k}$ & $V_{m2}$ - 406 V

Sol. 9 Option (C) is correct.

In the alternate mode it switches between channel A and channel B, letting each through for one cycle of horizontal sweep as shown in the figure.




Sol. 10 Option (A) is correct.

The compensating coil compensation the effect of impedance of current coil.

Sol. 11 Option (C) is correct.

Let $Z_1 = R_1 \parallel jw\,C_1$

so admittance $Y_1 = \frac{1}{Z_1} = \frac{1}{R_1} + jw\,C_1$

$$Z_2 = R_2 \text{ and } Z_4 = R_4$$

Let $Z_X = R_X + j\,\text{w}\,L_X$ (Unknown impedance)

For current balance condition of the Bridge

$$Z_2 Z_4 = Z_X Z_1 = \frac{Z_X}{Y_1}$$

Let $Z_X = Z_2 Z_4 Y_1$

$$R_X + j\text{w}\,L_X = R_2 R_4 \text{b} \frac{1}{R_1} + j\text{w}\,C_1 \text{l}$$

Equating imaginary and real parts

$$R_X = \frac{R_2 R_4}{R_1} \quad \text{and } L_X = R_2 R_4 C_1$$

Quality factor of inductance which is being measured

$$Q = \frac{\text{w}L_X}{R_X} = \text{w}R_1 C_1$$

From above equation we can see that for measuring high values of $Q$ we need a large value of resistance $R_4$ which is not suitable. This bridge is used for measuring low $Q$ coils.

*Note:* We can observe directly that this is a maxwell’s bridge which is suitable for low values of $Q$ (i.e. $Q < 10$)

**Sol. 12** Option (C) is correct.

$4\frac{1}{2}$ digit display will read from 000.00 to 199.99 So error of 10 counts is equal to =! 0.10 V

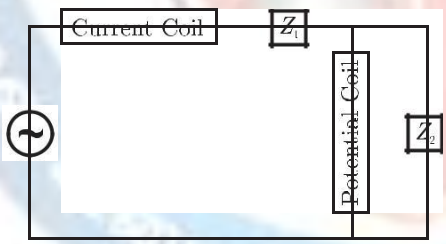
For 100 V, the maximum error is

$$e = !\,(100 \# 0.002 + 0.1) =!\,0.3 \text{ V}$$

Percentage error $=! \dfrac{0.3 \# 100}{100}\% =!\,0.3\%$ of reading

**Sol. 13** Option (D) is correct.

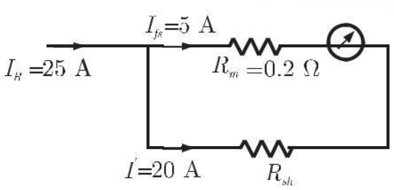
Since potential coil is applied across $Z_2$ as shown below




Wattmeter read power consumed by $Z_2$

**Sol. 14** Option (D) is correct.

Given that full scale current is 5 A




$$\text{Current in shunt } I\text{l} = I_R - I_{fs} = 25 - 5 = 20 \text{ A}$$

$$20 \# R_{sh} = 5 \# 0.2$$

$$R_{sh} = \frac{1}{20} = .05 \text{ W}$$

**Sol. 15** Option (A) is correct.

Overall gain of the system is

$$g = \frac{100}{1 + 100\left(\frac{9}{100}\right)} = 10 \quad \text{(zero error)}$$

Gain with error

$$g = \frac{100 + 10\%}{1 + (100 + 10\%)\left(\frac{9}{100}\right)} = \frac{110}{1 + \frac{110 \times 9}{100}} = 10.091$$

error $\Delta g = 10.091 - 10 = 0.1$

Similarly

$$g = \frac{100 - 10\%}{1 + (100 - 10\%)\left(\frac{9}{100}\right)} = \frac{90}{1 + 90 \times \frac{9}{100}}$$

$= 9.89$

error $\Delta g = 9.89 - 10 = -0.1$

So gain $g = 10 \pm 0.1 = 10 \pm 1\%$

**Sol. 16** Option (A) is correct.

At balance condition

$$(R + j\omega L)\left(R_4 \angle \frac{-j}{\omega C_4}\right) = R_2 R_3$$

$$(R + j\omega L)\left(\frac{\frac{-jR_4}{\omega C_4}}{R_4 - \frac{j}{\omega C_4}}\right) = R_2 R_3$$

$$\frac{jRR_4}{\omega C_4} + \frac{\omega L R_4}{\omega C_4} = R_2 R_3 R_4 - \frac{jR_2 R_3}{\omega C_4}$$

$$\frac{jRR_4}{\omega C_4} + \frac{LR_4}{C_4} = R_2 R_3 R_4 - \frac{jR_2 R_3}{\omega C_4}$$

Comparing real & imaginary parts.

$$\frac{RR_4}{\omega C_4} = \frac{R_2 R_3}{\omega C_4}$$

$$R = \frac{R_2 R_3}{R_4}$$

Similarly,

$$\frac{LR_4}{C_4} = R_2 R_3 R_4$$

$$L = R_2 R_3 C_4$$

**Sol. 17** Option (B) is correct.

Since Potential coil is connected across the load terminal, so it should be highly resistive, so that all the voltage appears across load.

**Sol. 18** Option (D) is correct.

A circle is produced when there is a 90° phase difference between vertical and horizontal inputs.

**Sol. 19** Option (C) is correct.

Wattmeter reading $P = V_{PC} I_{CC}$

$V_{PC}$ → Voltage across potential coil.

$I_{CC}$ → Current in current coil.

$$V_{PC} = V_{bc} = 400\angle -120°$$

$$I_{CC} = I_{ac} = \frac{400\angle 120°}{100} = 4\angle 120°$$

Power $P = 400+ - 120c \# 4+120c$

$= 1600+240c = 1600 \# \frac{1}{2} = 800$ Watt

Sol. 20 Option (D) is correct.

Average value of a triangular wave

$$V_{av} = \frac{V_m}{3}$$

rms value $V_{ms} = \frac{V_m}{\sqrt{3}}$

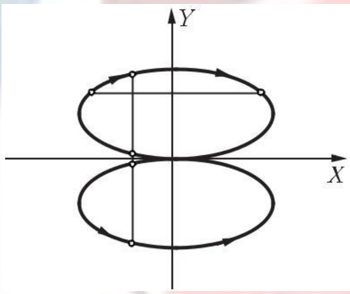
Given that $V_{av} = \frac{V_m}{3} = 10$ V

So $V_{rms} = \frac{V_m}{\sqrt{3}} = \sqrt{3} V_{av} = 10\sqrt{3}$ V

Sol. 21 Option (A) is correct.

Conversion time does not depend on input voltage so it remains same for both type of ADCs.

Sol. 22 Option (D) is correct.




Frequency ratio $\frac{f_Y}{f_X} = \frac{\text{meeting points of horizontal tangents}}{\text{meeting points of vertical tangents}}$

$$\frac{f_Y}{f_X} = \frac{2}{4}$$

$$f_Y = \frac{1}{2}(f_X)$$

$$w_2 = w_1/2$$

Since the Lissajous figures are ellipse, so there is a phase difference of 90c exists between vertical and horizontal inputs.

So $q\,(w_2\,t) = A \cos w_2\,t,\ w_2 = w_1/2$

Sol. 23 Option (A) is correct.

Impedance of different branches is given as

$$Z_{AB} = 500\ W$$

$$Z_{BC} = \frac{1}{j \# 2p \# 2 \# 10^3 \# 0.398\ mF} + 300\ W$$

$- (- 200j + 300)$ W

$$Z_{AD} = j \# 2p \# 2 \# 10^3 \# 15.91\ mH + 300\ W$$

$- (200j + 300)$ W

To balance the bridge

$$Z_{AB} Z_{CD} = Z_{AD} Z_{BC}$$

$$500Z = (200j + 300)(- 200j + 300)$$

$$500Z = 130000$$
$$Z = (260 + j0)\ \Omega$$

Sol. 24 Option (B) is correct.

Since both the waveform appeared across resistor and inductor are same so the common point is B. Signal Probe $S_1$ is connecte with A, $S_2$ is connected with C and both the grount probes $G_1$ and $G_2$ are connected with common point B.

Sol. 25 Option (A) is correct.

To balance the bridge

$$(R_1 + jX_1)(R_4 - jX_4) = R_2 R_3$$
$$(R_1 R_4 + X_1 X_4) + j(X_1 R_4 - R_1 X_4) = R_2 R_3$$

comparing real and imaginary parts on both sides of equations

$$R_1 R_4 + X_1 X_4 = R_2 R_3 \qquad ...(1)$$
$$X_1 R_4 - R_1 X_4 = 0 \Rightarrow \frac{X_1}{X_4} = \frac{R_1}{R_4} \qquad ...(2)$$

from eq(1) and (2) it is clear that for balancing the bridge first balance $R_4$ and then $R_1$.

Sol. 26 Option (C) is correct.

From the Calibration pulse we can obtain

$$\frac{\text{Voltage}}{\text{Division}}(3\text{ V}) = \frac{5}{2} = 2.5\text{ V}$$
$$\frac{\text{Time}}{\text{Division}}(3\text{ T}) = \frac{1\text{ ms}}{4} = \frac{1}{4}\text{ msec}$$

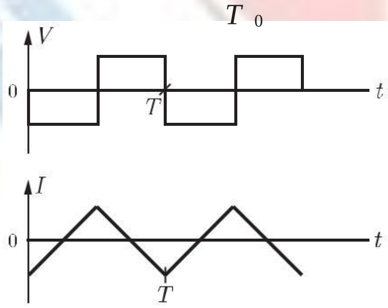
So amplitude (p-p) of unknown signal is

$$V_{P-P} = 3\text{ V} \times 5 = 2.5 \times 5 = 7.5\text{ V}$$
$$\text{Time period } T = 3\text{ T} \times 8 = \frac{1}{4} \times 8 = 2\text{ ms}$$

Sol. 27 Option (A) is correct.

Reading of wattmeter (Power) in the circuit

$$P_{av} = \frac{1}{T}\int_0^T VIdt = \text{Common are between } V - I$$




total common area = 0 (Positive and negative area are equal)

So $P_{av} = 0$

Sol. 28 Option (C) is correct.

PMMC instrument reads only dc value so

$$I_{PMMC} = -8\text{ A}$$

rms meter reads rms value so

$$I_{rms} = \sqrt{(-8)^2 + \frac{(6\sqrt{2})^2}{2}} = \sqrt{64 + 36} = 10\text{ A}$$

Moving iron instrument also reads rms value of current So

$$I_{MI} = 10 \text{ mA}$$

Reading are $(I_{PMMC}, I_{rms}, I_{MI}) = (-8\text{ A}, 10\text{ A}, 10\text{ A})$

**Sol. 29** Option (D) is correct.

$$\text{Given that } w = \frac{xy}{z}$$

$$\log w = \log x + \log y - \log z$$

Maximum error in w

$$\% \frac{dw}{w} = ! \frac{dx}{x} ! \frac{dy}{y} ! \frac{dz}{z}$$

$$\frac{dx}{x} = ! \ 0.5\% \text{ reading}$$

$$\frac{dy}{y} = ! \ 1\% \text{ full scale} = ! \frac{1}{100} \# 100 = ! \ 1$$

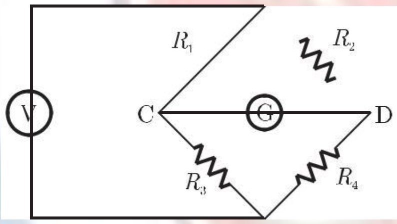
$$\frac{dy}{y} = ! \frac{1}{20} \# 100 = ! \ 5\% \text{ reading}$$

$$\frac{dz}{z} = 1.5\% \text{ reading}$$

So $$\% \frac{dw}{w} = ! \ 0.5\% \ ! \ 5\% \ ! \ 1.5\% = ! \ 7\%$$

**Sol. 30** Option ( ) is correct.

**Sol. 31** Option (B) is correct.




In balanced condition there is no current in CD arm so $V_C = V_D$

Writing node equation at $C$ and $D$

$$\frac{V_C - V}{R_1} + \frac{V_C}{R_3} = 0 \ \& \ V_C = V b \frac{R_3}{R_1 + R_3} l$$

$$\frac{V_0 - V}{R_2} + \frac{V_D}{R_4} = 0 \ \& \ V_D = V b \frac{R_4}{R_2 + R_4} l$$

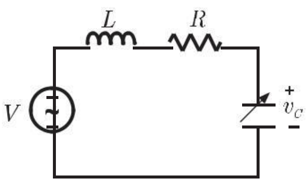
So $$V b \frac{R_3}{R_1 + R_3} l = V b \frac{R_4}{R_2 + R_4} l$$

$$R_2 R_3 + R_3 R_4 = R_1 R_4 + R_3 R_4$$

$$R_1 = R_2 R_3 / R_4$$

**Sol. 32** Option (C) is correct.

Q-meter works on the principle of series resonance.




At resonance $V_C = V_L$

and $I = \frac{V}{R}$

Quality factor $Q = \frac{\omega L}{R} = \frac{1}{\omega CR} = \frac{\omega L \times I}{R \times I} = \frac{V_L}{E} = \frac{V_C}{E}$

Thus, we can obtain Q

Sol. 33 Option (A) is correct.

PMMC instruments reads DC value only so it reads 2 V.

Sol. 34 Option (B) is correct.

Resolution of n-bit DAC = $\frac{V_{fs}}{2^n - 1}$

So $14\ mv = \frac{3.5\ \text{V}}{2^n - 1}$

$$2^n - 1 = \frac{3.5}{14 \times 10^{-3}}$$

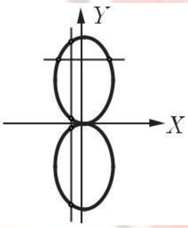
$$2^n - 1 = 250$$

$$2^n = 251$$

$$n = 8\ \text{bit}$$

Sol. 35 Option (B) is correct.

We can obtain the frequency ratio as following




$$\frac{f_Y}{f_X} = \frac{\text{meeting points of horizontal tangents}}{\text{meeting points of vertical tangents}}$$

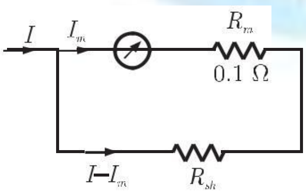
$$\frac{f_Y}{f_X} = \frac{2}{4}$$

$$f_Y = \frac{1}{2} f_X$$

There should exist a phase difference(15c) also to produce exact figure of-8.

Sol. 36 Option (C) is correct.

The configuration is shown below




It is given that $I_m = 100$ A

Range is to be extended to 0 - 500 A,

$$R. = 500\ \text{A}$$

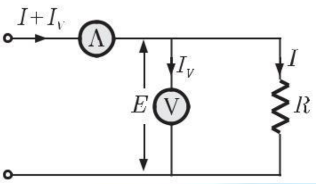
So $I_m R_m = (I - I_m) R_{sh}$

$$100 \times 0.1 = (500 - 100) R_{sh}$$

$$R_{sh} = \frac{100 \times 0.1}{400} = 0.025\ \Omega$$

**Sol. 37** Option (D) is correct.

The configuration is shown below




Current in voltmeter is given by

$$I_V = \frac{E}{2000} = \frac{180}{2000} = .09\ \text{A}$$

$$I + I_V = 2\ \text{amp}$$

So $\quad I = 2 - .09 = 1.91\ \text{V}$

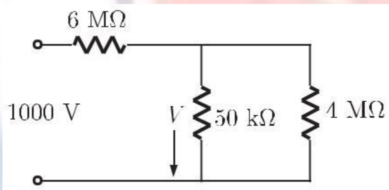
$$R = \frac{E}{I} = \frac{180}{1.91} = 94.24\ \Omega$$

Ideally $\quad R_0 = \frac{180}{2} = 90\ \Omega$

$$\%\ \text{error} = \frac{R - R_0}{R_0} \times 100 = \frac{94.24 - 90}{90} \times 100 = 4.71\%$$

**Sol. 38** Option (A) is correct.

The measurement system is shown below




Voltmeter reading

$$V = \left(\frac{1000}{6\ \text{M}\Omega + 50\ \text{k}\Omega \parallel 4\ \text{M}\Omega}\right)(50\ \text{k}\Omega \parallel 4\ \text{M}\Omega)$$

$$= \frac{1000}{6 + .049} \times .049 = 8.10\ \text{V}$$

**Sol. 39** Option (D) is correct.

Total power $P = P_1 + P_2 = 10.5 - 2.5 = 8$ kW

Power factor $= \cos\theta$

Where

$$\theta = \tan^{-1}\left[\sqrt{3}\,\frac{P_2 - P_1}{P_2 + P_1}\right] = \tan^{-1}\left[\sqrt{3} \times \left(\frac{-13}{8}\right)\right] = -70.43^\circ$$

Power factor $= \cos\theta = 0.334$

**Sol. 40** Option (B) is correct.

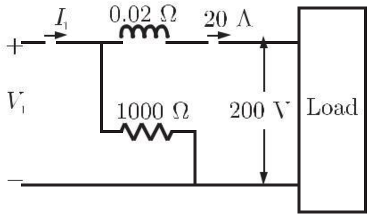
for the dc potentiometer $E \propto l$

so, $\quad \frac{E_1}{E_2} = \frac{l_1}{l_2}$

$$E_2 = E_1\left(\frac{l_1}{l_2}\right) = (1.18) \times \frac{680}{600} = 1.34\ \text{V}$$

**Sol. 41** Option (C) is correct.

Let the actual voltage and current are $I_1$ and $V_1$ respectively, then




Current in CC is 20 A

$$20 = I_1 b \frac{1000}{1000 + 0.02} l$$

$$I_1 = 20.0004 \text{ A} - 20 \text{ A}$$

$$\text{(B)} = V_1 - .02 \# 20 = 200.40$$

$$\text{Power measured } P_m = V_1 I_1 = 20(200.40) = 4008 \text{ W}$$

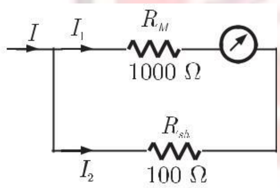
Load power $\quad P_L = 20 \# 200 = 4000$ W

$$\% \text{ Change} = \frac{P_m - P_L}{P_L} = \frac{4008 - 4000}{4000} \# 100$$

$$= 0.2\% \text{ more}$$

**Sol. 42** Option (C) is correct.

We have to obtain $n = \frac{I}{I_1}$




$$\frac{I_1}{I_2} = \frac{R_{sh}}{R_m} = \frac{100}{1000} = \frac{1}{10}$$

$$I_1 + I_2 = I$$

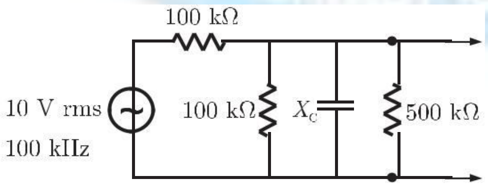
$$I_1 + 10 I_1 = I$$

$$11 I_1 = I$$

$$n = \frac{I}{I_1} = 11$$

**Sol. 43** Option (B) is correct.

In the following configuration




Rectance $\quad X_c = \frac{1}{jw C} = \frac{1}{2p \# 100 \# 10^3 \# 10 \# 10^{-12}}$

writing node equation at P

$$\frac{V_P - 10}{100} + V_P b \frac{1}{100} + \frac{1}{500} - \frac{j}{159} l = 0$$

$$10 - V_P = V_P(1.2 - j0.628)$$
$$10 = (2.2 - j\,0.628)V_P$$
$$V_P = \frac{10}{2.28} = 4.38 \text{ V}$$

Sol. 44 Option (A) is correct.

The torque on the coil is given by

$$D = NIBA$$

$N$ " no. of turns, N = 100

$I$ " current, I = 50 mA

$B$ " magnetic field, B = 200 mT$A$ " Area,

A = 10 mm # 20 mm

So, $t = 100 \# 50 \# 10^{-3} \# 200 \# 10^{-3} \# 200 \# 10^{-3} \# 10^{-3}$

$= 200 \# 10^{-6}$ Nm

Sol. 45 Option (C) is correct.

Meter constant (A-sec/rev) is given by

$$14.4 = \frac{I}{\text{speed}}$$
$$14.4 = \frac{I}{K \# \text{Power}}$$

Where '$K$' is the meter constant in rev/kWh.

$$14.4 = \frac{I}{K \# VI}$$
$$14.4 = \frac{15}{C \# 15 \# 250}$$
$$K = \frac{1}{250 \# 14.4}$$
$$K = \frac{1}{\frac{250 \# 14.4}{b\,1000 \# 3600\,l}} = \frac{1000 \# 3600}{3600} = 1000 \text{ rev/kWh.}$$

Sol. 46 Option (B) is correct.

For moving iron ameter full scale torque is given by

$$t_C = \frac{1}{2}I^2\frac{dL}{dq}$$
$$240 \# 10^{-6} = \frac{1}{2}(10)^2\frac{dL}{dq}$$

Change in inductance

$$\frac{dL}{dq} = 4.8 \text{ mH/radian}$$

Sol. 47 Option (B) is correct.

In the figure

$$V_{RY} = 415+30c$$
$$V_{BN} = \frac{415}{\sqrt{3}}+120c$$

Current in current coil

$$I_C = \frac{V_{RY}}{Z} = \frac{415+30c}{100+36.87c}$$

`power factor = 0.8

cos f = 0.8 & f = 36.87c

254.15+ - 6.87

$$\text{Power} = VI^{)} = \frac{415}{\sqrt{3}} +120c \# 4.15+6.87c$$

3. 994.3+126.87c

Reading of wattmeter

$$P = 994.3\text{^}\cos 126.87ch = 994.3(-0.60) =- 597 \text{ W}$$

**Sol. 48** Option (A) is correct.

For small values of phase angle

$$\frac{I_P}{I_S} = nf, \quad 5." \text{ Phase angle (radians)}$$

n " turns ratio

Magnetizing ampere-turns 26. 200

So primary current $I_P$= 200 # 1 = 200 amp

Turns ratio $n$ = 500

Secondary current $I_S$= 5 amp

So $\frac{200}{5} = 500f$

$$f \text{ (in degrees)} = b \frac{180}{p} lb \frac{200}{5 \# 500} l$$

- 4.58c

**Sol. 49** Option (B) is correct.

Voltage appeared at secondary winding

$$E_S = I_S \# Z_L = 5 \# 1 = 5 \text{ Volts}$$

Voltage induced is given by

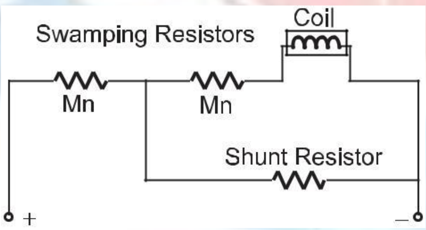
$$E_S = \sqrt{2}\, p fNf, \quad f \text{ " flux}$$

$$5 = \sqrt{2} \# 3.14 \# 50 \# 500 \# f$$

$$f = \frac{5}{\sqrt{2} \# 3.14 \# 25 \# 10^3} = 45 \# 10_{-6} \text{ wb}$$

**Sol. 50** Option (A) is correct.

In PMCC instruments, as temperature increases the coil resistance increases. Swamp resistors are connected in series with the moving coil to provide temperature compensation. Swamping resistors is made of magnin, which has a zero-temperature coefficient.




**Sol. 51** Option () is correct.

Effect of stray magnetic field is maximum when the operating field and stray fields are parallel.

**Sol. 52** Option (A) is correct.

Let $C_1 = 300$ pF

$$Q = 120 = \frac{1}{wC_1 R}$$

Now when $C_x$ is connected in parallel with variable resistor $C_1' = 200$ pF

$$Q = 120 = \frac{1}{w(C_1' + C_x)R}$$

So $$C_1 = C_1' + C_x$$

$$300 = 200 + C_x$$

$$C_x = 100 \text{ pF}$$

Sol. 53 Option (B) is correct.

Maximum frequency of input in dual slop A/D converter is given as

$$T_m = 2^n T_C$$

where $f_m = \frac{1}{T_m}$ " maximum frquency of input

$$f_C = \frac{1}{T_C} \text{ " clock frequency}$$

so $$f_m = \frac{f_C}{2^n}, \quad n = 10$$

$$= \frac{10^6}{1024} = 1 \text{ kHz (approax)}$$

Sol. 54 Option (A) is correct.

Kelvin Double bridge is used for measuring low values of resistances. (P " 2)

Low values of capacitances is precisely measured by schering bridge (Q " 3)

Inductance of a coil with large time constant or high quality factor is measured by hay's bridge ($R$ " 5)

Sol. 55 Option (C) is correct.

Full scale deflection is produced by a dc current of 1 mA

$$(I_{dc})_{fs} = 1 \text{ mA}$$

For full wave reactifier

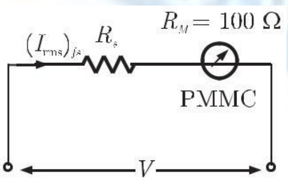
$$(I_{dc})_{fs} = \frac{2I_m}{p}, \quad I_m \text{ "peak value of ac current}$$

$$1 \text{ mA} = \frac{2I_m}{3.14}$$

$$I_m = 1.57 \text{ mA}$$

Full scale ac current

$$(I_{rms})_{fs} = \frac{1.57}{\sqrt{2}} = 1.11 \text{ mA}$$




$$= \ = (R_s + R_m)(I_{rms})_{fs}$$

$$100 = (R_s + 100)(1.11 \text{ mA})$$

$$\frac{12}{(1.11 \text{ mA})} = R_s + 100$$

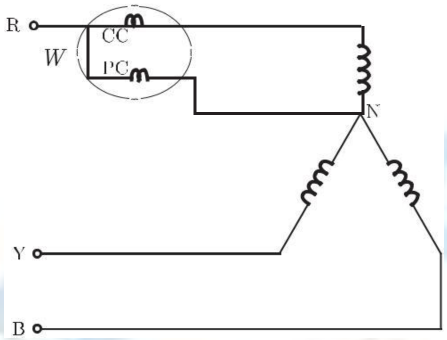
$$= R_s + 100$$

100 # 900

$$R_S = 89.9 \text{ kW}$$

Sol. 56 Option (B) is correct.

First the current coil is connected in R-phase and pressure coil is connected between this phase and the neutral as shown below

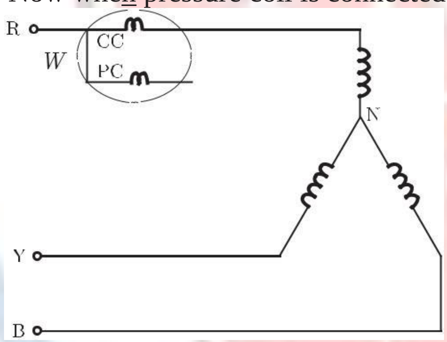



Reading of wattmeter

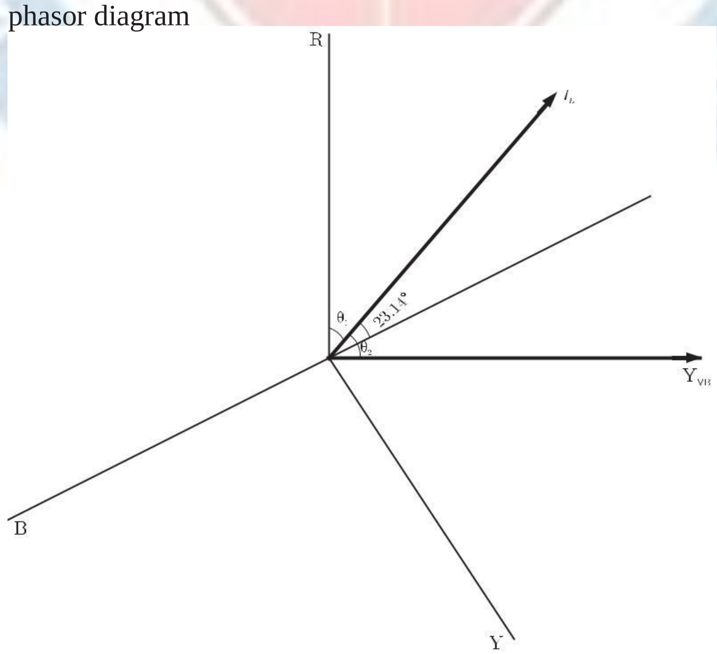
$$W_1 = I_P V_P \cos\theta_1, \cos\theta_1 = 0.8 \ \& \ \theta_1 = 36.86°$$

$$400 = \frac{I_L V_L}{\sqrt{3}} \times 0.8 \quad ...(1)$$

Now when pressure coil is connected between B and Y-phases, the circuit is




phasor diagram



angle $q_2 = 23.14c + 30c = 54.14c2$

now wattmeter reading $W_2 = V_{YB}\, I_L \cos q_2$

from equation (1) $V_L\, I_L = \dfrac{400 \# \sqrt{3}}{0.8}$

so $W_2 = \dfrac{400}{0.8} \sqrt{\#}\, 3 \# \cos 53.14c$

$= 519.5$ W

**Sol. 57** Option (C) is correct.

In a moving-iron ammeter control torque is given as

$$t_c = Kq = \frac{1}{2} I^2 \frac{dL}{dq}$$

Where

$K$ " control spring constant

q " deflection

$$\text{Given that } L = 10 + 3q - \frac{q^2}{4}$$

$$\frac{dL}{dq} = b\, 3 - \frac{q}{2}\, l \text{ mH/rad}$$

So,

$$t_c = (25 \# 10^{-6})q = \frac{1}{2}(5)^2\, b\, 3 - \frac{q}{2} l \# 10^{-6}$$

$$2q = 3 - \frac{q}{2}$$

$$\frac{5q}{2} = 3 \ \& \ q = \frac{6}{5} = 1.2 \text{ rad.}$$

**Sol. 58** Option (B) is correct.

Magnetizing current $I_m$ 12 $\dfrac{250}{1}$ = 250 amp

Primary current $I_p$ 13 500 amp

Secondary current $I_s$ 14 5 amp

Turn ratio $n$ 15 $\dfrac{I_p}{5} = \dfrac{500}{} = 100\, I_s$

Total primary current ($I_T$) F $\sqrt{[\text{primary current}(I_p)]^2 +}$

$$I_T = \sqrt{I_p^2 + I_m^2}$$

$$= \sqrt{(500)^2 + (250)^2} = 559.01 \text{ amp}$$

$$\text{Turn ratio } n' = \frac{I_T}{I_s} = \frac{559.01}{5} = 111.80$$

$$\text{Percentage ratio error } 3n = \frac{n - nl}{nl} \# 100$$

$$= \frac{100 - 111.80}{111.80} \# 100 = -10.55\%$$

**Sol. 59** Option (C) is correct.

Power read by meter $P_m = VI \sin(3\text{-}f)$

Where

3"Phase angle between supply voltage and pressure coil flux.
f "Phase angle of load
Here

3 = 85c, f = 60c "a cos f = 0.5

So measured power

$P_m$ = 200 # 5 sin(85c - 60c)

J 1100 sin 25c

K 464.88 W

Actual power $P_O$ = *VI* cos f = 220 # 5 # 0.5 = 550 W

Error in measurement = $P_m$ - $P_O$ = 464.88 - 550 =- 85.12 W

For unity power factor cos f = 1

f = 0c

So $P_m$ = 220 # 5 sin(85c - 0c) = 1095.81 W

$P_O$ = 220 # 5 cos 0c = 1100

Error in Measurement

BB 1095.81 - 1100 =- 4.19 W

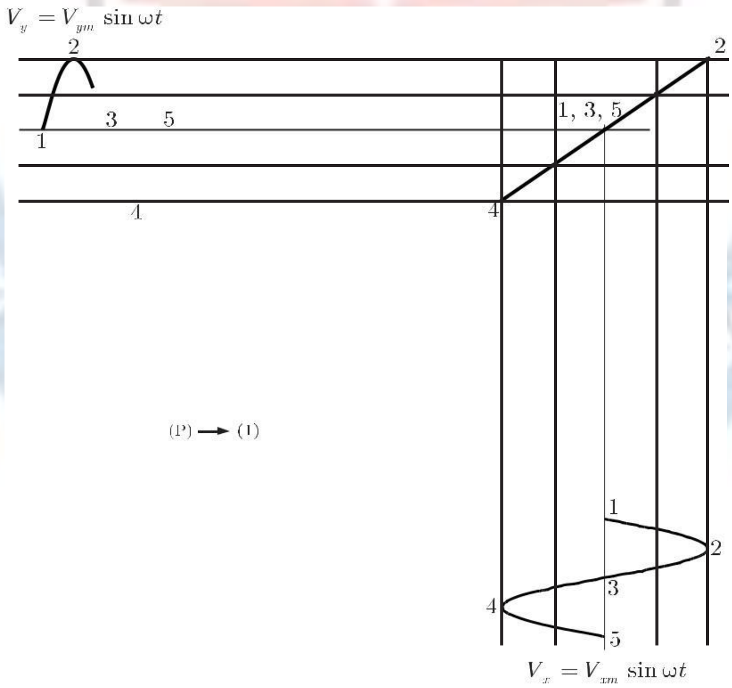
Option (A) is correct.

Sol. 60 We can obtain the Lissaju pattern (in X-Y mode) by following method.

For f = 0c, $V_x$ = $V_{xm}$ sin w*t*

$V_y$ = $V_{ym}$ sin(w *t* + 0c) = sin w*t*

Draw $V_x$ and $V_y$ as shown below

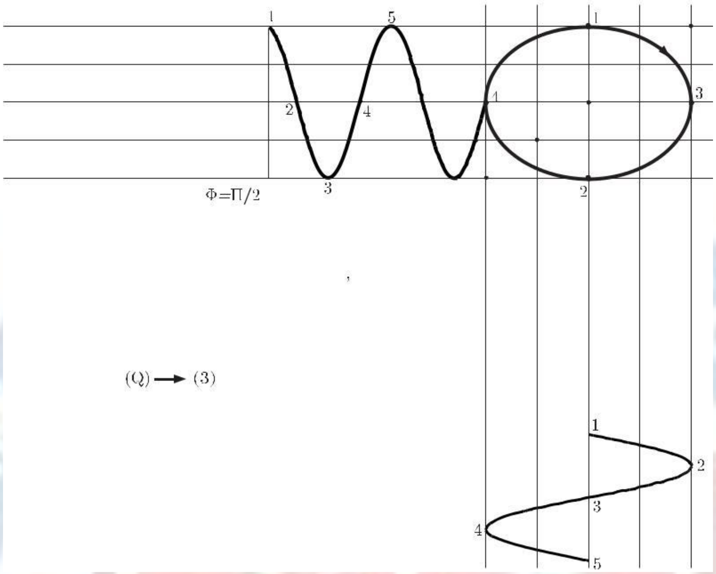



Divide both $V_y$ and $V_x$ equal parts and match the corresponding points on the screen.

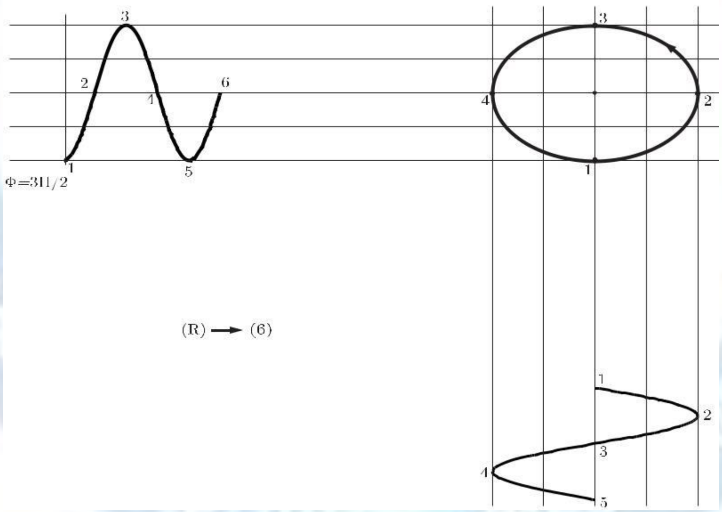
Similarly for f = 90c

$V_x$ = $V_{xm}$ sin w*t*

$V_y$ = $V_{ym}$ sin(w*t* + 90c)




Similarly for $f = \frac{3p}{2}$




we can also obtain for $0 < f < \frac{3p}{2}$

# ELECTRICAL MACHINE

Electrical machine is a converter of energy (or power converter) which converts:

electrical energy (power) into mechanical one,

or

mechanical energy (power) into electrical one,

or

electrical energy (power) into electrical - but usually of different parameters,

with the help of (by means of) magnetic field. Energy conversion in electrical machines is or is not accompanied with mechanical motion.

**Machine converters:**

*T* - *torque (moment) in N·m*

*H. - angular speed of the shaft in rad/s*

*P - power in W (watts)*

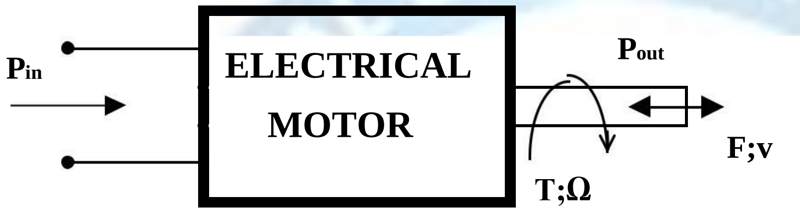
*F - force in linear motion in N*

*v - speed (linear) in m/s*

$P_{in}$ *- input power*

$P_{out}$ *- output power*

.......................................................................................




INPUT - ELECTRICAL POWER

OUTPUT - MECHANICAL POWER

$P = UI$ (DC circuit)

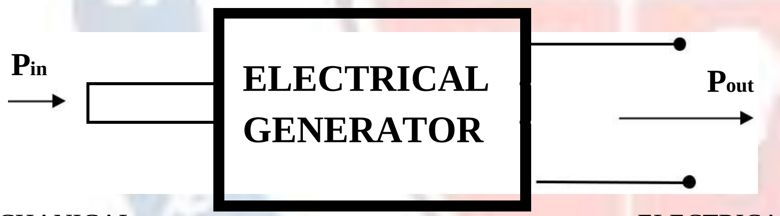
$P = T\Omega$ (rotational motion)

$P = UI\cos\phi$ (AC 1-phase)

$P = Fv$ (linear motion)

*F.* = $\sqrt{3}UI\cos\phi$ (AC 3-phase, line or phase-to-phase values) $P = 3U_{ph}I_{ph}\cos\phi$ (AC 3-phase, phase values)

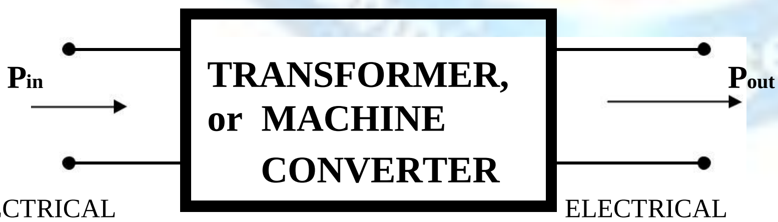
.......................................................................................




MECHANICAL INPUT

ELECTRICAL OUTPUT

.......................................................................................




ELECTRICAL INPUT

ELECTRICAL OUTPUT (OF DIFFERENT PARAMETERS)

.

**BASIC PRINCIPLES OF ENERGY CONVERSION IN ELECTRICAL MACHINE**

ELECTROMAGNETIC INDUCTION

Assume the coil having *N* turns. Each turn is linked with the magnetic flux $\Phi$. The total flux linked with the coil is

$$\Psi = N\Phi$$

and is called coil's flux linkage.
According to Faraday-Lenz law when the change of $\Psi$ is taking place the **electromotive force (emf)** is induced in the coil:

$$e = \frac{d\Psi}{dt} = N\frac{d\Phi}{dt}$$

Change of flux linkage may occur in two ways (separately or simultaneously):

(H) flux is constant, the coil moves through it; in electrical machines it is usually so arranged, that the straight parts of the coil turns move at speed *v* at right angles to the direction of the flux;

(I) coil is stationary with respect to the flux, the flux is varying in magnitude.

In general $\Phi$ = f(*x*,*t*), and

$$e = N\frac{d\Phi}{dt} = N\frac{\partial\Phi}{\partial x}\frac{dx}{dt} + N\frac{\partial\Phi}{\partial t} = e_r + e_p$$

Motional (rotational) emf in a single conductor of length *l* cutting across a magnetic field of uniform flux density *B* at speed *v* at right angle to the direction of the flux is

$$e = e_r = Blv$$

Pulsational emf (transformer emf) in a coil of *N* turns, induced due to the flux linked to the coil varying in time sinusoidally

$$(O) \quad = \Phi_m \sin\omega t = \Phi_m \sin 2\pi f t$$

has the value

$$e = e_p = N\frac{d\Phi}{dt} = 2\pi f N\Phi_m \cos\omega t = E_m \cos\omega t$$

Its root-mean-square (rms) value

$$\boxed{E = \frac{E_m}{\sqrt{2}} = 4,44\, fN\Phi_m}$$

# ELECTRODYNAMIC INTERACTION OF CURRENT AND MAGNETIC FIELD

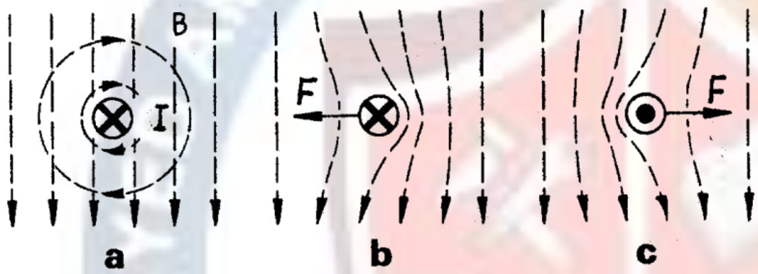
When a current $I$ flowing along the elementary conductor d$\boldsymbol{L}$ is under influence of magnetic field of density $\boldsymbol{B}$, an elementary mechanical force is developed on it, according to Lorentz relation:

$$d\mathbf{F} = I \cdot d\mathbf{L} \times \mathbf{B}$$

The highest value of the force is achieved when the conductor (and current $I$) is perpendicular to the magnetic field $\boldsymbol{B}$. In such a case, for the conductor of total length $L$, the total force acting at the conductor (current) is

$$F = BIL$$

and is perpendicular to both current and field.




*Tendency to align the magnetic field lines (alignment)*

# DETERMINATION OF EMF AND DYNAMIC FORCE DIRECTIONS

The method of three fingers of the right hand.

# AMPER'S RULE FOR MAGNETIC CIRCUIT

$$\oint_L \mathbf{H} \cdot d\mathbf{L} = NI = \Theta$$

or for finite number of the closed magnetic circuit parts of uniform cross-section and assignable length and permeability

$$\sum_x H_x L_x = NI$$

and hence

$$NI = \sum_x H_x L_x = \sum_x \left( \frac{B_x}{\mu_x} L_x \right) = \sum_x \left( \frac{\Phi}{A_x \mu_x} L_x \right) = \Phi \sum_x R_{\mu x}$$

where $A_x$ is a cross-section area of the $x$-th part of magnetic circuit

*H - magnetic field strength in A/m.*

*$NI = \Theta$ - magnetomotive force (mmf) in A (or in A-t)*

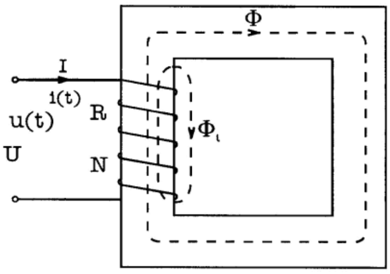
*(I) $=\mu_r\mu_o$ - absolute permeability in H/m.*

*$\mu_o = 4\pi\times10^{-7}$ H/m - absolute permeability of vacuum, air or nonmagnetic material*

*$\mu_r$ - relative permeability (in per unit -p.u.)*

$R_\mu = \dfrac{L}{A \cdot \mu}$ *- reluctance (magnetic resistance) in $H^{-1}$*

## ELECTROMAGNETIC CIRCUIT EXAMPLE




$R$ – winding resistance
$N$ – number of turns
$\Phi$ - the main flux ($A$; $l$; $\mu$)
$\Phi_l$ – leakage flux flowing mainly outside the magnetic circuit ($A_l$; $l_l$; $\mu_o$)

Assume $i = I_m \sin\omega t$ (or $i = \sqrt{2} I \sin\omega t$)

$I_m$ – **amplitude** of sinusoidally varying current
$I$ – **root-mean-square (rms)** value of current $i$

$\Phi = \Phi_m \sin\omega t$ $\quad \Phi = \frac{N \cdot i}{R_{\mu f}}$ $\quad R_{\mu f} = \frac{l}{A \cdot \mu}$ = var (saturation effect)

$\Phi_l = \Phi_{lm} \sin\omega t$ $\quad \Phi_l = \frac{N \cdot i}{R_{\mu l}}$ $\quad R_{\mu l} = \frac{l_l}{A_l \cdot \mu_o}$ = const

emf induced due to $\Phi$

$$e_f = N\frac{d\Phi}{dt} = N\Phi_m \omega\cos\omega t = N\frac{NI_m}{R_{\mu f}}\omega\cos\omega t = \frac{N^2}{R_{\mu f}}\omega I_m \cos\omega t$$

$\frac{N^2}{R_{\mu f}} = L_f$ – **inductance** of the winding corresponding to the main flux path parameters

$\frac{N^2}{R_{\mu f}}\omega = L_f\omega = X_f$ – so called **magnetizing reactance**

amplitude of $e_f$
$E_{fm} = X_f \cdot I_m$
rms value of $e_f$
$E_f = X_f \cdot I$

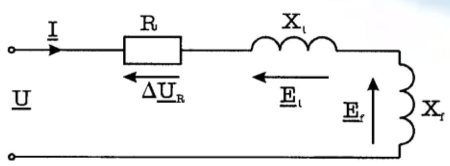
emf induced due to $\Phi_l$

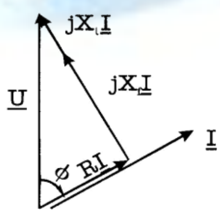
$$e_l = N\frac{d\Phi_l}{dt} = N\Phi_{lm} \omega\cos\omega t = N\frac{NI_m}{R_{\mu l}}\omega\cos\omega t = \frac{N^2}{R_{\mu l}}\omega I_m \cos\omega t$$

$\frac{N^2}{R_{\mu l}} = L_l$ – **inductance** of the winding corresponding to the leakage flux path parameters

$\frac{N^2}{R_{\mu l}}\omega = L_l\omega = X_l$ – so called **leakage reactance**

amplitude of $e_l$
$E_{lm} = X_l \cdot I_m$
rms value of $e_l$
$E_l = X_l \cdot I$




$X_f + X_l = X$
(total) reactance of the coil

Equivalent circuit with rms values of $U$, $I$ described at complex plane

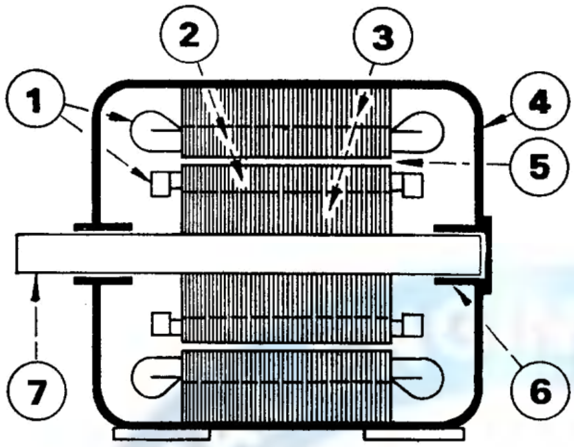
Phasor diagram

Voltage balance equation

$\phi$ - phase angle

$$\underline{U} = \Delta\underline{U}_R + \underline{E}_l + \underline{E}_f = R\underline{I} + jX_l\underline{I} + jX_f\underline{I}$$

## DESIGN AND CONSTRUCTIONAL FEATURES OF A ROTATING MACHINE




**1** - *windings of stator and rotor embedded in slots*

**2** - *slots and teeth*

**3** - *magnetic cores of stator and rotor (made of laminations)*

**4** – *frame, housing*

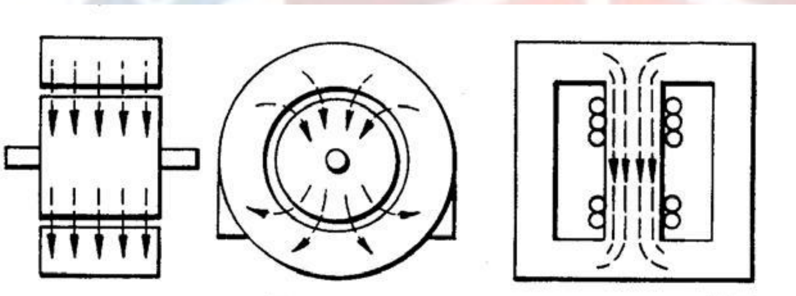
**5** – *air gap*

**6** - *bearings*

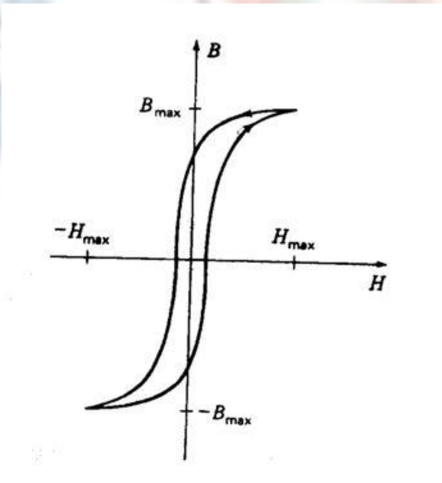
**7** - *shaft*

## CORE LOSS

(power loss in magnetic core)



Hysteresis loss - due to the cycling of the material through its hysteresis loop




Specific hysteresis loss (per mass unit of magnetic material)

$$p_h = k_h f B_m^2 \quad \text{[W/kg]}$$

Eddy-current loss - due to the induction of emfs and currents (eddy currents) circulating within the magnetic material.

Eddy-current specific loss

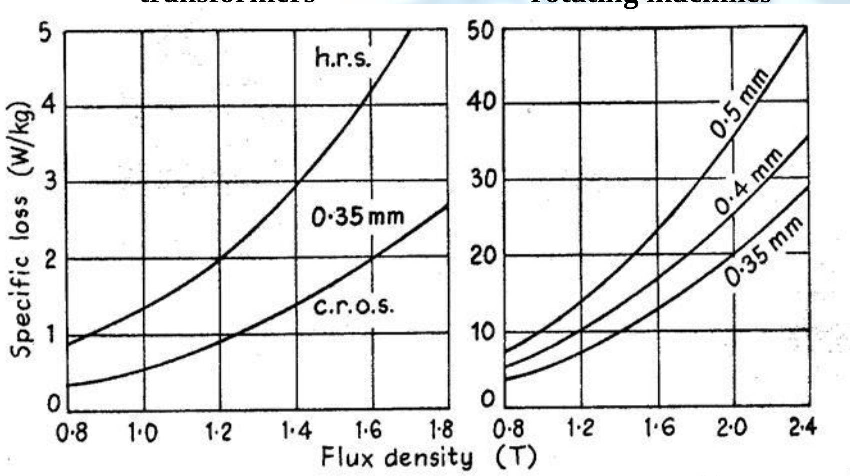
$$p_e = \frac{1}{\rho} k_e d^2 f^2 B_m^2 = k'_e f^2 B_m^2 \quad \text{[W/kg]}$$

*(F) - resistivity of magnetic material*

*d - thickness of lamination*

**Total core loss in**

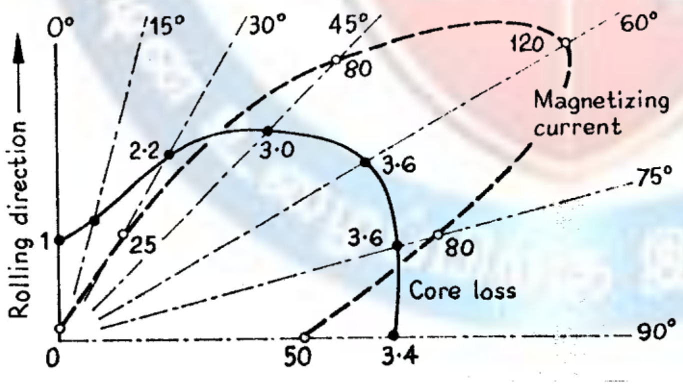
**transformers** **rotating machines**




**h.r.s.** - *hot-rolled steel (4-5% silicon content)*

**c.r.o.s** - *cold-rolled grain-oriented steel*

**Directional properties of cold-rolled grain-oriented steel**




*Magnetic properties in the rolling direction are far superior to those on any other axis.*

*Power loss and magnetising current in the rolling direction are each taken as unity.*

## COPPER ($I^2R$) LOSS

When current $I$ (rms value or DC) flows in a conductor (winding) of resistance $R$, the $I^2R$ loss appears.

Copper & aluminium - most common conducting metals used for electrical machine windings.

Total loss $\Delta P = \Delta P_{Cu} = I^2R$

$$R = \rho \frac{l}{S_{Cu}}$$

Specific $I^2R$ loss (per volume unit of conducting material (or per unit cube of conducting material)

$$\Delta p = J^2\rho$$

The resistance depends on temperature

$$R_\vartheta = R_{20}\,(1 + \alpha \cdot \Delta\vartheta) \qquad \Delta\vartheta = (\vartheta - 20)$$

Conducting materials properties

| Metal | $\rho$ Resistivity [μΩ.m] | $\alpha$ Resist - temper. coefficient [1/K] | Density [kg/m$^3$] |
|---|---|---|---|
| Copper | 0.0172 | 0.00393 | 8 900 |
| Aluminium | 0.045 | 0.00393 | 2 700 |

*l - length of conductor (winding)*

*(F) - resistivity* (Ω.m)

*$S_{Cu}$ – cross-section area of the conductor*

*J – current density* (A/m$^2$)

*(F) - temperature*

*$\Delta\vartheta$ - temperature rise*

*F - resistance-temperature coefficient*

*$R_{20}$ – resistance determined (measured) at* 20$^o$C

## MECHANICAL LOSS $\Delta P_m$

Power loss due to:

(F) bearing friction

(G) windage (fan - ventilator action, friction of rotating parts against coolant, f.e. air)

(H) brush friction

## EFFICIENCY OF ENERGY CONVERSION

Efficiency of power conversion is usually the most important parameter of electrical machine.

$$\frac{P_{out}}{P_{in}} = \eta \quad \text{efficiency}$$

$$P_{in} - P_{out} = \Sigma\Delta P \qquad \text{total power loss}$$

$$\text{(G)} \qquad \Delta P = \Delta P_{Fe} + \Delta P_{Cu} + \Delta P_{m}$$

$$\boxed{\eta = \frac{P_{out}}{P_{out} + \sum \Delta P} = \frac{P_{in} - \sum \Delta P}{P_{in}}}$$ can be also expressed in %

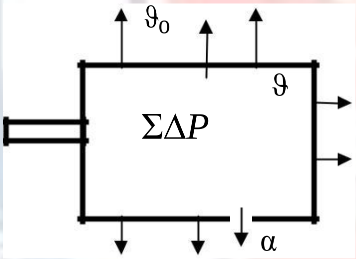
## TEMPERATURE RISE OF THE MACHINE

Simplifying assumptions:

(G) machine is an ideal homogeneous body,

(H) machine is internally heated by total power loss $\Sigma\Delta P$,

(I) machine is surface (externally) cooled (f.e. by means of external fan):




The energy balance equation for heated machine when running

$$\text{C}\,\Delta P \cdot d\,t = M \cdot c \cdot d\,\vartheta + A \cdot \alpha_h\,(\vartheta - \vartheta_o)$$

and its solution for temperature rise (above the ambient temperature) $\Delta\vartheta = \vartheta - \vartheta_o$

$$\Delta\vartheta = \Delta\vartheta_{max}\left(1 - e^{-\frac{t}{T_h}}\right) \qquad \Delta\vartheta_{max} = \frac{\sum \Delta P}{A \cdot \alpha_h} \qquad T_h = \frac{M \cdot c}{A \cdot \alpha_h}$$

The energy balance equation for cooling down (machine at rest)

$$0 = M \cdot c \cdot d\,\vartheta + A \cdot \alpha_c\,(\vartheta - \vartheta_o)$$

and

$$\Delta\vartheta = \Delta\vartheta_i\, e^{-\frac{t}{T_c}} \qquad T_c = \frac{M \cdot c}{A \cdot \alpha_c}$$

where $\Delta\vartheta_i$ is initial temperature rise (at the beginning of cooling)

*$\vartheta_o$ - ambient temperature (coolant temp.)*

*T.- machine temperature*

*(D)- heat transfer coefficient* [W/(m$^2$.K)]

*M - mass of the machine*

*c - specific heat of the machine body* [J/(kg.K)]

*A - area of machine surface at which the heat exchange occurs (cooling surface)*

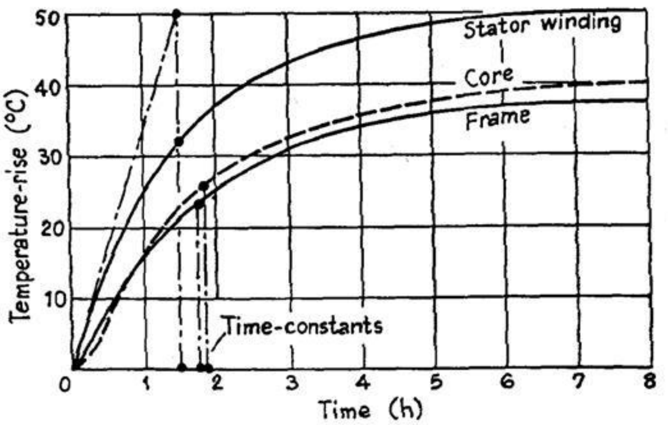
*$\alpha_h$ - heat transfer coeff. of running machine*

*$T_h$ - heating time constant*

*$\alpha_c$ - heat transfer coeff. of resting machine (while cooling at rest)*

*$T_c$ - cooling time constant (at rest)*

When we don't regard a machine as a homogeneous body, the temperature rises of the winding, core & frame can be different:




What maximum temperature (or temperature rise) can be allowed for any machine part?

Too high temperature (overheating) can damage the material or can shorten the material life expectancy (material life time).

Insulating materials are most sensitive to temperature. Therefore, almost all usable materials are subject to temperature limitations. They are classified in accordance with limits of operating temperature:

Thermal life expectancy

| Insulation class | **A** | **E** | **B** | **F** | **H** |
|---|---|---|---|---|---|
| Max temperature $^{o}$C | 105 | 120 | 130 | 155 | 180 |

Temperature of winding measured by means of resistance measurement method

or, when we assume the ambient temperature $\vartheta_o$ = 40$^{o}$C and take into consideration the average temperature rise (for example the temperature rise of the entire winding determined by means of its resistance increase), we can describe the maximum temperature rise:

| Insulation class | **A** | **E** | **B** | **F** | **H** |
|---|---|---|---|---|---|
| Max temp. rise, K | 60 | 75 | 80 | 105 | 125 |

*A, E, B, F, H – previously used abbreviations of machines' insulation classes (still in application in machines of older manufacturing)*

IEC and European Standard **60034-1 Edition 11: "Rotating electrical machines – Part 1: Rating and performance"** provides three degrees of thermal classification:

| Thermal classification | **130** | **155** | **180** |
|---|---|---|---|
| Max temp. rise, K | 80 | 105 | 125 |

*Most actual system of thermal classification*

For large machines the life expectancy is about 30 years, providing the maximum temperature of insulating material used in the machine is not exceeded. Increased temperature above the permissible value causes the quicker degradation of insulating material.

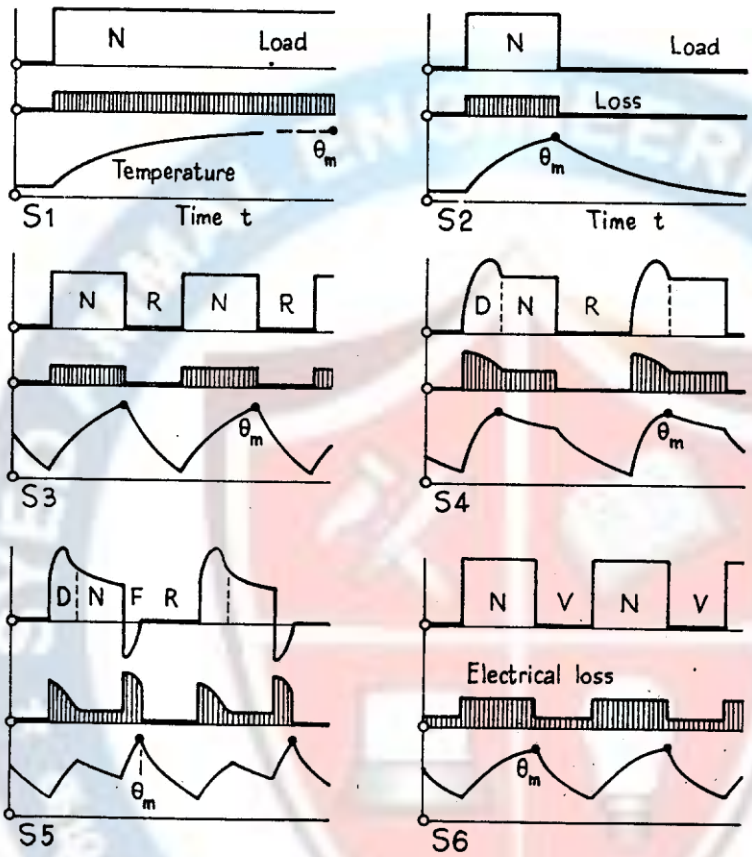
Machine life expectancy (time to failure) is halved for each 8$^{o}$C temperature rise above that maximum permissible value (continuously).

*8$^{o}$C rule*

*Montsinger's rule*

# DUTY TYPES OF THE MACHINE

There are various applications of the machines. Standard motors & transformers are rated in terms of continuous operation. But there are also other possible types of operation - *duty types*:




S1 - continuous running duty
S2 - short-time duty
S3 - intermittent periodic duty
S4 - intermittent periodic duty with starting
S5 - intermittent periodic duty with electric braking
S6 – continuous-operation periodic duty ….

Maximum temperature rise must not exceed the appropriate permissible value for the given insulation class of the machine.

Insulation class (thermal classification) of the machine is always given at the machine nominal plate.

The rated (nominal) power of the machine is referred to (corresponds to) the chosen duty type which should also be given at the machine nominal plate by means of: duty type symbol (S1 … S10), corresponding cyclic duration factor and moments of inertia of machine and of the load.

# ELECTRICAL MACHINES

Q. 1 Leakage flux in an induction motor is

(A) flux that leaks through the machine

(B) flux that links both stator and rotor windings

(C) flux that links none of the windings

(D) flux that links the stator winding or the rotor winding but not both

Q. 2 The angle *d* in the swing equation of a synchronous generator is the

6. angle between stator voltage and current
7. angular displacement of the rotor with respect to the stator
8. angular displacement of the stator mmf with respect to a synchronously rotating axis.
9. angular displacement of an axis fixed to the rotor with respect to a synchronously rotating axis

Q. 3 A single-phase transformer has no-load loss of 64 W, as obtained from an open circuit test. When a short-circuit test is performed on it with 90% of the rated currents flowing in its both LV and HV windings, he measured loss is 81 W. The transformer has maximum efficiency when operated at

(A) 50.0% of the rated current

(B) 64.0% of the rated current

(C) 80.0% of the rated current

(D) 88.8% of the rated current

Q. 4 A 4-pole induction motor, supplied by a slightly unbalanced three-phase 50 Hz source, is rotating at 1440 rpm. The electrical frequency in Hz of the induced negative sequence current in the rotor is

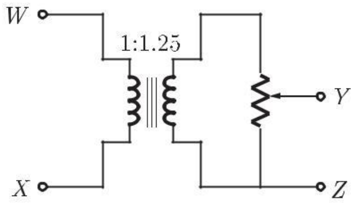
100

98

52

48

Q. 5 The following arrangement consists of an ideal transformer and an attenuator which attenuates by a factor of 0.8. An ac voltage $V_{WX1}$ = 100 V is applied across WX to get an open circuit voltage $V_{YZ1}$ across YZ. Next, an ac voltage $V_{YZ2}$ = 100 V is applied across YZ to get an open circuit voltage $V_{WX2}$ across WX. Then, $V_{YZ1}/V_{WX1}$, $V_{WX2}/V_{YZ2}$ are respectively,




(A) 125/100 and 80/100 (B) 100/100 and 80/100

Q. 6 The slip of an induction motor normally does not depend on

(A) rotor speed (B) synchronous speed

(C) shaft torque (D) core-loss component

Q. 7 A 220 V, 15 kW, 100 rpm shunt motor with armature resistance of 0.25 W, has a rated line current of 68 A and a rated field current of 2.2 A. The change in field flux required to obtain a speed of 1600 rpm while drawing a line current of 52.8 A and a field current of 1.8 A is

(A) 18.18% increase (B) 18.18% decrease

(C) 36.36% increase (D) 36.36% decrease

Q. 8 The locked rotor current in a 3-phase, star connected 15 kW, 4 pole, 230 V, 50 Hz induction motor at rated conditions is 50 A. Neglecting losses and magnetizing current, the approximate locked rotor line current drawn when the motor is connected to a 236 V, 57 Hz supply is

(A) 58.5 A (B) 45.0 A

(C) 42.7 A (D) 55.6 A

Q. 9 A single phase 10 kVA, 50 Hz transformer with 1 kV primary winding draws 0.5 A and 55 W, at rated voltage and frequency, on no load. A second transformer has a core with all its linear dimensions $\sqrt{2}$ times the corresponding dimensions of the first transformer. The core material and lamination thickness are the same in both transformer. The primary winding of both the transformers have the save number of turns. If a rate voltage of 2 kV at 50 Hz is applied to the primary of the second transformer, then the no load current and power, respectively, are

(A) 0.7 A, 77.8 A (B) 0.7 A, 155.6 W

(C) 1 A, 110 W (D) 1 A, 220 W

Q. 10 A 4 point starter is used to start and control the speed of a

(A) dc shunt motor with armature resistance control

(B) dc shunt motor with field weakening control

(C) dc series motor

(D) dc compound motor

Q. 11 A three phase, salient pole synchronous motor is connected to an infinite bus. It is operated at no load a normal excitation. The field excitation of the motor is first reduced to zero and then increased in reverse direction gradually. Then the armature current.

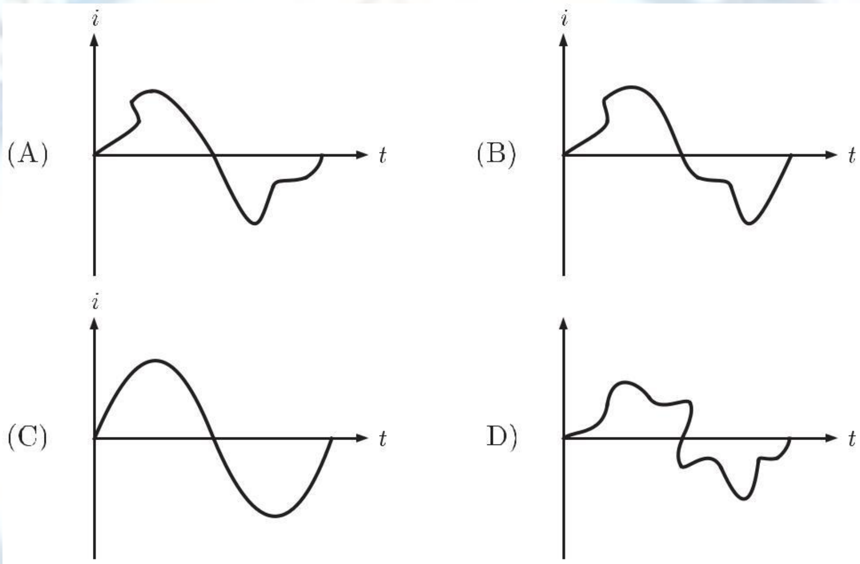
I. Increases continuously

J. First increases and then decreases steeply

K. First decreases and then increases steeply

L. Remains constant

Q. 12 A single phase air core transformer, fed from a rated sinusoidal supply, is operating at no load. The steady state magnetizing current drawn by the transformer from the supply will have the waveform




Q. 13 A 220 V, DC shunt motor is operating at a speed of 1440 rpm. The armature resistance is 1.0 W and armature current is 10 A. of the excitation of the machine is reduced by 10%, the extra resistance to be put in the armature circuit to maintain the same speed and torque will be

(A) 1.79 W (B) 2.1 W

(C) 18.9 W (D) 3.1 W

Q. 14 A three-phase 440 V, 6 pole, 50 Hz, squirrel cage induction motor is running at a slip of 5%. The speed of stator magnetic field to rotor magnetic field and speed of rotor with respect of stator magnetic field are

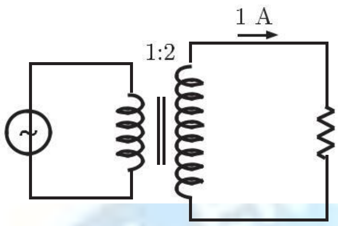
(A) zero, -5 rpm

(B) zero, 955 rpm

(C) 1000 rpm, -5 rpm

(D) 1000 rpm, 955 rpm

Q. 15 A Single-phase transformer has a turns ratio 1:2, and is connected to a purely resistive load as shown in the figure. The magnetizing current drawn is 1 A, and the secondary current is 1 A. If core losses and leakage reactances are neglected, the primary current is




1.41 A

2 A

2.24 A

3 A

Q. 16 A balanced three-phase voltage is applied to a star-connected induction motor, the phase to neutral voltage being $V$. The stator resistance, rotor resistance referred to the stator, stator leakage reactance, rotor leakage reactance referred to the stator, and the magnetizing reactance are denoted by $r_s$ , $r_r$ , $X_s$ , $X_r$ and $X_m$ , respectively. The magnitude of the starting current of the motor is given by

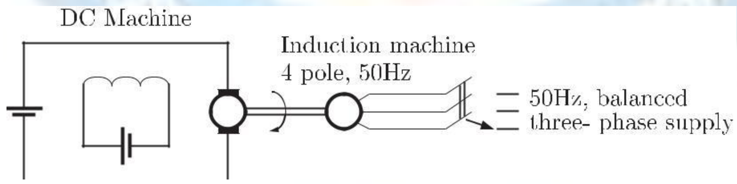
(A) $\frac{V_s}{\sqrt{(r_s + r_r)^2 + (X_s + X_r)^2}}$

(B) $\frac{V_s}{\sqrt{r_s^2 + (X_s + X_m)^2}}$

(C) $\frac{V_s}{\sqrt{(r_s + r_r)^2 + (X_m + X_r)^2}}$

(D) $\frac{V_s}{\sqrt{r_s^2 + (X_m + X_r)^2}}$

Q. 17 A separately excited dc machine is coupled to a 50 Hz, three-phase, 4-pole induction machine as shown in figure. The dc machine is energized first and the machines rotate at 1600 rpm. Subsequently the induction machine is also connected to a 50 Hz, three-phase source, the phase sequence being consistent with the direction of rotation. In steady state




(P) both machines act as generator

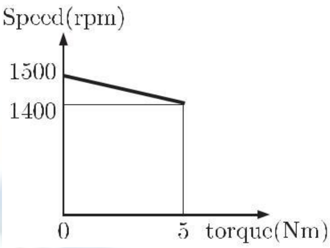
(Q) the dc machine acts as a generator, and the induction machine acts as a motor

(R) the dc machine acts as a motor, and the induction machine acts as a generator

(S) both machines act as motors

**Common Data for Questions 18 and 19**

A separately excited DC motor runs at 1500 rpm under no-load with 200 V applied to the armature. The field voltage is maintained at its rated value. The speed of the motor, when it delivers a torque of 5 Nm, is 1400 rpm as shown in figure. The rotational losses and armature reaction are neglected.




(G) 18 The armature resistance of the motor is

(A) 2 W (B) 3.4 W

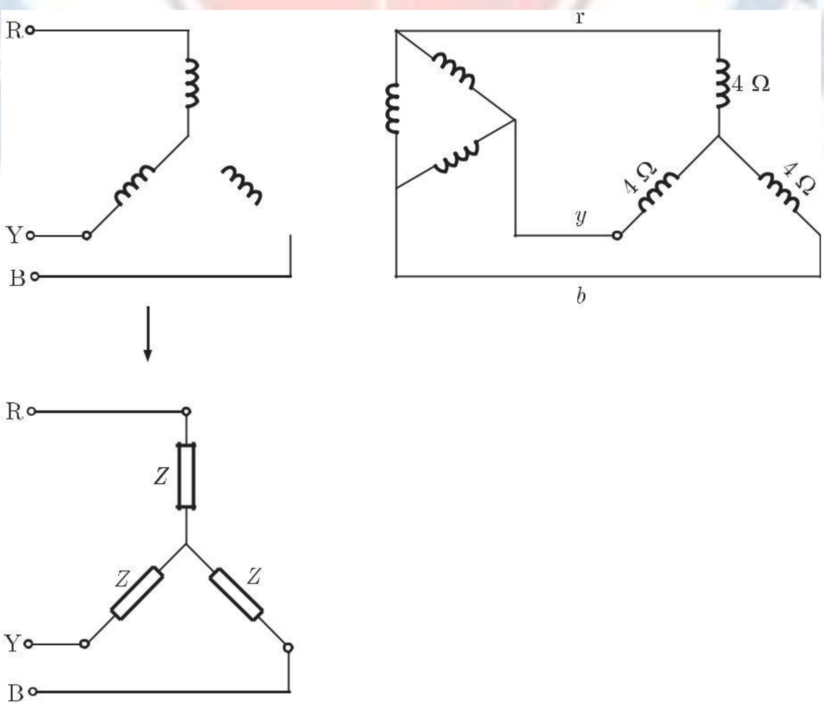
(C) 4.4 W (D) 7.7 W

(J) 19 For the motor to deliver a torque of 2.5 Nm at 1400 rpm, the armature voltage to be applied is

(A) 125.5 V (B) 193.3 V

(C) 200 V (D) 241.7 V

Q. 20 A balanced star-connected and purely resistive load is connected at the secondary of a star-delta transformer as shown in figure. The line-to line voltage rating of the transformer is 110 V/200 V.
Neglecting the non-idealities of the transformer, the impedance *Z* of the equivalent star-connected load, referred to the primary side of the transformer, is

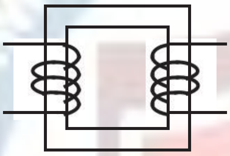


(A) $(3 + j0)$ W | (B) $(0.866 - j0.5)$ W
(C) $(0.866 + j0.5)$ W | (D) $(1 + j0)$ W

Q. 21 A field excitation of 20 A in a certain alternator results in an armature current of 400 A in short circuit and a terminal voltage of 2000 V on open circuit. The magnitude of the internal voltage drop within the machine at a load current of 200 A is

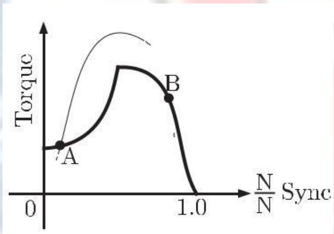
(A) 1 V (B) 10 V
(C) 100 V (D) 1000 V

Q. 22 The single phase, 50 Hz iron core transformer in the circuit has both the vertical arms of cross sectional area 20 $cm^2$ and both the horizontal arms of cross sectional area 10 $cm^2$. If the two windings shown were wound instead on opposite horizontal arms, the mutual inductance will



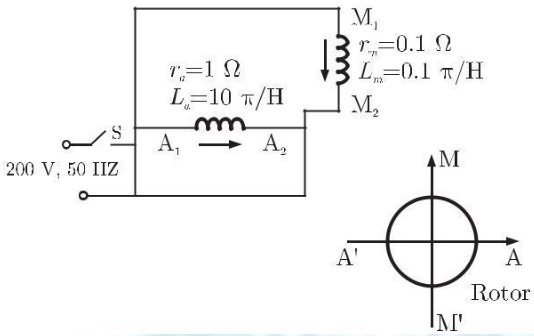
(A) double (B) remain same
(C) be halved (D) become one quarter

Q. 23 A 3-phase squirrel cage induction motor supplied from a balanced 3-phase source drives a mechanical load. The torque-speed characteristics of the motor(solid curve) and of the load(dotted curve) are shown. Of the two equilibrium points A and B, which of the following options correctly describes the stability of A and B ?




(A) A is stable, B is unstable (B) A is unstable, B is stable
(C) Both are stable (D) Both are unstable

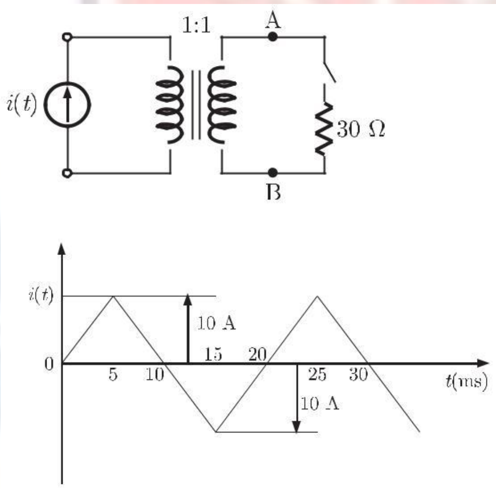
Q. 24 A 200 V, 50 Hz, single-phase induction motor has the following connection diagram and winding orientations as shown. MM' is the axis of the main stator winding($M_1$ $M_2$) and AA' is that of the auxiliary winding($A_1$ $A_2$). Directions of the winding axis indicate direction of flux when currents in the windings are in the directions shown. Parameters of each winding are indicated. When switch S is closed the motor




(G) rotates clockwise
(H) rotates anti-clockwise
(I) does not rotate
(J) rotates momentarily and comes to a halt

**Common Data for Questions 25 and 26 :**

The circuit diagram shows a two-winding, lossless transformer with no leakage flux, excited from a current source, *i* (*t*), whose waveform is also shown. The transformer has a magnetizing inductance of 400/p mH.



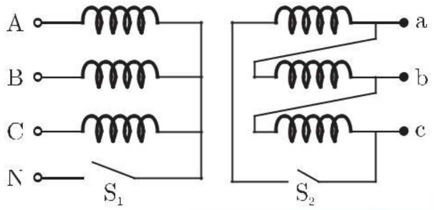

Q. 25 The peak voltage across A and B, with S open is

(A) $\frac{400}{p}$ V
(B) 800 V
(C) $\frac{4000}{p}$ V
(D) $\frac{800}{p}$ V

Q. 26 If the wave form of *i* (*t*) is changed to *i* (*t*) = 10 sin(100*pt*) A, the peak voltage across A and B with S closed is

(A) 400 V
(B) 240 V
(C) 320 V
(D) 160 V

**Common Data for Questions 27 and 28:**




The star-delta transformer shown above is excited on the star side with balanced, 4-wire, 3-phase, sinusoidal voltage supply of rated magnitude. The transformer is under no load condition

Q. 27 With both S1 and S2 open, the core flux waveform will be

(A) a sinusoid at fundamental frequency

(B) flat-topped with third harmonic

(C) peaky with third-harmonic

(D) none of these

Q. 28 With S2 closed and S1 open, the current waveform in the delta winding will be

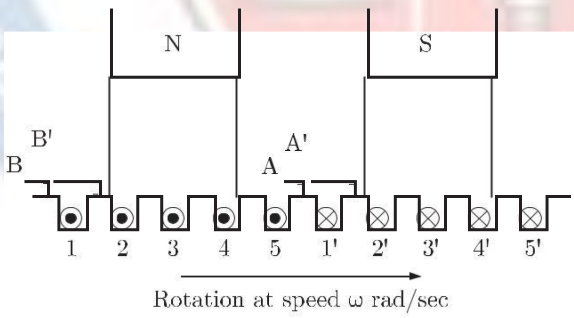
(A) a sinusoid at fundamental frequency

(B) flat-topped with third harmonic

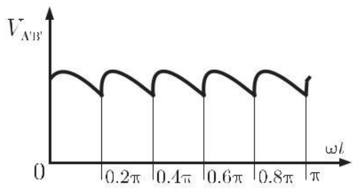
(C) only third-harmonic

(D) none of these

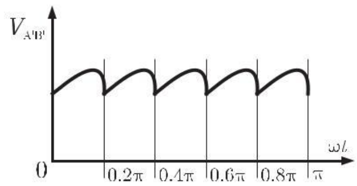
Q. 29 Figure shows the extended view of a 2-pole dc machine with 10 armature conductors. Normal brush positions are shown by A and B, placed at the interpolar axis. If the brushes are now shifted, in the direction of rotation, to A' and B' as shown, the voltage waveform $V_{A'B'}$ will resemble



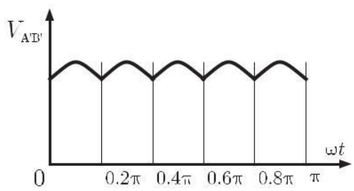

(A)



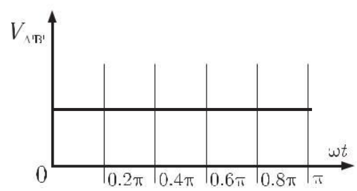

(C)



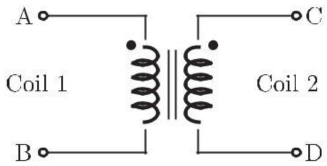

(B)




(D)



**Statement for Linked Answer Questions 30 and 31 :**




The figure above shows coils-1 and 2, with dot markings as shown, having 4000 and 6000 turns respectively. Both the coils have a rated current of 25 A. Coil-1 is excited with single phase, 400 V, 50 Hz supply.

Q. 30 The coils are to be connected to obtain a single-phase, $\frac{400}{1000}$ V, auto-transformer to drive a load of 10 kVA. Which of the options given should be exercised to realize the required auto-transformer ?

(A) Connect A and D; Common B

(B) Connect B and D; Common C

(C) Connect A and C; Common B

(D) Connect A and C; Common D

Q. 31 In the autotransformer obtained in Question 16, the current in each coil is

(A) Coil-1 is 25 A and Coil-2 is 10 A

(B) Coil-1 is 10 A and Coil-2 is 25 A

(C) Coil-1 is 10 A and Coil-2 is 15 A

(D) Coil-1 is 15 A and Coil-2 is 10 A

(I) 32 Distributed winding and short chording employed in AC machines will result in

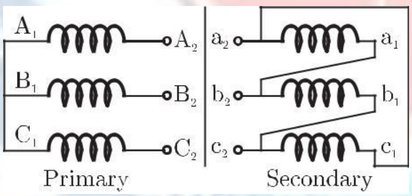
(G) increase in emf and reduction in harmonics

(H) reduction in emf and increase in harmonics

(I) increase in both emf and harmonics

(J) reduction in both emf and harmonics

(G) 33 Three single-phase transformer are connected to form a 3-phase transformer bank. The transformers are connected in the following manner :




The transformer connecting will be represented by

(A) Y d0

(B) Y d1

(C) Y d6

(D) Y d11

Q. 34 In a stepper motor, the detent torque means

(A) minimum of the static torque with the phase winding excited

(B) maximum of the static torque with the phase winding excited

(C) minimum of the static torque with the phase winding unexcited

(D) maximum of the static torque with the phase winding unexcited

Q. 35 It is desired to measure parameters of 230 V/115 V, 2 kVA, single-phase transformer. The following wattmeters are available in a laboratory:

$W_1$ : 250 V, 10 A, Low Power Factor

$W_2$ : 250 V, 5 A, Low Power Factor

$W_3$ : 150 V, 10 A, High Power Factor

$W_4$ : 150 V, 5 A, High Power Factor

The Wattmeters used in open circuit test and short circuit test of the transformer will respectively be

(A) $W_1$ and $W_2$

(B) $W_2$ and $W_4$

(C) $W_1$ and $W_4$

(D) $W_2$ and $W_3$

Y

Q. 36 A 230 V, 50 Hz, 4-pole, single-phase induction motor is rotating in the clockwise (forward) direction at a speed of 1425 rpm. If the rotor resistance at standstill is 7.8 W, then the effective rotor resistance in the backward branch of the equivalent circuit will be

G 2 W

H 4 W

I 78 W

J 156 W

Q. 37 A 400 V, 50 Hz 30 hp, three-phase induction motor is drawing 50 A current at 0.8 power factor lagging. The stator and rotor copper losses are 1.5 kW and 900 W respectively. The friction and windage losses are 1050 W and the core losses are 1200 W. The air-gap power of the motor will be

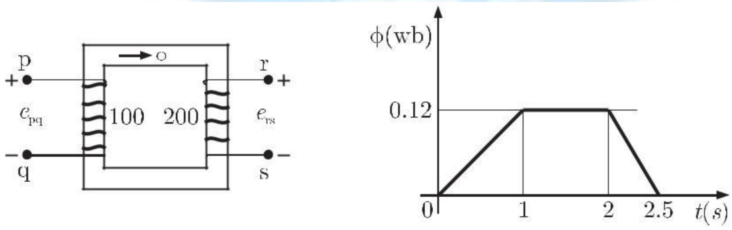
(H) 23.06 kW

(I) 24.11 kW

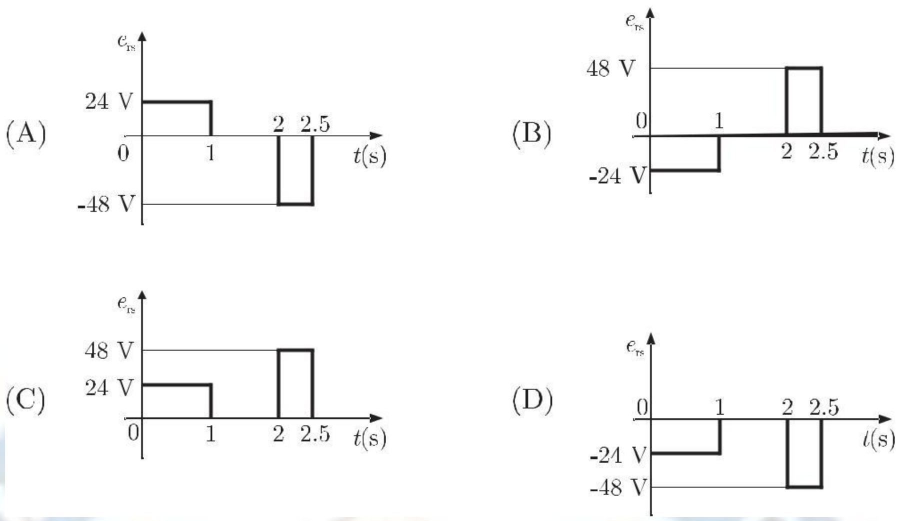
(J) 25.01 kW

(K) 26.21 kW

Q. 38 The core of a two-winding transformer is subjected to a magnetic flux variation as indicated in the figure.




The induced emf ($e_{rs}$) in the secondary winding as a function of time will be of the form




Q. 39 A 400 V, 50 Hz, 4-pole, 1400 rpm, star connected squirrel cage induction motor has the following parameters referred to the stator:

$R'_r$ = 1.0 W, $X_s$ = $X'_r$ = 1.5 W

Neglect stator resistance and core and rotational losses of the motor. The motor is controlled from a 3-phase voltage source inverter with constant *V*/*f* control. The stator line-to-line voltage(rms) and frequency to obtain the maximum torque at starting will be :

(A) 20.6 V, 2.7 Hz

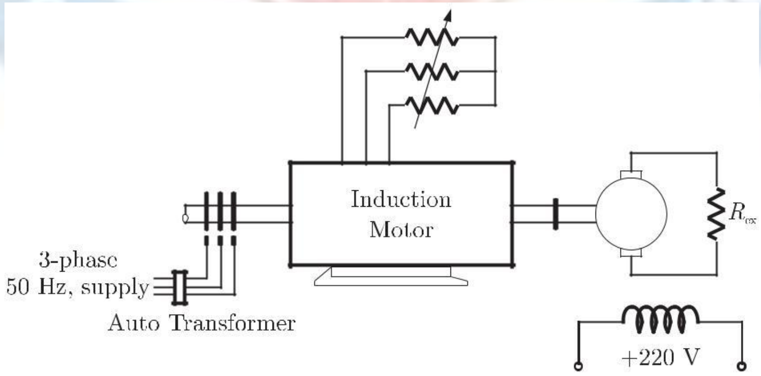
(B) 133.3 V, 16.7 Hz

(C) 266.6 V, 33.3 Hz

(D) 323.3 V, 40.3 Hz

**Common Data for Questions 40 and 41.**

A 3-phase, 440 V, 50 Hz, 4-pole slip ring induction motor is feed from the rotor side through an auto-transformer and the stator is connected to a variable resistance as shown in the figure.




