SSC JE CONVENTIONAL 2016

GENERAL ENGINEERING (ELECTRICAL)

1. (a) A conducting wire has a resistance of 5 Ω. What is the resistance of another wire of the same material but having half the diameter and four times the length ? [15 Marks]

Solution :

Conducting wire resistance is 5 Ω

Given condition is that material is same

$$R = \rho \frac{l}{A}$$

$$R \propto \frac{l}{d^2}$$

$$l_2 = 4l_1$$

$$d_2 = \frac{d_1}{2}$$

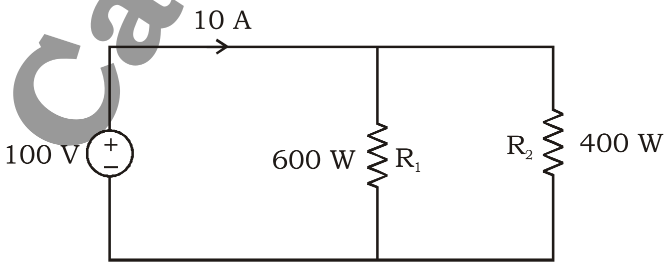
$$\frac{R_1}{R_2} = \frac{l_1 \left(\frac{d_1}{2}\right)^2}{d_1^2 4l_1}$$

$$\frac{5}{R_2} = \frac{1}{16}$$

$$\boxed{R_2 = 80\ \Omega}$$

(b) Two coils connected in parallel across a 100 V dc supply, take 10 A current from the supply. Power dissipated in one coil is 600 W. What is the resistance of each coil ? [15 Marks]

Solution :



Total power delivered by source is = V × I

= 100 × 10

= 1000 W

Power dissipated by one coil P_1 is 600 W

(by Tellegence Theorem)

So the power dissipation by other coil P_2 is

(1000 – 600) W = 400 W

Resistance of coil one is $R_1 = \frac{V^2}{P_1} = \frac{10000}{600}$

$$= \frac{50}{3}\ \Omega$$

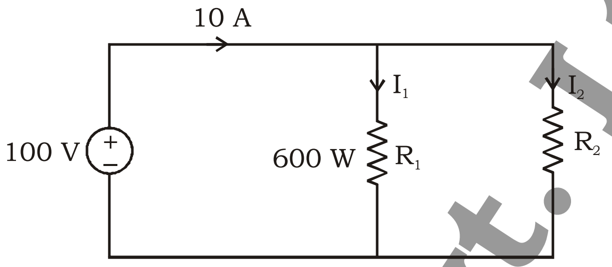
$$R_1 = 16.667\ \Omega$$

Resistance of other coil is $= \frac{V^2}{P_2} = \frac{10000}{400}$

$$R_2 = 25\ \Omega$$

$$\boxed{R_1 = 16.667\ \Omega\ R_2 = 25\ \Omega}$$

Alternate Solution :



$$R_1 = \frac{V^2}{P} = \frac{10000}{600} = 16.667\ \Omega$$

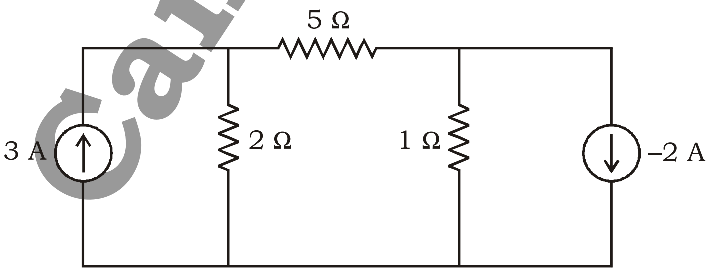
$$I_1 = \frac{P}{V} = \frac{600}{100} = 6\ A$$

$$I_2 = 10 - I_1 = 4\ \text{A}$$

$$R_2 = \frac{V}{I_2} = \frac{100}{4} = 25\ \Omega$$

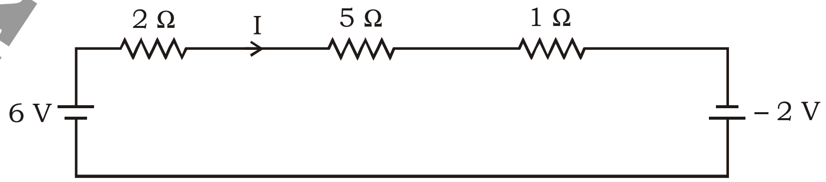
$$\boxed{R_1 = 16.667\ \Omega\ R_2 = 25\ \Omega}$$

(c) Determine the current through the 5 Ω resistor in the circuit of Figure. [15 Marks]



Solution :

By source transformation theorem



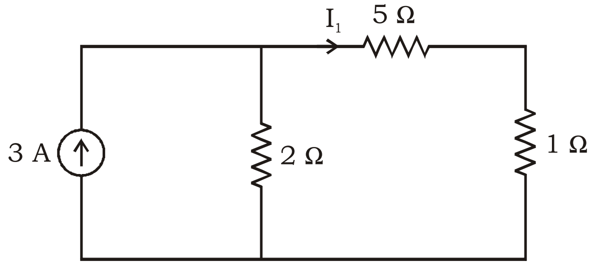
KVL Equation : $-6 + 2I + 5I + I - (-2) = 0$

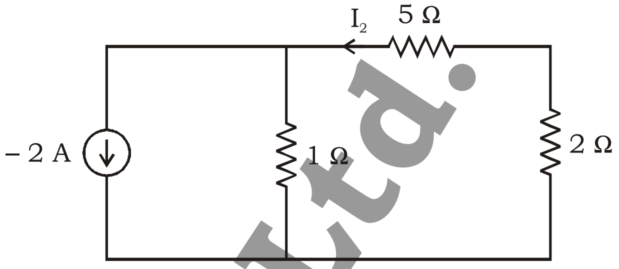
$$8I = 4$$

$$\boxed{I = 0.5\ A}$$

Alternate solution :

By superposition theorem



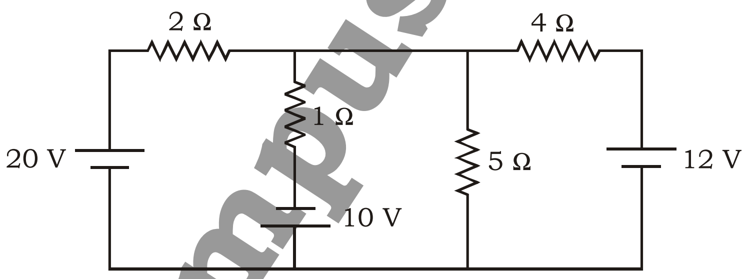


$$I_1 = 3 \times \frac{2}{3} = \frac{3}{4} A \qquad I_2 = -2 \times \frac{1}{8} = -\frac{1}{4} A$$

$$I = I_1 + I_2 = \frac{3}{4} - \frac{1}{4} = \frac{1}{2} A$$

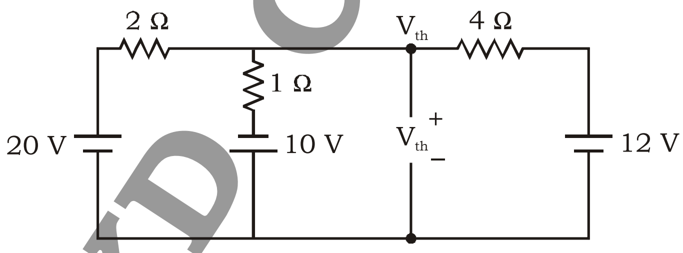
$$\boxed{I = 0.5\ A}$$

(d) Find the voltage across the 5 Ω resistance in the network shown in Figure using Thevenin's theorem. [15 Marks]

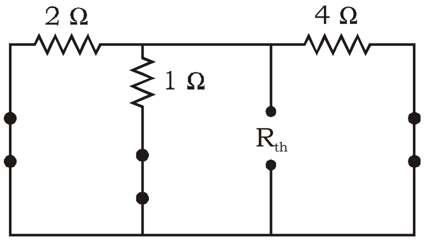


Solution :

V_{th} :



R_{th} :



