B.Tech.

SECOND SEMESTER EXAMINATION, 2008-09

ELECTRICAL ENGINEERING

Time : 3 Hours *Total Marks : 100*

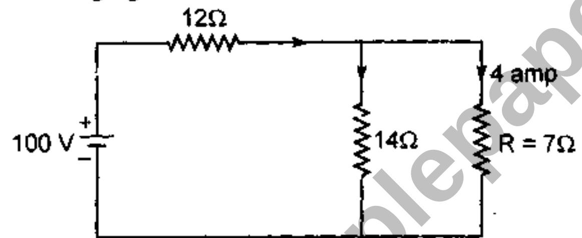
*Note : (1) Attempt **all** questions.*

*(2) All question carry **equal** marks.*

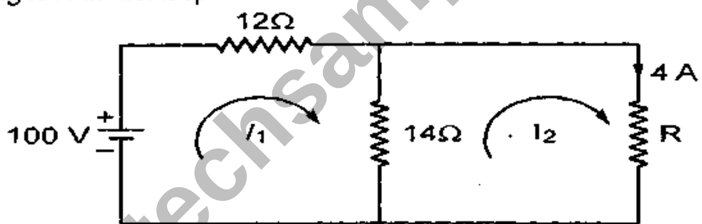
Q.1. Attempt all the parts of the following : **10×2=20**

(Fill in the blank/choose/match/determine

(i) In the circuit of following figure, find the value of R.



Ans. By applying KVI in first loop



$$100 - 12I_1 - 14(I_1 - 4) = 0$$

$$I_1 = \frac{156}{26} = 6\ A$$

Current following 14 Ω branch = 6 − 4 = 2A

By applying KV2 in second loop

$$4R + 14\ (4 - 6) = 0$$

$$4R = 28$$

$$R = 7\Omega$$

(ii) The value of the voltage of an independent voltage source is .... (dependent/not dependent) on either the magnitude or direction of the current flowing through the source.

Ans. Not dependent.

(iii) A voltage $v(t) = 170\sin(377t + 10°)$ is applied to a circuit. It causes a steady-state current to flow which is described by $i(t) = 14.14\sin(377t - 20°)$. The power factor of the circuit is $\cos 30° = 0.87$.

Ans. 0.87.

(iv) **The effective value of a sinusoid $i(t) = \text{Imsinwt}$ is equal to $I_m / \sqrt{2}$**

Ans. $I_m / \sqrt{2}$

(v) **A balanced star-connected load is supplied from a symmetrical 3-phase, 400 V (line to line) supply. The current in each phase is 50 A and lags 30° behind the phase voltage. The phase impedance is equal to $8/\sqrt{3} = 4.62$.**

Ans. 4.62Ω

(vi) **The full-scale deflection current of a meter is 1mA and its internal resistance is 100 Ω. If this meter is to have full scale deflection when 100 V is measured, the value of series resistor should be 99900 Ω.**

Ans. 99900 Ω.

(vii) **The normal sconday distribution voltage in our country is 400 V.**

Ans.400 V for 3-phase, 230 V for single-phase.

(viii) **If the frequency of the excitation mmf is f. The hysteresis losses and eddy-current losses would be proportional to f and f^2 respectively.**

Ans. f and f^2

(ix) **In a armature winding of a 4-pole, lap-wound dc machine having 760 active conductors and running at 1200 rpm with 20 mWb flux per pole, the induced voltage would be 304 V.**

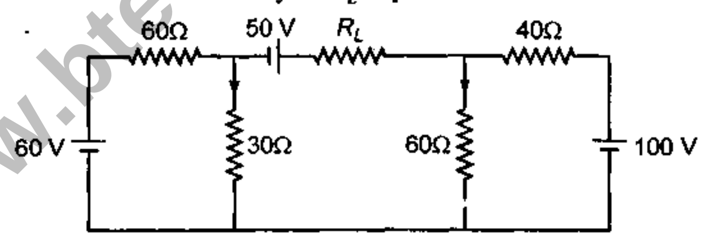
Ans. 304 V.

(x) **A three-phase induction motor has 4 pole runs at 4% slip and full load. If the speed of the motor is 720 rpm, the supply frequency is 25 Hz.**

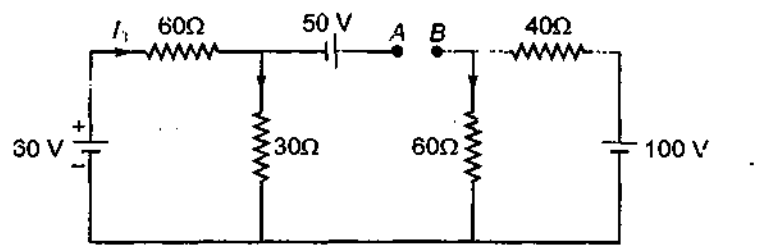
Ans. 25 Hz.