The motor is coupled to a 220 V, separately excited d.c generator feeding power to fixed resistance of 10 W. Two-wattmeter method is used to measure the input power to induction motor. The variable resistance is adjusted such the motor runs at 1410 rpm and the following readings were recorded $W_1$ = 1800 W, $W_2$ =- 200 W.

Q. 40 The speed of rotation of stator magnetic field with respect to rotor structure will be

(A) 90 rpm in the direction of rotation

(B) 90 rpm in the opposite direction of rotation

(C) 1500 rpm in the direction of rotation

(D) 1500 rpm in the opposite direction of rotation

Q. 41 Neglecting all losses of both the machines, the dc generator power output and the current through resistance ($R_{ex}$) will respectively be

(A) 96 W, 3.10 A (B) 120 W, 3.46 A

(C) 1504 W, 12.26 A (D) 1880 W, 13.71 A

**Statement for Linked Answer Question 42 and 43.**

A 240 V, dc shunt motor draws 15 A while supplying the rated load at a speed of 80 rad/s. The armature resistance is 0.5 W and the field winding resistance is 80 W.

Q. 42 The net voltage across the armature resistance at the time of plugging will be

(A) 6 V (B) 234 V

(C) 240 V (D) 474 V

Q. 43 The external resistance to be added in the armature circuit to limit the armature current to 125% of its rated value is

(A) 31.1 W (B) 31.9 W

(C) 15.1 W (D) 15.9 W

**Statement for Linked Answer Question 44 and 45.**

A synchronous motor is connected to an infinite bus at 1.0 pu voltage and draws 0.6 pu current at unity power factor. Its synchronous reactance is 1.0 pu resistance is negligible.

(J) 44 The excitation voltage ($E$ ) and load angle ($d$) will respectively be

(A) 0.8 pu and 36.86c lag (B) 0.8 pu and 36.86c lead

(C) 1.17 pu and 30.96c lead (D) 1.17 pu and 30.96c lag

D 45 Keeping the excitation voltage same, the load on the motor is increased such that the motor current increases by 20%. The operating power factor will become

(A) 0.995 lagging (B) 0.995 leading

(C) 0.791 lagging (D) 0.848 leading

Q. 46 In a transformer, zero voltage regulation at full load is

(A) not possible

(B) possible at unity power factor load

(C) possible at leading power factor load

(D) possible at lagging power factor load

Q. 47 The dc motor, which can provide zero speed regulation at full load without any controller is

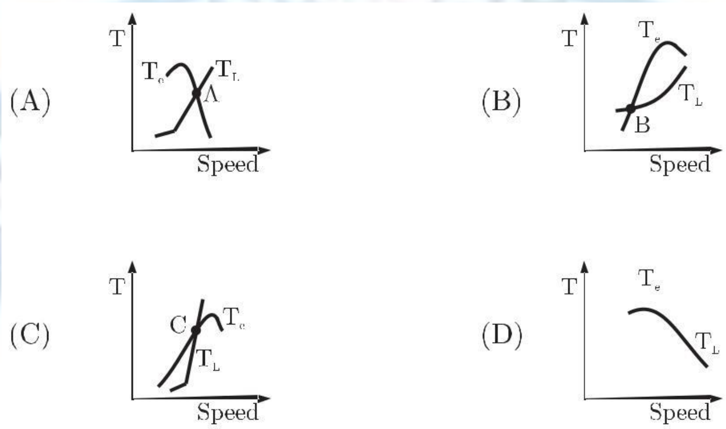
(A) series

(B) shunt

(C) cumulative compound

(D) differential compound

Q. 48 The electromagnetic torque $T_e$ of a drive and its connected load torque $T_L$ are as shown below. Out of the operating points A, B, C and D, the stable ones are




(A) A, C, D

(B) B, C

(C) A, D

(D) B, C, D

Q. 49 A three-phase synchronous motor connected to ac mains is running at full load and unity power factor. If its shaft load is reduced by half, with field current held constant, its new power factor will be

U. unity

V. leading

W. lagging

X. dependent on machine parameters

Q. 50 A 100 kVA, 415 V(line), star-connected synchronous machine generates rated open circuit voltage of 415 V at a field current of 15 A. The short circuit armature current at a field current of 10 A is equal to the rated armature current. The per unit saturated synchronous reactance is

(A) 1.731

(B) 1.5

(C) 0.666

(D) 0.577

Q. 51 A single-phase, 50 kVA, 250 V/500 V two winding transformer has an efficiency of 95% at full load, unity power factor. If it is re-configured as a 500 V/750 V auto-transformer, its efficiency at its new rated load at unity power factor will be

(A) 95.752%

(B) 97.851%

(C) 98.276%

(D) 99.241%

(E) 52 A three-phase, three-stack, variable reluctance step motor has 20 poles on each rotor and stator stack. The step angle of this step motor is

(A) 3c (B) 6c

(C) 9c (D) 18c

(G) 53 A three-phase squirrel cage induction motor has a starting torque of 150% and a maximum torque of 300% with respect to rated torque at rated voltage and rated frequency. Neglect the stator resistance and rotational losses. The value of slip for maximum torque is

(A) 13.48% (B) 16.42%

(C) 18.92% (D) 26.79%

**Common Data for Question 54, 55 and 56:**

A three phase squirrel cage induction motor has a starting current of seven times the full load current and full load slip of 5%

F 54 If an auto transformer is used for reduced voltage starting to provide 1.5 per unit starting torque, the auto transformer ratio(%) should be

(A) 57.77 % (B) 72.56 %

(C) 78.25 % (D) 81.33 %

(V) 55 If a star-delta starter is used to start this induction motor, the per unit starting torque will be

(A) 0.607 (B) 0.816

(C) 1.225 (D) 1.616

C 56 If a starting torque of 0.5 per unit is required then the per unit starting current should be

(A) 4.65 (B) 3.75

(C) 3.16 (D) 2.13

Q. 57 In transformers, which of the following statements is valid ?

S. In an open circuit test, copper losses are obtained while in short circuit test, core losses are obtained

T. In an open circuit test, current is drawn at high power factor

U. In a short circuit test, current is drawn at zero power factor

V. In an open circuit test, current is drawn at low power factor

Q. 58 For a single phase capacitor start induction motor which of the following statements is valid ?

S. The capacitor is used for power factor improvement

T. The direction of rotation can be changed by reversing the main winding terminals

U. The direction of rotation cannot be changed

V. The direction of rotation can be changed by interchanging the supply terminals

Q. 59 In a DC machine, which of the following statements is true ?

(S) Compensating winding is used for neutralizing armature reaction while interpole winding is used for producing residual flux

(T) Compensating winding is used for neutralizing armature reaction while interpole winding is used for improving commutation

(U) Compensating winding is used for improving commutation while interpole winding is used for neutralizing armature reaction

(V) Compensation winding is used for improving commutation while interpole winding is used for producing residual flux

Q. 60 A 220 V DC machine supplies 20 A at 200 V as a generator. The armature resistance is 0.2 ohm. If the machine is now operated as a motor at same terminal voltage and current but with the flux increased by 10%, the ratio of motor speed to generator speed is

(A) 0.87 (B) 0.95

(C) 0.96 (D) 1.06

Q. 61 A synchronous generator is feeding a zero power factor (lagging) load at rated current. The armature reaction is

(C) magnetizing

(D) demagnetizing

(E) cross-magnetizing

(F) ineffective

Q. 62 Two transformers are to be operated in parallel such that they share load in proportion to their kVA ratings. The rating of the first transformer is 500 kVA ratings. The rating of the first transformer is 500 kVA and its pu leakage impedance is 0.05 pu. If the rating of second transformer is 250 kVA, its pu leakage impedance is

(A) 0.20 (B) 0.10

(C) 0.05 (D) 0.025

Q. 63 The speed of a 4-pole induction motor is controlled by varying the supply frequency while maintaining the ratio of supply voltage to supply frequency ($V/f$) constant. At rated frequency of 50 Hz and rated voltage of 400 V its speed is 1440 rpm. Find the speed at 30 Hz, if the load torque is constant

(A) 882 rpm (B) 864 rpm

(C) 840 rpm (D) 828 rpm

Q. 64 A 3-phase, 4-pole, 400 V 50 Hz , star connected induction motor has following circuit parameters

$r_1 = 1.0$ W, $r'_2 = 0.5$ W, $X_1 = X'_2 = 1.2$ W, $X_m = 35$ W

The starting torque when the motor is started direct-on-line is (use approximate equivalent circuit model)

(A) 63.6 Nm (B) 74.3 Nm

(C) 190.8 Nm (D) 222.9 Nm

Q. 65 A 3-phase, 10 kW, 400 V, 4-pole, 50Hz, star connected induction motor draws 20 A on full load. Its no load and blocked rotor test data are given below.

| | | | |
|---|---|---|---|
| No Load Test : | 400 V | 6 A | 1002 W |
| Blocked Rotor Test : | 90 V | 15 A | 762 W |

Neglecting copper loss in no load test and core loss in blocked rotor test, estimate motor's full load efficiency

(A) 76% (B) 81%

(C) 82.4% (D) 85%

Q. 66 A 3-phase, 400 V, 5 kW, star connected synchronous motor having an internal reactance of 10 W is operating at 50% load, unity p.f. Now, the excitation is increased by 1%. What will be the new load in percent, if the power factor is to be kept same ? Neglect all losses and consider linear magnetic circuit.

(A) 67.9% (B) 56.9%

(C) 51% (D) 50%

**Data for Q. 67 to Q 69 are given below.**

A 4-pole, 50 Hz, synchronous generator has 48 slots in which a double layer winding is housed. Each coil has 10 turns and is short pitched by an angle to 36c electrical. The fundamental flux per pole is 0.025 Wb

Q. 67 The line-to-line induced emf(in volts), for a three phase star connection is approximately

(A) 808 (B) 888

(C) 1400 (D) 1538

Q. 68 The line-to-line induced emf(in volts), for a three phase connection is approximately

(A) 1143 (B) 1332

(C) 1617 (D) 1791

Q. 69 The fifth harmonic component of phase emf(in volts), for a three phase star connection is

(A) 0 (B) 269

(C) 281 (D) 808

**Statement for Linked Answer Questions 70 and 71.**

A 300 kVA transformer has 95% efficiency at full load 0.8 p.f. lagging and 96% efficiency at half load, unity p.f.

Q. 70 The iron loss ($P_i$) and copper loss ($P_c$) in kW, under full load operation are

(A) $P_c = 4.12$, $P_i = 8.51$ (B) $P_c = 6.59$, $P_i = 9.21$

(C) $P_c = 8.51$, $P_i = 4.12$ (D) $P_c = 12.72$, $P_i = 3.07$

Q. 71 What is the maximum efficiency (in %) at unity p.f. load ?

(A) 95.1 (B) 96.2

(C) 96.4 (D) 98.1

Q. 72 The equivalent circuit of a transformer has leakage reactances $X_1$, $X'_2$ and magnetizing reactance $X_M$ . Their magnitudes satisfy

(A) $X_1 >> X'_2 >> X_M$

(B) $X_1 << X'_2 << X_M$

(C) $X_1 . X'_2 >> X_M$

(D) $X_1 . X'_2 << X_M$

Q. 73 Which three-phase connection can be used in a transformer to introduce a phase difference of 30c between its output and corresponding input line voltages

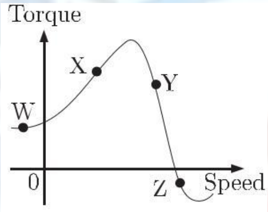
(A) Star-Star

(B) Star-Delta

(C) Delta-Delta

(D) Delta-Zigzag

Q. 74 On the torque/speed curve of the induction motor shown in the figure four points of operation are marked as W, X, Y and Z. Which one of them represents the operation at a slip greater than 1 ?




(A) W

(B) X

(C) Y

(D) Z

Q. 75 For an induction motor, operation at a slip $s$ , the ration of gross power output to air gap power is equal to

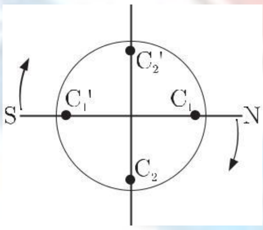
(A) $(1 - s)^2$

(B) $(1 - s)$

(C) $(1 - s)$

(D) $(1 - \sqrt{s})$

Q. 76 Two magnetic poles revolve around a stationary armature carrying two coil ($c_1 - c_1l$ , $c_2 - c_2l$) as shown in the figure. Consider the instant when the poles are in a position as shown. Identify the correct statement regarding the polarity of the induced emf at this instant in coil sides $c_1$ and $c_2$.




(A) 9 in $c_1$, no emf in $c_2$

(B) 7 in $c_1$, no emf in $c_2$

(C) 9 in $c_2$, no emf in $c_1$

(D) 7 in $c_2$, no emf in $c_1$

Q. 77 A 50 kW dc shunt is loaded to draw rated armature current at any given speed. When driven

(i) at half the rated speed by armature voltage control and

E at 1.5 times the rated speed by field control, the respective output powers delivered by the motor are approximately.

D 25 kW in (i) and 75 kW in (ii)

E 25 kW in (i) and 50 kW in (ii)

F 50 kW in (i) and 75 kW in (ii)

G 50 kW in (i) and 50 kW in (ii)

Q. 78 In relation to the synchronous machines, which on of the following statements is false ?

(A) In salient pole machines, the direct-axis synchronous reactance is greater than the quadrature-axis synchronous reactance.

(B) The damper bars help the synchronous motor self start.

(C) Short circuit ratio is the ratio of the field current required to produces the rated voltage on open circuit to the rated armature current.

(D) The V-cure of a synchronous motor represents the variation in the armature current with field excitation, at a given output power.

Q. 79 In relation to DC machines, match the following and choose the correct combination

| | List-I | | List-II |
|---|---|---|---|
| | **Performance Variables** | | **Proportional to** |
| **P.** | Armature emf ($E$) | **1.** | Flux($f$), speed ($w$) and armature current ($I_a$) |
| **Q.** | Developed torque ($T$) | **2.** | $f$ and $w$ only |
| **R** | Developed power ($P$) | **3.** | $f$ and $I_a$ only |
| | | **4.** | $I_a$ and $w$ only |
| | | **5.** | $I_a$ only |

**Codes:**

| | P | Q | R |
|---|---|---|---|
| (A) | 3 | 3 | 1 |
| (B) | 2 | 5 | 4 |
| (C) | 3 | 5 | 4 |
| (D) | 2 | 3 | 1 |

Q. 80 Under no load condition, if the applied voltage to an induction motor is reduced from the rated voltage to half the rated value,

26 the speed decreases and the stator current increases

27 both the speed and the stator current decreases

28 the speed and the stator current remain practically constant

29 there is negligible change in the speed but the stator current decreases

Q. 81 A three-phase cage induction motor is started by direct-on-line (DOL) switching at the rated voltage. If the starting current drawn is 6 times the full load current, and the full load slip is 4%, then ratio of the starting developed torque to the full load torque is approximately equal to

(A) 0.24 (B) 1.44

(C) 2.40 (D) 6.00

4. 82 In a single phase induction motor driving a fan load, the reason for having a high resistance rotor is to achieve

(A) low starting torque | (B) quick acceleration

(C) high efficiency | (D) reduced size

6. 83 Determine the correctness or otherwise of the following assertion[A] and the reason[R]

Assertion [A] : Under *V*/*f* control of induction motor, the maximum value of the developed torque remains constant over a wide range of speed in the sub-synchronous region.

Reason [R] : The magnetic flux is maintained almost constant at the rated value by keeping the ration *V*/*f* constant over the considered speed range.

27. Both [A] and [R] are true and [R] is the correct reason for [A]
28. Both [A] and [R] are true and but [R] is not the correct reason for [A]
29. Both [A] and [R] are false
30. [A] is true but [R] is false

**Statement for Linked Answer Questions 84 and 85**

A 1000 kVA, 6.6 kV, 3-phase star connected cylindrical pole synchronous generator has a synchronous reactance of 20 W. Neglect the armature resistance and consider operation at full load and unity power factor.

= 84 The induced emf(line-to-line) is close to

(A) 5.5 kV | (B) 7.2 kV

(C) 9.6 kV | (D) 12.5 kV

13 85 The power(or torque) angle is close to

(A) 13.9c | (B) 18.3c

(C) 24.6c | (D) 33.0c

Q. 86 A 500 kVA, 3-phase transformer has iron losses of 300 W and full load copper losses of 600 W. The percentage load at which the transformer is expected to have maximum efficiency is

(A) 50.0% | (B) 70.7%

(C) 141.4% | (D) 200.0%

16 87 For a given stepper motor, the following torque has the highest numerical value

(A) Detent torque | (B) Pull-in torque

(C) Pull-out torque | (D) Holding torque

G 88 The following motor definitely has a permanent magnet rotor

L DC commutator motor

M Brushless dc motor

N Stepper motor

O Reluctance motor

CC 89 The type of single-phase induction motor having the highest power factor at full load is

(A) shaded pole type (B) split-phase type

(C) capacitor-start type (D) capacitor-run type

D 90 The direction of rotation of a 3-phase induction motor is clockwise when it is supplied with 3-phase sinusoidal voltage having phase sequence A-B-C. For counter clockwise rotation of the motor, the phase sequence of the power supply should be

(A) B-C-A (B) C-A-B

(C) A-C-B (D) B-C-A or C-A-B

Q. 91 For a linear electromagnetic circuit, the following statement is true

2. Field energy is equal to the co-energy
3. Field energy is greater than the co-energy
4. Field energy is lesser than the co-energy
5. Co-energy is zero

6. 92 The synchronous speed for the seventh space harmonic mmf wave of a 3-phase, 8-pole, 50 Hz induction machine is

(A) 107.14 rpm in forward direction (B) 107.14 rpm in reverse direction

(C) 5250 rpm in forward direction (D) 5250 rpm in reverse direction

# 93 A rotating electrical machine its self-inductances of both the stator and the rotor windings, independent of the rotor position will be definitely not develop

w starting torque

w synchronizing torque

w hysteresis torque

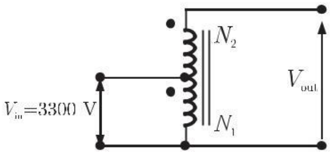
w reluctance torque

Q. 94 The armature resistance of a permanent magnet dc motor is 0.8 W. At no load, the motor draws 1.5 A from a supply voltage of 25 V and runs at 1500 rpm. The efficiency of the motor while it is operating on load at 1500 rpm drawing a current of 3.5 A from the same source will be

(A) 48.0% (B) 57.1%

(C) 59.2% (D) 88.8%

Q. 95 A 50 kVA, 3300/230 V single-phase transformer is connected as an auto-transformer shown in figure. The nominal rating of the auto- transformer will be




(A) 50.0 kVA (B) 53.5 kVA

(C) 717.4 kVA (D) 767.4 kVA

Q. 96 The resistance and reactance of a 100 kVA, 11000/400 V, 3- Y distribution transformer are 0.02 and 0.07 pu respectively. The phase impedance of the transformer referred to the primary is

(0.02 + $j$0.07) W

(0.55 + $j$1.925) W

(15.125 + $j$52.94) W

(72.6 + $j$254.1) W

Q. 97 A single-phase, 230 V, 50 Hz 4-pole, capacitor-start induction motor had the following stand-still impedances

Main winding $Z_m$ = 6.0 + $j$4.0 W, Auxiliary winding $Z_a$ = 8.0 + $j$6.0 W

The value of the starting capacitor required to produce 90c phase difference between the currents in the main and auxiliary windings will be

(A) 176.84 $m$F (B) 187.24 $m$F

(C) 265.26 $m$F (D) 280.86 $m$F

Q. 98 Two 3-phase, Y-connected alternators are to be paralleled to a set of common busbars. The armature has a per phase synchronous reactance of 1.7 W and negligible armature resistance. The line voltage of the first machine is adjusted to 3300 V and that of the second machine is adjusted to 3200 V. The machine voltages are in phase at the instant they are paralleled. Under this condition, the synchronizing current per phase will be

(A) 16.98 A (B) 29.41 A

(C) 33.96 A (D) 58.82 A

x 99 A 400 V, 15 kW, 4-pole, 50Hz, Y-connected induction motor has full load slip of 4%. The output torque of the machine at full load is

(A) 1.66 Nm (B) 95.50 Nm

(C) 99.47 Nm (D) 624.73 Nm

# 100 For a 1.8c, 2-phase bipolar stepper motor, the stepping rate is 100 steps/second. The rotational speed of the motor in rpm is

(A) 15 (B) 30

(C) 60 (D) 90

= 101 A 8-pole, DC generator has a simplex wave-wound armature containing 32 coils of 6 turns each. Its flux per pole is 0.06 Wb. The machine is running at 250 rpm. The induced armature voltage is

(A) 96 V (B) 192 V

(C) 384 V (D) 768 V

= 102 A 400 V, 50 kVA, 0.8 p.f. leading 3-connected, 50 Hz synchronous machine has a synchronous reactance of 2 W and negligible armature resistance. The friction and windage losses are 2 kW and the core loss is 0.8 kW. The shaft is supplying 9 kW load at a power factor of 0.8 leading. The line current drawn is

(A) 12.29 A (B) 16.24 A

(C) 21.29 A (D) 36.88 A

Q. 103 A 500 MW, 3-phase, Y-connected synchronous generator has a rated voltage of 21.5 kV at 0.85 p.f. The line current when operating at full load rated conditions will be

(A) 13.43 kA

(B) 15.79 kA

(C) 23.25 kA

(D) 27.36 kA

---

= 104 A simple phase transformer has a maximum efficiency of 90% at full load and unity power factor. Efficiency at half load at the same power factor is

(A) 86.7% (B) 88.26%

(C) 88.9% (D) 87.8%

Z 105 Group-I lists different applications and Group-II lists the motors for these applications. Match the application with the most suitable motor and choose the right combination among the choices given thereafter

| | Group-I | | Group-II |
|---|---|---|---|
| **P.** | Food mixer | **1.** | Permanent magnet dc motor |
| **M** | Cassette tape recorder | **2.** | Single-phase induction motor |
| **R.** | Domestic water pump | **3.** | Universal motor |
| **S.** | Escalator | **4.** | Three-phase induction motor |
| | | **5.** | DC series motor |
| | | **6.** | Stepper motor |

**Codes:**

| | P | Q | R | S |
|---|---|---|---|---|
| (A) | 3 | 6 | 4 | 5 |
| (B) | 1 | 3 | 2 | 4 |
| (C) | 3 | 1 | 2 | 4 |
| (D) | 3 | 2 | 1 | 4 |

Q. 106 A stand alone engine driven synchronous generator is feeding a partly inductive load. A capacitor is now connected across the load to completely nullify the inductive current. For this operating condition.

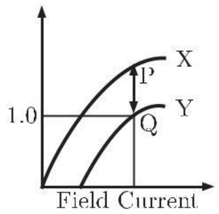
H the field current and fuel input have to be reduced

I the field current and fuel input have to be increased

J the field current has to be increased and fuel input left unaltered

K the field current has to be reduced and fuel input left unaltered

Q. 107 Curves X and Y in figure denote open circuit and full-load zero power factor(zpf) characteristics of a synchronous generator. Q is a point on the zpf characteristics at 1.0 p.u. voltage. The vertical distance PQ in figure gives the voltage drop across




(A) Synchronous reactance (B) Magnetizing reactance

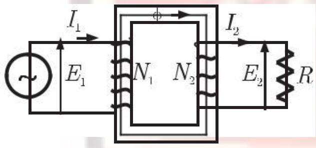
(C) Potier reactance (D) Leakage reactance

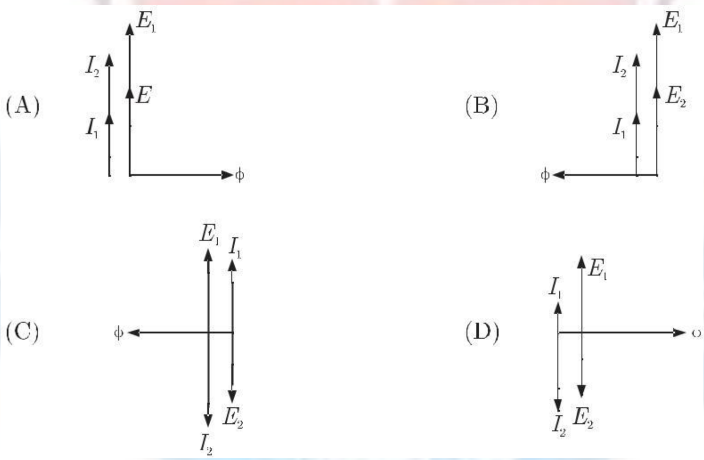
Q. 108 No-load test on a 3-phase induction motor was conducted at different supply voltage and a plot of input power versus voltage was drawn. This curve was extrapolated to intersect the y-axis. The intersection point yields

(A) Core loss (B) Stator copper loss

(C) Stray load loss (D) Friction and windage loss

Q. 109 Figure shows an ideal single-phase transformer. The primary and secondary coils are wound on the core as shown. Turns ratio $N_1 / N_2 = 2$.The correct phasors of voltages $E_1$, $E_2$, currents $I_1$, $I_2$ and core flux F are as shown in



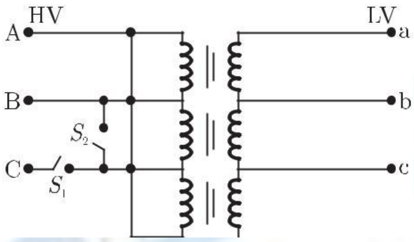




Q. 110 To conduct load test on a dc shunt motor, it is coupled to a generator which is identical to the motor. The field of the generator is also connected to the same supply source as the motor. The armature of generator is connected to a load resistance. The armature resistance is 0.02 p.u. Armature reaction and mechanical losses can be neglected. With rated voltage across the motor, the load resistance across the generator is adjusted to obtain rated armature current in both motor and generator. The p.u value of this load resistance is

(A) 1.0 (B) 0.98

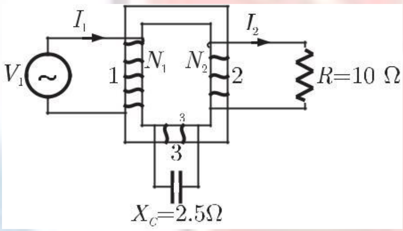
(C) 0.96 (D) 0.94

Q. 111 Figure shows a 3- $Y$ connected, 3-phase distribution transformer used to step down the voltage from 11000 V to 415 V line-to-line. It has two switches $S_1$ and $S_2$. Under normal conditions $S_1$ is closed and $S_2$ is open. Under certain special conditions $S_1$ is open and $S_2$ is closed. In such a case the magnitude of the voltage across the LV terminals a and c is




(A) 240 V (B) 480 V
(C) 415 V (D) 0 V

Q. 112 Figure shows an ideal three-winding transformer. The three windings 1, 2, 3 of the transformer are wound on the same core as shown. The turns ratio $N_1$: $N_2$: $N_3$ is 4:2:1. A resistor of 10 W is connected across winding-2. A capacitor of reactance 2.5 W is connected across winding-3. Winding-1 is connected across a 400 V, ac supply. If the supply voltage phasor $V_1$ = 400+0%, the supply current phasor $I_1$ is given by

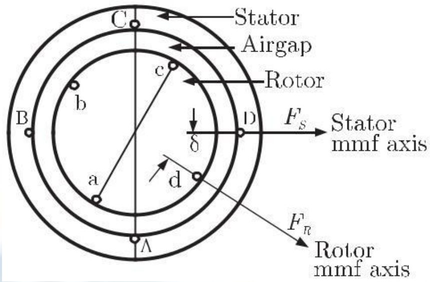



(A) (- 10 + $j$10) A (B) (- 10 - $j$10) A
(C) (10 + $j$10) A (D) (10 - $j$10) A

Q. 113 Following are some of the properties of rotating electrical machines
P. Stator winding current is dc, rotor winding current is ac.
Q. Stator winding current is ac, rotor winding current is dc.
R. Stator winding current is ac, rotor winding current is ac.
S. Stator has salient poles and rotor has commutator.
T. Rotor has salient poles and sliprings and stator is cylindrical.
U. Both stator and rotor have poly-phase windings.
DC machines, Synchronous machines and Induction machines exhibit some of the above properties as given in the following table.
Indicate the correct combination from this table

| DC Machine | Synchronous Machines | Induction Machines |
|---|---|---|
| (A) P,S | Q,T | R,U |
| (B) Q,U | P,T | R,S |
| (C) P,S | R,U | Q,T |
| (D) R,S | Q,U | P,T |

Q. 114 When stator and rotor windings of a 2-pole rotating electrical machine are excited, each would produce a sinusoidal mmf distribution in the airgap with peal values $F_s$ and $F_r$ respectively. The rotor mmf lags stator mmf by a space angle $d$ at any instant as shown in figure. Thus, half of stator and rotor surfaces will form one pole with the other half forming the second pole. Further, the direction of torque acting on the rotor can be clockwise or counter-clockwise.




The following table gives four set of statement as regards poles and torque. Select the correct set corresponding to the mmf axes as shown in figure.

| Stator Surface ABC forms | Stator Surface CDA forms | Rotor Surface abc forms | Rotor surface cda forms | Torque is |
|---|---|---|---|---|
| (A) North Pole | South Pole | North Pole | South Pole | Clockwise |
| (B) South Pole | North Pole | North Pole | South Pole | Counter Clockwise |
| (C) North Pole | South Pole | South Pole | North Pole | Counter Clockwise |
| (D) South Pole | North Pole | South Pole | North Pole | Clockwise |

Q. 115 A 4-pole, 3-phase, double-layer winding is housed in a 36-slot stator for an ac machine with 60c phase spread. Coil span is 7 short pitches. Number of slots in which top and bottom layers belong to different phases is

24

18

12

0

Q. 116 A 3-phase induction motor is driving a constant torque load at rated voltage and frequency. If both voltage and frequency are halved, following statements relate to the new condition if stator resistance, leakage reactance and core loss are ignored 1. The difference between synchronous speed and actual speed remains same

2. The airgap flux remains same

3. The stator current remains same

4. The p.u. slip remains same

Among the above, current statements are

(A) All (B) 1, 2 and 3

(C) 2, 3 and 4 (D) 1 and 4

Q. 117 A single-phase induction motor with only the main winding excited would exhibit the following response at synchronous speed

& Rotor current is zero

& Rotor current is non-zero and is at slip frequency

& Forward and backward rotaling fields are equal

& Forward rotating field is more than the backward rotating field

Q. 118 A dc series motor driving and electric train faces a constant power load. It is running at rated speed and rated voltage. If the speed has to be brought down to 0.25 p.u. the supply voltage has to be approximately brought down to

(A) 0.75 p.u (B) 0.5 p.u

(C) 0.25 p.u (D) 0.125 p.u

# SOLUTION

Sol. 1 Option (D) is correct.

Leakage flux in an induction motor is flux that linked the stator winding or the rotor winding but not both.

Sol. 2 Option (D) is correct.

The angle $d$ in the swing equation of a synchronous generator is the angular displacement of an axis fixed to the rotor with respect to a synchronously rotating axis.

Sol. 3 Option (C) is correct.

Since, the no-load loss (when load is not connected) is 64 W. So, the open circuit loss is

$$W_0 = 6 \text{ watt (no load)}$$

As the 90% of rated current flows in its both LV and HV windings, the lost is measured as

$$\text{copper loss at 90\% load} = 81 \text{ watt}$$

or, $$W_{cu}(at\ 90\%) = 81 \text{ watt}$$

Now, we have the copper loss for $x$ load as

$$W_{cu}(x) = W_{cu}(\text{at full load}) \times \left(\frac{I_x}{I_{FL}}\right)^2$$

or, $$W_{cu}(\text{at full load}) = W_{cu}(\text{at } x\% \text{ load}) \times \left(\frac{I_{FL}}{I_x}\right)^2$$

$$= (81) \times \left(\frac{1}{0.9}\right)^2$$

$$= 100 \text{ watt}$$

For maximum efficiency we must have

$$\text{copper lossed} = \text{no-load loss}$$

$$= 64 \text{ watt}$$

Consider at $x$% load copper loss is 64 watt. So,

$$(x^2)\, W_{cu}(\text{at full load}) = 64$$

or, $$x = \sqrt{\frac{64}{100}} = 0.8$$

or $$x = 80\% \text{ load}$$

Sol. 4 Option (B) is correct.

Given,

frequency of source, $f = 50$ Hz

no. of poles $P = 4$

rotating speed $N = 1440$ rpm

Now, the synchronous speed is determined as

$$N_S = \frac{120 f}{P}$$

$$= \frac{120}{4}(50) = 1500 \text{ rpm}$$

So, the slip in the motor is

(4) $= \frac{N_S - N}{N_S}$

$\frac{1500 - 1440}{1500} = 0.04$

Now, the electrical frequency of the induced negative sequence current in rotor is obtained as

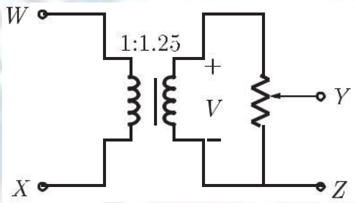
where $f$ is stator frequency given as $f = 50$ Hz.

Therefore, $f_0 = (2 - 0.04)50 = 98$ Hz

Sol. 5 Option (C) is correct.

For the given transformer, we have

$$\frac{V}{V_{WX}} = \frac{1.25}{1}$$




Since, $\frac{V_{YZ}}{V} = 0.8$ (attenuation factor)

So, $\frac{V_{YZ}}{V_{WX}} = (0.8)(1.25) = 1$

or, $V_{YZ} = V_{WX}$

at $V_{WX_1} = 100$ V; $\frac{V_{YZ_1}}{V_{WX_1}} = \frac{100}{100}$

at $V_{WZ_2} = 100$ V; $\frac{V_{WX_2}}{V_{YZ_2}} = \frac{100}{100}$

Sol. 6 Option (D) is correct.

Slip is given as $S = \frac{n_s - n}{n_s}$

where, $n_s$ = synchronous speed

(6) = rotor speed

Thus, slip depend on synchronous speed and the rotor speed. Also, torque increases with increasing slip up to a maximum value and then decreases. Slip does not depend on core/loss component.

Sol. 7 Option (D) is correct.

$$E \propto n\phi$$

where $n$ " speed, $\phi$ " flux and $E$ " back emf

Given that, $V_t = 250$ V, $R_a = 0.25$ W

$n_1 = 1000$ rpm, $I_{L1} = 68$ A, $I_{F1} = 2.2$ A

Armature current, $I_{a1} = I_{L1} - I_{F1} = 68 - 2.2 = 65.8$ A

$E_1 = V_t - I_a , R_a$

$= 250 - (65.8)(0.25) = 203.55$ V

Now, $n_2 = 1600$ rpm, $I_{L2} = 52.8$ A, $I_{F2} = 1.8$ A

Armature current, $I_{a2} = I_{L2} - I_{F2} = 52.8 - 1.8 = 51$ A

$E_2 = V_t - I_a R_a = 220 - (51)(0.25) = 207.25$ V

$\frac{E_1}{E_2} = a\frac{n_1}{n_2}kc\frac{f_1}{f_2}m$

$- \quad = b\frac{1000}{1600}lc$

$\frac{f_1}{f_2}$ m $f_2 = 0.6369 f_1$

- reduce in flux $= \frac{f_1 - f_2}{f_1} \# 100 = \frac{f_1 - 0.6369 f_1}{f_1} \# 100$

203.55

- 36.3%

Sol. 8 Option (B) is correct.

Given that magnetizing current and losses are to be neglected. Locked rotor line current.

$I_2 = \frac{E_2}{Z_2} = \frac{E_2}{\sqrt{R_2^2 + X_2^2}}$ $(R_2 = 0)$

$I_2 = \frac{E_2}{X_2} = \frac{E_2}{wL_2} \backslash \frac{E_2}{f}$

So $I_2 l = b\frac{230}{236} b\frac{57}{50} l$

$I_2 l = 45.0$ A

Sol. 9 Option (B) is correct.

Since the core length of the second transformer is $\sqrt{2}$ times of the first, so the core area of the second transformer is twice of the first.

Let subscript 1 is used for first transformer and 2 is used for second transform.

Area $a_2 = 2a_1$

Length $l_2 = \sqrt{2}\, l_1$

Magnetizing inductance, $L = \frac{N^2 ma}{l}$

= = no. of turns

$L$ = length of flux path $a$

= cross section area $l$ =

length

$L \backslash \frac{a}{l}$ $N$ and $m$ are same for both the transformer

$\frac{L_1}{L_2} = \frac{a_1}{a_2} : \frac{l_2}{l_1}$

$\frac{L_1}{L_2} = \frac{a_1}{2a_1} : \frac{\sqrt{2}\, l_1}{l_1}$

$L_2 = \sqrt{2}\, L_1$

Thus, magnetizing reactance of second transformer is $\sqrt{2}$ times of first.

Magnetizing current $X_{m2} = \sqrt{2}\, X_{m1}$

$I_m = \frac{V}{X_m}$

$\frac{I_{m1}}{I_{m2}} = \frac{V_1}{V_2} : \frac{X_{m2}}{X_{m1}} = b\frac{V_1}{2V_1}lc\frac{\sqrt{2}\, X_{m1}}{X_{m1}}m$ $(V_2 = 2V_1)$

$I_{m2} = \sqrt{2}\, I_{m1}$

Thus, magnetizing current of second transformer

$$I_{m2} = \sqrt{2} \times 0.5 = 0.707 \text{ A}$$

Since voltage of second transformer is twice that of first and current is $\sqrt{2}$ times that of first, so power will be $2\sqrt{2}$ times of first transformer.

$$P_2 = 2\sqrt{2} \times 55 = 155.6 \text{ W}$$

**Sol. 10** Option (A) is correct.

The armature current of DC shunt motor

$$I_a = \frac{V - E_b}{R_a}$$

at the time of starting, $E_b = 0$. If the full supply voltage is applied to the motor, it will draw a large current due to low armature resistance.

A variable resistance should be connected in series with the armature resistance to limit the starting current.

A 4-point starter is used to start and control speed of a dc shut motor.

**Sol. 11** Option (B) is correct.

The Back emf will go to zero when field is reduced, so Current input will be increased. But when Field increases (though in reverse direction) the back emf will cause the current to reduce.

**Sol. 12** Option (C) is correct.

An air-core transformer has linear $B$-$H$ characteristics, which implies that magnetizing current characteristic will be perfectly sinusoidal.

**Sol. 13** Option (A) is correct.

Initially $\quad E_{b1} = V - I_a R_a = 220 - 1 \times 10 = 210 \text{ V}$

Now the flux is reduced by 10% keeping the torque to be constant, so the current will be

$$I_{a1} \phi_1 = I_{a2} \phi_2$$

$$I_{a2} = I_{a1} \frac{\phi_1}{\phi_2} = 10 \times \frac{1}{0.9} = 11.11 \text{ A} \qquad \because \phi_2 = 0.9\phi_1$$

$$E_b \propto N\phi$$

& $$\frac{E_{b2}}{E_{b1}} = \frac{N_2 \phi_2}{N_1 \phi_1} = 0.9 \qquad N_1 = N_2$$

$$E_{b2} = 0.9E_{b1} = 0.9 \times 210 = 189 \text{ V}$$

Now adding a series resistor $R$ in the armature resistor, we have

$$E_{b2} = V - I_{a2}(R_a + R)$$

$$\Rightarrow \quad = 220 - 11.11(1 + R) \quad R$$

$$= 1.79\ \Omega$$

**Sol. 14** Option ( ) is correct.

The steady state speed of magnetic field

$$n_s = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

Speed of rotor $\quad n_r = (1 - S)\, n_s \qquad S = 0.05$

$$= 0.95 \times 1000 = 950 \text{ rpm}$$

In the steady state both the rotor and stator magnetic fields rotate in synchronism t so the speed of rotor field with respect to stator field would be zero.

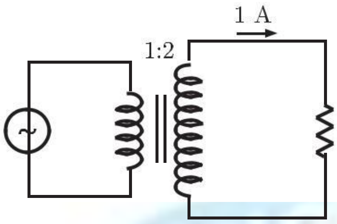
Speed of rotor which respect to stator field

$= n_r - n_s = 950 - 1000 = -50$ rpm

None of the option matches the correct answer.

Sol. 15 Option (C) is correct.

Given




$I_0 = 1$ amp (magnetizing current)

Primary current $I_P = ?$

$I_2 = 1$ A

$I_2 l$ = secondary current reffered to Primary

$= \frac{2}{1} \# 1 = 2$ amp

$I_P = \sqrt{i_0^2 + i_2^2} = \sqrt{1 + 4} = \sqrt{5} = 2.24$ Amp

Sol. 16 Option ( ) is correct.

Sol. 17 Option (C) is correct.

Synchronize speed of induction machine

$N_s = \frac{120f}{P} = \frac{120 \# 50}{4} = 1500$ rpm

Speed of machine $= 1600$ rpm

= Actual speed of induction machine

$\text{slip} = \frac{1500 - 1600}{1500} = \frac{-1}{15} = -0.066$(negative)

Hence induction machine acts as induction generator and dc machine as dc motor.

Sol. 18 Option ( ) is correct.

Sol. 19 Option (B) is correct.

Given no-load speed $N_1 = 1500$ rpm

$V_a = 200$ V, $T = 5$ Nm, $N = 1400$ rpm

emf at no load

$E_{b1} = V_a = 200$ V

$= \backslash E_b \& \frac{N_1}{N_2} = \frac{E_{b_1}}{E_{b_2}}$

$E_{b_2} = b \frac{N_2}{N_1} l E_{b_1} = \frac{1400}{1500} \# 200 = 186.67$ V

$T = E_b \wedge I_a / \omega h \& \frac{186.67 \# 60}{2p \# 1400} I_a = 5$

$I_a = 3.926$ A

$V = E_b + I_a R_a$

$R_a = \frac{V_a - E_b}{I_a} = \frac{200 - 186.67}{3.926} = 3.4$ W

Sol. 20 Option (B) is correct.

$T$ = 2.5 Nm at 1400 rpm

than $V$ = ?

$$T = \frac{E_b I_b}{\sim}$$

$$2.5 = \frac{186.6 \# I_a \# 60}{2p \# 1400}$$

$$I_a = 1.963 \text{ A}$$

$$V = E_b + I_a R_a = 186.6 + 1.963 \# 3.4 = 193.34 \text{ V}$$

Sol. 21 Option (D) is correct.

Given field excitation of = 20 A

Armature current = 400 A

Short circuit and terminal voltage = 200 V

On open circuit, load current = 200 A

So, Internal resistance = $\frac{2000}{400}$ = 5 W

Internal vol. drop = 5 # 200

= 1000 V

Sol. 22 Option (C) is correct.

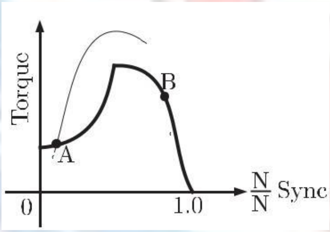
Given single-phase iron core transformer has both the vertical arms of cross section area 20 cm$^2$, and both the horizontal arms of cross section are 10 cm$^2$

So, Inductance = $\frac{NBA}{1}$ (proportional to cross section area)

When cross section became half, inductance became half.

Sol. 23 Option (A) is correct.

Given 3-phase squirrel cage induction motor.




At point A if speed -, Torque -

speed ., Torque .

So A is stable.

At point B if speed - Load torque .

So B is un-stable.

Sol. 24 Option ( ) is correct.

Sol. 25 Option (D) is correct.

Peak voltage across A and B with S open is

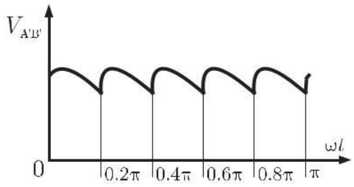
$$V = m\frac{di}{dt} = m \quad \# \text{ (slope of } I - t)$$

$$= \frac{400}{p} \# 10^{-3} \# \frac{10}{: 5 \# 10^{-3}} \quad D = \frac{800}{p} \text{ V}$$

Sol. 26 Option ( ) is correct.

Sol. 27 Option (A) is correct.

Wave form $V_{A'B'}$



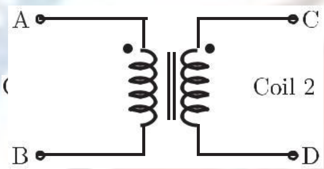

Sol. 28 Option (B) is correct.

When both S1 and S2 open, star connection consists 3rd harmonics in line current due to hysteresis A saturation.

Sol. 29 Option (A) is correct.

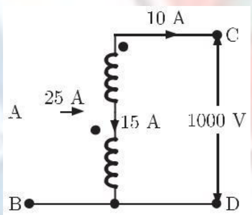
Since S2 closed and S1 open, so it will be open delta connection and output will be sinusoidal at fundamental frequency.

Sol. 30 Option (A) is correct.




$$N_1 = 4000$$
$$N_2 = 6000$$
$$I = 25 \text{ A}$$
$$V = 400 \text{ V}, f = 50 \text{ Hz}$$

Coil are to be connected to obtain a single Phase, $\frac{400}{1000}$ V auto transfer to drive Load 10 kVA. Connected A & D common B




Sol. 31 Option (D) is correct.

Given 3-phase, 400 V, 5 kW, Star connected synchronous motor.

Internal Resistance = 10 W

Operating at 50% Load, unity p.f. So

kVA rating = 25 # 400 = 1000

Internal Resistance = 10 W

So

kVA rating = 1000 # 10 = 10000 kVA

Sol. 32 Option (D) is correct.

Distributed winding and short chording employed in AC machine will result in reduction of emf and harmonics.

Sol. 33 Option (B) is correct.

Transformer connection will be represented by Y d1.

Sol. 34 Option (D) is correct.
Detent torque/Restraining toque:
The residual magnetism in the permanent magnetic material produced.
The detent torque is defined as the maximum load torque that can be applied to the shaft of an unexcited motor without causing continuous rotation. In case the motor is unexcited.

Sol. 35 Option (D) is correct.
Given: 1-f transformer, 230 V/115 V, 2 kVA

$W_1$ : 250 V, 10 A, Low Power Factor
$W_2$ : 250 V, 5 A, Low Power Factor
$W_3$ : 150 V, 10 A, High Power Factor
$W_4$ : 150 V, 5 A, High Power Factor

In one circuit test the wattmeter $W_2$ is used and in short circuit test of transformer $W_3$ is used.

Sol. 36 Option (B) is correct.
Given: 230 V, 50 Hz, 4-Pole, 1-f induction motor is rotating in clock-wise(forward) direction

$$N_s = 1425 \text{ rpm}$$

Rotar resistance at stand still($R_2$) = 7.8 W

So

$$N_s = \frac{120 \# 50}{4} = 1500$$

$$\text{Slip}(S) = \frac{1500 - 1425}{1500} = 0.05$$

$$\text{Resistance in backward branch } r_b = \frac{R_2}{2 - S} = \frac{7.8}{2 - 0.05} = 4 \text{ W}$$

Sol. 37 Option (C) is correct.
Given: a 400 V, 50 Hz, 30 hp, 3-f induction motor
Current = 50 A at 0.8 p.f. lagging
Stator and rotor copper losses are 1.5 kW and 900 W
fraction and windage losses = 1050 W
Core losses = 1200 W = 1.2 kW

So,

$$\text{Input power in stator} = \sqrt{3} \# 400 \# 50 \# 0.8 = 27.71 \text{ kW}$$

$$\text{Air gap power} = 27.71 - 1.5 - 1.2 = 25.01 \text{ kW}$$

Sol. 38 Option (A) is correct.

Induced emf in secondary $= - N_2 \dfrac{df}{dt}$

During $-0 < t < 1$, $E_1 = -(100) \dfrac{df}{dt} = -12$ V

$E_1$ and $E_2$ are in opposition

$$E_2 = 2E_1 = 24 \text{ V}$$

During time $1 < t < 2$, $\dfrac{df}{dt} = 0$, then $E_1 = E_2 = 0$

During $2 < t < 2.5$, $E_1 = -(100) \dfrac{df}{dt} = -24$ V

Then $E_2 =- 0 - 48$ V

Sol. 39 Option (B) is correct.

Given 400 V, 50 Hz, 4-Pole, 1400 rpm star connected squirrel cage induction motor.

$$R = 1.00 \text{ W}, X_s = Xl_r = 1.5 \text{ W}$$

$R_r$

So, for max. torque slip $S_m = \frac{1}{X_{sm} + Xl_{rm}}$

For starting torque $S_m = 1$

Then $X_{sm} + X_{rm} = R_r$

$$\frac{1}{2p\, f_m\, L_s + 0.2p f_m\, Ll_r} = 1$$

Frequency at max. torque

$$f_m = \frac{1}{2p(L_s + Ll_r)}$$

$$L_s = \frac{X_s}{2p \# 50} = \frac{1.5}{2p \# 50}$$

$$Ll_r = \frac{1.5}{2p \# 50}$$

$$f_m = \frac{1}{\frac{1.5}{50} + \frac{1.5}{50}} = \frac{50}{3} = 16.7 \text{ Hz}$$

In const $V/f$ control method

$$\frac{V_1}{f_1} = \frac{400}{50} = 8$$

$$\frac{V_2}{f_1} = 8$$

So $V_2 = f_2 \# 8 = 16.7 \# 8 = 133.3$ V

Sol. 40 Option (A) is correct.

Given 3-f, 440 V, 50 Hz, 4-Pole slip ring motor

Motor is coupled to 220 V

$$N = 1410 \text{ rpm}, W_1 = 1800 \text{ W}, W_2 = 200 \text{ W}$$

So, $N_s = \frac{120f}{P} = \frac{120 \# 50}{4} = 1500$ rpm

Relative speed = 1500 - 1410

= 90 rpm in the direction of rotation.

Sol. 41 Option (C) is correct.

Neglecting losses of both machines

$$\text{Slip}(S) = \frac{N_s - N}{N_s} = \frac{1500 - 1410}{1500} = 0.06$$

total power input to induction motor is

$$P_{in} = 1800 - 200 = 1600 \text{ W}$$

Output power of induction motor

$$P_{out} = (1 - S)\, P_{in} = (1 - 0.06)1600 = 1504 \text{ W}$$

Losses are neglected so dc generator input power = output power

= 1504 W

So, $I^2 R = 1504$

$$I = \sqrt{\frac{1504}{10}} = 12.26 \text{ A}$$

Sol. 42 Option (D) is correct.

Given: $V$ = 240 V, dc shunt motor

$I$ = 15 A

Rated load at a speed = 80 rad/s

Armature Resistance = 0.5 W

Field winding Resistance = 80 W

So, $E$ = 240 - 12 # 0.5 = 234

$V_{plugging}$ = $V$ + $E$ = 240 + 234 = 474 V

Sol. 43 Option (A) is correct.

External Resistance to be added in the armature circuit to limit the armature current to 125%.

So $I_a$ = 12 # 1.25 = $\frac{474}{R_a + R_{external}}$

$R_a + R_{external}$ = 31.6

$R_{external}$ = 31.1 W

Sol. 44 Option (D) is correct.

A synchronous motor is connected to an infinite bus at 1.0 p.u. voltage and 0.6 p.u. current at unity power factor. Reactance is 1.0 p.u. and resistance is negligible.

So,

$V$ = 1+0c p.u.

$I_a$ = 0.6+0c p.u.

$Z_s$ = $R_a$ + $jX_s$ = 0 + $j$1 = 1+90c p.u.

$V$ = $E$+d + $I_a$ $Z_s$ = 1+0c - 0.6+0c # 1+90c

$E$+d = 1.166+ - 30.96c p.u.

Excitation voltage = 1.17 p.u.

Load angle (d) = 30.96c(lagging)

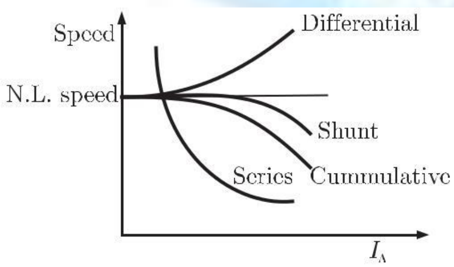
Sol. 45 Option ( ) is correct.

Sol. 46 Option (C) is correct.

In transformer zero voltage regulation at full load gives leading power factor.

Sol. 47 Option (B) is correct.

Speed-armature current characteristic of a dc motor is shown as following




The shunt motor provides speed regulation at full load without any controller.

Sol. 48 Option (C) is correct.

From the given characteristics point A and D are stable

Sol. 49

**Sol. 50** Option (B) is correct.

When the 3-f synchronous motor running at full load and unity power factor and shaft load is reduced half but field current is constant then it gives leading power factor.

Option (A) is correct.

Given star connected synchronous machine, $P = 100$ kVA

Open circuit voltage $V = 415$ V and field current is 15 A, short circuit armature current at a field current of 10 A is equal to rated armature current.

So,

Line synchronous impedance

**Sol. 51**

$$= \frac{\text{open circuit line voltage}}{\sqrt{3} \times \text{short ckt phase current}}$$

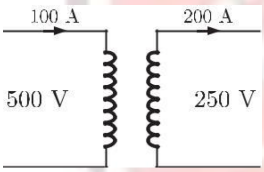
$$= \frac{415}{\sqrt{3} \times \left(\frac{100 \times 1000}{\sqrt{3} \times 415}\right)} = 1.722$$

Option (C) is correct.

Given 1-f transformer

$P = 50$ kVA, $V = 250$ V/500 V

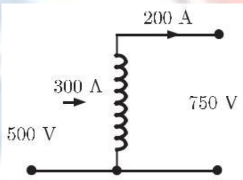
Two winding transformer efficiency 95% at full load unity power factor.




Efficiency $\quad 95\% = \dfrac{50 \times 1 \times 1}{50 \times W_{cu} + W_i}$

So $\quad W_{cu} + W_i = 2.631$

Reconfigured as a 500 V/750 V auto-transformer




auto-transformer efficiency

$$\eta = \frac{150}{150 + 2.631} = 98.276\%$$

**Sol. 52** Option (B) is correct.

Given 3-f, 3-stack

Variable reluctance step motor has 20-poles

Step angle $= \dfrac{360}{3 \times 20} = 6^\circ$

**Sol. 53** Option (D) is correct.

Given a 3-f squirrel cage induction motor starting torque is 150% and maximum torque 300%

So $\quad T_{Start} = 1.5 T_{FL}$

$\quad T_{max} = 3 T_{FL}$

Then $$\frac{T_{Start}}{T_{max}} = \frac{1}{2} \qquad ...(1)$$

$$\frac{T_{Start}}{T_{max}} = \frac{2S_{max}}{S_{max}^2 + 1^2} \qquad ...(2)$$

From equation (1) and (2)

$$\frac{2S_{max}}{S_{max}^2 + 1} = \frac{1}{2}$$

$$S_{max}^2 - 4S_{max} + 1 = 0$$

So $$S_{max} = 26.786\%$$

Sol. 54 Option (C) is correct.

Given 3-f squirrel cage induction motor has a starting current of seven the full load current and full load slip is 5%

$$I_{St} = 7I_{Fl}$$

$$S_{Fl} = 5\%$$

$$\frac{T_{St}}{T_{Fl}} = \left(\frac{I_{St}}{T_{Fl}}\right)^2 \times x^2 \times S_{Fl}$$

$$1.5 = (7)^2 \times x^2 \times 0.05$$

$$x = 78.252\%$$

Sol. 55 Option (B) is correct.

Star delta starter is used to start this induction motor. So

$$\frac{T_{St}}{T_{Fl}} = \frac{1}{3} \times \left(\frac{I_{St}}{I_{Fl}}\right)^2 \times S_{Fl} = \frac{1}{3} \times 7^2 \times 0.05$$

$$\frac{T_{St}}{T_{Fl}} = 0.816$$

Sol. 56 Option (C) is correct.

Given starting torque is 0.5 p.u.

So, $$\frac{T_{St}}{T_{Fl}} = \left(\frac{I_{sc}}{I_{Fl}}\right)^2 \times S_{Fl}$$

$$0.5 = \left(\frac{I_{sc}}{I_{Fl}}\right)^2 \times 0.05$$

Per unit starting current

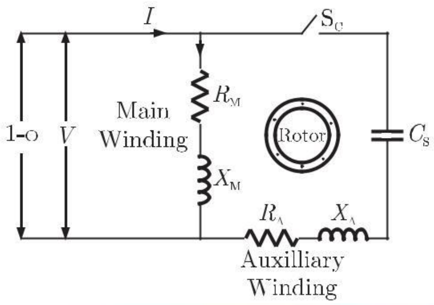
$$\frac{I_{sc}}{I_{Fl}} = \sqrt{\frac{0.5}{0.05}} = 3.16 \text{ A}$$

Sol. 57 Option (D) is correct.

In transformer, in open circuit test, current is drawn at low power factor but in short circuit test current drawn at high power factor.

Sol. 58 Option (B) is correct.

A single-phase capacitor start induction motor. It has cage rotor and its stator has two windings.




The two windings are displaced 90c in space. The direction of rotation can be changed by reversing the main winding terminals.

**Sol. 59** Option (B) is correct.

In DC motor, compensating winding is used for neutralizing armature reactance while interpole winding is used for improving commutation.

Interpoles generate voltage necessary to neutralize the e.m.f of self induction in the armature coils undergoing commutation. Interpoles have a polarity opposite to that of main pole in the direction of rotation of armature.

**Sol. 60** Option (A) is correct.

Given: A 230 V, DC machine, 20 A at 200 V as a generator.

$$R_a = 0.2 \text{ W}$$

The machine operated as a motor at same terminal voltage and current, flux increased by 10%

So for generator

$$E_g = V + I_a R_a$$
$$= 200 + 20 \# 0.2$$
$$E_g = 204 \text{ volt}$$

for motor

$$E_m = V - I_a R_a$$
$$= 200 - 20 \# 0.2$$
$$E_m = 196 \text{ volt}$$

So

$$\frac{E_g}{E_m} = \frac{N_g}{N_m} \# \frac{f_g}{f_m}$$
$$\frac{204}{196} = \frac{N_g}{N_m} \# \frac{1}{1.1}$$
$$\frac{N_m}{N_g} = \frac{196}{204 \# 1.1} = 0.87$$

**Sol. 61** Option (B) is correct.

A synchronous generator is feeding a zero power factor(lagging) load at rated current then the armature reaction is demagnetizing.

**Sol. 62** Option (B) is correct.

Given the rating of first transformer is 500 kVA

Per unit leakage impedance is 0.05 p.u.

Rating of second transformer is 250 kVA

So, Per unit impedance = $\frac{\text{actual impedance}}{\text{base impedance}}$

and, Per unit leakage impedance $\backslash \frac{1}{\text{kVA}}$

Then $500 \text{ kVA} \# 0.05 = 250 \text{ kVA} \# x$

$$x = \frac{500}{250} \times 0.05 = 0.1 \text{ p.u.}$$

**Sol. 63** Option (C) is correct.

Given speed of a 4-pole induction motor is controlled by varying the supply frequency when the ratio of supply voltage and frequency is constant.

$f = 50$ Hz, $V = 400$ V, $N = 1440$ rpm

So $$V \propto f$$

$$\frac{V_1}{V_2} = \frac{f_1}{f_2}$$

$$V_2 = 400 \times \frac{30}{50} = 240 \text{ V}$$

$$T \propto \left(\frac{V^2}{f}\right) S$$

So $$\frac{S_2}{S_1} = \left(\frac{V_1}{V_2}\right)^2 \times \frac{f_2}{f_1} \times \frac{T_2}{T_1}$$

Given $$T_1 = T_2$$

Then $$S_2 = 0.04 \times \left(\frac{400}{240}\right)^2 \times \frac{30}{50}$$

$$S_2 = 0.066$$

$$N_r = N_s(1 - S)$$

$$N_r = \frac{120f}{P}$$

So $$N_r = \frac{120 \times 30}{4}(1 - 0.066) = 840.6 \text{ rpm}$$

**Sol. 64** Option (A) is correct.

Given a 3-$\phi$ induction motor

$$P = 4,\ V = 400 \text{ V},\ f = 50 \text{ Hz}$$

$$r_1 = 1.0\ \Omega,\ r_2' = 0.5\ \Omega$$

$$X_1 = X_2' = 1.2\ \Omega,\ X_m = 35\ \Omega$$

So, Speed of motor is

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

Torque $$T_{st} = \frac{180}{2\pi N_s} \times \frac{V^2 r_2'}{(r_1 + r_2')^2 + X^2}$$

$$= \frac{180}{2 \times 3.14 \times 1500} \times \frac{\left(\frac{400}{\sqrt{3}}\right)^2 \times 0.5}{(1.5)^2 + (2.4)^2}$$

$$= 63.58 \text{ Nm}$$

**Sol. 65** Option (B) is correct.

Given that 3-$\phi$ induction motor star connected

$$P = 10 \text{ kW},\ V = 400 \text{ V},\ \text{Poles} = 4,\ f = 50 \text{ Hz}$$

Full load current $I_{Fl} = 20$ A

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

So

Cu losses at full load

$$= \left(\frac{20}{15}\right)^2 \times 762 = 1354.67$$

Total losses = 1354.67 + 1002 = 2356.67

$$\text{Efficiency} = \frac{10000}{10000 + 2356.67} \times 100 = 81\%$$

**Sol. 66** Option (A) is correct.

Given 3-$\phi$ star connected synchronous motor

internal reactance = 10 $\Omega$

Operating at 50% load, unity power factor, 400 V, 5 kW

Excitation increased = 1%

So,

full load current

$$I_{Fl} = \frac{5 \times 10^3}{\sqrt{3} \times 400 \times 1} = 7.22$$

$$E^2 = (V\cos\theta - I_a R_a)^2 + (V\sin\theta - I_a X_s)^2$$

So, $$E = \sqrt{\left(\frac{400}{\sqrt{3}}\right)^2 + (10 \times 3.6)^2} = 2133.7289$$

Excitation will increase 1% then $E_2$

$$E_2 = 2133.7289 \times 0.01 = 236$$

$$I_a X = \sqrt{(E_2)^2 - V^2} = \sqrt{(236)^2 - \left(\frac{400}{\sqrt{3}}\right)^2} = 48.932$$

$$I_a = \frac{48.932}{10} = 4.8932$$

$$\text{Load}(\%) = \frac{4.8932}{7.22} = 67.83\ \%$$

**Sol. 67** Option (C) is correct.

Given $P = 4$, $f = 50$ Hz

Slots = 48, each coil has 10 turns

Short pitched by an angle($\alpha$) to 36° electrical

Flux per pole = 0.05 Wb

So,

$$E_{ph} = 4.44\, f\phi T_{ph} K_W$$

$$\text{Slot/Pole/ph} = \frac{48}{4 \times 3} = 4$$

$$\text{Slot/Pole} = \frac{48}{4} = 12$$

$$K_d = \frac{\sin(4 \times 15/2)}{4\sin(15/2)} = 0.957$$

$$K_p = \cos\frac{\alpha}{2} = \cos 18^\circ = 0.951$$

No. of coil = No of slots

$$\text{No. of turns/ph} = \frac{48 \times 10}{3} = 160$$

Then $$E_{ph} = 4.44 \times 0.025 \times 50 \times 0.957 \times 0.951 \times 160$$

$$= 808\text{ V}$$

$$E_L = \sqrt{3} \# 808$$
$$E_L = 1400 \text{ V(approximate)}$$

Sol. 68 Option (A) is correct.

line to line induced voltage, so in 2 phase winding

$$\text{Slot/ pole/ph} = 6$$
$$T_{ph} = \frac{480}{2} = 240$$
$$\text{Slot angle} = \frac{180 \# 4}{48} = 15c$$
$$K_d = \frac{\sin 6 \# (15/2)}{6 \sin(15/2)} = 0.903$$
$$K_p = \cos b \frac{36}{2} l = 0.951$$
$$E_{ph} = 4.44 \# 0.025 \# 50 \# 240 \# 0.951 \# 0.903$$
$$= 1143$$

Sol. 69 Option (A) is correct.

Fifth harmonic component of phase emf

So $$\text{Angle} = \frac{180}{5} = 36c$$

the phase emf of fifth harmonic is zero.

Sol. 70 Option (C) is correct.

Given that: A 300 kVA transformer

Efficiency at full load is 95% and 0.8 p.f. lagging

96% efficiency at half load and unity power factor

So

For $I_{st}$ condition for full load

$$95\% = \frac{\text{kVA} \# 0.8}{\text{kVA} \# 0.8 + W_{cu} + W_i} \quad ...(1)$$

Second unity power factor half load

$$96\% = \frac{\text{kVA} \# 0.5}{\text{kVA} \# 0.5 + W_{cu} + W_i} \quad ...(2)$$

So $$W_{cu} + W_i = 12.63$$
$$0.25W_{cu} + 0.96W_i = 6.25$$

Then $$W_{cu} = 8.51, W_i = 4.118$$

Sol. 71 Option (B) is correct.

$$\text{Efficiency (h)} = \frac{X \# \text{p.f.} \# \text{kVA}}{X \# \text{kVA} + W_i + W_{cu} \# X^2}$$

So $$X = \sqrt{\frac{4.118}{8.51}} = 0.6956$$
$$\text{h\%} = \frac{0.6956 \# 1 \# 300}{0.6956 \# 300 + 4.118 + 8.51 \# (0.6956)^2}$$
$$\text{h} = 96.20\%$$

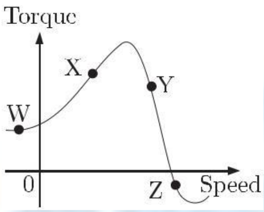
Sol. 72 Option (D) is correct.

The leakage reactances $X_1$, and $X_2$l are equal and magnetizing reactance $X_m$ is higher than $X_1$, and $X_2$l

$$X_1 . X_2 l << X_m$$

Sol. 73 Option (B) is correct.
Three phase star delta connection of transformer induces a phase difference of 30c between output and input line voltage.

Sol. 74 Option (A) is correct.
Given torque/speed curve of the induction motor



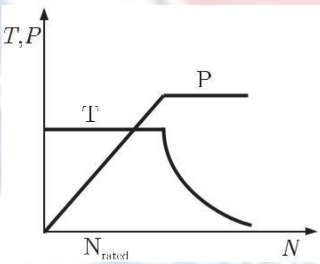

When the speed of the motor is in forward direction then slip varies from 0 to 1 but when speed of motor is in reverse direction or negative then slip is greater then 1. So at point W slip is greater than 1.

Sol. 75 Option (B) is correct.
For an induction motor the ratio of gross power output to air-gap is equal to (1 - $s$)

So $$\frac{\text{gross power}}{\text{airgap power}} = (1 - s)$$

Sol. 76 Option (A) is correct.
Given that two magnetic pole revolve around a stationary armature.
At $c_1$ the emf induced upward and no emf induced at $c_2$ and $c_2$l

Sol. 77 Option (B) is correct.
Given A 50 kW DC shunt motor is loaded, then
at half the rated speed by armature voltage control
So $P \setminus N$




$$P_{new} = \frac{50}{2} = 25 \text{ kW}$$

At 1.5 time the rated speed by field control

$P$ = constant

$P$ = 50 kW

Sol. 78

So

In synchronous machine, when the armature terminal are

Option (C) is correct.

shorted the field current should first be decreased to zero before started the alternator.
In open circuit the synchronous machine runs at rated synchronous speed. The field current is gradually increased in steps.

The short circuit ratio is the ratio of field current required to produced the rated voltage on open to the rated armature current.

Sol. 79 Option (D) is correct.

In DC motor, $E = PN\phi\left(\frac{Z}{A}\right)$

or $E = K\phi\omega_n$

So armature emf $E$ depends upon $\phi$ and $\omega$ only and torque developed depends upon

$$T = \frac{PZ\phi I_a}{2\pi A}$$

So, torque($T$) is depends of $\phi$ and $I_a$ and developed power($P$) is depend of flux $\phi$, speed $\omega$ and armature current $I_a$.

Sol. 80 Option ( ) is correct.

Sol. 81 Option (B) is correct.

Given a three-phase cage induction motor is started by direct on line switching at rated voltage. The starting current drawn is 6 time the full load current.

Full load slip = 4%

So

$$\left(\frac{T_{St}}{T_{Fl}}\right) = \left(\frac{I_{St}}{I_{Fl}}\right)^2 \times S_{Fl}$$

$$= (6)^2 \times 0.04 = 1.44$$

Sol. 82 Option (B) is correct.

Given single-phase induction motor driving a fan load, the resistance rotor is high

So

$$E_b = V - I_a R_a \quad ...(1)$$

$$P_{mech} = E_a I_a$$

$$\tau = \frac{P_{mech}}{\omega_m} \quad ...(2)$$

From equation (1) and (2) the high resistance of rotor then the motor achieves quick acceleration and torque of starting is increase.

Sol. 83 Option (A) is correct.

Given $V/f$ control of induction motor, the maximum developed torque remains same

we have, $E = 4.44K_{w1}\, f\phi T_1$

If the stator voltage drop is neglected the terminal voltage $E_1$. To avoid saturation and to minimize losses motor is operated at rated airgap flux by varying terminal voltage with frequency. So as to maintain ($V/f$) ratio constant at the rated value, the magnetic flux is maintained almost constant at the rated value which keeps maximum torque constant.

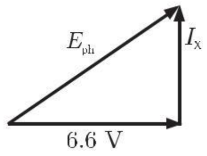
Sol. 84 Option (B) is correct.

Given $P$ = 1000 kVA, 6.6 kV

Reactance = 20 Ω and neglecting the armature resistance at full load and unity power factor

So $P = \sqrt{3}\, V_L I_L$

$$I = \frac{1000}{\sqrt{3} \times 6.6} = 87.47 \text{ A}$$




So, $IX = 87.47 \times 20 = 1.75$ kV

$$E_{ph}^2 = \left(\frac{6.5}{\sqrt{3}}\right)^2 + (1.75)^2$$

$$E_{ph} = \sqrt{\left(\frac{6.5}{\sqrt{3}}\right)^2 + (1.75)^2}$$

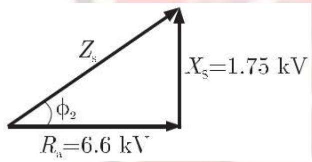
$$E_{ph} = 4.2 \text{ kV}$$

$$E_L = \sqrt{3} E_{ph} \qquad \text{a Star connection}$$

$$E_L = 1.732 \times 4.2 = 7.26 \text{ kV}$$

Sol. 85 Option (C) is correct.

$$\text{Torque angle } \alpha_z = \tan^{-1}\left(\frac{X_s}{R_a}\right)$$




$$\alpha_z = \tan^{-1}\left(\frac{\sqrt{3} \times 1.75}{6.6}\right) = 24.6°$$

Sol. 86 Option (B) is correct.
Given that
Transformer rating is 500 kVA

Iron losses = 300 W

full load copper losses = 600 W

Maximum efficiency condition

$$W_i = X^2 W_c$$

So, $$X = \sqrt{\frac{W_i}{W_c}} = \sqrt{\frac{300}{600}} = 0.707$$

efficiency% = $0.707 \times 100 = 70.7\%$

Sol. 87 Option (C) is correct.
Stepper motor is rotated in steps, when the supply is connected then the torque is produced in it. The higher value of torque is pull out torque and less torque when the torque is pull in torque.

Sol. 88 Option (C) is correct.
The stepper motor has the permanent magnet rotor and stator has made of windings, it’s connected to the supply.

Sol. 89 Option (D) is correct.
1-phase induction motor is not self starting, so it's used to start different method at full load condition, capacitor-run type motor have higher power factor. In this type the capacitor is connected in running condition.

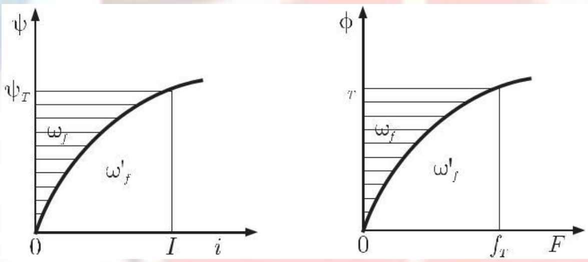
Sol. 90 Option (C) is correct.
Given that if 3-f induction motor is rotated in clockwise then the phase sequence of supply voltage is A-B-C. In counter clock wise rotation of the motor the phase sequence is change so in the counter clockwise rotation the phase sequence is A-C-B.

Sol. 91 Option (A) is correct.
In linear electromagnetic circuit the field energy is equal to the co-energy.

$$W_f = W_f' = \frac{1}{2}Li^2 = \frac{1}{2}\psi i = \frac{1}{2L}\psi^2$$

$W_f$ = field energy

$W_f'$ = co energy




Sol. 92 Option (A) is correct.
Given that
8-Pole, 50 Hz induction machine in seventh space harmonic mmf wave.
So,

Synchronous speed at 7th harmonic is = $N_s/7$

Speed of motor $N_s = \frac{120f}{P} = \frac{120 \times 50}{8} = 750$ rpm

Synchronous speed is = $\frac{N_s}{7} = \frac{750}{7}$ = 107.14 rpm in forward direction

Sol. 93 Option (B) is correct.
Rotating electrical machines having its self inductance of stator and rotor windings is independent of the rotor position of synchronizing torque. synchronizing torque

$$T_{synchronizing} = \frac{1}{\omega_s} m \frac{dP}{d\delta} \text{ Nm/elect. radian}$$

$$= \frac{1}{\omega_s} m \frac{dP}{d\delta} \frac{\pi P}{180} \text{ Nm/mech.degree}$$

Sol. 94 Option (A) is correct.
Given that the armature of a permanent magnet dc motor is

$R_a$ = 0.8 Ω

At no load condition

$V$ = 25 V, $I$ = 1.5 A, $N$ = 1500 rpm No

load losses = $E \times I$

a $E = V - IR_a$

So no load losses = (25 - 1.5 # 0.8)1.5 = 35.7 W

At load condition $I$ = 3.5 A

= 35.7 + 9.8 = 45.5 W

Total power $P = VI$

$P$ = 25 # 3.5

$P$ = 87.5 W

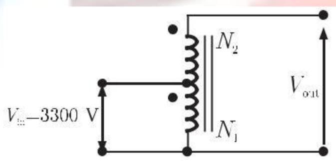
Efficiency = $\frac{\text{output}}{\text{input}}$

h = $\frac{\text{total power - losses}}{\text{total power}}$ = $\frac{87.5 - 45.5}{87.5}$ # 100

= 48.0%

Sol. 95 Option (D) is correct.

Given that 50 kVA, 3300/230 V, 1-f transform




$V_{in}$ = 3300 V

$V_{out}$ = 3300 + 230 = 3530 V

Output current $I_2$ and output voltage 230 V

So

$I_2 = \frac{50 \# 10^3}{230}$ = 217.4 A

When the output voltage is $V_{out}$ then kVA rating of auto transformer will be $I_2$ =

3530 # 217.4

= 767.42 kVA

Sol. 96 Option (D) is correct.

Given that 100 kVA, 11000/400 V, Delta-star distribution transformer resistance is 0.02 pu and reactance is 0.07 pu

So pu impedance $Z_{pu}$ = 0.02 + $j$0.07

Base impedance referred to primary

$Z_{Base} = \frac{V_P^2}{V_L I_L /3} = \frac{(11 \# 10^3)^2}{\frac{100 \# 10^3}{3}}$ = 3630 W

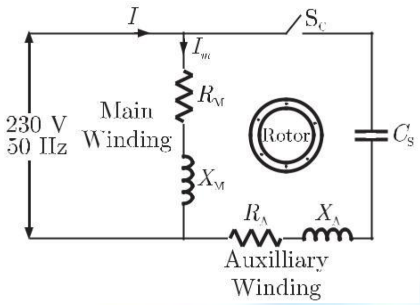
$Z_{primary} = Z_{pu} \# Z_{Base}$

= (0.02 + $j$0.07)(3630) = 72.6 + $j$254.1

Sol. 97 Option (A) is correct.

Given that

230 V, 50 Hz, 4-Pole, capacitor-start induction motor




$$Z_m = R_m + X_m = 6.0 + j4.0 \text{ W}$$
$$Z_A = R_A + X_A = 8.0 + j6.0 \text{ W}$$

Phase angle of main winding

$$+I_m = + - Z_m =- +(6 + j4) =-+33.7c$$

So angle of the auxiliary winding when the capacitor is in series.

$$+I_A =- +(8 + j\,6) \quad + \frac{1}{jwC} = +(8 + j\,6) - \frac{j}{wC}$$

$$a = +I_A - +I_m$$

So $$90 =- \tan^{-1} \left( \frac{6 - \frac{1}{wC}}{} \right) - (-33.7)$$

$$\frac{1}{wC} = 18 \qquad w = 2pf$$

So $$C = \frac{1}{18 \# 2pf} = \frac{1}{18 \# 2 \# 3.14 \# 50}$$
$$= 176.8 \text{ mF}$$

Sol. 98 Option (A) is correct.

Given that the armature has per phase synchronous reactance of 1.7 W and two alternator is connected in parallel

So,


both alternator voltage are in phase

So,

$$E_{f1} = \frac{3300}{\sqrt{3}}$$
$$E_{f2} = \frac{3200}{\sqrt{3}}$$

Synchronizing current or circulating current

$$= \frac{E_C}{T_{S1} + T_{S2}}$$

Reactance of both alternator are same

So $$= \frac{E_{f1} - E_{f2}}{T_{S1} + T_{S2}} = \frac{1}{\sqrt{3}} b \frac{3300 - 3200}{1.7 + 1.7} l = 16.98 \text{ A}$$

Sol. 99 Option (C) is correct.

Given $V = 400$ V, 15 kW power and $P = 4$

$$f = 50 \text{ Hz, Full load slip } (S) = 4\%$$

So $N_s = \frac{120f}{P} = \frac{120 \# 50}{4} = 1500$ rpm

Actual speed = synchronous speed - slip

$$N = 1500 - \frac{4}{100} \# 1500 = 1440 \text{ rpm}$$

Torque developed $T = \frac{P}{\omega_s (1 - S)}$, where $\omega_s (1 - S) = \frac{2\pi N}{60}$

$$= \frac{15 \# 10^3 \# 60}{2\pi \# 1440} = 99.47 \text{ Nm}$$

Sol. 100 Option (B) is correct.

Given 1.8c angle, 2-f Bipolar stepper motor and stepping rate is 100 step/second

So step required for one revolution

$$= \frac{360}{1.8} = 200 \text{ steps}$$

a Time required for one revolution = 2 seconds

rev/sec = 0.5 rps

and rev/min = 30 rpm

Sol. 101 Option (C) is correct.

Given that:

$P$ = 8 Pole, DC generator has wave-wound armature containing 32 coil of 6 turns each. Simplex wave wound flux per pole is 0.06 Wb

$N$ = 250 rpm

So induced armature voltage

$$E_g = \frac{\phi ZNP}{60A}$$

$Z$ = total no.of armature conductor = $2CN_C = 2 \# 32 \# 6 = 384$

$$E_g = \frac{0.06 \# 250 \# 3.84 \# 8}{60 \# 2}$$

a $A$ = 2 for wave winding

$E_g$ = 384 volt

Sol. 102 Option (C) is correct.

Given a 400 V, 50 Hz and 0.8 p.f. loading delta connection 50 Hz synchronous machine, the reactance is 2 W. The friction and windage losses are 2 kW and core losses is 0.8 kW and shaft is supply 9 kW at a 0.8 loading power factor So

Input power = 9 kW + 2 kW + 0.8 kW = 11.8 kW

a Input power = $\sqrt{3} V_2 I_2$ = 11.8 kW

$$I_2 = \frac{11.8 \text{ kW}}{\sqrt{3} \# 400 \# 0.8} = 21.29 \text{ A}$$

Sol. 103 Option (B) is correct.

Given that 500 MW, 3-f star connected synchronous generator has a rated voltage of 21.5 kV and 0.85 Power factor

So $\sqrt{3} V_L I_L$ = 500 MW

$$I_L = \frac{500 \# 10^6}{\sqrt{3} \# 21.5 \# 10^3 \# 0.85} = 15.79 \# 10^3$$

$I_L$ = 15.79 kA

Sol. 104 Option (D) is correct.

Given that 1-f transformer, maximum efficiency 90% at full load and unity power factor

So $$h = \frac{V_2 I_2 \cos f_2}{V_2 I_2 \cos f_2 + P_i + P_c} = \frac{(L.F)\cos f_2}{(L.F)\cos f_2 + P_{i(Pu)} + P_c}$$

where *L.F.* is the load fator.

At full load, load factor is

$$L.F. = \sqrt{\frac{P_i}{P_c}} = 1$$

$\cos f_2 = 1$ at unity power factor

so, $$90\% = \frac{1 \# 1}{1 + 2P_i}$$

$$P_i = 0.0555 \text{ MVA}$$

At half load, load factor is

$$L.F = \frac{1}{2} = .5$$

So, $$h = \frac{0.5 \# 1}{0.5 \# 0.0555 \# (0.5)^2 + 0.0555} \# 100 = 87.8\%$$

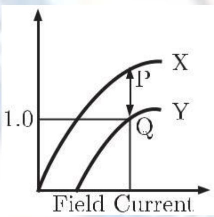
Sol. 105 Option (C) is correct.

In food mixer the universal motor is used and in cassette tap recorder permanent magnet DC motor is used. The Domestic water pump used the single and three phase induction motor and escalator used the three phase induction motor.

Sol. 106 Option (D) is correct.

Given a engine drive synchronous generator is feeding a partly inductive load. A capacitor is connected across the load to completely nullify the inductive current. Then the motor field current has to be reduced and fuel input left unaltered.

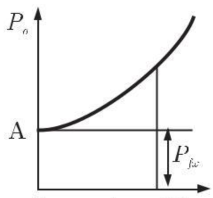
Sol. 107 Option (A) is correct.




Given open circuit and full-load zero power factor of a synchronous generator. At point Q the zero power factor at 1.0 pu voltage. The voltage drop at point PQ is across synchronous reactance.

Sol. 108 Option (D) is correct.

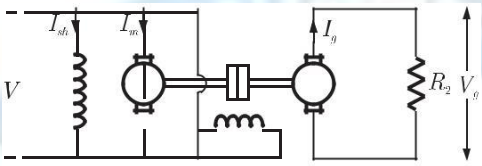
Given no load test on 3-f induction motor, the graph between the input power and voltage drop is shown in figure, the intersection point yield the friction and windage loss.



Separation of fraction and windage loss

Sol. 109 Option ( ) is correct.

Sol. 110 Option (C) is correct.




Given that: The armature resistance in per unit is 0.2

so, $R_a = 0.2$

back emf equation of motor is

$$E_b = V - I_a R_a$$

given that no mechanical losses and armature reaction is neglected, so per unit value of emf induced by motor is

$$E_b = 0.98$$

The DC shunt motor is mechanically coupled by the generator so the emf induced by motor and generator is equal

$$E_g = E_b$$

so voltage generated by the generator is

$$V = 0.98 - 1 \# 0.2 = 0.96$$

per unit value of load resistance is equal to 0.96

Sol. 111 Option (D) is correct.

Given that when the switch $S_1$ is closed and $S_2$ is open then the 11000 V is step down at 415 V output

Second time when the switch $S_1$ is open and switch $S_2$ is closed then 2-phase supply is connected to the transformer then the ratio of voltage is

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{11000}{415} = 26.50$$

The output terminal a and c are in opposite phase so cancelled with each other and terminal is equal to zero volt.

Sol. 112 Option (D) is correct.

Given that

$$N_1 : N_2 : N_3 \text{ is } 4:2:1$$

Resistance $R = 10$ W

$$V_1 = 400 \text{ V}$$

So
$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{4}{2}$$

$$V_2 = \frac{2V_1}{4} = 200 \text{ V}$$

and $\frac{V_1}{V_3} = \frac{N_1}{N_3} = \frac{4}{1}$

$V_3 = 100$ V

so current in secondary winding

$$I_2 = \frac{V_2}{R} = \frac{200}{10} = 20 \text{ A}$$

The current in third winding when the capacitor is connected

so $I_3 = \frac{V_3}{-jX_c} = \frac{100}{-j2.5} = j40$

When the secondary winding current $I_2$ is referred to primary side i.e $I_1'$

So $\frac{I_1'}{I_2} = \frac{N_2}{N_1} = \frac{2}{4}$

$$I_1' = \frac{20}{2} = 10 \text{ A}$$

and winding third current $I_3$ is referred to Primary side i.e $I_1''$. $I_3$ flows to opposite to $I_1$

So $\frac{I_1''}{-I_3} = \frac{N_3}{N_1} = \frac{1}{4}$

$$I_1'' = -j10$$

So total current in primary winding is

$$I_1 = I_1'' + I_2'' = 10 - j10 \text{ A}$$

Sol. 113 Option (A) is correct.

Given that:

P Stator winding current is dc, rotor winding current is ac

Q Stator winding current is ac, rotor winding current is dc

R Stator winding current is ac, rotor winding current is ac

S Stator has salient pole and rotor has commutator

T Rotor has salient pole and slip rings and stator is cylindrical

U Both stator and rotor have poly-phase windings

So

DC motor/machines:

The stator winding is connected to dc supply and rotor winding flows ac current. Stator is made of salient pole and Commutator is connected to the rotor so rotor winding is supply ac power.

Induction machines:

In induction motor the ac supply is connected to stator winding and rotor and stator are made of poly-phase windings.

Synchronous machines:

In this type machines the stator is connected to ac supply but rotor winding is excited by dc supply. The rotor is made of both salient pole and slip rings and stator is made of cylindrical.

Sol. 114 Option (C) is correct.

Given that

$F_s$ is the peak value of stator mmf axis. $F_r$ is the peak value of rotor mmf axis. The rotor mmf lags stator mmf by space angle d. The direction of torque acting on the rotor is clockwise or counter clockwise.

When the opposite pole is produced in same half portion of stator and rotor then the rotor moves. So portion of stator is north-pole in ABC and rotor abc is produced south pole as well as portion surface CDA is produced south pole and the rotor cda is produced North pole.

The torque direction of the rotor is clock wise and torque at surface is in counter clockwise direction.

**Sol. 115** Option (A) is correct.

Given that:

A 4-pole, 3-f, double layer winding has 36 slots stator with 60c phase spread, coil span is 7 short pitched

so,

$$\text{Pole pitch} = \frac{\text{slot}}{\text{pole}} = \frac{36}{4} = 9$$

Slot/pole/phase = 3

so, 3-slots in one phase, if it is chorded by 2 slots then Out

of 3 " 2 have different phase Out of 36

" 24 have different phase.

**Sol. 116** Option (B) is correct.

Given that:

3-f induction motor is driving a constant load torque at rated voltage and frequency. Voltage and frequency are halved and stator resistance, leakage reactance and core losses are ignored.

Then the motor synchronous speed and actual speed difference are same.

$$N_s = \frac{120f}{P}$$

The leakage reactance are ignored then the air gap flux remains same and the stator resistance are ignored then the stator current remain same.