Apply nodal analysis :

$$\frac{V_{th} - 20}{2} + \frac{V_{th} + 10}{1} + \frac{V_{th} - 12}{4} = 0$$

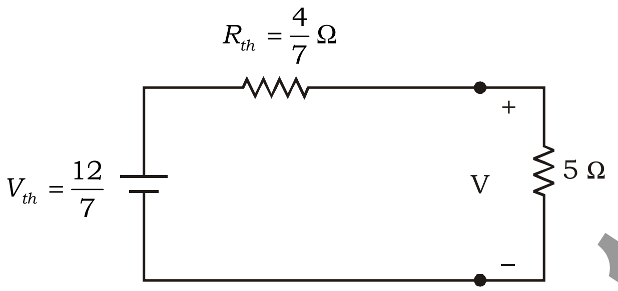
$$2V_{th} - 40 + 4V_{th} + 40 + V_{th} - 12 = 0$$

$$7\ V_{th} = 12$$

$$V_{th} = \frac{12}{7} V$$

$$R_{th} = 2//1//4$$

$$= \frac{4}{7}\ \Omega$$



$$V = \frac{12}{7} \times \frac{5}{5+\frac{4}{7}} = \frac{60}{39}\text{ Volt}$$

$$\boxed{V = \frac{60}{39}\text{ Volt}}$$

2. (a) An aeroplane with a wing span of 52 metres is flying horizontally at 1100 km/h. If the vertical component of the earth's magnetic field is 38 × 10^{-6} T, find the emf generated between the wing-tips. [10 Marks]

Solution :

Length of Aeroplane wings is l = 52 Metre

Velocity of aeroplane is v = 1100 Km/h

$$= 1100 \times \frac{5}{18}\text{ m/s}$$

= 305.56 m/s

Vertical component of magnetic field B is = 38 × 10^{-6} Tesla

generated emf $e = Bvl \sin\theta$ ($\theta = 90°$ $\sin\theta = 1$)

$= 38 \times 10^{-6} \times 305.56 \times 52$

$$\boxed{e = 0.6\,V}$$

(b) A coil of 200 turns is wound uniformly over a wooden ring having a mean circumference of 60 cm and a uniform cross-sectional area of 500 mm². If the current through the coil is 4 A, calculate the (i) magnetic field strength, (ii) flux density, and (iii) total flux. [15 Marks]

Solution :

N = 200
l = 60 cm
A = 500 mm^2
I = 4 A

(i) $$H = \frac{NI}{l}$$

$$= \frac{200 \times 4}{60 \times 10 - 2} = 1333.33\, {}^{AT}\!/_{m}$$

(ii) B = $\mu_0 \mu_r H$ $\mu_r = 1$

$$= 4\pi \times 10^{-7} \times 1333.33$$

$$= 1.67 \times 10^{-3}\text{ Tesla}$$

(iii) ϕ = BA

$$= 1.67 \times 10^{-3} \times 500 \times 10^{-6}$$

= 835 × 10^{-9} Wb

(c) An iron choke takes 4 A current when connected to a 20 V dc supply. When connected to a 65 V, 50 Hz ac supply, it takes 5 A current. Determine the power drawn by the coil. **[15 Marks]**

Solution :

When DC supply is connected

$i = 4$ A

$V = 20$ Volt

When AC supply connected

$I = 5$ A

$v = 65$ Volt, 50 Hz

Resistance of coil is $= \frac{V}{i} = \frac{20}{4} = 5\ \Omega$

And impedance of coil is $= \frac{v}{I} = \frac{65}{5} = 13\ \Omega$

Power dissipated by the coil is $= I^2R$

$= 25 \times 5$

$$\boxed{P = 125\ W}$$

(d) Define the following terms : **[20 Marks]**

(i) Mutual inductance
(ii) Resonance
(iii) MMF
(iv) Q-factor

Solution :

(i) Mutual inductance : When two circuits are so placed that a portion of the magnetic flux produced by one links with the turns of both the circuits, they are said to be ***mutually coupled***. Mutual inductance is the property of two circuits when a voltage is induced in one circuit by a change of current in the other circuit.

Consider two coils 1 and 2 with N_1 and N_2 turns respectively as shown in Fig. The coils are located physically close to one another so that a part of the flux produced by current in one coil links the second coil also. Let the current in coil 1 be i_1. It produces a magnetic flux ϕ_1. This flux has two components ϕ_{11} and ϕ_{12} that is.

$$\phi_1 = \phi_{11} + \phi_{12}$$

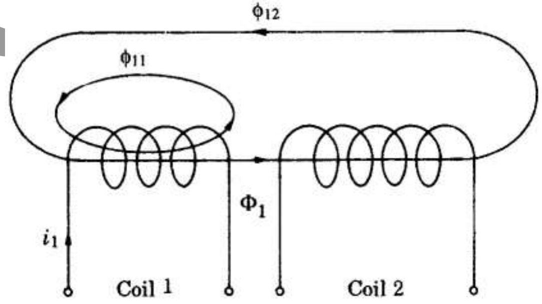


Fig. : *Mutually coupled coils*

The component ϕ_{11} links with turns of coil 1 only and does not link with turns of coil 2. The flux ϕ_{11} is called the ***self flux*** of coil 1. The other component ϕ_{12} links with turns of ***both*** the coils. It is called the ***mutual flux***.

If the current i changes with time the flux produced by it will also vary with time. Thus, the change of current in coil 1 changes the flux linkages in both the coils. Hence voltages are induced in both the coils. The voltage induced in coil 1 is called the ***self-induced voltage***, and the voltage induced in coil 2 is called the ***mutually-induced voltage.***

The voltage induced in coil 2 due to change of current in coil 1 is proportional to the rate of change of i_1. Mathematically it can be expressed as

$$e_2 \propto \frac{di_1}{dt}$$

$$e_2 = -M\,\frac{di_1}{dt}$$

where M is called the coefficient of mutual inductance or simply ***mutual inductance***. The negative sign is used to satisfy Lenz's law.

Unit of Mutual inductance

The unit of mutual inductance is henry (H).

(ii) Resonance : Resonance is defined as the condition in a circuit containing at least one inductor and one capacitor, when the supply voltage and the supply current are in phase. Thus, at resonance the equivalent impedance of the circuit is purely resistive. Since the supply voltage and supply current are in phase, the power factor of a resonant circuit is unity. At resonance the circuit impedance Z and the admittance Y are real quantities. Thus, if Z and Y are expressed in rectangular form their j terms are zero while if Z and Y are expressed in polar form their angles are zero.

For example,

(a) If $Z = R + jX$ and $Y = G + jB$

then at resonance

$I_m(Z) = X = 0$ or $I_m(Y) = B = 0$

(b) If $Z = Z\angle\phi$ and $Y = Y\angle\theta$

then at resonance

$\phi = 0$ and $\theta = 0$

(c) If $Z = \dfrac{a + jb}{c + jd}$

then at resonance

$$\frac{b}{a} = \frac{d}{c}$$

Similarly,

if $Y = \dfrac{l + jm}{p + jq}$

then at resonance

$$\frac{m}{l} = \frac{q}{p}$$

(iii) Magnetomotive Force (MMF) : The current flowing in an electrical circuit is due to the existence of electromotive force (emf) across the circuit. By analogy, to drive magnetic flux through a magnetic circuit, a magnetomotive force (mmf) is necessary.

Magnetomotive force can be produced when current flows in a coil of one or more turns. The magnitude of mmf is directly proportional to the current I and the number of turns of the coil N.

$$\text{mmf} = NI$$

I = Current through the coil (A)
N = Number of turns in the coil

Standard Unit of mmf : Ampere-turn (C-T)

(iv) Quality factor or circuit magnification factor (Q) : It is defined as,

$$Q = 2\pi \frac{\text{Maximum energy stored}}{\text{Energy dissipated per cycle}}$$

Also, quality factor for a circuit is defined as $Q = \frac{\text{Resonant frequency}}{\text{Bandwidth}} = \frac{\omega_0}{\omega_2 - \omega_1}$ and the selectivity of the circuit is defined as the reciprocal of quality factor, i.e.,

$$selectivity = \frac{1}{Q} = \frac{BW}{\omega_0}$$

Therefore, a circuit will be highly selective if it has a high value of Q. For a series RLC circuit, a high value of the quality factor implies a narrow resonant peak and a low value of Q implies broad resonant peak. The variations of magnitude and phase angle of current in an RLC series circuit for different values of quality factor (Q).

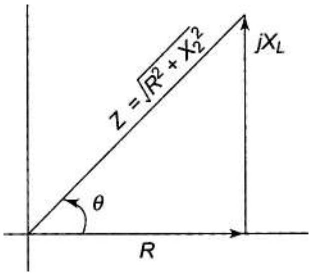
3. (a) Prove that the reactive power in ac circuit is equal to VI sin Φ. [10 Marks]

Solution :

We know that the average power dissipated is

$$P_{av} = V_{eff}[I_{eff}\cos\theta]$$

From the impedance triangle shown in Fig.



$$\cos\theta = \frac{R}{|Z|}$$

and $V_{eff} = I_{eff}Z$

If we substitute Eqs.

$$P_{av} = I_{eff}Z\left[I_{eff}\frac{R}{Z}\right]$$

$$= I_{eff}^2 \; R \text{ watts}$$

This gives the average power dissipated in a resistive circuit.

If we consider a circuit consisting of a pure inductor, the power in the inductor

$$P_r = iv_L$$

$$= iL\frac{di}{dt}$$

Consider $i = I_m \sin(\omega t + \theta)$

Then $P_r = I_m^2 \sin(\omega t + \theta)\, L\omega\cos(\omega t + \theta)$

$$= \frac{I_m^2}{2}(\omega L)\sin 2(\omega t + \theta)$$

$\therefore$ $P_r = I_{eff}^2(\omega L)\sin 2(\omega t + \theta)$

From the above equation, we can say that the average power delivered to the circuit is zero. This is called ***reactive*** power. It is expressed in volt-amperes reactive (VAR).

$$P_r = I_{eff}^2 X_L \; VAR$$

From Fig., we have

$$X_L = Z\sin\theta$$

Substituting Eqs.

$$P_r = I_{eff}^2 Z\sin\theta$$

$$= (I_{eff}Z)I_{eff}\sin\theta$$

$$= V_{eff}I_{eff}\sin\theta \text{ VAR}$$

(b) **A 50 μA meter movement with an internal resistance of 1 kΩ is to be used as a dc voltmeter of range 50 V. Calculate the (i) multiplier resistance required, and (ii) voltage multiplying factor.** **[10 Marks]**

Solution :

$i = 50\ \mu\text{ A}$

$R_m = 1\text{ K}\Omega$

$R_{se} = ?$ Voltage range = 50 V

(i) Multiplier Resistance Required

$$R_{se} = (m-1)\,R_m$$
$$= (1000-1)\ 1\text{ K}$$
$$R_{se} = 999\text{ K}\Omega$$

(ii) Voltage Multiplying Factor

$$m = \frac{V_{range}}{V_m} = \frac{50}{50\times10^{-6}\times1\,K} = 1000$$

(c) **In a gravity controlled instrument, the controlling weight is 0.005 kg and acts at a distance of 2.4 cm from the axis of the moving system. Determine the deflection in degrees corresponding to deflecting torque of 1.05 × 10^{-5} kgm.** **[10 Marks]**

Solution :

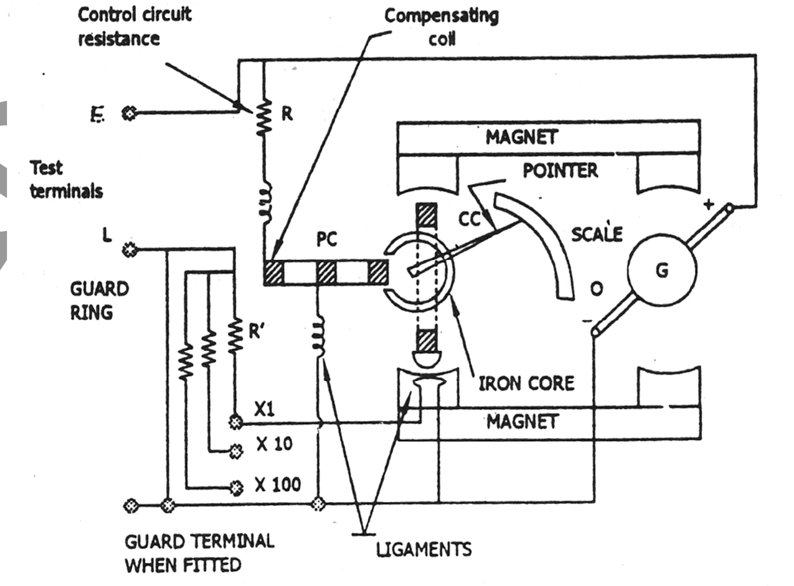
$$T_d = Wl\sin\theta$$
$$1.05\times10^{-5} = 0.005\times2.4\times10^{-2}\sin\theta$$
$$\sin\theta = \frac{1.05\times10^{-5}}{0.005\times2.4\times10^{-2}}$$
$$= 87.5\times10^{-3}$$
$$\sin\theta = 0.0875$$
$$\theta = \sin^{-1}(0.0875)$$
$$\boxed{\theta = 5^\circ}$$

(d) **Explain in brief :** **[30 Marks]**

(i) Megger
(ii) Two-wattmeter method
(iii) Signal generator
(iv) Earth fault detection
(v) AC bridge

Solution :

(i) **Megger :** Meggar is a hand driven generator it can be used for measurement of insulation and earth resistance. This the most commonly used method for measurement of high resistance. The essential parts of a megger are shown in the figure.



It consists of a hand driven d.c. generator and a direct reading ohmmeter. Permanent magnets provided field for both. The moving element consists of three coils, one current coil, potential or pressure coil and compensating coil. The coils are mounted over a rigid shaft and are free to rotate over a C-shaped stationary iron-core.

The coils are connected to the circuit by means of flexible leads or ligaments. E and L are the test terminals. The current coil is connected in series with the terminal L. The series resistance R' protects the current coil in case the test terminals are short-circuited and controls the range of the instrument. The pressure coil, in series with a compensating coil and protection resistance R is connected across the generator terminals. Compensating coil is provided for better scale proportions and to make the instrument astatic.

When the current from the generator flows through pressure coil, the coil tends to align itself at right angles to the permanent magnet field. For infinite resistance (i.e. test terminals open) no current flows through the current coil and pressure coil governs the motion of the moving element causing it to move its extreme counterclockwise position, the point under this condition is marked infinite resistance.

Current coil produces clockwise torque on moving element. When the terminals L and E are short-circuited, the current flowing through current coil (corresponding to zero external resistance) is large enough to move the pointer to its extreme clockwise position, marked zero. For any resistance connected between L and E, the opposing torque of the coils balance each other so that pointer comes to rest at some intermediate point on the scale.

From the diagram above, Torque developed due to I_1 = Torque developed due to I_2.

$$T_1 = T_2$$

or, $$\phi I_1 \cos\theta = \phi I_2 \cos(90 - \theta)$$

or, $$I_1 \cos\theta = I_2 \sin\theta \quad \text{or} \quad \tan\theta = \frac{I_1}{I_2} \quad \text{and} \quad I_1 = \frac{V}{R_1},\ I_2 = \frac{V}{R_2 + R_T}$$

$\therefore$ $$\tan\theta = \frac{I_1}{I_2} = \frac{R_2 + R_T}{R_1}$$

As R_1 and R_2 are constants.

Therefore, $\boxed{\theta \propto R_T}$, *i.e.* $\boxed{\text{Deflection} \propto \text{Unknown resistance}}$

Advantages of Meggar

(i) It is easily portable.

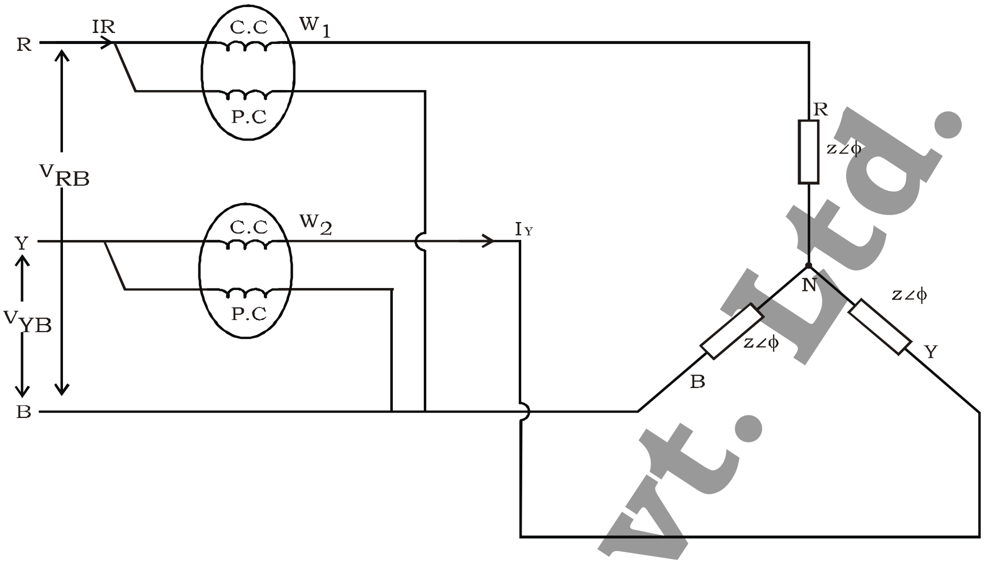
(ii) There is no external supply is required for a practical meggar because the hand driven generator produces the requires voltage source for the current coil and potential coil.

(iii) Widely used as "Insulation tester" as the insulation resistance are quite high.