**Sol. 117** Option (D) is correct.

Given that: 1-f induction motor main winding excited then the rotating field of motor changes, the forward rotating field of motor is greater then the back ward rotating field.

**Sol. 118** Option (B) is correct.

Given that:

A dc series motor driving a constant power load running at rated speed and rated voltage. It’s speed brought down 0.25 pu. Then Emf equation of dc series motor

$$E = V - (R_a + R_{se})$$

$$R_a + R_{se} = R$$

so, $E = V - IR = KfN$

then $N = \frac{E}{Kf}$

In series motor fa$I$

so, $N = \frac{V - IR}{KI}$

At constant power load

$$E \# I = T \# W = \text{Const} \qquad ...(1)$$

$$T = KfI = KI^2 \quad \text{...(2)}$$

If $W$ is decreased then torque increases to maintain power constant.

$$T \setminus I^2$$

$$W = \frac{1}{4} \text{ then } T = 4$$

So current is increased 2 time and voltage brought down to 0.5 pu.

## ELECTRIC CIRCUITS & FIELDS

### Electrical Components and Circuits

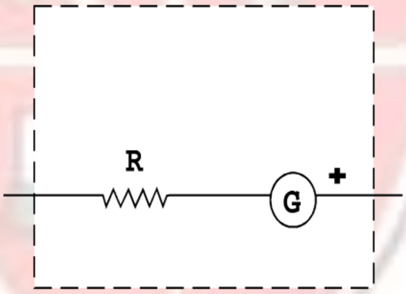
The purpose of this chapter is to discuss basic direct current (dc) circuit components in preparation for the two following chapters that deal with integrated circuits and microcomputers in instruments for chemical analysis.

### DIRECT CURRENT CIRCUITS AND MEASUREMENTS

Some basic direct current circuits and how they are used in making current, voltage, and resistance measurements will be considered.

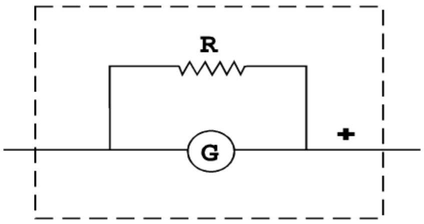
The general definition of a circuit is a closed path that may be followed by an electric current.

A galvanometer is a device with a rotating indicator that will rotate from its equilibrium position when a current passes through it. A galvanometer has negligible resistance.




Ampermeter

An ampermeter (ammeter) is a galvanometer with a calibrated current scale for its indicator and a bypass resistor (called a shunt) for a fixed fraction of the current, shown in Figure 1. Many ammeters have several selectable shunts which provide their corresponding current meter ranges. Typically, ammeters can be found with calibrated ranges of 1 micro-A for full scale deflection up to 1000 A for full scale deflection, and in multiples of 10 between these extremes.



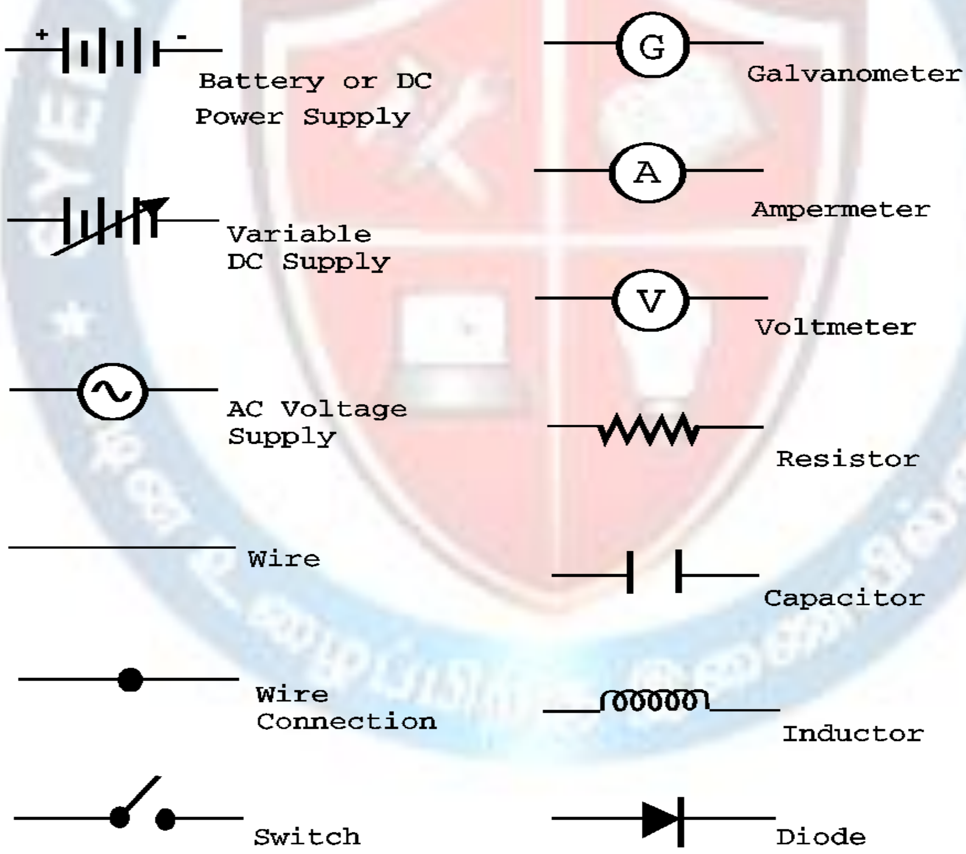

Voltmeter

A voltmeter, shown in Figure 2, is just a calibrated galvanometer with a series resistor so that the total resistance of the path is increased. The galvanometer range is calibrated for the current Ig passing through it. This scale is adjusted to display the potential difference between points A and B, (voltage) by substituting Vg values for Ig on the scale where Vg = Ig Rg and Rg is the total resistance of the voltmeter. Voltmeters may have more than one calibrated scale which can be selected by changing the resistance Rg.

Current in a circuit is the flow of the positive charge from a high potential (+) to a low potential (-). Meters are labeled to indicate the proper direction of current flow through them. A reverse flow of DC current may destroy a meter.

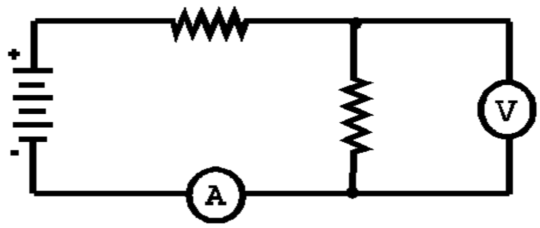
Electrical charge will not move through a conducting path unless there is a potential difference between the ends of the conductors. All materials resist the flow of current through them, requiring work to be done to move the charge through the material. The source of energy in a circuit which provides the energy to move the charge through the circuit can be a battery, photocell, or some other power supply.

An electrical circuit is a circuitous path of wire and devices. A schematic drawing of a real circuit utilizes the symbols shown in Figure 3.




Circuit Symbols

An example, Figure 4, shows a circuit with a DC. power supply in a series with a resistor, a parallel branch with a resistor and voltmeter, and an ammeter.




Example of an Electric Circuit.

BASIC ELECTRIC CIRCUIT

The flashlight is an example of a basic electric circuit. It contains a source of electrical energy (the dry cells in the flashlight), a load (the bulb) that changes the electrical energy into a more useful form of energy (light), and a switch to control the energy delivered to the load.

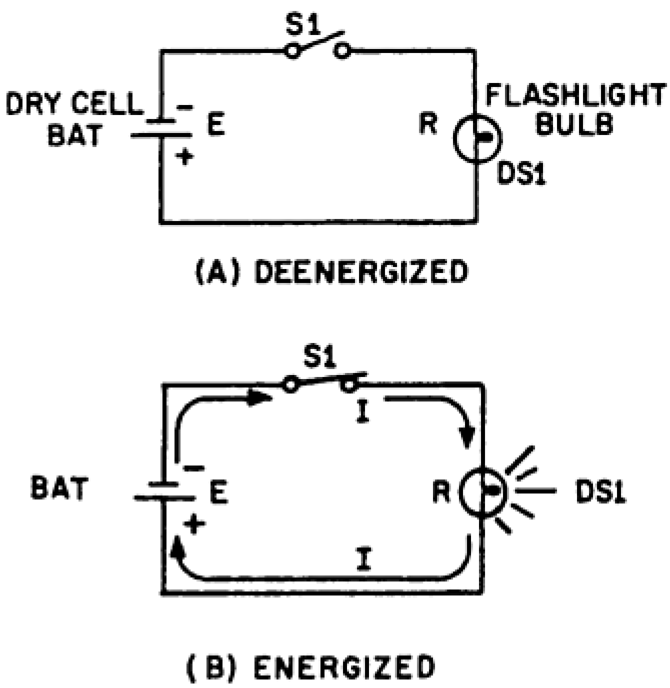
A load is any device through which an electrical current flows and which changes this electrical energy into a more useful form. The following are common examples of loads:

A light bulb (changes electrical energy to light energy).

An electric motor (changes electrical energy into mechanical energy).

A speaker in a radio (changes electrical energy into sound).

A source is the device that furnishes the electrical energy used by the load. It may be a simple dry cell (as in a flashlight), a storage battery (as in an automobile), or a power supply (such as a battery charger). A switch permits control of the electrical device by interrupting the current delivered to the load.



Schematic of a Basic Circuit, the Flashlight

Laws of Electricity

Ohm’s law describes the relationship among potential, resistance and current in a resistive series circuit. In a series circuit, all circuit elements are connected in sequence along a unique path, head to tail, as are the battery and three resistors shown in Figure 2-1. Ohm’s Law may be written as:

V = IR

Where V is the potential difference in volts between two points in a circuit, R is the resistance between the two points in ohms, and I is the resulting current in amperes.

diagrams for determining resistance and voltage in a basic circuit, respectively.

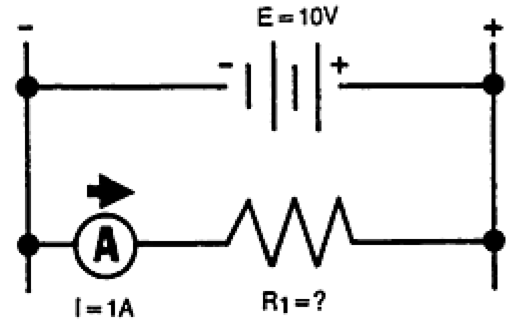



FIGURE 3-2. Determining Resistance in a Basic Circuit.

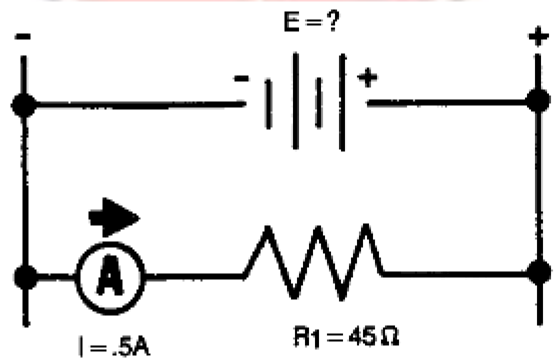



FIGURE 3-3. Determining Voltage in a Basic Circuit.

Using Ohms's Law, the resistance of a circuit can be determined knowing only the voltage and the current in the circuit. In any equation, if all the variables (parameters) are known except one, that unknown can be found. For example, using Ohm's Law, if current (I) and voltage (E) are known, you can determine resistance (R), the only parameter not known:

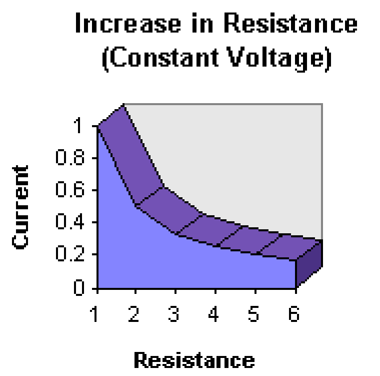
Basic formula: $I = \frac{E}{R}$

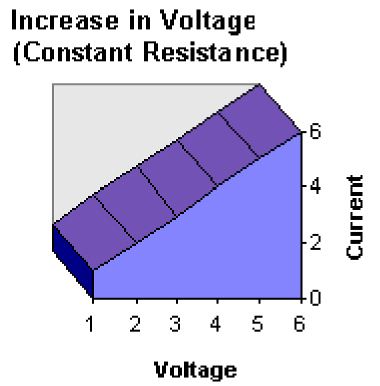
The formula may also be expressed as -

$E = I \times R$ or $R = \frac{E}{I}$

.

2) A steady increase in resistance, in a circuit with constant voltage, produces a progressively (not a straight-line if graphed) weaker current.




In simpler terms, Ohm's Law means:
1) A steady increase in voltage, in a circuit with constant resistance, produces a constant linear rise in current.

TECHNICAL DEFINITION ALERT!

Ohm's Law is a formulation of the relationship of voltage, current, and resistance, expressed as:

$$V = I \times R$$

or

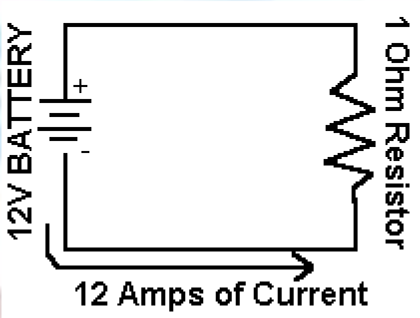
$$I = \frac{V}{R} \qquad R = \frac{V}{I}$$

Where:

V is the Voltage measured in volts

I is the Current measured in amperes
R is the resistance measured in Ohms
Therefore:
*Volts = Amps times Resistance*

Ohms Law is used to calculate a missing value in a circuit.




In this simple circuit there is a current of 12 amps (12A) and a resistive load of 1 Ohm (1W).
Using the first formula from above we determine the Voltage:

**V = 12 x 1 : V = 12 Volts (12V)**

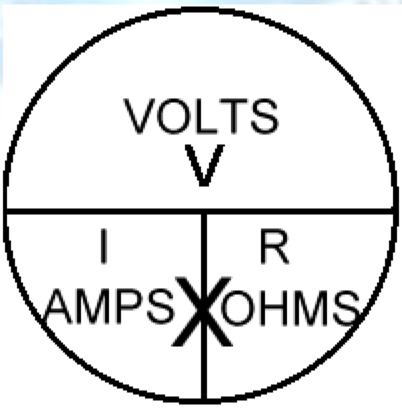
If we knew the battery was suppling 12 volt of pressure (voltage), and there was a resistive load of 1 Ohm placed in series, the current would be:

**I = 12 / 1 : I = 12 Amps (12A)**

If we knew the battery was suppling 12V and the current being generated was 12A, then the Resistance would be:

**R = 12/12 : R =** 1W

An easy way to remember the formulas is by using this diagram.



To determine a missing value, cover it with your finger. The horizontal line in the middle means to divide the two remaining values. The "X" in the bottom section of the circle means to multiply the remaining values.

• If you are calculating voltage, cover it and you have I X R left (V= I times R).

• If you are calculating amperage, cover it, and you have V divided by R left (I=V/R).

• If you are calculating resistance, cover it, and you have V divide by I left (R=V/I).

**Note:** The letter **E** is sometimes used instead of **V** for voltage.

Kirchhoff's Law

Kirchhoff's current law states that the algebraic sum of currents around any point in a circuit is zero. Kirchhoff's voltage law states that the algebraic sum of the voltages around a closed electrical loop is zero.

● Kirchhoff's Voltage Law

Kirchhoff's Voltage Law (or Kirchhoff's Loop Rule) is a result of the electrostatic field being conservative. It states that the total voltage around a closed loop must be zero. If this were not the case, then when we travel around a closed loop, the voltages would be indefinite. So

$$\sum V = 0$$

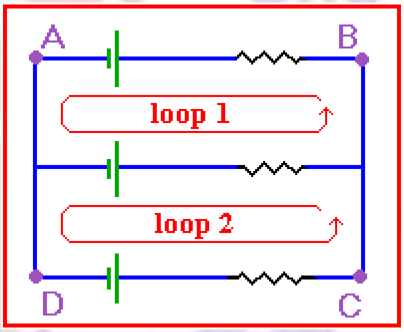



**Figure 1** *Around a closed loop, the total voltage should be zero*

In Figure 1 the total voltage around loop 1 should sum to zero, as does the total voltage in loop2. Furthermore, the loop which consists of the outer part of the circuit (the path ABCD) should also sum to zero.

We can adopt the convention that *potential gains* (i.e. going from lower to higher potential, such as with an emf source) is taken to be positive. *Potential losses* (such as across a resistor) will then be negative. However, as long as you are consistent in doing your problems, you should be able to choose whichever convention you like. It is a good idea to adopt the convention used in your class.

Power Law

The power law states that the power in watts dissipated in a resistive element is given by the product of the current in amperes and the potential difference across the resistance in volts:

$P = IV$

And substituting Ohm's law gives:

$P = I^2R = V^2/R$

Basic Direct Current Circuits

**The Schematic Diagram**

The schematic diagram consists of *idealized* circuit elements each of which represents some property of the *actual* circuit. The Figure shows some common circuit elements encountered in DC circuits. A two-terminal network is a circuit that has only two points of interest, say *A* and *B*.

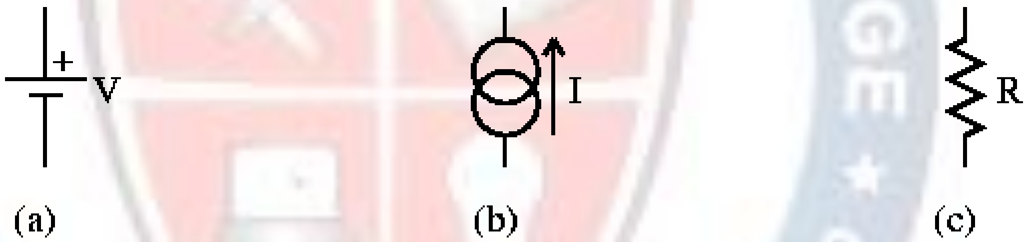
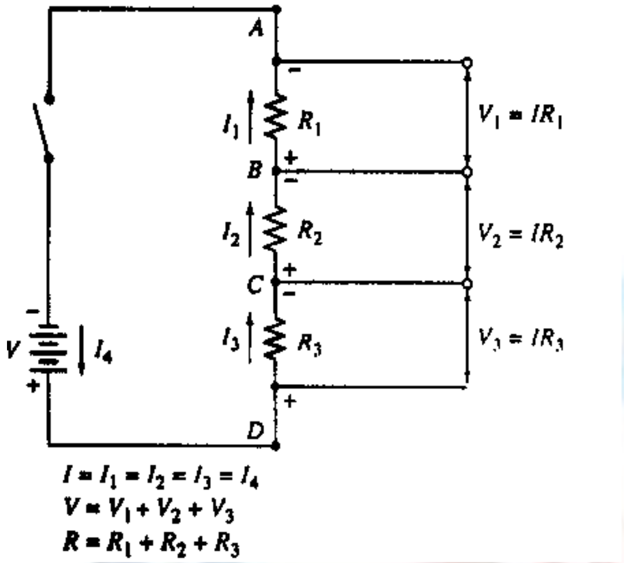



**Figure:** Common circuit elements encountered in DC circuits: a) ideal voltage source, b) ideal current source and c) resistor.

Two types of basic dc circuits will be described; series resistive circuits and parallel resistive circuits.

Series Circuits Figure 2-1 shows a basic series circuit, which consists of a battery, a switch,




and three resistors in series.

Figure 2-1 (Principles of Instrumental Analysis)

The current is the same at all points in a series circuit, that is:

$I = I_1 = I_2 = I_3 = I_4$

Application of Kirchhoff's voltage law to the circuit in Figure 2-1 yields:

$V = V_1 + V_2 + V_3$

The total resistance, $R_s$, of a series circuit is equal to the sum of the resistances of the individual components.

$R_s = R_1 + R_2 + R_3$

Parallel Circuits

Figure 2-2 shows a parallel dc circuit.

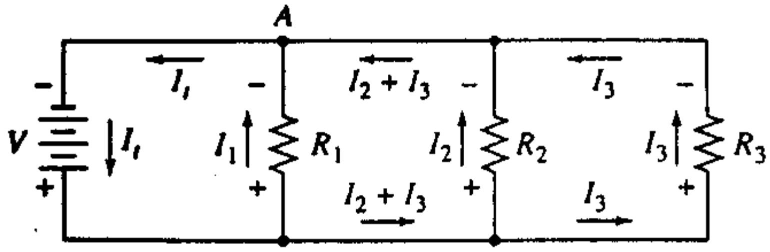



Figure 2-2 (Principles of Instrumental Analysis)

Applying Kirchhoff's current law, we obtain:

$I_t = I_1 + I_2 + I_3$

Applying Kirchhoff's voltage law to this circuit gives three independent equations.

$V = I_1R_1$

$V = I_2R_2$

$V = I_3R_3$

Substitution and division by V gives:

$1/ R_p = 1/R_1 + 1/R_2 + 1/R_3$

Since the conductance, G, of a resistor, R, is given by G = 1/R:

$G_p = G_1 + G_2 + G_3$

Conductances are additive in a parallel circuit rather than the resistance.

In conclusion, the most important things to remember about the differences between resistors in series and parallel are as follows:

Resistors in series have the same current and

Resistors in parallel have the same voltage.

**SEMICONDUCTOR DIODES**

Learning objectives are stated at the beginning of each chapter. These learning objectives serve as a preview of the information you are expected to learn in the chapter. The comprehensive check questions are based on the objectives. The learning objectives are listed below.

Upon completion of this chapter, you should be able to do the following:

- State, in terms of energy bands, the differences between a conductor, an insulator, and a semiconductor.
- Explain the electron and the hole flow theory in semiconductors and how the semiconductor is affected by doping.
- Define the term "diode" and give a brief description of its construction and operation.
- Explain how the diode can be used as a half-wave rectifier and as a switch.
- Identify the diode by its symbology, alphanumerical designation, and color code.
- List the precautions that must be taken when working with diodes and describe the different ways to test them.

A diode is a nonlinear device that has greater conductance in one direction than in another. Useful diodes are manufactured by forming adjacent n-type and p-type regions within a single germanium or silicon crystal: the interface between these regions is termed a pn junction.

Figure 2-3a is a cross section of one type of pn junction, which is formed by diffusing an excess of a p-type impurity, such as indium, into a minute silicon chip that has been doped with an n-type impurity, such as antimony. A junction of this kind permits movement of holes from the p region into the n region and movement of electrons in the in the reverse direction. As holes and electrons diffuse in the opposite direction, a region is created that is depleted of mobile charge carriers and thus has very high resistance. This region is referred to as the depletion region. Because there is a separation of charge across the depletion region, a potential difference develops across the region that causes a migration of holes and electrons in the opposite direction. The current that results from the diffusion of holes and electrons is balanced by the current produced by migration of the carriers in the electric field, thus there is no net current. The magnitude of potential difference across the depleted region depends upon the composition of the materials used in the pn junction. For silicon diodes, the potential difference is about 0.6V, and for germanium, it is about 0.3V. When a positive potential is applied across a pn junction, there is little resistance to current in the direction of the p-type to the n-type material. On the other hand, the pn junction offers a high resistance to the flow of holes in the opposite direction and is called a current rectifier.

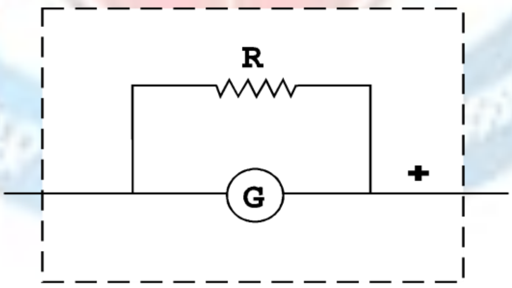
Figure 2-3b illustrates the symbol for a diode. The arrow points in the direction of low resistance to positive current. The triangular portion of the diode symbol may be imagined to point in the direction of current in a conducting diode.

Figure 2-3c shows the mechanism of conduction of charge when the p region is made positive with respect to the n region by application of a potential; this process is called forward biasing. The holes in the p region and the excess electrons in the n region move under the influence of the electric field toward the junction, where they combine and annihilate each other. The negative terminal of the battery injects new electrons into the n region, which can then continue the conduction process; the positive terminal extracts electrons from the p region, creating new holes that are free to migrate towards the pn junction.

Figure 2-3d shows when the diode is reverse-biased and the majority carriers in each region drift away from the junction to form the depletion layer, which contains few charges. Only the small concentration of minority carriers present in each region drifts toward the junction and creates a current.

Ampermeter

An ampermeter (ammeter) is a galvanometer with a calibrated current scale for its indicator and a bypass resistor (called a shunt) for a fixed fraction of the current, shown in Figure 1. Many ammeters have several selectable shunts which provide their corresponding current meter ranges. Typically, ammeters can be found with calibrated ranges of 1 micro-A for full scale deflection up to 1000 A for full scale deflection, and in multiples of 10 between these extremes.




Voltmeter

A voltmeter, shown in Figure 2, is just a calibrated galvanometer with a series resistor so that the total resistance of the path is increased. The galvanometer range is calibrated for the current Ig passing through it. This scale is adjusted to display the potential difference between points A and B, (voltage) by substituting Vg values for Ig on the scale where Vg = Ig Rg and Rg is the total resistance of the voltmeter. Voltmeters may have more than one calibrated scale which can be selected by changing the resistance Rg.

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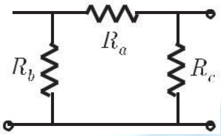
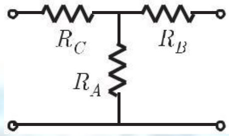
# ELECTRIC CIRCUITS & FIELDS

Q. 1 Consider a delta connection of resistors and its equivalent star connection as shown below. If all elements of the delta connection are scaled by a factor $k$ , $k > 0$ , the elements of the corresponding star equivalent will be scaled by a factor of




(A) $k^2$
(B) $k$
(C) $1/k$
(D) $\sqrt{k}$

Q. 2 The flux density at a point in space is given by $\vec{B} = 4xa\mathrm{v}_x + 2kya\mathrm{v}_y + 8a\mathrm{v}_z$ Wb/m$^2$. The value of constant $k$ must be equal to

(A) -2
(B) -0.5
(C) +0.5
(D) +2

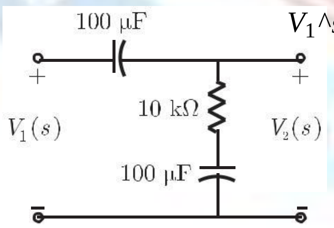
Q. 3 A single-phase load is supplied by a single-phase voltage source. If the current flowing from the load to the source is 10+ - 150cA and if the voltage at the load terminal is 100+60cV, then the

(A) load absorbs real power and delivers reactive power
(B) load absorbs real power and absorbs reactive power
(C) load delivers real power and delivers reactive power
(D) load delivers real power and absorbs reactive power

Q. 4 A source $v_s$ ^ $t$ h = $V$ cos 100$pt$ has an internal impedance of ^4 + $j$3hW. If a purely resistive load connected to this source has to extract the maximum power out of the source, its value in W should be

(A) 3
(B) 4
(C) 5
(D) 7

Q. 5 The transfer function $\frac{V_2 ^s h}{V_1 ^s h}$ of the circuit shown below is



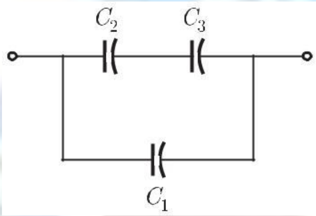

(A) $\frac{0.5s + 1}{s + 1}$
(B) $\frac{3s + 6}{s + 2}$
(C) $\frac{s + 2}{s + 1}$
(D) $\frac{s + 1}{s + 2}$

Q. 6 A dielectric slab with 500 mm # 500 mm cross-section is 0.4 m long. The slab is subjected to a uniform electric field of $\vec{E} = 6\vec{a}_x + 8\vec{a}_y$ kV/mm. The relative permittivity of the dielectric material is equal to 2. The value of constant $e_0$ is 8.85 # $10^{-12}$ F/m. The energy stored in the dielectric in Joules is

(A) 8.85 # $10^{-11}$ (B) 8.85 # $10^{-5}$

(C) 88.5 (D) 885

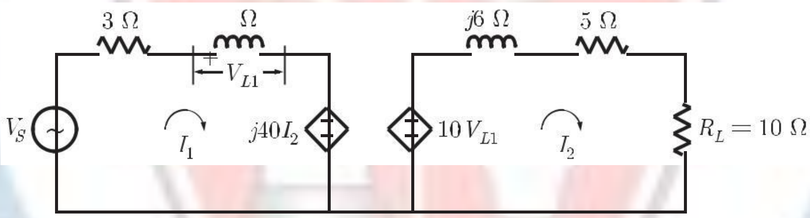
Q. 7 Three capacitors $C_1$, $C_2$ and $C_3$ whose values are 10 mF, 5 mF, and 2 mF respectively, have breakdown voltages of 10 V, 5 V and 2 V respectively. For the interconnection shown below, the maximum safe voltage in Volts that can be applied across the combination, and the corresponding total charge in mC stored in the effective capacitance across the terminals are respectively,




(A) 2.8 and 36 (B) 7 and 119

(C) 2.8 and 32 (D) 7 and 80

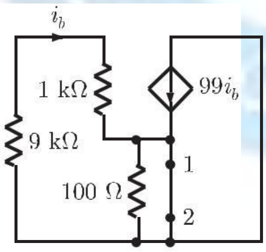
Q. 8 In the circuit shown below, if the source voltage $V_S = 100+53.13$cV then the Thevenin's equivalent voltage in Volts as seen by the load resistance $R_L$ is




(A) 100+90c (B) 800+0c

(C) 800+90c (D) 100+60c

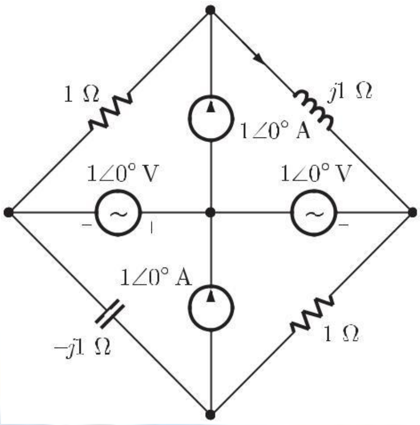
Q. 9 The impedance looking into nodes 1 and 2 in the given circuit is




(A) 50 W (B) 100 W

(C) 5 kW (D) 10.1 kW

Q. 10 In the circuit shown below, the current through the inductor is




(A) $\frac{2}{1+j}$ A (B) $\frac{-1}{1+j}$ A

(C) $\frac{1}{1+j}$ A (D) 0 A

10. 11 A system with transfer function $G(s) = \frac{(s^2+9)(s+2)}{(s+1)(s+3)(s+4)}$ is excited by sin($wt$). The steady-state output of the system is zero at

(A) $w$ = 1 rad/s (B) $w$ = 2 rad/s

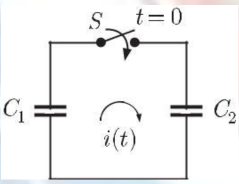
(C) $w$ = 3 rad/s (D) $w$ = 4 rad/s

G. 12 The average power delivered to an impedance (4 - $j$3) W by a current 5 cos(100$pt$ + 100) A is

(A) 44.2 W (B) 50 W

(C) 62.5 W (D) 125 W

M. 13 In the following figure, $C_1$ and $C_2$ are ideal capacitors. $C_1$ has been charged to 12 V before the ideal switch $S$ is closed at $t$ = 0. The current $i$ ($t$) for all $t$ is



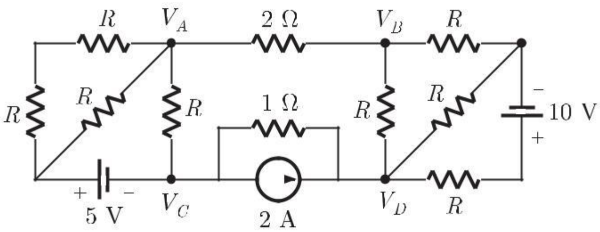

(J) zero

(K) a step function

(L) an exponentially decaying function

(M) an impulse function

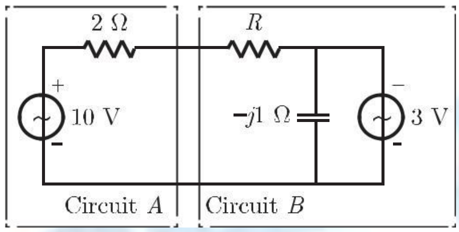
Q. 14 If $V_A$ - $V_B$ = 6 V then $V_C$ - $V_D$ is



(A) -5 V (B) 2 V

(C) 3 V (D) 6 V

Q. 15 Assuming both the voltage sources are in phase, the value of $R$ for which maximum power is transferred from circuit $A$ to circuit $B$ is




(A) 0.8 W (B) 1.4 W

(C) 2 W (D) 2.8 W

**Common Data for Questions 16 and 17 :**

With 10 V dc connected at port A in the linear nonreciprocal two-port network shown below, the following were observed :

(T) 1 W connected at port $B$ draws a current of 3 A

(U) 2.5 W connected at port $B$ draws a current of 2 A


Q. 16 With 10 V dc connected at port $A$, the current drawn by 7 W connected at port $B$ is

(A) 3/7 A (B) 5/7 A

(C) 1 A (D) 9/7 A

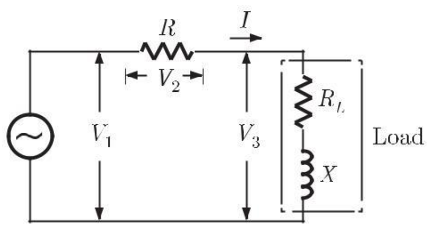
Q. 17 For the same network, with 6 V dc connected at port $A$, 1 W connected at port $B$ draws 7/3 A. If 8 V dc is connected to port $A$, the open circuit voltage at port $B$ is

(A) 6 V (B) 7 V

(C) 8 V (D) 9 V

**Statement for Linked Answer Questions 18 and 19 :**

In the circuit shown, the three voltmeter readings are $V_1$ = 220 V, $V_2$ = 122 V, $V_3$ = 136 V.



Q. 18 The power factor of the load is

(A) 0.45 (B) 0.50

(C) 0.55 (D) 0.60

Q. 19 If $R_L$ = 5 W, the approximate power consumption in the load is

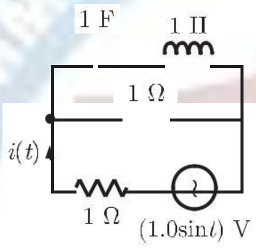
(A) 700 W (B) 750 W

(C) 800 W (D) 850 W

Q. 20 The r.m.s value of the current *i* (*t*) in the circuit shown below is

(A) $\frac{1}{2}$ A (B) $\frac{1}{\sqrt{2}}$ A

(C) 1 A (D) $\sqrt{2}$ A




Q. 21 The voltage applied to a circuit is $100\sqrt{2}$ cos(100p*t*) volts and the circuit draws a current of $10\sqrt{2}$ sin(100p*t* + p/4) amperes. Taking the voltage as the reference phasor, the phasor representation of the current in amperes is

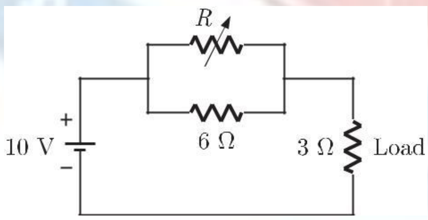
(H) $10\sqrt{2}$ ∠-p/4

(I) 10 -p/4

(J) 10 ∠+p/4

(K) $10\sqrt{2}$ ∠+p/4

Q. 22 In the circuit given below, the value of *R* required for the transfer of maximum power to the load having a resistance of 3 W is




(K) zero

(L) 3 W

(M) 6 W

(N) infinity

Q. 23 A lossy capacitor $C_x$ , rated for operation at 5 kV, 50 Hz is represented by an equivalent circuit with an ideal capacitor $C_p$ in parallel with a resistor $R_p$ . The value $C_p$ is found to be 0.102 μF and value of $R_p$ = 1.25 MW. Then the power loss and tan d of the lossy capacitor operating at the rated voltage, respectively, are

(A) 10 W and 0.0002 | (B) 10 W and 0.0025

(C) 20 W and 0.025 | (D) 20 W and 0.04

Q. 24 A capacitor is made with a polymeric dielectric having an $e_r$ of 2.26 and a dielectric breakdown strength of 50 kV/cm. The permittivity of free space is 8.85 pF/m. If the rectangular plates of the capacitor have a width of 20 cm and a length of 40 cm, then the maximum electric charge in the capacitor is

(A) 2 μC | (B) 4 μC

(C) 8 μC | (D) 10 μC

**Common Data For Q. 25 and 26**

The input voltage given to a converter is $v_i = 100\sqrt{2}\sin(100pt)$ V

The current drawn by the converter is

$i_i = 10\sqrt{2}\sin(100pt - p/3) + 5\sqrt{2}\sin(300p\,t + p/4) + 2\sqrt{2}\sin(500pt - p/6)$ A

Q. 25 The input power factor of the converter is

(A) 0.31 | (B) 0.44

(C) 0.5 | (D) 0.71

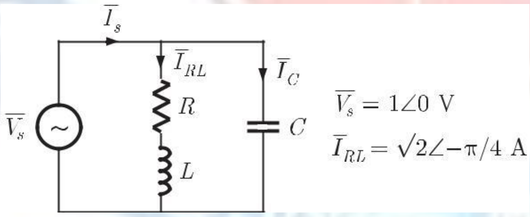
Q. 26 The active power drawn by the converter is

(A) 181 W | (B) 500 W

(C) 707 W | (D) 887 W

**Common Data For Q. 27 and 28**

An RLC circuit with relevant data is given below.




Q. 27 The power dissipated in the resistor $R$ is

(A) 0.5 W | (B) 1 W

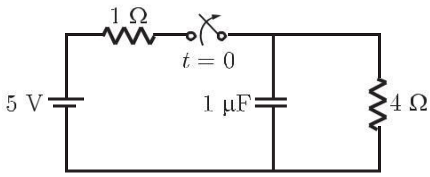
(C) $\sqrt{2}$ W | (D) 2 W

Q. 28 The current $\overline{I_C}$ in the figure above is

(A) $-j2$ A | (B) $-j\frac{1}{\sqrt{2}}$ A

(C) $+j\frac{1}{\sqrt{2}}$ A | (D) $+j2$A

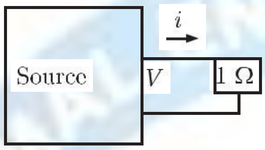
Q. 29 The switch in the circuit has been closed for a long time. It is opened at $t = 0$. At $t = 0^+$, the current through the 1 *m*F capacitor is




(A) 0 A (B) 1 A

(C) 1.25 A (D) 5 A

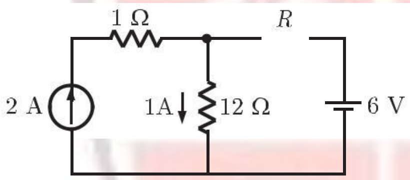
Q. 30 As shown in the figure, a 1 W resistance is connected across a source that has a load line $v + i = 100$. The current through the resistance is




(A) 25 A (B) 50 A

(C) 100 A (C) 200 A

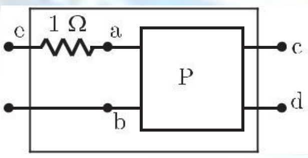
Q. 31 If the 12 W resistor draws a current of 1 A as shown in the figure, the value of resistance *R* is




(A) 4 W (B) 6 W

(C) 8 W (D) 18 W

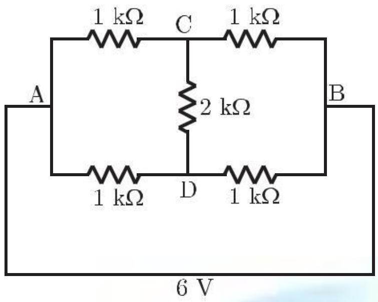
Q. 32 The two-port network P shown in the figure has ports 1 and 2, denoted by terminals (a,b) and (c,d) respectively. It has an impedance matrix *Z* with parameters denoted by $Z_{ij}$ . A 1 W resistor is connected in series with the network at port 1 as shown in the figure. The impedance matrix of the modified two-port network (shown as a dashed box ) is




(A) $\begin{bmatrix} Z_{11} + 1 & Z_{12} + 1 \\ Z_{21} & Z_{22} + 1 \end{bmatrix}$ (B) $\begin{bmatrix} Z_{11} + 1 & Z_{12} \\ Z_{21} & Z_{22} + 1 \end{bmatrix}$

(C) $\begin{bmatrix} Z_{11} + 1 & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}$ (D) $\begin{bmatrix} Z_{11} + 1 & Z_{12} \\ Z_{21} + 1 & Z_{22} \end{bmatrix}$

Q. 33 The current through the 2 kW resistance in the circuit shown is




(A) 0 mA (B) 1 mA

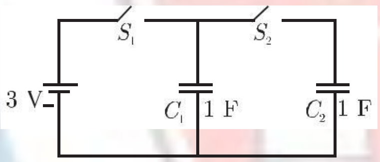
(C) 2 mA (D) 6 mA

Q. 34 How many 200 W/220 V incandescent lamps connected in series would consume the same total power as a single 100 W/220 V incandescent lamp ?

(A) not possible (B) 4

(C) 3 (D) 2

Q. 35 In the figure shown, all elements used are ideal. For time $t < 0$, $S_1$ remained closed and $S_2$ open. At $t = 0$, $S_1$ is opened and $S_2$ is closed. If the voltage $V_{c2}$ across the capacitor $C_2$ at $t = 0$ is zero, the voltage across the capacitor combination at $t = 0^+$ will be



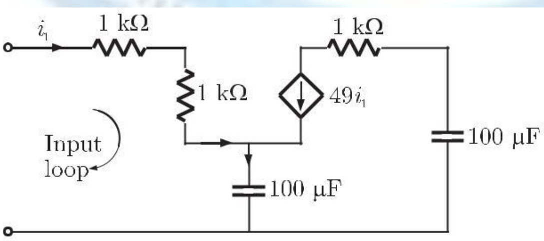

(K) 1 V

(L) 2 V

(M) 1.5 V

(N) 3 V

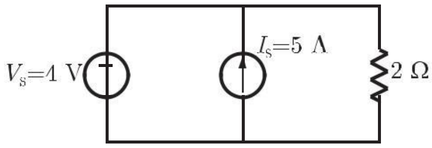
Q. 36 The equivalent capacitance of the input loop of the circuit shown is




(A) 2 *m*F (B) 100 *m*F

(C) 200 *m*F (D) 4 *m*F

Q. 37 For the circuit shown, find out the current flowing through the 2 W resistance. Also identify the changes to be made to double the current through the 2 W resistance.



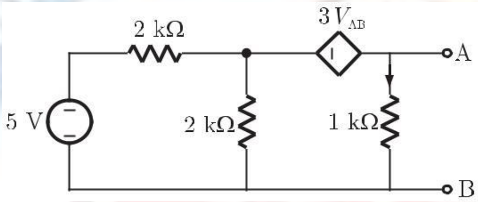

(J) (5 A;Put$V_S$ = 30 V)

(K) (2 A; Put$V_S$ = 8 V)

(L) (5 A; Put $I_S$ = 10 A)

(M) (7 A; Put $I_S$ = 12 A)

**Statement for Linked Answer Question 38 and 39 :**




Q. 38 For the circuit given above, the Thevenin's resistance across the terminals A and B is

(H) 0.5 kW

(I) 0.2 kW

(J) 1 kW

(K) 0.11 kW

Q. 39 For the circuit given above, the Thevenin's voltage across the terminals A and B is

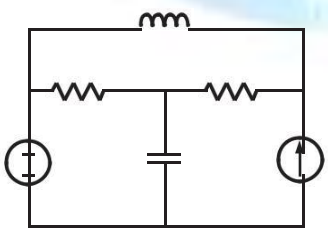
(K) 1.25 V

(L) 0.25 V

(M) 1 V

(N) 0.5 V

Q. 40 The number of chords in the graph of the given circuit will be



(A) 3

(B) 4

(C) 5

(D) 6

Q. 41 The Thevenin's equivalent of a circuit operation at $w$ = 5 rads/s, has $V_{oc}$ = 3.71+ -15.9% V and $Z_0$ = 2.38 - $j$0.667 W. At this frequency, the minimal realization of the Thevenin's impedance will have a

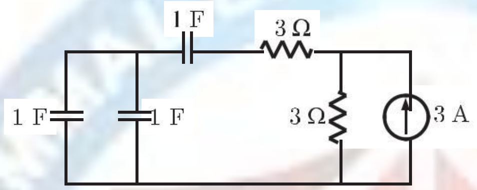
K resistor and a capacitor and an inductor

L resistor and a capacitor

M resistor and an inductor

N capacitor and an inductor

Q. 42 The time constant for the given circuit will be



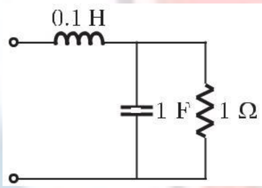

(L) 1/9 s

(M) 1/4 s

(N) 4 s

(O) 9 s

Q. 43 The resonant frequency for the given circuit will be



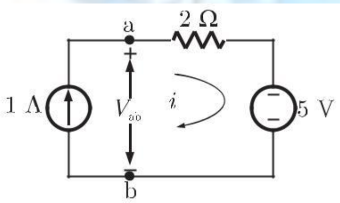

(K) 1 rad/s

(L) 2 rad/s

(M) 3 rad/s

(N) 4 rad/s

Q. 44 Assuming ideal elements in the circuit shown below, the voltage $V_{ab}$ will be




E -3 V

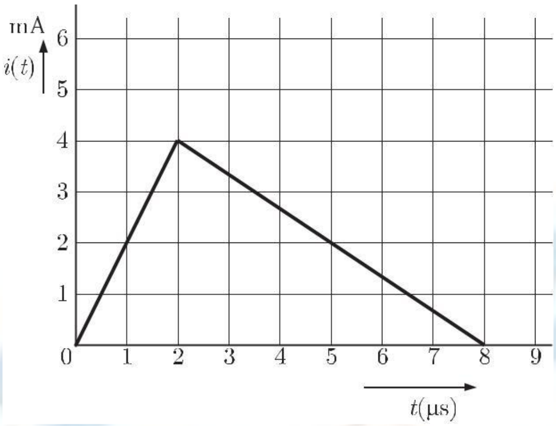
F 0 V

G 3 V

H 5 V

**Statement for Linked Answer Question 45 and 46**

The current $i$ ($t$) sketched in the figure flows through a initially uncharged 0.3 nF capacitor.




Y. 45 The charge stored in the capacitor at $t$ = 5 $m$s, will be

(A) 8 nC (B) 10 nC

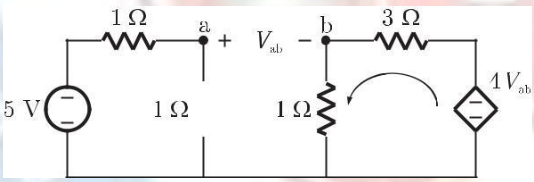
(C) 13 nC (D) 16 nC

(F) 46 The capacitor charged upto 5 ms, as per the current profile given in the figure, is connected across an inductor of 0.6 mH. Then the value of voltage across the capacitor after 1 $m$s will approximately be

(A) 18.8 V (B) 23.5 V

(C) -23.5 V (D) -30.6 V

(H) 47 In the circuit shown in the figure, the value of the current $i$ will be given by




(A) 0.31 A (B) 1.25 A

(C) 1.75 A (D) 2.5 A

Q. 48 Two point charges $Q_1$ = 10 $m$C and $Q_2$ = 20 mC are placed at coordinates (1,1,0) and (- 1, - 1,0) respectively. The total electric flux passing through a plane $z$ = 20 will be

(A) 7.5 $mC$ (B) 13.5 $mC$

(C) 15.0 $mC$ (D) 22.5 $mC$

Q. 49 A capacitor consists of two metal plates each 500 # 500 mm2 and spaced 6 mm apart. The space between the metal plates is filled with a glass plate of 4 mm thickness and a layer of paper of 2 mm thickness. The relative primitivities of the glass and paper are 8 and 2 respectively. Neglecting the fringing effect, the capacitance will be (Given that $e_0$ = 8.85 # $10^{-12}$ F/m )

(A) 983.3 pF (B) 1475 pF

(C) 637.7 pF (D) 9956.25 pF

**Q. 50** A coil of 300 turns is wound on a non-magnetic core having a mean circumference of 300 mm and a cross-sectional area of 300 mm2. The inductance of the coil corresponding to a magnetizing current of 3 A will be

(Given that $m_0 = 4p \# 10^{-7}$ H/m)

(A) 37.68 $m$H (B) 113.04 $m$H

(C) 3.768 $m$H (D) 1.1304 $m$H

---

**Q. 51** Divergence of the vector field

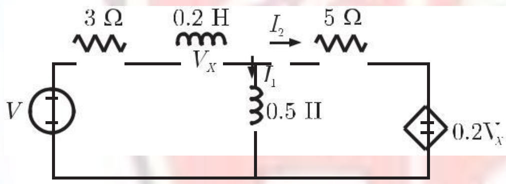
$V(x, y, z) = -(x \cos xy + y)\hat{i} + (y \cos xy)\hat{j} + (\sin z^2 + x^2 + y^2)\hat{k}$ is

(A) $2z \cos z^2$ (B) $\sin xy + 2z \cos z^2$

(C) $x \sin xy - \cos z$ (D) None of these

---

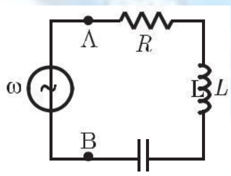
**Q. 52** The state equation for the current $I_1$ in the network shown below in terms of the voltage $V_X$ and the independent source $V$, is given by



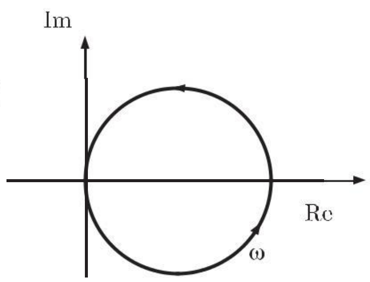

(A) $\frac{dI_1}{dt} = -1.4V_X - 3.75I_1 + \frac{5}{4}V$ (B) $\frac{dI_1}{dt} = 1.4V_X - 3.75I_1 - \frac{5}{4}V$

(C) $\frac{dI_1}{dt} = -1.4V_X + 3.75I_1 + \frac{5}{4}V$ (D) $\frac{dI_1}{dt} = -1.4V_X + 3.75I_1 - \frac{5}{4}V$

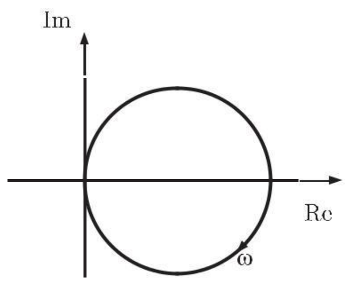
**Q. 53** The R-L-C series circuit shown in figure is supplied from a variable frequency voltage source. The admittance - locus of the R-L-C network at terminals AB for increasing frequency $w$ is

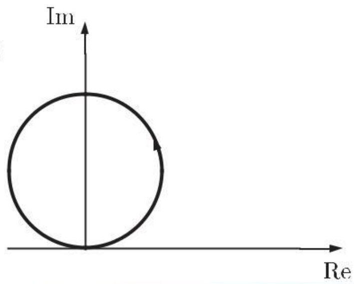


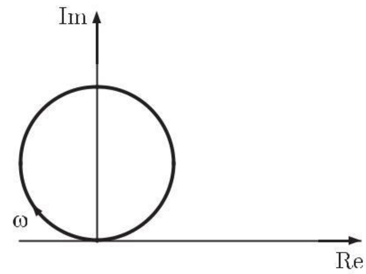

(A)



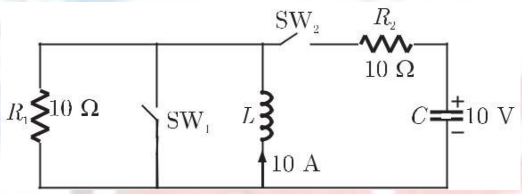

(B)



(C) 


(D) 


Q. 54 In the circuit shown in figure. Switch $SW_1$ is initially closed and $SW_2$ is open. The inductor $L$ carries a current of 10 A and the capacitor charged to 10 V with polarities as indicated. $SW_2$ is closed at $t = 0$ and $SW_1$ is opened at $t = 0$. The current through $C$ and the voltage across $L$ at ($t = 0^+$) is




(A) 55 A, 4.5 V

(B) 5.5 A, 45 V

(C) 45 A, 5.5 A

(D) 4.5 A, 55 V

Q. 55 A 3 V DC supply with an internal resistance of 2 W supplies a passive non-linear resistance characterized by the relation $V_{NL} = I_{NL}^2$ . The power dissipated in the non linear resistance is

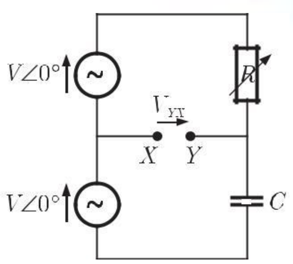
(A) 1.0 W

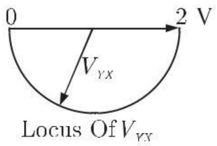
(B) 1.5 W

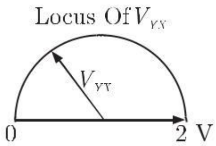
(C) 2.5 W

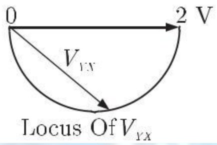
(D) 3.0 W

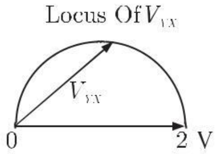
Q. 56 In the figure given below all phasors are with reference to the potential at point "$O$". The locus of voltage phasor $V_{YX}$ as $R$ is varied from zero to infinity is shown by



(A) 


(B) 


(C) 


(D) 


Q. 57 The matrix A given below in the node incidence matrix of a network. The columns correspond to branches of the network while the rows correspond to nodes. Let $V = [V_1\ V_2\ .....V_6]^T$ denote the vector of branch voltages while $I = [i_1\ i_2\ .....i_6]^T$ that of branch currents. The vector $E = [e_1\ e_2\ e_3\ e_4]^T$ denotes the vector of node voltages relative to a common ground.

$$\begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & -1 & 1 & 0 \\ -1 & 0 & 0 & 0 & -1 & -1 \\ 0 & 0 & -1 & 1 & 0 & 1 \end{bmatrix}$$

Which of the following statement is true ?

(W) The equations $V_1 - V_2 + V_3 = 0, V_3 + V_4 - V_5 = 0$ are KVL equations for the network for some loops

(X) The equations $V_1 - V_3 - V_6 = 0, V_4 + V_5 - V_6 = 0$ are KVL equations for the network for some loops

(Y) $E = AV$

(Z) $AV = 0$ are KVI equations for the network

Q. 58 A solid sphere made of insulating material has a radius $R$ and has a total charge $D$ distributed uniformly in its volume. What is the magnitude of the electric field intensity, $E$, at a distance $r$ $(0 < r < R)$ inside the sphere ?

(A) $\frac{1}{4pe_0}\frac{Qr}{R^3}$ (B) $\frac{3}{4pe_0}\frac{Qr}{R^3}$

(C) $\frac{1}{4pe_0}\frac{Q}{r^2}$ (D) $\frac{1}{4pe_0}\frac{QR}{r^3}$

**Statement for Linked Answer Question 59 and 60.**

An inductor designed with 400 turns coil wound on an iron core of 16 $cm^2$ cross sectional area and with a cut of an air gap length of 1 mm. The coil is connected to a 230 V, 50 Hz ac supply. Neglect coil resistance, core loss, iron reluctance and leakage inductance, $(m_0 = 4p \# 10^{-7}$ H/M)

Q. 59 The current in the inductor is

(A) 18.08 A (B) 9.04 A

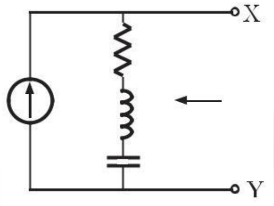
(C) 4.56 A (D) 2.28 A

Q. 60 The average force on the core to reduce the air gap will be

(A) 832.29 N (B) 1666.22 N

(C) 3332.47 N (D) 6664.84 N

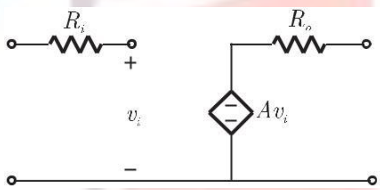
Q. 61 In the figure the current source is 1+0 A, $R$ = 1 W, the impedances are $Z_C$ =- $j$ W and $Z_L$ = 2$j$ W. The Thevenin equivalent looking into the circuit across X-Y is




(A) $\sqrt{2}$ +0 V,(1 + 2$j$) W (B) $\sqrt{2}$+45% V,(1 - 2$j$) W

(C) 2+45% V,(1 + $j$) W (D) 2+45% V,(1 + $j$) W

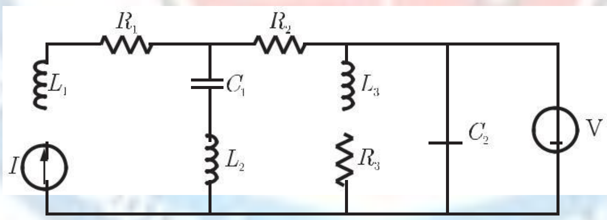
Q. 62 The parameters of the circuit shown in the figure are $R_i$ = 1 MW $R_0$ = 10 W, A = $10^6$ V/V If $v_i$ = 1 $m$V, the output voltage, input impedance and output impedance respectively are




(A) 1 V,3,10 W (B) 1 V,0,10 W

(C) 1 V, 0, 3 (D) 10 V, 3, 10 W

Q. 63 In the circuit shown in the figure, the current source $I$ = 1 A, the voltage source $V$ = 5 V, $R_1$ = $R_2$ = $R_3$ = 1 W, $L_1$ = $L_2$ = $L_3$ = 1 H,$C_1$ = $C_2$ = 1 F

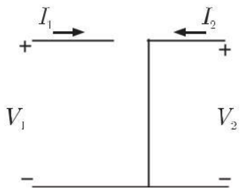



The currents (in A) through $R_3$ and through the voltage source $V$ respectively will be

(A) 1, 4 (B) 5, 1

(C) 5, 2 (D) 5, 4

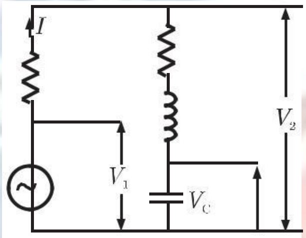
Q. 64 The parameter type and the matrix representation of the relevant two port parameters that describe the circuit shown are



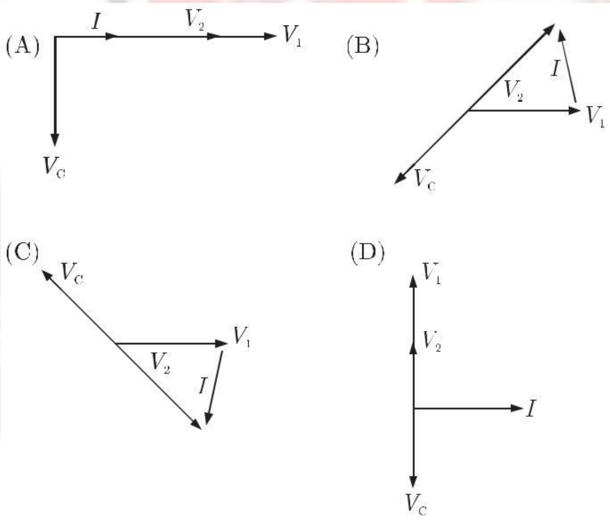

(A) z parameters, $= \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$ (B) h parameters, $= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

(C) h parameters, $= \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$ (D) z parameters, $= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

Q. 65 The circuit shown in the figure is energized by a sinusoidal voltage source $V_1$ at a frequency which causes resonance with a current of $I$.




The phasor diagram which is applicable to this circuit is




Q. 66 An ideal capacitor is charged to a voltage $V_0$ and connected at $t = 0$ across an ideal inductor L. (The circuit now consists of a capacitor and inductor alone). If we let $w_0 = \frac{1}{\sqrt{LC}}$, the voltage across the capacitor at time $t > 0$ is given by

(A) $V_0$ (B) $V_0 \cos(w_0 t)$

(C) $V_0 \sin(w_0 t)$ (D) $V_0 e^{-w_0 t} \cos(w_0 t)$

Q. 67 An energy meter connected to an immersion heater (resistive) operating on an AC 230 V, 50 Hz, AC single phase source reads 2.3 units (kWh) in 1 hour. The heater is removed from the supply and now connected to a 400 V peak square wave source of 150 Hz. The power in kW dissipated by the heater will be

(A) 3.478 (B) 1.739

(C) 1.540 (D) 0.870

Q. 68 Which of the following statement holds for the divergence of electric and magnetic flux densities ?

(A) Both are zero

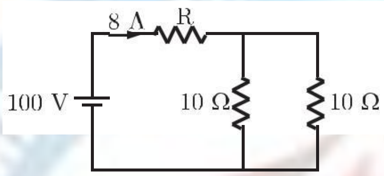
(B) These are zero for static densities but non zero for time varying densities.

(C) It is zero for the electric flux density

(D) It is zero for the magnetic flux density

---

Q. 69 In the figure given below the value of $R$ is




(A) 2.5 W (B) 5.0 W

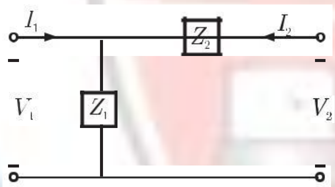
(C) 7.5 W (D) 10.0 W

W. 70 The RMS value of the voltage $u(t) = 3 + 4\cos(3t)$ is

(A) $\sqrt{17}$ V (B) 5 V

(C) 7 V (D) $(3 + 2\sqrt{2})$ V

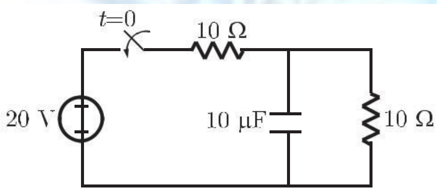
W. 71 For the two port network shown in the figure the $Z$-matrix is given by




(A) $= \begin{bmatrix} Z_1 & Z_1 + Z_2 \\ Z_1 + Z_2 & Z_2 \end{bmatrix}$ (B) $= \begin{bmatrix} Z_1 & Z_1 \\ Z_1 + Z_2 & Z_2 \end{bmatrix}$

(C) $= \begin{bmatrix} Z_1 & Z_2 \\ Z_2 & Z_1 + Z_2 \end{bmatrix}$ (D) $= \begin{bmatrix} Z_1 & Z_1 \\ Z_1 & Z_1 + Z_2 \end{bmatrix}$

Q. 72 In the figure given, for the initial capacitor voltage is zero. The switch is closed at $t = 0$. The final steady-state voltage across the capacitor is




(A) 20 V (B) 10 V

(C) 5 V (D) 0 V

Q. 73 If $\vec{E}$ is the electric intensity, $\nabla \cdot (\nabla \times \vec{E})$ is equal to

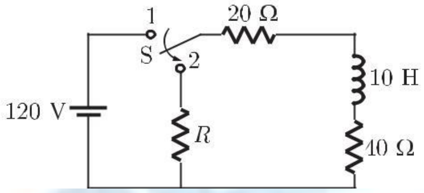
(A) $\vec{E}$ (B) $|\vec{E}|$

(C) null vector (D) Zero

**Statement for Linked Answer Question 74 and 75.**

A coil of inductance 10 H and resistance 40 W is connected as shown in the figure. After the switch S has been in contact with point 1 for a very long time, it is moved to point 2 at, $t = 0$.

Q. 74 If, at $t = 0^+$, the voltage across the coil is 120 V, the value of resistance $R$ is

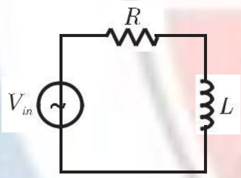



(A) 0 W
(B) 20 W
(C) 40 W
(D) 60 W

Q. 75 For the value as obtained in (a), the time taken for 95% of the stored energy to be dissipated is close to

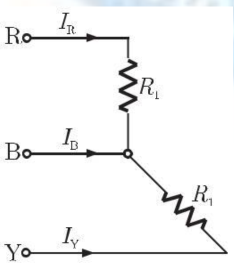
(A) 0.10 sec
(B) 0.15 sec
(C) 0.50 sec
(D) 1.0 sec

Q. 76 The RL circuit of the figure is fed from a constant magnitude, variable frequency sinusoidal voltage source $V_{in}$ . At 100 Hz, the $R$and $L$ elements each have a voltage drop $m_{RMS}$ .If the frequency of the source is changed to 50 Hz, then new voltage drop across $R$ is




(A) $\sqrt{\frac{5}{8}}$uRMS
(B) $\sqrt{\frac{2}{3}}$uRMS
(C) $\sqrt{\frac{8}{5}}$uRMS
(D) $\sqrt{\frac{3}{2}}$uRMS

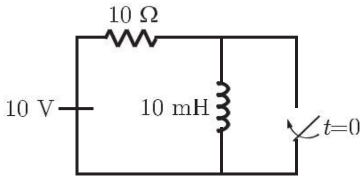
Q. 77 For the three-phase circuit shown in the figure the ratio of the currents $I_R$: $I_Y$ : $I_B$ is given by




(A) $1 :1 : \sqrt{3}$
(B) 1 :1 : 2
(C) 1 :1 : 0
(D) $1 :1 : \sqrt{3/2}$

Q. 78

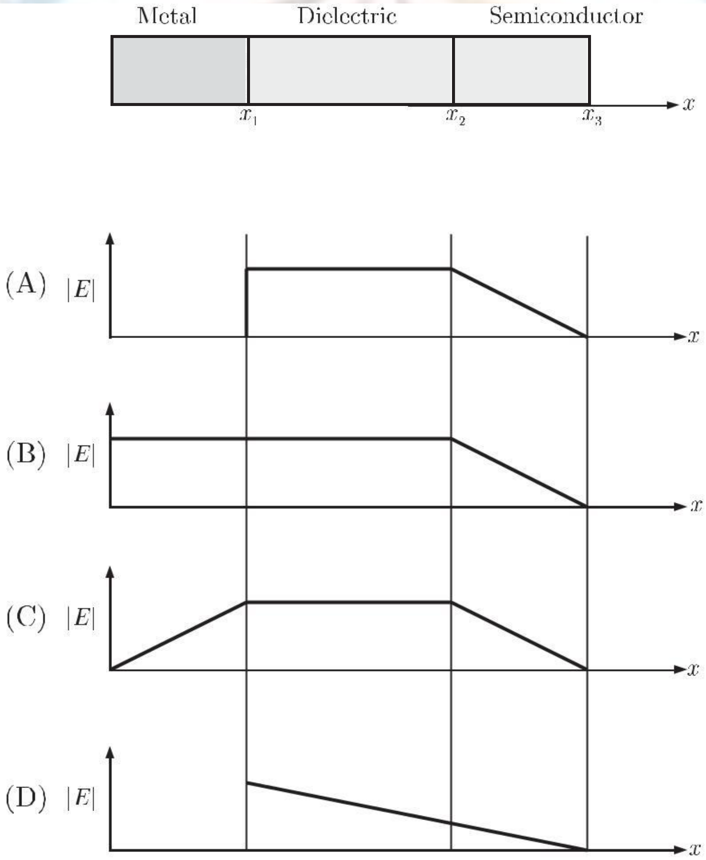
The circuit shown in the figure is in steady state, when the switch is closed at $t = 0$. Assuming that the inductance is ideal, the current through the inductor at $t = 0^+$ equals




(A) 0 A
(B) 0.5 A
(C) 1 A
(D) 2 A

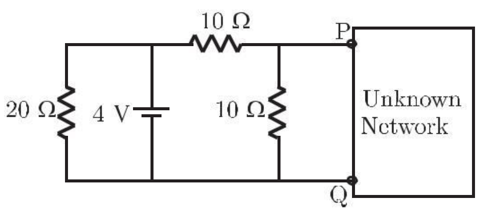
Q. 79

The charge distribution in a metal-dielectric-semiconductor specimen is shown in the figure. The negative charge density decreases linearly in the semiconductor as shown. The electric field distribution is as shown in




Q. 80

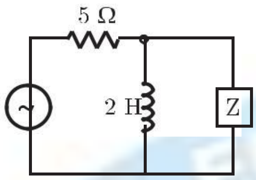
In the given figure, the Thevenin's equivalent pair (voltage, impedance), as seen at the terminals P-Q, is given by



(A) (2 V, 5 W) (B) (2 V, 7.5 W)
(C) (4 V, 5 W) (D) (4 V, 7.5 W)

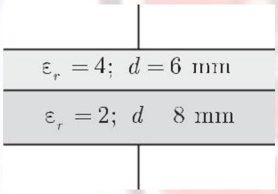
---

Q. 81 The value of Z in figure which is most appropriate to cause parallel resonance at 500 Hz is




(A) 125.00 mH (B) 304.20 *m*F
(C) 2.0 *m*F (D) 0.05 *m*F

Q. 82 A parallel plate capacitor is shown in figure. It is made two square metal plates of 400 mm side. The 14 mm space between the plates is filled with two layers of dielectrics of $e_r$ = 4, 6 mm thick and $e_r$ = 2, 8 mm thick. Neglecting fringing of fields at the edge the capacitance is

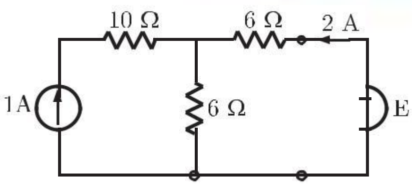



(W) 1298 pF F 944 pF
(G) 354 pF H 257 pF

Q. 83 The inductance of a long solenoid of length 1000 mm wound uniformly with 3000 turns on a cylindrical paper tube of 60 mm diameter is
(A) 3.2 *m*H (B) 3.2 mH
(C) 32.0 mH (D) 3.2 H

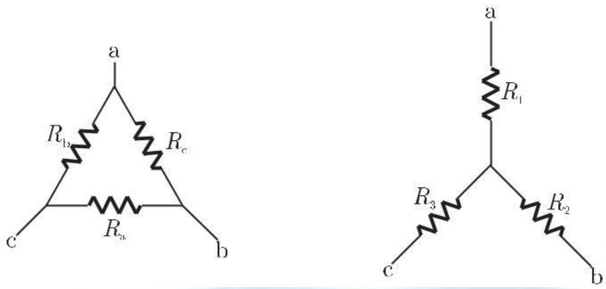
---

Q. 84 In figure, the value of the source voltage is



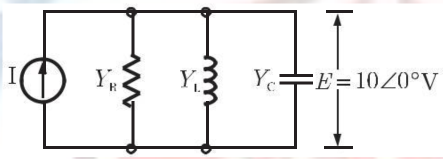

(A) 12 V (B) 24 V
(C) 30 V (D) 44 V

Q. 85 In figure, $R_a$ , $R_b$ and $R_c$ are 20 W, 20 W and 10 W respectively. The resistances $R_1$ , $R_2$ and $R_3$ in W of an equivalent star-connection are



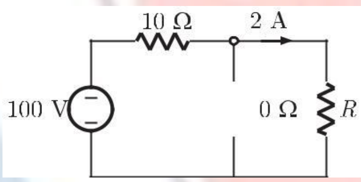

(A) 2.5, 5, 5
(B) 5, 2.5, 5
(C) 5, 5, 2.5
(D) 2.5, 5, 2.5

Q. 86 In figure, the admittance values of the elements in Siemens are $Y_R = 0.5 + j0, Y_L = 0 - j1.5, Y_C = 0 + j0.3$ respectively. The value of $I$ as a phasor when the voltage $E$ across the elements is 10+0% V



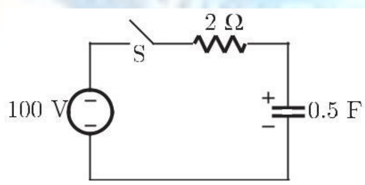

(A) 1.5 + $j$0.5
(B) 5 - $j$18
(C) 0.5 + $j$1.8
(D) 5 - $j$12

Q. 87 In figure, the value of resistance $R$ in W is




(A) 10
(B) 20
(C) 30
(D) 40

Q. 88 In figure, the capacitor initially has a charge of 10 Coulomb. The current in the circuit one second after the switch S is closed will be




(A) 14.7 A
(B) 18.5 A
(C) 40.0 A
(D) 50.0 A

Q. 89 The rms value of the current in a wire which carries a d.c. current of 10 A and a sinusoidal alternating current of peak value 20 A is
(A) 10 A
(B) 14.14 A
(C) 15 A
(D) 17.32 A

0.9 0.2

Q. 90 The Z-matrix of a 2-port network as given by $=_{0.2\ 0.6}$G

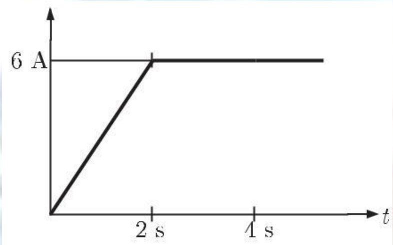
The element $Y_{22}$ of the corresponding Y-matrix of the same network is given by

(A) 1.2 (B) 0.4

(C) -0.4 (D) 1.8

---

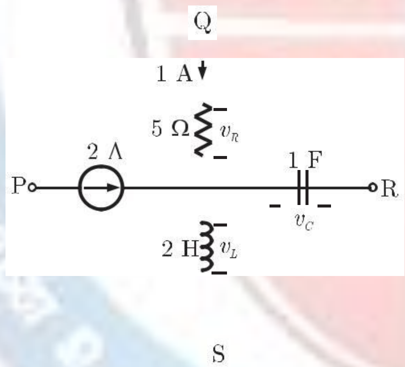
Q. 91 Figure Shows the waveform of the current passing through an inductor of resistance 1 W and inductance 2 H. The energy absorbed by the inductor in the first four seconds is




(A) 144 J (B) 98 J

(C) 132 J (D) 168 J

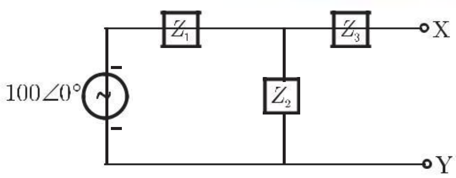
Q. 92 A segment of a circuit is shown in figure $v_R = 5V$, $v_c = 4 \sin 2t$ .The voltage $v_L$ is given by




(A) $3 - 8 \cos 2t$ (B) $32 \sin 2t$

(C) $16 \sin 2t$ (D) $16 \cos 2t$

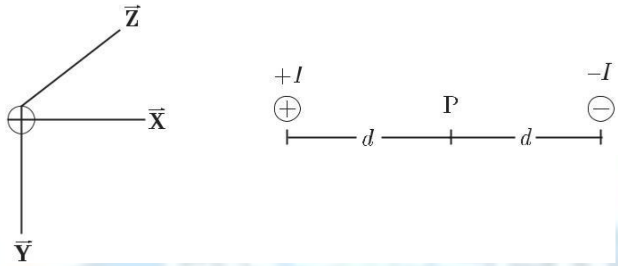
Q. 93 In the figure, $Z_1$ = 10+ - 60%, $Z_2$ = 10+ 60%, $Z_3$ = 50+53.13%.
Thevenin impedance seen form X-Y is




(A) 56.66+45% (B) 60+30%

(C) 70+30% (D) 34.4+65%

Q. 94 Two conductors are carrying forward and return current of +I and -$I$ as shown in figure. The magnetic field intensity $\vec{\mathbf{H}}$ at point P is



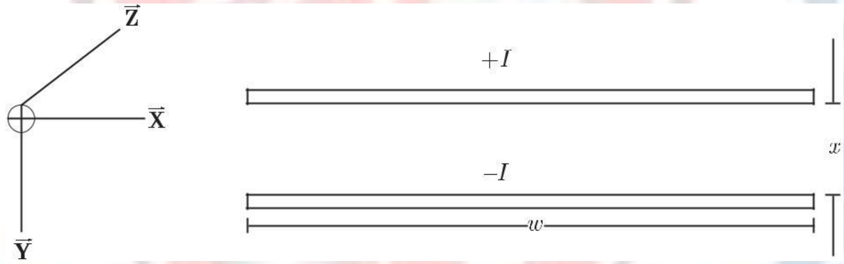

(A) $\frac{I}{pd}$ Y

(B) $\frac{I}{pd}$ X

(C) $\frac{I}{2pd}$ Y

(D) $\frac{I}{2pd}$ X

Q. 95 Two infinite strips of width w m in $x$ -direction as shown in figure, are carrying forward and return currents of +I and -$I$ in the $z$ - direction. The strips are separated by distance of x m. The inductance per unit length of the configuration is measured to be $L$ H/m. If the distance of separation between the strips in snow reduced to x/2 m, the inductance per unit length of the configuration is



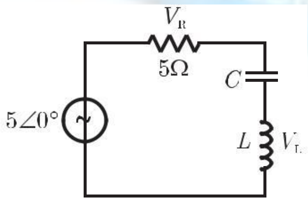

30 2$L$ H/m

7. $L$/4 H/m

5. $L$ /2 H/m

31. 4$L$ H/m

Q. 96 In the circuit of figure, the magnitudes of $V_L$ and $V_C$ are twice that of $V_R$ . Given that $f$ = 50 Hz, the inductance of the coil is



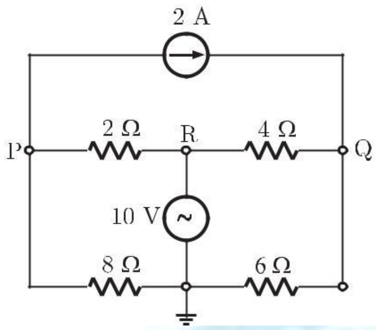

(A) 2.14 mH

(B) 5.30 H

(C) 31.8 mH

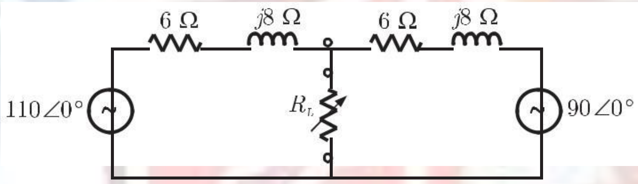
(D) 1.32 H

Q. 97 In figure, the potential difference between points P and Q is



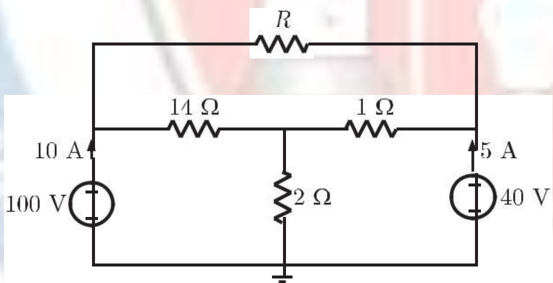

(A) 12 V
(B) 10 V
(C) -6 V
(D) 8 V

Q. 98 Two ac sources feed a common variable resistive load as shown in figure. Under the maximum power transfer condition, the power absorbed by the load resistance $R_L$ is



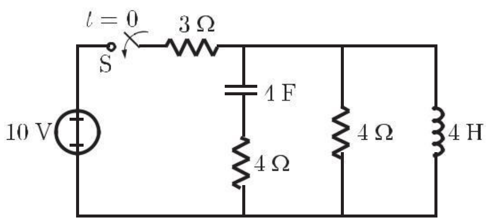

(A) 2200 W
(B) 1250 W
(C) 1000 W
(D) 625 W

Q. 99 In figure, the value of $R$ is




(A) 10 W
(B) 18 W
(C) 24 W
(D) 12 W

Q. 100 In the circuit shown in figure, the switch S is closed at time (t = 0). The voltage across the inductance at $t = 0^+$, is

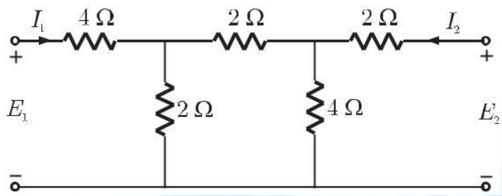



(A) 2 V
(B) 4 V
(C) -6 V
(D) 8 V

Q. 101 The h-parameters for a two-port network are defined by

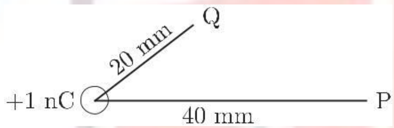
$$\begin{bmatrix} E_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ E_2 \end{bmatrix}$$

For the two-port network shown in figure, the value of $h_{12}$ is given by




(A) 0.125
(B) 0.167
(C) 0.625
(D) 0.25

Q. 102 A point charge of +I nC is placed in a space with permittivity of 8.85 # $10^{-12}$ F/m as shown in figure. The potential difference $V_{PQ}$ between two points P and Q at distance of 40 mm and 20 mm respectively fr0m the point charge is

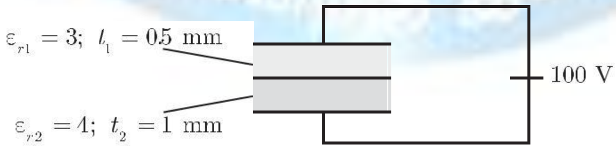



(A) 0.22 kV
(B) -225 V
(C) -2.24 kV
(D) 15 V

Q. 103 A parallel plate capacitor has an electrode area of 100 $mm^2$, with spacing of 0.1 mm between the electrodes. The dielectric between the plates is air with a permittivity of 8.85 # $10^{-12}$ F/m. The charge on the capacitor is 100 V. The stored energy in the capacitor is

(A) 8.85 pJ
(B) 440 pJ
(C) 22.1 nJ
(D) 44.3 nJ

Q. 104 A composite parallel plate capacitor is made up of two different dielectric material with different thickness ($t_1$ and $t_2$) as shown in figure. The two different dielectric materials are separated by a conducting foil F. The voltage of the conducting foil is




(A) 52 V
(B) 60 V
(C) 67 V
(D) 33 V

# SOLUTION

**Sol. 1** Option (B) is correct.

In the equivalent star connection, the resistance can be given as

$$R_C = \frac{R_b R_a}{R_a + R_b + R_c}\ ; R_B = \frac{R_a R_c}{R_a + R_b + R_c} \text{ and } R_A = \frac{R_b R_c}{R_a + R_b + R_c}$$

So, if the delta connection components $R_a$, $R_b$ and $R_c$ are scaled by a factor $k$ then

$$R_A' = \frac{(k R_b)(k R_c)}{kR_a + kR_b + kR_c} = \frac{k^2}{k}\frac{R_b R_c}{R_a + R_b + R_c} = k R_A$$

Hence, it is also scaled by a factor $k$

**Sol. 2** Option (A) is correct.

Given, flux density

$$\vec{B} = 4x\,\hat{a}_x + 2ky\,\hat{a}_y + 8\,\hat{a}_z$$

Since, magnetic flux density is always divergence less.

i.e., $\nabla\cdot\vec{B} = 0$

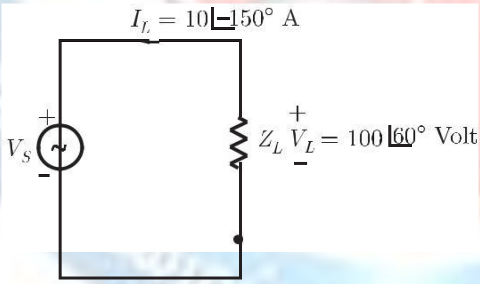
So, for given vector flux density, we have

$$\nabla\cdot\vec{B} = 4 + 2k + 0 = 0$$

or, $k = -2$

**Sol. 3** Option (B) is correct.

Consider the voltage source and load shown in figure




We obtain the power delivered by load as

$$P_{delivered} = I_L^* V_L = (10\angle{+150^\circ})(10\angle{60^\circ}) = 100\angle{210^\circ}$$

$$= 1000\cos 210^\circ + j1000\sin 210^\circ$$

$$= -866.025 - j500$$

As both the reactive and average power (real power) are negative so, power is absorbed by load. i.e., load absorbs real as well as reactive power.

**Sol. 4** Option (C) is correct.

For the purely resistive load, maximum average power is transferred when

$$R_L = \sqrt{R_{Th}^2 + X_{Th}^2}$$

where $R_{Th} + jX_{Th}$ is the equivalent thevinin (input) impedance of the circuit.

i.e., $R_L = \sqrt{4^2 + 3^2} = 5\ W$

Sol. 5 Option (D) is correct.

For the given capacitance, $C = 100mF$ in the circuit, we have the reactance.

$$X_C = \frac{1}{sc} = \frac{1}{s \# 100 \# 10^{-6}} = \frac{10^4}{s}$$

So, $$\frac{V_2(s)}{V_1(s)} = \frac{\frac{10^4}{s} + 10^4}{\frac{10^4}{s} + 10^4 + \frac{10^4}{s}} = \frac{s+1}{s+2}$$

Sol. 6 Option (B) is correct.

Energy density stored in a dielectric medium is obtained as

$$w_E = \frac{1}{2} e |E|^2 \quad J/m^2$$

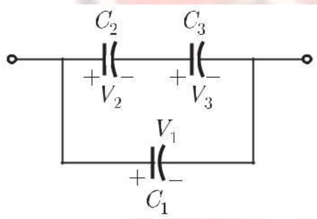
The electric field inside the dielectric will be same to given field in free space only if the field is tangential to the interface

So, $$w_E = \frac{1}{2} 2e_0 \left(\sqrt{6^2 + 8^2}\right)^2 \# 10^6 /mm^2$$

Therefore, the total stored energy is

$$W_E = \#_v W_E\, dv = e_0\, 100 \# 10^6 /mm^2 \# (500 \# 500)\, mm^2 \# (0.4)$$
$$= e_0 \# 100 \# 10^6 \# 0.4 \# 25 \# 10^4$$
$$= 8.85 \# 10^{-12} \# 10^{13} = 88.5\ J$$

Sol. 7 Option (C) is correct.




Consider that the voltage across the three capacitors $C_1$, $C_2$ $V_3$ and $C_3$ are $V_1$, $V_2$ and respectively. So, we can write

$$\frac{V_2}{V_3} = \frac{C_3}{C_2} \qquad ....(1)$$

Since, Voltage is inversely proportional to capacitance

Now, given that

$$C_1 = 10\ mF\ ;\ (V_1)_{max} = 10V$$
$$C_2 = 5\ mF\ ;\ (V_2)_{max} = 5\ V$$
$$C_3 = 2\ mF\ ;\ (V_3)_{max} = 2V$$

So, from Eq (1) we have

$$\frac{V_2}{V_3} = \frac{2}{5}$$

for $(V_3)_{max} = 2$

We obtain,

$$V_2 = \frac{2 \# 2}{5} = 0.8 \text{ volt} < 5$$

i.e., $V_2 < (V_2)_{max}$

Hence, this is the voltage at $C_2$. Therefore,

$$V_3 = 2 \text{ volt}$$

$$V_2 = 0.8 \text{ volt}$$

and $$V_1 = V_2 + V_3 = 2.8 \text{ volt}$$

Now, equivalent capacitance across the terminal is

$$C_{eq} = \frac{C_2 C_3}{C_2 + C_3} + C_1 = \frac{5 \# 2}{5 + 2} + 10 = \frac{80}{7} \text{ mF}$$

Equivalent voltage is (max. value)

$$V_{max} = V_1 = 2.8$$

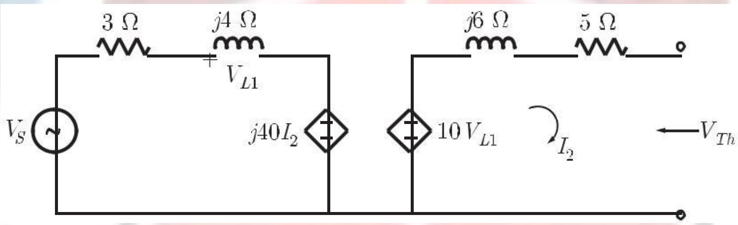
So, charge stored in the effective capacitance is

$$14 = C_{eq} V_{max} = \text{b} \frac{80}{7} \text{l} \#^\wedge 2.8\text{h} = 32 \text{ mC}$$

Sol. 8 Option (C) is correct.