Application of Meggar

It is used for the measurement of insulation resistance of cable, transformer, bushing insulation and winding insulation of electrical motors, generators and transformers.

(ii) Two-wattmeter method : Measurement of power by two wattmeter method is given below,



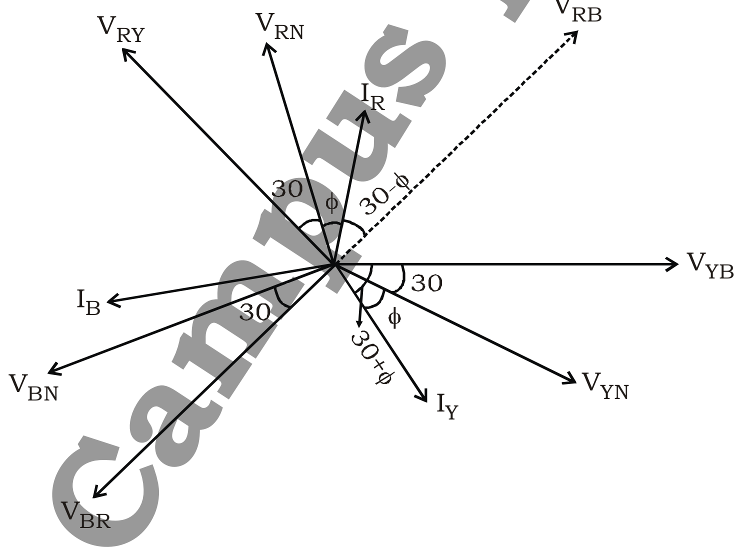


***Fig. :** Phasor for a star load*

Reading of wattmeter 1

$$W_1 = V_{RB} I_R \cos\angle(V_{RB} - I_R)$$

$$W_1 = V_L I_L \cos(30 - \phi) \quad \text{..............} (1)$$

Reading of wattmeter 2

$$W_2 = V_{YB} I_Y \cos\angle(V_{YB} - I_Y)$$

$$W_2 = V_L I_L \cos(30 + \phi) \quad \text{..............} (2)$$

Now on adding equations (1) & (2), we get

$$W = W_1 + W_2$$

$$= V_L I_L \cos(30\text{-}\phi) + V_L I_L \cos(30\text{-}\phi)$$

$$= V_L I_L [\cos(30\text{-}\phi) + \cos(30\text{-}\phi)]$$

$$= V_L I_L 2\cos 30 \cos\phi$$

$$\boxed{W = \sqrt{3} V_L I_L \cos\phi} \quad \text{..............} (3)$$

This result shows that it is the power for 3 - ϕ system.

Now on subtracting equations (1) & (2), we get

$$W_1 - W_2 = V_L I_L \cos(30 - \phi) - V_L I_L \cos(30 + \phi)$$

$$= V_L I_L [\cos(30 - \phi) - \cos(30 + \phi)]$$

$$= V_L I_L \,.\, 2 \sin 30.\, \sin\phi$$

$$\boxed{W_1 - W_2 = V_L I_L \sin\phi} \qquad \text{.............} (4)$$

On Dividing equation (4) by equation (3), we get

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{V_L I_L \sin\phi}{\sqrt{3} V_L I_L \cos\phi}$$

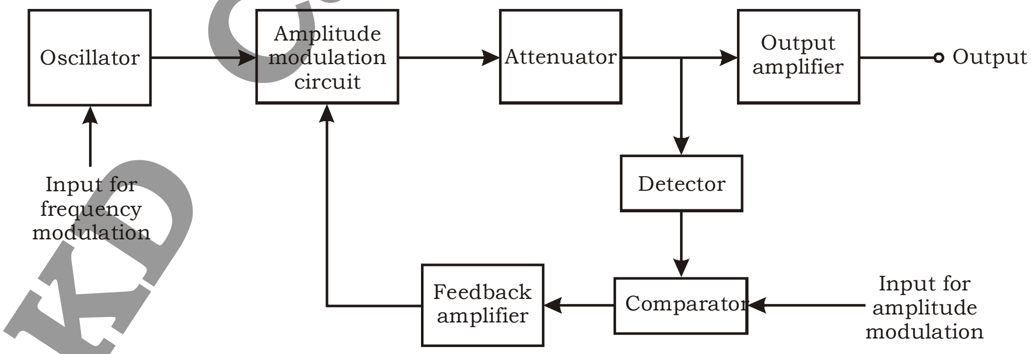
$$\tan\phi = \sqrt{3}\frac{(W_1 - W_2)}{(W_1 + W_2)}$$

Power factor angle, $\boxed{\phi = \tan^{-1}\left\{\sqrt{3}\frac{(W_1 - W_2)}{(W_1 + W_2)}\right\}}$

Power factor, $\boxed{\cos\phi = \cos\left[\tan^{-1}\left\{\sqrt{3}\frac{(W_1 - W_2)}{(W_1 + W_2)}\right\}\right]}$

(iii) Signal generator : The signal generator, like an oscillator, is a source of sinusoidal signals but the signal generator is also capable of modulating its sinusoidal output signal with other signals. This is the main difference between the two instruments (signal generator and oscillator). When the signal generators are employed for producing an unmodulated sinusoidal output they are said to be producing CW (continuous height wave) signal. When the produced output signal is modulated, the modulating waveforms may be either externally applied sine-waves, square waves, triangular waves, pulses or more complex signals, as well as internally generated sine-waves. Amplitude modulation (AM) or frequency modulation (FM) may be used. Normally amplitude (AM) modulation is employed.

Signal generators are primarily employed for providing appropriate signals for calibration, testing, and troubleshooting of the amplifier circuits used in communications, electronics such as radio and television amplifiers. They are also employed for measurement of characteristics of antennas and transmission lines.



(iv) Earth fault detection :

1. All the parts of electrical equipment, like casings of machines, switches and circuit breakers, lead sheathing and armouring of cables, tanks of transformers, etc. which have to be at earth potential, must be connected to an earth electrode. The purpose of this is to protect the various parts of the installation, as well as the persons working against damage in case the insulation of a system fails at any point. By connecting V these parts to an earthed electrode a continuous low resistance path is available for leakage currents to flow to earth. This current operates the protective devices and thus the faulty circuit is isolated in case a fault occurs.

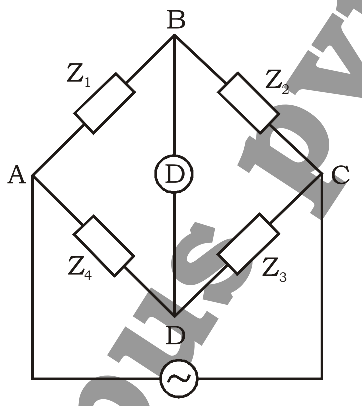
2. The earth electrode ensures that in the event of over voltage on the system due to lightning discharges or other system faults, those parts of equipment which are normally dead as far as voltages are concerned, do not attain dangerously high potentials.

3. In a three phase circuit the neutral of the system is earned in order to stabilize the potential of the circuit with respect to earth.

(v) AC bridge : Resistances can be measured by direct-current Wheatstone bridge, for which the condition of balance is that

$$\frac{R_1}{R_2} = \frac{R_4}{R_3} \text{ or } R_1R_3 \quad R_2R_4$$

Inductances and capacitances can also be measured by a similar four-arm bridge, instead of using a source of direct current, alternating current is employed and galvanometer is replaced by a vibration galvanometer (for commercial frequencies or by telephone detector if frequencies are higher (500 to 2000 Hz)).



The condition for balance is the same as before but instead of resistances, impedances are used *i.e.*

$$Z_1 / Z_2 = Z_4 / Z_3 \text{ or } Z_1Z_3 = Z_2Z_4$$

But there is one important difference *i.e.* not only should there be balance for the magnitudes of the impedances but also a phase balance. Writing the impedances in their polar form, the above condition becomes

$$Z_1\angle\phi_1.Z_3\angle\phi_3 = Z_2\angle\phi_2.Z_4\angle\phi_4 \text{ or } Z_1Z_3\angle\phi_1 + \phi_3 = Z_2Z_4\angle\phi_2 + \phi_4$$

Hence, we see that, in fact, there are two balance conditions which must be satisfied simultaneously in a four-arm a.c. impedance bridge.

(i) $Z_1Z_3 = Z_2Z_4$ ... for magnitude balance

(ii) $\phi_1 + \phi_3 = \phi_2 + \phi_4$ ... for phase angle balance

4. (a) Explain the braking methods of DC series motors. [20 Marks]

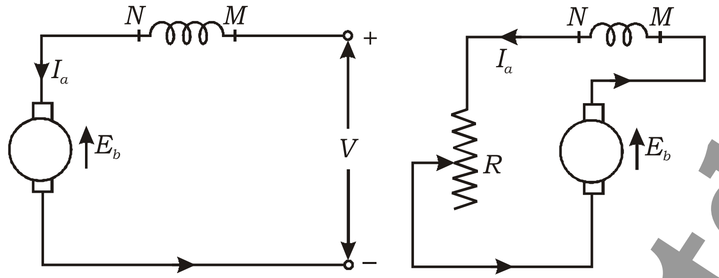
Solution :

Braking Methods of DC Series Motors

(i) Rheostatic (or Dynamic) Braking : The motor is disconnected from the supply, the field connections ***are reversed*** and the motor is connected in series with a variable resistance *R* as shown in Fig. Obviously, now, the machine is running as a generator.

The field connections are reversed to make sure that current through field winding flows in the same direction as before (*i.e.*, from *M* to *N*) in order to assist residual magnetism. In practice, the variable resistance employed for starting purpose is itself used for braking purposes. As in the case of shunt motors,

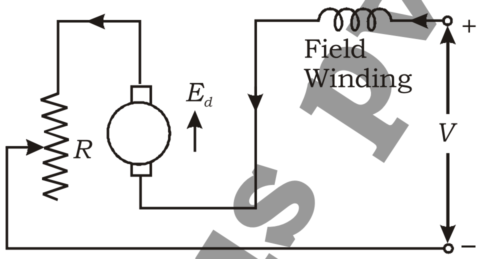
$$T_B = k_2\phi^2N = k_3\ I_{a2}N$$



(*a*) (*b*)

(ii) Plugging or Reverse Current Braking : As in the case of shunt motors, in this case also the connections of the armature are reversed and a variable resistance *R* is put in series with the armature as shown in Fig.

$$T_B = k_2\phi + k_3\phi^2 N$$



(iii) Regenerative Braking : This type of braking of a sereis motor is not possible without modification because reversal of I_a would also mean reversal of the field and hence of E_b. However, this method is sometimes used with traction motors, special arrangements being necessary for the purpose.

(b) Explain the parallel operation of 3-phase transformers. [10 Marks]

Solution :

All the conditions which apply to the parallel operation of single-phase transformers also apply to the parallel running of 3-phase transformers but with the following additions :

1. The voltage ratio must refer to the terminal ***voltage of primary and secondary.*** It is obvious that this ratio may not be equal to the ratio of the number of turns per phase. For example, if V_1, V_2 are the primary and secondary terminal voltages, then for Y/Δ connection, the turn ratio is $V_2/(V_1/\sqrt{3}) = \sqrt{3}V_2/V_1$.
2. The phase displacement between primary and secondary voltages must be the same for all transformers which are to be connected for parallel operation.
3. The phase sequence must be the same.
4. All three transformers in the 3-phase transformer bank will be of the same construction either core or shell.

Note :

(i) In dealing with 3-phase transformers, calculations are made for one phase only. The value of equivalent impedance used is the equivalent impedance per phase referred to secondary.

(ii) In case the impedances of primary and secondary windings are given separately, then primary impedance must be referred to secondary by multiplying it with (transformation ratio)^2.

(iii) For Y/Δ or Δ/Y transformers, it should be remembered that the voltage ratios as given in the questions, refer to terminal voltages and are quite different from turn ratio.

(c) Draw and explain equivalent circuit of a 1–phase transformer. Draw its phasor diagram for leading power factor load. [20 Marks]

Solution :

Equivalent Circuit of a 1–Phase Transformer :

Figure shows the equivalent circuit of a single-phase transformer having load impedance Z_L. Figure is the equivalent circuit of Figure. The secondary winding resistance (R_2), leakage reactance (X_2) and load impedance (Z_L) connected to secondary terminal is transferred to primary side.

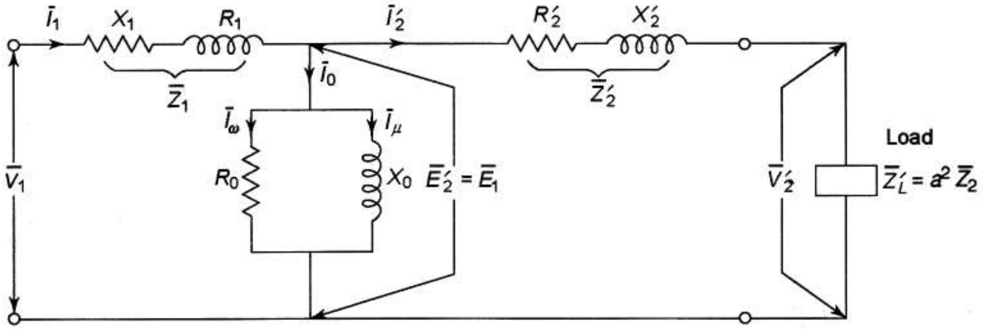


Fig. : *Exact Equivalent Circuit*

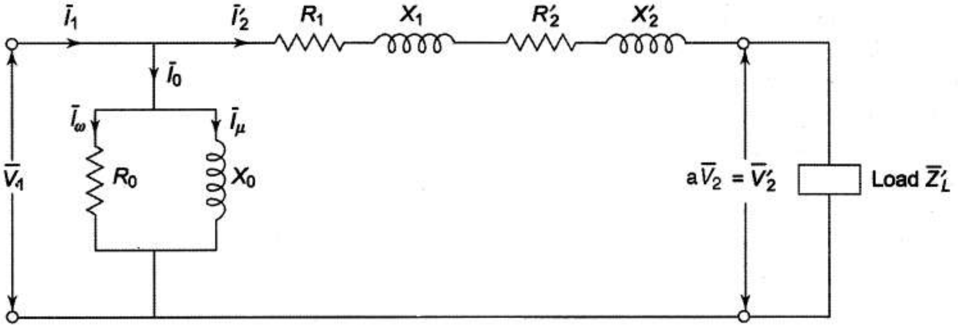


Fig. : *Approximate Equivalent Circuit*

Since I_0 is small compared to full-load current, we can shift the excitation circuit towards the terminal voltage side shown in Figure is the approximate equivalent circuit, whereas Figure is the exact equivalent circuit of Figure.

From Figure, the total input impedance between input terminals becomes

$$\overline{Z} = \overline{Z}_1 + \overline{Z}_m \parallel (\overline{Z}'_2 + \overline{Z}'_L) = \overline{Z}_1 + \frac{(\overline{Z}_m \overline{Z}'_2 + \overline{Z}'_L)}{\overline{Z}_m + \overline{Z}'_2 + \overline{Z}'_L}$$

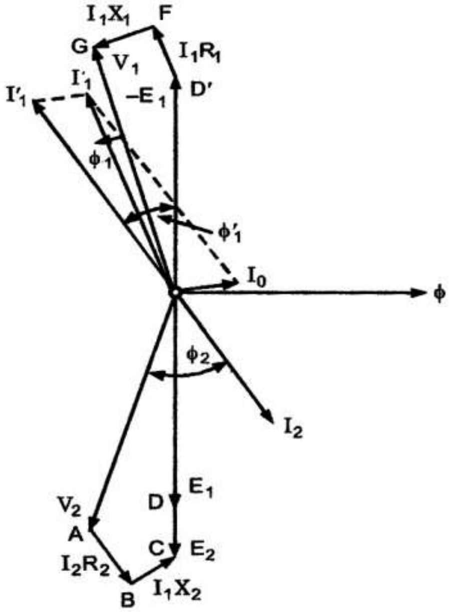
where $$\overline{Z}'_L + \overline{R}'_L + jX'_L$$

and $\overline{Z}_m$ is the impedance of the exciting circuit.

$$\overline{V}_1 = \overline{I}_1 \overline{Z} = \overline{I}_1 \left[\overline{Z}_1 + \frac{\overline{Z}_m (\overline{Z}'_2 + \overline{Z}'_L)}{\overline{Z}_m + \overline{Z}_2 + \overline{Z}'_L} \right]$$

R_0, X_0, R_{01} and X_{01} are the four important parameters of the transformer. From open circuit and short circuit test of a transformer, R_0, X_0 and R_{01}, X_{01} can be determined respectively.