For evaluating the equivalent thevenin voltage seen by the load $R_L$ , we open the circuit across it (also if it consist dependent source).

The equivalent circuit is shown below




As the circuit open across $R_L$ so

$$I_2 = 0$$

or, $$j40I_2 = 0$$

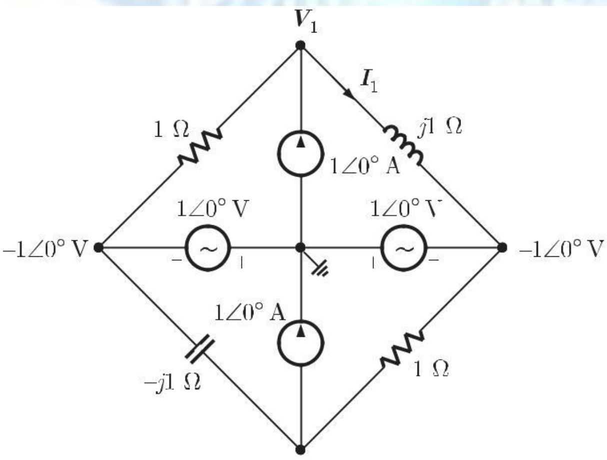
i.e., the dependent source in loop 1 is short circuited. Therefore,

$$17_{L1} = \frac{^\wedge j\ 4\text{h}V_s}{j4 + 3}$$

$$V_{Th} = 10V_{L1} = \frac{j40}{j4 + 3}\ 100\angle 53.13c = \frac{40\angle 90c}{5\angle 53.13c}\ 100\angle 53.13c$$

$$\text{H } 800\angle 90c$$

Sol. 9 Option (C) is correct.



Applying nodal analysis at top node.

$$\frac{V_1 + 1\angle 0^\circ}{1} + \frac{V_1 + 1\angle 0^\circ}{j1} = 1\angle 0^\circ$$

$$V_1(j1 + 1) + j1 + 1\angle 0^\circ = j1$$

$$V_1 = \frac{-1}{1 + j1}$$

Current $\quad I_1 = \frac{V_1 + 1\angle 0^\circ}{j1} = \frac{-\frac{1}{1+j} + 1}{j1} = \frac{j}{(1+j)j} = \frac{1}{1+j}$ A

Sol. 10 Option (C) is correct.

$$G(s) = \frac{(s^2 + 9)(s + 2)}{(s + 1)(s + 3)(s + 4)}$$

$$G(j\omega) = \frac{(-\omega^2 + 9)(j\omega + 2)}{(j\omega + 1)(j\omega + 3)(j\omega + 4)}$$

The steady state output will be zero if

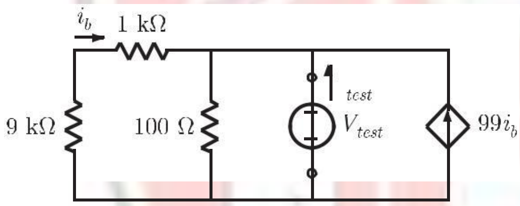
$$|G(j\omega)| = 0$$

$$-\omega^2 + 9 = 0$$

$$\omega = 3 \text{ rad/s}$$

Sol. 11 Option (A) is correct.

We put a test source between terminal 1, 2 to obtain equivalent impedance




$$Z_{Th} = \frac{V_{test}}{I_{test}}$$

Applying KCL at top right node

$$\frac{V_{test}}{9k + 1k} + \frac{V_{test}}{100} - 99I_b = I_{test}$$

$$\frac{V_{test}}{10k} + \frac{V_{test}}{100} - 99I_b = I_{test} \qquad ...(i)$$

But $\quad I_b = -\frac{V_{test}}{9k + 1k} = -\frac{V_{test}}{10k}$

Substituting $I_b$ into equation (i), we have

$$\frac{V_{test}}{10k} + \frac{V_{test}}{100} + \frac{99V_{test}}{10k} = I_{test}$$

$$\frac{100V_{test}}{10 \times 10^3} + \frac{V_{test}}{100} = I_{test}$$

$$\frac{2V_{test}}{100} = I_{test}$$

$$Z_{Th} = \frac{V_{test}}{I_{test}} = 50\ \Omega$$

Sol. 12 Option (B) is correct.

In phasor form $\quad Z = 4 - j3$

$$Z = 5\angle -36.86^\circ\ \Omega$$

$$\mathbf{I} = 5\angle 100^\circ \text{ A}$$

Average power delivered :

$$P_{avg.} = \frac{1}{2}|\mathbf{I}|^2 Z\cos\theta = \frac{1}{2} \times 25 \times 5\cos 36.86^\circ = 50 \text{ W}$$

**Alternate Method:**

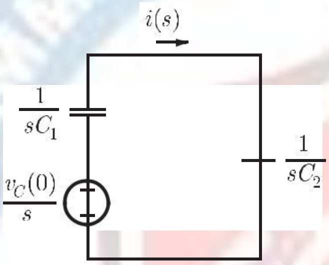
$$P = (4 - j3) \text{ W}$$

$$DD = 5\cos(100\pi t + 100) \text{ A}$$

$$P_{avg} = \frac{1}{2}\text{Re}\{|I|^2 Z\} = \frac{1}{2} \times \text{Re}\{(5)^2 \times (4 - j3)\} = \frac{1}{2} \times 100 = 50 \text{ W}$$

Sol. 13 Option (D) is correct.

The $s$ -domain equivalent circuit is shown as below.




$$I(s) = \frac{v_c(0)/s}{\frac{1}{C_1 s} + \frac{1}{C_2 s}} = \frac{v_c(0)}{\frac{1}{C_1} + \frac{1}{C_2}}$$

$$= \left(\frac{C_1 C_2}{C_1 + C_2}\right)(12 \text{ V}) \qquad v_C(0) = 12 \text{ V}$$

$$= 12C_{eq}$$

Taking inverse Laplace transform for the current in time domain,

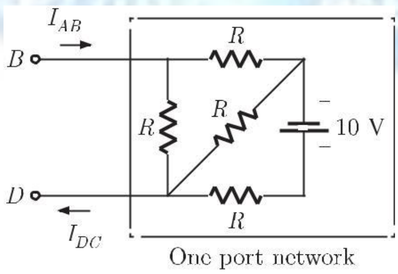
$$i(t) = 12C_{eq}\,\delta(t) \qquad \text{(Impulse)}$$

Sol. 14 Option (A) is correct.

In the given circuit, $V_A - V_B = 6$ V

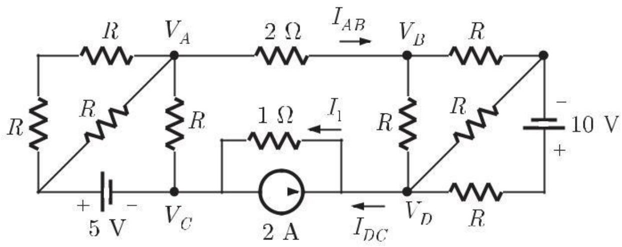
So current in the branch, $I_{AB} = \frac{6}{2} = 3$ A

We can see, that the circuit is a one port circuit looking from terminal $BD$ as shown below




For a one port network current entering one terminal, equals the current leaving the second terminal. Thus the outgoing current from $A$ to $B$ will be equal to the incoming current from $D$ to $C$ as shown

i.e. $I_{DC} = I_{AB} = 3$ A




The total current in the resistor 1 W will be

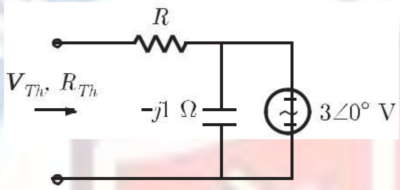
$$I_1 = 2 + I_{DC} \qquad \text{(Writing KCL at node } D\text{)}$$

$$= 2 + 3 = 5 \text{ A}$$

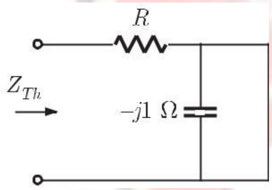
So, $\qquad V_{CD} = 1 \times (-I_1) = -5 \text{ V}$

Sol. 15 Option (A) is correct.

We obtain Thevenin equivalent of circuit $B$ .




**Thevenin Impedance :**

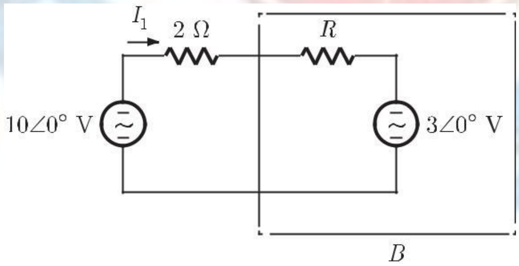



$$Z_{Th} = R$$

**Thevenin Voltage :**

$$V_{Th} = 3\angle 0° \text{ V}$$

Now, circuit becomes as




Current in the circuit, $\qquad I_1 = \dfrac{10-3}{2+R}$

Power transfer from circuit $A$ to $B$

$$E = (I_1^2)^2 R + 3I_1$$

$$= \left(\frac{10-3}{2+R}\right)^2 R + 3\left(\frac{10-3}{2+R}\right) = \frac{49R}{(2+R)^2} + \frac{21}{(2+R)}$$

$$= \frac{49R + 21(2+R)}{(2+R)^2} = \frac{42+70R}{(2+R)^2}$$

$$\frac{dP}{dR} = \frac{(2+R)^2\,70 - (42+70R)2(2+R)}{(2+R)^4} = 0$$

$$(2+R)[(2+R)70 - (42+70R)2] = 0$$

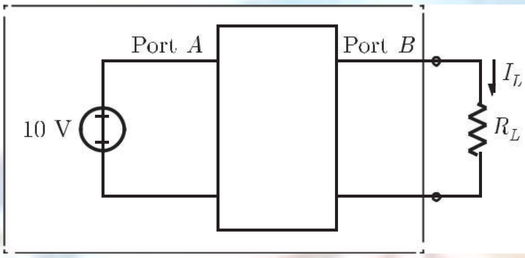
$$140 + 70R - 84 - 140R = 0$$

$$56 = 70R$$

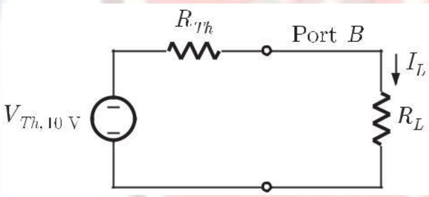
$$R = 0.8\ \text{W}$$

**Sol. 16** Option (C) is correct.

When 10 V is connected at port $A$ the network is




Now, we obtain Thevenin equivalent for the circuit seen at load terminal, let Thevenin voltage is $V_{Th,\,10\text{ V}}$ with 10 V applied at port $A$ and Thevenin resistance is $R_{Th}$ .




$$I_L = \frac{V_{Th,10\text{ V}}}{R_{Th} + R_L}$$

For $R_L = 1$ W, $I_L = 3$ A

$$3 = \frac{V_{Th,10\text{ V}}}{R_{Th} + 1} \qquad \text{...(i)}$$

For $R_L = 2.5$ W, $I_L = 2$ A

$$2 = \frac{V_{Th,10\text{ V}}}{R_{Th} + 2.5} \qquad \text{...(ii)}$$

Dividing above two

$$\frac{3}{2} = \frac{R_{Th} + 2.5}{R_{Th} + 1}$$

$$3R_{Th} + 3 = 2R_{Th} + 5$$

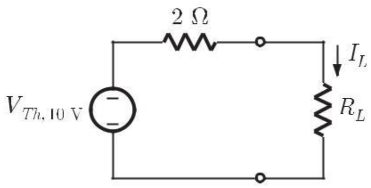
$$R_{Th} = 2\ \text{W}$$

Substituting $R_{Th}$ into equation (i)

$$V_{Th,10\text{ V}} = 3(2+1) = 9\ \text{V}$$

Note that it is a non reciprocal two port network. Thevenin voltage seen at port 7. depends on the voltage connected at port $A$. Therefore we took subscript $V_{Th,10\text{ V}}$ . This is Thevenin voltage only when 10 V source is connected at input port $A$. If the voltage connected to port $A$ is different, then Thevenin voltage will be different. However, Thevenin's resistance remains same.

Now, the circuit is

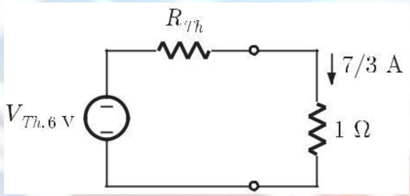



For $R_L = 7$ W, $\quad I_L = \frac{V_{Th,10\text{ V}}}{2 + R_L} = \frac{9}{2+7} = 1$ A

**Sol. 17** Option (B) is correct.

Now, when 6 V connected at port $A$ let Thevenin voltage seen at port $B$ is $V_{Th,6\text{ V}}$ .

Here $R_L = 1$ W and $I_L = \frac{7}{3}$ A




$$V_{Th,\,6\text{ V}} = R_{Th} \# \frac{7}{3} + 1 \# \frac{7}{3} = 2 \# \frac{7}{3} + \frac{7}{3} = 7\text{ V}$$

This is a linear network, so $V_{Th}$ at port $B$ can be written as

$$V_{Th} = V_1 a + b$$

where $V_1$ is the input applied at port $A$.

We have $V_1 = 10$ V, $V_{Th,10\text{ V}} = 9$ V

$$9 = 10a + b \qquad \text{...(i)}$$

When $V_1 = 6$ V, $V_{Th,\,6\text{ V}} = 9$ V

$$7 = 6a + b \qquad \text{...(ii)}$$

Solving (i) and (ii)

$$\# = 0.5,\ b = 4$$

Thus, with any voltage $V_1$ applied at port $A$, Thevenin voltage or open circuit voltage at port $B$ will be

So, $\quad V_{Th,\,V_1} = 0.5V_1 + 4$

For $\quad V_1 = 8$ V

$$V_{Th,8\text{ V}} = 0.5 \# 8 + 4 = 8 = V_{oc} \qquad \text{(open circuit voltage)}$$

**Sol. 18** Option (A) is correct.

By taking $\boldsymbol{V}_1$, $\boldsymbol{V}_2$ and $\boldsymbol{V}_3$ all are phasor voltages.

$$\boldsymbol{V}_1 = \boldsymbol{V}_2 + \boldsymbol{V}_3$$

Magnitude of $\boldsymbol{V}_1$, $\boldsymbol{V}_2$ and $\boldsymbol{V}_3$ are given as

$$V_1 = 220\text{ V},\ V_2 = 122\text{ V},\ V_3 = 136\text{ V}$$

Since voltage across $R$ is in same phase with $\boldsymbol{V}_1$ and the voltage $V_3$ has a phase difference of $q$ with voltage $\boldsymbol{V}_1$, we write in polar form

$$\boldsymbol{V}_1 = V_2\angle 0c + V_3\angle q$$

$$\boldsymbol{V}_1 = V_2 + V_3\cos q + jV_3\sin q$$

$$\boldsymbol{V}_1 = (V_2 + V_3\cos q) + jV_3\sin q$$

$$|\boldsymbol{V}_1| = \sqrt{(V_2 + V_3\cos q)^2 + (V_2\sin q)^2}$$

$$220 = \sqrt{(122 + 136\cos q)^2 + (136\sin q)^2}$$

Solving, power factor

$$\cos\theta = 0.45$$

Sol. 19 Option (B) is correct.

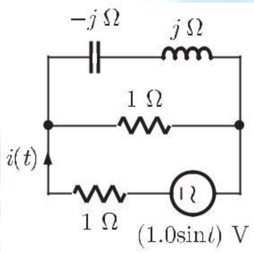
Voltage across load resistance

$$V_{RL} = V_3 \cos\theta = 136 \times 0.45 = 61.2 \text{ V}$$

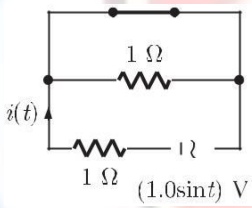
Power absorbed in $R_L$ $\quad P_L = \frac{V_{RL}^2}{R_L} = \frac{(61.2)^2}{5} - 750 \text{ W}$

Sol. 20 Option (B) is correct.

The frequency domains equivalent circuit at $\omega = 1$ rad/sec.




Since the capacitor and inductive reactances are equal in magnitude, the net impedance of that branch will become zero. Equivalent circuit




Current $\quad i(t) = \frac{\sin t}{1\,\Omega} = (1 \sin t)$ A

rms value of current $\quad i_{rms} = \frac{1}{\sqrt{2}}$ A

Sol. 21 Option (D) is correct.

Voltage in time domain

$$v(t) = 100\sqrt{2}\cos(100\pi t)$$

Current in time domain

$$i(t) = 10\sqrt{2}\sin(100\pi t + \pi/4)$$

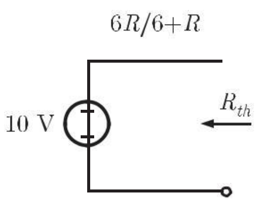
Applying the following trigonometric identity

$$\sin(\phi) = \cos(\phi - 90^\circ)$$

So, $\quad i(t) = 10\sqrt{2}\cos(100\pi t + \pi/4 - \pi/2) = 10\sqrt{2}\cos(100\pi t - \pi/4)$

In phasor form, $\quad \boldsymbol{I} = \frac{10\sqrt{2}}{\sqrt{2}}\angle -\pi/4$

Sol. 22 Option (A) is correct.



Power transferred to the load

$$P = I^2 R_L = \left(\frac{10}{R_{th} + R_L}\right)^2 R_L$$

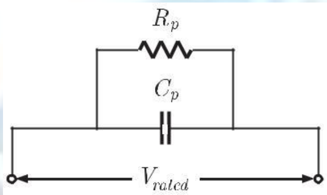
For maximum power transfer $R_{th}$ , should be minimum.

$$R_{th} = \frac{6R}{6+R} = 0$$

$$w = 0$$

Note: Since load resistance is constant so we choose a minimum value of $R_{th}$

Sol. 23 Option (C) is correct.




$$\text{Power loss} = \frac{V_{rated}^2}{R_p} = \frac{(5 \# 10^3)^2}{1.25 \# 10^6} = 20 \text{ W}$$

For an parallel combination of resistance and capacitor

$$\tan d = \frac{1}{wC_p R_p} = \frac{1}{2p \# 50 \# 1.25 \# 0.102} = \frac{1}{40} = 0.025$$

Sol. 24 Option (C) is correct.

Charge $Q = CV = \frac{e_0 e_r A}{d} V = (e_0 e_r A) \frac{V}{d}$ $\qquad C = \frac{e_0 e_r A}{d}$

$- = Q_{max}$

We have $e_0 = 8.85 \# 10^{-14}$ F/cm, $e_r = 2.26$, $A = 20 \# 40$ cm$^2$

$$\frac{V}{d} = 50 \# 10^3 \text{ kV/cm}$$

Maximum electrical charge on the capacitor

when $\frac{V}{d} = \left(\frac{V}{d}\right)_{max} = 50$ kV/cm

Thus, $Q = 8.85 \# 10^{-14} \# 2.26 \# 20 \# 40 \# 50 \# 10^3 = 8$ mC

Sol. 25 Option (C) is correct.

$$v_i = 100\sqrt{2} \sin(100pt) \text{ V}$$

Fundamental component of current

$$i_{i1} = 10\sqrt{2} \sin(100p\, t - p/3) \text{ A}$$

Input power factor

$$pf = \frac{I_{1(rms)}}{I_{rms}} \cos f_1$$

$I_{1(rms)}$ is rms values of fundamental component of current and $I_{rms}$ is the rms value of converter current.

$$pf = \frac{10}{\sqrt{10^2 + 5^2 + 2^2}} \cos p/3 = 0.44$$

Sol. 26 Option (B) is correct.

Only the fundamental component of current contributes to the mean ac input power. The power due to the harmonic components of current is zero.

So, $P_{in} = V_{rms} I_{1rms} \cos f_1 = 100 \# 10 \cos p/3 = 500$ W

**Sol. 27** Option (B) is correct.

Power delivered by the source will be equal to power dissipated by the resistor.

$$P = V_s I_s \cos\pi/4 = 1 \times \sqrt{2}\cos\pi/4 = 1 \text{ W}$$

**Sol. 28** Option (D) is correct.

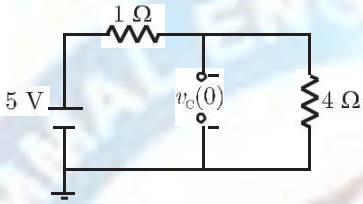
$$\overline{I_C} = \overline{I_s} - \overline{I_{RL}} = \sqrt{2}\angle\pi/4 - \sqrt{2}\angle-\pi/4$$

$$= \sqrt{2}\left[\left(\cos\pi/4 + j\sin\pi/4\right) - \left(\cos\pi/4 - j\sin\pi/4\right)\right]$$

$$= 2\sqrt{2}\, j\sin\pi/4 = 2j$$

**Sol. 29** Option (B) is correct.

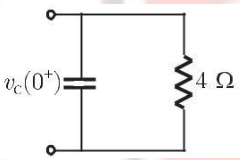
For $t < 0$, the switch was closed for a long time so equivalent circuit is




Voltage across capacitor at $t = 0$

$$v_c(0) = 4\left(\frac{5}{4+1}\right) = 4 \text{ V}$$

Now switch is opened, so equivalent circuit is




For capacitor at $t = 0^+$

$$v_c(0^+) = v_c(0) = 4 \text{ V}$$

current in 4 Ω resistor at $t = 0^+$, $i_1 = \frac{v_c(0^+)}{4} = 1$ A

so current in capacitor at $t = 0^+$, $i_c(0^+) = i_1 = 1$ A

**Sol. 30** Option (B) is correct.

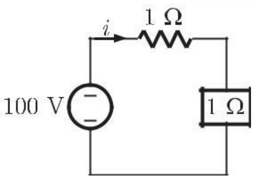
Thevenin equivalent across 1 Ω resistor can be obtain as following

Open circuit voltage $\qquad v_{th} = 100$ V $\qquad (i = 0)$

Short circuit current $\qquad i_{sc} = 100$ A $\qquad (v_{th} = 0)$

So, $\qquad R_{th} = \frac{v_{th}}{i_{sc}} = \frac{100}{100} = 1\ \Omega$

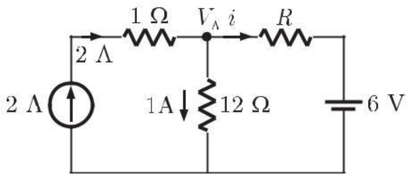
Equivalent circuit is




$$i = \frac{100}{1+1} = 50 \text{ A}$$

**Sol. 31** Option (B) is correct.

The circuit is




Current in $R$ W resistor is

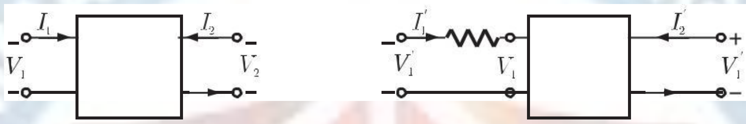
$$y = 2 - 1 = 1 \text{ A}$$

Voltage across 12 W resistor is

$$V_A = 1 \# 12 = 12 \text{ V}$$

So, $$i = \frac{V_A - 6}{R} = \frac{12 - 6}{1} = 6 \text{ W}$$

Sol. 32 Option (C) is correct.




$V_1 = Z_{11} I_1 + Z_{12} I_2$ $\quad$ $V l_1 = Z l_{11} I l_1 + Z l_{12} I l_2$

$V_2 = Z_{21} I_1 + Z_{22} I_2$ $\quad$ $V l_2 = Z l_{21} I l_1 + Z l_{22} I l_2$

Here, $I_1 = I l_1$, $I_2 = I l_2$

When $R = 1$ W is connected

$$V l_1 = V_1 + I l_1 \# 1 = V_1 + I_1$$

$$V l_1 = Z_{11} I_1 + Z_{12} I_2 + I_1$$

$$V l_1 = (Z_{11} + 1) I_1 + Z_{12} I_2$$

So, $$Z l_{11} = Z_{11} + 1$$

$$Z l_{12} = Z_{12}$$

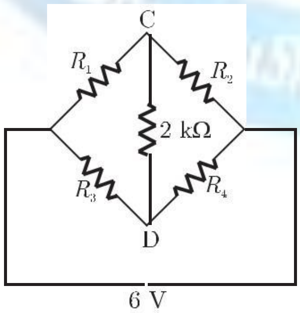
Similarly for output port

$$V l_2 = Z l_{21} I l_1 + Z l_{22} I l_2 = Z l_{21} I_1 + Z l_{22} I_2$$

So, $Z l_{21} = Z_{21}$, $Z l_{22} = Z_{22}$

Z-matrix is $$Z = \begin{bmatrix} Z_{11} + 1 & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}$$

Sol. 33 Option (A) is correct.




In the bridge

$$R_1 R_4 = R_2 R_3 = 1$$

So it is a balanced bridge

$$\# = 0 \text{ mA}$$

Sol. 34 Option (D) is correct.

Resistance of the bulb rated 200 W/220 V is

$$R_1 = \frac{V^2}{P_1} = \frac{(220)^2}{200} = 242\ \text{W}$$

Resistance of 100 W/220 V lamp is

$$R_T = \frac{V^2}{P_2} = \frac{(220)^2}{100} = 484\ \text{W}$$

To connect in series

$$R_T = n \# R_1$$

$$484 = n \# 242$$

$$n = 2$$

Sol. 35 Option (D) is correct.

For $t < 0$, $S_1$ is closed and $S_2$ is opened so the capacitor $C_1$ will charged upto 3 volt.

$$V_{C1}(0) = 3\ \text{Volt}$$

Now when switch positions are changed, by applying charge conservation

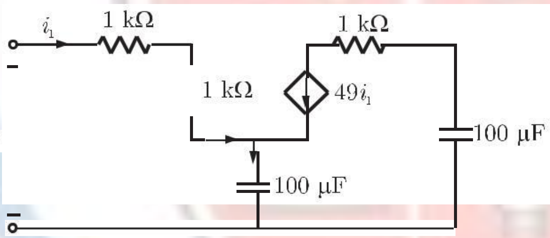
$$C_{eq} V_{C_1}(0^+) = C_1 V_{C_1}(0^+) + C_2 V_{C_2}(0^+)$$

$$(2+1) \# 3 = 1 \# 3 + 2 \# V_{C_2}(0^+)$$

$$9 = 3 + 2V_{C_2}(0^+)$$

$$V_{C_2}(0^+) = 3\ \text{Volt}$$

Sol. 36 Option (A) is correct.




Applying KVL in the input loop

$$v_1 - i_1(1+1) \# 10^3 - \frac{1}{j\text{w}C}(i_1 + 49i_1) = 0$$

$$v_1 = 2 \# 10^3\, i_1 + \frac{1}{j\text{w}C} 50 i_1$$

Input impedance, $\quad Z_1 = \frac{v_1}{i_1} = 2 \# 10^3 + \frac{1}{j\text{w}(C/50)}$

Equivalent capacitance, $\quad C_{eq} = \frac{C}{50} = \frac{100\ n\text{F}}{50} = 2\ n\text{F}$

Sol. 37 Option (B) is correct.

Voltage across 2 X resistor, $V_S = 2$ V

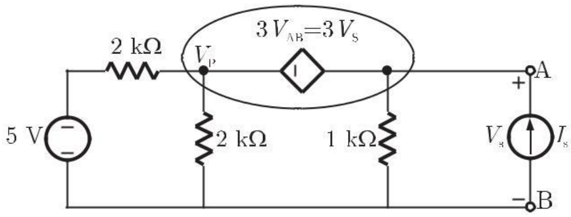
Current, $\quad I_{2\text{W}} = \frac{V_S}{2} = \frac{4}{2} = 2$ A

To make the current double we have to take

$$V_S = 8\ \text{V}$$

Sol. 38 Option (B) is correct.

To obtain equivalent Thevenin circuit, put a test source between terminals AB




Applying KCL at super node

$$\frac{V_P - 5}{2} + \frac{V_P}{2} + \frac{V_S}{1} = I_S$$

$$V_P - 5 + V_P + 2V_S = 2I_S$$

$$2V_P + 2V_S = 2I_s + 5$$

$$V_P + V_S = I_S + 2.5 \qquad \text{...(1)}$$

$$V_P - V_S = 3V_S$$

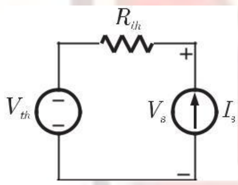
& $$V_P = 4V_S$$

So, $$4V_S + V_S = I_S + 2.5$$

$$5V_S = I_S + 2.5$$

$$V_S = 0.2I_S + 0.5 \qquad \text{...(2)}$$

For Thevenin equivalent circuit




$$V_S = I_S R_{th} + V_{th} \qquad \text{...(3)}$$

By comparing (2) and (3),

Thevenin resistance $R_{th} = 0.2$ kW

Sol. 39 Option (D) is correct.

From above $V_{th} = 0.5$ V

Sol. 40 Option (A) is correct.

No. of chords is given as

$$l = b - n + 1$$

$b$ " no. of branches

$n$ " no. of nodes

$l$ " no. of chords

$b = 6$, $n = 4$

$$l = 6 - 4 + 1 = 3$$

Sol. 41 Option (A) is correct.

Impedance $Z_o = 2.38 - j0.667$ W

Constant term in impedance indicates that there is a resistance in the circuit. Assume that only a resistance and capacitor are in the circuit, phase difference in Thevenin voltage is given as

$$q = -\tan^{-1}(wCR) \qquad \text{(Due to capacitor)}$$

$$Z_o = R - \frac{j}{wC}$$

So, $\frac{1}{\omega C} = 0.667$

and $R = 2.38\ \Omega$

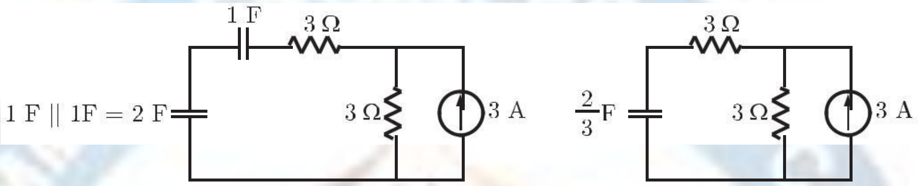
$$\theta = -\tan^{-1}\left(\frac{1\times 2.38}{0.667}\right) = -74.34^\circ = [\ -15.9^\circ$$

given $V_{oc} = 3.71\angle -15.9^\circ$

So, there is an inductor also connected in the circuit

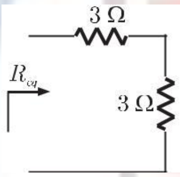
Sol. 42 Option (C) is correct.

Time constant of the circuit can be calculated by simplifying the circuit as follows




$$C_{eq} = \frac{2}{3}\ \text{F}$$

Equivalent Resistance




$$R_{eq} = 3 + 3 = 6\ \Omega$$

Time constant $\tau = R_{eq} C_{eq} = 6 \times \frac{2}{3} = 4$ sec

Sol. 43 Option (C) is correct.

Impedance of the circuit is

$$Z = j\omega L + \frac{\frac{1}{j\omega C} R}{\frac{1}{j\omega C} + R} = j\omega L + \frac{R}{1 + j\omega CR} \times \frac{1 - j\omega CR}{1 - j\omega CR}$$

$$= j\omega L + \frac{R(1 - j\omega CR)}{1 + \omega^2 C^2 R^2} = \frac{j\omega L(1 + \omega^2 C^2 R^2) + R - j\omega CR^2}{1 + \omega^2 C^2 R^2}$$

$$= \frac{R}{1 + \omega^2 C^2 R^2} + \frac{j[\omega L(1 + \omega^2 C^2 R^2) - \omega CR^2]}{1 + \omega^2 C^2 R^2}$$

For resonance $\text{Im}(Z) = 0$

So, $\omega L(1 + \omega^2 C^2 R^2) = \omega CR^2$

$L = 0.1$ H, $C = 1$ F, $R = 1\ \Omega$

So, $\omega \times 0.1[1 + \omega^2 (1)(1)] = \omega(1)(1)^2$

$$1 + \omega^2 = 10$$

& $\omega = \sqrt{9} = 3$ rad/sec

Sol. 44 Option (A) is correct.

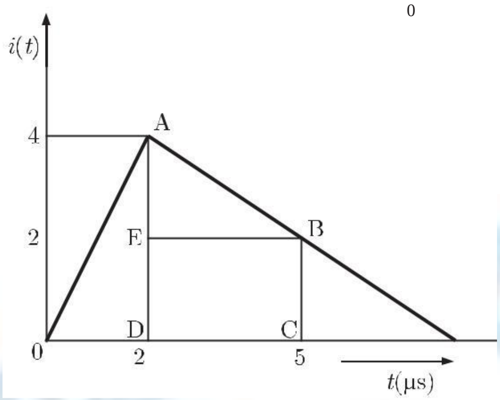
Applying KVL in the circuit

$$V_{ab} - 2i + 5 = 0$$

$i = 1$ A, $V_{ab} = 2 \times 1 - 5 = -3$ Volt

Sol. 45 Option (C) is correct.
Charge stored at $t = 5$ m sec

$$Q = \int_0^5 i(t)dt = \text{area under the curve}$$




$$= \text{Area OABCDO}$$
$$= \text{Area (OAD)} + \text{Area(AEB)} + \text{Area(EBCD)}$$
$$\frac{1}{2} \times 2 \times 4 + \frac{1}{2} \times 2 \times 3 + 3 \times 2$$
$$4 + 3 + 6 = 13 \text{ nC}$$

Sol. 46 Option (D) is correct.
Initial voltage across capacitor

$$V_0 = \frac{Q_o}{C} = \frac{13 \text{ nC}}{0.3 \text{ nF}} = 43.33 \text{ Volt}$$

When capacitor is connected across an inductor it will give sinusoidal esponse as $v_c(t) = V_o \cos \omega_o t$

where $$\omega_o = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{0.3 \times 10^{-9} \times 0.6 \times 10^{-3}}}$$
$$= 2.35 \times 10^6 \text{ rad/sec}$$

At $t = 1$ m sec, $$v_c(t) = 43.33 \cos(2.35 \times 10^6 \times 1 \times 10^{-6})$$
$$= 43.33 \times (-0.70) = -30.44 \text{ V}$$

Sol. 47 Option (B) is correct.
Writing node equations at node A and B

$$\frac{V_a - 5}{1} + \frac{V_a - 0}{1} = 0$$
$$2V_a - 5 = 0$$
$$V_a = 2.5 \text{ V}$$

Similarly

$$\frac{V_b - 4V_{ab}}{3} + \frac{V_b - 0}{1} = 0$$
$$\frac{V_b - 4(V_a - V_b)}{3} + V_b = 0$$
$$V_b - 4(2.5 - V_b) + 3V_b = 0$$
$$8V_b - 10 = 0$$
$$V_b = 1.25 \text{ V}$$

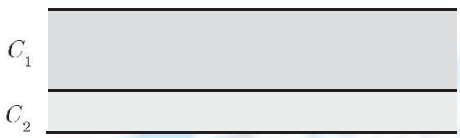
Current $$i = \frac{V_b}{1} = 1.25 \text{ A}$$

Sol. 48 Option ( ) is correct.

Sol. 49 Option (B) is correct.

Here two capacitance $C_1$ and $C_2$ are connected in series, so equivalent capacitance is

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$




$$C_1 = \frac{e_0 e_{r1} A}{d_1} = \frac{8.85 \# 10^{-12} \# 8 \# 500 \# 500 \# 10^{-6}}{4 \# 10^{-3}}$$

$$= 442.5 \# 10^{-11} \text{ F}$$

$$C_2 = \frac{e_0 e_{r2} A}{d_2} = \frac{8.85 \# 10^{-12} \# 2 \# 500 \# 500 \# 10^{-6}}{2 \# 10^{-3}}$$

$$= 221.25 \# 10^{-11} \text{ F}$$

$$C_{eq} = \frac{442.5 \# 10^{-11} \# 221.25 \# 10^{-11}}{442.5 \# 10^{-11} + 221.25 \# 10^{-11}} = 147.6 \# 10^{-11}$$

AA 1476 pF

Sol. 50 Option (B) is correct.

Circumference $l = 300$ mm

no. of turns $n = 300$

Cross sectional area $A = 300 \text{ mm}^2$

Inductance of coil $L = \frac{m_0 n^2 A}{l} = \frac{4p \# 10^{-7} \# (300)^2 \# 300 \# 10^{-6}}{(300 \# 10^{-3})}$

$= 113.04$ mH

Sol. 51 Option (A) is correct.

Divergence of a vector field is given as

Divergence $= 4 : V$

In cartesian coordinates

$$N = \frac{2}{2x}\hat{i} + \frac{2}{2y}\hat{j} + \frac{2}{2z}\hat{k}$$

So $4 : V = \frac{2}{2x}$ 6 $-(x \cos xy + y)$ @ $+ \frac{2}{2y}$ 6 $(y \cos xy)$ @ $+ \frac{2}{2z}$ 6 $(\sin z^2 + x^2 + y^2)$ @

$$L - x(-\sin xy)y + y(-\sin xy)x + 2z \cos z^2 = 2z \cos z^2$$

Sol. 52 Option (A) is correct.

Writing KVL for both the loops

$$V - 3(I_1 + I_2) - V_x - 0.5\frac{dI_1}{dt} = 0$$

$$V - 3I_1 - 3I_2 - V_x - 0.5\frac{dI_1}{dt} = 0 \qquad ...(1)$$

In second loop

$$-5I_2 + 0.2V_x + 0.5\frac{dI_1}{dt} = 0$$

$$I_2 = 0.04V_x + 0.1\frac{dI_1}{dt} \qquad \text{...(2)}$$

Put $I_2$ from eq(2) into eq(2)

$$V - 3I_1 - 3\left[0.04V_x + 0.1\frac{dI_1}{dt}\right] - V_x - 0.5\frac{dI_1}{dt} = 0$$

$$\frac{dI_1}{dt} = -1.4V_x - 3.75I_1 + \frac{5}{4}V$$

Sol. 53

Option (A) is correct.

Impedance of the given network is

$$Z = R + j\left(\omega L - \frac{1}{\omega C}\right)$$

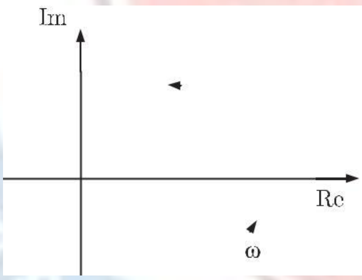
$$\text{Admittance } Y = \frac{1}{Z} = \frac{1}{R + j\left(\omega L - \frac{1}{\omega C}\right)}$$

$$= \frac{1}{R + j\left(\omega L - \frac{1}{\omega C}\right)} \times \frac{R - j\left(\omega L - \frac{1}{\omega C}\right)}{R - j\left(\omega L - \frac{1}{\omega C}\right)} = \frac{R - j\left(\omega L - \frac{1}{\omega C}\right)}{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

$$= \frac{R}{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} - \frac{j\left(\omega L - \frac{1}{\omega C}\right)}{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

$$\Rightarrow \text{Re}(Y) + \text{Im}(Y)$$

Varying frequency for Re($Y$) and Im($Y$) we can obtain the admittance-locus.




Sol. 54

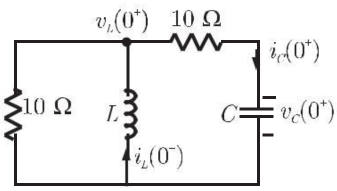
Option (D) is correct.

At $t = 0^+$, when switch positions are changed inductor current and capacitor voltage does not change simultaneously

So at $t = 0^+$ $\qquad v_c(0^+) = v_c(0^-) = 10$ V

$\qquad i_L(0^+) = i_L(0^-) = 10$ A

The equivalent circuit is




Applying KCL

$$\frac{v_L(0^+)}{10} + \frac{v_L(0^+) - v_c(0^+)}{10} = i_L(0^+) = 10$$

$$2v_L(0^+) - 10 = 100$$

Voltage across inductor at $t = 0^+$

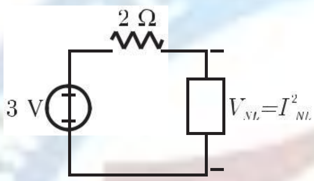
$$v_L(0^+) = \frac{100 + 10}{2} = 55 \text{ V}$$

So, current in capacitor at $t = 0^+$

$$i_C(0^+) = \frac{v_L(0^+) - v_c(0^+)}{10} = \frac{55 - 10}{10} = 4.5 \text{ A}$$

Sol. 55 Option (A) is correct.

The circuit is




Applying KVL

$$3 - 2 \# I_{NL}^2 = V_{NL}$$

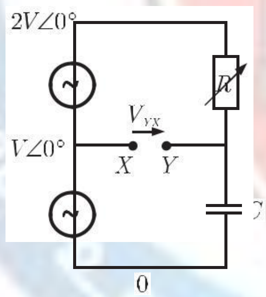
$$3 - 2I_{NL}^2 = I_{NL}^2$$

$$3I_{NL}^2 = 3 \; \& \; I_{NL} = 1 \text{ A}$$

$$V_{NL} = (1)^2 = 1 \text{ V}$$

Sol. 56 Option (B) is correct.

In the circuit




$$V_X = V{+}0c$$

$$\frac{V_y - 2V{+}0c}{R} + (V_y) j\,\text{w}C = 0$$

$$V_y(1 + j\,\text{w}CR) = 2V{+}0c$$

$$V_y = \frac{2V{+}0c}{1 + j\,\text{w}CR}$$

$$V_{YX} = V_X - V_Y = V - \frac{2V}{1 + j\,\text{w}CR}$$

$R$ " 0, $\quad V_{YX} = V - 2V =- V$

$R$ " 3, $\quad V_{YX} = V - 0 = V$

So power dissipated in the non-linear resistance

$$P = V_{NL} I_{NL} = 1 \# 1 = 1 \text{ W}$$

**Sol. 57** Option (C) is correct.

In node incidence matrix

$$\begin{array}{c|cccccc} & b_1 & b_2 & b_3 & b_4 & b_5 & b_6 \\ \hline n_1 & 1 & 1 & 1 & 0 & 0 & 0 \\ n_2 & 0 & -1 & 0 & -1 & 1 & 0 \\ n_3 & -1 & 0 & 0 & 0 & -1 & -1 \\ n_4 & 0 & 0 & -1 & 1 & 0 & 1 \end{array}$$

In option (C)

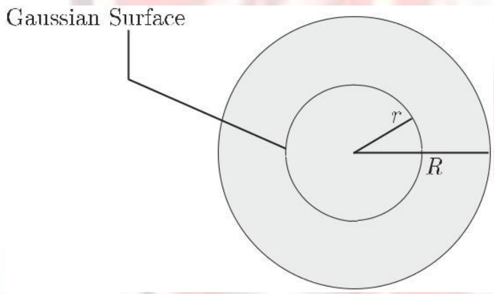
$$E = AV$$

$$\begin{bmatrix} e_1 & e_2 & e_3 & e_4 \end{bmatrix}^T = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & -1 & 1 & 0 \\ -1 & 0 & 0 & 0 & -1 & -1 \\ 0 & 0 & -1 & 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_1 & V_2 & \cdots & V_6 \end{bmatrix}^T$$

$$\begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \end{bmatrix} = \begin{bmatrix} V_1 + V_2 + V_3 \\ -V_2 - V_4 + V_5 \\ -V_1 - V_5 - V_6 \\ -V_3 + V_4 + V_6 \end{bmatrix}$$ which is true.

**Sol. 58** Option (A) is correct.

Assume a Gaussian surface inside the sphere ($x < R$)




From gauss law

$$\psi = Q_{enclosed}$$

$$= \oint D \cdot ds = Q_{enclosed}$$

$$Q_{enclosed} = \frac{Q}{\frac{4}{3}\pi R^3} \times \frac{4}{3}\pi r^3 = \frac{Qr^3}{R^3}$$

So, $$\oint D \cdot ds = \frac{Qr^3}{R^3}$$

or $$D \times 4\pi r^2 = \frac{Qr^3}{R^3} = \frac{Q}{4\pi\varepsilon_0}\frac{r}{R^3} \qquad \because D = \varepsilon_0 E$$

**Sol. 59** Option (D) is correct.

Inductance is given as

$$L = \frac{\mu_0 N^2 A}{l} = \frac{4\pi \times 10^{-7} \times (400)^2 \times (16 \times 10^{-4})}{(1 \times 10^{-3})} = 321.6 \text{ mH}$$

$$V = IX_L = \frac{230}{2\pi f L} \qquad \because X_L = 2\pi f L$$

$$= \frac{230}{2 \times 3.14 \times 50 \times 321.6 \times 10^{-3}} = 2.28 \text{ A}$$

**Sol. 60** Option (A) is correct.

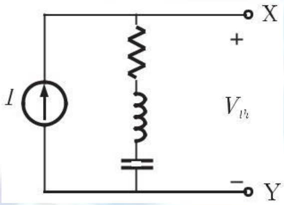
Energy stored is inductor

$$= \; = \frac{1}{2} LI^2 = \frac{1}{2} \# 321.6 \# 10^{-3} \# (2.28)^2$$

$$F = \frac{E}{l} = \frac{0.835}{1 \# 10^{-3}} = 835 \text{ N}$$

Sol. 61 Option (D) is correct.

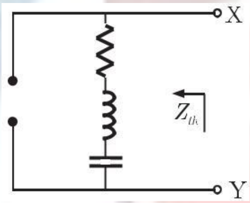
Thevenin voltage:




$$V_{th} = I(R + Z_L + Z_C) = 1+0c[1 + 2j - j]$$

$$w \; 1(1 + j) = \sqrt{2} + 45^{\%} \text{ V}$$

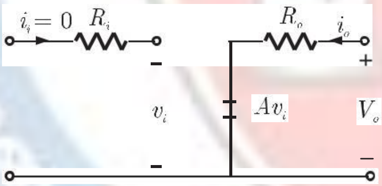
Thevenin impedance:




$$Z_{th} = R + Z_L + Z_C = 1 + 2j - j = (1 + j) \text{ W}$$

Sol. 62 Option (A) is correct.

In the given circuit




Output voltage

$$v_o = Av_i = 10^6 \# 1 \text{ mV} = 1 \text{ V}$$

Input impedance

$$Z_i = \frac{v_i}{i_i} = \frac{v_i}{0} = 3$$

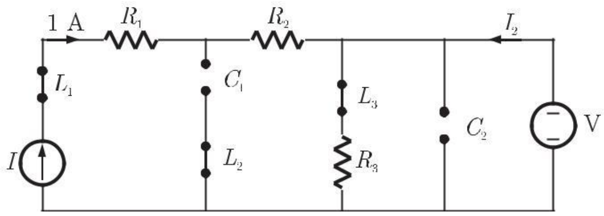
Output impedance

$$Z_o = \frac{v_o}{i_o} = \frac{Av_i}{i_o} = R_o = 10 \text{ W}$$

Sol. 63 Option (D) is correct.

All sources present in the circuit are DC sources, so all inductors behaves as short circuit and all capacitors as open circuit

Equivalent circuit is




Voltage across $R_3$ is

$$5 = I_1 R_3$$
$$5 = I_1(1)$$
$$I_1 = 5\text{ A} \qquad \text{(current through } R_3\text{)}$$

By applying KCL, current through voltage source

$$1 + I_2 = I_1$$
$$I_2 = 5 - 1 = 4\text{ A}$$

**Sol. 64** Option () is correct.

Given Two port network can be described in terms of h-parametrs only.

**Sol. 65** Option (A) is correct.

At resonance reactance of the circuit would be zero and voltage across inductor and capacitor would be equal

$$V_L = V_C$$

At resonance impedance of the circuit

$$Z_R = R_1 + R_2$$

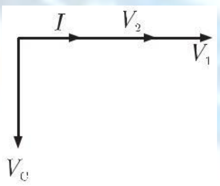
Current $$I_R = \frac{V_1+0c}{R_1 + R_2}$$

Voltage $$V_2 = I_R R_2 + j\,(V_L - V_C)$$
$$V_2 = \frac{V_1+0c}{R_1 + R_2} R_2$$

Voltage across capacitor

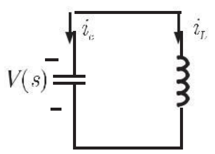
$$V_C = \frac{1}{jwC} \# I_R = \frac{1}{j\,wC} \# \frac{V_R+0c}{R_1 + R_2} = \frac{V_R + -90c}{wC\,(R_1 + R_2)}$$

So phasor diagram is




**Sol. 66** Option (B) is correct.

This is a second order LC circuit shown below




Capacitor current is given as

$$i_C(t) = C\frac{dv_c(t)}{dt}$$

Taking Laplace transform

$$I_C(s) = CsV(s) - V(0),\ V(0) \text{ " initial voltage}$$

Current in inductor

$$i_L(t) = \frac{1}{L}\int v_c(t)dt$$

$$I_L(s) = \frac{1}{L}\frac{V(s)}{s}$$

For $t > 0$, applying KCL(in s-domain)

$$I_C(s) + I_L(s) = 0$$

$$CsV(s) - V(0) + \frac{1}{L}\frac{V(s)}{s} = 0$$

$$\left(s^2 + \frac{1}{LCs}\right)V(s) = V_o$$

$$V(s) = V_o\frac{s}{s^2 + \omega_0^2}, \qquad \omega_0^2 = \frac{1}{LC}$$

Taking inverse Laplace transformation

$$v(t) = V_o \cos \omega_o t, \qquad t > 0$$

Sol. 67 Option (B) is correct.

Power dissipated in heater when AC source is connected

$$P = 2.3\text{ kW} = \frac{V_{rms}^2}{R}$$

$$2.3 \times 10^3 = \frac{(230)^2}{R}$$

$$R = 23\ \Omega \text{ (Resistance of heater)}$$

Now it is connected with a square wave source of 400 V peak to peak

Power dissipated is

$$P = \frac{V_{rms}^2}{R}, \qquad V_{p-p} = 400\text{ V} \ \&\ V_p = 200\text{ V}$$

$$= \frac{(200)^2}{23} = 1.739\text{ kW} \qquad V_{rms} = V_p = 200 \text{ (for square wave)}$$

Sol. 68 Option (D) is correct.

From maxwell's first equation

$$\nabla \cdot D = \rho_v$$

$$\nabla \cdot E = \frac{\rho_v}{\varepsilon} \qquad \text{(Divergence of electric field intensity is non-Zero)}$$

Maxwell's fourth equation

$$\nabla \cdot B = 0 \qquad \text{(Divergence of magnetic field intensity is zero)}$$

Sol. 69 Option (C) is correct.

Current in the circuit

$$I = \frac{100}{R + (10 \parallel 10)} = 8\text{ A} \qquad \text{(given)}$$

$$\frac{100}{R + 5} = 8$$

Or $$R = \frac{60}{8} = 7.5\ \Omega$$

**Sol. 70** Option (A) is correct.

Rms value is given as

$$m_{rms} = \sqrt{3^2 + \frac{(4)^2}{2}} = \sqrt{9+8} = \sqrt{17}\text{ V}$$

**Sol. 71** Option (D) is correct.

Writing KVL in input and output loops

$$V_1 - (i_1 + i_2)Z_1 = 0$$

$$V_1 = Z_1 i_1 + Z_1 i_2 \quad ...(1)$$

Similarly

$$V_2 - i_2 Z_2 - (i_1 + i_2)Z_1 = 0$$

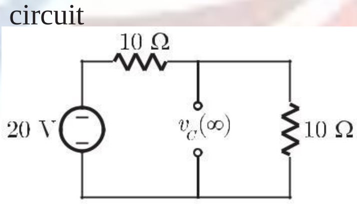
$$V_2 = Z_1 i_1 + (Z_1 + Z_2) i_2 \quad ...(2)$$

From equation (1) and (2) $Z$ -matrix is given as

$$Z = \begin{bmatrix} Z_1 & Z_1 \\ Z_1 & Z_1 + Z_2 \end{bmatrix}$$

**Sol. 72** Option (B) is correct.

In final steady state the capacitor will be completely charged and behaves as an open circuit




Steady state voltage across capacitor

$$v_c(3) = \frac{20}{10+10}(10) = 10\text{ V}$$

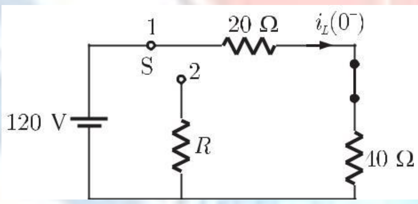
**Sol. 73** Option (D) is correct.

We know that divergence of the curl of any vector field is zero

$$\nabla \cdot (\nabla \times \vec{\mathbf{E}}) = 0$$

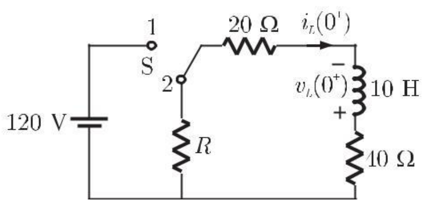
**Sol. 74** Option (A) is correct.

When the switch is at position 1, current in inductor is given as




$$i_L(0^-) = \frac{120}{20+40} = 2\text{ A}$$

At $t = 0$, when switch is moved to position 1,inductor current does not change simultaneously so




$$i_L(0^+) = i_L(0^-) = 2\text{ A}$$

Voltage across inductor at $t = 0^+$

$$v_L(0^+) = 120 \text{ V}$$

By applying KVL in loop

$$(7) \quad = 2(40 + R + 20)$$

$$- \quad = 120 + R$$

$$R = 0 \text{ W}$$

Sol. 75 Option (C) is correct.

Let stored energy and dissipated energy are $E_1$ and $E_2$ respectively. Then Current

$$\frac{i_2^2}{i_1^2} = \frac{E_2}{E_1} = 0.95$$

$$i_2 = \sqrt{0.95}\, i_1 = 0.97 i_1$$

Current at any time t, when the switch is in position (2) is given by

$$i(t) = i_1 e^{-\frac{R}{L}t} = 2e^{-\frac{60}{10}t} = 2e^{-6t}$$

After 95% of energy dissipated current remaining in the circuit is

$$i = 2 - 2 \# 0.97 = 0.05 \text{ A}$$

So, $$0.05 = 2e^{-6t}$$

$$t \,.\, 0.50 \text{ sec}$$

Sol. 76 Option (C) is correct.

At $f_1 = 100$ Hz, voltage drop across $R$ and $L$ is $m_{RMS}$

$$m_{RMS} = \left|\frac{V_{in}\,.\,R}{R + j\,w_1 L}\right| = \left|\frac{V_{in}\,(jw_1 L)}{R + jw_1 L}\right|$$

So, $$R = w_1 L$$

At $f_2 = 50$ Hz, voltage drop across $R$

$$m^l_{RMS} = \left|\frac{V_{in}\,.\,R}{R + jw_2 L}\right|$$

$$\frac{m_{RMS}}{m^l_{RMS}} = \left|\frac{R + jw_2 L}{R + j\,w_1 L}\right| = \sqrt{\frac{R^2 + w_2^2 L^2}{R^2 + w_1^2 L^2}}$$

$$= \sqrt{\frac{w_1^2 L^2 + w_2^2 L^2}{w_1^2 L^2 + w_1^2 L^2}}, \quad R = w_1 L$$

$$= \sqrt{\frac{w_1^2 + w_2^2}{2w_1^2}} = \sqrt{\frac{f_1^2 + f_2^2}{2f_1^2}} = \sqrt{\frac{(100)^2 + (50)^2}{2(100)^2}} = \sqrt{\frac{5}{8}}$$

$$m^l_{RMS} = \sqrt{\frac{8}{5}}\, m_{RMS}$$

Sol. 77 Option (A) is correct.

In the circuit

$$\overline{I}_B = I_R +0c + I_y +120c$$

$$I_B^2 = I_R^2 + I_y^2 + 2I_R I_y \cos b \frac{120c}{2} l = I_R^2 + I_y^2 + I_R I_y$$

Since $$I_R = I_y$$

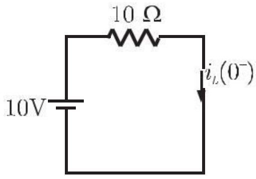
so, $$I_B^2 = I_R^2 + I_R^2 + I_R^2 = 3I_R^2$$

$$I_B = \sqrt{3}\, I_R = \sqrt{3}\, I_y$$

$$I_R : I_y : I_B = 1 : 1 : \sqrt{3}$$

**Sol. 78** Option (C) is correct.

Switch was opened before $t = 0$, so current in inductor for $t < 0$




$$i_L(0^-) = \frac{10}{10} = 1 \text{ A}$$

Inductor current does not change simultaneously so at $t = 0$ when switch is closed current remains same

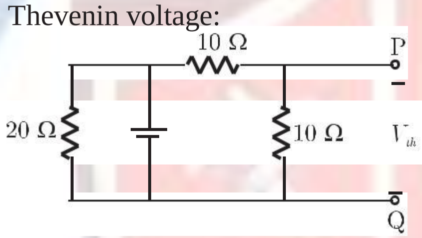
$$i_L(0^+) = i_L(0^-) = 1 \text{ A}$$

**Sol. 79** Option (A) is correct.

Electric field inside a conductor (metal) is zero. In dielectric charge distribution os constant so electric field remains constant from $x_1$ to $x_2$. In semiconductor electric field varies linearly with charge density.

**Sol. 80** Option (A) is correct.

Thevenin voltage:

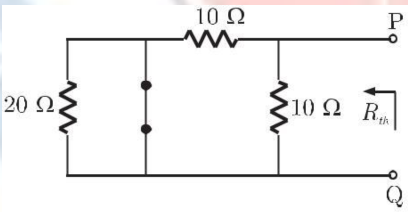



Nodal analysis at $P$

$$\frac{V_{th} - 4}{10} + \frac{V_{th}}{10} = 0$$

$$V_{th} = 2 \text{ V}$$

Thevenin resistance:




$$R_{th} = 10 \text{ W} \,||\, 10 \text{ W} = 5 \text{ W}$$

**Sol. 81** Option (D) is correct.

Resonance will occur only when $Z$ is capacitive, in parallel resonance condition, suseptance of circuit should be zero.

$$\frac{1}{j\text{w}L} + j\,\text{w}C = 0$$

$$1 - \text{w}^2 LC = 0$$

$$\text{w} = \frac{1}{\sqrt{LC}} \quad \text{(resonant frequency)}$$

$$C = \frac{1}{\text{w}^2 L} = \frac{1}{4 \,\#\, \text{p}^2 \,\#\, (500)^2 \,\#\, 2} = 0.05 \text{ mF}$$

**Sol. 82**

Option (D) is correct.

Here two capacitor $C_1$ and $C_2$ are connected in series so equivalent Capacitance is

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

$$C_1 = \frac{\epsilon_0 \epsilon_{r1} A}{d_1} = \frac{8.85 \times 10^{-12} \times 4 (400 \times 10^{-3})^2}{6 \times 10^{-3}}$$

$$= \frac{8.85 \times 10^{-12} \times 4 \times 16 \times 10^{-2}}{6 \times 10^{-3}} = 94.4 \times 10^{-11} \text{ F}$$

Similarly

$$C_2 = \frac{\epsilon_0 \epsilon_{r2} A}{d_2} = \frac{8.85 \times 10^{-12} \times 2 \times (400 \times 10^{-3})^2}{8 \times 10^{-3}}$$

$$= \frac{8.85 \times 10^{-12} \times 2 \times 16 \times 10^{-12}}{8 \times 10^{-3}} = 35.4 \times 10^{-11} \text{ F}$$

$$C_{eq} = \frac{94.4 \times 10^{-11} \times 35.4 \times 10^{-11}}{(94.4 + 35.4) \times 10^{-11}} = 25.74 \times 10^{-11} - 257 \text{ pF}$$

**Sol. 83**

Option (C) is correct.

Inductance of the Solenoid is given as

$$L = \frac{\mu_0 N^2 A}{l}$$

Where $A$ " are of Solenoid

$l$ " length

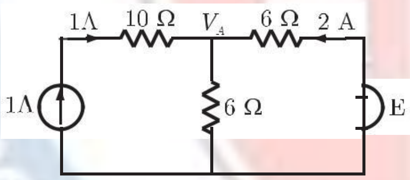
$$= = \frac{4\pi \times 10^{-7} \times (3000)^2 \times \pi_3 (30 \times 10^{-3})^2}{(1000 \times 10\ )} = 31.94 \times 10^{-3} \text{ H}$$

32 mH

**Sol. 84**

Option (C) is correct.

In the circuit




Voltage $V_A = (2 + 1) \times 6 = 18$ Volt

So,

$$2 = \frac{E - V_A}{6}$$

$$2 = \frac{E - 18}{6}$$

$$E = 12 + 18 = 30 \text{ V}$$

**Sol. 85**

Option (A) is correct.

Delta to star ($T - Y$) conversions is given as

$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c} = \frac{10 \times 10}{20 + 10 + 10} = 2.5\ \Omega$$

$$R_2 = \frac{R_a R_c}{R_a + R_b + R_c} = \frac{20 \times 10}{20 + 10 + 10} = 5\ \Omega$$

$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c} = \frac{20 \times 10}{20 + 10 + 10} = 5\ \Omega$$

**Sol. 86**

Option (D) is correct.

For parallel circuit

$$I = \frac{E}{Z_{eq}} = EY_{eq}$$

$Y_{eq}$ = Equivalent admittance of the circuit

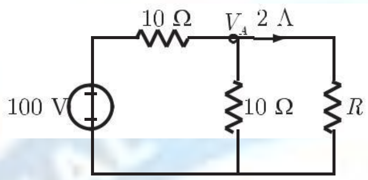
$$Y_{eq} = Y_R + Y_L + Y_C = (0.5 + j\,0) + (0 - j\,1.5) + (0 + j0.3)$$

$$\approx 0.5 - j1.2$$

So, current $\quad I = 10(0.5 - j1.2) = (5 - j12)$ A

**Sol. 87** Option (B) is correct.

In the circuit




Voltage $\quad V_A = \frac{100}{10 + (10 \parallel R)} \times (10 \parallel R) = \frac{100}{\left(10 + \frac{10R}{10 + R}\right)}\left(\frac{10R}{10 + R}\right)$

$$= \frac{1000R}{100 + 20R} = \frac{50R}{5 + R}$$

Current in $R$ Ω resistor

$$2 = \frac{V_A}{R}$$

$$2 = \frac{50R}{R(5 + R)}$$

or $\quad R = 20$ Ω

**Sol. 88** Option (A) is correct.

Since capacitor initially has a charge of 10 coulomb, therefore

$$Q_0 = Cv_c(0) \qquad v_c(0) = \text{initial voltage across capacitor}$$

$$10 = 0.5v_c(0)$$

$$v_c(0) = \frac{10}{0.5} = 20 \text{ V}$$

When switch $S$ is closed, in steady state capacitor will be charged completely and capacitor voltage is

$$v_c(\infty) = 100 \text{ V}$$

At any time $t$ transient response is

$$v_c(t) = v_c(\infty) + [v_c(0) - v_c(\infty)]e^{-\frac{t}{RC}}$$

$$v_c(t) = 100 + (20 - 100)e^{-\frac{t}{2 \times 0.5}} = 100 - 80e^{-t}$$

Current in the circuit

$$i(t) = C\frac{dv_c}{dt} = C\frac{d}{dt}[100 - 80e^{-t}]$$

$$= C \times 80e^{-t} = 0.5 \times 80e^{-t} = 40e^{-t}$$

At $t = 1$ sec,

$$i(t) = 40e^{-1} = 14.71 \text{ A}$$

**Sol. 89** Option (D) is correct.

Total current in the wire

$$I = 10 + 20\sin\omega t$$

$$I_{rms} = \sqrt{10^2 + \frac{(20)^2}{2}} = \sqrt{100 + 200} = \sqrt{300} = 17.32 \text{ A}$$

Sol. 90 Option (D) is correct.

From $Z$ to $Y$ parameter conversion

$$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}^{-1}$$

So,
$$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{12} & Y_{22} \end{bmatrix} = \frac{1}{0.50} \begin{bmatrix} 0.6 & -0.2 \\ -0.2 & 0.9 \end{bmatrix}$$

$$Y_{22} = \frac{0.9}{0.50} = 1.8$$

Sol. 91 Option (C) is correct.

Energy absorbed by the inductor coil is given as

$$E_L = \int_0^t P dt$$

Where power
$$P = VI = I\left(L\frac{dI}{dt}\right)$$

So,
$$E_L = \int_0^t LI\left(\frac{dI}{dt}\right) dt$$

For $0 \le t \le 4$ sec

$$E_L = 2\int_0^4 I\left(\frac{dI}{dt}\right) dt$$

$$= 2\int_0^2 I\,(3)dt + 2\int_2^4 I\,(0)dt \qquad \because \frac{dI}{dt} = \begin{cases} 3, & 0 \le t \le 2, \\ 0, & 2 < t < 4 \end{cases}$$

$$= 6\int_0^2 I.dt = 6(\text{area under the curve } i(t) - t)$$

$$= 6 \times \frac{1}{2} \times 2 \times 6 = 36 \text{ J}$$

Energy absorbed by 1 W resistor is

$$E_R = \int_0^t I^2 R dt = \int_0^2 (3t)^2 \times 1 dt + \int_2^4 (6)^2 dt \qquad \begin{pmatrix} I = 3t, & 0 \le t \le 2 \\ = 6 \text{ A} & 2 \le t \le 4 \end{pmatrix}$$

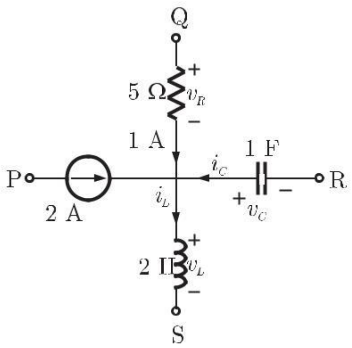
$$= 9 \times \left[\frac{t^3}{3}\right]_0^2 + 36[t]_2^4 = 24 + 72 = 96 \text{ J}$$

Total energy absorbed in 4 sec

$$E = E_L + E_R = 36 + 96 = 132 \text{ J}$$

Sol. 92 Option (B) is correct.

Applying KCL at center node




$$i_L = i_C + 1 + 2$$

$$i_L = i_C + 3$$

$$i_C = -C\frac{dv_c}{dt} = -1\frac{d}{dt}[4\sin 2t]$$

$$= -8\cos 2t$$

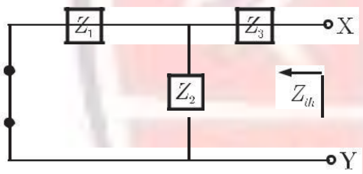
so $\qquad i_L = -8\cos 2t + 3 \qquad$ (current through inductor)

Voltage across inductor

$$v_L = L\frac{di_L}{dt} = 2\times\frac{d}{dt}[3 - 8\cos 2t] = 32\sin 2t$$

Sol. 93 Option (A) is correct.

Thevenin impedance can be obtain as following




$$Z_{th} = Z_3 + (Z_1 \parallel Z_2)$$

Given that $\qquad Z_1 = 10\angle -60^\circ = 10\left(\frac{1-\sqrt{3}j}{2}\right) = 5(1-\sqrt{3}j)$

$$Z_2 = 10\angle 60^\circ = 10\left(\frac{1+\sqrt{3}j}{2}\right) = 5(1+\sqrt{3}j)$$

$$Z_3 = 50\angle 53.13^\circ = 50\left(\frac{3+4j}{5}\right) = 10(3+4j)$$

So, $\qquad Z_{th} = 10(3+4j) + \frac{5(1-\sqrt{3}j)\,5(1+\sqrt{3}j)}{5(1-\sqrt{3}j)+5(1+\sqrt{3}j)}$

$$= 10(3+4j) + \frac{25(1+3)}{10} = 30 + 40j + 10$$

$\approx 40 + 40j$

$$Z_{th} = 40\sqrt{2}\angle 45^\circ\ \Omega$$

Sol. 94 Option (A) is correct.

Due to the first conductor carrying $+I$ current, magnetic field intensity at point P is

$$\vec{H}_1 = \frac{I}{2\pi d}\vec{Y} \text{ (Direction is determined using right hand rule)}$$

Similarly due to second conductor carrying $-I$ current, magnetic field intensity is $\vec{H}_2 = \frac{-I}{2\pi d}(-\vec{Y}) = \frac{I}{2\pi d}\vec{Y}$

Total magnetic field intensity at point P.

$$\mathbf{J} = \mathbf{H}_1 + \vec{\mathbf{H}}_2 = \frac{I}{2p\,d}\,Y + \frac{I}{2p\,d}\,Y = \frac{I}{p\,d}\,Y$$

**Sol. 95** Option ( ) is correct.

**Sol. 96** Option (C) is correct.

Given that magnitudes of $V_L$ and $V_C$ are twice of $V_R$

$$|V_L| = |V_C| = 2V_R \quad \text{(Circuit is at resonance)}$$

Voltage across inductor

$$V_L = i_R \# jwL$$

Current $i_R$ at resonance

$$i_R = \frac{5+0^{\%}}{R} = \frac{5}{5} = 1\text{ A}$$

so, $|V_L| = wL = 2V_R$

$$wL = 2 \# 5 \qquad V_R = 5\text{ V, at resonance}$$

$$2 \# p \# 50 \# L = 10$$

$$L = \frac{10}{314} = 31.8\text{ mH}$$

**Sol. 97** Option (C) is correct.

Applying nodal analysis in the circuit

At node $P$

$$2 + \frac{V_P - 10}{2} + \frac{V_P}{8} = 0$$

$$16 + 4V_P - 40 + V_P = 0$$

$$5V_P - 24 = 0$$

$$V_P = \frac{24}{5}\text{ Volt}$$

At node $Q$

$$2 = \frac{V_Q - 10}{4} + \frac{V_Q - 0}{6}$$

$$24 = 3V_Q - 30 + 2V_Q$$

$$5V_Q - 54 = 0$$

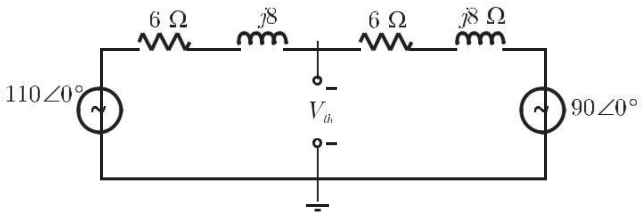
$$V_Q = \frac{54}{5}\text{ V}$$

Potential difference between P-Q

$$V_{PQ} = V_P - V_Q = \frac{24}{5} - \frac{54}{5} = -6\text{ V}$$

**Sol. 98** Option (D) is correct.

First obtain equivalent Thevenin circuit across load $R_L$



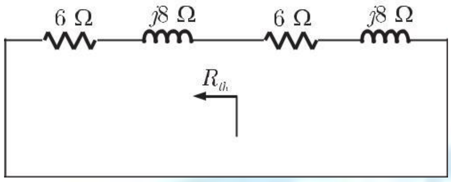

Thevenin voltage

$$\frac{V_{th} - 110\angle 0c}{6 + 8j} + \frac{V_{th} - 90\angle 0c}{6 + 8j} = 0$$

$$2V_{th} - 200\angle 0^\circ = 0$$

$$V_{th} = 100\angle 0^\circ \text{ V}$$

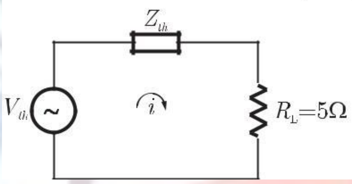
Thevenin impedance




$$Z_{th} = (6 + 8j)\Omega \parallel (6 + 8j)\,\Omega = (3 + 4j)\Omega$$

For maximum power transfer

$$R_L = |Z_{th}| = \sqrt{3^2 + 4^2} = 5\ \Omega$$



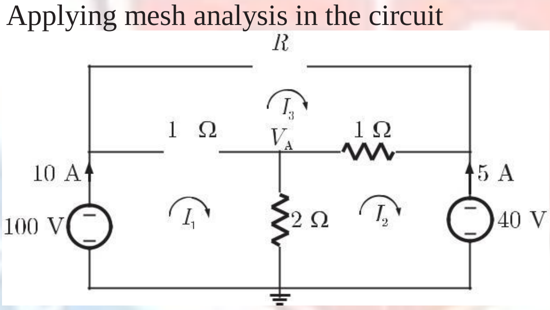

Power in load

$$P = i_{eff}^2 R_L$$

$$P = \left|\frac{100}{3 + 4j + 5}\right|^2 \times 5 = \frac{(100)^2}{80} \times 5 = 625 \text{ Watt}$$

Option (D) is correct.

Sol. 99 Applying mesh analysis in the circuit



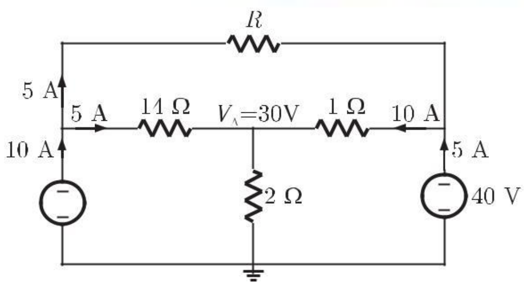

$I_1 = 10$ A, $I_2 = -5$ A

Current in 2 Ω resistor

$$I_{2\Omega} = I_1 - (-I_2) = 10 - (-5) = 15 \text{ A}$$

So, voltage $V_A = 15 \times 2 = 30$ Volt

Now we can easily find out current in all branches as following




Current in resistor $R$ is 5 A

$$W = \frac{100 - 40}{R}$$

$$R = \frac{60}{5} = 12 \text{ W}$$

**Sol. 100** Option (B) is correct.

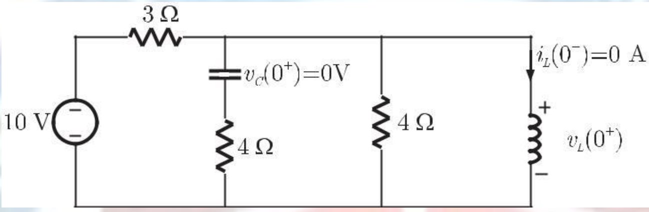
Before $t = 0$, the switch was opened so current in inductor and voltage across capacitor for $t < 0$ is zero

$v_c(0^-) = 0,\quad i_L(0^-) = 0$

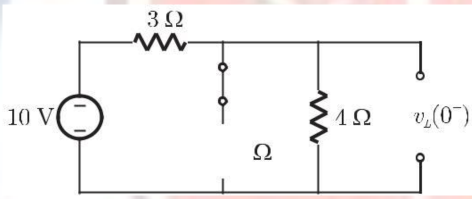
at $t = 0$, when the switch is closed, inductor current and capacitor voltage does not change simultaneously so

$v_c(0^+) = v_c(0^-) = 0,\quad i_L(0^+) = i_L(0^-) = 0$

At $t = 0^+$ the circuit is




Simplified circuit




Voltage across inductor (at $t = 0^+$)

$$v_L(0^+) = \frac{10}{3+2} \# 2 = 4 \text{ Volt}$$

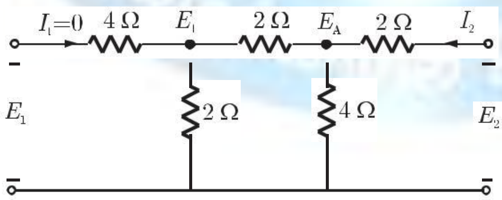
**Sol. 101** Option (D) is correct.

Given that $\quad E_1 = h_{11} I_1 + h_{12} E_2$

and $\quad I_2 = h_{21} I_1 + h_{22} E_2$

Parameter $h_{12}$ is given as

$$h_{12} = \left.\frac{E_1}{E_2}\right|_{I_1 = 0 \text{(open circuit)}}$$




At node $A$

$$\frac{E_A - E_1}{2} + \frac{E_A - E_2}{2} + \frac{E_A}{4} = 0$$

$$5E_A = 2E_1 + 2E_2 \qquad \text{...(1)}$$

Similarly

$$\frac{E_1 - E_A}{2} + \frac{E_1}{2} = 0$$

$$2E_1 = E_A \qquad ...(2)$$

From (1) and (2)

$$5(2E_1) = 2E_1 + 2E_2 4$$

$$8E_1 = 2E_2$$

$$h_{12} = \frac{E_1}{E_2} = \frac{1}{4}$$

Sol. 102 Option (B) is correct.

$$V_{PQ} = V_P - V_Q = \frac{KQ}{OP} - \frac{KQ}{OQ}$$

$$W \quad \frac{9 \# 10^9 \# 1 \# 10^{-9}}{40 \# 10^{-3}} - \frac{9 \# 10^9 \# 1 \# 10^{-9}}{20 \# 10^{-3}}$$

$$= 9 \# 10^3 : \frac{1}{40} - \frac{1}{20} D =- 225 \text{ Volt}$$

Sol. 103 Option (D) is correct.

Energy stored in Capacitor is

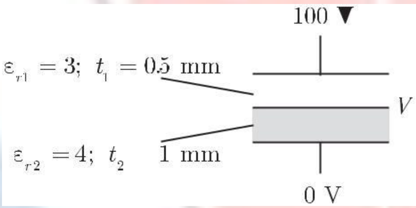
$$E = \frac{1}{2} CV^2$$

$$Q = \frac{e_0 A}{d} = \frac{8.85 \# 10^{-12} \# 100 \# 10^{-6}}{\# 10^{-3}} = 8.85 \# 10^{-12} \text{ F}$$

$$= \ = \frac{1}{2} \# 8.85 \# 10^{-12} \# (100)^2 = 44.3 \text{ nJ}$$

Sol. 104 Option (B) is correct.

The figure is as shown below




The Capacitor shown in Figure is made up of two capacitor $C_1$ and $C_2$ connected in series.

$$C_1 = \frac{e_0 e_{r1} A}{t_1}, C_2 = \frac{e_0 e_{r2} A}{t_2}$$

Since $C_1$ and $C_2$ are in series charge on both capacitor is same.

$$Q_1 = Q_2$$

$$C_1 (100 - V) = C_2 V \text{ (Let V is the voltage of foil)}$$

$$\frac{e_0 e_{r1} A}{t_1}(100 - V) = \frac{e_0 e_{r2} A}{t_2} V$$

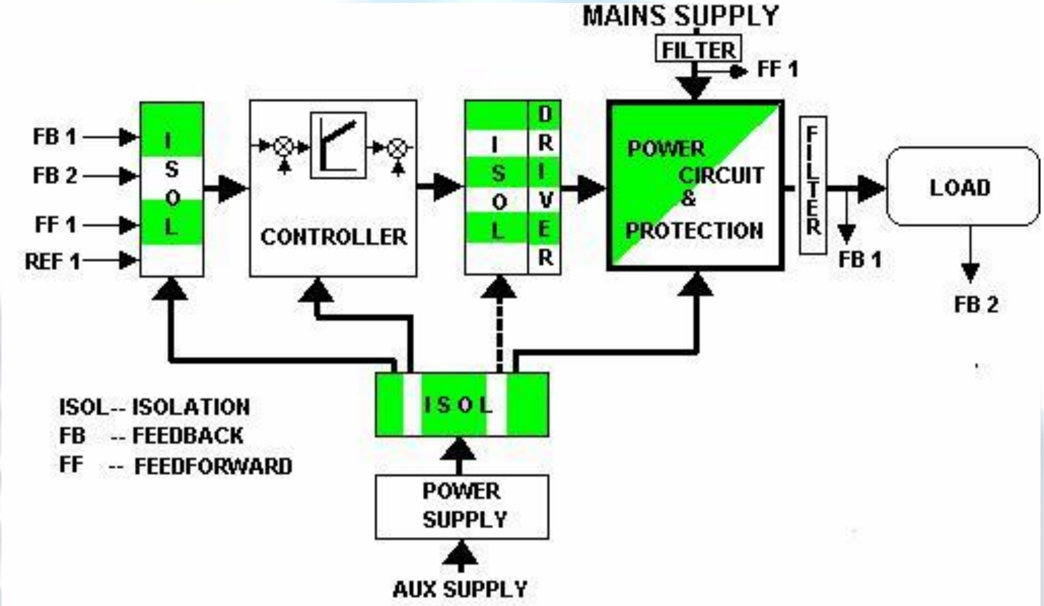
$$\frac{3}{0.5}(100 - V) = \frac{4}{1} V$$

$$300 = 5V \& V = 60 \text{ Volt}$$

**POWER ELECTRONICS**

Power Electronics is the art of converting electrical energy from one form to another in an efficient, clean, compact, and robust manner for convenient utilisation.

H. passenger lift in a modern building equipped with a Variable-Voltage-Variable-Speed induction-machine drive offers a comfortable ride and stops exactly at the floor level. Behind the scene it consumes less power with reduced stresses on the motor and corruption of the utility mains.




**The block diagram of a typical Power Electronic converter Power**

**Electronics involves the study of**

- Power semiconductor *devices* - their physics, characteristics, drive requirements and their protection for optimum utilisation of their capacities,
- Power converter *topologies* involving them,
- *Control* strategies of the converters,
- Digital, analogue and micro*electronics* involved,
- Capacitive and magnetic energy storage elements,
- Rotating and static *electrical devices*,
- *Quality* of waveforms generated,
- Electro Magnetic and Radio Frequency *Interference*,

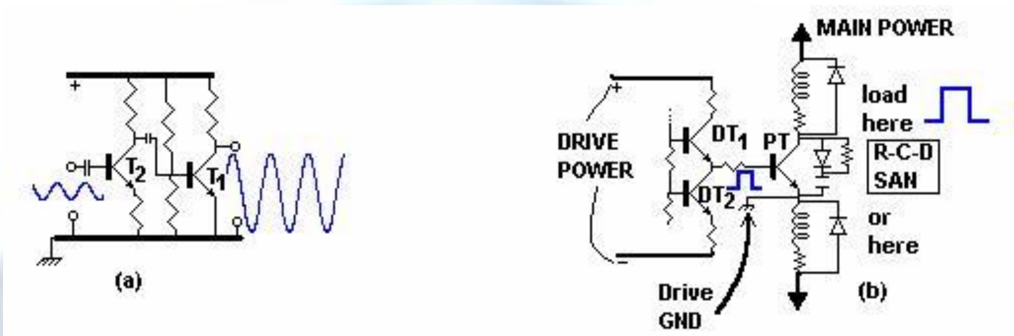
## How is Power electronics distinct from linear electronics?

It is not primarily in their power handling capacities.

N.

While power management IC's in mobile sets working on Power Electronic principles are meant to handle only a few milliwatts, large linear audio amplifiers are rated at a few thousand watts.

The utilisation of the Bipolar junction transistor, Fig. 1.2 in the two types of amplifiers best symbolises the difference. In Power Electronics all devices are operated in the switching mode - either 'FULLY-ON' or 'FULLY-OFF' states. The linear amplifier concentrates on fidelity in signal amplification, requiring transistors to operate strictly in the linear (active) zone, Fig 1.3. Saturation and cutoff zones in the $V_{CE}$ - $I_C$ plane are avoided. In a Power electronic switching amplifier, only those areas in the $V_{CE}$ - $I_C$ plane which have been skirted above, are suitable. On-state dissipation is minimum if the device is in saturation (or quasi-saturation for optimising other losses). In the off-state also, losses are minimum if the BJT is reverse biased. A BJT switch will try to traverse the active zone as fast as possible to minimise switching losses.




**Typical Bipolar transistor based (a) linear (common emitter) (*voltage*) amplifier stage and (b) switching (*power*) amplifier**

| Linear operation | Switching operation |
|---|---|
| Active zone selected:<br>Good linearity between input/output | Active zone avoided :<br>High losses, encountered only during transients |
| Saturation & cut-off zones avoided: poor linearity | Saturation & cut-off (negative bias) zones selected: low losses |
| Transistor biased to operate around quiescent point | No concept of quiescent point |
| Common emitter, Common collector, common base modes | Transistor driven directly at base - emitter and load either on collector or emitter |
| Output transistor barely protected | Switching-Aid-Network (SAN) and other protection to main transistor |
| Utilisation of transistor rating of secondary importance | Utilisation of transistor rating optimised |

## Power Semiconductor device

Power electronics and converters utilizing them made a head start when the first device the Silicon Controlled Rectifier was proposed by Bell Labs and commercially produced by General Electric in the earlier fifties. The Mercury Arc Rectifiers were well in use by that time and the robust and compact SCR first started replacing it in the rectifiers and cycloconverters. The necessity arose of extending the application of the SCR beyond the line-commutated mode of action, which called for external measures to circumvent its turn-off incapability via its control terminals. Various turn-off schemes were proposed and their classification was suggested but it became increasingly obvious that a device with turn-off capability was desirable, which would permit it a wider application. The turn-off networks and aids were impractical at higher powers.

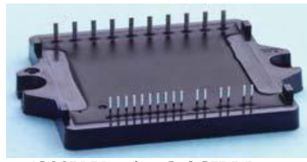
The Bipolar transistor, which had by the sixties been developed to handle a few tens of amperes and block a few hundred volts, arrived as the first competitor to the SCR. It is superior to the SCR in its turn-off capability, which could be exercised via its control terminals. This permitted the replacement of the SCR in all forced-commutated inverters and choppers. However, the gain (power) of the SCR is a few decades superior to that of the Bipolar transistor and the high base currents required to switch the Bipolar spawned the Darlington. Three or more stage Darlingtons are available as a single chip complete with accessories for its convenient drive. Higher operating frequencies were obtainable with a discrete Bipolars compared to the 'fast' inverter-grade SCRs permitting reduction of filter components. But the Darlington's operating frequency had to be reduced to permit a sequential turn- off of the drivers and the main transistor. Further, the incapability of the Bipolar to block reverse voltages restricted its use.

The Power MOSFET burst into the scene commercially near the end seventies. This device also represents the first successful marriage between modern integrated circuit and discrete power semiconductor manufacturing technologies. Its voltage drive capability – giving it again a higher gain, the ease of its paralleling and most importantly the much higher operating frequencies reaching upto a few MHz saw it replacing the Bipolar also at the sub-10 KW range mainly for SMPS type of applications. Extension of VLSI manufacturing facilities for the MOSFET reduced its price vis-à-vis the Bipolar also. However, being a majority carrier device its on-state voltage is dictated by the $R_{DS(ON)}$ of the device, which in turn is proportional to about $V_{DSS}^{2.3}$ rating of the MOSFET. Consequently, high-voltage MOSFETS are not commercially viable.

Improvements were being tried out on the SCR regarding its turn-off capability mostly by reducing the turn-on gain. Different versions of the Gate-turn-off device, the Gate turn-off Thyristor (GTO), were proposed by various manufacturers - each advocating their own symbol for the device. The requirement for an extremely high turn-off control current via the gate and the comparatively higher cost of the device restricted its application only to inverters rated above a few hundred KVA.