Phasor Diagram for Leading Power Factor Load



(d) A 3–phase 400 V, 50 Hz 6-pole star connected induction motor develops maximum torque at a speed of 940 rpm. If the rotor resistance per phase is 0.1 Ω, determine the standstill rotor reactance. [10 Marks]

Solution :

$$P = 6$$

$$N_r = 940 \text{ rpm}$$

$$N_s = \frac{120f}{P}$$

$$= \frac{120 \times 50}{6}$$

$$N_s = 1000 \text{ rpm}$$

$$s = \frac{N_s - N_s}{N_s} = \frac{1000 - 940}{1000} = \frac{60}{1000}$$

$$s = 0.06$$

Condition for maximum torque

$$R = sX$$

$$X = \frac{R}{s}$$

$$= \frac{0.1}{0.06}$$

$$X = 1.67\ \Omega/\text{phase}$$

5. (a) How is the rating of circuit breakers decided ? Explain in brief. [10 Marks]

Solution :

Rating of circuit breaker

Duties of circuit breaker : Three main duties of circuit breaker–

(i) It must be capable of opening the faulty circuit and breaking the fault current.

(ii) It must be capable of being dosed on to a fault.

(iii) It must be capable of carrying fault current for a short time while another circuit breaker is clearing the fault.

Corresponding to the above mentioned duties, the circuit breaker have three ratings.

(i) Breaking capacity.
(ii) Making capacity.
(iii) Short time rating.

(i) Breaking Capacity : It is current (r.m.s.) that a circuit breaker is capable of breaker at given recovery voltage and under specified condition. (e.g.- power factor, RRRV etc).

- Symmetrical breaking capacity = $\sqrt{3}$ × Rated line voltage (kV) × Sub transient c/n (kA) × 10^{-6} MVA
- Asymmetrical breaking capacity = 1.6 × Symmetrical Breaking capacity MVA

(ii) Making capacity : The peak value of current (including d.c. component) during the first cycle of current wave after the closure of circuit breaking is known as "making Capacity".

- Making capacity = 2.55 × Symmetrical breaking capacity.

(iii) Short time rating : It is the period for which the circuit breaker is able to carry fault current while remaining closed.

(b) Explain Merz-Price protection of generators with appropriate circuit diagram.

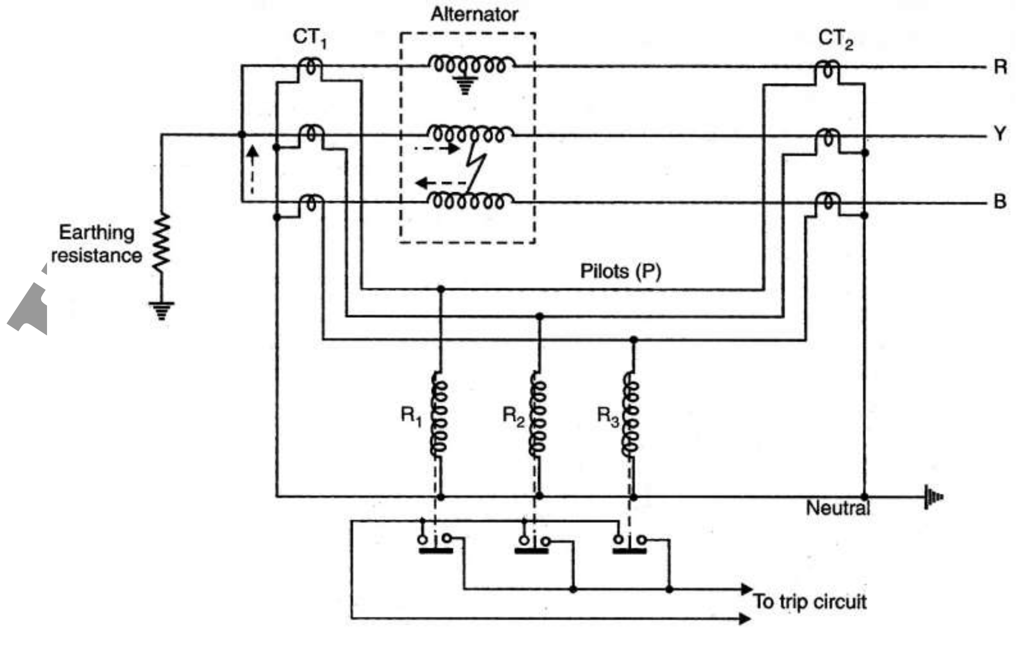
[10 Marks]

Solution :

In this scheme of protection, currents at the two ends of the protected section are compared. Under normal operating conditions, these currents are equal but ma become unequal on the occurrence of a fault in the protected section. The difference of the current under fault conditions is arranged to pass through the operating coil of the relay. The relay then closes its contacts to isolate protected section from the system. This form of protection is also known as Merz-Price circulating current scheme.

Circuit diagram : The schematic arrangement of current differential protection for a 3-phase alternator. Identical current transformer pairs CT_1 and CT_2 are placed on either side of each phase of the stator windings. The secondaries of each set of current transformers are connected in star ; the two neutral points and the corresponding terminals of the two star groups being connected together by means of a four-core pilot cable. Thus there is an independent path for the currents circulating in each pair of current transfonners and the corresponding pilot P.

The relay coils are connected in star, the neutral point being connected to the current-transformer common neutral and the outer ends one to each of the other three pilots. In order that burden on each current transformer is the same, the relays are connected across equipotential points of the three pilot wires and these equipotential points would naturally be located at the middle of the pilot wires. The relays are generally of electromagnetic type and are arranged for instantaneous action since fault should be cleared as quickly as possible.



(c) Define the following terms : **[30 Marks]**

(i) Demand factor

(ii) Tariff

(iii) HRC fuses

(iv) Diversity factor

(v) Derating factor of a cable

Solution :

(i) Demand factor : Ratio of maximum demand on the power station to its connected load i.e.

$$\boxed{\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}}$$

It is usually less than 1.

Ex.: It is expected because max. demand on the power station is generally less than the connected load.

80 MW and the connected load is 100 MW.

Demand factor plays an important role in determining the capacity of plant equipment.

(ii) Tariff : The rate at which electrical energy is supplied to a consumer is known as **tariff.**

Objectives of tariff :

- Recovery of cost of producing electrical energy at the power station.
- Recovery of cost on the capital investment in transmission and distribution systems.
- Recovery of cost of operation and maintenance of supply of electrical energy *e.g.*- metering equipment, billing etc.
- A suitable profit on the capital investment.

The commonly used types of tariff :

1. Simple tariff : When there is a fixed rate per unit of energy consumed, it is called a simple tariff or uniform rate tariff.
2. Flat rate tariff : When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff.
3. Block rate tariff : When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a block rate tariff.
4. Two-part tariff : When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a two-part tariff.

   The consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed *i.e.,*

   $$\text{Total charges} = \text{Rs}\ (b \times \text{kW} + c \times \text{kWh})$$

   where, b = charge per kW of maximum demand

   c = charge per kWh of energy consumed

   This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.
5. Maximum demand tariff : It is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer.
6. Power factor tariff : The tariff in which power factor of the consumer's load is taken into consideration is known as power factor tariff.
7. Three-part tariff : When the total charge to be made from the consumer is split into three parts viz., fixed charge, semi-fixed charge and running charge, it is known as a three-part tariff. i.e.,

   $$\text{Total charge} = \text{Rs}\ (a + b \times \text{kW} + c \times \text{kWh})$$

   where, a = fixed charge made during each billing period. It includes interest and depreciation on the cost of secondary distribution and labour cost of collecting revenues,

   b = charge per kW of maximum demand,

   c = charge per kWh of energy consumed.

(iii) HRC fuses :

The HRC fuses cope with increasing rupturing capacity on the distribution system and overcome the serious disadvantages suffered by the semi-enclosed rewirable fuses.

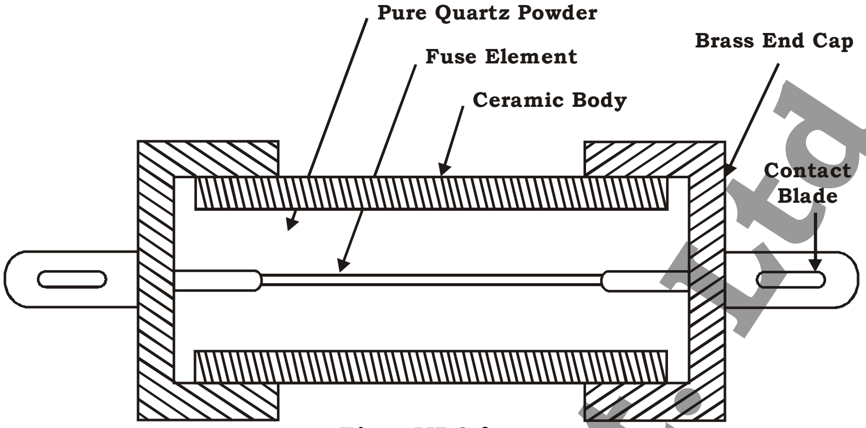


Fig. : *HRC fuse*

The fuse element is either pure silver or bimetalic in nature.

Normally, the fuse element has two or more sections joined together by means of a tin joint.

The fuse element in the form of a long cylindrical wire is not used, because after melting, it will form a string of droplets and an arc will be struck between each of the droplets.

The shape of the fuse element depends upon the characteristic desired.

When the fuse carries normal rated current, the heat energy generated is not sufficient to melt the fuse element. But when a fault occurs, the fuse element melts before the fault current reaches its first peak. As the element melts, it vaporizes and disperses.

Advantages of HRC Fuses

(i) Capability of clearing high values of fault currents
(ii) Fast operation
(iii) Non-deterioration for long periods
(iv) No maintenance needed
(v) Reliable discrimination
(vi) Consistent in performance
(vii) Cheaper than other circuit interrupting devices
(viii) Current limitation by cut-off action
(ix) Inverse time-current characteristic

Disadvantages of HRC fuses

(i) It requires replacement after each operation.
(ii) Inter-locking is not possible.
(iii) It produces overheating of the adjacent contacts.

Applications of HRC Fuses

(i) Protection of low voltage distribution systems against overloads and short-circuits
(ii) Protection of cables
(iii) Protection of busbars
(iv) Protection of motors
(v) Protection of semiconductor devices
(vi) Back up protection to circuit breakers.

(iv) Diversity factor : The ratio of the sum of individual maximum demands to the maximum demand on power station is known as ***diversity factor*** *i.e.,*

$$\boxed{\text{Diversity factor} = \frac{\text{Sum of individual maximum demand}}{\text{Maximum demand on power station}}}$$

A power station supplies load to various types of consumers whose maximum demands generally do not occur at the same time. Therefore, the maximum demand on the power station is always less than the sum of individual maximum demands of the consumers. Obviously, diversity factor will always be greater than. The greater the diversity factor, the lesser is the cost of generation of power.

(v) Derating factor of a cable : A power cable designed with standard operating conditions may not operate so in paractical. Therefore, the current carrying capacity may get impacted due to this.

Some examples of this : Cables installed deep under the ground will have reduced current carrying capacity than cables installed in air. This is impacted due to multiple factors like soil temperature soil thermal resistivity etc.

In order to deal with this, a Derating Factor is associated with cables to arrive at actual value of current carrying capacity.

Actual Current Carrying Capacity = Derating Factor × Cable current carrying capacity under stdandard conditions

Thus for a 100 A cable with a derating factor of 0.8 the actual current carrying capacity would be: 0.8 × 100 = 80 A

(d) What are the different methods of power factor improvement ? [10 Marks]

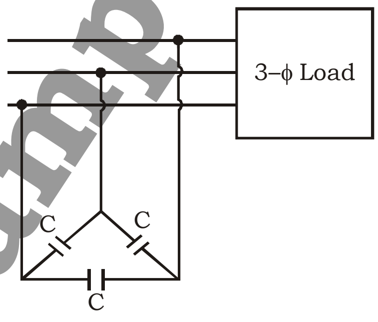
Solution :

Power factor improvement : The low power factor is mainly due to the fact that most of the power loads are inductive and, therefore, take lagging currents. In order to improve the power factor, some device taking leading power should be connected in parallel with the load.

This can be achieved by the following equipment :

1. Static capacitors. 2. Synchronous condenser. 3. Phase advancers.

1. Static capacitor : The power factor can be improved by connecting capacitors in parallel with the equipment operating at lagging power factor. The capacitor (generally known as static capacitor) draws a leading current and partly or completely neutralises the lagging reactive component of load current. This raises the power factor of the load. For three-phase loads, the capacitors can be connected in delta or star as shown in Fig. Static capacitors are invariably used for power factor improvement in factories.



(i)

Advantages

(i) They have low losses.

(ii) They require little maintenance as there are no rotating parts.

(iii) They can be easily installed as they are light and require no foundation.

(iv) They can work under ordinary atmospheric conditions.

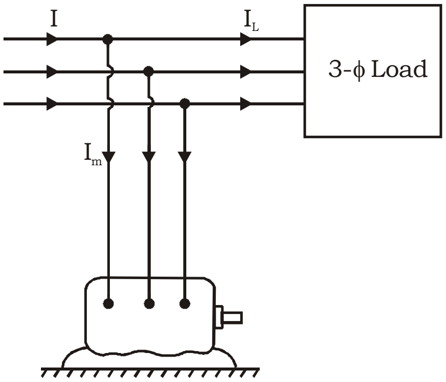
Disadvantages

(i) They have short service life ranging from 8 to 10 years.

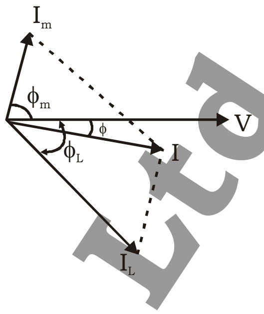
(ii) They are easily damaged if the voltage exceeds the rated value.

(iii) Once the capacitors are damaged, their repair is uneconomical.

2. Synchronous condenser : A synchronous motor takes a leading current when over-excited and, therefore, behaves as a capacitor. An over-excited synchronous motor running on no load is known as *synchronous condenser.* When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralises the lagging reactive component of the load. Thus the power factor is improved.



3-ϕ Synchronous motor



Advantages

(i) By varying the field excitation, the magnitude of current drawn by the motor can be changed by any amount. This helps in achieving stepless control of power factor.

(ii) The motor windings have high thermal stability to short circuit currents.

(iii) The faults can be removed easily.

Disadvantages

(i) There are considerable losses in the motor.

(ii) The maintenance cost is high.

(iii) It produces noise.

(iv) Except in sizes above 500 kVA, the cost is greater than that of static capacitors of the same rating.

(v) As a synchronous motor has no self-starting torque, therefore, an auxiliary equipment has to be provided for this purpose.

3. **Phase advancers :** Phase advancers are used to improve the power factor of induction motors. The low power factor of an induction motor is due to the fact that its stator winding draws exciting current which lags behind the supply voltage by 90°. If the exciting ampere turns can be provided from some other a.c. source, then the stator winding will be relieved of exciting current and the power factor of the motor can be improved.

6. (a) Explain earthing practices in brief. [15 Marks]

Solution :

Earthing : The main reason for doing earthing in electrical network is for the safety. When all metallic parts in electrical equipments are grounded then if the insulation inside the equipments fails there are no dangerous voltages present in the equipment case. If the live wire touches the grounded case then the circuit is effectively shorted and fuse will immediately blow. When the fuse is blown then the dangerous voltages are away.

Purpose of Earthing :

(1) Safety for Human life/ Building/Equipments :

To save human life from danger of electrical shock or death by blowing a fuse i.e. To provide an alternative path for the fault current to flow so that it will not endanger the user.

To protect buildings, machinery & appliances under fault conditions.

To ensure that all exposed conductive parts do not reach a dangerous potential.

To provide safe path to dissipate lightning and short circuit currents.

To provide stable platform for operation of sensitive electronic equipments i.e. To maintain the voltage at any part of an electrical system at a known value so as to prevent over current or excessive voltage on the appliances or equipment.

(2) Over voltage protection :

Lightning, line surges or unintentional contact with higher voltage lines can cause dangerously high voltages to the electrical distribution system. Earthing provides an alternative path around the electrical system to minimize damages in the System.

(3) Voltage stabilization :

There are many sources of electricity. Every transformer can be considered a separate source. If there were not a common reference point for all these voltage sources it would be extremely difficult to calculate their relationships to each other. The earth is the most omnipresent conductive surface, and so it was adopted in the very beginnings of electrical distribution systems as a nearly universal standard for all electric systems.

Conventional Methods of Earthing :

(1) Plate type Earthing :

Generally for plate type earthing normal Practice is to use.

Cast iron plate of size 600 mm × 600 mm × 12 mm.

Galvanized iron plate of size 600 mm × 600 mm × 6 mm.

Copper plate of size 600 mm × 600 mm × 3.15 mm.

Plate burred at the depth of 8 feet in the vertical position and GI strip of size 50 mm × 6 mm bolted with the plate is brought up to the ground level.

These types of earth pit are generally filled with alternate layer of charcoal & salt up to 4 feet from the bottom of the pit.

(2) Pipe type Earthing :

For Pipe type earthing normal practice is to use.

GI pipe [C-class] of 75 mm diameter, 10 feet long welded with 75 mm diameter GI flange having 6 numbers of holes for the connection of earth wires and inserted in ground by auger method. These types of earth pit are generally filled with alternate layer of charcoal & salt or earth reactivation compound.