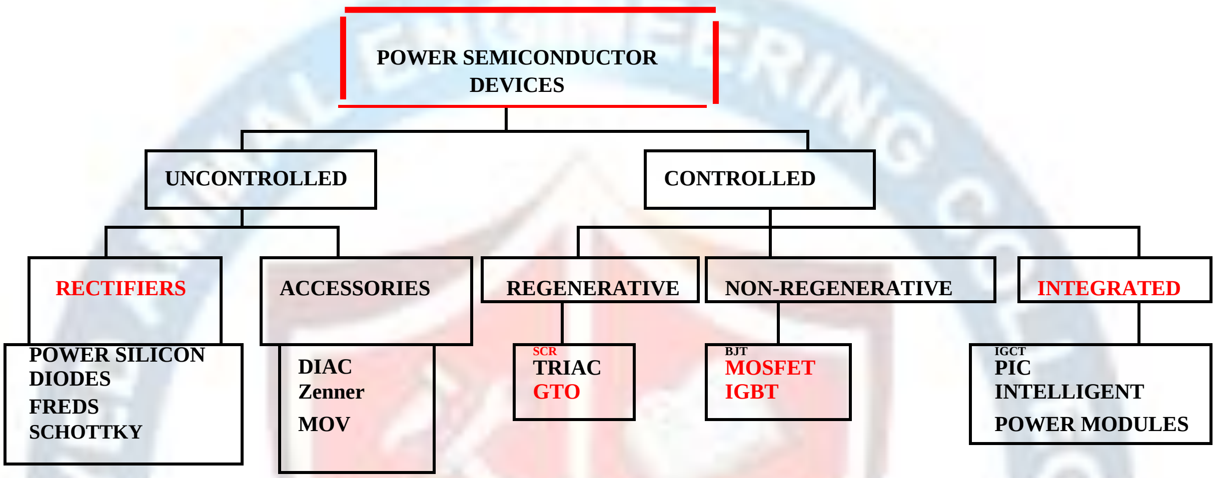
The lookout for a more efficient, cheap, fast and robust turn-off-able device proceeded in different directions with MOS drives for both the basic thysistor and the Bipolar. The Insulated Gate Bipolar Transistor (IGBT) – basically a MOSFET driven Bipolar from its terminal characteristics has been a successful proposition with devices being made available at about 4 KV and 4 KA. Its switching frequency of about 25 KHz and ease of connection and drive saw it totally removing the Bipolar from practically all applications. Industrially, only the MOSFET has been able to continue in the sub – 10 KVA range primarily because of its high switching frequency. The IGBT has also pushed up the GTO to applications above 2-5 MVA.

Subsequent developments in converter topologies – especially the three-level inverter permitted use of the IGBT in converters of 5 MVA range. However at ratings above that the GTO (6KV/6KA device of Mitsubishi) based converters had some space. Only SCR based converters are possible at the highest range where line-commutated or load-commutated converters were the only solution. The surge current, the peak repetition voltage and $I^2t$ ratings are applicable only to the thyristors making them more robust, specially thermally, than the transistors of all varieties.



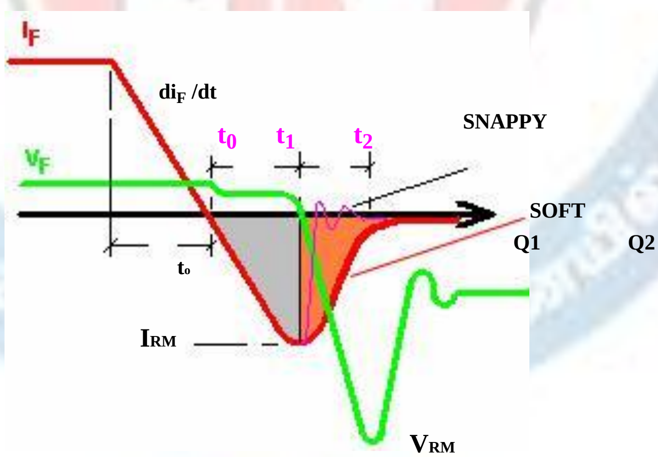
**1200V Version 3 ASIPM**

Presently there are few hybrid devices and Intelligent Power Modules (IPM) are marketed by some manufacturers. The IPMs have already gathered wide acceptance. The 4500 V, 1200 A




**Power semiconductor device variety**

## Power Diodes




**Typical turn-off dynamics of a soft and a 'snappy' diode'**

Silicon Power diodes are the successors of Selenium rectifiers having significantly improved forward characteristics and voltage ratings. They are classified mainly by their turn-off (dynamic) characteristics Fig. 1.6. The minority carriers in the diodes require finite time - $t_{rr}$ (reverse recovery time) to recombine with opposite charges and neutralise. Large values of $Q_{rr}$ (= $Q_1$ + $Q_2$) - the charge to be dissipated as a negative current when the and diode turns off and $t_{rr}$ (= $t_2$ - $t_0$) - the time it takes to regain its blocking features, impose strong current stresses on the controlled device in series. Also a 'snappy' type of recovery of the diode effects high di/dt voltages on all associated power device in the converter

**Fast recovery diodes:** Fast recovery diffused diodes and fast recovery epitaxial diodes, FRED's, have significantly lower $Q_{rr}$ and $t_{rr}$ (~ 1.0 sec). They areavailable at high powers and are mainly used in association with fast controlled-devices as free-wheeling or DC-DC choppers and rectifier applications. Fast recovery diodes also find application in induction heating, UPS and traction.

**Schottky rectifiers:** These are the fastest rectifiers being majority carrier devices without any $Q_{rr..}$ However, they are available with voltage ratings up to a hundred volts only though current ratings may be high. Their conduction voltages specifications are excellent (~0.2V). The freedom from minority carrier recovery permits reduced snubber requirements. Schottky diodes face no competition in low voltage SPMS applications and in instrumentation.

## Silicon Controlled Rectifier (SCR)

The Silicon Controlled Rectifier is the most popular of the thyristor family of four layer regenerative devices. It is normally turned on by the application of a gate pulse when a forward bias voltage is present at the main terminals. However, being regenerative or 'latching', it cannot be turned off via the gate terminals specially at the extremely high amplification factor of the gate. There are two main types of SCR's**.**

**Converter grade or Phase Control thyristors** These devices are the work horses of the Power Electronics. They are turned off by natural (line) commutation and are reverse biased at least for a few milliseconds subsequent to a conduction period. No fast switching feature is desired of these devices. They are available at voltage ratings in excess of 5 KV starting from about 50 V and current ratings of about 5 KA. The largest converters for HVDC transmission are built with series- parallel combination of these devices. Conduction voltages are device voltage rating dependent and range between 1.5 V (600V) to about 3.0 V (+5 KV). These devices are unsuitable for any 'forced-commutated' circuit requiring unwieldy large commutation components.

The dynamic di/dt and dv/dt capabilities of the SCR have vastly improved over the years borrowing emitter shorting and other techniques adopted for the faster variety. The requirement for hard gate drives and di/dt limting inductors have been eliminated in the process.

**Inverter grade thyristors:** Turn-off times of these thyristors range from about 5 to 50 μsecs when hard switched. They are thus called fast or 'inverter grade' SCR's. The SCR's are mainly used in circuits that are operated on DC supplies and no alternating voltage is available to turn them off. Commutation networks have to be added to the basic converter only to turn-off the SCR's. The efficiency, size and weight of these networks are directly related to the turn-off time, $t_q$ of the SCR. The commutation circuits utilised resonant networks or charged capacitors. Quite a few commutation networks were designed and some like the McMurray-Bedford became widely accepted.

**Asymmetrical, light-activated, reverse conducting SCR's** Quite a few varieties of the basic SCR have been proposed for specific applications. The Asymmetrical thyristor is convenient when reactive powers are involved and the light activated SCR assists in paralleling or series operation.

# MOSFET

The Power MOSFET technology has mostly reached maturity and is the most popular device for SMPS, lighting ballast type of application where high switching frequencies are desired but operating voltages are low. Being a voltage fed, majority carrier device (resistive behaviour) with a typically rectangular Safe Operating Area, it can be conveniently utilized. Utilising shared manufacturing processes, comparative costs of MOSFETs are attractive. For low frequency applications, where the currents drawn by the equivalent capacitances across its terminals are small, it can also be driven directly by integrated circuits. These capacitances are the main hindrance to operating the MOSFETS at speeds of several MHz. The resistive characteristics of its main terminals permit easy paralleling externally also. At high current low voltage applications the MOSFET offers best conduction voltage specifications as the $R_{DS(ON)}$ specification is current rating dependent. However, the inferior features of the inherent anti-parallel diode and its higher conduction losses at power frequencies and voltage levels restrict its wider application.

# The IGBT

It is a voltage controlled four-layer device with the advantages of the MOSFET driver and the Bipolar Main terminal. IGBTs can be classified as punch-through (PT) and non-punch-through (NPT) structures. In the punch-through IGBT, a better trade-off between the forward voltage drop and turn -off time can be achieved. Punch-through IGBTs are available up to about 1200 V. NPT IGBTs of up to about 4 KV have been reported in literature and they are more robust than PT IGBTs particularly under short circuit conditions. However they have a higher forward voltage drop than the PT IGBTs. Its switching times can be controlled by suitably shaping the drive signal. This gives the IGBT a number of advantages: it does not require protective circuits, it can be connected in parallel without difficulty, and series connection is possible without dv/dt snubbers. The IGBT is presently one of the most popular device in view of its wide ratings, switching speed of about 100 KHz a easy voltage drive and a square Safe Operating Area devoid of a Second Breakdown region.

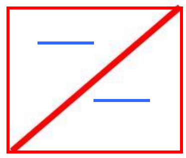
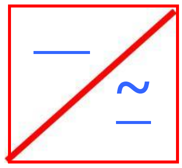
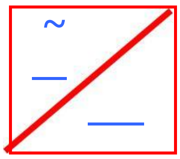
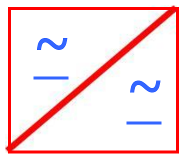
# The GTO

The GTO is a power switching device that can be turned on by a short pulse of gate current and turned off by a reverse gate pulse. This reverse gate current amplitude is dependent on the anode current to be turned off. Hence there is no need for an external commutation circuit to turn it off. Because turn-off is provided by bypassing carriers directly to the gate circuit, its turn-off time is short, thus giving it more capability for highfrequency operation than thyristors. The GTO symbol and turn-off characteristics are shown in Fig. 30.3. GTOs have the $I^2t$ withstand capability and hence can be protected by semiconductor fuses. For reliable operation of GTOs, the critical aspects are proper design of the gate turn-off circuit and the snubber circuit.

# Power Converter Topologies

A Power Electronic Converter processes the available form to another having a different frequency and/or voltage magnitude. There can be four basic types of converters depending upon the function performed:

**CONVERSION**

| FROM/TO | NAME | FUNCTION | SYMBOL |
|---|---|---|---|
| DC to DC | Chopper | Constant to variable DC or variable to constant DC |  |
| DC to AC | Inverter | DC to AC of desired voltage and frequency |  |
| AC to DC | Rectifier | AC to unipolar (DC) current |  |
| AC to AC | Cycloconverter, AC-PAC, Matrix converter | AC of desired frequency and/or magnitude from generally line AC |  |

## Base / gate drive circuit

All discrete controlled devices, regenerative or otherwise have three terminals. Two of these are the Main Terminals. One of the Main Terminals and the third form the Control Terminal. The amplification factor of all the devices (barring the now practically obsolete BJT) are quite high, though turn-on gain is not equal to turn-off gain. The drive circuit is required to satisfy the control terminal characteristics to efficiently tun -on each of the devices of the converter, turn them off, if possible, again optimally and also to protect the device against faults, mostly over-currents. Being driven by a common controller, the drives must also be isolated from each other as the potentials of the Main Terminal which doubles as a Control terminal are different at various locations of the converter. Gate-turn-off-able devices require precise gate drive waveform for optimal switching. This necessitates a wave-shaping amplifier. This amplifier is located after the isolation stage.

## Protection of Power devices and converters

Power electronic converters often operate from the utility mains and are exposed to the disturbances associated with it. Even otherwise, the transients associated with switching circuits and faults that occur at the load point stress converters and devices. Consequently, several protection schemes must be incorporated in a converter. It is necessary to protect both the Main Terminals and the control terminals. Some of these techniques are common for all devices and converters. However, differences in essential features of devices call for special protection schemes particular for those devices. The IGBT must be protected against latching, and similarly the GTO's turn-off drive is to be disabled if the Anode current exceeds the maximum permissible turn-off-able current specification. Power semiconductor devices are commonly protected against:

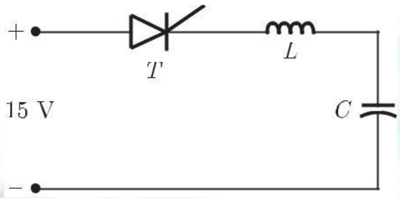
(V) Over-current;
(W) di/dt;
(X) Voltage spike or over-voltage;
(Y) dv/dt ;
(Z) Gate-under voltage;
(AA) Over voltage at gate;
(BB) Excessive temperature rise;
(CC) Electro-static discharge;

Semiconductor devices of all types exhibit similar responses to most of the stresses, however there are marked differences. The SCR is the most robust device on practically all counts. That it has an $I^2$ t rating is proof that its internal thermal capacities are excellent. A HRC fuse, suitably selected, and in co-ordination with fast circuit breakers would mostly protect it. This sometimes becomes a curse when the cost of the fuse becomes exorbitant. All transistors, specially the BJT and the IGBT is actively protected (without any operating cost!) by sensing the Main Terminal voltage, as shown in Fig. 1.7. This voltage is related to the current carried by the device. Further, the transistors permit designed gate current waveforms to minimise voltage spikes as a consequence of sharply rising Main terminal currents. Gate resistances have significant effect on turn-on and turn-off times of these devices - permitting optimisation of switching times for the reduction of switching losses and voltage spikes.

Thus separate isolated power supplies are also required for each Power device in the converter (the ones having a common Control Terminal - say the Emitter in an IGBT - may require a few less). There are functionally two types of isolators: the pulse transformer which can transmit after isolation, in a multi- device converter, both the un-shaped signal and power and optical isolators which transmit only the signal. The former is sufficient for a SCR without isolated power supplies at the secondary. The latter is a must for practically all other devices. Fig. 1.7 illustrates to typical drive circuits for an IGBT and an SCR.

## POWER ELECTRONICS

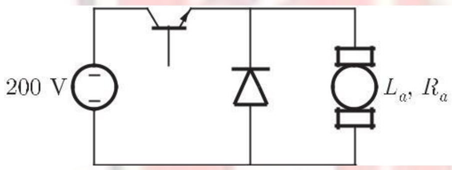
Q. 1 Thyristor $T$ in the figure below is initially off and is triggered with a single pulse of width 10 ms. It is given that $L = \left(\frac{100}{\pi}\right)$ mH and $C = \left(\frac{100}{\pi}\right)$ mF. Assuming latching and holding currents of the thyristor are both zero and the initial charge on $C$ is zero, $T$ conducts for




(A) 10 ms (B) 50 ms

(C) 100 ms (D) 200 ms

Q. 2 The separately excited dc motor in the figure below has a rated armature current of 20 A and a rated armature voltage of 150 V. An ideal chopper switching at 5 kHz is used to control the armature voltage. If $L_a = 0.1$ mH, $R_a = 1\ \Omega$, neglecting armature reaction, the duty ratio of the chopper to obtain 50% of the rated torque at the rated speed and the rated field current is

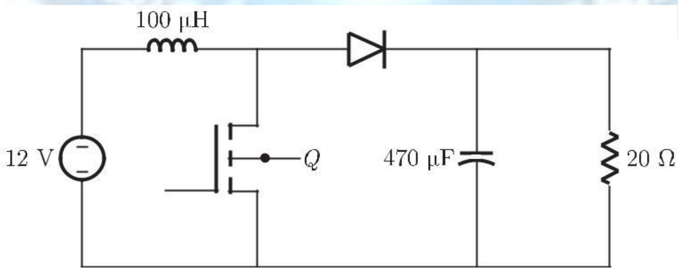



(A) 0.4 (B) 0.5

(C) 0.6 (D) 0.7

### Common Data For Q. 3 and 4

In the figure shown below, the chopper feeds a resistive load from a battery source. MOSFET $Q$ is switched at 250 kHz, with duty ratio of 0.4. All elements of the circuit are assumed to be ideal



11. 3 The Peak to Peak source current ripple in amps is

(A) 0.96 (B) 0.144

(C) 0.192 (D) 0.228

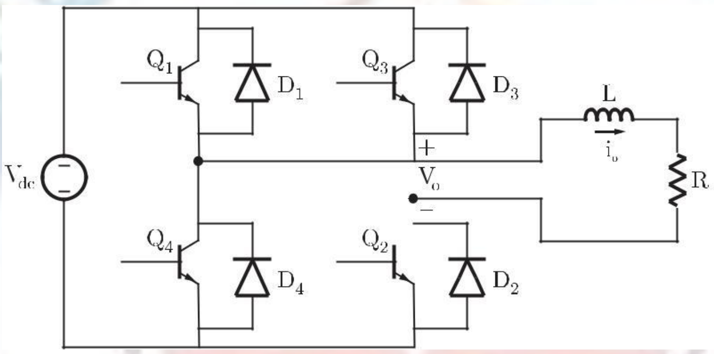
I. 4 The average source current in Amps in steady-state is

(A) 3/2 (B) 5/3

(C) 5/2 (D) 15/4

**Statement for Linked Answer Questions: 5 and 6**

The Voltage Source Inverter (VSI) shown in the figure below is switched to provide a 50 Hz, square wave ac output voltage $V_o$ across an *RL* load. Reference polarity of $V_o$ and reference direction of the output current $i_o$ are indicated in the figure. It is given that $R$ = 3 ohms, $L$ = 9.55 mH.




Q. 5 In the interval when $V_0 < 0$ and $i_0 > 0$ the pair of devices which conducts the load current is

(A) $Q_1, Q_2$ (B) $Q_3, Q_4$

(C) $D_1, D_2$ (D) $D_3, D_4$

Q. 6 Appropriate transition i.e., Zero Voltage Switching ^ h *ZVS* /Zero Current Switching *ZCS* of the IGBTs during turn-on/turn-off is ^ h

(A) ZVS during turn off (B) ZVS during turn-on

(C) ZCS during turn off (D) ZCS during turn-on

---

Q. 7 A half-controlled single-phase bridge rectifier is supplying an *R-L* load. It is operated at a firing angle *a* and the load current is continuous. The fraction of cycle that the freewheeling diode conducts is

(A) 1/2 (B) (1 - *a*/*p*)

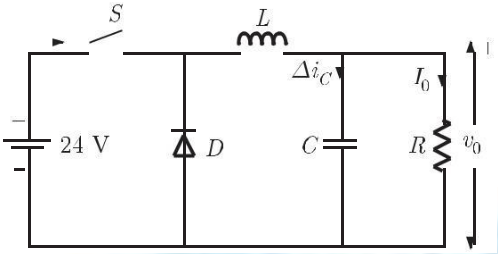
(C) *a* /2*p* (D) *a*/*p*

Q. 8 The typical ratio of latching current to holding current in a 20 A thyristor is

(A) 5.0 (B) 2.0

(C) 1.0 (D) 0.5

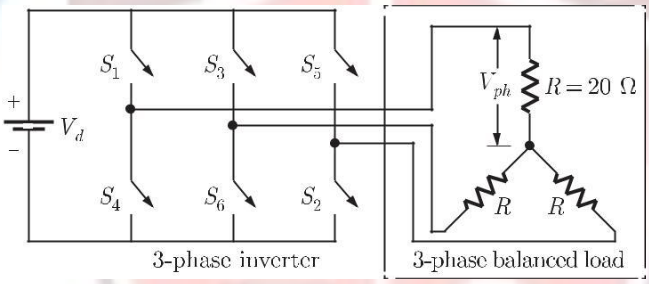
Q. 9 In the circuit shown, an ideal switch $S$ is operated at 100 kHz with a duty ratio of 50%. Given that $Di_c$ is 1.6 A peak-to-peak and $I_0$ is 5 A dc, the peak current in $S$, is




(A) 6.6 A
(B) 5.0 A
(C) 5.8 A
(D) 4.2 A

**Common Data for Questions 10 and 11**

In the 3-phase inverter circuit shown, the load is balanced and the gating scheme is 180c conduction mode. All the switching devices are ideal.



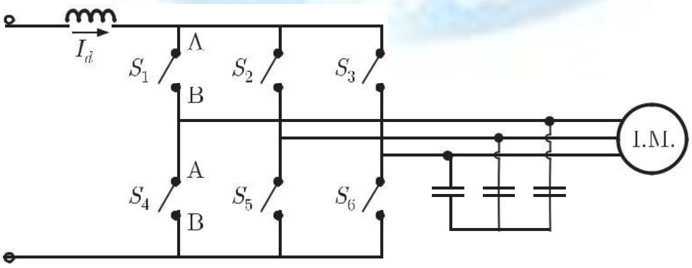

Q. 10 The rms value of load phase voltage is

(A) 106.1 V
(B) 141.4 V
(C) 212.2 V
(D) 282.8 V

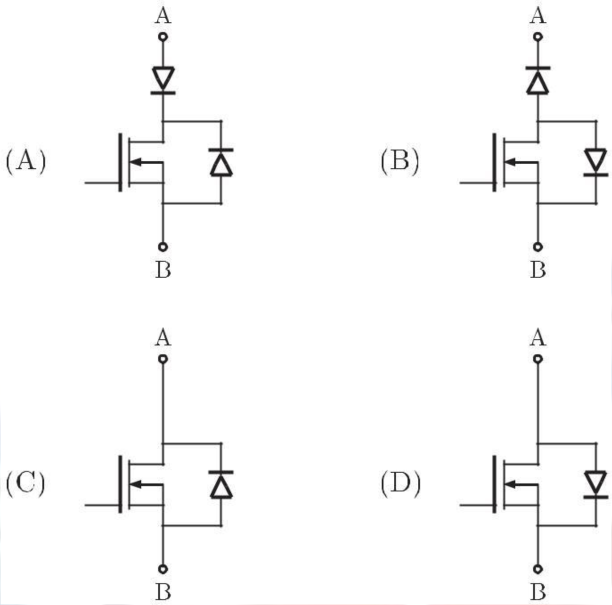
Q. 11 If the dc bus voltage $V_d = 300$ V, the power consumed by 3-phase load is

(A) 1.5 kW
(B) 2.0 kW
(C) 2.5 kW
(D) 3.0 kW

Q. 12 A three phase current source inverter used for the speed control of an induction motor is to be realized using MOSFET switches as shown below. Switches $S_1$ to $S_6$ are identical switches.



The proper configuration for realizing switches $S_1$ to $S_6$ is




Q. 13 Circuit turn-off time of an SCR is defined as the time

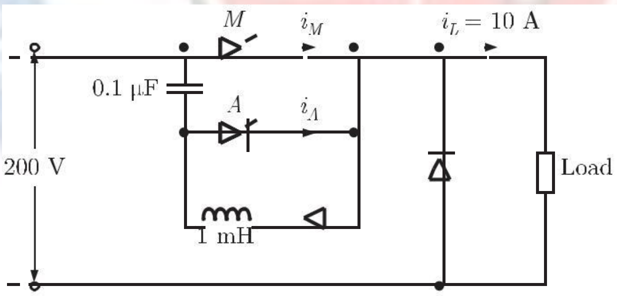
P. taken by the SCR turn to be off

Q. required for the SCR current to become zero

R. for which the SCR is reverse biased by the commutation circuit

S. for which the SCR is reverse biased to reduce its current below the holding current

Q. 14 A voltage commutated chopper circuit, operated at 500 Hz, is shown below.




If the maximum value of load current is 10 A, then the maximum current through the main ($M$) and auxiliary ($A$) thyristors will be

(N) $i_{M\max} = 12$ A and $i_{A\max} = 10$ A

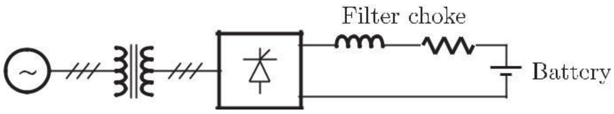
(O) $i_{M\max} = 12$ A and $i_{A\max} = 2$ A

(P) $i_{M\max} = 10$ A and $i_{A\max} = 12$ A

(Q) $i_{M\max} = 10$ A and $i_{A\max} = 8$ A

**Statement for Linked Answer Questions: 15 & 16**

A solar energy installation utilize a three – phase bridge converter to feed energy into power system through a transformer of 400 V/400 V, as shown below.




The energy is collected in a bank of 400 V battery and is connected to converter through a large filter choke of resistance 10 W.

(DD) 15 The maximum current through the battery will be

(A) 14 A (B) 40 A

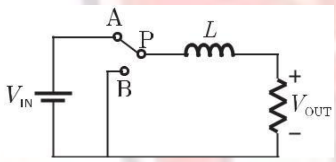
(C) 80 A (D) 94 A

(L) 16 The kVA rating of the input transformer is

(A) 53.2 kVA (B) 46.0 kVA

(C) 22.6 kVA (D) 7.5 kVA

Q. 17 The power electronic converter shown in the figure has a single-pole double-throw switch. The pole P of the switch is connected alternately to throws A and B. The converter shown is a



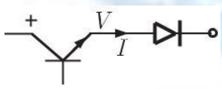

(O) step down chopper (buck converter)

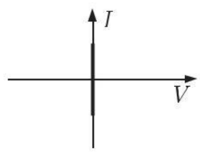
(P) half-wave rectifier

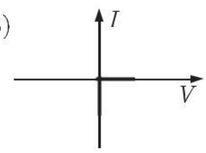
(Q) step-up chopper (boost converter)

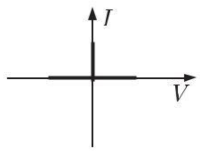
(R) full-wave rectifier

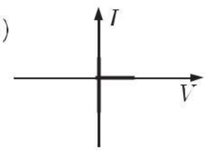
Q. 18 Figure shows a composite switch consisting of a power transistor (BJT) in series with a diode. Assuming that the transistor switch and the diode are ideal, the $I$ -$V$ characteristic of the composite switch is



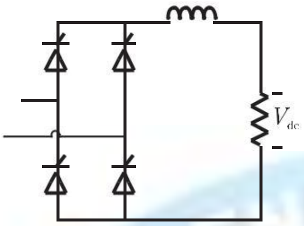

(A)



(B)



(C)



(D)


Q. 19 The fully controlled thyristor converter in the figure is fed from a single-phase source. When the firing angle is 0c, the dc output voltage of the converter is 300 V. What will be the output voltage for a firing angle of 60c, assuming continuous conduction




(A) 150 V
(B) 210 V
(C) 300 V
(D) 100p V

---

Q. 20 An SCR is considered to be a semi-controlled device because

(A) It can be turned OFF but not ON with a gate pulse.

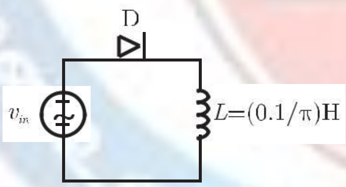
(B) It conducts only during one half-cycle of an alternating current wave.

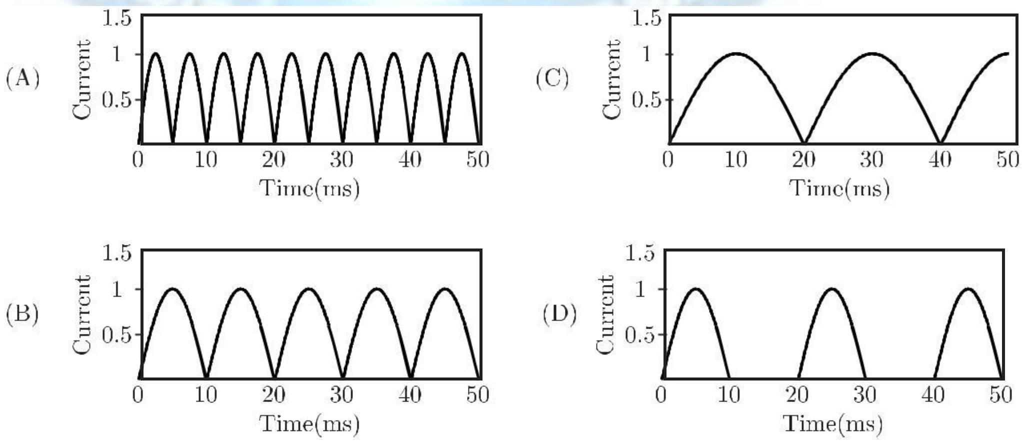
(C) It can be turned ON but not OFF with a gate pulse.

(D) It can be turned ON only during one half-cycle of an alternating voltage wave.

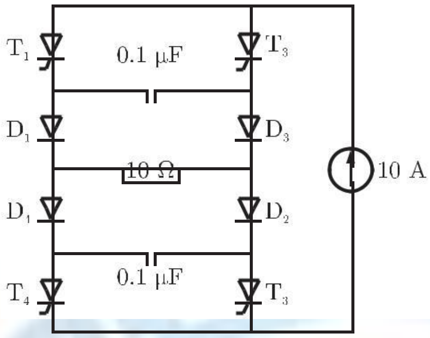
---

Q. 21 The circuit shows an ideal diode connected to a pure inductor and is connected to a purely sinusoidal 50 Hz voltage source. Under ideal conditions the current waveform through the inductor will look like.



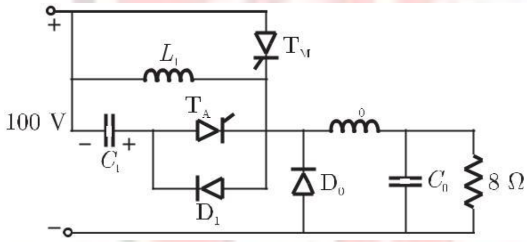



Q. 22 The Current Source Inverter shown in figure is operated by alternately turning on thyristor pairs ($T_1$,$T_2$) and ($T_3$,$T_4$). If the load is purely resistive, the theoretical maximum output frequency obtainable will be



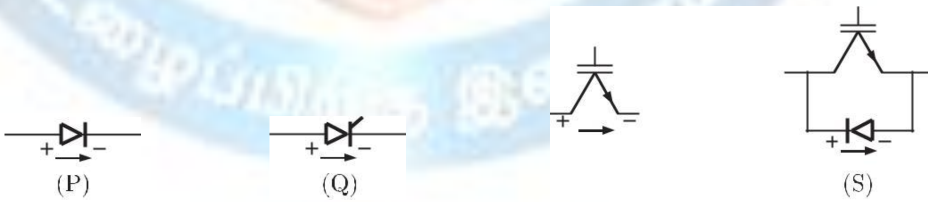

(A) 125 kHz
(B) 250 kHz
(C) 500 kHz
(D) 50 kHz

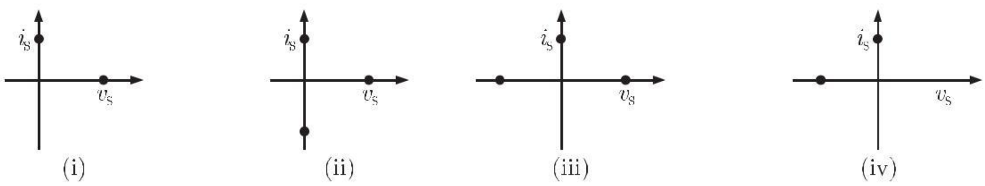
Q. 23 In the chopper circuit shown, the main thyristor ($T_M$) is operated at a duty ratio of 0.8 which is much larger the commutation interval. If the maximum allowable reapplied *dv* /*dt* on $T_M$ is 50 V/ms, what should be the theoretical minimum value of $C_1$ ? Assume current ripple through $L_0$ to be negligible.




(A) 0.2 mF
(B) 0.02 mF
(C) 2 mF
(D) 20 mF

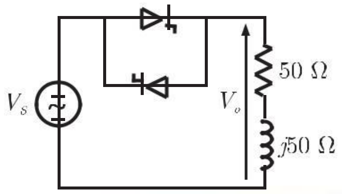
Q. 24 Match the switch arrangements on the top row to the steady-state *V* -*I* characteristics on the lower row. The steady state operating points are shown by large black dots.




(A) P-I, Q-II, R-III, S-IV
(B) P-II, Q-IV, R-I, S-III
(C) P-IV, Q-III, R-I, S-II
(D) P-IV, Q-III, R-II, S-I

Q. 25 In the single phase voltage controller circuit shown in the figure, for what range of triggering angle (*a*), the input voltage ($V_0$) is not controllable ?




(A) 0c < *a* < 45c
(B) 45c < *a* < 135c
(C) 90c < *a* < 180c
(D) 135c < *a* < 180c

Q. 26 A 3-phase voltage source inverter is operated in 180c conduction mode. Which one of the following statements is true ?

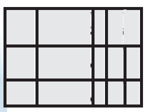
(O) Both pole-voltage and line-voltage will have 3rd harmonic components

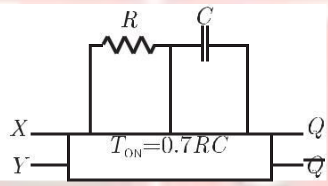
(P) Pole-voltage will have 3rd harmonic component but line-voltage will be free from 3rd harmonic

(Q) Line-voltage will have 3rd harmonic component but pole-voltage will be free from 3rd harmonic

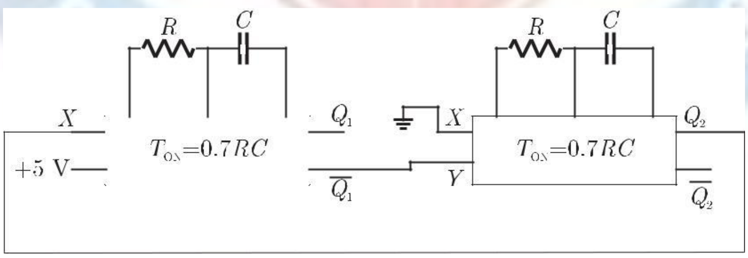
(R) Both pole-voltage and line-voltage will be free from 3rd harmonic components

Q. 27 The truth table of monoshot shown in the figure is given in the table below :






Two monoshots, one positive edge triggered and other negative edge triggered, are connected shown in the figure, The pulse widths of the two monoshot outputs $Q_1$ and $Q_2$ are $T_{ON_1}$ and $T_{ON_2}$ respectively.




The frequency and the duty cycle of the signal at $Q_1$ will respectively be

(A) $f = \frac{1}{T_{ON_1} + T_{ON_2}}$, $D = \frac{1}{5}$

(B) $f = \frac{1}{T_{ON_1} + T_{ON_2}}$, $D = \frac{T_{ON_2}}{T_{ON_1} + T_{ON_2}}$

(C) $f = \frac{1}{T_{ON_1}}$, $D = \frac{T_{ON_1}}{T_{ON_1} + T_{ON_2}}$

(D) $f = \frac{1}{T_{ON_2}}$, $D = \frac{T_{ON_1}}{T_{ON_1} + T_{ON_2}}$

Q. 28 A single phase fully controlled bridge converter supplies a load drawing constant and ripple free load current, if the triggering angle is 30c, the input power factor will be

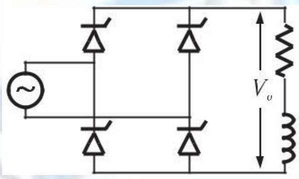
0.65

0.78

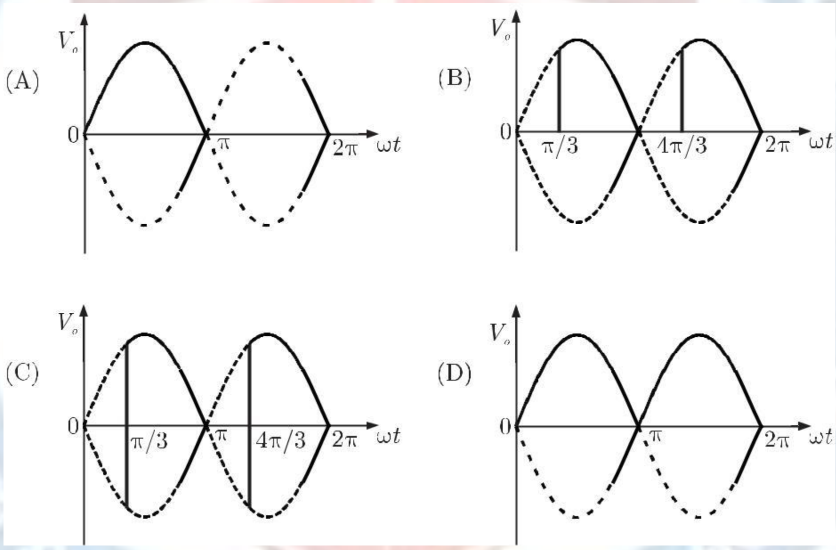
0.85

0.866

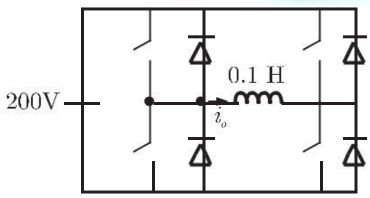
Q. 29 A single-phase half controlled converter shown in the figure feeding power to highly inductive load. The converter is operating at a firing angle of 60c.




If the firing pulses are suddenly removed, the steady state voltage ($V_0$) waveform of the converter will become




Q. 30 A single phase source inverter is feeding a purely inductive load as shown in the figure. The inverter is operated at 50 Hz in 180c square wave mode. Assume that the load current does not have any dc component. The peak value of the inductor current $i_0$ will be




(L) 6.37 A

(M) 10 A

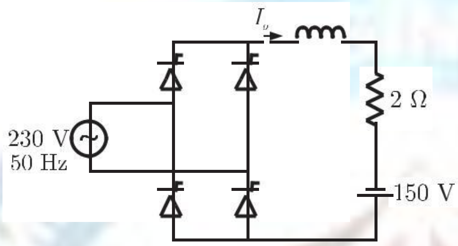
(N) 20 A

(O) 40 A

Q. 31 A three phase fully controlled bridge converter is feeding a load drawing a constant and ripple free load current of 10 A at a firing angle of 30c. The approximate Total harmonic Distortion (%THD) and the rms value of fundamental component of input current will respectively be

(A) 31% and 6.8 A
(B) 31% and 7.8 A
(C) 66% and 6.8 A
(D) 66% and 7.8 A

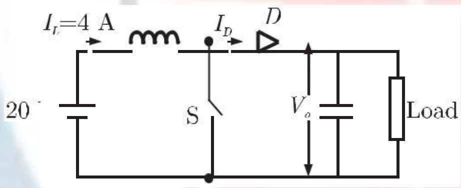
Q. 32 A single phase fully controlled converter bridge is used for electrical braking of a separately excited dc motor. The dc motor load is represented by an equivalent circuit as shown in the figure.




Assume that the load inductance is sufficient to ensure continuous and ripple free load current. The firing angle of the bridge for a load current of $I_0 = 10$ A will be

(A) 44c
(B) 51c
(C) 129c
(D) 136c

Q. 33 In the circuit shown in the figure, the switch is operated at a duty cycle of 0.5. A large capacitor is connected across the load. The inductor current is assumed to be continuous.




The average voltage across the load and the average current through the diode will respectively be

(A) 10 V, 2 A
(B) 10 V, 8 A
(C) 40 V 2 A
(D) 40 V, 8 A

---

Q. 34 A single-phase fully controlled thyristor bridge ac-dc converter is operating at a firing angle of 25c and an overlap angle of 10c with constant dc output current of 20 A. The fundamental power factor (displacement factor) at input ac mains is

(A) 0.78
(B) 0.827
(C) 0.866
(D) 0.9

Q. 35 A three-phase, fully controlled thyristor bridge converter is used as line commutated inverter to feed 50 kW power 420 V dc to a three-phase, 415 V(line), 50 Hz ac mains. Consider dc link current to be constant. The rms current of the thyristor is

(A) 119.05 A
(B) 79.37 A
(C) 68.73 A
(D) 39.68 A

Q. 36 A single phase full-wave half-controlled bridge converter feeds an inductive load. The two SCRs in the converter are connected to a common DC bus. The converter has to have a freewheeling diode.

(O) because the converter inherently does not provide for free-wheeling

(P) because the converter does not provide for free-wheeling for high values of triggering angles

(Q) or else the free-wheeling action of the converter will cause shorting of the AC supply

(R) or else if a gate pulse to one of the SCRs is missed, it will subsequently cause a high load current in the other SCR.

Q. 37 "Six MOSFETs connected in a bridge configuration (having no other power device) must be operated as a Voltage Source Inverter (VSI)". This statement is

O True, because being majority carrier devices MOSFETs are voltage driven.

P True, because MOSFETs hav inherently anti-parallel diodes

Q False, because it can be operated both as Current Source Inverter (CSI) or a VSI

R False, because MOSFETs can be operated as excellent constant current sources in the saturation region.

Q. 38 A single-phase voltages source inverter is controlled in a single pulse-width modulated mode with a pulse width of 150c in each half cycle. Total harmonic distortion is defined as

$$THD = \frac{\sqrt{V_{rms}^2 - V_1^2}}{V_1} \# 100$$

where $V_1$ is the rms value of the fundamental component of the output voltage. The THD of output ac voltage waveform is

(A) 65.65%

(B) 48.42%

(C) 31.83%

(D) 30.49%

Q. 39 A three-phase, 440 V, 50 Hz ac mains fed thyristor bridge is feeding a 440 V dc, 15 kW, 1500 rpm separately excited dc motor with a ripple free continuos current in the dc link under all operating conditions, Neglecting the losses, the power factor of the ac mains at half the rated speed is

(A) 0.354 (B) 0.372

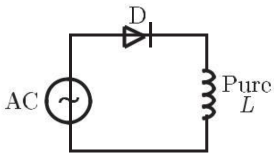
(C) 0.90 (D) 0.955

Q. 40 A single-phase, 230 V, 50 Hz ac mains fed step down transformer (4:1) is supplying power to a half-wave uncontrolled ac-dc converter used for charging a battery (12 V dc) with the series current limiting resistor being 19.04 W. The charging current is

(A) 2.43 A (B) 1.65 A

(C) 1.22 A (D) 1.0 A

Q. 41 In the circuit of adjacent figure the diode connects the ac source to a pure inductance *L*.

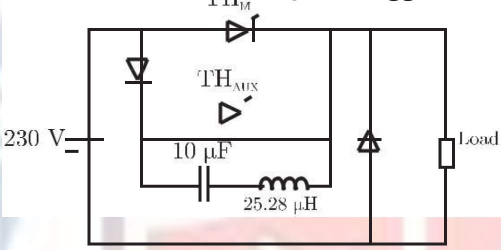



The diode conducts for

(A) 90c (B) 180c

(C) 270c (D) 360c

Q. 42 The circuit in the figure is a current commutated dc-dc chopper where, $Th_M$ is the main SCR and $Th_{AUX}$ is the auxiliary SCR. The load current is constant at 10 A. $Th_M$ is ON. $Th_{AUX}$ is trigged at $t = 0$. $Th_M$ is turned OFF between.




(P) 0 *m* s < *t* # 25 *ms*

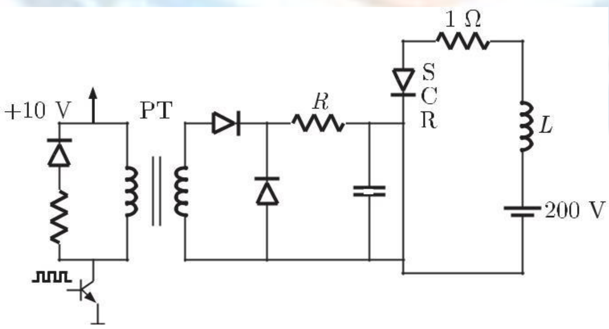
(Q) 25 *m* s < *t* # 50 *ms*

(R) 50 *m* s < *t* # 75 *ms*

(S) 75 *m* s < *t* # 100 *ms*

**Common Data for Question 43 and 44.**

A 1:1 Pulse Transformer (PT) is used to trigger the SCR in the adjacent figure. The SCR is rated at 1.5 kV, 250 A with $I_L$ = 250 mA, $I_H$ = 150 mA, and $I_{Gmax}$ = 150 mA, $I_{Gmin}$ = 100 mA. The SCR is connected to an inductive load, where $L$ = 150 mH in series with a small resistance and the supply voltage is 200 V dc. The forward drops of all transistors/diodes and gate-cathode junction during ON state are 1.0 V




Q. 43 The resistance *R* should be

(A) 4.7 kW (B) 470 kW

(C) 47 W (D) 4.7 W

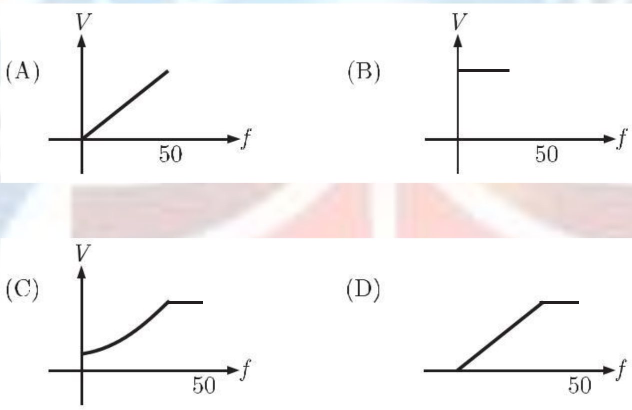
Q. 44 The minimum approximate volt-second rating of pulse transformer suitable for triggering the SCR should be : (volt-second rating is the maximum of product of the voltage and the width of the pulse that may applied)

(A) 2000 *m*V-s (B) 200 *m*V-s

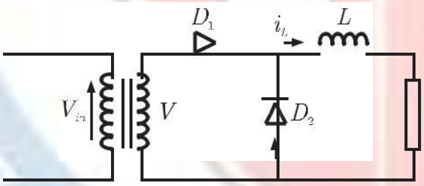
(C) 20 *m*V-s (D) 2 *m*V-s

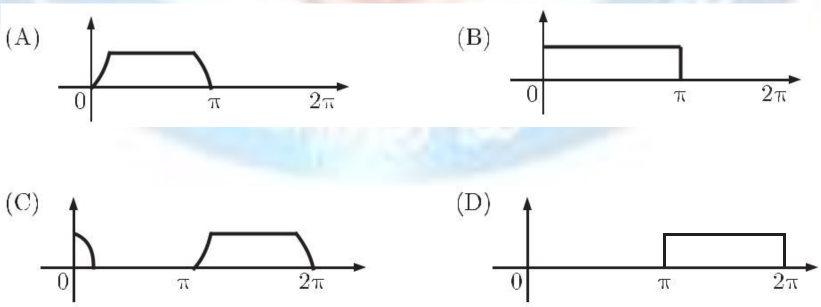


Q. 45 The speed of a 3-phase, 440 V, 50 Hz induction motor is to be controlled over a wide range from zero speed to 1.5 time the rated speed using a 3-phase voltage source inverter. It is desired to keep the flux in the machine constant in the constant torque region by controlling the terminal voltage as the frequency changes. The inverter output voltage vs frequency characteristic should be

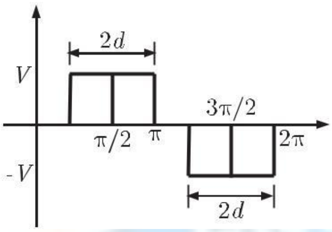



Q. 46 A single-phase half wave uncontrolled converter circuit is shown in figure. A 2-winding transformer is used at the input for isolation. Assuming the load current to be constant and $V = V_m \sin wt$ , the current waveform through diode $D_2$ will be



Q. 47 A single-phase inverter is operated in PWM mode generating a single-pulse of width $2d$ in the centre of each half cycle as shown in figure. It is found that the output voltage is free from $5_{th}$ harmonic for pulse width 144c. What will be percentage of $3^{rd}$ harmonic present in the output voltage ($V_{o\,3}/V_{o1\max}$) ?




0.0%

19.6%

31.7%

53.9%

I 48A 3-phase fully controlled bridge converter with free wheeling diode is fed from 400 V, 50 Hz AC source and is operating at a firing angle of 60c. The load current is assumed constant at 10 A due to high load inductance. The input displacement factor (IDF) and the input power factor (IPF) of the converter will be

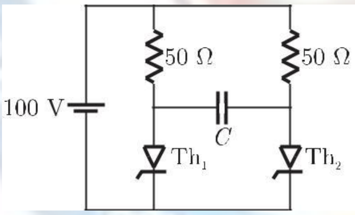
(A) IDF = 0.867;IPF = 0.828

(B) IDF = 0.867; IPF = 0.552

(C) IDF = 0.5; IPF = 0.478

(D) IDF = 0.5; IPF = 0.318

Z. 49A voltage commutation circuit is shown in figure. If the turn-off time of the SCR is 50 *m*sec and a safety margin of 2 is considered, then what will be the approximate minimum value of capacitor required for proper commutation ?




2.88 *m*F

1.44 *m*F

0.91 *m*F

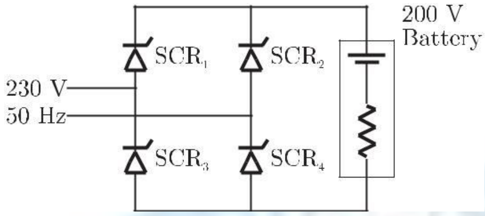
0.72 *m*F

(G) 50A solar cell of 350 V is feeding power to an ac supply of 440 V, 50 Hz through a 3-phase fully controlled bridge converter. A large inductance is connected in the dc circuit to maintain the dc current at 20 A. If the solar cell resistance is 0.5 W ,then each thyristor will be reverse biased for a period of

(A) 125c (B) 120c

(C) 60c (D) 55c

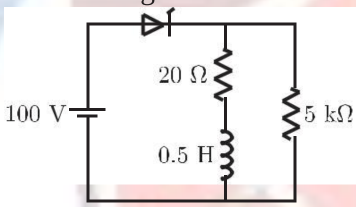
Q. 51 A single-phase bridge converter is used to charge a battery of 200 V having an internal resistance of 0.2 W as shown in figure. The SCRs are triggered by a constant dc signal. If $SCR_2$ gets open circuited, what will be the average charging current ?




(A) 23.8 A (B) 15 A

(C) 11.9 A (D) 3.54 A

Q. 52 An SCR having a turn ON times of 5 *m*sec, latching current of 50 A and holding current of 40 mA is triggered by a short duration pulse and is used in the circuit shown in figure. The minimum pulse width required to turn the SCR ON will be

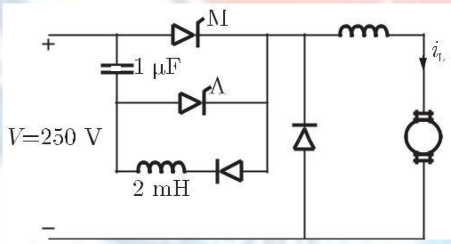



(A) 251 *m*sec (B) 150 *m*sec

(C) 100 *m*sec (D) 5 *m*sec

**Common Data For Q. 53 and 54**

A voltage commutated chopper operating at 1 kHz is used to control the speed of dc as shown in figure. The load current is assumed to be constant at 10 A




(I) 53 The minimum time in *m*sec for which the SCR M should be ON is.

(A) 280 (B) 140

(C) 70 (D) 0

G 54 The average output voltage of the chopper will be

(AA) 70 V

(BB) 47.5 V

(CC) 35 V

(DD) 0 V

E 55 The conduction loss versus device current characteristic of a power MOSFET is best approximated by

(A) a parabola
(B) a straight line
(C) a rectangular hyperbola
(D) an exponentially decaying function

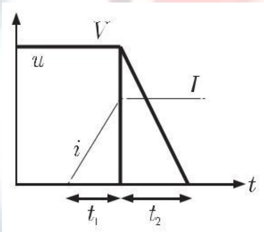
X. 56 A three-phase diode bridge rectifier is fed from a 400 V RMS, 50 Hz, three-phase AC source. If the load is purely resistive, then peak instantaneous output voltage is equal to

X. 400 V
(B) $400\sqrt{2}$ V
(X) $400\sqrt{\frac{2}{3}}$ V
(D) $\frac{400}{\sqrt{3}}$ V

Q. 57 The output voltage waveform of a three-phase square-wave inverter contains

(A) only even harmonics
(B) both odd and even harmonic
(C) only odd harmonics
(D) only triple harmonics

Q. 58 The figure shows the voltage across a power semiconductor device and the current through the device during a switching transitions. If the transition a turn ON transition or a turn OFF transition ? What is the energy lost during the transition?




(A) Turn ON, $\frac{VI}{2}(t_1 + t_2)$
(B) Turn OFF, $VI\,(t_1 + t_2)$
(C) Turn ON, $VI\,(t_1 + t_2)$
(D) Turn OFF, $\frac{VI}{2}(t_1 + t_2)$

Q. 59 An electronics switch S is required to block voltage of either polarity during its OFF state as shown in the figure (a). This switch is as required to conduct in only one direction its ON state as shown in the figure (b)

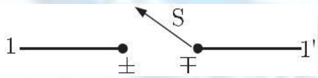



fig (a)

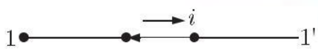
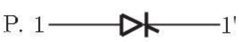
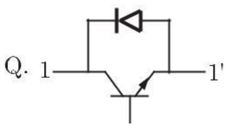
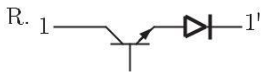


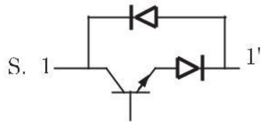

fig (b)

Which of the following are valid realizations of the switch S?



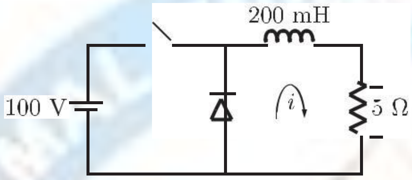





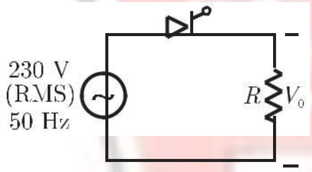

(A) Only P
(B) P and Q
(C) P and R
(D) R and S

Q. 60 The given figure shows a step-down chopper switched at 1 kHz with a duty ratio *D* = 0.5. The peak-peak ripple in the load current is close to




(A) 10 A
(B) 0.5 A
(C) 0.125 A
(D) 0.25 A

Q. 61 Consider a phase-controlled converter shown in the figure. The thyristor is fired at an angle *a* in every positive half cycle of the input voltage. If the peak value of the instantaneous output voltage equals 230 V, the firing angle *a* is close to




(A) 45c
(B) 135c
(C) 90c
(D) 83.6c

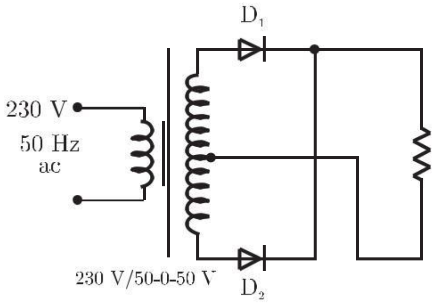
Q. 62 An electric motor, developing a starting torque of 15 Nm, starts with a load torque of 7 Nm on its shaft. If the acceleration at start is 2 rad/sec$^2$ , the moment of inertia of the system must be (neglecting viscous and coulomb friction)

(A) 0.25 kg-m$^2$
(B) 0.25 Nm$^2$
(C) 4 kg-m$^2$
(D) 4 Nm$^2$

Q. 63 A bipolar junction transistor (BJT) is used as a power control switch by biasing it in the cut-off region (OFF state) or in the saturation region (ON state). In the ON state, for the BJT

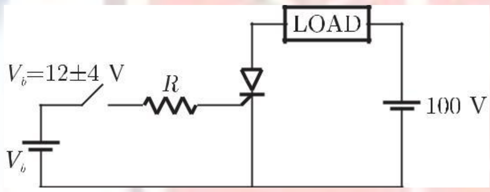
(H) both the base-emitter and base-collector junctions are reverse biased
(I) the base-emitter junction is reverse biased, and the base-collector junction is forward biased
(J) the base-emitter junction is forward biased, and the base-collector junction is reverse biased
(K) both the base-emitter and base-collector junctions are forward biased

Q. 64 The circuit in figure shows a full-wave rectifier. The input voltage is 230 V (rms) single-phase ac. The peak reverse voltage across the diodes $D_1$ and $D_2$ is



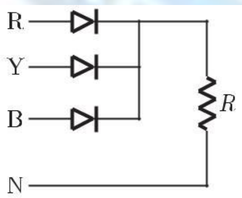

$100\sqrt{2}$ V
100 V
$50\sqrt{2}$ V
50 V

I 65 The triggering circuit of a thyristor is shown in figure. The thyristor requires a gate current of 10 mA, for guaranteed turn-on. The value of *R* required for the thyristor to turn on reliably under all conditions of $V_b$ variation is



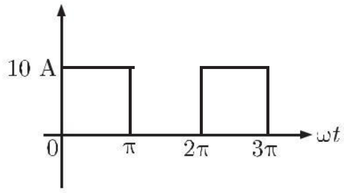

10000 W
1600 W
1200 W
800 W

31 66 The circuit in figure shows a 3-phase half-wave rectifier. The source is a symmetrical, 3-phase four-wire system. The line-to-line voltage of the source is 100 V. The supply frequency is 400 Hz. The ripple frequency at the output is



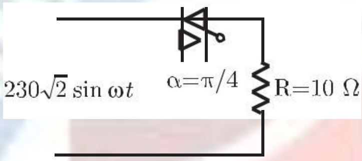

400 Hz
800 Hz
1200 Hz
2400 Hz

Q. 67 A MOSFET rated for 15 A, carries a periodic current as shown in figure. The ON state resistance of the MOSFET is 0.15 W. The average ON state loss in the MOSFET is



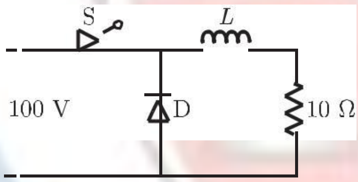

(A) 33.8 W
(B) 15.0 W
(C) 7.5 W
(D) 3.8 W

Q. 68 The triac circuit shown in figure controls the ac output power to the resistive load. The peak power dissipation in the load is



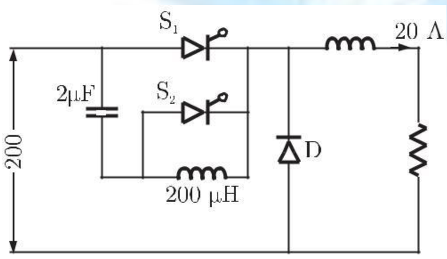

(A) 3968 W
(B) 5290 W
(C) 7935 W
(D) 10580 W

Q. 69 Figure shows a chopper operating from a 100 V dc input. The duty ratio of the main switch S is 0.8. The load is sufficiently inductive so that the load current is ripple free. The average current through the diode D under steady state is




(A) 1.6 A
(B) 6.4 A
(B) 8.0 A
(D) 10.0 A

Q. 70 Figure shows a chopper. The device $S_1$ is the main switching device. $S_2$ is the auxiliary commutation device. $S_1$ is rated for 400 V, 60 A. $S_2$ is rated for 400 V, 30 A. The load current is 20 A. The main device operates with a duty ratio of 0.5. The peak current through $S_1$ is



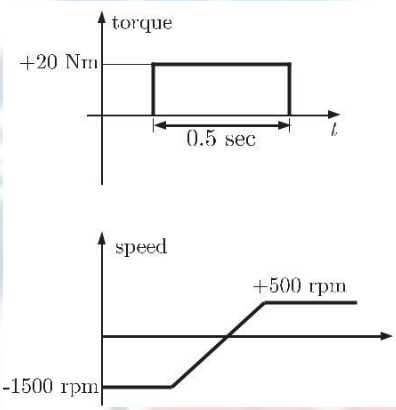

(A) 10 A
(B) 20 A
(C) 30 A
(D) 40 A

Q. 71 A single-phase half-controlled rectifier is driving a separately excited dc motor. The dc motor has a back emf constant of 0.5 V/rpm. The armature current is 5 A without any ripple. The armature resistance is 2 W. The converter is working from a 230 V, single-phase ac source with a firing angle of 30c. Under this operating condition, the speed of the motor will be

(A) 339 rpm (B) 359 rpm

(C) 366 rpm (D) 386 rpm

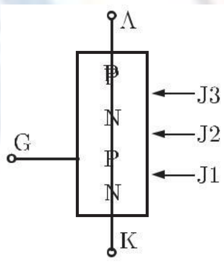
Q. 72 A variable speed drive rated for 1500 rpm, 40 Nm is reversing under no load. Figure shows the reversing torque and the speed during the transient. The moment of inertia of the drive is




(A) 0.048 kg-$m^2$ (B) 0.064 km-$m^2$

(C) 0.096 kg-$m^2$ (D) 0.128 kg-$m^2$

Q. 73 Figure shows a thyristor with the standard terminations of anode (A), cathode (K), gate (G) and the different junctions named J1, J2 and J3. When the thyristor is turned on and conducting



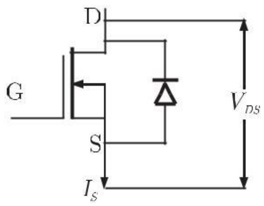

J1 and J2 are forward biased and J3 is reverse biased

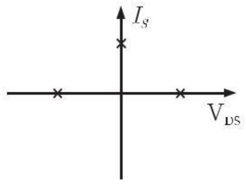
J1 and J3 are forward biased and J2 is reverse biased

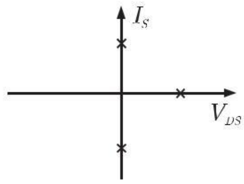
J1 is forward biased and J2 and J3 are reverse biased

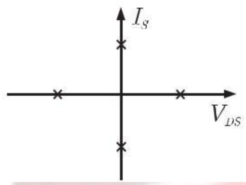
J1, J2 and J3 are all forward biased

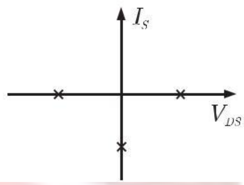
Q. 74 Figure shows a MOSFET with an integral body diode. It is employed as a power switching device in the ON and OFF states through appropriate control. The ON and OFF states of the switch are given on the $V_{DS}$ - $I_S$ plane by




(A) 


(B) 


(C) 


(D) 


Q. 75 The speed/torque regimes in a dc motor and the control methods suitable for the same are given respectively in List-II and List-I

| | **List-I** | | **List-II** |
|---|---|---|---|
| **P.** | Field Control | **1.** | Below base speed |
| **Q.** | Armature Control | **2.** | Above base speed |
| | | **3.** | Above base torque |
| | | **4.** | Below base torque |

**Codes:**

(A) P-1, Q-3 (B) P-2, Q-1

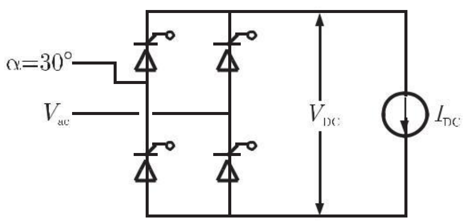
(C) P-2, Q-3 (D) P-1, Q-4

Q. 76 A fully controlled natural commutated 3-phase bridge rectifier is operating with a firing angle $\alpha = 30°$, The peak to peak voltage ripple expressed as a ratio of the peak output dc voltage at the output of the converter bridge is

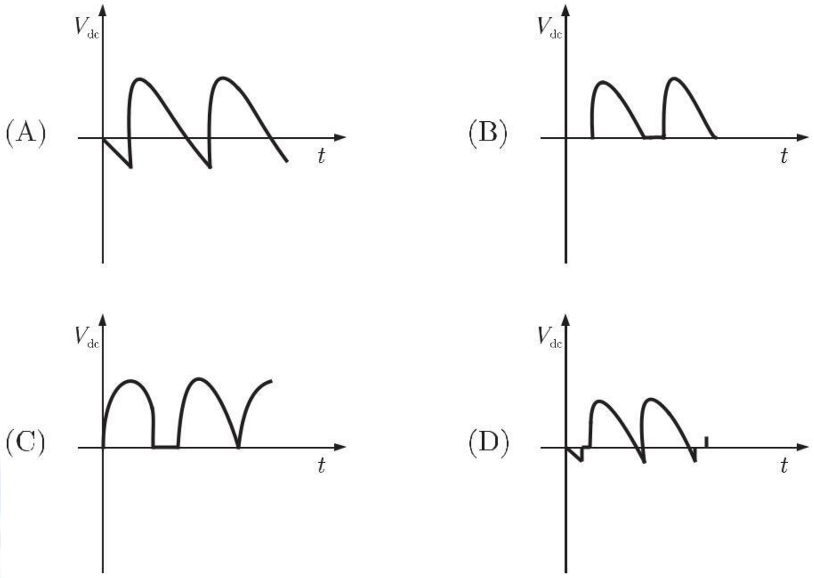
(A) 0.5 (B) $\sqrt{3}/2$

(C) $\left(1 - \frac{\sqrt{3}}{2}\right)$ (D) $\sqrt{3} - 1$

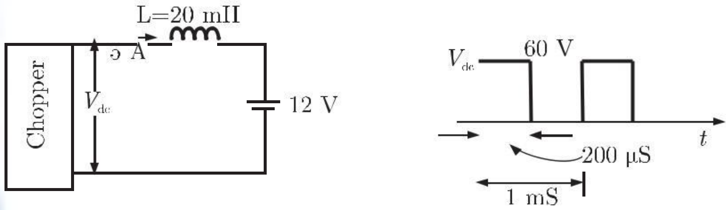
Q. 77 A phase-controlled half-controlled single-phase converter is shown in figure. The control angle $\alpha = 30°$




The output dc voltage wave shape will be as shown in



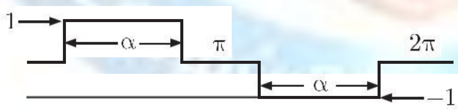

Q. 78 A chopper is employed to charge a battery as shown in figure. The charging current is 5 A. The duty ratio is 0.2. The chopper output voltage is also shown in the figure. The peak to peak ripple current in the charging current is




(A) 0.48 A (B) 1.2 A

(C) 2.4 A (D) 1 A

Q. 79 An inverter has a periodic output voltage with the output wave form as shown in figure




When the conduction angle *a* = 120c, the rms fundamental component of the output voltage is

(A) 0.78 V (B) 1.10 V

(C) 0.90 V (D) 1.27 V

Q. 80 With reference to the output wave form given in above figure , the output of the converter will be free from 5$^{th}$ harmonic when

(A) *a* = 72c

(B) *a* = 36c

(C) *a* = 150c

(D) *a* = 120c

Q. 81 An ac induction motor is used for a speed control application. It is driven from an inverter with a constant $V/f$ control. The motor name-plate details are as follows (no. of poles = 2)

$V$:415 V $V_{Ph}$:3 V $f$:50 Hz $N$:2850 rpm

The motor runs with the inverter output frequency set at 40 Hz, and with half the rated slip. The running speed of the motor is

(A) 2400 rpm (B) 2280 rpm

(C) 2340 rpm (D) 2790 rpm

# SOLUTION

Sol. 1 Option (C) is correct.

Given,

$$L = \frac{100}{p}\text{mH}$$

$$C = \frac{100}{p}\text{mF}$$

When the circuit is triggered by 10 ms pulse, the thyristor is short circuited and so, we consider

$$I_C = I_m \sin wt$$

Therefore, voltage stored across capacitor is

$$V_C = C1$$

8. $V_m$ ^1 - cos $wt$h

where $w$ is angular frequency obtained as

$$w = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{\frac{100}{p} \# 10^{-6}}} = p \# 10^4$$

So, $T = \frac{1}{f} = \frac{2p}{w} = 200$ ms

As $I_C = I_m \sin wt$ oscillates between -ve and -ve half cycle so, circuit is conducting for only half of cycle and thyristor is open after half cycle.

i.e., the conduction period = $\frac{T}{2}$ = 100 ms

Sol. 2 Option (D) is correct.

Given, the rated armature current

$$I_{a\,\text{rated}} = 20 \text{ A}$$

as rated armature voltage

$$V_{a\,\text{rated}} = 150 \text{ volt}$$

Also, for the armature, we have

$$L_a = 0.1 \text{ mH}, R_a = 1 \text{ W}$$

and $T = 50\%$ of $T_{rated}$ ^T " Torqueh

So, we get

32. = $6I_{a\,\text{rotated}}$@^0.5h = 10 A

= = $N_{\text{rated}}$ ,

$I_f = I_{f\,rated}$ " rated field current At

the rated conditions,

$$E = V - I_{a\,\text{rated}} R_a$$

$$= 150 - 20(1) = 130 \text{ volt}$$

For given torque, $V = E + I_a R_a = 130 + (10)(1) = 140$ V

Therefore, chopper output = 140 V

or, $D(200) = 140$

or, $D = \frac{140}{200} = 0.7$ ($D$ " duty cycle)

Sol. 3 Option (C) is correct.

Here, as the current from source of 12 V is the same as that pass through inductor. So, the peak to peak current ripple will be equal to peak to peak inductor current. Now, the peak to peak inductor current can be obtained as

$$I_L \text{ (Peak to Peak)} = \frac{V_s}{L} D\,T_s$$

where, $V_s$ " source voltage = 12 volt,

$L$ " inductance = 100mH = $10^{-4}$ H,

$D$ " Duty ration = 0.4,

$T_S$ " switching time period of MOSFET = $\frac{1}{f_S}$

and $f_s$" switching frequency = 250 kHz

Therefore, we get

$$I_{L\,(\text{Peak to Peak})} = \frac{12}{10^{-4}} \# 0.4 \# \frac{1}{250 \# 10^3} = 0.192 \text{ A}$$

This is the peak to peak source current ripple.

Sol. 4 Option (B) is correct.

Here, the average current through the capacitor will be zero. (since, it is a boost converter). We consider the two cases :

Case I : When MOSFET is ON

$$i_{c_1} = -i_0 \qquad (i_0 \text{ is output current})$$

(since, diode will be in cut off mode)

Case II : When MOSFET is OFF

Diode will be forward biased and so

$$i_{c_1} = I_s - i_0 \qquad (I_s \text{ is source current})$$

Therefore, average current through capacitor

$$I_{c,\,avg} = \frac{i_{c1} + I_{c2}}{2}$$

& $$0 = \frac{DT_s(-i_0) + (1 - D)T_s(I_s - i_0)}{2} \qquad (D \text{ is duty ratio})$$

Solving the equation, we get

$$I_s = \frac{i_0}{(1-D)} \qquad ....(1)$$

Since, the output load current can be given as

$$i_0 = \frac{V_0}{R} = \frac{V_s/1-D}{R} = \frac{12/0.6}{20} = 1\text{A}$$

Hence, from Eq. (1)

$$I_s = \frac{i_0}{1-D} = \frac{1}{0.6} = \frac{5}{3}\text{A}$$

Sol. 5 Option (D) is correct.

We consider the following two cases :

Case I : When $Q_1$, $Q_2$ ON

In this case the +ve terminal of $V_0$ will be at higher voltage. i.e. $V_0 > 0$ and so $i_0 > 0$ (i.e., it will be +ve). Now, when the $Q_1$, $Q_2$ goes to OFF condition we consider the second case.

Case II : When $Q_3$, $Q_4$ ON and $Q$ , $Q_2$ OFF :

In this condition, -ve terminal of applied voltage $V_0$ will be at higher potential i.e., $V_0 < 0$ and since, inductor opposes the change in current so, although the polarity of voltage $V_0$ is inversed, current remains same in inductor i.e. $I_0 > 0$.

This is the condition when conduction have been asked.

In this condition $V_0 > 0$, $I_0 > 0$ since, IGBT's can't conduct reverse currents therefore current will flow through $D_3$, $D_4$ until $I_D$ becomes negative.

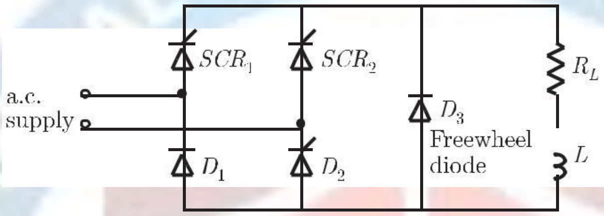
Thus, $D_3$ and $D_4$ conducts.

**Sol. 6** Option (D) is correct.

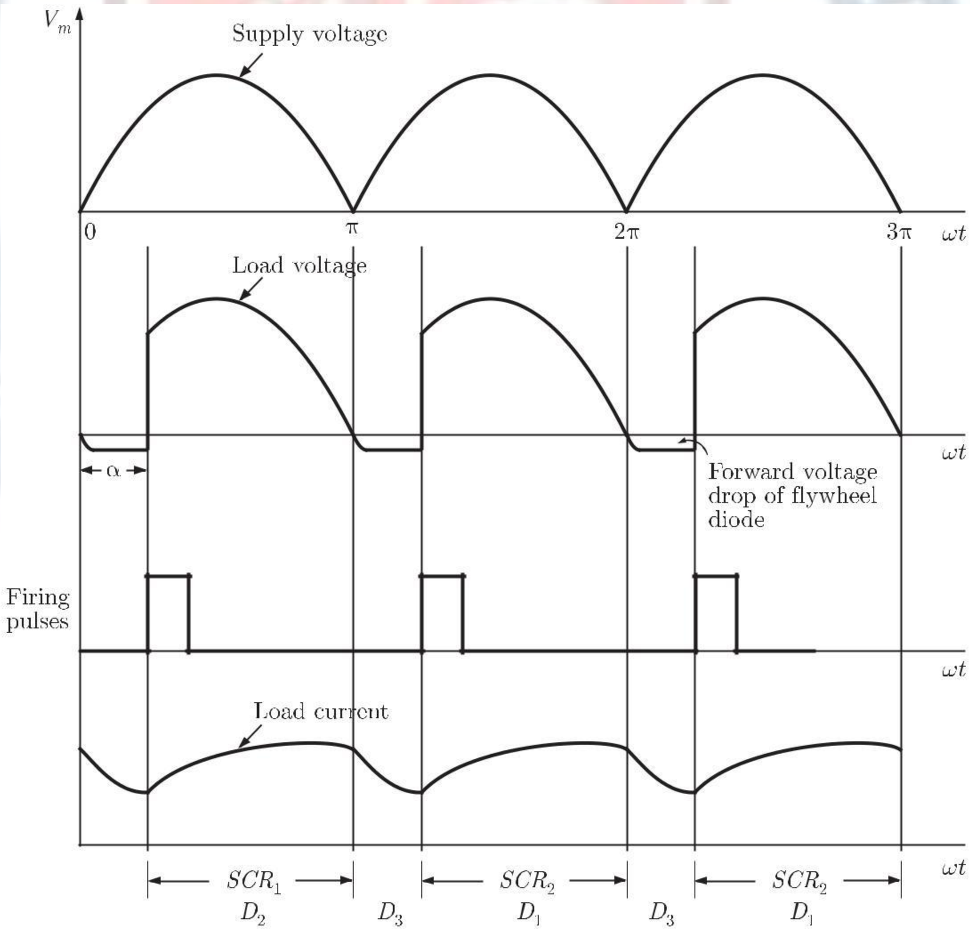
When $Q_3$, $Q_4$ is switched ON, initially due to the reverse current it remain in OFF state and current passes through diode. In this condition the voltage across $Q_3$ and $Q_4$ are zero as diodes conduct. Hence, it shows zero voltage switching during turn-ON

**Sol. 7** Option (D) is correct.

The circuit of a single-phase half controlled bridge rectifier with *RL* load and free wheel diode is shown as below.




The voltage current wave forms are shown in figure below.




We note that, for continuous load current, the flywheel diode conducts from *p* to *p* + *a* in a cycle. Thus, fraction of cycle that freewheel diode conducts is *a* / *p*.

Thus fraction of cycle that freewheel diode conducts is $a / p$.

Sol. 8 Option (B) is correct.
The latching current is higher than the holding current. Usually, latching current is taken two to three times the holding currents.

Sol. 9 Option (C) is correct.

$$I_S = I_0 + \frac{Ti_c}{2} = 5 + 0.8 = 5.8 \text{ A}$$

Sol. 10 Option (B) is correct.
For a three-phase bridge inverter, rms value of output line voltage is

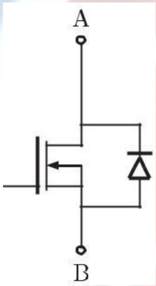
$$V_L = \frac{\sqrt{2}}{3} V_{dc} = \frac{\sqrt{2}}{3} \# 300 \qquad V_{dc} = 300 \text{ V}$$

15141.4 V

Sol. 11 Option (D) is correct.

$$P = 3 \# \frac{V_L^2}{R} = 3 \# \frac{(141.4)^2}{20} - 3 \text{ kW}$$

Sol. 12 Option (C) is correct.
Only option C allow bi direction power flow from source to the drive




Sol. 13 Option (C) is correct.
Once the SCR start conducting by an forward current, the gate has no control on it and the device can be brought back to the blocking state only by reducing the forward current to a level below that of holding current. This process of turn-off is called commutation. This time is known as the circuit turn-off time of an SCR.

Sol. 14 Option (A) is correct.
Maximum current through main thyristor

$$I_M (\text{max}) = I_0 + V_s \sqrt{\frac{C}{L}} = 10 + 200 \sqrt{\frac{0.1 \# 10^{-6}}{1 \# 10^{3}}} = 12 \text{ A}$$

Maximum current through auxiliary thyristor

$$I_A (\text{max}) = I_0 = 10 \text{ A}$$

Sol. 15 Option (A) is correct.
Output voltage of 3-phase bridge converter

$$V_0 = \frac{3\sqrt{3}}{p} V_{ph} \cos a$$

Maximum output

$$(V_0)_{max} = \frac{3\sqrt{3}}{p} V_{ph} \quad \cos a = 1$$

$$18 \frac{3\sqrt{3}}{p} \# \frac{400 \# \sqrt{2}}{\sqrt{3}} = 540.6 \text{ V}$$

Resistance of filter choke is 10 W, So

$$(V_0)_{max} = E + IR_{chock}$$
$$540.6 = 400 + I(10)$$
$$I \approx 14\text{ A}$$

**Sol. 16** Option (D) is correct.

$$\text{kVA rating} = \sqrt{3} V_L I_L = \sqrt{3} \times 400 \times \frac{\sqrt{6}}{\pi} \times 14$$
$$= 7.5\text{ kVA}$$

**Sol. 17** Option (A) is correct.

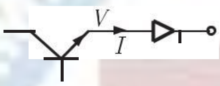
The figure shows a step down chopper circuit.

$$\therefore \quad V_{out} = DV_{in}$$

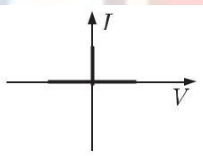
where, $D$ = Duty cycle and $D < 1$

**Sol. 18** Option (C) is correct.

Given figure as




The $I$ -$V$ characteristic are as




Since diode connected in series so $I$ can never be negative.

When current flows voltage across switch is zero and when current is zero than there may be any voltage across switch.

**Sol. 19** Option (A) is correct.

Given fully-controlled thyristor converter, when firing angle $\alpha = 0$, dc output voltage $V_{dc_0} = 300$ V

$$\text{If } \alpha = 60°, \text{ then } V_{dc} = ?$$

For fully-controlled converter

$$V_{dc_0} = \frac{2\sqrt{2} V_{dc_1}}{\pi} \cos\alpha$$

$$\therefore \quad \alpha = 0, V_{dc_0} = 300\text{ V}$$

$$300 = \frac{2\sqrt{2} V_{dc_1}}{\pi} \cos 0°$$

$$V_{dc_1} = \frac{300\pi}{2\sqrt{2}}$$

At $\alpha = 60°$, $V_{dc_2} = ?$

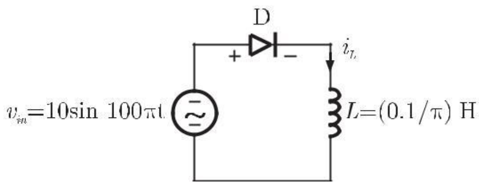
$$V_{dc_2} = \frac{2\sqrt{2}}{\pi} \times \frac{300\pi}{2\sqrt{2}} \cos 60° = 300 \times \frac{1}{2} = 150\text{ V}$$

**Sol. 20** Option (C) is correct.

SCR has the property that it can be turned ON but not OFF with a gate pulse,

So SCR is being considered to be a semi-controlled device.

Sol. 21 Option (D) is correct.




Current wave form for $i_L$

$$v_L = L\frac{di_L}{dt}$$

$$i_L = \frac{1}{2} \# v_L\, dt$$

for 0 < w$_t$ +p, $v_L = v_{in} = 10\sin wt = \frac{di_L}{dt}$

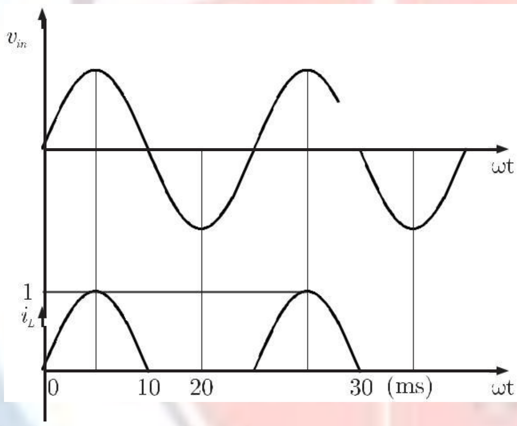
$$i_L = \frac{1}{2} \# v_L\, dt =- \cos 100pt + C$$

at 100p$t$ = p/2, $i_L = 0, C = 0$

$$i_L =- 100 \cos pt$$

$i_{L(peak)}$ = 1 Amp

for p < w$t$ $v_L = v_{in} = 0$

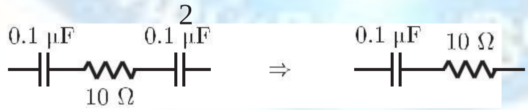



Sol. 22 Option (C) is correct.

In CSI let $T_3$ and $T_4$ already conducting at $t = 0$

At triggering $T_1$ and $T_2$, $T_3$ and $T_4$ are force cumulated.

Again at $t = \frac{t}{2}$, $T_1$ and $T_2$ are force cumulated. This completes a cycle.




Time constant t = $RC$ = 4 # 0.5 = 2 m sec

$$\text{Frequency } f = \frac{1}{t} = \frac{1}{2 \# 10^{-6}} = 500 \text{ kHz}$$

Sol. 23 Option (A) is correct.

duty ratio $T_M$ = 0.8

Maximum $\frac{dv}{dt}$ on $T_M$ = 50 V/msec

Minimum value of $C_1$ = ?

Given that current ripple through $L_0$ is negligible.

Current through $T_M = I_m$ = duty ratio# current

$I \quad 0.8 \# 12.5 = 10$ A

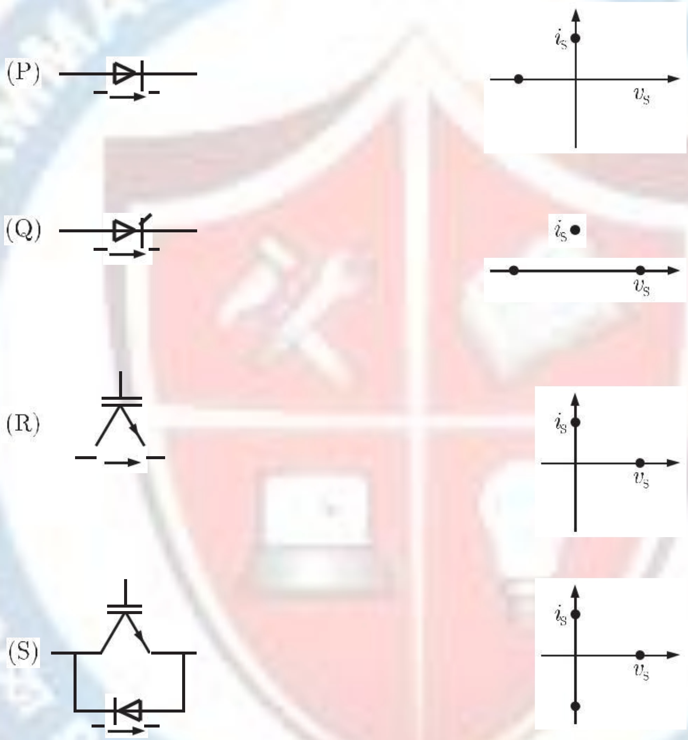
a $\quad I_m = C_1 \frac{dv}{dt}$

$10 = C_1 \# \frac{50}{10^{-6}}$

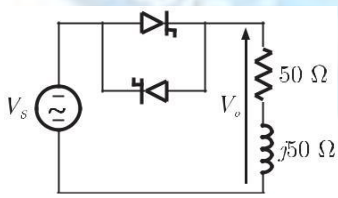
$C_1 = \frac{50}{10} \# 10^{-6} = 0.2$ mF

Sol. 24 Option (C) is correct.

Characteristics are as




Sol. 25 Option (A) is correct.




$R + jXL = 50 + 50j$

` $\quad \tan f = \frac{wL}{R} = \frac{50}{50} = 1$

f = 45c

so, firing angle ‘a’ must be higher the 45c, Thus for 0 < a < 45c, $V_0$ is uncontrollable.

Sol. 26 Option (D) is correct.

A 3-f voltage source inverter is operated in 180c mode in that case third harmonics are absent in pole voltage and line voltage due to the factor cos($n$p/6). so both are free from 3rd harmonic components.

Sol. 27 Option (B) is correct.

In this case
$$f = \frac{1}{T_{ON\,1} + T_{ON2}}$$

and,
$$D = \frac{T_{ON2}}{T_{ON\,1} + T_{ON2}}$$

Sol. 28 Option (B) is correct.

Given a = 30c, in a 1-f fully bridge converter

we know that,

$$\text{Power factor} = \text{Distortion factor} \# \cos a$$

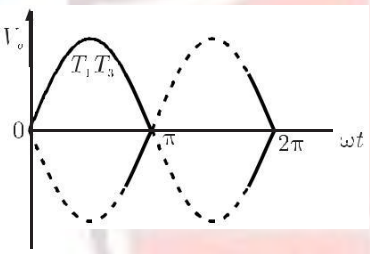
$$\text{D.f. (Distortion factor)} = I_{s\,(\text{fundamental})}/I_s = 0.9$$

$$\text{power factor} = 0.9 \# \cos 30c$$

$$= 0.78$$

Sol. 29 Option (A) is correct.

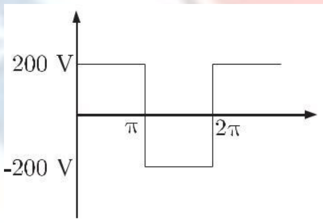
Output of this




Here the inductor makes $T_1$ and $T_3$ in ON because current passing through $T_1$ and $T_3$ is more than the holding current.

Sol. 30 Option (C) is correct.

Input is given as




Here load current does not have any dc component

Q Peak current occur at (p/w)

R
$$V_s = L\frac{di}{dt}$$

$$200 = 0.1 \# \frac{di}{dt}$$

Here
$$di = a\frac{p}{2p}kb\frac{1}{50}l = \frac{1}{100}$$

So
$$di_{(max)} = 200 \# \frac{1}{100} \# \frac{1}{0.1} = 20\text{ A}$$

Sol. 31 Option (B) is correct.

$$\text{Total rms current } I_a = \sqrt{\frac{2}{3}} \# 10 = 8.16 \text{ A}$$

$$\text{Fundamental current } I_{a1} = 0.78 \# 10 = 7.8 \text{ A}$$

$$\text{THD} = \sqrt{\frac{1}{DF^2} - 1}$$

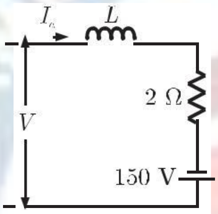
where

$$DF = \frac{I_{a1}}{I_a} = \frac{0.78 \# 10}{0.816 \# 10} = 0.955$$

$$` \quad \text{THD} = \sqrt{\left(\frac{1}{0.955}\right)^2 - 1} = 31\%$$

Sol. 32 Option (C) is correct.