(b) With the help of neat and labelled circuit diagram, explain the process of electroplating. [15 Marks]

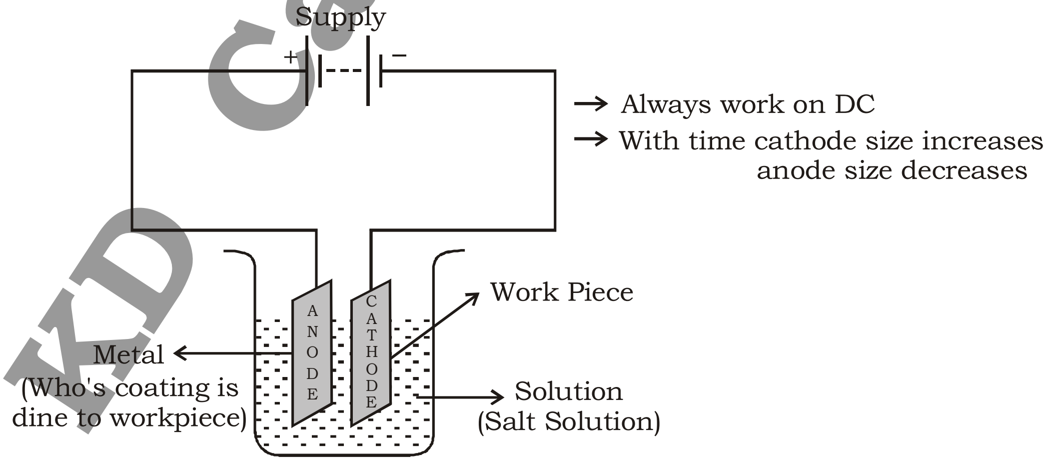
Solution :

Electroplating :

Electroplating is defined as electro-deposition of metal upon metallic surfaces.

This is done for,

(i) protection of metals against corrosion
(ii) giving a shiny appearance to articles
(iii) giving reflecting properties to reflectors
(iv) replacing worn-out material.



→ Always work on DC
→ With time cathode size increases anode size decreases

Various operations involved in electroplating are degreasing and, surface cleaning, deposition of metal by passing current and polishing.

(i) Cleaning Operation : If electroplating is done on an undergreased and unclean surface, the deposit formed is not well adherent to the base metal and is likely to peel off. Therefore, to reduce percentage of spoilage, great attention is given to cleaning operation.

(ii) Deposition of Metal : In all types of metal deposition processes, article to be electroplated is made cathode, solution is made up of salt of the metal to be deposited and anode is often of the same metal which is to be deposited.

(iii) Polishing and Buffing : Silver, nickel or chromium plating requires polishing by mops driven at peripheral speed of 2000 to 3000 m/minute. Mops may be of leather canvas or felt. It is very important to run these mops at high speeds indicated above. Lower speeds than this cause the mop to drag and the article becomes hot and burnishing, rather than polishing, effect is obtained.

(iv) Periodic Reverse Current Process : According to this process, at regular intervals, plating current is reversed for a second or so.

(v) Polarization : As electroplating current density is increased, rate of deposition of metal is also increased up to certain limit after which electrolyte surrounding the base metal becomes so much depleted of metal ions that rate of deposition does not increase with the increase in current density. If current density more than this limit, is employed, it will result in electrolysis of water and hydrogen deposition on the cathode. This hydrogen evolved, blankets the base metal which diminishes the rate of metal deposition. This phenomenon is known as polarization. Blanketing effect can be reduced by agitating the electrolyte.

(vi) Throwing Power : It is defined as the ability of the electrolyte to produce even irregular surfaces.

(c) How is the synchronous motor started ? Explain the various methods of starting of a synchronous motor in brief. [15 Marks]

Solution :

Procedure for Starting a Synchronous Motor :

1. First, main field winding is short-circuited.
2. Reduced voltage with the help of auto-transformers is applied across stator terminals. The motor starts up.
3. When it reaches a steady speed (as judged by its sound), a weak d.c. excitation is applied by removing the short-circuit on the main field winding. If excitation is sufficient, then the machine will be pulled into synchronism.
4. Full supply voltage is applied across stator terminals by cutting out the auto-transformers.
5. The motor may be operated at any desired power factor by changing the d.c. excitation.

Methods of Starting Synchronous Motor :

(i) Change in frequency : To reduce the speed of the rotating magnetic field of the stator to a low enough value that the rotor can easily accelerate and lock in with it during one half-cycle of the rotating magnetic field's rotation. This is done by reducing the frequency of the applied electric power. This method is usually followed in the case of inverter-fed synchronous motor operating under variable speed drive applications.

(ii) To use an external prime mover to accelerate the rotor of synchronous motor near to its synchronous speed and then supply the rotor as well as stator. Ofcourse care should be taken to ensure that the direction of rotation of the rotor as well as that of the rotating magnetic field of the stator are the same. This method is usually followed in the laboratory- the synchronous machine is started as a generator and is then connected to the supply mains by following the synchronization or paralleling procedure. Then the power supply to the prime mover is disconnected so that the synchronous machine will continue to operate as a motor.

(iii) Damper winding starting : To use damper windings or amortisseur windings if these are provided in the machine. The damper windings or amortisseur windings are provided in most of the large synchronous motors in order to nullify the oscillations of the rotor whenever the synchronous machine is subjected to a periodically varying load.

(iv) Auxiliary Motor Starting : It is a small dc or induction motor (much smaller in size than the synchronous motor). Because of the universal availability of ac supply induction motor is preferred choice. It should have the same number of poles as the synchronous motor and run from the same ac supply, i.e., same frequency and so same synchronous speed.

(d) What are the different configurations of an NPN transistor ? Explain each in brief with neat and labelled circuit diagram. [15 Marks]

Solution :

(i) Common-Base Configuration : Base is common to both the input and output sides of the configuration.

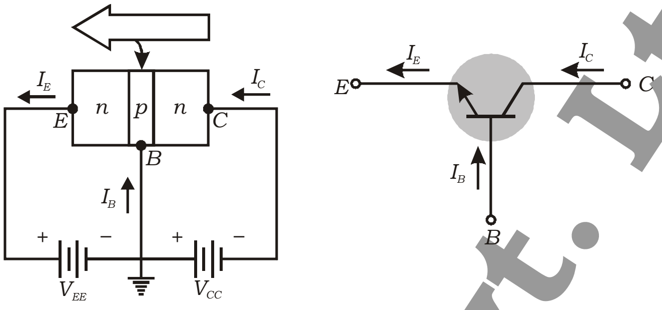


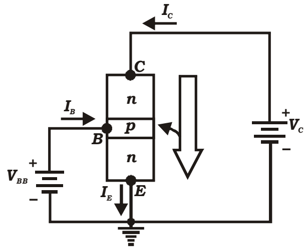
Fig. : *npn transistor*

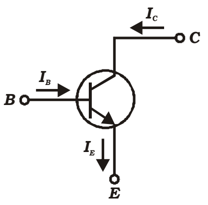
To describe the behavior of a three-terminal device such as the common-base amplifiers of Fig. requires two sets of characteristics—one for the driving point or input parameters and the other for the output side. The input set for the common-base amplifier as shown in Fig. relates an input current (I_E) to an input voltage (V_{BE}) for various levels of output voltage (V_{CB}).

Alpha (α) : In the dc mode the levels of I_C and I_E due to the majority carriers are related by a quantity called alpha and defined by the following equation:

$$\boxed{\alpha_{dc} = \frac{I_C}{I_E}}$$

(ii) Common Emitter Configuration : The most frequently encountered transistor configuration appears in Fig. for the pnp and npn transistors. It is called the common-emitter configuration because the emitter is common or reference to both the input and output terminals (in this case common to both the base and collector terminals). Two sets of characteristics are again necessary to describe fully the behavior of the common-emitter configuration: one for the input or base-emitter circuit and one for the output or collector-emitter circuit.





Beta (β) : In the dc mode the levels of I_C and I_B are related by a quantity called beta and defined by the following equation:

$$\boxed{\beta_{dc} = \frac{I_C}{I_E}}$$

Relation between α and β

$$I_E = I_C + I_B$$

we have $$\frac{I_C}{\alpha} = I_C + \frac{I_C}{\beta}$$

and dividing both sides of the equation by I_C results in

$$\frac{I}{\alpha} = 1 + \frac{1}{\beta}$$

or $$\beta = \alpha\beta + \alpha = (\beta + 1)\alpha$$

so that $$\boxed{\alpha = \frac{\beta}{\beta + 1}}$$

or $$\boxed{\beta = \frac{\alpha}{1 - \alpha}}$$

(iii) Common-Collector Configuration : The third and final transistor configuration is the common-collector configuration, shown in Fig. with the proper current directions and voltage notation. The common-collector configuration is used primarily for impedance-matching purposes since it has a high input impedance and low output impedance, opposite to that of the common-base and common- emitter configuration.