Here for continuous conduction mode, by Kirchoff's voltage law, average load current




$$V - 2I_a + 150 = 0$$

$$I_a = \frac{V + 150}{2}$$

` $I_1 = 10$ A, So

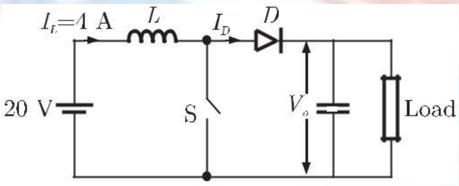
$$E = -130 \text{ V}$$

$$\frac{2V_m}{p} \cos a = -130$$

$$\frac{2 \# \sqrt{2} \# 230}{p} \cos a = -130c$$

$$F = 129c$$

Sol. 33 Option (C) is correct.




In the given diagram

when switch S is open $I_0 = I_L = 4$ A, $V_s = 20$ V

when switch S is closed $I_D = 0, V_0 = 0$ V

Duty cycle = 0.5 so average voltage is $\frac{V_s}{1 - d}$

$$\text{Average current} = \frac{0 + 4}{2} = 2 \text{ amp}$$

$$\text{Average voltage} = \frac{20}{1 - 0.5} = 40 \text{ V}$$

Sol. 34

Option (A) is correct.

Firing angle $a = 25c$

Overlap angle $m = 10c$

so, $I_0 = \frac{V_m}{wLs}[\cos a - \cos(a + m)]$

` $20 = \frac{230\sqrt{2}}{2p \# 50Ls}[\cos 25c - \cos(25c + 10c)]$

` $Ls = 0.0045$ H

$$V_0 = \frac{2V_m}{p}\cos a - \frac{wLsI_0}{p}$$

$$7. \frac{2 \# 230 \sqrt{2} \cos 25c}{3.14} - \frac{2 \# 3.14 \# 50 \# 4.5 \# 10^{-3} \# 20}{3.14}$$

$$8.\ 187.73 - 9 = 178.74c$$

$$\text{Displacement factor} = \frac{V_0 I_0}{V_s I_s} = \frac{178.25 \# 20}{230 \# 20} = 0.78$$

Sol. 35

Option (C) is correct.

Given that

$$P = 50 \# 1000 \text{ W}$$

$$V_d = 420$$

So $P = V_d \# I_d$

$$I_d = \frac{50 \# 1000}{420} = 119.05$$

$$\text{RMS value of thyristor current} = \frac{119.05}{\sqrt{3}} = 68.73$$

Sol. 36

Option (B) is correct.

Single phase full wave half controlled bridge converter feeds an Inductive load. The two SCRs in the converter are connected to a common dc bus. The converter has to have free wheeling diode because the converter does not provide for free wheeling for high values of triggering angles.

Sol. 37

Option (D) is correct.

If we connect the MOSFET with the VSI, but the six MOSFETs are connected in bridge configuration, in that case they also operated as constant current sources in the saturation region so this statement is false.

Sol. 38

Option (C) is correct.

Given that, total harmonic distortion

$$THD = \frac{\sqrt{V_{rms}^2 - V_1^2}}{V_1} \# 100$$

Pulse width is 150c

Here $V_{rms} = b\sqrt{\frac{150}{180}}\, l V_s = 0.91V_s$

$$V_1 = V_{rms(fundamental)} = \frac{0.4V_s}{p \# \sqrt{2}} \sin 75c = 0.8696V_s$$

$$THD = \sqrt{\frac{(0.91V_s)^2 - (0.87V_s)^2}{(0.87V_s)^2}} = 31.9\%$$

Sol. 39

Option (A) is correct.

When losses are neglected,

$$750 \# \frac{2p}{60} \frac{\# \# 2 \# 440}{p} \quad \cos a = K_m \#$$

Here back emf e with f is constant

$$e = V_0 = K_m w_m$$

$$440 = K_m \# \frac{1500 \# 2p}{60}$$

$$K_m = 2.8$$

$$\cos a = 0.37$$

at this firing angle

$$V_t = \frac{3\sqrt{2} \# 440}{p} \# (0.37) = 219.85 \text{ V}$$

$$I_a = \frac{1500}{440} = 34.090$$

$$I_{sr} = I_a \sqrt{2/3} = 27.83$$

$$\text{p.f.} = \frac{V_t I_s}{\sqrt{3} V_s I_{sr}} = 0.354$$

**Sol. 40** Option (D) is correct.

$$V_s = \frac{230}{4} = 57.5$$

Here charging current = $I$

$$V_m \sin q = 12$$

$$q_1 = 8.486 = 0.148 \text{ radian}$$

$$V_m = 81.317 \text{ V}$$

$$e = 12 \text{ V}$$

There is no power consumption in battery due to ac current, so average value of charging current.

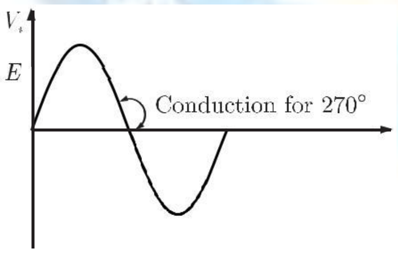
$$I_{av(charging)} = \frac{1}{2p \# 19.04} [2V_m \cos q_1 - e(p - 2q_1)]$$

$$= \frac{1}{2p \# 19.04} [2 \# V_m \# \cos q_1 - 12(p - 2q_1)]$$

$$= 1.059 \text{ W/A}$$

**Sol. 41** Option (C) is correct.

Conduction angle for diode is 270c as shown in fig.




**Sol. 42** Option ( ) is correct.

**Sol. 43** Option (C) is correct.

Here, $V_m$ = maximum pulse voltage that can be applied

so = 10 - 1 - 1 - 1 = 7 V

Here 1 V drop is in primary transistor side, so that we get 9V pulse on the secondary side. Again there are 1 V drop in diode and in gate cathode junction each.

$$I_{g\,max} = 150 \text{ mA}$$

So $$R = \frac{V_m}{\text{wmax}} = \frac{7}{150 \text{ mA}} = 46.67\,\text{W}$$

Sol. 44 Option (A) is correct.

We know that the pulse width required is equal to the time taken by $i_a$ to rise upto $i_L$

so, $$V_s = L\frac{di}{dt} + R_i (V_T . 0)$$

$$i_a = \frac{200}{1}[1 - e^{-t/0.15}]$$

Here also $t = T$, $i_a = i_L = 0.25$

$$0.25 = 200[1 - e^{-T/0.5}]$$

$$- = 1.876 \# 10^{-4} = 187.6 \text{ ms}$$

Width of pulse = 187.6 ms

Magnitude of voltage = 10 V

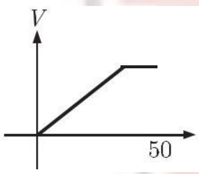
$V_{sec}$ rating of P.T. = 10# 187.6 ms

= 1867 mV-s is approx to 2000 mV-s

Sol. 45 Option (D) is correct.

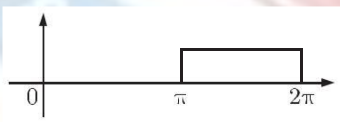
If we varying the frequency for speed control, $V/f$ should be kept as constant so that, minimum flux density ($B_m$) also remains constant

So, $$V = 4.44NB_m Af$$




Sol. 46 Option (D) is correct.

In first half cycle $D_1$ will conduct and $D_2$ will not and at q = 0 there is zero voltage. So current wave form is as following




Sol. 47 Option (B) is correct.

In the PWM inverter

$V_0$ = output voltage of inverter

$$V_0 = /_{n=1}^{3} \frac{4V_s}{np} \sin nd \sin n \text{ w } t \sin np/2$$

So the pulse width = 2$d$ = 144c

$$V_{01} = \frac{4V_s}{p} \sin 72c \sin wt$$

$$V_{03} = \frac{4V_s}{3p} \sin\text{^}3 \# 72c h \sin 3wt$$

so, $\left(\frac{V_{03}}{V_{01max}}\right) = \dfrac{\frac{4V_s}{3\pi} \times \sin(3 \times 72°)}{\frac{4V_s}{\pi}\sin 72°} = 19.61\%$

**Sol. 48** Option (C) is correct.

Given that

400 V, 50 Hz AC source, $\alpha = 60°, I_L = 10$ A

so,

$$\text{Input displacement factor} = \cos\alpha = 0.5$$

and, $\text{input power factor} = \text{D.F.} \times \cos\alpha$

$$\text{distortion factor} = \frac{I_{s(fundamental)}}{I_s} = \frac{\frac{4 \times 10}{\pi \times \sqrt{2}}\sin 60°}{10\sqrt{2/3}}$$

$$= 0.955$$

so, $\text{input power factor} = 0.955 \times 0.5 = 0.478$

**Sol. 49** Option (A) is correct.

We know that

$$T = RC \ln 2$$

So $C = \frac{T}{R \times 0.693} = \frac{100}{50 \times 0.693} = 2.88$ mF

**Sol. 50** Option (A) is correct.

Let we have

$$R_{solar} = 0.5\ \Omega, I_0 = 20 \text{ A}$$

so $V_s = 350 - 20 \times 0.5 = 340$ V

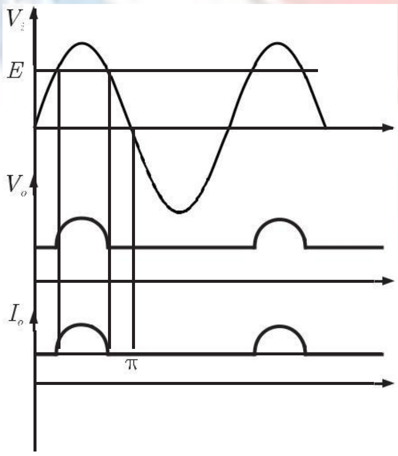
` $340 = \frac{3 \times 440 \times \sqrt{2}}{\pi}\cos\alpha$

$$\cos\alpha = 55°$$

So each thyristor will reverse biased for $180° - 55° = 125°$.

**Sol. 51** Option (C) is correct.

In this circuitry if SCR gets open circuited, than circuit behaves like a half wave rectifier.




So $I_{avg}$ = Average value of current

$$= \frac{1}{2\pi R}\int_{\theta_1}^{\pi-\theta_1}(V_m \sin\omega t - E)\,d\theta$$

z $I_{0(avg)} = \frac{1}{2\pi R}[2V_m \cos\theta - E(\pi - 2\theta_1)]$

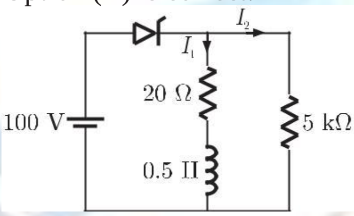
$= \frac{1}{2\pi \times 2}[2 \times (230 \times \sqrt{2})\cos\theta - 200(\pi - 2\theta_1)]$

$\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right) = \sin^{-1}\left(\frac{200}{230\sqrt{2}}\right) = 38° = 0.66 \text{ Rad}$

` $I_{0\,(avg)} = \frac{1}{2\pi \times 2}[2\sqrt{2} \times 230 \cos 38° - 200(\pi - 2 \times 0.66)]$

$= 11.9$ A

Sol. 52 Option (B) is correct.




In this given circuit minimum gate pulse width time= Time required by $i_a$ rise up to $i_L$

$i_2 = \frac{100}{5 \times 10^3} = 20$ mA

$i_1 = \frac{100}{20}[1 - e^{-40t}]$

` anode current $I = I_1 + I_2 = 0.02 + 5[1 - e^{-40t}]$

$0.05 = 0.05 + 5[1 - e^{-40t}]$

$1 - e^{-40t} = \frac{0.03}{5}$

$T = 150$ ms

Sol. 53 Option (B) is correct.

Given $I_L = 10$ A. So in the +ve half cycle, it will charge the capacitor, minimum time will be half the time for one cycle.

so min time required for charging

$= \frac{\pi}{\omega_0} = \pi\sqrt{LC} = 3.14 \times \sqrt{2 \times 10^{-3} \times 10^{-6}} = 140$ m sec

Sol. 54 Option (C) is correct.

Given $T_{on} = 140$ m sec

Average output $= \frac{T_{on}}{T_{total}} \times V$

$T_{total} = 1/f = \frac{1}{10^3} = 1$ msec

so average output $= \frac{140 \times 10^{-6}}{1 \times 10^{-3}} \times 250 = 35$ V

Sol. 55 Option (A) is correct.

The conduction loss v/s MOSFET current characteristics of a power MOSFET is best approximated by a parabola.

Sol. 56 Option (B) is correct.

In a 3-f bridge rectifier $V_{rms} = 400$ V, $f = 50$ Hz

This is purely resistive then

instantaneous voltage $V_0 = \sqrt{2}\,V_{rms} = 400\sqrt{2}$ V

**Sol. 57** Option (C) is correct.

A 3-f square wave (symmetrical) inverter contains only odd harmonics.

**Sol. 58** Option (A) is correct.

In Ideal condition we take voltage across the device is zero.

average power loss during switching = $\frac{VI}{2}(t_1 + t_2)$ (turn ON)

**Sol. 59** Option (C) is correct.

So in P thyristor blocks voltage in both polarities until gate is triggered and also in R transistor along with diode can do same process.

**Sol. 60** Option (C) is correct.

Duty ratio a = 0.5

here $T = \frac{1}{1 \# 10^{-3}} = 10^{-3}$ sec

$T_a = \frac{L}{R} = \frac{200 \text{ mH}}{5} = 40$ msec

$$\text{Ripple} = \frac{V_s}{R} = \frac{(1 - e^{-aT/T_s})(1 - e^{-(1-a)T/T_a})}{1 - e^{-T/T_s}} \text{G}$$

$$(TI)_{max} = \frac{V_s}{4fL} = \frac{100}{4 \# 10^3 \# 200 \# 10^{-3}}$$

$= 0.125$ A

**Sol. 61** Option (B) is correct.

We know that $V_{rms} = 230$ V

so, $V_m = 230 \# 2\sqrt{V}$

If whether a 1 90c

Then $V_{peak} = V_m \sin a = 230$

$230\sqrt{2} \sin a = 230$

$\sin a = \frac{1}{\sqrt{2}}$

angle a = 135c

**Sol. 62** Option (C) is correct.

$T_{st} = 15$ Nm

$T_L = 7$ Nm

a = 2 rad/sec$^2$

$T = Ia$

so $T = T_{st} - T_L = 8$ Nm

$I = \frac{8}{2} = 4$ kgm$^2$

**Sol. 63** Option (D) is correct.

When we use BJT as a power control switch by biasing it in cut-off region or in the saturation region. In the on state both the base emitter and base-collector junction are forward biased.

**Sol. 64** Option (A) is correct.

Peak Inverse Voltage (PIV) across full wave rectifier is $2V_m$

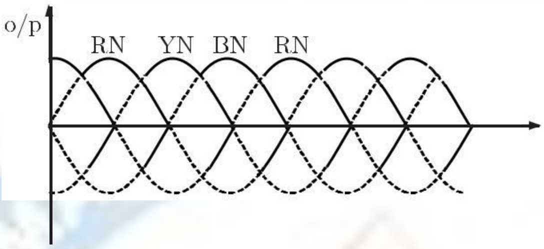
$V_m = 50\sqrt{2}$ V

so, PIV = $100\sqrt{2}$ V

Sol. 65 Option (D) is correct.

$$V_b = 12 \ ! \ 4 \text{ V}$$
$$V_{b\max} = 16 \text{ V}$$
$$V_{b\min} = 8 \text{ V}$$
$$\text{Required value of } R = \frac{V_b\,(\text{min})}{I_g} = \frac{8}{10 \# 10^{-3}} = 800 \text{ W}$$

Sol. 66 Option (C) is correct.




Ripple frequency = $3f = 3 \# 400 = 1200$ Hz

So from $V_0$ ripple frequency = 1200 Hz

Sol. 67 Option (C) is correct.

Given that $R = 0.15$ W

$I = 15$ A

So average power losses $= \frac{1}{(2p/w)} \int_0^{p/w} I^2 R\,dt$

$= \frac{w}{2p} \# 10^2 \# 0.15 \# p/w = 7.5$ W

Sol. 68 Option (D) is correct.

Output dc voltage across load is given as following

$$V_{dc} = \sqrt{2}\, V; \frac{1}{ap} \&(2p - a) + \frac{\sin 2a}{2} 0E^{\frac{1}{2}}$$

$$= \sqrt{2} \# 230 \; \sqrt{2} = \frac{1}{\frac{1}{4} \# p} a 2p - \frac{p}{4} k + b \frac{\sin p/2}{2} l1 G^{\frac{1}{2}} = 317.8 \text{ V}$$

$$\text{losses} = \frac{V_{dc}^2}{R} = \frac{(317.8)^2}{100} = 10100 \text{ W}$$

Sol. 69 Option (C) is correct.

$V_s = 100$ V, duty ratio= 0.8, $R = 10$ W

So average current through diode $= \frac{aV_s}{R} = \frac{0.8 \# 100}{10} = 8$ A

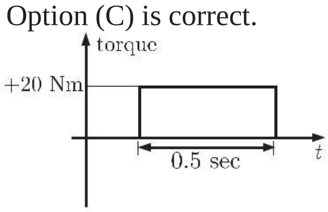
Sol. 70 Option (D) is correct.

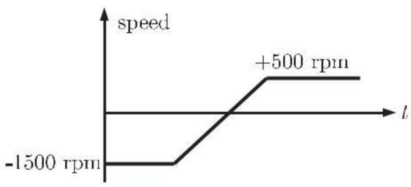
Peak current through $S_1$

$$I = I_0 + V_S \sqrt{C/L} = 20 + 200 \sqrt{\frac{2 \# 10^{-6}}{200 \# 10^{-6}}} = 40 \text{ A}$$

Sol. 71 Option ( ) is correct.

Sol. 72 Option (C) is correct.



so

$$= \left[\frac{500 - (-1500)}{0.560}\right] \times 2p = 418.67 \text{ rad/sec}^2$$

and $T = 40$ Nm

$BB = Ia$

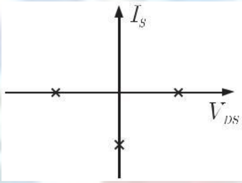
$$O = \frac{T}{a} = \frac{40}{418.67} = 0.096 \text{ kgm}^2$$

Sol. 73 Option (D) is correct.

When thyristor turned on at that time J2 junction will break. So J1, J2, J3 all are in forward bias.

Sol. 74 Option (D) is correct.

The ON-OFF state of switch is given on $V_{DS} - I_S$ plane as following




When $V_{DS}$ =+ ve, diode conducts and $I_S = 0$

$V_{DS}$ =- ve, diode opens, but $I_S = 0$, D "- ve potential.

Sol. 75 Option (B) is correct.

P. Field control-Above base speed

Q. Armature control-below base torque

Sol. 76 Option (A) is correct.

As we know in fully controlled rectifier.

$$V_{PP} = V_m - V_m \cos(p/6 + a) \qquad a\ a = 30c$$

or $$V_{PP} = V_m [1 - \cos(p/6 + 30c)]$$

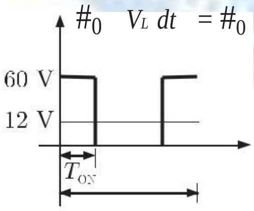
or $$\frac{V_{PP}}{V_m} = 0.5$$

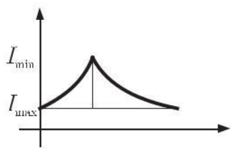
Sol. 77 Option ( ) is correct.

Sol. 78 Option (A) is correct.

In the chopper during turn on of chopper $V$ -$t$ area across $L$ is,

$$\int_0^{T_{on}} V_L\, dt = \int_0^{T_{on}} L\left(\frac{di}{dt}\right) dt = \int_{i_{min}}^{i_{max}} L\, di = L(i_{max} - i_{min}) = L(\Delta I)$$

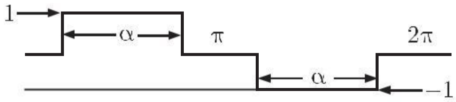


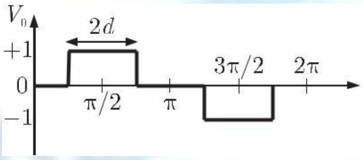




$V$ -$t$ are applied to '$L$' is $= (60 - 12)T_{on} = 48T_{on}$

So now volt area $\Delta I = \frac{48T_{on}}{L} = \frac{48 \times 0.2 \times 10^{-3}}{20 \times 10^{-3}} = 0.48$ A

Sol. 79 Option (A) is correct.




Output voltage $V_0 = \sum_{n=1,3,5}^{\infty} \left(\frac{4V_S}{n\pi}\right) \sin nd \, \sin n\omega t \, \sin n\pi/2$

$\therefore$ RMS value of fundamental component

$$V_{rms(\text{fundamental})} = \frac{4V_S}{\sqrt{2}\pi} \sin d \times 1$$

$\alpha = 120°$, $2d = 120°$ & $d = 60°$

$$V_{rms(\text{fundamental})} = \frac{4V_S}{\sqrt{2}\pi} \times \sin 60°$$

$$= 0.78V_S = 0.78 \text{ V}$$

Sol. 80 Option (A) is correct.

After removing $5^{th}$ harmonic

$$5d = 0, \pi, 2\pi$$

M Pulse width $= 2d = \alpha = 0, \frac{2\pi}{5}, \frac{4\pi}{5} = 0°, 72°, 144°$

Sol. 81 Option (C) is correct.

$$N_{Sa} = 3000 \text{ rpm}$$

$$N_a = 2850 \text{ rpm}$$

$$S_{FL} = \frac{3000 - 2850}{3000} = 0.05$$

where by $(V/f)$ control

$$N_{sb} = 3000\left(\frac{40}{50}\right) = 2400 \text{ rpm}$$

$\therefore$ $N_2$ = new running speed of motor

$$= 2400\left(1 - \frac{0.05}{2}\right) = 2340 \text{ rpm}$$

## POWER SYSTEMS

The three basic elements of electrical engineering are resistor, inductor and capacitor. The resistor consumes ohmic or dissipative energy whereas the inductor and capacitor store in the positive half cycle and give away in the negative half cycle of supply the magnetic field and electric field energies respectively. The ohmic form of energy is dissipated into heat whenever a current flows in a resistive medium. If $I$ is the current flowing for a period of $t$ seconds through a resistance of $R$ ohms, the heat dissipated will be $I^2Rt$ watt sec. In case of an inductor the energy is stored in the form of magnetic field. For a coil of $L$ henries and a current of $I$ amperes flowing, the energy stored is given by $\frac{1}{2}LI^2$. The energy is stored between the metallic plates of the capacitor in the form of electric field and is given by $\frac{1}{2}CV^2$ where $C$ is the capacitance and $V$ is the voltage across the plates.

We shall start with power transmission using 1-φ circuits and assume in all our analysis that the source is a perfect sinusoidal with fundamental frequency component only.

# Single Phase Transmission

Let us consider an inductive circuit and let the instantaneous voltage be

$$v = V_m \sin \omega t \qquad (1.1)$$

Then the current will be $i = I_m \sin(\omega t - \varphi)$ where $\varphi$ is the angle by which the current lags the voltage (Fig. 1.1).

The instantaneous power is given by

$$\begin{aligned} p = vi &= V_m \sin \omega t \, . \, I_m \sin(\omega t - \varphi) \\ &= V_m I_m \sin \omega t \sin(\omega t - \varphi) \qquad (1.2) \\ &= \frac{V_m I_m}{2} [\cos \varphi - \cos(2\omega t - \varphi)] \end{aligned}$$

The value of '$p$' is positive when both $v$ and $i$ are either positive or negative and represents the rate at which the energy is being consumed by the load. In this case the current flows in the direction of voltage drop. On the other hand, power is negative when the current flows in the direction of voltage rise which means that the energy is being transferred from the load into the network to which it is connected. If the circuit is purely reactive the voltage and current will be 90° out of phase and hence the power will have equal positive and negative half cycles and the average value will be zero. From equation (1.2) the power pulsates around the average power at double the supply frequency.

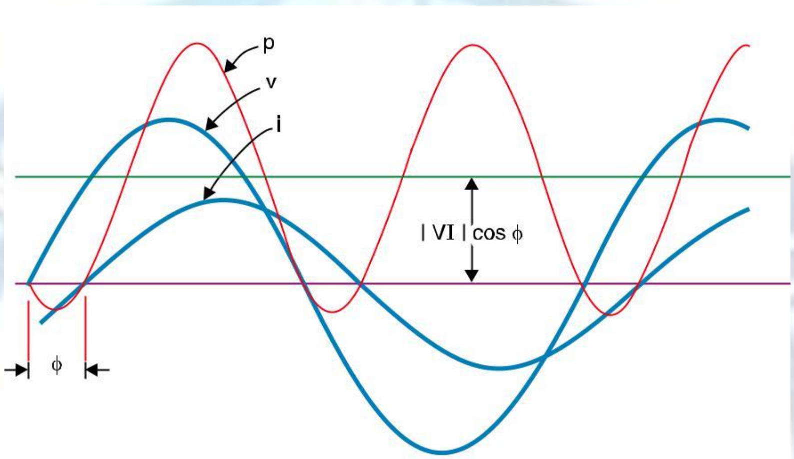



**Fig. 1.1** Voltage, current and power in single phase circuit.

Equation (1.2) can be rewritten as

$$p = VI \cos \varphi \,(1 - \cos 2\omega t) - VI \sin \varphi \sin 2\omega t \qquad (1.3)$$

I II

We have decomposed the instantaneous power into two components (Fig. 1.2).

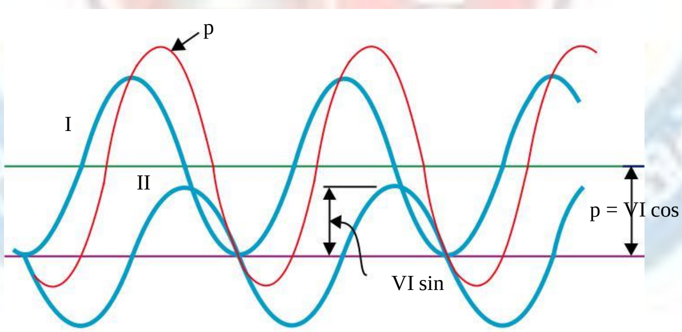



**Fig. 1.2** Active, reactive and total power in a single phase circuit.

(*i*) The component $p$ marked $I$ pulsates around the same average power $VI \cos \varphi$ but never goes negative as the factor $(1 - \cos 2\omega t)$ can at the most become zero but it will never go negative. We define this average power as the real power $P$ which physically means the useful power being transmitted.

(*ii*) The component marked II contains the term $\sin \varphi$ which is negative for capacitive cir-cuit and is positive for inductive circuit. This component pulsates and has zero as its average value. This component is known as reactive power as it travels back and forth on the line without doing any useful work.

Equation (1.3) is rewritten as

$$p = P(1 - \cos 2\omega t) - Q \sin 2\omega t \qquad (1.4)$$

Both $P$ and $Q$ have the same dimensions of watts but to emphasise the fact that $Q$ represents a nonactive power, it is measured in terms of voltamperes reactive *i.e.*, *V Ar*.

The term $Q$ requires more attention because of the interesting property of sin φ which is – ve for capacitive circuits and is +ve for inductive circuits. This means a capacitor is a generator of positive reactive *V Ar*, a concept which is usually adopted by power system engineers. So it is better to consider a capacitor supplying a lagging current rather than taking a leading current (Fig. 1.3).

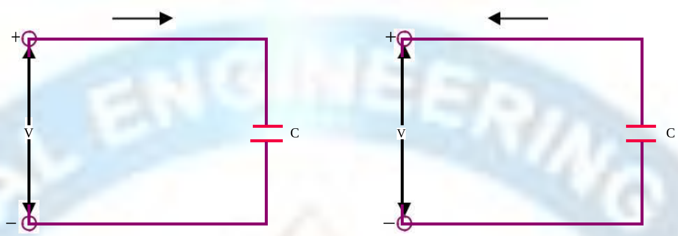



**Fig. 1.3** V-I relations in a capacitor.

Consider a circuit is which an inductive load is shunted by a capacitor. If $Q$ is the total reactive power requirement of the load and $Q'$ is the reactive power that the capacitor can generate, the net reactive power to be transmitted over the line will be $(Q - Q')$. This is the basic concept of synchronous phase modifiers for controlling the voltage of the system. The phase modifier controls the flow of reactive power by suitable excitation and hence the voltage is controlled. The phase modifier is basically a synchronous machine working as a capacitor when overexcited and as an inductor when underexcited.

It is interesting to consider the case when a capacitor and an inductor of the same reactive power requirement are connected in parallel (Fig. 1.4).

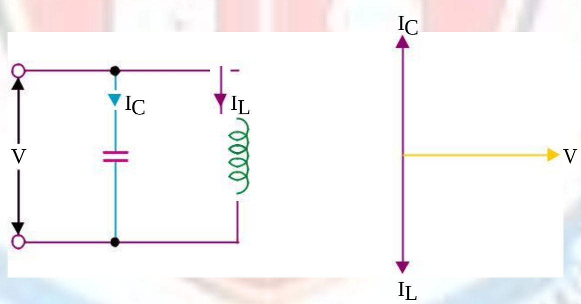



**Fig. 1.4** Power flow in L-C circuit.

The currents $I_L$ and $I_C$ are equal in magnitude and, therefore, the power requirement is same. The line power will , therefore, be zero. Physically this means that the energy travels back and forth between the capacitor and the inductor. In one half cycle at a particular moment the capacitor is fully charged and the coil has no energy stored. Half a voltage cycle later the coil stores maximum energy and the capacitor is fully discharged.

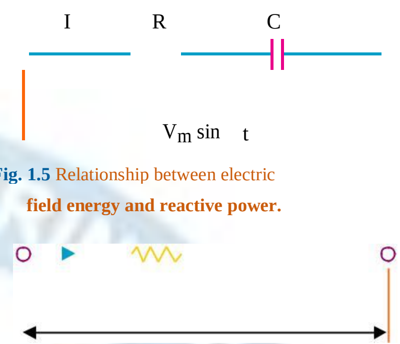



**Fig. 1.5** Relationship between electric **field energy and reactive power.**

The following example illustrates the relationship between the reactive power and the electric field energy stored by the capacitor. Consider an *RC* circuit (Fig. 1.5).

From Fig. 1.5

$$I = \frac{V}{\sqrt{R^2 + (1/\omega C)^2}} = \frac{V\omega C}{\sqrt{R^2\omega^2C^2 + 1}} \tag{1.5}$$

and if voltage is taken as reference *i.e.*, $v = V_m \sin \omega t$ the current

$$i = I_m \sin(\omega t + \varphi)$$

$$\therefore \qquad i = \frac{V_m \omega C}{\sqrt{R^2\omega^2C^2 + 1}} \cdot \sin(\omega t + \varphi) \tag{1.6}$$

where $$\sin\varphi = \frac{I/\omega C}{\sqrt{I^2R^2 + (I/\omega C)^2}} = \frac{1}{\sqrt{R^2\omega^2C^2 + 1}} \tag{1.7}$$

Now $$\text{reactive power } Q = VI \sin\varphi \tag{1.8}$$

Substituting for $I$ and $\sin\varphi$, we have

$$Q = V \cdot \frac{V\omega C}{\sqrt{R^2\omega^2C^2 + 1}} \cdot \frac{1}{\sqrt{R^2\omega^2C^2 + 1}} = \frac{V^2\omega C}{R^2\omega^2C^2 + 1} \tag{1.9}$$

$$\therefore \quad \text{Reactive power} = \frac{V^2\omega C}{R^2\omega^2C^2 + 1}$$

Now this can be related with the electric energy stored by the capacitor. The energy stored by the capacitor.

$$W = \tfrac{1}{2}Cv^2 \tag{1.10}$$

Now $$v = \frac{1}{C}\int i\,dt = \frac{1}{C}\,\frac{V_m \omega C}{\sqrt{R^2\omega^2C^2 + 1}}\left(-\frac{\cos(\omega t + \varphi)}{\omega}\right) = -\frac{V_m \cos(\omega t + \varphi)}{\sqrt{R^2\omega^2C^2 + 1}} \tag{1.11}$$

$$\therefore \qquad W = \tfrac{1}{2}C \cdot \frac{V_m^2 \cos^2(\omega t + \varphi)}{R^2\omega^2C^2 + 1} = \frac{V_m^2 C \cos^2(\omega t + \varphi)}{R^2\omega^2C^2 + 1} \tag{1.12}$$

**3 phase**

Assuming that the system is balanced which means that the three-phase voltages and currents are balanced. These quantities can be expressed mathematically as follows:

$$V_a = V_m \sin \omega t$$
$$V_b = V_m \sin (\omega t - 120°)$$
$$V_c = V_m \sin (\omega t + 120°) \quad (1.14)$$
$$i_a = I_m \sin (\omega t - \varphi)$$
$$i_b = I_m \sin (\omega t - \varphi - 120°)$$
$$i_c = I_m \sin (\omega t - \varphi + 120°)$$

The total power transmitted equals the sum of the individual powers in each phase.

$$(A) \quad = V_a i_a + V_b i_b + V_c i_c$$
$$V_m \sin \omega t\, I_m \sin (\omega t - \varphi) + V_m \sin (\omega t - 120°)\, I_m \sin (\omega t - 120° - \varphi)$$
$$V_m I_m \sin (\omega t + 120°) \sin (\omega t + 120° - \varphi)$$
$$VI[2 \sin \omega t \sin (\omega t - \varphi) + 2 \sin (\omega t - 120°) \sin (\omega t - 120° - \varphi)$$
$$2 \sin (\omega t + 120°) \sin (\omega t + 120° - \varphi)]$$
$$VI[\cos \varphi - \cos (2\omega t - \varphi) + \cos \varphi - \cos (2\omega t - 240° - \varphi)$$
$$\cos \varphi - \cos (2\omega t + 240° - \varphi)]$$
$$= 3VI \cos \varphi \quad (1.15)$$

This shows that the total instantaneous 3-phase power is constant and is equal to three times the real power per phase *i.e.*, $p = 3P$, where $P$ is the power per phase.

In case of single phase transmission we noted that the instantaneous power expression contained both the real and reactive power expression but here in case of 3-phase we find that the instantaneous power is constant. This does not mean that the reactive power is of no importance in a 3-phase system.

For a 3-phase system the sum of three currents at any instant is zero, this does not mean that the current in each phase is zero. Similarly, even though the sum of reactive power instantaneously in 3-phase system is zero but in each phase it does exist and is equal to $VI$ sin

(EE) and, therefore, for 3-φ the reactive power is equal to $Q_{3\varphi} = 3VI \sin \varphi = 3Q$, where $Q$ is the reactive power in each phase. It is to be noted here that the term $Q_{3\varphi}$ makes as little physical sense as would the concept of three phase currents $I_{3\varphi} = 3I$. Nevertheless the reactive power in a 3-phase system is expressed as $Q_{3\varphi}$. This is done to maintain symmetry between the active and reactive powers.

Consider a single phase network and let

$$V = |V|e^{j\alpha} \text{ and } I = |I|e^{j\beta} \quad (1.16)$$

where α and β are the angles that $V$ and $I$ subtend with respect to some reference axis. We calculate the real and reactive power by finding the product of $V$ with the conjugate of $I$ *i.e.*

The quantity $S$ is called the complex power. The magnitude of $S$ = $P^{2} + Q^{2}$ is termed as the apparent power and its unit is volt-amperes and the larger units are kVA or MVA. The practical significance of apparent power is as a rating unit of generators and transformers, as the apparent power rating is a direct indication of heating of machine which determines the rating of the machines. It is to be noted that $Q$ is positive when $(\alpha - \beta)$ is positive *i.e.* when $V$ leads $I$ *i.e.* the load is inductive and $Q$ is –ve when $V$ lags $I$ *i.e.* the load is capacitive. This agrees with the normal convention adopted in power system *i.e.* taking $Q$ due to an inductive load as +ve and $Q$ due to a capacitive load as negative. Therefore, to obtain proper sign for reactive power it is necessary to find out $VI^*$ rather than $V^*I$ which would reverse the sign for

*(S)* as

$$V^*I = |V|e^{-j\alpha}\ |I|e^{j\beta} = |V|\ |I|e^{-j(\alpha-\beta)}$$

$$(S)\ \ |V|\ |I| \cos(\alpha - \beta) - j|V|\ |I| \sin(\alpha - \beta)$$

$$(T)\ \ |V|\ |I| \cos\varphi - j|V|\ |I| \sin\varphi$$

$$= P - jQ \qquad (1.19)$$

**Load Charactersics**

## LOAD CHARACTERISTICS

In an electric power system it is difficult to predict the load variation accurately. The load devices may vary from a few watt night lamps to multi-megawatt induction motors. The following category of loads are present in a system:

| | |
|---|---|
| (*i*) Motor devices | 70% |
| (*ii*) Heating and lighting equipment | 25% |
| (*iii*) Electronic devices | 5% |

The heating load maintains constant resistance with voltage change and hence the power varies with $(\text{voltage})^2$ whereas lighting load is independent of frequency and power consumed varies as $V^{1.6}$ rather than $V^2$.

For an impedance load *i.e.* lumped load

$$P = \frac{V^2}{R^2 + (2\pi f L)^2} . R$$

and

$$Q = \frac{V^2}{R^2 + (2\pi f L)^2} . (2\pi f L) \qquad (1.20)$$

From this it is clear that both $P$ and $Q$ increase as the square of voltage magnitude. Also with increasing frequency the active power $P$ decreases whereas $Q$ increases.

The above equations are of the form

$$P = P[f, |V|]$$

$$Q = Q[f, |V|] \qquad (1.21)$$

Composite loads which form a major part of the system load are also function of voltage and frequency and can in general be written as in equation (1.21). For this type of load, however, no direct relationship is available as for impedance loads. For a particular composite load an empirical relation between the load, and voltage and frequency can be obtained. Normally we are concerned with incremental changes in $P$ and $Q$ as a function of incremental changes in $| V |$ and $f$. From equation (1.21)

$$P \simeq \frac{\partial P}{\partial |V|} . |V| + \frac{\partial P}{\partial f} . f$$

and

$$Q \simeq \frac{\partial Q}{\partial |V|} . |V| + \frac{\partial Q}{\partial f} . f \qquad (1.22)$$

The four partial derivatives can be obtained empirically. However, it is to be remembered that whereas an impedance load $P$ decreases with increasing frequency, a composite load will increase. This is because a composite load mostly consists of induction motors which always will experience increased load, as frequency or speed increases.

The need for ensuring a high degree of service reliability in the operation of modern electric systems can hardly be over-emphasized. The supply should not only be reliable but should be of good quality *i.e.*, the voltage and frequency should vary within certain limits, otherwise operation of the system at subnormal frequency and lower voltage will result in serious problems especially in case of fractional horse-power motors. In case of refrigerators reduced frequency results into reduced efficiency and high consumption as the motor draws larger current at reduced power factor. The system operation at subnormal frequency and voltage leads to the loss of revenue to the suppliers due to accompanying reduction in load demand. The most serious effect of subnormal frequency and voltage is on the operation of the thermal power station auxiliaries. The output of the auxiliaries goes down as a result of which the generation is also decreased. This may result in complete shut-down of the plant if corrective measures like load shedding is not resorted to. Load shedding is done with the help of under-frequency relays which automatically disconnect blocks of loads or sectionalise the transmission system depending upon the system requirements.

Per unit system

In a large interconnected power system with various voltage levels and various capacity equipments it has been found quite convenient to work with per unit (p.u.) system of quantities for analysis purposes rather than in absolute values of quantities. Sometimes per cent values are used instead of p.u. but it is always convenient to use p.u. values. The p.u. value of any quantity is defined as

$$\frac{\text{the actual value of the quantity (in any unit)}}{\text{the base or reference value in the same unit}}$$

In electrical engineering the three basic quantities are voltage, current and impedance. If we choose any two of them as the base or reference quantity, the third one automatically will have a base or reference value depending upon the other two *e.g.*, if $V$ and $I$ are the base voltage and current in a system, the base impedance of the system is fixed and is given by

$$Z = \frac{V}{I}$$

The ratings of the equipments in a power system are given in terms of operating voltage and the capacity in kVA. Therefore, it is found convenient and useful to select voltage and $kVA$ as the base quantities. Let $V_b$ be the base voltage and $kVA_b$ be the base kilovoltamperes, then

$$V_{p.u.} = \frac{V_{actual}}{V_b}$$

$$\text{The base current} = \frac{kVA_b \times 1000}{V_b}$$

$$\therefore \quad \text{p.u. current} = \frac{\text{Actual current}}{\text{Base current}} = \frac{\text{Actual current}}{kVA_b \times 1000} \times V_b$$

$$\text{Base impedance} = \frac{\text{Base voltage}}{\text{Base current}}$$

$$= \frac{V_b^2}{kVA_b \times 1000}$$

$$\text{p.u. impedance} = \frac{\text{Actual impedance}}{\text{Base impedance}}$$

$$= \frac{Z \cdot kVA_b \times 1000}{V_b^2} = \frac{Z \cdot MVA_b}{(kV_b)^2}$$

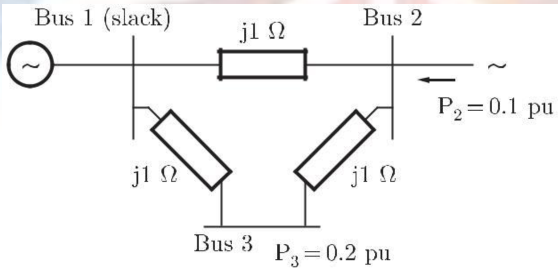
Q. 1 For a power system network with $n$ nodes, $Z_{33}$ of its bus impedance matrix is $j0.5$ per unit. The voltage at node 3 is $1.3\angle -10^\circ$ per unit. If a capacitor having reactance of $-j3.5$ per unit is now added to the network between node 3 and the reference node, the current drawn by the capacitor per unit is

(A) $0.325\angle -100^\circ$ (B) $0.325\angle 80^\circ$

(C) $0.371\angle -100^\circ$ (D) $0.433\angle 80^\circ$

**Statement for Linked Answer Questions: 2 and 3**

In the following network, the voltage magnitudes at all buses are equal to 1 pu, the voltage phase angles are very small, and the line resistances are negligible. All the line reactances are equal to $j1\ \Omega$




Q. 2 The voltage phase angles in rad at buses 2 and 3 are

(A) $\theta_2 = -0.1$, $\theta_3 = -0.2$ (B) $\theta_2 = 0$, $\theta_3 = -0.1$

(C) $\theta_2 = 0.1$, $\theta_3 = 0.1$ (D) $\theta_2 = 0.1$, $\theta_3 = 0.2$

Q. 3 If the base impedance and the line-to line base voltage are 100 ohms and 100 kV respectively, then the real power in MW delivered by the generator connected at the slack bus is

(A) -10 (B) 0

(C) 10 (D) 20

Q. 4 The bus admittance matrix of a three-bus three-line system is

$$Y = j\begin{bmatrix} -13 & 10 & 5 \\ 10 & -18 & 10 \\ 5 & 10 & -13 \end{bmatrix}$$

If each transmission line between the two buses is represented by an equivalent $\pi$ network, the magnitude of the shunt susceptance of the line connecting bus 1 and 2 is

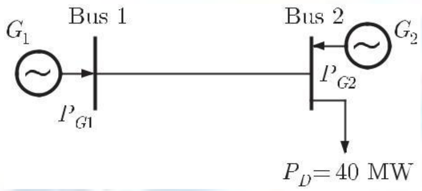
(A) 4 (B) 2

(C) 1 (D) 0

Q. 5 A two-phase load draws the following phase currents : $i_1(t) = I_m \sin(wt - f_1)$, $i_2(t) = I_m \cos(wt - f_2)$. These currents are balanced if $f_1$ is equal to.

(A) $-f_2$
(B) $f_2$
(C) $(p/2 - f_2)$
(D) $(p/2 + f_2)$

Q. 6 The figure shows a two-generator system applying a load of $P_D = 40$ MW, connected at bus 2.




The fuel cost of generators $G_1$ and $G_2$ are :
$C_1(P_{G1}) = 10000$ Rs/MWh and $C_2(P_{G2}) = 12500$ Rs/MWh and the loss in the line is $P_{loss\,(pu)} = 0.5 P_{G1\,(pu)}^2$, where the loss coefficient is specified in pu on a 100 MVA base. The most economic power generation schedule in MW is

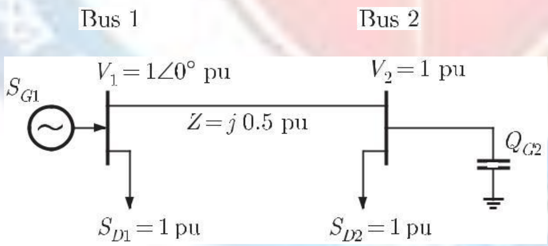
(A) $P_{G1} = 20, P_{G2} = 22$
(B) $P_{G1} = 22, P_{G2} = 20$
(C) $P_{G1} = 20, P_{G2} = 20$
(D) $P_{G1} = 0, P_{G2} = 40$

Q. 7 The sequence components of the fault current are as follows : $I_{positive} = j1.5$ pu, $I_{negative} = -j0.5$ pu, $I_{zero} = -j1$ pu. The type of fault in the system is

(A) *LG*
(B) *LL*
(C) *LLG*
(D) *LLLG*

---

Q. 8 For the system below, $\boldsymbol{S}_{D1}$ and $\boldsymbol{S}_{D2}$ are complex power demands at bus 1 and bus 2 respectively. If $|\boldsymbol{V}_2| = 1$ pu, the VAR rating of the capacitor ($\boldsymbol{Q}_{G2}$) connected at bus 2 is

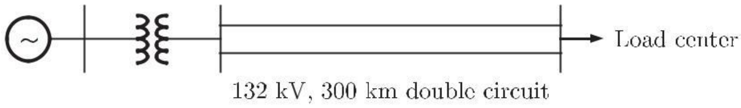


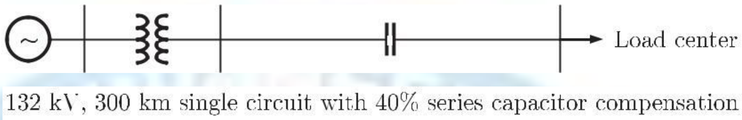

(A) 0.2 pu
(B) 0.268 pu
(C) 0.312 pu
(D) 0.4 pu

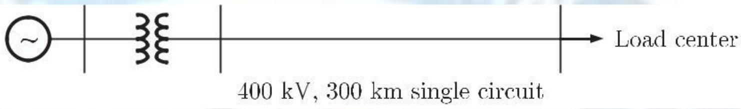
Q. 9 A cylinder rotor generator delivers 0.5 pu power in the steady-state to an infinite bus through a transmission line of reactance 0.5 pu. The generator no-load voltage is 1.5 pu and the infinite bus voltage is 1 pu. The inertia constant of the generator is 5 MW-s/MVA and the generator reactance is 1 pu. The critical clearing angle, in degrees, for a three-phase dead short circuit fault at the generator terminal is

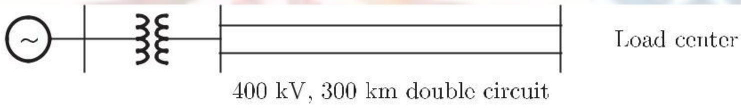
(A) 53.5
(B) 60.2
(C) 70.8
(D) 79.6

Q. 10 A nuclear power station of 500 MW capacity is located at 300 km away from a load center. Select the most suitable power evacuation transmission configuration among the following options

(A)



(B)



(C)



(D)



12. 11 A negative sequence relay is commonly used to protect

(A) an alternator (B) an transformer

(C) a transmission line (D) a bus bar

J. 12 For enhancing the power transmission in along EHV transmission line, the most preferred method is to connect a

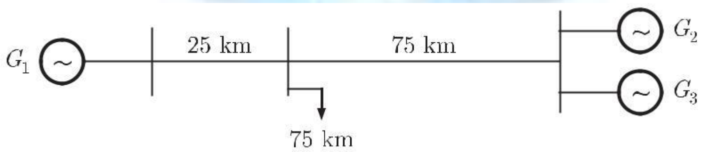
T. Series inductive compensator in the line

U. Shunt inductive compensator at the receiving end

V. Series capacitive compensator in the line

W. Shunt capacitive compensator at the sending end

Q. 13 A load center of 120 MW derives power from two power stations connected by 220 kV transmission lines of 25 km and 75 km as shown in the figure below. The three generators $G_1$, $G_2$ and $G_3$ are of 100 MW capacity each and have identical fuel cost characteristics. The minimum loss generation schedule for supplying the 120 MW load is




(A) $P_1 = 80$ MW + losses, $P_2 = 20$ MW, $P_3 = 20$ MW

(B) $P_1 = 60$ MW, $P_2 = 30$ MW + losses, $P_3 = 30$ MW

$P_1 = 40$ MW | $P_1 = 30$ MW + losses

(C) $P_2 = 40$ MW | (D) $P_2 = 45$ MW

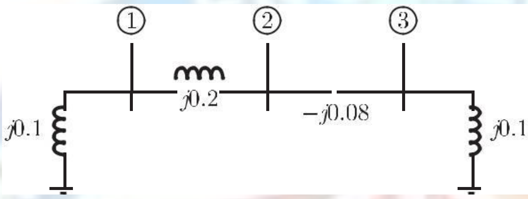
$P_3 = 40$ MW + losses | $P_3 = 45$ MW

Q. 14 The direct axis and quadrature axis reactances of a salient pole alternator are 1.2 p.u and 1.0 p.u respectively. The armature resistance is negligible. If this alternator is delivering rated kVA at upf and at rated voltage then its power angle is

(A) 30c (B) 45c

(C) 60c (D) 90c

Q. 15 A three – bus network is shown in the figure below indicating the p.u. impedance of each element.



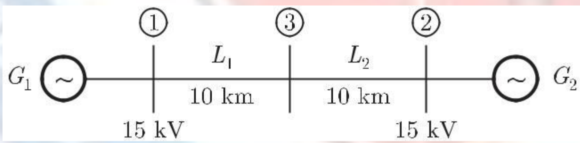

The bus admittance matrix, $Y$ -bus, of the network is

(A) $j\begin{bmatrix} 0.3 & -0.2 & 0 \\ -0.2 & 0.12 & 0.08 \\ 0 & 0.08 & 0.02 \end{bmatrix}$ (B) $j\begin{bmatrix} -15 & 5 & 0 \\ 5 & 7.5 & -12.5 \\ 0 & -12.5 & 2.5 \end{bmatrix}$

(C) $j\begin{bmatrix} 0.1 & 0.2 & 0 \\ 0.2 & 0.12 & -0.08 \\ 0 & -0.08 & 0.10 \end{bmatrix}$ (D) $j\begin{bmatrix} -10 & 5 & 0 \\ 5 & 7.5 & 12.5 \\ 0 & 12.5 & -10 \end{bmatrix}$

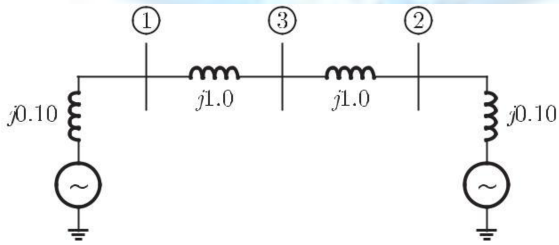
**Statement For Linked Answer Questions : 13 & 14**

Q. 16 Two generator units $G_1$ and $G_2$ are connected by 15 kV line with a bus at the mid-point as shown below

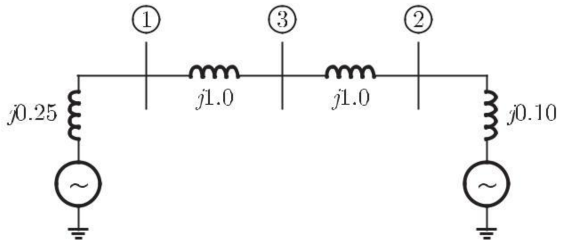



$G_1$ = 250 MVA, 15 kV, positive sequence reactance $X_{G1}$ = 25% on its own base $G_2$ = 100 MVA, 15 kV, positive sequence reactance $X_{G2}$ = 10% on its own base $L_1$ and $L_2$ = 10 km, positive sequence reactance $X_L$ = 0.225 W/km

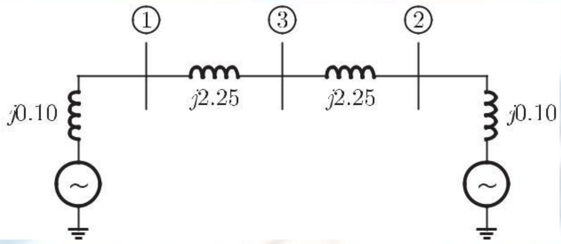
(A)



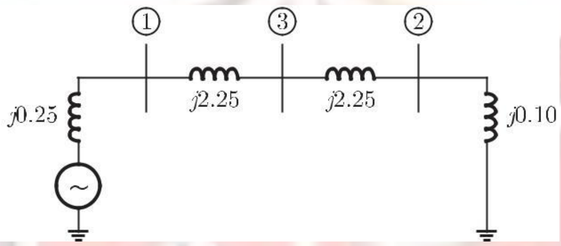
(B)




(C)




(D)

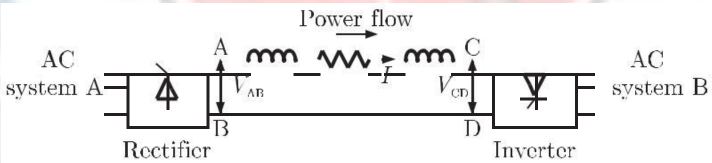



Q. 17 In the above system, the three-phase fault MVA at the bus 3 is

(A) 82.55 MVA (B) 85.11 MVA

(C) 170.91 MVA (D) 181.82 MVA

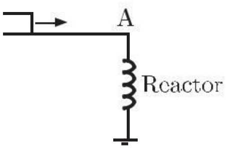
Q. 18 Power is transferred from system A to system B by an HVDC link as shown in the figure. If the voltage $V_{AB}$ and $V_{CD}$ are as indicated in figure, and $I$ 2 0, then




(A) $V_{AB}$ 1 0, $V_{CD} < 0$, $V_{AB} > V_{CD}$ (B) $V_{AB}$ 2 0, $V_{CD}$ 2 0, $V_{AB}$ 1 $V_{CD}$

(C) $V_{AB}$ 2 0, $V_{CD}$ 2 0, $V_{AB} > V_{CD}$ (D) $V_{AB}$ 2 0, $V_{CD} < 0$

Q. 19 Consider a step voltage of magnitude 1 pu travelling along a lossless transmission line that terminates in a reactor. The voltage magnitude across the reactor at the instant travelling wave reaches the reactor is




(A) -1 pu (B) 1 pu

(C) 2 pu (D) 3 pu

Q. 20 Consider two buses connected by an impedence of (0 + 5*j*) W. The bus ‘1’ voltage is 100+30c V, and bus ‘2’ voltage is 100+0c V. The real and reactive power supplied by bus ‘1’ respectively are

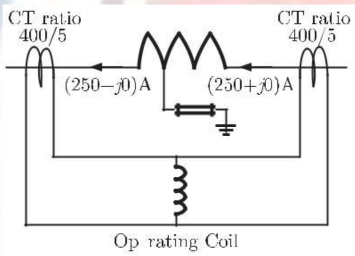
(A) 1000 W, 268 VAr
(B) -1000 W, -134 VAr
(C) 276.9 W, -56.7 VAr
(D) -276.9 W, 56.7 VAr

---

(B) 21 A three-phase, 33 kV oil circuit breaker is rated 1200 A, 2000 MVA, 3 s. The symmetrical breaking current is

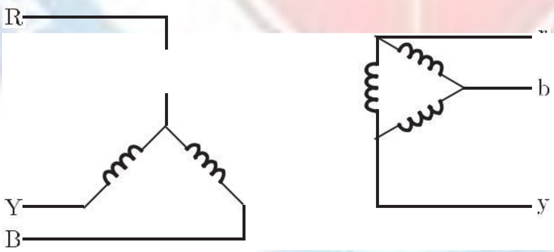
(A) 1200 A
(B) 3600 A
(C) 35 kA
(D) 104.8 kA

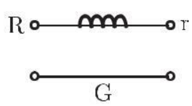
(FF) 2 2 Consider a stator winding of an alternator with an internal high-resistance ground fault. The currents under the fault condition are as shown in the figure The winding is protected using a differential current scheme with current transformers of ratio 400/5 A as shown. The current through the operating coils is

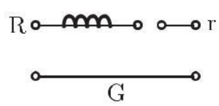


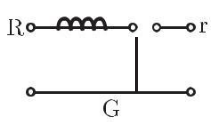

(A) 0.1875 A
(B) 0.2 A
(C) 0.375 A
(D) 60 kA

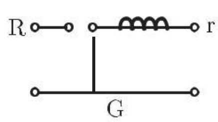
Q. 23 The zero-sequence circuit of the three phase transformer shown in the figure is



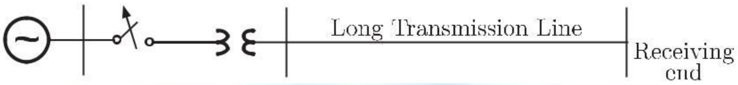

(A)



(B)



(C)



(D)


Q. 24 A 50 Hz synchronous generator is initially connected to a long lossless transmission line which is open circuited at the receiving end. With the field voltage held constant, the generator is disconnected from the transmission line. Which of the following may be said about the steady state terminal voltage and field current of the generator ?



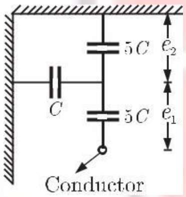

(M) The magnitude of terminal voltage decreases, and the field current does not change.

(N) The magnitude of terminal voltage increases, and the field current does not change.

(O) The magnitude of terminal voltage increases, and the field current increases

(P) The magnitude of terminal voltage does not change and the field current decreases.

Q. 25 Consider a three-phase, 50 Hz, 11 kV distribution system. Each of the conductors is suspended by an insulator string having two identical porcelain insulators. The self capacitance of the insulator is 5 times the shunt capacitance between the link and the ground, as shown in the figures. The voltages across the two insulators are



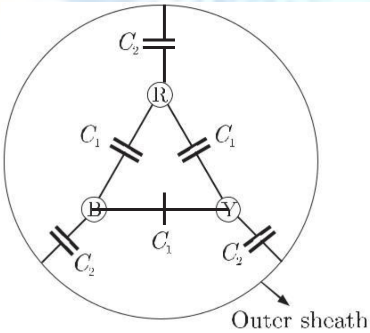

(A) $e_1 = 3.74$ kV, $e_2 = 2.61$ kV

(B) $e_1 = 3.46$ kV, $e_2 = 2.89$ kV

(C) $e_1 = 6.0$ kV, $e_2 = 4.23$ kV

(D) $e_1 = 5.5$ kV, $e_2 = 5.5$ kV

Q. 26 Consider a three-core, three-phase, 50 Hz, 11 kV cable whose conductors are denoted as *R*, *Y* and *B* in the figure. The inter-phase capacitance($C_1$) between each line conductor and the sheath is 0.4 mF . The per-phase charging current is




(A) 2.0 A

(B) 2.4 A

(C) 2.7 A

(D) 3.5 A

Q. 27 For the power system shown in the figure below, the specifications of the components are the following :

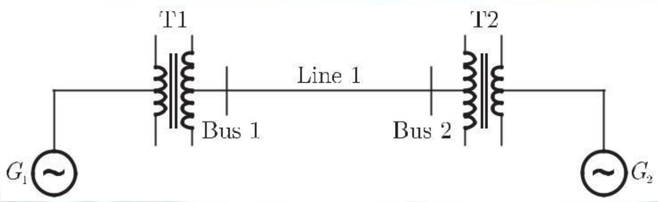
$G_1$: 25 kV, 100 MVA, $X$ = 9%

$G_2$: 25 kV, 100 MVA, $X$ = 9%

$T_1$: 25 kV/220 kV, 90 MVA, $X$ = 12%

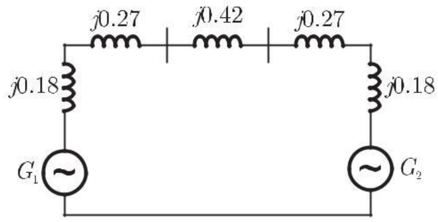
$T_2$: 220 kV/25 kV, 90 MVA, $X$ = 12%

Line 1: 200 kV, $X$ = 150 ohms

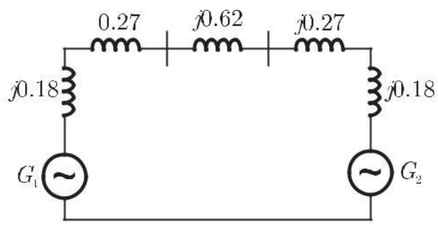



Choose 25 kV as the base voltage at the generator $G_1$, and 200 MVA as the MVA base. The impedance diagram is

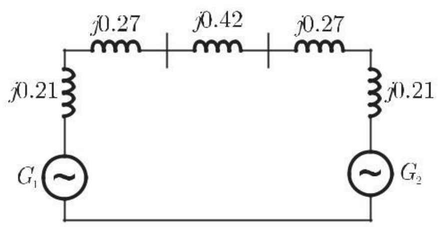
(A)



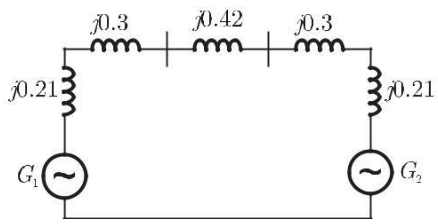

(B)




(C)




(D)



Q. 28 Out of the following plant categories

(i) Nuclear

(ii) Run-of-river

(iii) Pump Storage

(iv) Diesel

The base load power plant are

(A) (i) and (ii) (B) (ii) and (iii)

(C) (i), (ii) and (iv) (D) (i), (iii) and (iv)

Q. 29 For a fixed value of complex power flow in a transmission line having a sending end voltage $V$, the real loss will be proportional to

(A) $V$ (B) $V^2$

(C) $\frac{1}{V^2}$ (D) $\frac{1}{V}$

Q. 30 For the Y-bus matrix of a 4-bus system given in per unit, the buses having shunt elements are

$$Y_{BUS} = j\begin{bmatrix} -5 & 2 & 2.5 & 0 \\ 2 & -10 & 2.5 & 4 \\ 2.5 & 2.5 & -9 & 4 \\ 0 & 4 & 4 & -8 \end{bmatrix}$$

(A) 3 and 4 (B) 2 and 3

(C) 1 and 2 (D) 1, 2 and 4

Q. 31 Match the items in List-I (To) with the items in the List-II (Use) and select the correct answer using the codes given below the lists.

| | List-I | | List-II |
|---|---|---|---|
| **a.** | improve power factor | **1.** | shunt reactor |
| **b.** | reduce the current ripples | **2.** | shunt capacitor |
| **c.** | increase the power flow in line | **3.** | series capacitor |
| **d.** | reduce the Ferranti effect | **4.** | series reactor |

(T) a " 2, b " 3, c " 4, d " 1

(U) a " 2, b " 4, c " 3, d " 1

(V) a " 4, b " 3, c " 1, d " 2

(W) a " 4, b " 1, c " 3, d " 2

Q. 32 Match the items in List-I (Type of transmission line) with the items in List-II (Type of distance relay preferred) and select the correct answer using the codes given below the lists.

| | List-I | | List-II |
|---|---|---|---|
| **a.** | Short Line | **1.** | Ohm Relay |
| **b.** | Medium Line | **2.** | Reactance Relay |
| **c.** | Long Line | **3.** | Mho Relay |

(A) a " 2, b " 1, c " 3 (B) a " 3, b " 2, c " 1

(C) a " 1, b " 2, c " 3 (D) a " 1, b " 3, c " 2

Q. 33 Three generators are feeding a load of 100 MW. The details of the generators are

| | **Rating (MW)** | **Efficiency (%)** | **Regulation (Pu.) ( on 100 MVA base)** |
|---|---|---|---|
| Generator-1 | 100 | 20 | 0.02 |
| Generator-2 | 100 | 30 | 0.04 |
| Generator-3 | 100 | 40 | 0.03 |

In the event of increased load power demand, which of the following will happen ?

All the generator will share equal power

Generator-3 will share more power compared to Generator-1

Generator-1 will share more power compared to Generator-2

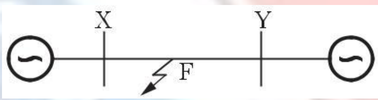
Generator-2 will share more power compared to Generator-3

Q. 34 A 500 MW, 21 kV, 50 Hz, 3-phase, 2-pole synchronous generator having a rated p.f = 0.9, has a moment of inertia of 27.5 # $10^3$ kg-$m^2$ .The inertia constant ($H$ ) will be

(A) 2.44 s (B) 2.71 s

(C) 4.88 s (D) 5.42 s

Q. 35 A two machine power system is shown below. The Transmission line XY has positive sequence impedance of $Z_1$ W and zero sequence impedance of $Z_0$ W




An 'a' phase to ground fault with zero fault impedance occurs at the centre of the transmission line. Bus voltage at X and line current from X to F for the phase 'a', are given by $V_a$ Volts and $I_a$ amperes, respectively. Then, the impedance measured by the ground distance relay located at the terminal X of line XY will be given by

(A) ^$Z_1$ /2h W (B) ^$Z_0$ /2h W

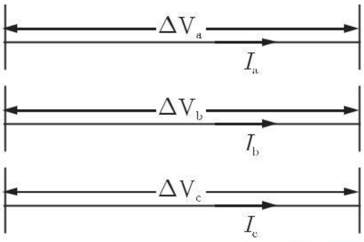
(C) ($Z_0$ + $Z_1$)/2 W (D) ^$V_a$ /$I_a$h W

Q. 36 An extra high voltage transmission line of length 300 km can be approximate by a lossless line having propagation constant $b$ = 0.00127 radians per km. Then the percentage ratio of line length to wavelength will be given by

(A) 24.24 % (B) 12.12 %

(C) 19.05 % (D) 6.06 %

Q. 37 A-3-phase transmission line is shown in figure :




Voltage drop across the transmission line is given by the following equation :

R V R VR
S3Va W SZs Zm Zm WSIa W
S3Vb W = SZm Zs Zm WSIb W
S W S WS W
S3Vc W SZm Zm Zs WSIc W
T X T XT

Shunt capacitance of the line can be neglect. If the has positive sequence impedance of 15 W and zero sequence impedance of 48 W, then the values of $Z_s$ and $Z_m$ will be

(A) $Z_s$ = 31.5 W; $Z_m$ = 16.5 W
(B) $Z_s$ = 26 W; $Z_m$ = 11 W
(C) $Z_s$ = 16.5 W; $Z_m$ = 31.5 W
(D) $Z_s$ = 11 W; $Z_m$ = 26 W

Q. 38 Voltages phasors at the two terminals of a transmission line of length 70 km have a magnitude of 1.0 per unit but are 180 degree out of phase. Assuming that the maximum load current in the line is 1/5th of minimum 3-phase fault current. Which one of the following transmission line protection schemes will not pick up for this condition ?

(N) Distance protection using ohm relay with zoen-1 set to 80% of the line impedance.
(O) Directional over current protection set to pick up at 1.25 times the maximum load current
(P) Pilot relaying system with directional comparison scheme
(Q) Pilot relaying system with segregated phase comparison scheme

Q. 39 A loss less transmission line having Surge Impedance Loading (SIL) of 2280 MW is provided with a uniformly distributed series capacitive compensation of 30%. Then, SIL of the compensated transmission line will be

(A) 1835 MW
(B) 2280 MW
(C) 2725 MW
(D) 3257 MW

Q. 40 A loss less power system has to serve a load of 250 MW. There are tow generation ($G_1$ and $G_2$) in the system with cost curves $C_1$ and $C_2$ respectively defined as follows ;

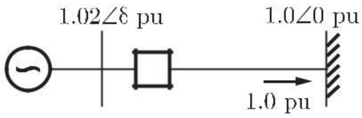
$C_1 (P_{G1}) = P_{G1} + 0.055 \# P_{G1}^2$

$C_2 (P_{G2}) = 3P_{G2} + 0.03 \# P_{G2}^2$

Where $P_{G1}$ and $P_{G2}$ are the MW injections from generator $G_1$ and $G_2$respectively. Thus, the minimum cost dispatch will be

(A) $P_{G1}$ = 250 MW; $P_{G2}$ = 0 MW
(B) $P_{G1}$ = 150 MW; $P_{G2}$ = 100 MW
(C) $P_{G1}$ = 100 MW; $P_{G2}$ = 150 MW
(D) $P_{G1}$ = 0 MW; $P_{G2}$ = 250 MW

Q. 41 A loss less single machine infinite bus power system is shown below :




The synchronous generator transfers 1.0 per unit of power to the infinite bus. The critical clearing time of circuit breaker is 0.28 s. If another identical synchronous generator is connected in parallel to the existing generator and each generator is scheduled to supply 0.5 per unit of power, then the critical clearing time of the circuit breaker will

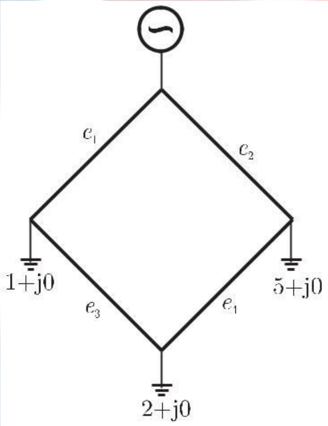
reduce to 0.14 s

reduce but will be more than 0.14 s

remain constant at 0.28 s

increase beyond 0.28 s

Q. 42 Single line diagram of a 4-bus single source distribution system is shown below. Branches $e_1$, $e_2$, $e_3$ and $e_4$ have equal impedances. The load current values indicated in the figure are in per unit.

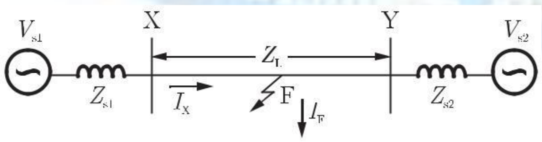



Distribution company's policy requires radial system operation with minimum loss. This can be achieved by opening of the branch

(A) $e_1$ (B) $e_2$

(C) $e_3$ (D) $e_4$

**Common Data For Q. 43 and 44**




Given that: $V_{s1} = V_{s2} = 1 + j0$ p.u;

The positive sequence impedance are

$Z_{s1} = Z_{s2} = 0.001 + j0.01$ p.u and $Z_L = 0.006 + j0.06$ p.u

3-phase Base MVA = 100

voltage base = 400 kV(Line to Line)

Nominal system frequency= 50 Hz.

The reference voltage for phase 'a' is defined as $V(t) = V_m \cos(wt)$.

A symmetrical three phase fault occurs at centre of the line, i.e. point ‘F’ at time ‘$t_0$ ’. The positive sequence impedance from source $S_1$ to point ‘F’ equals 0.004 + $j$0.04 p.u. The wave form corresponding to phase ‘a’ fault current from bus X reveals that decaying d.c. offset current is negative and in magnitude at its maximum initial value, Assume that the negative sequence impedances are equal to positive sequence impedance and the zero sequence impedances are three times positive sequence impedances.

Q. 43 The instant ($t_0$) of the fault will be

(A) 4.682 ms (B) 9.667 ms

(C) 14.667 ms (D) 19.667 ms

Q. 44 The rms value of the component of fault current ($I_f$ ) will be

(A) 3.59 kA (B) 5.07 kA

(C) 7.18 kA (D) 10.15 kA

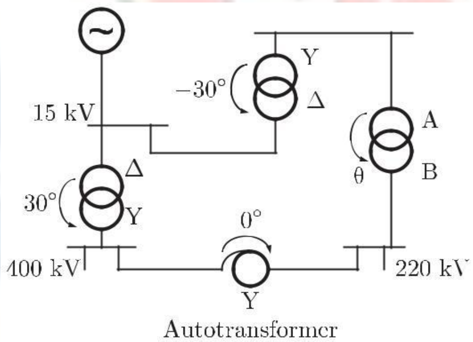
Q. 45 Instead of the three phase fault, if a single line to ground fault occurs on phase ‘a’ at point ‘F’ with zero fault impedance, then the rms of the ac component of fault current ($I_x$) for phase ‘a’ will be

(A) 4.97 p.u (B) 7.0 p.u

(C) 14.93 p.u (D) 29.85 p.u

Q. 46 Consider the transformer connections in a part of a power system shown in the figure. The nature of transformer connections and phase shifts are indicated for all but one transformer

Which of the following connections, and the corresponding phase shift $q$, should be used for the transformer between A and B ?



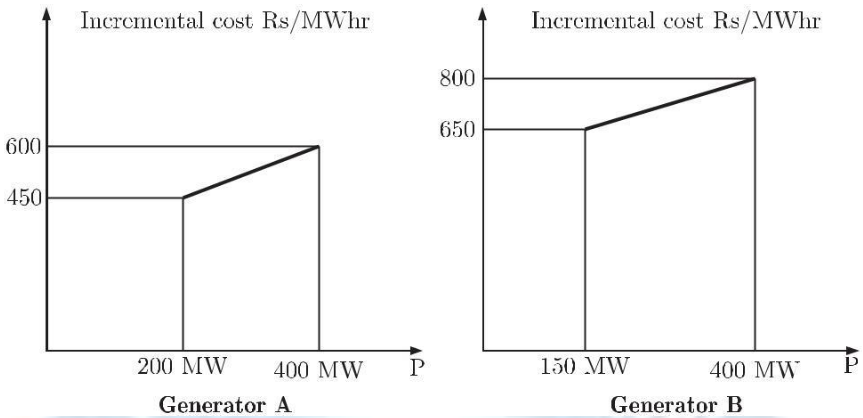

(A) Star-star ($q$ = 0%)

(B) Star-Delta ($q$ =- 30%)

(C) Delta-star ($q$ = 30%)

(D) Star-Zigzag ($q$ = 30%)

Q. 47 The incremental cost curves in Rs/MWhr for two generators supplying a common load of 700 MW are shown in the figures. The maximum and minimum generation limits are also indicated. The optimum generation schedule is :



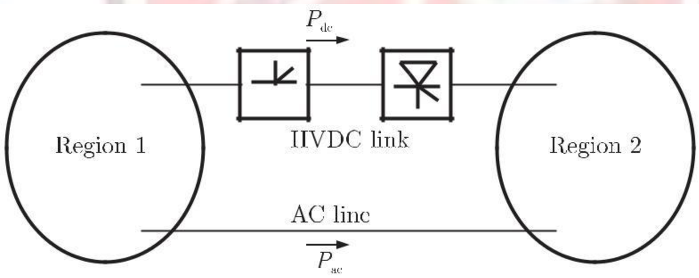

Generator A : 400 MW, Generator B : 300 MW

Generator A : 350 MW, Generator B : 350 MW

Generator A : 450 MW, Generator B : 250 MW

Generator A : 425 MW, Generator B : 275 MW

Q. 48 Two regional systems, each having several synchronous generators and loads are inter connected by an ac line and a HVDC link as shown in the figure. Which of the following statements is true in the steady state :



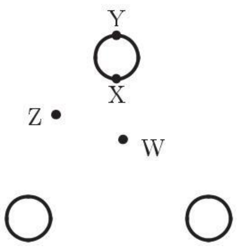

(A) Both regions need not have the same frequency

(B) The total power flow between the regions ($P_{ac}$ + $P_{dc}$) can be changed by controlled the HDVC converters alone

(C) The power sharing between the ac line and the HVDC link can be changed by controlling the HDVC converters alone.

(D) The directions of power flow in the HVDC link ($P_{dc}$ ) cannot be reversed

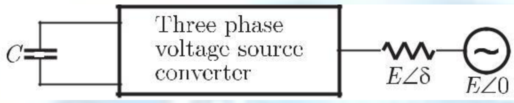
Q. 49 Considered a bundled conductor of an overhead line consisting of three identical sub-conductors placed at the corners of an equilateral triangle as shown in the figure. If we neglect the charges on the other phase conductor and ground, and assume that spacing between sub-conductors is much larger than their radius, the maximum electric field intensity is experienced at



(A) Point X (B) Point Y

(C) Point Z (D) Point W

Q. 50 The figure below shows a three phase self-commutated voltage source converter connected to a power system. The converter's dc bus capacitor is marked as $C$ in the figure. The circuit in initially operating in steady state with $d = 0$ and the capacitor dc voltage is equal to $V_{dc0}$. You may neglect all losses and harmonics. What action should be taken to increase the capacitor dc voltage slowly to a new steady state value.




Make $d$ positive and maintain it at a positive value

Make $d$ positive and return it to its original value

Make $d$ negative and maintain it at a negative value

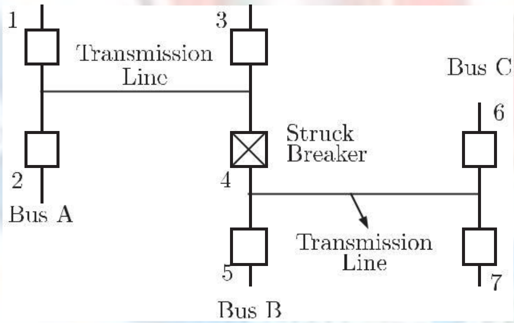
Make $d$ negative and return it to its original value

Q. 51 The total reactance and total suspectance of a lossless overhead EHV line, operating at 50 Hz, are given by 0.045 pu and 1.2 pu respectively. If the velocity of wave propagation is $3 \# 10^5$ km/s, then the approximate length of the line is

(A) 122 km (B) 172 km

(C) 222 km (D) 272 km

Q. 52 Consider the protection system shown in the figure below. The circuit breakers numbered from 1 to 7 are of identical type. A single line to ground fault with zero fault impedance occurs at the midpoint of the line (at point F), but circuit breaker 4 fails to operate (''Stuck breaker''). If the relays are coordinated correctly, a valid sequence of circuit breaker operation is




(A) 1, 2, 6, 7, 3, 5 (B) 1, 2, 5, 5, 7, 3

(C) 5, 6, 7, 3, 1, 2 (D) 5, 1, 2, 3, 6, 7

Q. 53 A three phase balanced star connected voltage source with frequency $w$ rad/s is connected to a star connected balanced load which is purely inductive. The instantaneous line currents and phase to neutral voltages are denoted by $(i_a , i_b , i_c)$ and $(V_{an} , V_{bn} , V_{cn})$ respectively, and their rms values are denoted by $V$ and $I$ .

If $R = [V_{an}\ V_{bn}\ V_{cn}]\begin{bmatrix} 0 & \frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{3}} \\ -\frac{1}{\sqrt{3}} & 0 & \frac{1}{\sqrt{3}} \\ \frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{3}} & 0 \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$, then the magnitude of $R$ is

(A) $3VI$

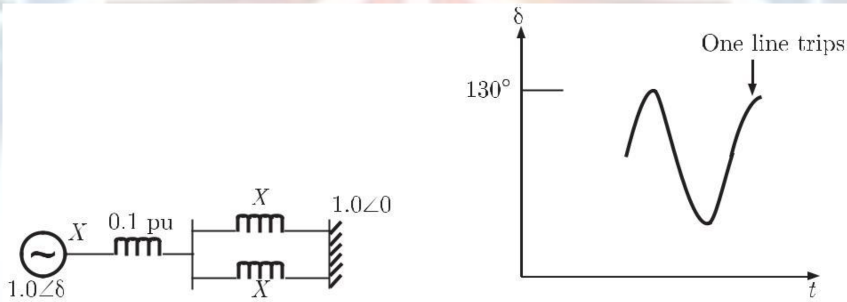
(B) $VI$

(C) $0.7VI$

(D) 0

Q. 54

Consider a synchronous generator connected to an infinite bus by two identical parallel transmission line. The transient reactance 'x' of the generator is 0.1 pu and the mechanical power input to it is constant at 1.0 pu. Due to some previous disturbance, the rotor angle (d) is undergoing an undamped oscillation, with the maximum value of $d(t)$ equal to 130% .One of the parallel lines trip due to the relay maloperation at an instant when $d(t) = 130\%$ as shown in the figure. The maximum value of the per unit line reactance, x such that the system does not lose synchronism subsequent to this tripping is




(A) 0.87

(B) 0.74

(C) 0.67

(D) 0.54

Q. 55

Suppose we define a sequence transformation between "a-b-c" and "p-n-o" variables as follows :

$$\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = k\begin{bmatrix} 1 & 1 & 1 \\ a^2 & a & 1 \\ a & a^2 & 1 \end{bmatrix}\begin{bmatrix} f_p \\ f_n \\ f_o \end{bmatrix}$$

where $a = e^{j\frac{2\pi}{3}}$ and $k$ is a constant

Now, if it is given that : $\begin{bmatrix} V_p \\ V_n \\ V_o \end{bmatrix} = \begin{bmatrix} 0.5 & 0 & 0 \\ 0 & 0.5 & 0 \\ 0 & 0 & 2.0 \end{bmatrix}\begin{bmatrix} i_p \\ i_n \\ i_0 \end{bmatrix}$ and $\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = Z\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$ then,

(A) $Z = \begin{bmatrix} 1.0 & 0.5 & 0.75 \\ 0.75 & 1.0 & 0.5 \\ 0.5 & 0.75 & 1.0 \end{bmatrix}$

(B) $Z = \begin{bmatrix} 1.0 & 0.5 & 0.5 \\ 0.5 & 1.0 & 0.5 \\ 0.5 & 0.5 & 1.0 \end{bmatrix}$

(C) $Z = 3k^2\begin{bmatrix} 1.0 & 0.75 & 0.5 \\ 0.5 & 1.0 & 0.75 \\ 0.75 & 0.5 & 1.0 \end{bmatrix}$

(D) $Z = \frac{k^2}{3}\begin{bmatrix} 1.0 & -0.5 & -0.5 \\ -0.5 & 1.0 & -0.5 \\ -0.5 & -0.5 & 1.0 \end{bmatrix}$

Q. 56

A 230 V (Phase), 50 Hz, three-phase, 4-wire, system has a phase sequence ABC. A unity power-factor load of 4 kW is connected between phase A and neutral N. It is desired to achieve zero neutral current through the use of a pure inductor and a pure capacitor in the other two phases. The value of inductor and capacitor is

(E) 72.95 mH in phase C and 139.02 mF in Phase B

(F) 72.95 mH in Phase B and 139.02 mF in Phase C

(G) 42.12 mH in Phase C and 240.79 mF in Phase B

(H) 42.12 mH in Phase B and 240.79 mF in Phase C

Q. 57 An isolated 50 Hz synchronous generator is rated at 15 MW which is also the maximum continuous power limit of its prime mover. It is equipped with a speed governor with 5% droop. Initially, the generator is feeding three loads of 4 MW each at 50 Hz. One of these loads is programmed to trip permanently if the frequency falls below 48 Hz .If an additional load of 3.5 MW is connected then the frequency will settle down to

(A) 49.417 Hz
(B) 49.917 Hz
(C) 50.083 Hz
(D) 50.583 Hz

Q. 58 Consider the two power systems shown in figure A below, which are initially not interconnected, and are operating in steady state at the same frequency. Separate load flow solutions are computed individually of the two systems, corresponding to this scenario. The bus voltage phasors so obtain are indicated on figure A. These two isolated systems are now interconnected by a short transmission line as shown in figure B, and it is found that $P_1 = P_2 = Q_1 = Q_2 = 0$.

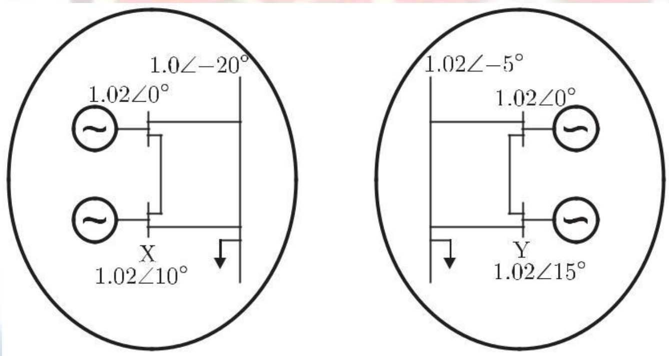



Fig A

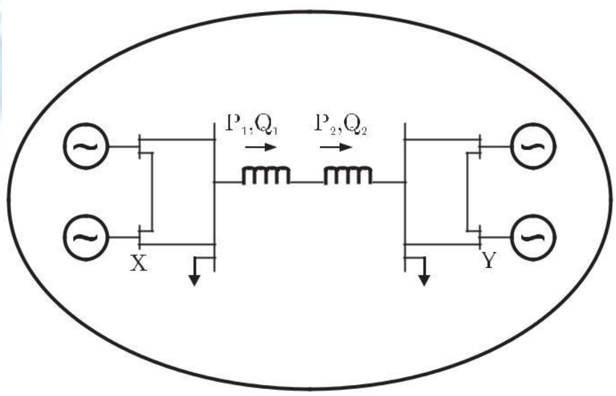



Fig B

The bus voltage phase angular difference between generator bus X and generator bus Y after interconnection is

(A) 10c
(B) 25c
(C) -30c
(D) 30c

Q. 59 The concept of an electrically short, medium and long line is primarily based on the

(A) nominal voltage of the line
(B) physical length of the line
(C) wavelength of the line
(D) power transmitted over the line

Q. 60 Keeping in view the cost and overall effectiveness, the following circuit breaker is best suited for capacitor bank switching

(A) vacuum
(B) air blast
(C) $SF_6$
(D) oil

Q. 61 In a biased differential relay the bias is defined as a ratio of

(A) number of turns of restraining and operating coil
(B) operating coil current and restraining coil current
(C) fault current and operating coil current
(D) fault current and restraining coil current

Q. 62 An HVDC link consist of rectifier, inverter transmission line and other equipments. Which one of the following is true for this link ?

(A) The transmission line produces/ supplies reactive power
(B) The rectifier consumes reactive power and the inverter supplies reactive power from/ to the respective connected AC systems
(C) Rectifier supplies reactive power and the inverted consumers reactive power to/ from the respective connected AC systems
(D) Both the converters (rectifier and inverter) consume reactive power from the respective connected AC systems

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AA.63 The $A$, $B$ , $C$ , $D$ constants of a 220 kV line are : $A = D = 0.94+1c$, $B = 130+73c$ (J) $C = 0.001+90c$ If the sending end voltage of the line for a given load delivered at nominal voltage is 240 kV, the % voltage regulation of the line is

(A) 5
(B) 9
(C) 16
(D) 21

(H) 64 A single phase transmission line and a telephone line are both symmetrically strung one below the other, in horizontal configurations, on a common tower, The shortest and longest distances between the phase and telephone conductors are 2.5 m and 3 m respectively.

The voltage (volt/km) induced in the telephone circuit, due to 50 Hz current of 100 amps in the power circuit is

(A) 4.81
(B) 3.56
(C) 2.29
(D) 1.27

Q. 65 Three identical star connected resistors of 1.0 pu are connected to an unbalanced 3-phase supply. The load neutral is isolated. The symmetrical components of the line voltages in pu. are: $V_{ab_1} = X+q_1$ , $V_{ab_2} = Y+q_2$. If all the pu calculations are with the respective base values, the phase to neutral sequence voltages are

(A) $V_{an_1} = X+(q_1 + 30c), V_{an_2} = Y(q_2 - 30c)$

(B) $V_{an^1} = X+(q_1 - 30c), V_{an^2} = Y+(q_2 + 30c)$

(C) $V_{an^1} = \frac{1}{\sqrt{3}}X+(q_1 - 30c), V_{an^2} = \frac{1}{\sqrt{3}}Y+(q_2 - 30c)$

(D) $V_{an^1} = \frac{1}{\sqrt{3}}X+(q_1 - 60c), V_{an^2} = \frac{1}{\sqrt{3}}Y+(q_2 - 60c)$

Q. 66 A generator is connected through a 20 MVA, 13.8/138 kV step down transformer, to a transmission line. At the receiving end of the line a load is supplied through a step down transformer of 10 MVA, 138/69 kV rating. A 0.72 pu. load, evaluated on load side transformer ratings as base values , is supplied from the above system. For system base values of 10 MVA and 69 kV in load circuit, the value of the load (in per unit) in generator will be

(A) 36 (B) 1.44

(C) 0.72 (D) 0.18

Q. 67 The Gauss Seidel load flow method has following disadvantages. Tick the incorrect statement.

(A) Unreliable convergence

(B) Slow convergence

(C) Choice of slack bus affects convergence

(D) A good initial guess for voltages is essential for convergence

**Common Data For Q. 68 and 69**

A generator feeds power to an infinite bus through a double circuit transmission line. A 3-phase fault occurs at the middle point of one of the lines. The infinite bus voltage is 1 pu, the transient internal voltage of the generator is 1.1 pu and the equivalent transfer admittance during fault is 0.8 pu. The 100 MVA generator has an inertia constant of 5 MJ/MVA and it was delivering 1.0 pu power prior of the fault with rotor power angle of 30c. The system frequency is 50 Hz.

H 68 The initial accelerating power (in pu) will be

(A) 1.0 (B) 0.6

(C) 0.56 (D) 0.4

(EE) 6 9 If the initial accelerating power is $X$ pu, the initial acceleration in elect-deg/sec, and the inertia constant in MJ-sec/elect-deg respectively will be

(A) 31.4$X$ , 18 (B) 1800$X$ , 0.056

(C) $X$/1800, 0.056 (D) $X$/31.4, 18

**Common Data For Q. 70 and 71**

For a power system the admittance and impedance matrices for the fault studies are as follows.

$$Y_{bus} = \begin{bmatrix} -j8.75 & j1.25 & j2.50 \\ j1.25 & -j6.25 & j2.50 \\ j2.50 & -j2.50 & -j5.00 \end{bmatrix} \qquad Z_{bus} = \begin{bmatrix} j0.16 & j0.08 & j0.12 \\ j0.08 & j0.24 & j0.16 \\ j0.12 & j0.16 & j0.34 \end{bmatrix}$$

The pre-fault voltages are 1.0 pu. at all the buses. The system was unloaded prior to the fault. A solid 3-phase fault takes place at bus 2.

F 70 The post fault voltages at buses 1 and 3 in per unit respectively are

(A) 0.24, 0.63 (B) 0.31, 0.76

(C) 0.33, 0.67 (D) 0.67, 0.33

Y. 71 The per unit fault feeds from generators connected to buses 1 and 2 respectively are

(A) 1.20, 2.51 (B) 1.55, 2.61

(C) 1.66, 2.50 (D) 5.00, 2.50

Y. 72 A 400 V, 50 Hz, three phase balanced source supplies power to a star connected load whose rating is $12\sqrt{3}$ kVA, 0.8 pf (lag). The rating (in kVAR) of the delta connected (capacitive) reactive power bank necessary to bring the pf to unity is

(A) 28. 78 (B) 21.60

(C) 16.60 (D) 12.47

---

Q. 73 The p.u. parameter for a 500 MVA machine on its own base are:
inertia, $M$ = 20 p.u. ; reactance, $X$ = 2 p.u.
The p.u. values of inertia and reactance on 100 MVA common base, respectively, are

(A) 4, 0.4 (B) 100, 10

(C) 4, 10 (D) 100, 0.4

Q. 74 An 800 kV transmission line has a maximum power transfer capacity of $P$ . If it is operated at 400 kV with the series reactance unchanged, the new maximum power transfer capacity is approximately

(A) $P$ (B) $2P$

(C) $P/2$ (D) $P/4$

(Y) 75 The insulation strength of an EHV transmission line is mainly governed by

G load power factor]

H switching over-voltages

I harmonics

J corona

(L) 76 High Voltage DC (HVDC) transmission is mainly used for

(A) bulk power transmission over very long distances

J inter-connecting two systems with same nominal frequency

32 eliminating reactive power requirement in the operation

33 minimizing harmonics at the converter stations

---

Q. 77 The parameters of a transposed overhead transmission line are given as :
Self reactance $X_S$ = 0.4W/km and Mutual reactance $X_m$ = 0.1W/km The positive sequence reactance $X_1$ and zero sequence reactance $X_0$, respectively in W/km are

(A) 0.3, 0.2 (B) 0.5, 0.2

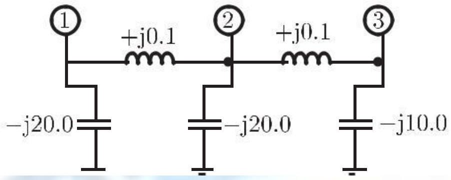
(C) 0.5, 0.6 (D) 0.3, 0.6

Q. 78 At an industrial sub-station with a 4 MW load, a capacitor of 2 MVAR is installed to maintain the load power factor at 0.97 lagging. If the capacitor goes out of service, the load power factor becomes

(A) 0.85 (B) 1.00

(C) 0.80 lag (D) 0.90 lag

Q. 79 The network shown in the given figure has impedances in p.u. as indicated. The diagonal element $Y_{22}$ of the bus admittance matrix $Y_{BUS}$ of the network is



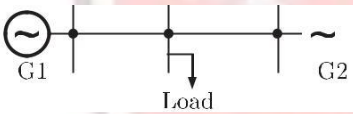

(A) -$j$19.8 (B) +$j$20.0

(C) +$j$0.2 (D) -$j$19.95

Q. 80 A load centre is at an equidistant from the two thermal generating stations $G_1$ and $G_2$ as shown in the figure. The fuel cost characteristic of the generating stations are given by

$F_1 = a + bP_1 + cP_1^2$ Rs/hour

$F_2 = a + bP_2 + 2cP_2^2$ Rs/ hour

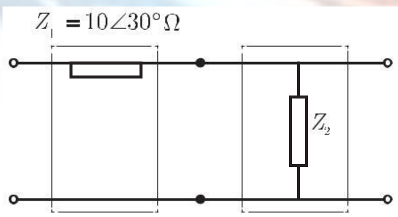



Where $P_1$ and $P_2$ are the generation in MW of $G_1$ and $G_2$, respectively. For most economic generation to meet 300 MW of load $P_1$ and $P_2$ respectively, are

(A) 150, 150 (B) 100, 200

(C) 200, 100 (D) 175, 125

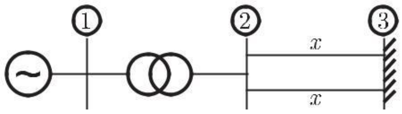
Q. 81 Two networks are connected in cascade as shown in the figure. With usual notations the equivalent $A$, $B$, $C$ and $D$ constants are obtained. Given that, $C$ = 0.025+45c , the value of $Z_2$ is




(A) 10+30c W (B) 40+ - 45c W

(C) 1 W (D) 0 W

Q. 82 A generator with constant 1.0 p.u. terminal voltage supplies power through a step-up transformer of 0.12 p.u. reactance and a double-circuit line to an infinite bus bar as shown in the figure. The infinite bus voltage is maintained at 1.0 p.u. Neglecting the resistances and suspectances of the system, the steady state stability power limit of the system is 6.25 p.u. If one of the double-circuit is tripped, then resulting steady state stability power limit in p.u. will be




(A) 12.5 p.u.

(B) 3.125 p.u.

(C) 10.0 p.u.

(D) 5.0 p.u.

**Common Data For Q. 83 and 84**

At a 220 kV substation of a power system, it is given that the three-phase fault level is 4000 MVA and single-line to ground fault level is 5000 MVA Neglecting the resistance and the shunt suspectances of the system.

6. 83 The positive sequence driving point reactance at the bus is

(A) 2.5 W

(B) 4.033 W

(C) 5.5 W

(D) 12.1 W

9. 84 The zero sequence driving point reactance at the bus is

(A) 2.2 W

(B) 4.84 W

(C) 18.18 W

(D) 22.72 W

Q. 85 Total instantaneous power supplied by a 3-phase ac supply to a balanced R-L load is

16 zero

17 constant

18 pulsating with zero average

19 pulsating with the non-zero average

33. 86 The rated voltage of a 3-phase power system is given as

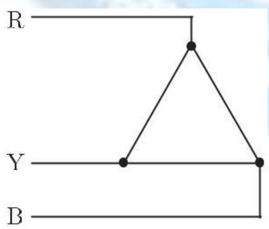
(A) rms phase voltage

(B) peak phase voltage

(C) rms line to line voltage

(D) peak line to line voltage

= 87 The phase sequences of the 3-phase system shown in figure is




(A) RYB

(B) RBY

(C) BRY

(D) YBR

Q. 88 In the thermal power plants, the pressure in the working fluid cycle is developed by

(A) condenser

(B) super heater

(C) feed water pump

(D) turbine

19 89 For harnessing low variable waterheads, the suitable hydraulic turbine with high percentage of reaction and runner adjustable vanes is

(A) Kaplan | (B) Francis
(C) Pelton | (D) Impeller

J 90 The transmission line distance protection relay having the property of being inherently directional is

(A) impedance relay | (B) MHO relay
(C) OHM relay | (D) reactance relay

Q. 91 A 800 kV transmission line is having per phase line inductance of 1.1 mH/km and per phase line capacitance of 11.68 nF/km. Ignoring the length of the line, its ideal power transfer capability in MW is

(A) 1204 MW | (B) 1504 MW
(C) 2085 MW | (D) 2606 MW

Q. 92 A 110 kV, single core coaxial, XLPE insulated power cable delivering power at 50 Hz, has a capacitance of 125 nF/km. If the dielectric loss tangent of XLPE is $2 \# 10^{-4}$, then dielectric power loss in this cable in W/km is

(A) 5.0 | (B) 31.7
(C) 37.8 | (D) 189.0

Q. 93 A lightning stroke discharges impulse current of 10 kA (peak) on a 400 kV transmission line having surge impedance of 250 W The magnitude of transient over-voltage travelling waves in either direction assuming equal distribution from the point of lightning strike will be

(A) 1250 kV | (B) 1650 kV
(C) 2500 kV | (D) 2900 kV

Q. 94 The generalized circuit constants of a 3-phase, 220 kV rated voltage, medium length transmission line are

$S = D = 0.936 + j0.016 = 0.936+0.98c$

$T = 35.5 + j138 = 142.0+76.4c$ W

$FF = (- 5.18 + j914) \# 10^{-6}$ W

If the load at the receiving end is 50 MW at 220 kV with a power factor of 0.9 lagging, then magnitude of line to line sending end voltage should be

(A) 133.23 kV | (B) 220.00 kV
(C) 230. 78 kV | (D) 246.30 kV

Q. 95 A new generator having $E_g = 1.4+30c$ pu. [equivalent to (1.212 + $j$0.70) pu] and synchronous reactance '$X_S$' of 1.0 pu on the system base, is to be connected to a bus having voltage $V_t$, in the existing power system. This existing power system can be represented by Thevenin's voltage $E_{th} = 0.9+0c$ pu in series with Thevenin's impedance $Z_{th} = 0.25+90c$ pu. The magnitude of the bus voltage $V_t$ of the system in pu will be

(A) 0.990 | (B) 0.973
(C) 0.963 | (D) 0.900

Q. 96 A 3-phase generator rated at 110 MVA, 11 kV is connected through circuit breakers to a transformer . The generator is having direct axis sub-transient reactance $X''_d$ = 19%, transient reactance $X'_d$ = 26% and synchronous reactance =130%. The generator is operating at no load and rated voltage when a three phase short circuit fault occurs between the breakers and the transformer . The magnitude of initial symmetrical rms current in the breakers will be

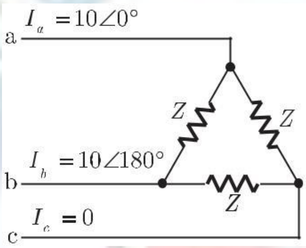
4.44 kA

22.20 kA

30.39 kA

38.45 kA

Q. 97 A 3-phase transmission line supplies 3-connected load $Z$ . The conductor ‘c’ of the line develops an open circuit fault as shown in figure. The currents in the lines are as shown on the diagram. The +ve sequence current component in line ‘a’ will be




(A) 5.78+ - 30c (B) 5.78+90c

(C) 6.33+90c (D) 10.00+ - 30c

Q. 98 A 500 MVA, 50 Hz, 3-phase turbo-generator produces power at 22 kV. Generator is Y-connected and its neutral is solidly grounded. It sequence reactances are $X_1 = X_2 = 0.15$ pu and $X_0 = 0.05$ pu.It is operating at rated voltage and disconnected from the rest of the system (no load). The magnitude of the sub-transient line current for single line to ground fault at the generator terminal in pu will be

(A) 2.851 (B) 3.333

(C) 6.667 (D) 8.553

Q. 99 A 50 Hz, 4-pole, 500 MVA, 22 kV turbo-generator is delivering rated megavolt-amperes at 0.8 power factor. Suddenly a fault occurs reducing in electric power output by 40%. Neglect losses and assume constant power input to the shaft. The accelerating torque in the generator in MNm at the time of fault will be

(A) 1.528 (B) 1.018

(C) 0.848 (D) 0.509

Q. 100 A hydraulic turbine having rated speed of 250 rpm is connected to a synchronous generator. In order to produce power at 50 Hz, the number of poles required in the generator are

(A) 6 (B) 12

(C) 16 (D) 24

Q. 101 Bundled conductors are mainly used in high voltage overhead transmission lines to

8. reduces transmission line losses
9. increase mechanical strength of the line
10. reduce corona
11. reduce sag

Q. 102 A power system consist of 300 buses out of which 20 buses are generator bus, 25 buses are the ones with reactive power support and 15 buses are the ones with fixed shunt capacitors. All the other buses are load buses. It is proposed to perform a load flow analysis in the system using Newton-Raphson method. The size of the Newton Raphson Jacobian matrix is

(A) 553 # 553 (B) 540 # 540

(C) 555 # 555 (D) 554 # 554

Q. 103 Choose two appropriate auxiliary components of a HVDC transmission system from the following

P. D.C line inductor

Q. A.C line inductor

R. Reactive power sources

S. Distance relays on D.C line

T. Series capacitance on A.C. line

(A) P and Q (B) P and R

(C) Q and S (D) S and T

Q. 104 A round rotor generator with internal voltage $E_1 = 2.0$ pu and $X = 1.1$ pu is connected to a round rotor synchronous motor with internal voltage $E_2 = 1.3$ pu and $X = 1.2$ pu. The reactance of the line connecting the generator to the motor is 0.5 pu. When the generator supplies 0.5 pu power, the rotor angle difference between the machines will be

(A) 57.42 c (B) 1c

(C) 32.58c (D) 122.58c

Q. 105 The interrupting time of a circuit breaker is the period between the instant of

(A) initiation of short circuit and the arc extinction on an opening operation

(B) energizing of the trip circuit and the arc extinction on an opening operation

(C) initiation of short circuit and the parting of primary arc contacts

(D) energizing of the trip circuit and the parting of primary arc contacts

Q. 106 The *ABCD* parameters of a 3-phase overhead transmission line are *9.* = *D* = 0.9+ 0c, *B* = 200+90c W and *C* = 0.95 # $10^{-3}$ +90% S. At no-load condition a shunt inductive, reactor is connected at the receiving end of the line to limit the receiving-end voltage to be equal to the sending-end voltage. The ohmic value of the reactor is

(A) 3 W (B) 2000 W

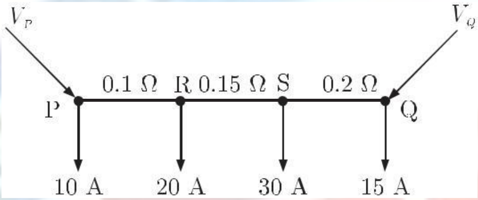
(C) 105.26 W (D) 1052.6 W

Q. 107 A surge of 20 kV magnitude travels along a lossless cable towards its junction with two identical lossless overhead transmission lines. The inductance and the capacitance of the cable are 0.4 mH and 0.5 *m*F per km. The inductance and capacitance of the overhead transmission lines are 1.5 mH and 0.015 *m*F per km. The magnitude of the voltage at the junction due to surge is

(A) 36.72 kV (B) 18.36 kV

(C) 6.07 kV (D) 33.93 kV

Q. 108 A dc distribution system is shown in figure with load current as marked. The two ends of the feeder are fed by voltage sources such that $V_P - V_Q = 3$ V. The value of the voltage $V_P$ for a minimum voltage of 220 V at any point along the feeder is




(A) 225.89 V (B) 222.89 V

(C) 220.0 V (D) 228.58 V

Q. 109 A balanced delta connected load of (8 + *j*6) W per phase is connected to a 400 V, 50 Hz, 3-phase supply lines. If the input power factor is to be improved to 0.9 by connecting a bank of star connected capacitor the required kVAR of the of the bank is

(A) 42.7 (B) 10.2

(C) 28.8 (D) 38.4

Q. 110 A 3-phase 11 kV generator feeds power to a constant power unity power factor load of 100 MW through a 3-phase transmission line. The line-to line voltage at the terminals of the machine is maintained constant at 11 kV. The per unit positive sequence impedance of the line based on 100 MVA and 11 kV is *j*0.2. The line to line voltage at the load terminals is measured to be less than 11 kV. The total reactive power to be injected at the terminals of the load to increase the line-to-line voltage at the load terminals to 11 kV is

(A) 100 MVAR (B) 10.1 MVAR

(C) -100 MVAR (D) -10.1 MVAR

Q. 111 The bus impedance matrix of a 4-bus power system is given by

$$Z_{bus} = \begin{bmatrix} j0.3435 & j0.2860 & j0.2723 & j0.2277 \\ j0.2860 & j0.3408 & j0.2586 & j0.2414 \\ j0.2723 & j0.2586 & j0.2791 & j0.2209 \\ j0.2277 & j0.2414 & j0.2209 & j0.2791 \end{bmatrix} W$$

A branch having an impedance of *j*0.2 W is connected between bus 2 and the reference. Then the values of $Z_{22,new}$ and $Z_{23,new}$ of the bus impedance matrix of the modified network are respectively

(A) *j*0.5408 W and *j*0.4586 W (B) *j*0.1260 W and *j*0.0956 W

(C) *j*0.5408 W and *j*0.0956 W (D) *j*0.1260 W and *j*0.1630 W

Q. 112 A 20-MVA, 6.6-kV, 3-phase alternator is connected to a 3-phase transmission line. The per unit positive-sequence, negative-sequence and zero-sequence impedances of the alternator are $j0.1$, $j0.1$ and $j0.04$ respectively. The neutral of the alternator is connected to ground through an inductive reactor of $j0.05$ p.u. The per unit positive-, negative- and zero-sequence impedances of transmission line are $j0.1$, $j0.1$ and $j0.3$, respectively. All per unit values are based on the machine ratings. A solid ground fault occurs at one phase of the far end of the transmission line. The voltage of the alternator neutral with respect to ground during the fault is

513.8 V
889.9 V
1112.0 V
642.2 V

Q. 113 Incremental fuel costs (in some appropriate unit) for a power plant consisting of three generating units are

$IC_1 = 20 + 0.3P_1$, $IC_2 = 30 + 0.4P_2$, $IC_3 = 30$

Where $P_1$ is the power in MW generated by unit $i$ for $i$ = 1,2 and 3. Assume that all the three units are operating all the time. Minimum and maximum loads on each unit are 50 MW and 300 MW respectively. If the plant is operating on economic load dispatch to supply the total power demand of 700 MW, the power generated by each unit is

$P_1$ = 242.86 MW; $P_2$ = 157.14 MW; and $P_3$ = 300 MW
$P_1$ = 157.14 MW; $P_2$ = 242.86 MW; and $P_3$ = 300 MW
$P_1$ = 300 MW; $P_2$ = 300 MW; and $P_3$ = 100 MW
$P_1$ = 233.3 MW; $P_2$ = 233.3 MW; and $P_3$ = 233.4 MW

Q. 114 A list of relays and the power system components protected by the relays are given in List-I and List-II respectively. Choose the correct match from the four choices given below:

| | List-I | | List-II |
|---|---|---|---|
| **P.** | Distance relay | **1.** | Transformers |
| **Q.** | Under frequency relay | **2.** | Turbines |
| **R.** | Differential relay | **3.** | Busbars |
| **S.** | Buchholz relay | **4.** | Shunt capacitors |
| | | **5.** | Alternators |
| | | **6.** | Transmission lines |

**Codes:**

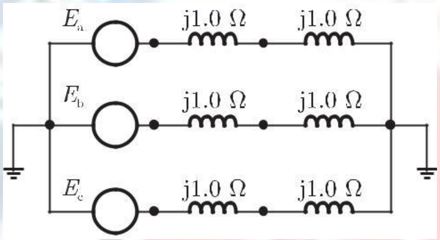
| | P | Q | R | S |
|---|---|---|---|---|
| (A) | 6 | 5 | 3 | 1 |
| (B) | 4 | 3 | 2 | 1 |
| (C) | 5 | 2 | 1 | 6 |
| (D) | 6 | 4 | 5 | 3 |

Q. 115 A generator delivers power of 1.0 p.u. to an infinite bus through a purely reactive network. The maximum power that could be delivered by the generator is 2.0 p.u. A three-phase fault occurs at the terminals of the generator which reduces the generator output to zero. The fault is cleared after $t_c$ second. The original network is then restored. The maximum swing of the rotor angle is found to be $d_{max}$ = 110 electrical degree. Then the rotor angle in electrical degrees at $t = t_c$ is

(A) 55 (B) 70

(C) 69.14 (D) 72.4

Q. 116 A three-phase alternator generating unbalanced voltages is connected to an unbalanced load through a 3-phase transmission line as shown in figure. The neutral of the alternator and the star point of the load are solidly grounded. The phase voltages of the alternator are $E_a$ = 10+ 0c V, $E_b$ = 10+ - 90c V, $E_c$ = 10+120c V . The positive-sequence component of the load current is




(A) 1.310+ - 107c A (B) 0.332+ - 120c A

(C) 0.996+ - 120c A (D) 3.510+ - 81c A

# SOLUTION

**Sol. 1** Option (D) is correct.

**Sol. 2** Option (C) is correct.

Consider the voltage phase angles at buses 2 and 3 be $\theta_2$ and $\theta_3$ since, all the three buses have the equal voltage magnitude which is 1 *Pu* so, it is a D.C. load flow. The injections at Bus 2 and 3 are respectively

$$P_2 = 0.1 \text{ pu}$$
$$P_3 = -0.2 \text{ pu}$$

Therefore, the phase angles are obtained as

$$\begin{bmatrix}\theta_2 \\ \theta_3\end{bmatrix} = [B]^{-1}\begin{bmatrix}P_2 \\ P_3\end{bmatrix}$$

where $B$ is obtained as

$$[B] = \begin{bmatrix}\frac{1}{X_{12}} + \frac{1}{X_{23}} & \frac{-1}{X_{23}} \\ \frac{-1}{X_{23}} & \frac{1}{X_{23}} + \frac{1}{X_{13}}\end{bmatrix}$$

$$= \begin{bmatrix}1+1 & -1 \\ -1 & 1+1\end{bmatrix} = \begin{bmatrix}2 & -1 \\ -1 & 2\end{bmatrix}$$

Its inverse is obtained as

$$[B]^{-1} = \begin{bmatrix}2 & -1 \\ -1 & 2\end{bmatrix}^{-1} = \frac{1}{3}\begin{bmatrix}2 & 1 \\ 1 & 2\end{bmatrix}\begin{bmatrix}0.1 \\ -0.2\end{bmatrix}$$

Therefore,

$$\begin{bmatrix}\theta_2 \\ \theta_3\end{bmatrix} = \frac{1}{3}\begin{bmatrix}2 & 1 \\ 1 & 2\end{bmatrix}\begin{bmatrix}0.1 \\ -0.2\end{bmatrix} = \frac{1}{3}\begin{bmatrix}0 \\ -0.3\end{bmatrix} = \begin{bmatrix}0 \\ -0.1\end{bmatrix}$$

i.e., $\theta_2 = 0$

and $\theta_3 = -0.1$ rad

**Sol. 3** Option (C) is correct.

From the above solution, we have

$$P_2 = 0.1$$
$$P_3 = -0.2$$

since,

$$P_1 + P_2 + P_3 = 0 \text{ (Where } P_1 \text{ is injection at bus 1)}$$

So, $P_1 = -P_2 - P_3 = -0.1 + 0.2 = 0.1$ pu

Now, the apparent power delivered to base is

$$|S| = \frac{|V|^2}{R} = \frac{(100 \times 10^3)^2}{100}$$
$$= 100 \times 10^6 \text{ VA}$$

Therefore, the real power delivered by slack bus (bus 1)

$$P = P_1 |S| = (0.1) \times 100 \times 10^6 = 10 \times 10^6 \text{ watt} = 10 \text{ MW}$$

**Sol. 4** Option (B) is correct.

For bus admittance matrix,

$$Y_{11} + (Y_{12} + y_{line}) + Y_{13} = 0$$

$$-j13 + (j10 + y_{line}) + j5 = 0$$

$$y_{line} = -j2$$

Magnitude of susceptance is +2

**Sol. 5** Option (A) is correct.

$$i_1(t) = I_m \sin(\omega t - \phi_1)$$

$$i_2(t) = I_m \cos(\omega t - \phi_2)$$

We know that, $\cos(\theta - 90°) = \sin\theta$

So, $i_1(t)$ can be written as

$$i_1(t) = I_m \cos(\omega t - \phi_1 - 90°)$$

$$i_2(t) = I_m \cos(\omega t - \phi_2)$$

Now, in phasor form $\boldsymbol{I}_1 = I_m \angle \phi_1 + 90°$

$$\boldsymbol{I}_2 = I_m \angle \phi_2$$

Current are balanced if $\boldsymbol{I}_1 + \boldsymbol{I}_2 = 0$

$$I_m \angle \phi_1 + 90° + I_m \angle \phi_2 = 0$$

$$I_m \cos(\phi_1 + 90°) + jI_m \sin(\phi_1 + 90°) + \cos\phi_2 + j\sin\phi_2 = 0$$

$$I_m [\cos(\phi_1 + 90°) + j\sin(\phi_1 + 90°)] + I_m [\cos\phi_2 + j\sin\phi_2] = 0$$

$$I_m [\cos(\phi_1 + 90°) + \cos\phi_2] + jI_m [\sin\phi_2 + \sin(\phi_1 + 90°)] = 0$$

$$\cos(\phi_1 + 90°) + \cos\phi_2 = 0$$

$$\cos(\phi_1 + 90°) = -\cos\phi_2 = \cos(\pi + \phi_2)$$

$$\phi_1 + 90° = \pi + \phi_2$$

or, $$\phi_1 = \frac{\pi}{2} + \phi_2$$

**Sol. 6** Option (A) is correct.

Let penalty factor of plant $G_1$ is $L_1$ given as

$$L_1 = \frac{1}{1 - \frac{\partial P_L}{\partial P_{G_1}}}$$

$$P_L = 0.5 P_{G_1}^2$$

$$\frac{\partial P_L}{\partial P_{G_2}} = 0.5(2P_{G_1}) = P_{G_1}$$

So, $$L_1 = \frac{1}{1 - P_{G_2}}$$

Penalty factor of plant $G_2$ is

$$L_2 = \frac{1}{1 - \frac{\partial P_L}{\partial P_{G_2}}} = 1 \qquad \left(\frac{\partial P_L}{\partial P_{G_2}} = 0\right)$$

For economic power generation

$$C_1 \times L_1 = C_2 \times L_2$$

where $C_1$ and $C_2$ are the incremental fuel cost of plant $G_1$ and $G_2$.

So, $$(10000)\left(\frac{1}{1 - P_{G_2}}\right) = 12500 \times 1$$

$$\frac{4}{5} = 1 - P_{G_2}$$

$$P_{G_2} = \frac{1}{5} \text{ pu}$$

It is an 100 MVA, so $$P_{G_2} = \frac{1}{5} \times 100 = 20 \text{ MW}$$

Loss $P_L = 0.5b\,\frac{1}{5}\,1^{2} = \frac{1}{50}$ pu

or $P_L = \frac{1}{50} \# 100 = 2$ MW

Total power, $P_L = P_{G1} + P_{G2} - P_L$

aa $= 20 + P_2 - 2$

$P_{G2} = 22$ MW

Sol. 7 Option (C) is correct.

For double line-to-ground ($LLG$) fault, relation between sequence current is

$$I_{positive} =- ^I_{negative} + I_{zero}h$$

Gives values satisfy this relation, therefore the type of fault is $LLG$.

Sol. 8 Option (B) is correct.

Complex power for generator

$$S_{G1} = S_{D1} + S_{D2} = 1 + 1 = 2 \text{ pu} \qquad \text{(Line is lossless)}$$

Power transferred from bus 1 to bus 2 is 1 pu, so

$$1 = \frac{|V_1||V_2|\sin(q_1 - q_2)}{X}$$

$$= \frac{1 \# 1}{0.5}\sin(q_1 - q_2) \qquad |V_1| = |V_2| = 1 \text{ pu}, \; X = 0.5 \text{ pu}$$

$$0.5 = \sin(q_1 - q_2)$$

$$q_1 - q_2 = 30c$$

$$q_2 = q_1 - 30c =- 30c \qquad (q_1 = 0c)$$

So, $V_1 = 1\angle 0c$ V

$V_2 = 1\angle -30c$ V

Current, $I_{12} = \frac{V_1 - V_2}{Z} = \frac{1\angle 0c - 1\angle 30c}{j0.5} = (1 - j0.288)$ pu

Current in $S_{D2}$ is $I_2$, $S_{D2} = V_2 I_2^{)}$

$1 = 1\angle -30c I_2^{)}$

$I_2 = 1\angle -30c$ pu

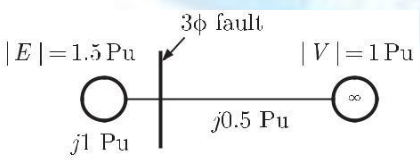
Current in $Q_{G2}$, $I_G = I_2 - I_{12} = 1\angle -30c - (1 - j0.288)$

$\# \; 0.268\angle -120c$

VAR rating of capacitor,

$$Q_C = |V_2||V_G| = 1 \# 0.268 = 0.268 \text{ pu}$$

Sol. 9 Option (D) is correct.




Total reactance, $= = j1 + j0.5 = j1.5$ pu

Critical angle is given as, $d_{cr} = \cos^{-1}[(p - 2d_0)\sin d_0 - \cos d_0]$ ...(i)

$d_0$ " steady state torque angle.

Steady state power is given as

$$P_m = P_{max}\sin d_0$$

where, $$P_{\max} = \frac{|E||V|}{|X|}$$

So, $$P_m = \frac{|E||V|}{|X|}\sin d_0$$

$$0.5 = \frac{(1.5)(1)}{1.5}\sin d_0 \qquad P_m = 0.5 \text{ pu}$$

$$\sin d_0 = 0.5$$

$$d_0 = 30c$$

In radian, $$d_0 = 30c \# \frac{p}{180c} = 0.523$$

Substituting $d_0$ into equation (i)

$$d_{cr} = \cos^{-1}[(p - 2 \# 0.523)\sin 30c - \cos 30c]$$

$$= \cos^{-1}[(2.095)(0.5) - 0.866]$$

$$= \cos^{-1}(0.1815) - 79.6c$$

Sol. 10 Option ( ) is correct

Sol. 11 Option (A) is correct.

Negative phase sequence relay is used for the protection of alternators against unbalanced loading that may arise due to phase-to-phase faults.

Sol. 12 Option (C) is correct.

Steady state stability or power transfer capability

$$P_{\max} = \frac{|E||V|}{X}$$

To improve steady state limit, reactance $X$ should be reduced. The stability may be increased by using two parallel lines. Series capacitor can also be used to get a better regulation and to increase the stability limit by decreasing reactance.

Hence (C) is correct option.

Sol. 13 Option (A) is correct.

We know that

$$loss \setminus P_G^2$$

$$loss \setminus \text{length}$$

Distance of load from $G_1$ is 25 km Distance of load from $G_2$ &$G_3$ is 75 km generally we supply load from nearest generator. So maximum of load should be supplied from $G_1$. But $G_2$ &$G_3$ should be operated at same minimum generation.

Sol. 14 Option (B) is correct.

Power angle for salient pole alternator is given by

$$\tan d = \frac{V_t \sin f + I_a X_q}{V_t \cos f + I_a R_a}$$

Since the alternator is delivering at rated kVA rated voltage

$$I_a = 1 \text{ pu}$$

$$V_t = 1 \text{ pu}$$

$$= \; = 0c$$

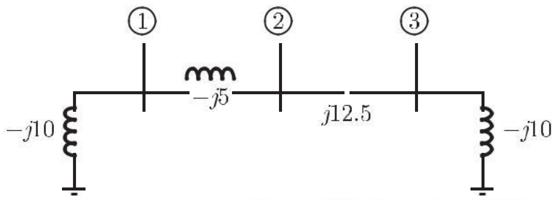
$$\sin f = 0, \; \cos f = 1$$

$$X_q = 1 \text{ pu}, \; X_d = 1.2 \text{ pu}$$

$$\tan d = \frac{1 \# 0 + 1(1)}{1 + 0} = 1 \; \& \; d = 45c$$

Sol. 15 Option (B) is correct.

The admittance diagram is shown below




here

$$y_{10} = -10j,\ y_{12} = -5j,\ y_{23} = 12.5j,\ y_{30} = -10j$$

*Note*: $y_{23}$ is taken positive because it is capacitive.

$$Y_{11} = y_{10} + y_{12} = -10j - 5j = -15j$$
$$Y_{12} = Y_{21} = -y_{21} = 5j$$
$$Y_{13} = Y_{31} = -y_{13} = 0$$
$$Y_{22} = y_{20} + y_{21} + y_{23} = 0 + (-5j) + (12.5j) = 7.5j$$
$$Y_{23} = Y_{32} = -y_{23} = -12.5j$$
$$Y_{33} = y_{30} + y_{13} + y_{23} = -10j + 0 + 12.5j = 2.5j$$

So the admittance matrix is

$$Y = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{33} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} = \begin{bmatrix} -15j & 5j & 0 \\ 5j & 7.5j & -12.5j \\ 0 & -12.5j & 2.5j \end{bmatrix}$$

Sol. 16 Option (A) is correct.

For generator $G_1$

$$X'_{G_1} = 0.25 \times \frac{100}{250} = 0.1 \text{ pu}$$

For generator $G_2$

$$X'_{G_1} = 0.10 \times \frac{100}{100} = 0.1 \text{ pu}$$

$$X_{L_2} = X_{L_1} = 0.225 \times 10 = 2.25\ \Omega$$

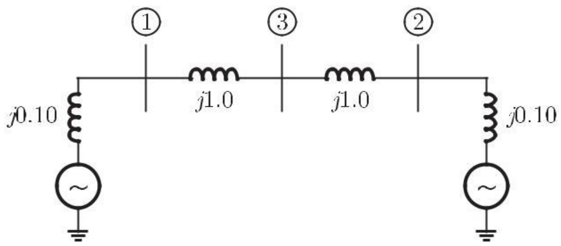
For transmission lines $L_1$ and $L_2$

$$Z_{base} = \frac{kV_{base}^2}{MVA_{base}} = \frac{15 \times 15}{100} = 2.25\ \Omega$$

$$X'_{L_2}\text{ (pu)} = \frac{2.25}{2.25} = 1 \text{ pu}$$

$$X'_{L_1}\text{ (pu)} = \frac{2.25}{2.25} = 1 \text{ pu}$$

So the equivalent pu reactance diagram



**Sol. 17** Option (D) is correct.

We can see that at the bus 3, equivalent thevenin's impedance is given by

$$X_{th} = ^\wedge j0.1 + j1.0h \,||\, ^\wedge j0.1 + j1.0h = j1.1 \,||\, j1.1 = j0.55 \text{ pu}$$

$$\text{Fault MVA} = \frac{\text{Base MVA}}{X_{th}} = \frac{100}{0.55} = 181.82 \text{ MVA}$$

**Sol. 18** Option (C) is correct.

Given that,

$$I > 0$$

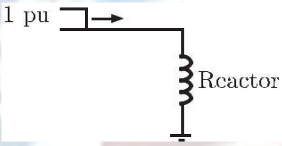
a $\qquad V_{AB} > 0$ since it is Rectifier O/P

$\qquad V_{CD} > 0$ since it is Inverter I/P

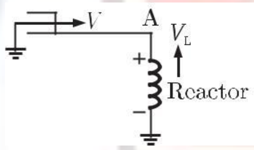
a $I > 0$ so $\qquad V_{AB} > V_{CD}$, Than current will flow in given direction.

**Sol. 19** Option (A) is correct.

Given step voltage travel along lossless transmission line.




a Voltage wave terminated at reactor as.




By Applying KVL

$$V + V_L = 0$$

$$V_L = - V$$

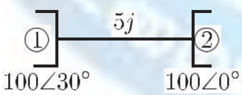
$$V_L = - 1 \text{ pu}$$

**Sol. 20** Option (A) is correct.

Given two buses connected by an Impedance of $(0 + j5)$W

The Bus '1' voltage is 100+30c V and Bus '2' voltage is 100+0c V

We have to calculate real and reactive power supply by bus '1'




$$P + jQ = VI \quad = 100{+}30c; \frac{100{+}30c - 100{+}0c}{5j} \text{E}$$

$$= 100{+}30c\,[20{+} - 60c - 20{+} - 90c]$$

$$= 2000{+} - 30c - 2000{+} - 60c$$

$$P + jQ = 1035{+}15c$$

real power $\qquad P = 1035 \cos 15c = 1000$ W

reactive power $\qquad Q = 1035 \sin 15c = 268$ VAR

**Sol. 21** Option (C) is correct.

Given 3-f, 33 kV oil circuit breaker.

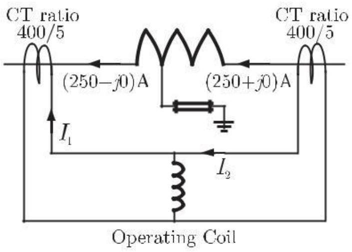
Rating 1200 A, 2000 MVA, 3 sec

Symmetrical breaking current $I_b$ = ?

$$I_b = \frac{MVA}{\sqrt{3}\text{ kV}}\text{ kA} = \frac{2000}{\sqrt{3} \# 33} = 34.99\text{ kA} - 35\text{ kA}$$

Sol. 22 Option (C) is correct.

Given a stator winding of an alternator with high internal resistance fault as shown in figure



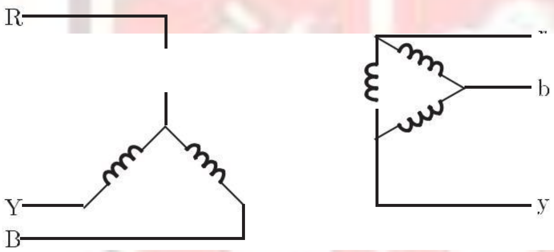

Current through operating coil

$$I_1 = 220 \# \frac{5}{400}\text{ A}, I_2 = 250 \# \frac{5}{400}\text{ A}$$

Operating coil current $= I_2 - I_1 = (250 - 220) \# 5/400 = 0.375$ Amp

Sol. 23 Option (C) is correct.

Zero sequence circuit of 3-f transformer shown in figure is as following:




No option seems to be appropriate but (C) is the nearest.

Sol. 24 Option (D) is correct.

Given that

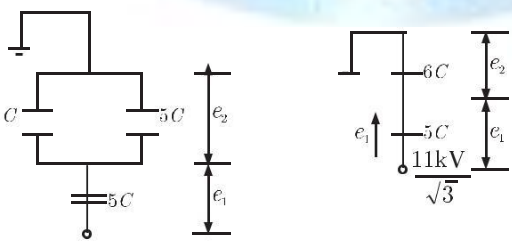
A 50 Hz Generator is initially connected to a long lossless transmission line which is open circuited as receiving end as shown in figure.

Due to ferranti effect the magnitude of terminal voltage does not change, and the field current decreases.

Sol. 25 Option (B) is correct.

Given : 3-f, 50 Hz, 11 kV distribution system, We have to find out $e_1$, $e_2$ = ?

Equivalent circuit is as following




$$e_1 = \frac{\frac{11}{\sqrt{3}}(6C)}{6C + 5C} = \frac{11}{\sqrt{3}} \# \frac{6}{11} = 3.46\text{ kV}$$

$$e_2 = \frac{11}{\sqrt{3}} \# \frac{5}{11} = 2.89 \text{ kV}$$

Sol. 26 Option (A) is correct.

Given : 3-f, 50 Hz, 11 kV cable

$$C_1 = 0.2 \text{ mF}$$

$$C_2 = 0.4 \text{ mF}$$

Charging current $I_C$ per phase = ?

$$\text{Capacitance Per Phase } C = 3C_1 + C_2$$

$$C = 3 \# 0.2 + 0.4 = 1 \text{ mF}$$

$$w = 2pf = 314$$

$$\text{Changing current } I_C = \frac{V}{X_C} = V(wC) = \frac{11 \# 10^3}{\sqrt{3}} \# 314 \# 1 \# 10^{-6}$$

$$= 2 \text{ Amp}$$

Sol. 27 Option (B) is correct.

Generator $G_1$ and $G_2$

$$X_{G1} = X_{G2} = X_{old} \# \frac{\text{New MVA}}{\text{Old MVA}} \# b \frac{\text{Old kV}}{\text{New kV}} l^2$$

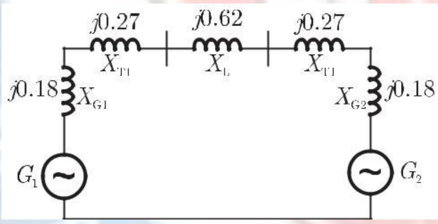
$$= j0.9 \# \frac{200}{100} \# b \frac{25}{25} l^2 =$$

$$j0.18 \text{ Same as } X_{T1} = j0.12 \# \frac{200}{90} \# b \frac{25}{25} l^2 =$$

$$j0.27 \; X_{T2} = j0.12 \# \frac{200}{90} \# b \frac{25}{25} l^2 = j0.27$$

$$X_{Line} = 150 \# \frac{220}{(220)^2} =$$

$j0.62$ The Impedance diagram is being given by as




Sol. 28 Option ( ) is correct.

Sol. 29 Option (C) is correct.

We know complex power

$$S = P + jQ = VI(\cos f + j \sin f) = VIe^{jf}$$

$$I = \frac{S}{Ve^{jf}}$$

a Real Power loss $= I^2 R$

$$P_L = c\,\frac{S}{Ve^{jf}} m^2 R = \frac{S^2 R}{e^{j2f}} \# \frac{1}{V^2} \quad \text{a} \quad \frac{S^2 R}{e^{j2f}} = \text{Constant}$$

So $$P_L \propto \frac{1}{V^2}$$

**Sol. 30** Option (C) is correct.

$Y_{Bus}$ matrix of Y-Bus system are given as

$$Y_{Bus} = j\begin{bmatrix} -5 & 2 & 2.5 & 0 \\ 2 & -10 & 2.5 & 4 \\ 2.5 & 2.5 & -9 & 4 \\ 0 & 4 & 4 & -8 \end{bmatrix}$$

We have to find out the buses having shunt element

We know

$$Y_{Bus} = \begin{bmatrix} y_{11} & y_{12} & y_{13} & y_{14} \\ y_{21} & y_{22} & y_{23} & y_{24} \\ y_{31} & y_{32} & y_{33} & y_{34} \\ y_{41} & y_{42} & y_{43} & y_{44} \end{bmatrix}$$

Here

$y_{11} = y_{10} + y_{12} + y_{13} + y_{14} = -5j$

$y_{22} = y_{20} + y_{21} + y_{23} + y_{24} = -10j$

$y_{33} = y_{30} + y_{31} + y_{32} + y_{34} = -9j$

$y_{44} = y_{40} + y_{41} + y_{42} + y_{43} = -8j$

$y_{12} = y_{21} = -y_{12} = 2j$

$y_{13} = y_{31} = -y_{13} = 2.5j$

$y_{14} = y_{41} = -y_{14} = 0j$

$y_{23} = y_{32} = -y_{23} = 2.5j$

$y_{24} = y_{42} = -y_{24} = 4j$

So

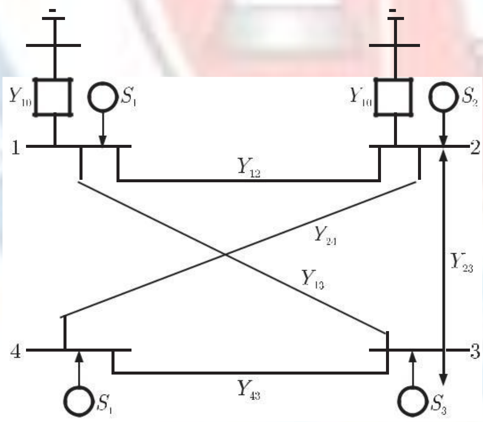
$y_{10} = y_{11} - y_{12} - y_{13} - y_{14} = -5j + 2j + 2.5j + 0j = -0.5j$

$y_{20} = y_{22} - y_{12} - y_{23} - y_{24} = -10j + 2j + 2.5j + 4j = -1.5j$

$y_{30} = y_{33} - y_{31} - y_{32} - y_{34} = -9j + 2.5j + 2.5j + 4j = 0$

$y_{40} = y_{44} - y_{41} - y_{42} - y_{43} = -8j - 0 + 4j + 4j = 0$

Admittance diagram is being made by as




From figure. it is cleared that branch (1) & (2) behaves like shunt element.

**Sol. 31** Option (B) is correct.

We know that

- Shunt Capacitors are used for improving power factor.
- Series Reactors are used to reduce the current ripples.
- For increasing the power flow in line we use series capacitor.
- Shunt reactors are used to reduce the Ferranti effect.

**Sol. 32** Option (C) is correct.

We know that for different type of transmission line different type of distance relays are used which are as follows.

Short Transmission line -Ohm reactance used

Medium Transmission Line -Reactance relay is used

Long Transmission line -Mho relay is used

**Sol. 33** Option (C) is correct.

Given that three generators are feeding a load of 100 MW. For increased load power demand, Generator having better regulation share More power, so Generator -1 will share More power than Generator -2.

**Sol. 34** Option (A) is correct.

Given Synchronous generator of 500 MW, 21 kV, 50 Hz, 3-f, 2-pole

P.F = 0.9, Moment of inertia $M = 27.5 \# 10^3$ kg-m$^2$

Inertia constant $H$ = ?

Generator rating in MVA $G = \frac{P}{\cos f} = \frac{500 \text{ MW}}{0.9}$ = 555.56 MVA

$CC = \frac{120 \# f}{\text{pole}} = \frac{120 \# 50}{2}$ = 3000 rpm

Stored K.E = $\frac{1}{2} M w^2 = \frac{1}{2} M b \frac{2p N}{60} l^2$

P $\frac{1}{2}$ # 27.5 # $10^3$ #b $\frac{2p \# 3000}{60}$ l MJ

N 1357.07 MJ

- = $\frac{1357.07}{555.56}$

= 2.44 sec

**Sol. 35** Option (D) is correct.

Given for X to F section of phase 'a'

$V_a$ -Phase voltage and $I_a$ -phase current.

Impedance measured by ground distance,

Relay at X = $\frac{\text{Bus voltage}}{\text{Current from phase 'a'}} = \frac{V_a}{I_a}$ W

**Sol. 36** Option (D) is correct.

For EHV line given data is

Length of line = 300 km and b = 0.00127S rad/km

wavelength $l = \frac{2p}{b} = \frac{2p}{0.00127}$ = 4947.39 km

So $\frac{l}{l}$ % = $\frac{300}{4947.39}$ # 100 = 0.06063 # 100

$\frac{l}{l}$ % = 6.063

**Sol. 37** Option (B) is correct.

For three phase transmission line by solving the given equation

We get,

$$\begin{bmatrix} DV_a \\ DV_b \\ DV_c \end{bmatrix} = \begin{bmatrix} (X_s - X_m) & 0 & 0 \\ 0 & (X_s - X_m) & 0 \\ 0 & 0 & (X_s + 2X_m) \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

Zero sequence Impedance = $X_s + 2X_m = 48$ ...(1)

and Positive Sequence Impedance = Negative Sequence Impedance

$= (X_s - X_m)$

$= 15$ ...(2)

By solving equation (1) and (2)

$$Z_s \text{ or } X_s = 26 \text{ and } Z_m \text{ or } X_m = 11$$

**Sol. 38** Option ( ) is correct.

**Sol. 39** Option (B) is correct.

SIL has no effect of compensation

So SIL = 2280 MW

**Sol. 40** Option (C) is correct.

Given $P_{G1} + P_{G2} = 250$ MW ...(1)

and
$$C_1(P_{G1}) = P_{G1} + 0.055P_{G1}^2$$
$$C_2(P_{G2}) = 3P_{G2} + 0.03P_{G2}^2$$ ...(2)

from equation (2)

$$\frac{dC_1}{dP_{G1}} = 1 + 0.11P_{G1}$$ ...(3a)

and $$\frac{dC_2}{dP_{G2}} = 3 + 0.06P_{G2}$$ ...(3b)

Since the system is loss-less

Therefore $$\frac{dC_1}{dP_{G1}} = \frac{dC_2}{dP_{G2}}$$

So from equations (3a) and (3b)

We have $0.11P_{G1} - 0.06P_{G2} = 2$ ...(4)

Now solving equation (1) and (4), we get

$$P_{G1} = 100 \text{ MW}$$
$$P_{G2} = 150 \text{ MW}$$

**Sol. 41** Option (B) is correct.

After connecting both the generators in parallel and scheduled to supply 0.5 Pu of power results the increase in the current.

& Critical clearing time will reduced from 0.28 s but will not be less than 0.14 s for transient stability purpose.

**Sol. 42** Option (D) is correct.

Given that the each section has equal impedance.

Let it be $R$ or $Z$, then by using the formula

$$\text{line losses} = /I^2 R$$

On removing ($e_1$); losses = $(1)^2 R + (1+2)^2 R + (1+2+5)^2 R =$
$R + 9R + 64R = 74R$

Similarly,

On removing $e_2$;losses = $5^2 R + (5+2)^2 R + (5+2+1)^2 R = 138R$

lossess on removing $e_3 = (1)^2 R + (2)^2 R + (5+2)^2 R$

$= 1R + 4R + 49R = 54R$

on removing $e_4$ lossless = $(2)^2 R + (2+1)^2 R + 5^2 R$

$= 4R + 9R + 25R = 38R$

So, minimum losses are gained by removing $e_4$ branch.

Sol. 43 Option (A) is correct.

Given : $V(t) = V_m \cos(wt)$

For symmetrical 3 - f fault, current after the fault

$$i(t) = Ae^{-(R/L)\,t} + \frac{\sqrt{2}\,V_m}{|Z|}\cos(w\,t - a)$$

At the instant of fault i.e $t = t_0$, the total current $i(t) = 0$

$$` \quad 0 = Ae^{-(R/L)\,t_0} + \frac{\sqrt{2}\,V_m}{|Z|}\cos(w\,t_0 - a)$$

$$Ae^{-(R/L)\,t_0} = -\frac{\sqrt{2}\,V_m}{|Z|}\cos(w\,t_0 - a)$$

Maximum value of the dc offset current

$$Ae^{-(R/L)\,t_0} = -\frac{\sqrt{2}\,V_m}{|Z|}\cos(w\,t_0 - a)$$

For this to be negative max.

$$(w\,t_0 - a) = 0$$

or $\quad t_0 = \frac{a}{w}$ ...(1)

and $\quad Z = 0.004 + j0.04$

$$Z = |Z| + a = 0.0401995 + 84.29c$$

$$a = 84.29c \text{ or } 1.471 \text{ rad.}$$

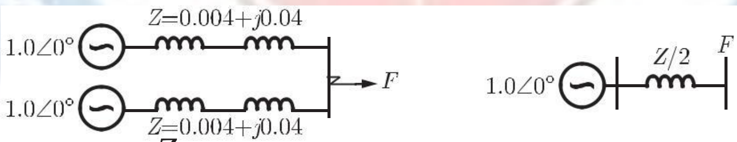
From equation (1)

$$t_0 = \frac{1.471}{(2p \# 50)} = 0.00468 \text{ sec}$$

$$t_0 = 4.682 \text{ ms}$$

Sol. 44 Option (C) is correct.

Since the fault 'F' is at mid point of the system, therefore impedance seen is same from both sides.




$\frac{Z}{2} = 0.0201 + 84.29c$

$Z_1$(Positive sequence) $= \frac{Z}{2} = 0.0201 + 84.29c$

also $Z_1 = Z_2 = Z_0$ (for 3-f fault)

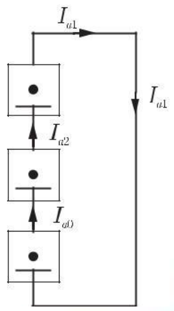
$$` \quad I_f(\text{pu}) = \frac{1+0c}{Z_1} = \frac{1+0c}{0.0201+84.29c}$$

So magnitude $\quad |I_f|_{(\text{p.u.})} = 49.8$

` Fault current $\quad I_f = 49.8 \# \frac{100}{\sqrt{3} \# 400} = 7.18 \text{ kA}$

Sol. 45 Option (A) is correct.

If fault is LG in phase 'a'




$$Z_1 = \frac{Z}{2} = 0.0201+84.29c$$

$$Z_2 = Z_1 = 0.0201+84.29c$$

and $$Z_0 = 3Z_1 = 0.0603+84.29c$$

Then $$I_a/3 = I_{a1} = I_{a2} = I_{a0}$$

$$I_{a1}(pu) = \frac{1.0+0c}{Z_1 + Z_2 + Z_0}$$

and $$|I_{a1}| = \frac{1.0}{(0.0201 + 0.0201 + 0.0603)} = 9.95 \text{ pu}$$

$$\text{Fault Current } I_f = I_a = 3I_{a1} = 29.85 \text{ pu}$$

So $$\text{Fault current } I_f = 29.85 \# \frac{100}{\sqrt{3} \# 400} = 4.97 \text{ kA}$$

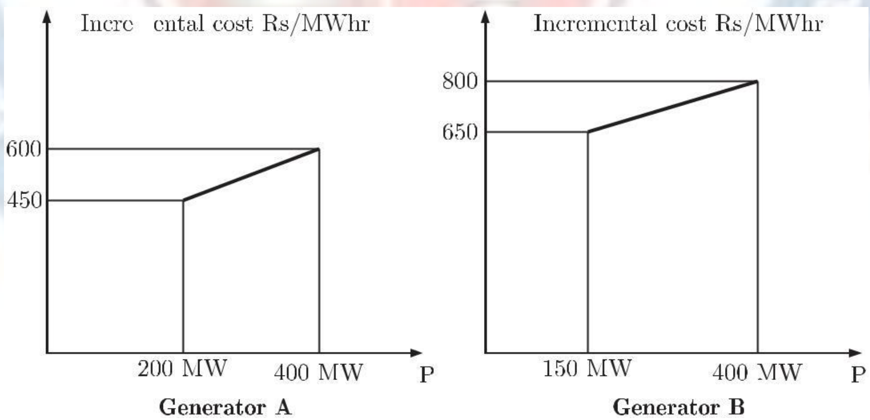
**Sol. 46** Option (A) is correct.

a Equal Phase shift of point A & B with respect to source from both bus paths.

So the type of transformer Y-Y with angle 0c.

**Sol. 47** Option (C) is correct.

Given incremental cost curve




$$P_A + P_B = 700 \text{ MW}$$

For optimum generator $P_A = ?$, $P_B = ?$

From curve, maximum incremental cost for generator A

= 600 at 450 MW

and maximum incremental cost for generator B

= 800 at 400 MW

minimum incremental cost for generator B

= 650 at 150 MW

Maximim incremental cost of generation A is less than the minimum incremental constant of generator B. So generator A operate at its maximum load = 450 MW for optimum generation.

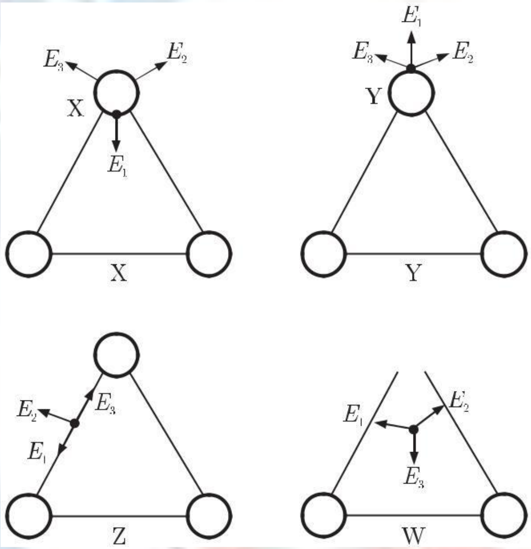
$$P_A = 450 \text{ MW}$$
$$P_B = (700 - 450)$$
$$= 250 \text{ MW}$$

Sol. 48 Option (C) is correct.

Here power sharing between the AC line and HVDC link can be changed by controlling the HVDC converter alone because before changing only grid angle we can change the power sharing between the AC line and HVDC link.

Sol. 49 Option (B) is correct.

We have to find out maximum electric field intensity at various points. Electric field intensity is being given by as follows




From figures it is cleared that at point Y there is minimum chances of cancelation. So maximum electric field intensity is at point Y.

Sol. 50 Option (D) is correct.

To increase capacitive dc voltage slowly to a new steady state value first we have to make d =- ve than we have to reach its original value.

Sol. 51 Option (B) is correct.

Given that

Reactance of line $= 0.045$ pu & $L = \frac{.045}{2p \# 50}$

Suspectance of Line $= 1.2$ pu & $C = \frac{1}{2p \# 50} \# \frac{1}{1.2}$

Velocity of wave propagation $= 3 \# 10^5$ Km/sec

Length of line $l = ?$

We know velocity of wave propagation

$$V_X = \frac{l}{\sqrt{LC}}$$

$$l = V_X \sqrt{LC} = 3 \# 10^5 \sqrt{\frac{.45}{2p \# 50} \# \frac{1}{2p \# 50} \# \frac{1}{1.2}} = 185 \text{ Km}$$

**Sol. 52** Option (C) is correct.

Due to the fault 'F' at the mid point and the failure of circuit-breaker '4' the sequence of circuit-breaker operation will be 5, 6, 7, 3, 1, 2 (as given in options) (due to the fault in the particular zone, relay of that particular zone must operate first to break the circuit, then the back-up protection applied if any failure occurs.)

**Sol. 53** Option (A) is correct.

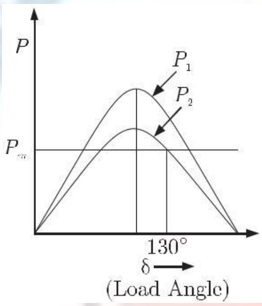
$$R = [V_{an}\ V_{bn}\ V_{cn}] \begin{bmatrix} 0 & \frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{3}} \\ -\frac{1}{\sqrt{3}} & 0 & \frac{1}{\sqrt{3}} \\ \frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{3}} & 0 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Solving we get

$$= \frac{V_{an}}{\sqrt{3}}(i_b - i_c) + \frac{V_{bn}}{\sqrt{3}}(i_c - i_a) + \frac{V_{cn}}{\sqrt{3}}(i_a - i_b)$$

$$w = 3(VI), \text{ where } \frac{(i_b - i_c)}{\sqrt{3}} = I \text{ and } V_{an} = V$$

**Sol. 54** Option (C) is correct.




Here $P_1$ " power before the tripping of one ckt

$P_2$ " Power after tripping of one ckt

$$P = \frac{EV}{X}\sin\delta$$

Since $P_{max} = \frac{EV}{X}$

` $P_{2max} = \frac{EV}{X_2}$, here, $[X_2 = (0.1 + X)(\text{pu})]$

To find maximum value of $X$ for which system does not loose synchronism

$P_2 = P_m$ (shown in above figure)

` $\frac{EV}{X_2}\sin\delta_2 = P_m$

as $P_m = 1$ pu, $E = 1.0$ pu, $V = 1.0$ pu

$$\frac{1.0 \times 1.0}{X_2}\sin 130° = 1$$

& $X_2 = 0.77$

& $(0.1 + X) = 0.77$

& $X = 0.67$

**Sol. 55** Option (B) is correct.

Given that $F_P = KAF_S$ ...(1)

where, Phase component $F_P = \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix}$, sequence component $F_S = \begin{bmatrix} f_p \\ f_n \\ f_o \end{bmatrix}$

and $A = $ R 1 V / S 2 1 1W / Sa a 1W / S 2 W / Sa a 1W / T X

$$V_P = KAV_S \qquad ...(2)$$

$$I_P = KAI_S$$

and $$V_S = Z_1 [I_S] \qquad ...(3)$$

where $$Z_1 = \begin{bmatrix} 0.5 & 0 & 0 \\ 0 & 0.5 & 0 \\ 0 & 0 & 2.0 \end{bmatrix}$$

We have to find out $Z$ if $V_P = ZI_P$ ...(4)

From equation (2) and (3)

$$V_P = KAZ_1 [I_S]$$

$$V_P = KAZ_1 \left( \frac{A^{-1}}{K} \right) I_P$$

$$V_P = [AZ_1 A^{-1}] V_P \qquad ...(5)$$

$A = $ S 1 2 1 1W / Sa a 1W / S 2 W / Sa a 1W

$$A^{-1} = \frac{\text{Adj } A}{|A|}$$

Adj $A$ = R 2 V / S1 a a W / S 2 a W / S W / S1 1 1 W / T X

$$|A| = \frac{1}{3}$$

$A^{-1} = \frac{1}{3}$ R 2 V / s1 a a W / S 2 W / S aW / S1 1 1 W / T X

From equation (5)

$V_P =$ R 1 1 1 0.5 0 / $\frac{1}{3}$ S 2 WS 0 S1 a a W / Sa a 1WS 0 0.5 0W 1 / S 2 WS 0 WS 1 W / Sa a 1WS 0 2WS1 1 W / T XT XT X ; R 1 0.5 0.5 V / S0.5 W / S W / S0.5 0.5 1 W / T X $I_p$ ...(6)

Comparing of equation (5) and (6)

$$Z = \begin{bmatrix} 1 & 0.5 & 0.5 \\ 0.5 & 1 & 0.5 \\ 0.5 & 0.5 & 1 \end{bmatrix}$$

**Sol. 56** Option (B) is correct.

Given that, 230 V, 50 Hz, 3-f, 4-wire system

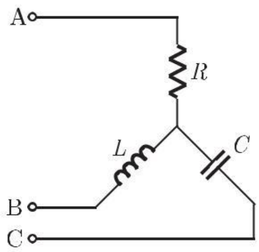
$P$ = Load = 4 kw at unity Power factor

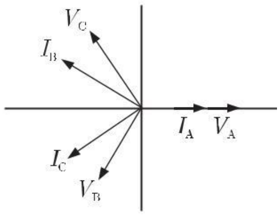
$I_N = 0$ through the use of pure inductor and capacitor

Than $L = ?, C = ?$

a $$I_N = 0 = I_A + I_B + I_C \qquad ...(1)$$

Network and its Phasor is being as




Here the inductor is in phase B and capacitor is in Phase C.

We know $P = VI$

So $I_a = \frac{P}{V} = \frac{4 \# 10^3}{230} = 17.39$ Amp.

From equation (1)

$$\overline{I_A} = -(\overline{I_B} + \overline{I_C}) \qquad a\ I_b - I_c$$

` $I_A = -c\ I_B \# \frac{\sqrt{3}}{2} + I_C \# \frac{\sqrt{3}}{2} m$

` $I_A = \sqrt{3} I_B = \sqrt{3} I_C$

$I_B - I_C = \frac{17.39}{\sqrt{3}} - 10$ Amp

Now $X_C = \frac{v}{I_C} = \frac{230}{10} - 23\ W$

and $X_C = \frac{1}{2pfC}$

& $C = \frac{1}{2pfX_C} = \frac{1}{2p \# 50 \# 23} = 139.02$ mF

$X_L = \frac{v}{I_L} = \frac{230}{10} - 23\ W = 2pfL$

& $L = \frac{X_L}{2pf} = \frac{23}{2p \# 100} = 72.95$ mH

So $L = 72.95$ mH in phase B

(8)= 139.02 mF in phase C

Sol. 57 Option (A) is correct.

Maximum continuous power limit of its prime mover with speed governor of 5% droop.

Generator feeded to three loads of 4 MW each at 50 Hz.

Now one load Permanently tripped

` $f = 48$ Hz

If additional load of 3.5 MW is connected than $f$ = ?

a Change in Frequency w.r.t to power is given as

$$Df = \frac{\text{drop out frequency}}{\text{rated power}} \# \text{Change in power}$$

$$= \frac{5}{15} \# 3.5 = 1.16\% = 1.16 \# \frac{50}{100} = 0.58 \text{ Hz}$$

System frequency is = 50 - 0.58 = 49.42 Hz

Sol. 58 Option (A) is correct.

Given that the first two power system are not connected and separately loaded.

Now these are connected by short transmission line.

as $P_1 = P_2 = Q_1 = Q_2 = 0$

So here no energy transfer. The bus bar voltage and phase angle of each system should be same than angle difference is

$$- = 30c - 20c = 10c$$

Sol. 59 Option (B) is correct.

With the help of physical length of line, we can recognize line as short, medium and long line.

Sol. 60 Option (A) is correct.

For capacitor bank switching vacuum circuit breaker is best suited in view of cost and effectiveness.

Sol. 61 Option (B) is correct.

Ratio of operating coil current to restraining coil current is known as bias in biased differential relay.

Sol. 62 Option (B) is correct.

HVDC links consist of rectifier, inverter, transmission lines etc, where rectifier consumes reactive power from connected AC system and the inverter supplies power to connected AC system.

Sol. 63 Option (C) is correct.

Given *ABCD* constant of 220 kV line

$A = D = 0.94+10c$, $B = 130+730c$, $C = 0.001+900c$, $V_S = 240$ kV

% voltage regulation is being given as

$$\%\text{V.R.} = \frac{(V_R)_{\text{No Load}} - (V_R)_{\text{Full load}}}{V_R\,(\text{Full load})} \# 100$$

At no load $I_R = 0$

$$(V_R)_{NL} = V_S/A,\ (V_R)_{\text{Full load}} = 220 \text{ kV}$$

$$\%\text{V.R.} = \frac{\frac{240}{0.94} - 220}{220} \# 100$$

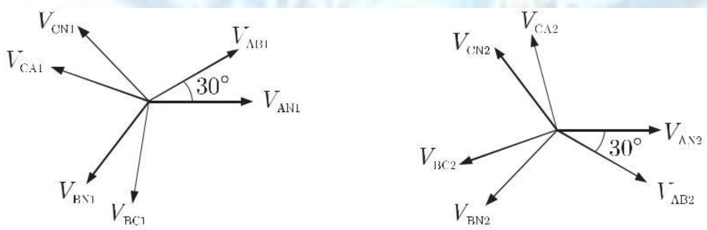
$$\%\text{V.R.} = 16$$

Sol. 64 Option ( ) is correct.

Sol. 65 Option (B) is correct.

Given that,

$V_{ab1} = X+q_1$, $V_{ab2} = Y+q_2$, Phase to neutral sequence volt= ? First we draw phasor of positive sequence and negative sequence.




Positive sequence    Negative sequence

From figure we conclude that positive sequence line voltage leads phase voltage by 30c

$$V_{AN1} = X+q_1 - 30c$$

$$V_{AN2} = 4+q_2 + 30c$$

**Sol. 66** Option (A) is correct.

For system base value 10 MVA, 69 kV, Load in pu($Z_{new}$) = ?

$$Z_{new} = Z_{old} \# \frac{(MVA)_{old}}{(MVA)_{new}} \# b \frac{kV_{new}}{kV_{old}} l^2$$

$$Z_{new} = 0.72 \# \frac{20}{10} \# b \frac{69}{13.8} l^2 = 36 \text{ pu}$$

**Sol. 67** Option (A) is correct.

Unreliable convergence is the main disadvantage of gauss seidel load flow method.

**Sol. 68** Option (C) is correct.

Generator feeds power to infinite bus through double circuit line 3-f fault at middle of line.

Infinite bus voltage($V$) = 1 pu

Transient internal voltage of generator($E$)= 1.1 pu

Equivalent transfer admittance during fault = 0.8 pu = $1/X$

delivering power($P_S$) = 1.0 pu

Perior to fault rotor Power angle d = 30c, $f$ = 50 Hz

Initial accelerating power($P_a$)= ?

$$P_a = P_S - P_{m2} \sin d$$

$$= 1 - \frac{EV}{X} \sin 30c = 1 - \frac{1.1 \# 1}{1/0.8} \# \frac{1}{2} = 0.56 \text{ pu}$$

**Sol. 69** Option (B) is correct.

If initial acceleration power = $X$ pu

Initial acceleration = ?

Inertia constant = ?

$$a = \frac{P_a}{M} = \frac{X(pu) \# S}{SH/180F} = \frac{180 \# 50 \# X \# S}{S \# S}$$

$$a = 1800X \text{ deg / sec}^2$$

$$\text{Inertia const.} = \frac{1}{18} = 0.056$$

**Sol. 70** Option (D) is correct.

The post fault voltage at bus 1 and 3 are.

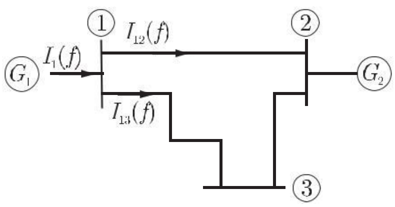
Pre fault voltage.

$$V_{Bus} = \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} 1+0c \\ 1+0c \\ 1+0c \end{bmatrix}$$

At bus 2 solid fault occurs $Z(f) = 0$, $r = 2$

$$\text{Fault current } I_f = \frac{V_r c}{Z_{rr} + Z_f} = \frac{V_2 c}{Z_{22} + Z_f}$$

$$Z_f = \frac{1+0c}{j0.24} = -4j$$



$V_i(f) = V_i c(0) - Z_{ir} I(f)$, $V_i c$ = Prefault voltage

$V_1(f) = V_i c - Z_{12} I_f = 1{+}0c - j\,0.08(-j4) = 1 - 0.32$

$V_1(f) = 0.68$ pu

$V_3(f) = V_3 c - Z_{32} I_f = 1{+}0c - j0.16(-j4) = 1 - 0.64$

$V_3(f) = 0.36$ pu

Sol. 71 Option ( ) is correct.

Sol. 72 Option (D) is correct.

Rating of D-connected capacitor bank for unity p.f.

real power $P_L = S\cos f = 12\sqrt{3} \# 0.8 = 16.627$ kW

reactive power $Q_L = S\sin f = 12\sqrt{3} \# 0.6 = 12.47$ kW

For setting of unity p.f. we have to set capacitor bank equal to reactive power = 12.47 kW

Sol. 73 Option (D) is correct.

Given that pu parameters of 500 MVA machine are as following

$N = 20$ pu, $X = 2$ pu

Now value of $M$ and $X$ at 100 MVA base are for inertia ($M$)

$(\text{pu})_{new} = (\text{pu})_{old} \# \frac{\text{old MVA}}{\text{new MVA}}$

$$(M_{pu})_{new} = (M_{Pu})_{old} \# \frac{500}{100} = 20 \# \frac{5}{1} = 100$$

pu and for reactance ($X$)

$(\text{pu})_{new} = (\text{pu})_{old} \# \frac{\text{new MVA}}{\text{old MVA}}$

$$(X_{pu})_{new} = (X_{pu})_{old} \# \frac{100}{500}$$

$$(X_{Pu})_{new} = 2 \# \frac{1}{5} = 0.4 \text{ pu}$$

Sol. 74 Option (D) is correct.

800 kV has Power transfer capacity = $P$

At 400 kV Power transfer capacity = ?

We know Power transfer capacity

$$P = \frac{EV}{X}\sin d$$

$$P \setminus V^2$$

So if $V$ is half than Power transfer capacity is $\frac{1}{4}$ of previous value.

Sol. 75 Option (B) is correct.

In EHV lines the insulation strength of line is governed by the switching over voltages.

Sol. 76 Option (A) is correct.

For bulk power transmission over very long distance HVDC transmission preferably used.

Sol. 77 Option (D) is correct.

Parameters of transposed overhead transmission line $X_S$ = 0.4 W/km, $X_m$ = 0.1 W/km f ve sequence reactance $X_1 = ?$

Zero sequence reactance $X_0 = ?$

We know for transposed overhead transmission line.

ve sequence component $X_1 = X_S - X_m = 0.4 - 0.1 = 0.3$ W/km Zero

sequence component $X_0 = X_S + 2X_m$

$= 0.4 + 2(0.1) = 0.6$ W/km

Sol. 78 Option (C) is correct.

Industrial substation of 4 MW load $= P_L$

$Q_C = 2$ MVAR for load p.f. = 0.97 lagging

If capacitor goes out of service than load p.f. = ?

$$\cos f = 0.97$$

$$\tan f = \tan(\cos^{-1} 0.97) = 0.25$$

$$\frac{Q_L - Q_C}{P_L} = 0.25$$

$$\frac{Q_L - 2}{4} = 0.25 \ \& \ Q_L = 3 \text{ MVAR}$$

$$f = \tan^{-1}\left(\frac{Q_L}{P_L}\right) = \tan^{-1}\left(\frac{3}{4}\right) = 36c$$

$$\cos f = \cos 36c = 0.8 \text{ lagging}$$

Sol. 79 Option (D) is correct.

$$Y_{22} = ?$$

$$I_1 = V_1 Y_{11} + (V_1 - V_2)Y_{12}$$

$$= 0.05V_1 - j10(V_1 - V_2) = -j9.95V_1 + j10V_2$$

$$I_2 = (V_2 - V_1) Y_{21} + (V_2 - V_3)Y_{23}$$

$$= j\,10V_1 - j9.9V_2 - j\,0.1V_3$$

$$Y_{22} = Y_{11} + Y_{23} + Y_2 = -j9.95 - j\,9.9 - 0.1j = -j19.95$$

Sol. 80 Option (C) is correct.

$$F_1 = a + bP_1 + cP_1^2 \text{ Rs/hour}$$

$$F_2 = a + bP_2 + 2cP_2^2 \text{ Rs/hour}$$

For most economical operation

$$P_1 + P_2 = 300 \text{ MW then } P_1, P_2 = ?$$

We know for most economical operation

$$\frac{2F_1}{2P_1} = \frac{2F_2}{2P_2}$$

$$2cP_1 + b = 4cP_2 + b$$

$$P_1 = 2P_2 \qquad ...(1)$$

$$P_1 + P_2 = 300 \qquad ...(2)$$

From eq (1) and (2)

$$P_1 = 200 \text{ MW}, P_2 = 100 \text{ MW}$$

Sol. 81 Option (B) is correct.

We know that *ABCD* parameters $\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_1 \end{bmatrix}$

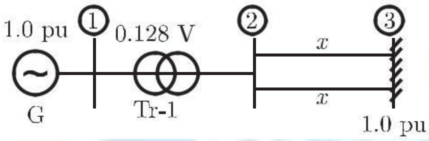
$$B = \frac{V_1}{I_2}\bigg|_{V_2 = 0}, \ C = \frac{I_1}{V_2}\bigg|_{I_2 = 0}$$

In figure $C = \dfrac{\dfrac{V_1}{Z_1 + Z_2}}{\dfrac{V_1}{Z_1 + Z_2} \# Z_2} = \dfrac{1}{Z_2}$

or $Z_2 = \dfrac{1}{C} = \dfrac{1}{0.025+45c} = 40+ - 45c$

Sol. 82 Option (D) is correct.

Given




Steady state stability Power Limit = 6.25 pu

If one of double circuit is tripped than

Steady state stability power limit = ?

$$P_{m1} = \frac{EV}{X} = \frac{1 \# 1}{0.12 + \frac{x}{2}} = 6.25$$

$$\frac{1}{0.12 + 0.5X} = 6.25$$

& $X = 0.008$ pu

If one of double circuit tripped than

$$P_{m2} = \frac{EV}{X} = \frac{1 \# 1}{0.12 + X} = \frac{1}{0.12 + 0.08}$$

$$P_{m2} = \frac{1}{0.2} = 5 \text{ pu}$$

Sol. 83 Option (D) is correct.

Given data

Substation Level = 220 kV

3-f fault level = 4000 MVA

LG fault level = 5000 MVA

Positive sequence reactance:

$$\text{Fault current } I_f = \frac{4000}{\sqrt{3} \# 220}$$

$$X_1 = V_{ph}/I_f$$

$$= \frac{\frac{220}{\sqrt{3}}}{\frac{4000}{\sqrt{3} \# 220}} = \frac{220 \# 220}{4000} = 12.1\ \text{W}$$

Sol. 84 Option (B) is correct.

Zero sequence Reactance $X_0$ = ?

$$I_f = \frac{5000}{\sqrt{3} \# 220}$$

$$I_{a1} = I_{a2} = I_{a0} = \frac{I_f}{3} = \frac{5000}{\sqrt{3}\ 3 \# 220}$$

$$X_1 + X_2 + X_0 = \frac{V_{ph}}{I_{a1}} = \frac{\frac{220}{\sqrt{3}}}{\frac{5000}{220 \# 3\sqrt{3}}}$$

$$X_1 + X_2 + X_0 = \frac{220 \# 220}{3 \# 5000} = 29.04 \text{ W}$$

$$X_1 = X_2 = 12.1 \text{ W}$$

$$X_0 = 29.04 - 12.1 - 12.1 = 4.84 \text{ W}$$

Sol. 85 Option (B) is correct.

Instantaneous power supplied by 3-f ac supply to a balanced $R$-$L$ load.

$$= V_a I_a + V_a I_b + V_c I_c$$

$$\text{w } (V_m \sin \text{w } t)\, I_m \sin(\text{w } t - \text{f}) + V_m \sin(\text{w } t - 120\text{c})\, I_m \sin(\text{w } t - 120\text{c} - \text{f})$$

$$V_m \sin(\text{w } t - 240\text{c})\, I_m \sin(\text{w } t - 240\text{c} - \text{f})$$

$$VI\, [\cos \text{f} - \cos(2\text{w } t - \text{f}) + \cos \text{f} - \cos(2\text{w } t - 240 - \text{f}) + \cos \text{f}$$

$$\cos(2\text{w } t + 240 - \text{f})]$$

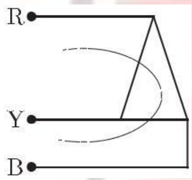
$$P = \; 3VI \cos \text{f} \qquad ...(1)$$

equation (1) implies that total instantaneous power is being constant.

Sol. 86 Option (C) is correct.

In 3-f Power system, the rated voltage is being given by RMS value of line to line voltage.

Sol. 87 Option (B) is correct.




In this figure the sequence is being given as RBY

Sol. 88 Option (C) is correct.

In thermal power plants, the pressure in the working fluid cycle is developed by the help to feed water pump.

Sol. 89 Option (A) is correct.

Kaplan turbines are used for harnessing low variable waterheads because of high percentage of reaction and runner adjustable vanes.

Sol. 90 Option (B) is correct.

MHO relay is the type of distance relay which is used to transmission line protection. MHO Relay has the property of being inherently directional.

Sol. 91 Option (C) is correct.

Surge impedance of line is being given by as

$$Z = \sqrt{\frac{L}{C}} = \sqrt{\frac{11 \# 10^{-3}}{11.68 \# 10^{-9}}} = 306.88 \text{ W}$$

Ideal power transfer capability

$$P = \frac{V^2}{Z_0} = \frac{(800)^2}{306.88} = 2085 \text{ MW}$$

Sol. 92 Option (D) is correct.

Given that,

Power cable voltage = 110 kV

$$C = 125 \text{ nF/km}$$

Dielectric loss tangent = tan d = 2 # $10^{-4}$

Dielectric power loss = ?

dielectric power loss is given by

$= \; = 2V^2$ w $C$ tan d

2(110 # $10^3)^2$ # 2 p$f$ # 125 # $10^{-9}$ # 2 # $10^{-4}$

2(121 # $10^8$ # 2 # 3.14 # 50 # 250 # $10^{-13}$) = 189 W/km

Sol. 93 Option (A) is correct.

Given data

Lightening stroke discharge impulse current of $I$ = 10 kA

Transmission line voltage = 400 kV

Impedance of line $Z$ = 250 W

Magnitude of transient over-voltage = ?

The impulse current will be equally divided in both directions since there is equal distribution on both sides.

Then magnitude of transient over-voltage is

$$V = IZ/2 = \frac{10}{2} \# 10^3 \# 250 =$$

$$1250 \# 10^3 \text{ V} = 1250 \text{ kV}$$

Sol. 94 Option (C) is correct.

The $A$, $B$, $C$, $D$ parameters of line

$A = D$ = 0.936+0.98c

$B$ = 142+76.4c

$C$ = (- 5.18 + $j$914)$10^{-6}$ W

At receiving end $P_R$ = 50 MW, $V_R$ = 220 kV

p.f = 0.9 lagging

$V_S$ = ?

Power at receiving end is being given by as follows

$$P_R = \frac{|V_S||V_R|}{|B|}\cos(b - d) - \frac{|A||V_R|^2}{|B|}\cos(b - a)$$

$$= \frac{|V_S| \# 220}{142}\cos(76.4c - d) - \frac{0.936(220)^2}{142}\cos 75.6c$$

$$\text{K} \; V_S \cos(76.4 - d) = \frac{50 \# 142}{220} + 0.936 \# 220 \# 0.2486 = 32.27 + 51.19$$

$$V_S \cos(76.4 - d) = 83.46 \qquad ...(1)$$

Same as $Q_R = P_R \tan f = P_R \tan(\cos^{-1} f) = 50 \tan(\cos^{-1} 0.9)$

= 24.21 MW

$$Q_R = \frac{|V_S||V_R|}{|B|}\sin(b - d) - \frac{|A||V_R|^2}{|B|}\sin(b - a)$$

$$= \frac{|V_S| \# 220}{142}\sin(76.4c - d) - \frac{0.936 \# (220)^2}{142}\sin 75.6c$$

$$(24.21)\frac{142}{220} + 0.936 \# 220 \# 0.9685 = |V_S|\sin(76.4c - d) \qquad ...(2)$$

from equation (1) & (2)

$$|V_S|^2 = (215)^2 + (83.46)^2$$

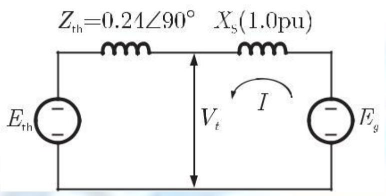
$$|V_S| = \sqrt{53190.5716} = 230.63 \text{ kV}$$

**Sol. 95** Option (B) is correct.

A new generator of $E_g = 1.4+30c$ pu

$X_S = 1.0$ pu, connected to bus of $V_t$ Volt

Existing Power system represented by thevenin's equivalent as $E_{th} = 0.9+0c$, $Z_{th} = 0.25+90c$, $V_t = ?$




From the circuit given

$$X = \frac{E_g - E_{th}}{Z_{th} + X_S} = \frac{1.4+30c - 0.9+0c}{j(1.25)} = \frac{1.212 + j7 - 0.9}{j(1.25)}$$

$$X = \frac{0.312 + j7}{j(1.25)} = 0.56 - 0.2496j$$

$$V_t = E_g - IX_S = 1.212 + j7 - (0.56 - 0.2496j)(j1)$$

$$R\ 1.212 - 0.2496 + j(0.7 - 0.56) = 0.9624 + j0.14\ V_t$$

$$= 0.972+8.3c$$

**Sol. 96** Option (C) is correct.

Given that

3-f Generator rated at 110 MVA, 11 kV

$X_d m = 19\%$, $X_d l = 26\%$

$X_S = 130\%$, Operating at no load

3-f short circuit fault between breaker and transformer

symmetrical $I_{rms}$ at breaker = ?

We know short circuit current

$$I_{sc} = \frac{1}{X_d m} = \frac{1}{j0.19} = -j5.26 \text{ pu}$$

$$\text{Base current } I_B = \frac{\text{rating MVA of generator}}{\sqrt{3} \# \text{kV of generator}}$$

$$I_B = \frac{110 \# 10^6}{\sqrt{3} \# 11 \# 10^3}$$

$$I_B = 5773.67 \text{ Amp}$$

Symmetrical RMS current $= I_B \# I_{sc}$

$$= 5773.67 \# 5.26 = 30369.50 \text{ Amp}$$

$$\& I_{rms} = 30.37 \text{ kA}$$

**Sol. 97** Option (A) is correct.

$$= \text{ve sequence current } I_a = \frac{1}{3}[I_a + aI_b + a^2 I_c]$$

$$\frac{1}{3}[10+0c + 1+120c \# 10+180c + 0]$$

$$\frac{1}{3}[10+0c + 10+300c] = \frac{1}{3}[10 + 5 - j8.66]$$

$$= \frac{1}{3}[15 - j8.66] = \frac{17.32\angle -30°}{3} = 5.78\angle -30°$$

Sol. 98

Option (D) is correct.

Given data 500 MVA , 50 Hz, 3 - $\phi$ generator produces power at 22 kV

Generator $\to$ $Y$ connected with solid neutral

Sequence reactance $X_1 = X_2 = 0.15$, $X_0 = 0.05$ pu

Sub transient line current = ?

$$I_{a1} = \frac{E}{Z_1 + Z_2 + Z_0} = \frac{1}{j0.15 + j0.15 + j0.05} = \frac{1}{0.35j} - 2.857j$$

Now sub transient Line current $I_a = 3I_{a1}$

$$I_a = 3(-2.857j) = -8.57j$$

Sol. 99

Option (B) is correct.

Given: 50 Hz, 4-Pole, 500 MVA, 22 kV generator

p.f. = 0.8 lagging

Fault occurs which reduces output by 40%.

Accelerating torque = ?

Power = 500 # 0.8 = 400 MW

After fault, Power = 400 # 0.6 = 240 MW

$$\because P_a = T_a \times \omega$$

$$T_a = \frac{P_a}{\omega}$$

Where $\omega = 2\pi f_{mechanical}$

$$f_{mechanical} = f_{electrical} \times \frac{2}{P} = f_{electrical} \times \frac{2}{4}$$

$$P_a = 400 - 240 = 160 \text{ MW}$$

$$T_a = \frac{160}{2 \times \pi \times 50/2}$$

$$T_a = 1.018 \text{ MN}$$

Sol. 100

Option (D) is correct.

Turbine rate speed $N = 250$ rpm

To produce power at $f = 50$ Hz.

No. of Poles $P = ?$

$$\because N = \frac{120f}{P}$$

$$P = \frac{120f}{N} = \frac{120 \times 50}{250} = 24$$

$$P = 24 \text{ Poles}$$

Sol. 101

Option (C) is correct.

In case of bundled conductors, We know that self GMD of conductor is increased and in a conductor critical disruptive voltage of line depends upon GMD of conductor. Since GMD of conductor is increased this causes critical disruptive voltage is being reduced and if critical disruptive voltage is reduced, the corona loss will also be reduced.

Sol. 102 Option (B) is correct.

Given that no. of buses $n = 300$

Generator bus = 20

Reactive power support buses = 25

Fixed buses with Shunt Capacitor = 15

Slack buses $(n_s) = 20 + 25 - 15 = 30$

a Size of Jacobian Matrix is given as

$$= 2(n - n_s) \# 2(n - n_s)$$
$$= 2(300 - 30) \# 2(300 - 30)$$
$$= 540 \# 540$$

Sol. 103 Option (B) is correct.

Auxiliary component in HVDC transmission system are DC line inductor and reactive power sources.

Sol. 104 Option (C) is correct.

a Exchanged electrical power is being given as follows

$$P = \frac{EV}{X_d} 6\sin(d_1 - d_2)@ \qquad ...(1)$$

Given that $P$ " Power supply by generator = 0.5 pu

= " Voltage for rotar generator = 2.0 pu

$V$ " Voltage of motor rotor = 1.3 pu

$X_d = X_{eq}$ = Reactance of generator + Reactance of motor

Recatance of connecting line

$X_d = 1.1 + 1.2 + 0.5 = 2.8$

$d_1 - d_2$ = Rotor angle difference = ?

from eq(1), $0.5 = \frac{Q\# 1.3}{2.82.6} \sin(d_1 - d_2)$ & $d_1 - d_2 = \sin^{-1} b\frac{2.8 \# 0.5}{} l = 32.58$

Sol. 105 Option (B) is correct.

Time period between energization of trip circuit and the arc extinction on an opening operation is known as the interrupting time of Circuit breaker.

Sol. 106 Option (B) is correct.

Given that $ABCD$ parameters of line as

$U = D = 0.9+0c$, $B = 200+90^{\%}$ W, $C = 0.95 \# 10^{-3}+90\%$ S. at no-load condition,

Receiving end voltage($V_R$) = sending end voltage($V_S$)

ohmic value of reactor = ?

We know $V_S = AV_R + BI_R$

$$V_S = V_R$$
$$V_R = AV_R + BI_R$$
$$V_R(1 - A) = BI_R$$
$$\frac{V_R}{I_R} = \frac{B}{1 - A} = \frac{200+90c}{1 - 0.9+0c}$$
$$\frac{V_R}{I_R} = 2000+90c$$

The ohmic value of reactor = 2000 W

Sol. 107 Option (A) is correct.

Surge impedance of cable

$$Z_1 = \sqrt{\frac{L}{C}} \; ; \qquad L = 0.4 \text{ mH/km}, C = 0.5 \text{ mF/km}$$

$$f \sqrt{\frac{0.4 \# 10^{-3}}{0.5 \# 10^{-6}}} = 28.284$$

surge impedance of overhead transmission line

$$Z_2 = Z_3 = \sqrt{\frac{L}{C}} \; ; \qquad L = 1.5 \text{ mm/km}, C = 0.015 \text{ mF/km}$$

$$Z_2 = Z_3 = \sqrt{\frac{1.5 \# 10^{-5}}{0.015 \# 10^{-6}}} = 316.23$$

Now the magnitude of voltage at junction due to surge is being given by as

$$V_l = \frac{2 \# V \# Z_2}{Z_2 + Z_1} \quad V = 20 \text{ kV}$$

$$= \frac{2 \# 20 \# 10^3 \# 316.23}{316 + 28.284} = 36.72 \text{ kV}$$

Sol. 108 Option (D) is correct.

Let that current in line is $I$ amp than from figure current in line section PR is ($I$ - 10) amp current in line section RS is ($I$ - 10 - 20) = ($I$ - 30) amp current in SQ Section is ($I$ - 30 - 30) = ($I$ - 60) amp Given that $V_P$ and $V_Q$ are such that

$$V_P - V_Q = 3 \text{ V}$$

Applying KVL through whole line

$$V_P - V_Q = (I - 10)0.1 + (I - 30)0.15 + (I - 60) \# 0.2$$

$$= \quad 3 = 0.45I - 17.5$$

$$= = \frac{20.5}{0.45} = 45.55 \text{ amp}$$

Now the line drop is being given as

$$(I - 10)0.1 + (I - 30)0.15 + (I - 60)0.2$$

$$(33.55)0.1 + (15.55)0.15 + (14.45)0.2$$

$$8.58 \text{ V}$$

$$= 220 + \text{Line voltage} = 220 + 8.58$$

$$= 228.58 \text{ V}$$

Sol. 109 Option (B) is correct.

A balanced delta connected load = 8 + 6$j$ = 2

$$V_2 = 400 \text{ volt}$$

Improved Power Factor $\cos f_2 = 0.9$

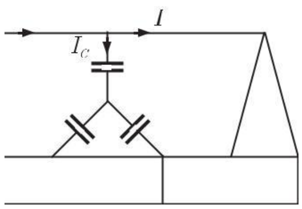
$$f_1 = \tan^{-1} 6/8 = 36.85c$$

$$f_2 = \cos^{-1}(0.9) = 25.84c$$

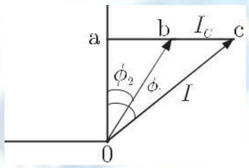
$$I = \frac{V}{Z} = \frac{400}{8 + 6j} = \frac{400}{10+36.86c} = 40+ - 36.86c$$

$$= 32 - j24$$

Since Power factor is Improved by connecting a Y-connected capacitor bank like as




Phasor diagram is being given by as follows




In figure $oa = I l \cos f_2 = I \cos f_1$

$Il \cos 25.84c = 32$

$Il \# 0.9 = 32$

$Il = 35.55$

$ac = 24$ Amp. $(ac = I \sin f_1)$

$ab = Il \sin f_2 = 35.55 \sin 25.84c$

$ab = 15.49$ Amp

$I_c = bc = ac - ab = 24 - 15.49 = 8.51$ Amp

KVAR of Capacitor bank = $\dfrac{3 \# V \# I_C}{1000} = \dfrac{3 \# 400 \# 8.51}{1000}$

= 10.2 KVAR

Sol. 110 Option (D) is correct.

Given Load Power = 100 MW

$V_S = V_R = 11$ kV

Impedance of line $Z_L = \dfrac{\text{p.u.} \# (\text{kV})^2}{\text{MV}} = \dfrac{j0.2 \# (11)^2}{100} = j0.242$ W

We know $P_L = \dfrac{|V_S||V_R| \sin d}{X}$

$O \quad \# 10^6 = \dfrac{11 \# 10^3 \# 11 \# 10^3}{0.242} \sin d$

$AA \quad \dfrac{\# 0.242}{121} = \sin d$

$F = \sin^{-1}(0.2) = 11.537c$

Reactive Power is being given by

$Q_L = \dfrac{|V_S||V_R|}{X} \cos d - \dfrac{|V_R|^2}{X}$

$W \dfrac{11 \# 10^3 \# 11 \# 10^3}{0.242} \cos(11.537c) - \dfrac{(11 \# 10^3)^2}{0.242}$

$V \dfrac{121 \# 10^6}{0.242} [\cos(11.537c) - 1]$

$W \quad - 10.1$ MVAR

**Sol. 111** Option (B) is correct.

Given the bus Impedance Matrix of a 4-bus Power System

$$Z_{bus} = \begin{bmatrix} j0.3435 & j0.2860 & j0.2723 & j0.2277 \\ j0.2860 & j0.3408 & j0.2586 & j0.2414 \\ j0.2723 & j0.2586 & j0.2791 & j0.2209 \\ j0.2277 & j0.2414 & j0.2209 & j0.2791 \end{bmatrix}$$

Now a branch os $j0.2\ \Omega$ is connected between bus 2 and reference

$$Z_{B(New)} = Z_{B(Old)} - \frac{1}{Z_{ij} + Z_b}\begin{bmatrix} Z_{ij} \\ \vdots \\ Z_{nj} \end{bmatrix}\begin{bmatrix} Z_{ji} & \cdots & Z_{jn} \end{bmatrix}$$

New element $Z_b = j0.2\ \Omega$ is connected in $j^{th}$ and reference bus $j = 2$, $n = 4$ so

$$\frac{1}{Z_{ij} + Z_b}\begin{bmatrix} Z_{12} \\ Z_{22} \\ Z_{23} \\ Z_{24} \end{bmatrix}\begin{bmatrix} Z_{21} & Z_{22} & Z_{23} & Z_{24} \end{bmatrix}$$

$$= \frac{1}{j(0.3408) + j0.2}\begin{bmatrix} j0.2860 \\ j0.3408 \\ j0.2586 \\ j0.2414 \end{bmatrix}\begin{bmatrix} j0.2860 & j0.3408 & j0.2586 & j0.2414 \end{bmatrix} \qquad \text{...(1)}$$

Given that we are required to change only $Z_{22}, Z_{23}$

So in equation (1)

$$Z'_{22} = \frac{j^2 (0.3408)^2}{j(0.5408)} = j0.2147$$

$$Z'_{23} = \frac{j^2 (0.3408)(0.2586)}{0.5408} = j0.16296$$

$$Z_{22(New)} = Z_{22(Old)} - Z'_{22} = j0.3408 - j0.2147 = j0.1260$$

$$Z_{23(New)} = Z_{23(Old)} - Z'_{23} = j0.2586 - j0.16296 = j0.0956$$

**Sol. 112** Option (D) is correct.

Total zero sequence impedance, $+ve$ sequence impedance and $-ve$ sequence impedances

$$Z_0 = (Z_0)_{Line} + (Z_0)_{Generator} = j0.04 + j0.3 = j0.34 \text{ pu}$$

$$Z_1 = (Z_1)_{Line} + (Z_1)_{Generator} = j0.1 + j0.1 = j0.2 \text{ pu}$$

$$Z_2 = (Z_2)_{Line} + (Z_2)_{Generator} = j0.1 + j0.1 = j0.2 \text{ pu}$$

$$Z_n = j0.05 \text{ pu}$$

for L-G fault

$$I_{a1} = \frac{E_a}{Z_0 + Z_1 + Z_2 + 3Z_n} = \frac{0.1}{j0.2 + j0.2 + j0.34 + j0.15}$$

$$\simeq -j1.12 \text{ pu}$$

$$I_B = \frac{\text{generator MVA}}{\sqrt{3}\ \text{generator kV}} = \frac{20 \times 10^6}{\sqrt{3} \times 6.6 \times 10^3} = 1750 \text{ Amp}$$

Fault current

$$I_f = (3I_a) I_B = 3(-j1.12)(1750) = -j5897.6 \text{ Amp}$$

Neutral Voltage

$$V_n = I_f Z_n$$

and

$$Z_n = Z_B \times Z_{pu}$$

$$= \frac{(6.6)^2}{20} \times 0.05 = 0.1089\ \Omega$$

$$V_n = 5897.6 \# 0.1089 = 642.2 \text{ V}$$

**Sol. 113** Option (A) is correct.

We know that Optimal Generation

$$IC_1 = IC_2, \text{ and } P_3 = 300 \text{ MW (maximum load)}$$

$$IC_3 = 30 \qquad \text{(Independent of load)}$$

$$20 + 0.3P_1 = 30 + 0.4 P_2$$

$$0.3P_1 - 0.4P_2 = 10 \qquad ...(1)$$

$$P_1 + P_2 + P_3 = 700$$

$$P_1 + P_2 + 300 = 700$$

$$P_1 + P_2 = 400 \qquad ...(2)$$

From equation (1) and (2)

$$P_1 = 242.8 \text{ MW}$$

$$P_2 = 157.14 \text{ MW}$$

**Sol. 114** Option (A) is correct.

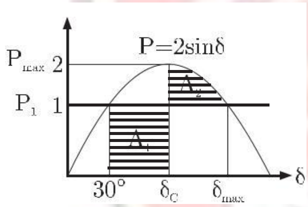
For transmission line protection-distance relay

For alternator protection-under frequency relay

For bus bar protection-differential relay

For transformer protection-Buchholz relay

**Sol. 115** Option (C) is correct.




We know by equal area criteria

$$P_S (d_m - d_0) = \#_{d_C}^{d_m} P_{max} \sin d d d$$

$$P_{max} \sin d_0 (d_m - d_0) = P_{max} [\cos d_0 - \cos d_m] \qquad ...(1)$$

$$P_{max} = 2$$

$$P_0 = P_{max} \sin d_0 = 1$$

$$d_0 = 30c$$

$$d_{max} = 110c \text{ (given)}$$

Now from equation (1)

$$2 \sin 30c(110 - 30) \frac{p}{180} = 2[\cos d_c - \cos 110c]$$

$$0.5 \# \frac{80p}{180} = \cos d_c + 0.342$$

$$\cos d_c = 0.698 - 0.342$$

$$d_c = 69.138c$$

**Sol. 116** Option (D) is correct.

a Both sides are granted

So, $$I_a = \frac{E_a}{Z_a} = \frac{10+0c}{2j} = 5+ - 90c$$

$$I_b = \frac{E_b}{Z_b} = \frac{10+ - 90c}{3j} = 3.33+ - 180c$$

$$I_c = \frac{E_c}{Z_c} = \frac{10+120c}{4j} = 2.5+30c$$

We know $I_{a_1} = \frac{1}{3}[I_a + aI_b + a^2 I_c]$

where a = 1+120c & $a^2$ = 1+240c

$$I_{a1} = \frac{1}{3}[5+ - 90c + 3.33+ \hat{}- 180c + 120ch + 2.5+\hat{}240c + 30ch]$$

$$I_{a1} = \frac{1}{3}[5+ - 90c + 3.33+ - 60c + 2.5+270c]$$

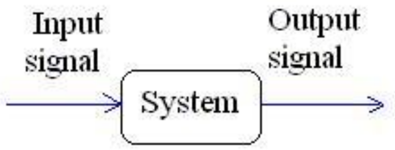
$$= \frac{1}{3}[- 5j + 1.665 - j2.883 - 2.5j]$$

$$= \frac{1}{3}[1.665 - j10.383] = 3.5+ - 80.89c$$

# SIGNALS & SYSTEMS

The intent of this introduction is to give the reader an idea about **Signals and Systems** as a field of study and its applications. But we must first, at least vaguely define what signals and systems are.

- Signals are functions of one or more variables .
- Systems respond to an input signal by producing an output signal .




**Examples of signals include :**

13. **A voltage signal**: voltage across two points varying as a function of time.
14. **A force pattern**: force varying as a function of 2-dimensional space.
15. **A photograph***:* color and intensity as a function of 2-dimensional space.
16. **A video signal:** color and intensity as a function of 2-dimensional space and time.

**Examples of systems include :**

K. **An oscilloscope**: takes in a voltage signal, outputs a 2-dimensional image characteristic of the voltage signal.
L. **A computer monitor:** inputs voltage pulses from the CPU and outputs a time varying display.
M. **An accelerating mass :** force as a function of time may be looked at as the input signal, and velocity as a function of time as the output signal.
N. **A capacitance:** terminal voltage signal may be looked at as the input, current signal as the output.

**Examples of mechanical and electrical systems**

You are surely familiar with many of these signals and systems and have probably analyzed them as well, but in isolation . For instance, you must have studied accelerating masses in a mechanics course (see Fig (a)), and capacitances in an electrostatic course (see Fig (b)), separately.

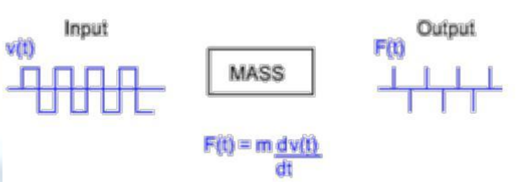



Fig (a)

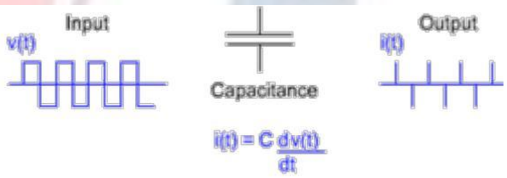



Fig (b)

As you can see, there is a similarity in the way the input signal is related to the output signal. These similarities will interest us in this course as we may be able to make inferences common to both these systems from these similarities.

We will develop very general tools and techniques of analyzing systems, independent of the actual context of their use. Our approach in this course would be to define certain properties of signals and systems (inspired of course by properties real-life examples we have), and then link these properties to consequences. These "links" can then be used directly in connection with a large variety of systems: electrical, mechanical, chemical, biological… knowing only how the input and output signal are related! Thus, our focus when dealing with signals and systems will be on the relationship between the input and output signal and not really on the internals of the system.

## Issues that will concern us in signals and systems include

X. Characterization (description of behavior) of systems and signals.
Y. Design of systems with certain desired properties.
Z. Modification of existing systems to our advantage.

# SIGNALS & SYSTEMS

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**Q. 1** A band-limited signal with a maximum frequency of 5 kHz is to be sampled. According to the sampling theorem, the sampling frequency which is not valid is

(A) 5 kHz (B) 12 kHz

(C) 15 kHz (D) 20 kHz

**Q. 2** For a periodic signal $v(t) = 30 \sin 100t + 10 \cos 300t + 6 \sin(500t + \pi/4)$, the fundamental frequency in rad/s

(A) 100 (B) 300

(C) 500 (D) 1500

**Q. 3** Two systems with impulse responses $h_1(t)$ and $h_2(t)$ are connected in cascade. Then the overall impulse response of the cascaded system is given by

- product of $h_1(t)$ and $h_2(t)$
- sum of $h_1(t)$ and $h_2(t)$
- convolution of $h_1(t)$ and $h_2(t)$
- subtraction of $h_2(t)$ from $h_1(t)$

**Q. 4** Which one of the following statements is NOT TRUE for a continuous time causal and stable LTI system?

- All the poles of the system must lie on the left side of the $j\omega$ axis
- Zeros of the system can lie anywhere in the s-plane
- All the poles must lie within $|s| = 1$
- All the roots of the characteristic equation must be located on the left side of the $j\omega$ axis.

**Q. 5** The impulse response of a system is $h(t) = tu(t)$. For an input $u(t-1)$, the output is

(A) $\frac{t^2}{2} u(t)$ (B) $\frac{t(t-1)}{2} u(t-1)$

(C) $\frac{(t-1)^2}{2} u(t-1)$ (D) $\frac{t^2 - 1}{2} u(t-1)$

**Q. 6** The rms value of the resultant current in a wire which carries a dc current of 10 A and a sinusoidal alternating current of peak value 20 is

(A) 14.1 A (B) 17.3 A

(C) 22.4 A (D) 30.0 A

Q. 7 If $x[n] = (1/3)^{|n|} - (1/2)^n u[n]$, then the region of convergence (ROC) of its $z$-transform in the $z$-plane will be

(A) $\frac{1}{3} < |z| < 3$ (B) $\frac{1}{3} < |z| < \frac{1}{2}$

(C) $\frac{1}{2} < |z| < 3$ (D) $\frac{1}{3} < |z|$

Q. 8 The unilateral Laplace transform of $f(t)$ is $\frac{1}{s^2 + s + 1}$. The unilateral Laplace transform of $tf(t)$ is

(A) $-\frac{s}{(s^2 + s + 1)^2}$ (B) $-\frac{2s + 1}{(s^2 + s + 1)^2}$

(C) $\frac{s}{(s^2 + s + 1)^2}$ (D) $\frac{2s + 1}{(s^2 + s + 1)^2}$

Q. 9 Let $y[n]$ denote the convolution of $h[n]$ and $g[n]$, where $h[n] = (1/2)^n u[n]$ and $g[n]$ is a causal sequence. If $y[0] = 1$ and $y[1] = 1/2$, then $g[1]$ equals

(A) 0 (B) 1/2

(C) 1 (D) 3/2

Q. 10 The Fourier transform of a signal $h(t)$ is $H(j\omega) = (2\cos\omega)(\sin 2\omega)/\omega$. The value of $h(0)$ is

(A) 1/4 (B) 1/2

(C) 1 (D) 2

Q. 11 The input $x(t)$ and output $y(t)$ of a system are related as $y(t) = \int_{-\infty}^{t} x(\tau)\cos(3\tau)\,d\tau$. The system is

(A) time-invariant and stable

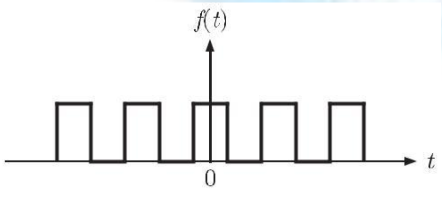
(B) stable and not time-invariant

(C) time-invariant and not stable

(D) not time-invariant and not stable

---

Q. 12 The Fourier series expansion $f(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos n\omega t + b_n \sin n\omega t$ of the periodic signal shown below will contain the following nonzero terms




(A) $a_0$ and $b_n, n = 1,3,5,...\infty$ (B) $a_0$ and $a_n, n = 1,2,3,...\infty$

(C) $a_0$, $a_n$ and $b_n, n = 1,2,3,...\infty$ (D) $a_0$ and $a_n$ $n = 1,3,5,...\infty$

Q. 13 Given two continuous time signals $x(t) = e^{-t}$ and $y(t) = e^{-2t}$ which exist for $t > 0$, the convolution $z(t) = x(t) * y(t)$ is

(A) $e^{-t} - e^{-2t}$ (B) $e^{-3t}$

(C) $e^{+t}$ (D) $e^{-t} + e^{-2t}$

Q. 14 Let the Laplace transform of a function $f(t)$ which exists for $t > 0$ be $F_1(s)$ and the Laplace transform of its delayed version $f(t - t)$ be $F_2(s)$. Let $F_1^*(s)$ be the complex conjugate of $F_1(s)$ with the Laplace variable set $s = s + jw$. If $G(s) = \frac{F_2(s) F_1^*(s)}{|F_1(s)|^2}$, then the inverse Laplace transform of $G(s)$ is an ideal

(A) impulse d($t$) (B) delayed impulse d ($t$ - t)

(C) step function $u(t)$ (D) delayed step function $u(t - t)$

Q. 15 The response $h(t)$ of a linear time invariant system to an impulse d($t$), under initially relaxed condition is $h(t) = e^{-t} + e^{-2t}$. The response of this system for a unit step input $u(t)$ is

(A) $u(t) + e^{-t} + e^{-2t}$ (B) $(e^{-t} + e^{-2t})u(t)$

(C) $(1.5 - e^{-t} - 0.5e^{-2t})u(t)$ (D) $e^{-t}$ d $(t) + e^{-2t} u(t)$

Q. 16 For the system $2/(s + 1)$, the approximate time taken for a step response to reach 98% of the final value is

(A) 1 s (B) 2 s

(C) 4 s (D) 8 s

Q. 17 The period of the signal $x(t) = 8 \sin\left(0.8pt + \frac{p}{\ }\right)$ is

(A) $0.4p$ s (B) $0.8p$ s

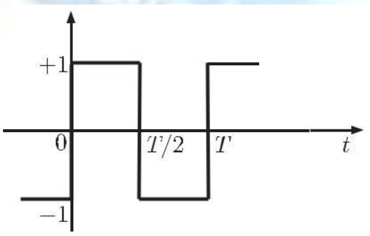
(C) 1.25 s (D) 2.5 s

Q. 18 The system represented by the input-output relationship $y(t) = \int_{-3}^{5t} x(t)\, dt$, $t > 0$ is

(A) Linear and causal (B) Linear but not causal

(C) Causal but not linear (D) Neither liner nor causal

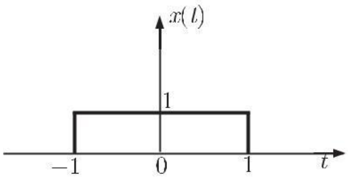
Q. 19 The second harmonic component of the periodic waveform given in the figure has an amplitude of




(A) 0 (B) 1

(C) $2/p$ (D) $\sqrt{5}$

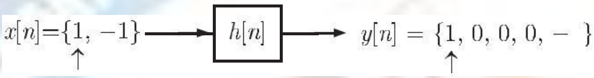
Q. 20 $x(t)$ is a positive rectangular pulse from $t = -1$ to $t = +1$ with unit height as shown in the figure. The value of $\#_{-3}^{3} |X(w)|^2 dw$ where $X(w)$ is the Fourier transform of $x(t)$} is.




(A) 2 (B) $2p$

(C) 4 (D) $4p$

Q. 21 Given the finite length input $x[n]$ and the corresponding finite length output $y[n]$ of an LTI system as shown below, the impulse response $h[n]$ of the system is

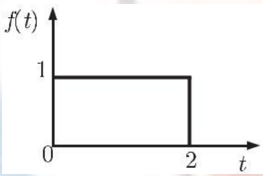


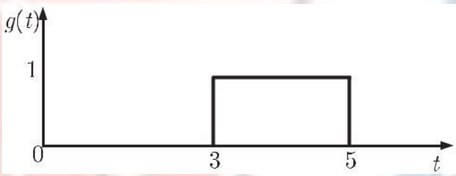

(A) $h[n] = \{1, 0, 0, 1\}$ (B) $h[n] = \{1, 0, 1\}$

(C) $h[n] = \{1, 1, 1, 1\}$ (D) $h[n] = \{1, 1, 1\}$

**Common Data Questions Q.22-23.**

Given $f(t)$ and $g(t)$ as show below




Q. 22 $g(t)$ can be expressed as

(A) $g(t) = f(2t - 3)$ AA. $g(t) = f\left(\frac{t}{2} - 3\right)$

(C) $g(t) = f\left(2t - \frac{3}{2}\right)$ (C) $g(t) = f\left(\frac{t}{2} - \frac{3}{2}\right)$

Q. 23 The Laplace transform of $g(t)$ is

(A) $\frac{1}{s}(e^{3s} - e^{5s})$ (GG) $\frac{1}{s}(e^{-5s} - e^{-3s})$

(C) $\frac{e^{-3s}}{s}(1 - e^{-2s})$ (Q) $\frac{1}{s}(e^{5s} - e^{3s})$

Q. 24 A Linear Time Invariant system with an impulse response $h(t)$ produces output $y(t)$ when input $x(t)$ is applied. When the input $x(t - t)$ is applied to a system with impulse response $h(t - t)$, the output will be

(A) $y(t)$ (B) $y(2(t - t))$

(C) $y(t - t)$ (D) $y(t - 2t)$

Q. 25 A cascade of three Linear Time Invariant systems is causal and unstable. From this, we conclude that

(A) each system in the cascade is individually causal and unstable

(B) at least on system is unstable and at least one system is causal

(C) at least one system is causal and all systems are unstable

(D) the majority are unstable and the majority are causal

Q. 26 The Fourier Series coefficients of a periodic signal $x(t)$ expressed as $x(t) = /_{k=-3}^{3} a_k e^{j 2pkt/T}$ are given by $a_{-2} = 2 - j1$, $a_{-1} = 0.5 + j0.2$, $a_0 = j2$, $a_1 = 0.5 - j0.2$, $a_2 = 2 + j1$ and $a_k = 0$ for $|k| > 2$

Which of the following is true ?

(X) $x(t)$ has finite energy because only finitely many coefficients are non-zero

(Y) $x(t)$ has zero average value because it is periodic

(Z) The imaginary part of $x(t)$ is constant

(AA) The real part of $x(t)$ is even

Q. 27 The z-transform of a signal $x[n]$ is given by $4z^{-3} + 3z^{-1} + 2 - 6z^{2} + 2z^{3}$

It is applied to a system, with a transfer function $H(z) = 3z^{-1} - 2$

Let the output be $y[n]$. Which of the following is true ?

(A) $y[n]$ is non causal with finite support

(B) $y[n]$ is causal with infinite support

(C) $y[n] = 0; |n| > 3$

(D) $\mathrm{Re}[Y(z)]_{z = e^{ji}} =- \mathrm{Re}[Y(z)]_{z = e^{-ji}}$

$\mathrm{Im}[Y(z)]_{z = e^{ji}} = \mathrm{Im}[Y(z)]_{z = e^{-ji}}; - p \# q < p$

Q. 28 The impulse response of a causal linear time-invariant system is given as $h(t)$.

Now consider the following two statements :

**Statement (I)**: Principle of superposition holds

**Statement (II):** $h(t) = 0$ for $t < 0$

Which one of the following statements is correct ?

(A) Statements (I) is correct and statement (II) is wrong

(B) Statements (II) is correct and statement (I) is wrong

(C) Both Statement (I) and Statement (II) are wrong

(D) Both Statement (I) and Statement (II) are correct

Q. 29 A signal $e^{-at}\sin(wt)$ is the input to a real Linear Time Invariant system. Given $K$ and $f$ are constants, the output of the system will be of the form $Ke^{-bt}\sin(vt + f)$ where

(A) $b$ need not be equal to $a$ but $v$ equal to $w$

(B) $v$ need not be equal to $w$ but $b$ equal to $a$

(C) $b$ equal to $a$ and $v$ equal to $w$

(D) $b$ need not be equal to $a$ and $v$ need not be equal to $w$

Q. 30 A system with $x(t)$ and output $y(t)$ is defined by the input-output relation :

$$y(t) = \#_{-3}^{-2t} x(t)\, dt$$

The system will be

(A) Casual, time-invariant and unstable

(B) Casual, time-invariant and stable

(C) non-casual, time-invariant and unstable

(D) non-casual, time-variant and unstable

Q. 31 A signal $x(t)$ = sinc($at$) where a is a real constant ^ sinc($x$) = $\frac{\sin(px)}{px}$ h is the input to a Linear Time Invariant system whose impulse response $h(t)$ = sinc($bt$), where *(U)* is a real constant. If min ($a$ , $b$) denotes the minimum of $a$ and $b$ and similarly, max (a, b) denotes the maximum of a and b, and K is a constant, which one of the following statements is true about the output of the system ?

(A) It will be of the form $K$sinc($gt$) where $g$ = min($a$, $b$)

(B) It will be of the form $K$sinc($gt$) where $g$ = max($a$ , $b$)

(C) It will be of the form $K$sinc($at$)

(D) It can not be a sinc type of signal

Q. 32 Let $x(t)$ be a periodic signal with time period $T$ , Let $y(t) = x(t - t_0) + x(t + t_0)$ for some $t_0$. The Fourier Series coefficients of $y(t)$ are denoted by $b_k$ . If $b_k = 0$ for all odd $k$ , then $t_0$ can be equal to

(A) $T/8$ (B) $T/4$

(C) $T/2$ (D) $2T$

Q. 33 $H(z)$ is a transfer function of a real system. When a signal $x[n] = (1 + j)^n$ is the input to such a system, the output is zero. Further, the Region of convergence (ROC) of ^1 - $\frac{1}{2}z^{-1}$h H(z) is the entire Z-plane (except $z = 0$). It can then be inferred that $H(z)$ can have a minimum of

(A) one pole and one zero

(B) one pole and two zeros

(C) two poles and one zero

D) two poles and two zeros

Q. 34 Given $X(z) = \frac{z}{\quad}$ with $|z| > a$ , the residue of $n - 1$ at $z = a$ for $n$ $ 0 will be

(A) $a^{n-1}$

(B) $a^n$

(C) $na^n$

(D) $na^{n-1}$

Q. 35 Let $x(t)$ = rect^$t$ - $\frac{1}{2}$h (where *rect* ($x$) = 1 for - $\frac{1}{2}$ # $x$ # $\frac{1}{2}$ and zero otherwise.
If sinc($x$) = $\frac{\sin(px)}{px}$, then the FTof $x(t) + x(-t)$ will be given by

(A) sinc` $\frac{w}{2p}$ j (B) 2sinc` $\frac{w}{2p}$ j

(C) 2sinc` $\frac{w}{2p}$ j cos` $\frac{w}{2}$ j (D) sinc` $\frac{w}{2p}$ j sin` $\frac{w}{2}$ j

Q. 36 Given a sequence $x[n]$, to generate the sequence $y[n] = x[3 - 4n]$, which one of the following procedures would be correct ?

(A) First delay $x(n)$ by 3 samples to generate $z_1[n]$, then pick every $4^{th}$ sample of $z_1[n]$ to generate $z_2[n]$, and than finally time reverse $z_2[n]$ to obtain $y[n]$.

(B) First advance $x[n]$ by 3 samples to generate $z_1[n]$, then pick every $4_{th}$ sample of $z_1[n]$ to generate $z_2[n]$, and then finally time reverse $z_2[n]$ to obtain $y[n]$

(C) First pick every fourth sample of $x[n]$ to generate $v_1[n]$, time-reverse $v_1[n]$ to obtain $v_2[n]$, and finally advance $v_2[n]$ by 3 samples to obtain $y[n]$

(D) First pick every fourth sample of $x[n]$ to generate $v_1[n]$, time-reverse $v_1[n]$ to obtain $v_2[n]$, and finally delay $v_2[n]$ by 3 samples to obtain $y[n]$

Q. 37 Let a signal $a_1 \sin(w_1 t + f)$ be applied to a stable linear time variant system. Let the corresponding steady state output be represented as $a_2 F(w_2 t + f_2)$. Then which of the following statement is true?

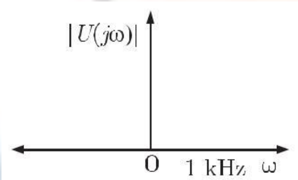
(A) $F$ is not necessarily a “Sine” or “Cosine” function but must be periodic with $w_1 = w_2$.

(B) $F$ must be a “Sine” or “Cosine” function with $a_1 = a_2$

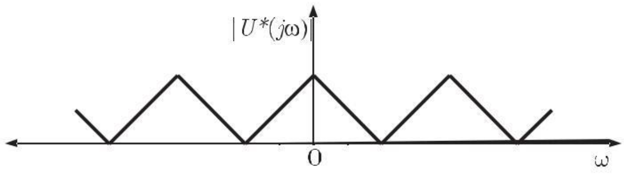
(C) $F$ must be a “Sine” function with $w_1 = w_2$ and $f_1 = f_2$

(D) $F$ must be a “Sine” or “Cosine” function with $w_1 = w_2$

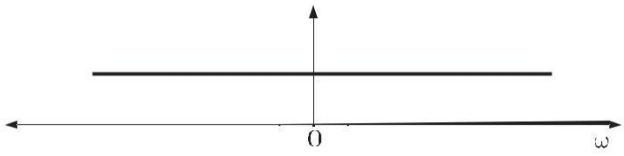
Q. 38 The frequency spectrum of a signal is shown in the figure. If this is ideally sampled at intervals of 1 ms, then the frequency spectrum of the sampled signal will be



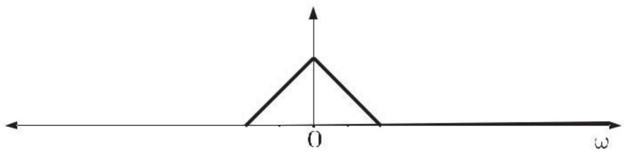
(A)



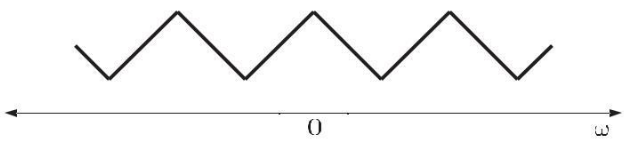

(B)




(C)




(D)




Q. 39 A signal $x(t)$ is given by

$$x(t) = \begin{cases} 1, & -T/4 < t \le 3T/4 \\ -1, & 3T/4 < t \le 7T/4 \\ -x(t+T) & \end{cases}$$

Which among the following gives the fundamental fourier term of $x(t)$ ?

(R) $\frac{4}{\pi}\cos\left(\frac{\pi t}{T} - \frac{\pi}{4}\right)$

(S) $\frac{\pi}{4}\cos\left(\frac{\pi t}{2T} + \frac{\pi}{4}\right)$

(T) $\frac{4}{\pi}\sin\left(\frac{\pi t}{T} - \frac{\pi}{4}\right)$

(U) $\frac{\pi}{4}\sin\left(\frac{\pi t}{2T} + \frac{\pi}{4}\right)$

**Common Data Questions Q. 40 - 41**

A signal is processed by a causal filter with transfer function $G(s)$

Q. 40 For a distortion free output signal wave form, $G(s)$ must

(P) provides zero phase shift for all frequency

(Q) provides constant phase shift for all frequency

(R) provides linear phase shift that is proportional to frequency

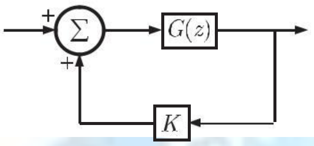
(S) provides a phase shift that is inversely proportional to frequency

Q. 41 $G(z) = az^{-1} + bz^{-3}$ is a low pass digital filter with a phase characteristics same as that of the above question if

(A) $a = b$ (S) $a = -b$

(C) $a = b^{(1/3)}$ S $a = b^{(-1/3)}$

Q. 42 Consider the discrete-time system shown in the figure where the impulse response of $G(z)$ is $g(0) = 0, g(1) = g(2) = 1, g(3) = g(4) = g = 0$




This system is stable for range of values of $K$

(A) $[-1, \frac{1}{2}]$ (B) $[-1, 1]$

(C) $[-\frac{1}{2}, 1]$ (D) $[-\frac{1}{2}, 2]$

Q. 43 If $u(t)$, $r(t)$ denote the unit step and unit ramp functions respectively and $u(t) * r(t)$ their convolution, then the function $u(t+1) * r(t-2)$ is given by

(A) $\frac{1}{2}(t-1)u(t-1)$ (B) $\frac{1}{2}(t-1)u(t-2)$

(C) $\frac{1}{2}(t-1)^2 u(t-1)$ (D) None of the above

Q. 44 $X(z) = 1 - 3z^{-1}$, $Y(z) = 1 + 2z^{-2}$ are Z transforms of two signals $x[n]$, $y[n]$ respectively. A linear time invariant system has the impulse response $h[n]$ defined by these two signals as $h[n] = x[n-1] * y[n]$ where * denotes discrete time convolution. Then the output of the system for the input $d[n-1]$

(A) has Z-transform $z^{-1}X(z)Y(z)$

(B) equals $d[n-2] - 3d[n-3] + 2d[n-4] - 6d[n-5]$

(C) has Z-transform $1 - 3z^{-1} + 2z^{-2} - 6z^{-3}$

(D) does not satisfy any of the above three

---

Q. 45 The following is true

(A) A finite signal is always bounded

(B) A bounded signal always possesses finite energy

(C) A bounded signal is always zero outside the interval $[-t_0, t_0]$ for some $t_0$

(D) A bounded signal is always finite

Q. 46 $x(t)$ is a real valued function of a real variable with period $T$. Its trigonometric Fourier Series expansion contains no terms of frequency $w = 2p(2k)/T$; $k = 1,2g$ Also, no sine terms are present. Then $x(t)$ satisfies the equation

(A) $x(t) = -x(t-T)$

(B) $x(t) = x(T-t) = -x(-t)$

(C) $x(t) = x(T-t) = -x(t-T/2)$

(D) $x(t) = x(t-T) = x(t-T/2)$

Q. 47 A discrete real all pass system has a pole at $z = 2+30\%$: it, therefore

(A) also has a pole at $\frac{1}{2} + 30\%$

(B) has a constant phase response over the $z$-plane: $\arg H(z) =$ constant

constant

(T) is stable only if it is anti-causal

(U) has a constant phase response over the unit circle: arg $H(e^{iW})$ = constant

Q. 48 $x[n] = 0$; $n < -1$, $n > 0$, $x[-1] = -1$, $x[0] = 2$ is the input and $y[n] = 0; n < -1, n > 2, y[-1] = -1 = y[1], y[0] = 3, y[2] = -2$ is the output of a discrete-time LTI system. The system impulse response $h[n]$ will be

(P) $h[n] = 0; n < 0, n > 2, h[0] = 1, h[1] = h[2] = -1$

(Q) $h[n] = 0; n < -1, n > 1, h[-1] = 1, h[0] = h[1] = 2$

(R) $h[n] = 0; n < 0, n > 3, h[0] = -1, h[1] = 2, h[2] = 1$

(S) $h[n] = 0; n < -2, n > 1, h[-2] = h[1] = h[-1] = -h[0] = 3$

Q. 49 The discrete-time signal $x[n] \longleftrightarrow X(z) = /_{n=0}^{3} \frac{3^n}{2+n} z^{2n}$, where $\longleftrightarrow$ denotes a transform-pair relationship, is orthogonal to the signal

J $y_1[n]) Y_1(z) = /_{n=0}^{3} `\frac{2}{3} j^n z^{-n}$

K $y_2[n]) Y_2(z) = /_{n=0}^{3} (5^n - n) z^{-(2n+1)}$

L $y_3[n]) Y_3(z) = /_{n=-3}^{3} 2^{-|n|} z^{-n}$

M $y_4[n]) Y_4(z) = 2z^{-4} + 3z^{-2} + 1$

Q. 50 BB. continuous-time system is described by $y(t) = e^{-|x(t)|}$, where $y(t)$ is the output and $x(t)$ is the input. $y(t)$ is bounded

(A) only when $x(t)$ is bounded

(B) only when $x(t)$ is non-negative

(C) only for $t \# 0$ if $x(t)$ is bounded for $t \$ 0$

(D) even when $x(t)$ is not bounded

Q. 51 The running integration, given by $y(t) = \#_{-3}^{t} x(t') dt'$

(I) has no finite singularities in its double sided Laplace Transform $Y(s)$

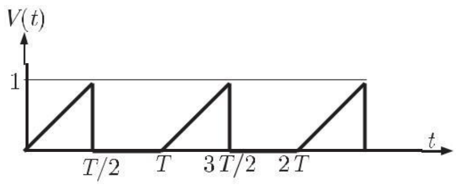
(J) produces a bounded output for every causal bounded input

(K) produces a bounded output for every anticausal bounded input

(L) has no finite zeroes in its double sided Laplace Transform $Y(s)$

Y

Q. 52 For the triangular wave from shown in the figure, the RMS value of the voltage is equal to



(A) $\sqrt{\frac{1}{6}}$ (B) $\sqrt{\frac{1}{3}}$

(C) $\frac{1}{3}$ (D) $\sqrt{\frac{2}{3}}$

Q. 53 The Laplace transform of a function $f(t)$ is $F(s) = \frac{5s^2 + 23s + 6}{s(s^2 + 2s + 2)}$ as $t$ " 3, $f(t)$ approaches

(A) 3 (B) 5

(C) $\frac{17}{2}$ (D) 3

Q. 54 The Fourier series for the function $f(x) = \sin^2 x$ is

(A) $\sin x + \sin 2x$ (B) $1 - \cos 2x$

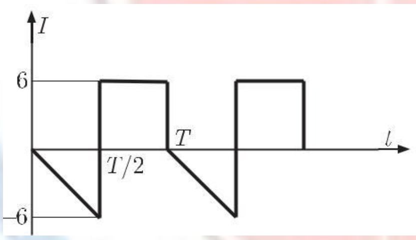
(C) $\sin 2x + \cos 2x$ (D) $0.5 - 0.5 \cos 2x$

Q. 55 If $u(t)$ is the unit step and $d(t)$ is the unit impulse function, the inverse $z$-transform of $F(z) = \frac{1}{z+1}$ for $k > 0$ is

(A) $(-1)^k d(k)$ (B) $d(k) - (-1)^k$

(C) $(-1)^k u(k)$ (D) $u(k) - (-1)^k$

Q. 57 The rms value of the periodic waveform given in figure is




(A) $2\sqrt{6}$ A (B) $6\sqrt{2}$ A

(C) $\sqrt{4/3}$ A (D) 1.5 A

# SOLUTION

Sol. 1 Option (A) is correct.

Given, the maximum frequency of the band-limited signal

$$f_m = 5 \text{ kHz}$$

According to the Nyquist sampling theorem, the sampling frequency must be greater than the Nyquist frequency which is given as

$$f_N = 2f_m = 2 \# 5 = 10 \text{ kHz}$$

So, the sampling frequency $f_s$ must satisfy

$$f_s \$ f_N$$

$$f_s \$ 10 \text{ kHz}$$

only the option (A) does not satisfy the condition therefore, 5 kHz is not a valid sampling frequency.

Sol. 2 Option (A) is correct.

Given, the signal

$$v \wedge t\, h = 30 \sin 100t + 10 \cos 300t + 6 \sin\wedge 500t + \tfrac{p}{4} h$$

So we have $w_1 = 100$ rad/s; $w_2 = 300$ rad/s and $w_3 = 500$ rad/s

Therefore, the respective time periods are

$$T_1 = \frac{2p}{w_1} = \frac{2p}{100} \text{ sec}$$

$$T_2 = \frac{2p}{w_2} = \frac{2p}{300} \text{ sec}$$

$$T_3 = \frac{2p}{500} \text{ sec}$$

So, the fundamental time period of the signal is

$$\text{L.C.M.}\,(K)\, T_1, T_2\, T_3\, h = \frac{LCM\wedge 2p, 2p, 2p h}{HCF\wedge 100, 300, 500 h}$$

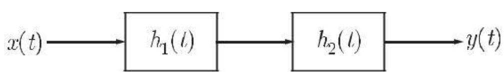
or, $$T_0 = \frac{2p}{100}$$

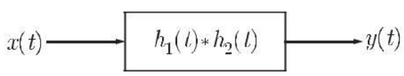
Thus, the fundamental frequency in rad/sec is

$$w_0 = \frac{2p}{10} = 100 \text{ rad/s}$$

Sol. 3 Option (C) is correct.

If the two systems with impulse response $h_1 \wedge t\, h$ and $h_2 \wedge t\, h$ are connected in cascaded configuration as shown in figure, then the overall response of the system is the convolution of the individual impulse responses.



**Sol. 4** Option (C) is correct.

For a system to be casual, the R.O.C of system transfer function $H(s)$ which is rational should be in the right half plane and to the right of the right most pole.

For the stability of $LTI$ system. All poles of the system should lie in the left half of $S$-plane and no repeated pole should be on imaginary axis. Hence, options (A), (B), (D) satisfies both stability and causality an $LTI$ system.

But, Option (C) is not true for the stable system as, $|S| = 1$ have one pole in right hand plane also.

**Sol. 5** Option (C) is correct.

Given, the input

$$x(t) = u(t-1)$$

It's Laplace transform is

$$X(s) = \frac{e^{-s}}{s}$$

The impulse response of system is given

$$h(t) = t\,u(t)$$

Its Laplace transform is

$$H(s) = \frac{1}{s^2}$$

Hence, the overall response at the output is

$$Y(s) = X(s)H(s) = \frac{e^{-s}}{s^3}$$

Its inverse Laplace transform is

$$y(t) = \frac{(t-1)^2}{2}\,u(t-1)$$

**Sol. 6** Option (B) is correct.

Given, the impulse response of continuous time system

$$h(t) = \delta(t-1) + \delta(t-3)$$

From the convolution property, we know

$$x(t) * \delta(t-t_0) = x(t-t_0)$$

So, for the input

$$x(t) = u(t) \text{ (Unit step fun}^n\text{)}$$

The output of the system is obtained as

$$y(t) = u(t) * h(t)$$

$$= u(t) * [\delta(t-1) + \delta(t-3)]$$

$$= u(t-1) + u(t-3)$$

At $t = 2$ $\quad y(2) = u(2-1) + u(2-3) = 1$

**Sol. 7** Option (C) is correct.

$$x[n] = \left(\frac{1}{3}\right)^{|n|} - \left(\frac{1}{2}\right)^n u[n]$$

$$= \left(\frac{1}{3}\right)^n u[n] + \left(\frac{1}{3}\right)^{-n} u[-n-1] - \left(\frac{1}{2}\right)^n u(n)$$

Taking $z$-transform

$$X[z] = \sum_{n=-\infty}^{\infty} \left(\frac{1}{3}\right)^n z^{-n} u[n] + \sum_{n=-\infty}^{\infty} \left(\frac{1}{3}\right)^{-n} z^{-n} u[-n-1]$$

$$- \sum_{n=-\infty}^{\infty} \left(\frac{1}{2}\right)^n z^{-n} u[n]$$

$$= \sum_{n=0}^{\infty} \left(\frac{1}{3}\right)^n z^{-n} + \sum_{n=-\infty}^{-1} \left(\frac{1}{3}\right)^{-n} z^{-n} - \sum_{n=0}^{\infty} \left(\frac{1}{2}\right)^n z^{-n}$$

$$= \underbrace{\sum_{n=0}^{\infty} \left(\frac{1}{3z}\right)^n}_{\text{I}} + \underbrace{\sum_{m=1}^{\infty} \left(\frac{1}{3} z\right)^m}_{\text{II}} - \underbrace{\sum_{n=0}^{\infty} \left(\frac{1}{2z}\right)^n}_{\text{III}} \qquad \text{Taking } m = -n$$

Series I converges if $\left|\frac{1}{3z}\right| < 1$ or $|z| > \frac{1}{3}$

Series II converges if $\left|\frac{1}{3}z\right| < 1$ or $|z| < 3$

Series III converges if $\left|\frac{1}{2z}\right| < 1$ or $|z| > \frac{1}{2}$

Region of convergence of $X(z)$ will be intersection of above three

So, ROC : $\frac{1}{2} < |z| < 3$

**Sol. 8** Option (D) is correct.

Using $s$-domain differentiation property of Laplace transform.

If $f(t) \overset{L}{\longleftrightarrow} F(s)$

$$tf(t) \overset{L}{\longleftrightarrow} -\frac{dF(s)}{ds}$$

So, $\mathcal{L}[tf(t)] = \frac{-d}{ds}\left[\frac{1}{s^2 + s + 1}\right] = \frac{2s + 1}{(s^2 + s + 1)^2}$

**Sol. 9** Option (A) is correct.

Convolution sum is defined as

$$y[n] = h[n] * g[n] = \sum_{k=-\infty}^{\infty} h[n]\, g[n-k]$$

For causal sequence, $y[n] = \sum_{k=0}^{\infty} h[n]\, g[n-k]$

$$y[n] = h[n]g[n] + h[n]g[n-1] + h[n]g[n-2] + .....$$

For $n = 0$, $y[0] = h[0]g[0] + h[1]g[-1] + ...........$

$= h[0]g[0]$ $\qquad g[-1] = g[-2] = ....0$

$= h[0]g[0]$ $\qquad ...(i)$

For $n = 1$, $y[1] = h[1]g[1] + h[1]g[0] + h[1]g[-1] + ....$

$= h[1]g[1] + h[1]g[0]$

$\frac{1}{2} = \frac{1}{2}g[1] + \frac{1}{2}g[0]$ $\qquad h[1] = \left(\frac{1}{2}\right)^1 = \frac{1}{2}$

$1 = g[1] + g[0]$

$g[1] = 1 - g[0]$

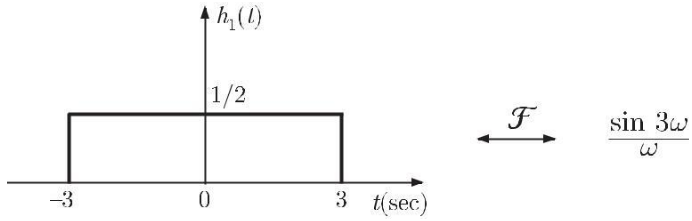
From equation (i), $g[0] = \frac{y[0]}{h[0]} = \frac{1}{1} = 1$

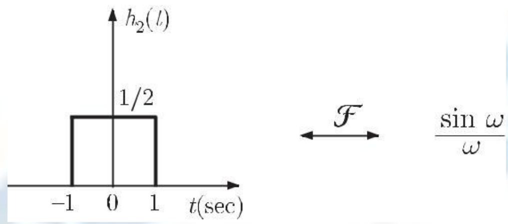
So, $g[1] = 1 - 1 = 0$

**Sol. 10** Option (C) is correct.

$$H(j\omega) = \frac{(2\cos\omega)(\sin 2\omega)}{\omega} = \frac{\sin 3\omega}{\omega} + \frac{\sin\omega}{\omega}$$

We know that inverse Fourier transform of sin $c$ function is a rectangular function.




So, inverse Fourier transform of $H(jw)$

$$h(t) = h_1(t) + h_2(t)$$

$$h(0) = h_1(0) + h_2(0) = \frac{1}{2} + \frac{1}{2} = 1$$

Option (D) is correct.

**Sol. 11**

$$y(t) = \int_{-\infty}^{t} x(t)\cos(3t)\,dt$$

**Time invariance :**

Let, $x(t) = d(t)$

$$y(t) = \int_{-\infty}^{t} d(t)\cos(3t)\,dt = u(t)\cos(0) = u(t)$$

For a delayed input $(t - t_0)$ output is

$$y(t, t_0) = \int_{-\infty}^{t} d(t - t_0)\cos(3t)\,dt = u(t)\cos(3t_0)$$

Delayed output

$$y(t - t_0) = u(t - t_0)$$

$$y(t, t_0) \neq y(t - t_0)$$

System is not time invariant.

**Stability :**

Consider a bounded input $x(t) = \cos 3t$

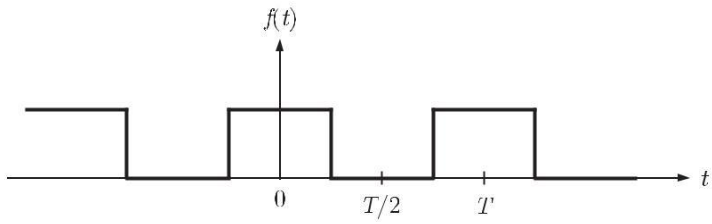
$$y(t) = \int_{-\infty}^{t} \cos^2 3t = \int_{-\infty}^{t} \frac{1 - \cos 6t}{2} = \frac{1}{2}\int_{-\infty}^{t} 1\,dt - \frac{1}{2}\int_{-\infty}^{t} \cos 6t\,dt$$

As $t \to \infty$, $y(t) \to \infty$ (unbounded)

System is not stable.

**Sol. 12**

Option (D) is correct.




$$f(t) = a_0 + \sum_{n=1}^{\infty}(a_n \cos wt + b_n \sin n w t)$$

- The given function $f(t)$ is an even function, therefore $b_n = 0$

(FF) $f(t)$ is a non zero average value function, so it will have a non-zero value of $a_0$

$$a_0 = \frac{1}{^T/2h} \#_0^{T/2} f(t)\, dt \text{ (average value of } f(t))$$

- $a_n$ is zero for all even values of $n$ and non zero for odd $n$

$$a_n = \frac{2}{T} \#_0^{T} f(t) \cos(n\text{w}\, t)\, d\,(\text{w}t)$$

So, Fourier expansion of $f(t)$ will have $a_0$ and $a_n$ , $n = 1,3,5$f3

Sol. 13 Option (A) is correct.

$$x(t) = e^{-t}$$

Laplace transformation

$$X(s) = \frac{1}{s+1}$$

$$y(t) = e^{-2t}$$

$$Y(s) = \frac{1}{s+2}$$

Convolution in time domain is equivalent to multiplication in frequency domain. $z(t)$

$$= x(t)\, )\, y(t)$$

$$Z(s) = X(s)\, Y(s) = \text{b} \frac{1}{s+1} \text{lb} \frac{1}{s+2}\text{l}$$

By partial fraction and taking inverse Laplace transformation, we get

$$Z(s) = \frac{1}{s+1} - \frac{1}{s+2}$$

$$z(t) = e^{-t} - e^{-2t}$$

Sol. 14 Option (D) is correct.

$$f(t) \overset{\text{L}}{\longleftrightarrow} F_1(s)$$

$$f(t - t) \overset{\text{L}}{\longleftrightarrow} e^{-st} F_1(s) = F_2(s)$$

$$G(s) = \frac{F_2(s)\, F_1^{)}(s)}{\left|F_1(s)\right|^2} = \frac{e^{-st} F_1(s)\, F_1^{)}(s)}{\left|F_1(s)\right|^2}$$

$$= \frac{e^{-sE} \left|F_1(s)\right|^2}{\left|F_1(s)\right|^2} \qquad \text{"a } F_1(s)\, F_1^{)}(s) = \left|F_1(s)\right|^2$$

$$= e^{-st}$$

Taking inverse Laplace transform

$$g(t) = \text{L}^{-1}[e^{-st}] = d(t - t)$$

Sol. 15 Option (C) is correct.

$$h(t) = e^{-t} + e^{-2t}$$

Laplace transform of $h(t)$ i.e. the transfer function

$$H(s) = \frac{1}{s+1} + \frac{1}{s+2}$$

For unit step input

$$r(t) = \text{m}(t)$$

or $$R(s) = \frac{1}{s}$$

Output, $$Y(s) = R(s)\, H(s) = \frac{1}{s} : \frac{1}{s+1} + \frac{1}{s+2} \text{D}$$

By partial fraction

$$Y(s) = \frac{3}{2}\frac{1}{s} - \frac{1}{s+1} - \frac{1}{2}\frac{1}{s+2}$$

Taking inverse Laplace

$$y(t) = \frac{3}{2}u(t) - e^{-t}u(t) - \frac{e^{-2t}u(t)}{2}$$

$$= u(t)[1.5 - e^{-t} - 0.5e^{-2t}]$$

Sol. 16 Option (C) is correct.

System is given as

$$H(s) = \frac{2}{(s+1)}$$

Step input $\quad R(s) = \frac{1}{s}$

Output $\quad Y(s) = H(s)R(s) = \frac{2}{(s+1)}\left(\frac{1}{s}\right) = \frac{2}{s} - \frac{2}{(s+1)}$

Taking inverse Laplace transform

$$y(t) = (2 - 2e^{-t})u(t)$$

Final value of $y(t)$,

$$y_{ss}(t) = \lim_{t \to \infty} y(t) = 2$$

Let time taken for step response to reach 98% of its final value is $t_s$.

So,

$$2 - 2e^{-t_s} = 2 \times 0.98$$

$$0.02 = e^{-t_s}$$

$$t_s = \ln 50 = 3.91 \text{ sec.}$$

Sol. 17 Option (D) is correct.

Period of $x(t)$,

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{0.8\pi} = 2.5 \text{ sec}$$

Sol. 18 Option (B) is correct.

Input output relationship

$$y(t) = \int_{-\infty}^{5t} x(\tau)\,d\tau, \qquad t > 0$$

**Causality :**

$y(t)$ depends on $x(5t)$, $t > 0$ system is non-causal.

For example $t = 2$

$y(2)$ depends on $x(10)$ (future value of input)

**Linearity :**

Output is integration of input which is a linear function, so system is linear.

Sol. 19 Option (A) is correct.

Fourier series of given function

$$x(t) = A_0 + \sum_{n=1}^{\infty} a_n \cos n\omega_0 t + b_n \sin n\omega_0 t$$

$$\because x(t) = -x(t) \text{ odd function}$$

So, $\quad A_0 = 0$

$$a_n = 0$$

$$b_n = \frac{2}{T}\int_0^T x(t)\sin n\omega_0 t\,dt$$

$$= \frac{2}{T}\left[\int_0^{T/2}(1)\sin n\omega_0 t\,dt + \int_{T/2}^{T}(-1)\sin n\omega_0 t\,dt\right]$$

$$= \frac{2}{T}\left[\left(\frac{\cos n\omega_0 t}{-n\omega_0}\right)_0^{T/2} - \left(\frac{\cos n\omega_0 t}{-n\omega_0}\right)_{T/2}^{T}\right]$$

$$= \frac{2}{n\omega_0 T}\left[(1 - \cos n\pi) + (\cos 2n\pi - \cos n\pi)\right]$$

$$= \frac{2}{n\pi}\left[1 - (-1)^n\right]$$

$$b_n = \begin{cases} \frac{4}{n\pi}, & n \text{ odd} \\ 0, & n \text{ even} \end{cases}$$

So only odd harmonic will be present in $x(t)$

For second harmonic component ($n = 2$) amplitude is zero.

$$\frac{1}{2\pi}\int_{-\infty}^{\infty}|X(\omega)|^2 d\omega = \int_{-\infty}^{\infty}|x(t)|^2 dt$$

$$\int_{-\infty}^{\infty}|X(\omega)|^2 d\omega = 2\pi \times 2 = 4\pi$$

Option (C) is correct.

Sol. 21 Given sequences $x[n] = \{\underset{\uparrow}{1}, -1\},\ 0 \le n \le 1$

$$y[n] = \{\underset{\uparrow}{1},0,0,0,-1\},\ 0 \le n \le 4$$

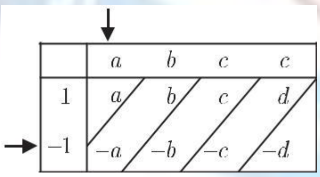
If impulse response is $h[n]$ then

$$y[n] = h[n] * x[n]$$

Length of convolution ($y[n]$) is 0 to 4, $x[n]$ is of length 0 to 1 so length of $h[n]$ will be 0 to 3.

Let $h[n] = \{\underset{\uparrow}{a}, b, c, d\}$

Convolution




$$y[n] = \{\underset{\uparrow}{a}, -a+b, -b+c, -c+d, -d\}$$

By comparing

$$a = 1$$
$$-a + b = 0 \ \Rightarrow b = a = 1$$
$$-b + c = 0 \ \Rightarrow c = b = 1$$
$$-c + d = 0 \ \Rightarrow d = c = 1$$

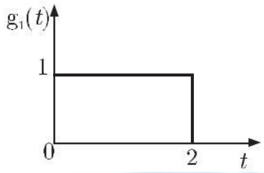
So, $h[n] = \{\underset{\uparrow}{1},1,1,1\}$

Sol. 22 Option (D) is correct.

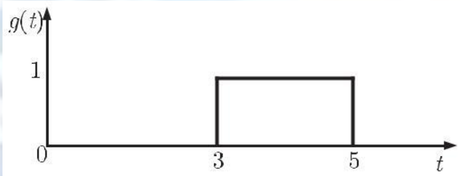
We can observe that if we scale $f(t)$ by a factor of $\frac{1}{2}$ and then shift, we will get $g(t)$.

First scale $f(t)$ by a factor of $\frac{1}{2}$

$$g_1(t) = f(t/2)$$




Shift $g_1(t)$ by 3, $g(t) = g_1(t-3) = f\left(\frac{t-3}{2}\right)$




$$g(t) = f\left(\frac{t}{2} - \frac{3}{2}\right)$$

Sol. 23 Option (C) is correct.

$g(t)$ can be expressed as

$$g(t) = u(t-3) - u(t-5)$$

By shifting property we can write Laplace transform of $g(t)$

$$G(s) = \frac{1}{s}e^{-3s} - \frac{1}{s}e^{-5s} = \frac{e^{-3s}}{s}(1 - e^{-2s})$$

Sol. 24 Option (D) is correct.

Let $x(t) \xleftrightarrow{L} X(s)$

$y(t) \xleftrightarrow{L} Y(s)$

$h(t) \xleftrightarrow{L} H(s)$

So output of the system is given as

$$Y(s) = X(s)H(s)$$

Now for input $x(t-t) \xleftrightarrow{L} e^{-st}X(s)$ (shifting property)

$h(t-t) \xleftrightarrow{L} e^{-st}H(s)$

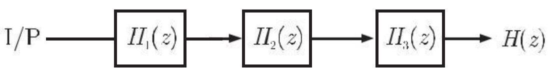
So now output is $Y'(s) = e^{-st}X(s) \$ e^{-ts}H(s)$

$= e^{-2st}X(s)H(s) = e^{-2st}Y(s)$

$y'(t) = y(t-2t)$

Sol. 25 Option (B) is correct.

Let three LTI systems having response $H_1(z)$, $H_2(z)$ and $H_3(z)$ are Cascaded as showing below




Assume $H_1(z) = z^2 + z^1 + 1$ (non-causal)

$H_2(z) = z^3 + z^2 + 1$ (non-causal)

Overall response of the system

$$H(z) = H_1(z)\, H_2(z)\, H_3(z)$$

$$H(z) = (z^2 + z^1 + 1)(z^3 + z^2 + 1) H_3(z)$$

To make $H(z)$ causal we have to take $H_3(z)$ also causal.

Let $$H_3(z) = z^{-6} + z^{-4} + 1$$

$$= (z^2 + z^1 + 1)(z^3 + z^2 + 1)(z^{-6} + z^{-4} + 1)$$

$H(z)$ " causal

Similarly to make $H(z)$ unstable atleast one of the system should be unstable.

Sol. 26 Option (C) is correct.

Given signal

$$x(t) = \sum_{k=-3}^{3} a_k e^{j2\pi kt/T}$$

Let $\omega_0$ is the fundamental frequency of signal $x(t)$

$$x(t) = \sum_{k=-3}^{3} a_k e^{jk\omega_0 t} \qquad \because \frac{2\pi}{T} = \omega_0$$

$$x(t) = a_{-2} e^{-j2\omega_0 t} + a_{-1} e^{-j\omega_0 t} + a_0 + a_1 e^{j\omega_0 t} + a_2 e^{j2\omega_0 t}$$

$$= (2 - j)\, e^{-2j\omega_0 t} + (0.5 + 0.2j)\, e^{-j\omega_0 t} + 2j + (0.5 - 0.2j) e^{j\omega_0 t} + (2 + j) e^{j2\omega_0 t}$$

$$= 2\left[e^{-j2\omega_0 t} + e^{j2\omega_0 t}\right] + j\left[e^{j2\omega_0 t} - e^{-j2\omega_0 t}\right] + 0.5\left[e^{j\omega_0 t} + e^{-j\omega_0 t}\right] - 0.2j\left[e^{j\omega_0 t} - e^{-j\omega_0 t}\right] + 2j$$

$$= 2(2\cos 2\omega_0 t) + j(2j \sin 2\omega_0 t) + 0.5(2\cos \omega_0 t) - 0.2j(2j \sin \omega_0 t) + 2j$$

$$= 4\cos 2\omega_0 t - 2\sin 2\omega_0 t + \cos \omega_0 t + 0.4 \sin \omega_0 t + 2j$$

$$\text{Im}[x(t)] = 2 \text{ (constant)}$$

Sol. 27 Option (A) is correct.

Z-transform of $x[n]$ is

$$X(z) = 4z^{-3} + 3z^{-1} + 2 - 6z^2 + 2z^3$$

Transfer function of the system

$$H(z) = 3z^{-1} - 2$$

Output

$$Y(z) = H(z)\, X(z)$$

$$Y(z) = (3z^{-1} - 2)(4z^{-3} + 3z^{-1} + 2 - 6z^2 + 2z^3)$$

$$= 12z^{-4} + 9z^{-2} + 6z^{-1} - 18z + 6z^2 - 8z^{-3} - 6z^{-1} - 4 + 12z^2 - 4z^3$$

$$= 12z^{-4} - 8z^{-3} + 9z^{-2} - 4 - 18z + 18z^2 - 4z^3$$

Or sequence $y[n]$ is

$$y[n] = 12\delta[n-4] - 8\delta[n-3] + 9\delta[n-2] - 4\delta[n] - 18\delta[n+1] + 18\delta[n+2] - 4\delta[n+3]$$

$$y[n] \neq 0,\ n < 0$$

So $y[n]$ is non-causal with finite support.

Sol. 28 Option (D) is correct.

Since the given system is LTI, So principal of Superposition holds due to linearity.

For causal system $h(t) = 0,\ t < 0$

Both statement are correct.

**Sol. 29** Option (C) is correct.

For an LTI system output is a constant multiplicative of input with same frequency.

Here input $g(t) = e^{-\alpha t}\sin(\omega t)$

output $y(t) = Ke^{-\beta t}\sin(vt + \phi)$

Output will be in form of $Ke^{-\alpha t}\sin(\omega t + \phi)$

So $\alpha = \beta,\ v = \omega$

**Sol. 30** Option (D) is correct.

Input-output relation

$$y(t) = \int_{-\infty}^{-2t} x(\tau)\,d\tau$$

**Causality :**

Since $y(t)$ depends on $x(-2t)$, So it is non-causal.

**Time-variance :**

$$y(t) = \int_{-\infty}^{-2t} x(\tau - t_0)\,d\tau \ne y(t - t_0)$$

So this is time-variant.

**Stability :**

Output $y(t)$ is unbounded for an bounded input.

For example

Let $x(t) = e^{-t}$ (bounded)

$$y(t) = \int_{-\infty}^{-2t} e^{-\tau}\,d\tau = \left[\frac{e^{-\tau}}{-1}\right]_{-\infty}^{-2t} \to \text{Unbounded}$$

**Sol. 31** Option (A) is correct.

Output $y(t)$ of the given system is

$$y(t) = x(t) * h(t)$$

Or $$Y(j\omega) = X(j\omega)H(j\omega)$$

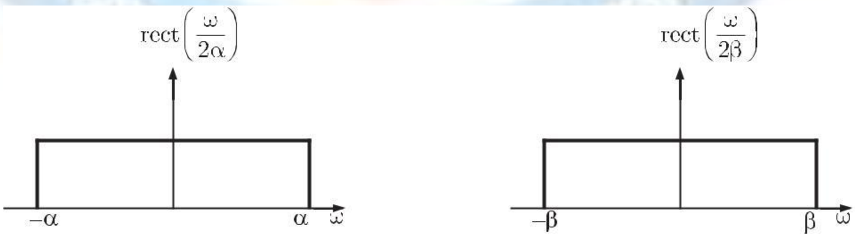
Given that, $x(t) = \text{sinc}(\alpha t)$ and $h(t) = \text{sinc}(\beta t)$

Fourier transform of $x(t)$ and $h(t)$ are

$$X(j\omega) = F[x(t)] = \frac{\pi}{\alpha}\,\text{rect}\left(\frac{\omega}{2\alpha}\right),\ -\alpha < \omega < \alpha$$

$$H(j\omega) = F[h(t)] = \frac{\pi}{\beta}\,\text{rect}\left(\frac{\omega}{2\beta}\right),\ -\beta < \omega < \beta$$

$$Y(j\omega) = \frac{\pi^2}{\alpha\beta}\,\text{rect}\left(\frac{\omega}{2\alpha}\right)\text{rect}\left(\frac{\omega}{2\beta}\right)$$




So, $$Y(j\omega) = K\,\text{rect}\left(\frac{\omega}{2\gamma}\right)$$

Where $\gamma = \min(\alpha, \beta)$

And $y(t) = K\,\text{sinc}(\gamma t)$

**Sol. 32** Option (B) is correct.

Let $a_k$ is the Fourier series coefficient of signal $x(t)$

Given $y(t) = x(t - t_0) + x(t + t_0)$

Fourier series coefficient of $y(t)$

$$b_k = e^{-jk\omega t_0} a_k + e^{jk\omega t_0} a_k$$

$$b_k = 2a_k \cos k\omega t_0$$

$$b_k = 0 \text{ (for all odd } k\text{)}$$

$$k\omega t_0 = \frac{\pi}{2}, \; k \to \text{odd}$$

$$k\frac{2\pi}{T} t_0 = \frac{\pi}{2}$$

For $k = 1$, $t_0 = \frac{T}{4}$

Sol. 33 Option ( ) is correct.

Sol. 34 Option (D) is correct.

Given that $X(z) = \frac{z}{(z-a)^2}, \; |z| > a$

Residue of $X(z) z^{n-1}$ at $z = a$ is

$$34.\; \frac{d}{dz}(z-a)^2 X(z) z^{n-1}\Big|_{z=a}$$

$$= \frac{d}{dz}(z-a)^2 \frac{z}{(z-a)^2} z^{n-1}\Big|_{z=a}$$

$$= \frac{d}{dz} z^n\Big|_{z=a} = nz^{n-1}\Big|_{z=a} = na^{n-1}$$

Sol. 35 Option (C) is correct.

Given signal

$$x(t) = \text{rect}\left(t - \frac{1}{2}\right)$$

So,

$$x(t) = \begin{cases} 1, & -\frac{1}{2} \le t - \frac{1}{2} \le \frac{1}{2} \text{ or } 0 \le t \le 1 \\ 0, & \text{elsewhere} \end{cases}$$

Similarly

$$x(-t) = \text{rect}\left(-t - \frac{1}{2}\right)$$

$$x(-t) = \begin{cases} 1, & -\frac{1}{2} \le -t - \frac{1}{2} \le \frac{1}{2} \text{ or } -1 \le t \le 0 \\ 0, & \text{elsewhere} \end{cases}$$

$$F[x(t) + x(-t)] = \int_{-\infty}^{\infty} x(t) e^{-j\omega t} dt + \int_{-\infty}^{\infty} x(-t) e^{-j\omega t} dt$$

$$= \int_0^1 (1) e^{-j\omega t} dt + \int_{-1}^0 (1) e^{-j\omega t} dt$$

$$= \left[\frac{e^{-j\omega t}}{-j\omega}\right]_0^1 + \left[\frac{e^{-j\omega t}}{-j\omega}\right]_{-1}^0 = \frac{1}{j\omega}(1 - e^{-j\omega}) + \frac{1}{j\omega}(e^{j\omega} - 1)$$

$$= \frac{e^{-j\omega/2}}{j\omega}(e^{j\omega/2} - e^{-j\omega/2}) + \frac{e^{j\omega/2}}{j\omega}(e^{j\omega/2} - e^{-j\omega/2})$$

$$= \frac{(e^{j\omega/2} - e^{-j\omega/2})(e^{-j\omega/2} + e^{j\omega/2})}{j\omega}$$

$$= \frac{2}{\omega} \sin\left(\frac{\omega}{2}\right) 2\cos\left(\frac{\omega}{2}\right) = 2\cos\left(\frac{\omega}{2}\right) \text{sinc}\left(\frac{\omega}{2\pi}\right)$$

Sol. 36

Option (B) is correct.

In option (A)

$$z_1 [n] = x [ n - 3]$$
$$z_2 [n] = z_1 [4n] = x [4n - 3]$$
$$y [n] = z_2 [- n ] = x [ - 4n - 3] =Y x [3 - 4n]$$

In option (B)

$$z_1 [n] = x [ n + 3]$$
$$z_2 [n] = z_1 [4n] = x [4n + 3]$$
$$y [n] = z_2 [- n ] = x [ - 4n + 3]$$

In option (C)

$$v_1 [n] = x [4n]$$
$$v_2 [n] = v_1 [- n] = x [ - 4n]$$
$$y [n] = v_2 [ n + 3] = x [ - 4(n + 3)] =Y x [3 - 4n]$$

In option (D)

$$v_1 [n] = x [4n]$$
$$v_2 [n] = v_1 [- n] = x [ - 4n]$$
$$y [n] = v_2 [ n - 3] = x [ - 4(n - 3)] =Y x [3 - 4n]$$

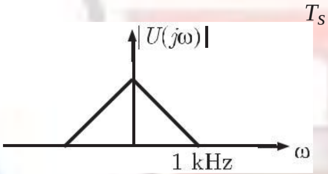
Sol. 37

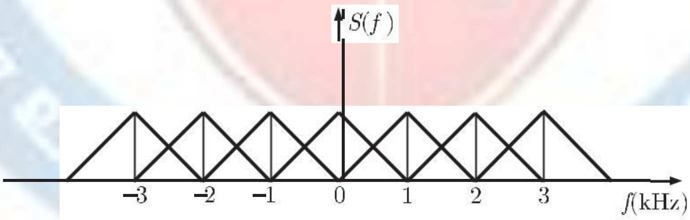
Option ( ) is correct.

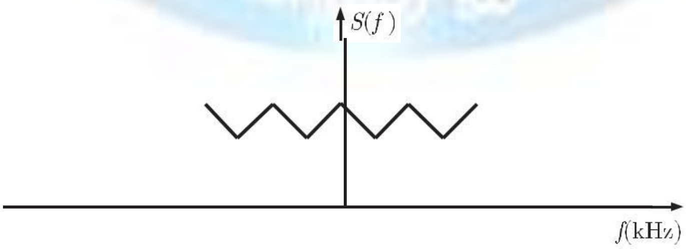
The spectrum of sampled signal $s (jw)$ contains replicas of $U (jw)$ at frequencies $!nf_s$ .

Where $n = 0,1,2.......$

$$f_s = \frac{1}{T_s} = \frac{1}{1 \text{ m sec}} = 1 \text{ kHz}$$




Sol. 38

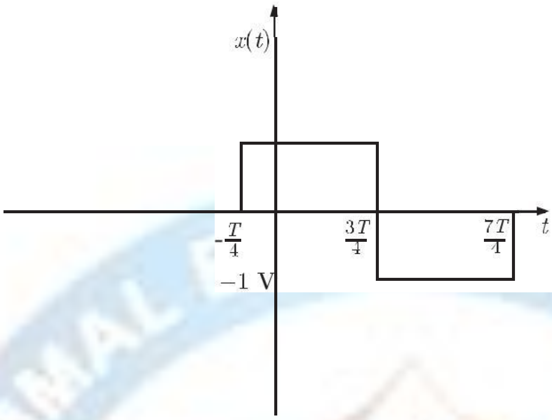
Option (D) is correct.

For an LTI system input and output have identical wave shape (i.e. frequency of input-output is same) within a multiplicative constant (i.e. Amplitude response is constant)

So $F$ must be a sine or cosine wave with $w_1 = w_2$

Sol. 39 Option (C) is correct.

Given signal has the following wave-form




Function x(t) is periodic with period $2T$ and given that

$$x(t) = -x(t+T) \text{ (Half-wave symmetric)}$$

So we can obtain the fourier series representation of given function.

Sol. 40 Option (C) is correct.

Output is said to be distortion less if the input and output have identical wave shapes within a multiplicative constant. A delayed output that retains input waveform is also considered distortion less.

Thus for distortion less output, input-output relationship is given as

$$y(t) = Kg(t - t_d)$$

Taking Fourier transform.

$$Y(w) = KG(w)e^{-jwt_d} = G(w)H(w)$$

$H(w)$ & transfer function of the system

So, $H(w) = Ke^{-jwt_d}$

Amplitude response $|H(w)| = K$

Phase response, $q_n(w) = -wt_d$

For distortion less output, phase response should be proportional to frequency.

Sol. 41 Option (A) is correct.

$$G(z)\big|_{z=e^{jw}} = ae^{-jw} + be^{-3jw}$$

for linear phase characteristic a = b.

Sol. 42 Option (A) is correct.

System response is given as

$$H(z) = \frac{G(z)}{1 - KG(z)}$$

$$g[n] = d[n-1] + d[n-2]$$

$$G(z) = z^{-1} + z^{-2}$$

So $$H(z) = \frac{(z^{-1} + z^{-2})}{1 - K(z^{-1} + z^{-2})} = \frac{z+1}{z^2 - Kz - K}$$

For system to be stable poles should lie inside unit circle.

$$|z| \le 1$$

$$z = \frac{K \pm \sqrt{K^2 + 4K}}{2} \le 1 \quad K \pm \sqrt{K^2 + 4K} \le 2$$

$$\sqrt{K^2 + 4K} \le 2 - K$$

$$K^2 + 4K \le 4 - 4K + K^2$$

$$8K \le 4$$

$$K \le 1/2$$

**Sol. 43** Option (C) is correct.

Given Convolution is,

$$h(t) = u(t + 1) * r(t - 2)$$

Taking Laplace transform on both sides,

$$H(s) = \mathcal{L}[h(t)] = \mathcal{L}[u(t + 1)] * \mathcal{L}[r(t - 2)]$$

We know that, $\mathcal{L}[u(t)] = 1/s$

$$\mathcal{L}[u(t + 1)] = e^{s}\left(\frac{1}{s^2}\right) \qquad \text{(Time-shifting property)}$$

and $\mathcal{L}[r(t)] = 1/s^2$

$$\mathcal{L}[r(t - 2)] = e^{-2s}\left(\frac{1}{s^2}\right) \qquad \text{(Time-shifting property)}$$

So

$$H(s) = \left[e^{s}\left(\frac{1}{s}\right)\right]\left[e^{-2s}\left(\frac{1}{s^2}\right)\right]$$

$$H(s) = e^{-s}\left(\frac{1}{s^3}\right)$$

Taking inverse Laplace transform

$$h(t) = \frac{1}{2}(t - 1)^2 u(t - 1)$$

**Sol. 44** Option (C) is correct.

Impulse response of given LTI system.

$$h[n] = x[n - 1] * y[n]$$

Taking $z$-transform on both sides.

$$H(z) = z^{-1} X(z)\, Y(z) \qquad \because x[n - 1] \xrightarrow{Z} z^{-1} x(z)$$

We have $X(z) = 1 - 3z^{-1}$ and $Y(z) = 1 + 2z^{-2}$

So

$$H(z) = z^{-1}(1 - 3z^{-1})(1 + 2z^{-2})$$

Output of the system for input $u[n] = \delta[n - 1]$ is,

$$y(z) = H(z)\, U(z) \qquad U[n] \xrightarrow{Z} U(z) = z^{-1}$$

So

$$Y(z) = z^{-1}(1 - 3z^{-1})(1 + 2z^{-2})z^{-1}$$

$$20\, z^{-2}(1 - 3z^{-1} + 2z^{-2} - 6z^{-3}) = z^{-2} - 3z^{-3} \quad 202z^{-4} - 6z^{-5}$$

Taking inverse z-transform on both sides we have output.

$$y[n] = \delta[n - 2] - 3\delta[n - 3] + 2\delta[n - 4] - 6\delta[n - 5]$$

**Sol. 45** Option (B) is correct.

A bounded signal always possesses some finite energy.

$$E = \int_{-t_0}^{t_0} |g(t)|^2 dt < \infty$$

Sol. 46 Option (C) is correct.

Trigonometric Fourier series is given as

$$x(t) = A_0 + \sum_{n=1}^{\infty} a_n \cos n\omega_0 t + b_n \sin n\omega_0 t$$

Since there are no sine terms, so $b_n = 0$

$$b_n = \frac{2}{T_0}\int_0^{T_0} x(t)\sin n\omega_0 t\,dt$$

$$= \frac{2}{T_0}\left[\int_0^{T_0/2} x(t)\sin n\omega_0 t\,dt + \int_{T_0/2}^{T} x(t)\sin n\omega_0 t\,dt\right]$$

Where $t = T - t$ & $dt = -dt$

$$= \frac{2}{T_0}\left[\int_{T_0}^{T_0/2} x(T-t)\sin n\omega_0 (T-t)(-dt) + \int_{T_0/2}^{T} x(t)\sin n\omega_0 t\,dt\right]$$

$$= \frac{2}{T_0}\left[\int_{T_0/2}^{T_0} x(T-t)\sin n\left(\frac{2\pi}{T} - t\right)dt + \int_{T_0/2}^{T} x(t)\sin n\omega_0 t\,dt\right]$$

$$= \frac{2}{T_0}\left[\int_{T_0/2}^{T_0} x(T-t)\sin(2n\pi - n\omega_0)dt + \int_{T_0/2}^{T_0} x(t)\sin n\omega_0 t\,dt\right]$$

$$= \frac{2}{T_0}\left[-\int_{T_0/2}^{T_0} x(T-t)\sin(n\omega_0 t)\,dt + \int_{T_0/2}^{T_0} x(t)\sin n\omega_0 t\,dt\right]$$

$b_n = 0$ if $x(t) = x(T-t)$

From half wave symmetry we know that if

$$x(t) = -x\left(t \pm \frac{T}{2}\right)$$

Then Fourier series of $x(t)$ contains only odd harmonics.

Sol. 47 Option (C) is correct.

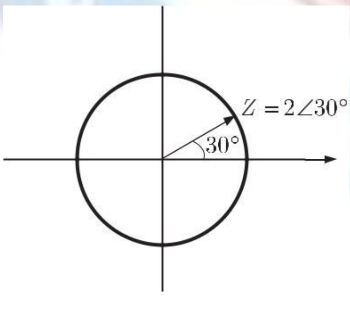
$Z$-transform of a discrete all pass system is given as

$$H(z) = \frac{z^{-1} - z_0^*}{1 - z_0 z^{-1}}$$

It has a pole at $z_0$ and a zero at $1/z_0^*$.

Given system has a pole at

$$z = 2\angle 30^\circ = 2\frac{(\sqrt{3} + j)}{2} = (\sqrt{3} + j)$$




system is stable if $|z| < 1$ and for this it is anti-causal.

Sol. 48 Option (A) is correct.

According to given data input and output Sequences are

$$x[n] = \{-1, \underline{2}\}, \quad -1 \le n \le 0$$

$$y[n] = \{-1, \underline{3}, -1, -2\}, \quad -1 \le n \le 2$$

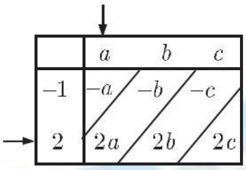
If impulse response of system is $h[n]$ then output

$$y[n] = h[n] * x[n]$$

Since length of convolution ($y[n]$) is -1 to 2, $x[n]$ is of length -1 to 0 so length of $h[n]$ is 0 to 2.

Let $h[n] = \{a, b, c\}$

Convolution




$$y[n] = \{-a, 2a-b, 2b-c, 2c\}$$

$$y[n] = \{-1, 3, -1, -2\}$$

So, $a = 1$

$2a - b = 3$ & $b = -1$

$2a - c = -1$ & $c = -1$

Impulse response $h[n] = \{1, -1, -1\}$

Sol. 49 Option ( ) is correct.

Sol. 50 Option (D) is correct.

Output $y(t) = e^{-x(t)}$

If $x(t)$ is unbounded, $x(t) \to \infty$

$y(t) = e^{-x(t)} \to 0$ (bounded)

So $y(t)$ is bounded even when $x(t)$ is not bounded.

Sol. 51 Option (B) is correct.

Given $y(t) = \int_{-\infty}^{t} x(t')\,dt'$

Laplace transform of $y(t)$

$$Y(s) = \frac{X(s)}{s}, \text{ has a singularity at } s = 0$$

For a causal bounded input, $y(t) = \int_{-\infty}^{t} x(t')\,dt'$ is always bounded.

Sol. 52 Option (A) is correct.

RMS value is given by

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2(t)\,dt}$$

Where

$$V(t) = \begin{cases} \left(\frac{2}{T}\right)t, & 0 \le t \le \frac{T}{2} \\ 0, & \frac{T}{2} < t \le T \end{cases}$$

So

$$\frac{1}{T}\int_0^T V^2(t)\,dt = \frac{1}{T}\left[\int_0^{T/2}\left(\frac{2t}{T}\right)^2 dt + \int_{T/2}^{T} 0\,dt\right]$$

$$= \frac{1}{T}\cdot\frac{4}{T^2}\int_0^{T/2} t^2\,dt = \frac{4}{T^3}\left[\frac{t^3}{3}\right]_0^{T/2} = \frac{4}{3T^3}\cdot\frac{T^3}{24} = \frac{1}{6}$$

$$V_{rms} = \sqrt{\frac{1}{6}}\ \text{V}$$

Sol. 53 Option (A) is correct.

By final value theorem

$$\lim_{t \to \infty} f(t) = \lim_{s \to 0} sF(s) = \lim_{s \to 0} s\frac{(5s^2 + 23s + 6)}{s(s^2 + 2s + 2)} = \frac{6}{2} = 3$$

Sol. 54 Option (D) is correct.

$$f(x) = \sin^2 x = \frac{1 - \cos 2x}{2}$$
$$= 0.5 - 0.5 \cos 2x$$

$$f(x) = A_0 + \sum_{n=1}^{\infty} a_n \cos n\omega_0 x + b_n \sin n\omega_0 x$$

$f(x) = \sin^2 x$ is an even function so $b_n = 0$

$$A_0 = 0.5$$

$$a_n = \begin{cases} -0.5, & n = 1 \\ 0, & \text{otherwise} \end{cases}$$

$$\omega_0 = \frac{2\pi}{T_0} = \frac{2\pi}{T} = 2$$

Sol. 55 Option (B) is correct.

Z-transform $F(z) = \frac{1}{z+1} = 1 - \frac{z}{z+1} = 1 - \frac{1}{1 + z^{-1}}$

so, $f(k) = \delta(k) - (-1)^k$

Thus $(-1)^k \xleftrightarrow{Z} \frac{1}{1 + z^{-1}}$

Sol. 56 Option (B) is correct.

Total current in wire

$$I = 10 + 20 \sin \omega t$$

$$I_{rms} = \sqrt{(10)^2 + \frac{(20)^2}{2}} = 17.32\ \text{A}$$

Sol. 57 Option (A) is correct.

Root mean square value is given as

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T I^2(t)\,dt}$$

From the graph, $I(t) = \begin{cases} \frac{12}{T}t, & 0 \le t < \frac{T}{2} \\ 6, & T/2 < t \le T \end{cases}$

So $\frac{1}{T}\int_0^T I^2 dt = \frac{1}{T}\left[\int_0^{T/2}\left(\frac{12t}{T}\right)^2 dt + \int_{T/2}^{T}(6)^2 dt\right]$

$$= \frac{1}{T}\left[\frac{144}{T^2}\left(\frac{t^3}{3}\right)_0^{T/2} + 36\,(t)_{T/2}^{T}\right]$$

$$= \frac{1}{T}\left[\frac{144}{T^2}\left(\frac{T^3}{24}\right) + 36\left(\frac{T}{2}\right)\right]$$

$$= \frac{1}{T}[6T + 18T] = 24$$

$$I_{rms} = \sqrt{24} = 2\sqrt{6}\ \text{A}$$