Q.2. Attempt any three parts of the following : **10×3=30**

Q.2.(a) (i) Use Thevenin's theorem to replace the three loop circuit of following figure by a single-loop equivalent circuit in which the indentity of R_L is preserved.



Ans.



$$I_1 = \frac{60}{90} = \frac{2}{3} \text{ A}$$

V.D. across $\qquad 30\Omega = 30\times\frac{2}{3} = 20\,V$

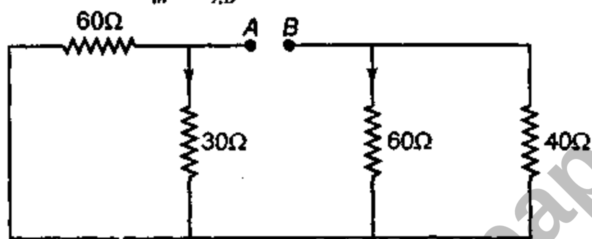
Potential at $\qquad A = 20+50 = 70\,V$

$$I_2 = \frac{100}{100} = 1\,A$$

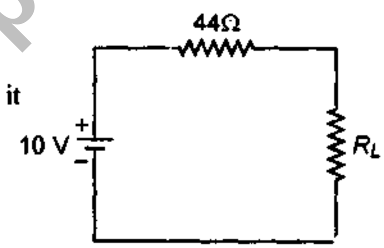
V.D. across $\qquad 60\Omega = 60\times 1 = 60\,V$

Potential at $\qquad B = 60\,V$

$$V_{th} = V_{AB} = 70-60 = 10V$$



$$R_{th} = \frac{60\times 30}{60+30} + \frac{60\times 40}{60+40} = \frac{1800}{90} + \frac{2400}{100} = 44\Omega$$



If the voltage across resistance is constant V and the current through it is constant I then the energy for $t \geq 0$ is given by,

$$W = \int_0^t VI\,dt = VI\,t \text{ joules}$$

while, $\qquad P = VI = \frac{V^2}{R} = I^2 R$ watts

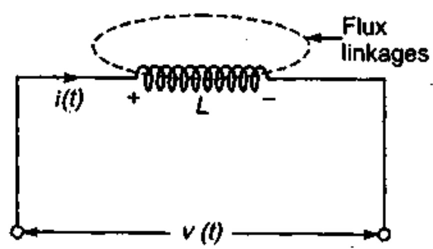
Q.2.(a) (ii) Discuss the characteristics of the following elements.

(a) Capacitor **(b) Inductor**

Ans. Inductor

An inductance is the element in which energy is stored in the form of electromagnetic field. The inductance is denoted as 'L' and is measured in henries (H).

For an inductance, the voltage across it is proportional to the rate of change of current passing through it.



$$\therefore \qquad V(t) \propto \frac{di(t)}{dt}$$

- The constant of proportionality in the above equation is the inductance L.

$$\therefore \qquad \boxed{V(t) = L\frac{di(t)}{dt}}$$

- If the voltage $V(t)$ is known across an inductor then the current is given by,

$$\therefore \qquad \boxed{i(t) = \frac{1}{L}\int_{-\infty}^{t} V(t)\,dt}$$

- If the the industance has N turns and the flux ϕ produced by the current $i(t)$ entirely links with the coil of N turns then according to Faraday's law,

$$V(t) = N\frac{d\phi}{dt}$$

- The total flux linkages $N\phi$ are thus proportional to the current through the coil.

$$\therefore \quad N\phi = Li$$

$$\therefore \quad L = \frac{N\phi}{i}$$

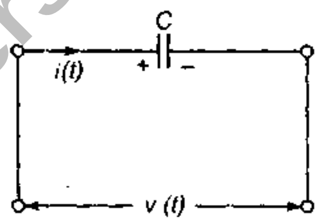
The power in the inductor is given by,

$$p(t) = Vi = Li(t)\frac{di(t)}{dt}$$

The energy stored in the inductor in the form of an electromagnetic field is,

$$\therefore \quad \boxed{W = \frac{1}{2}Li^2(t)\text{joules}}$$

(b) Capacitance



An element in which energy is stored in the form of an electrostatic field is known as capacitance. It is made up of two conducting plates separated by a dielectric materia. It is denoted as 'C' and is measured in farads (F).

- For a capacitor, the current through it is proportional to the rate of change of voltage across it.

$$i(t) \propto \frac{dv(t)}{dt}$$

- The constant of proportionality is the capacitor C.

$$\therefore \quad \boxed{i(t) = C\frac{dv(t)}{dt}}$$

- While the ratio of the charge stored to the voltage across the capacitor is known as the capacitance C.

$$\therefore \quad \boxed{C = \frac{q}{v}}$$

- The power in the capacitor is given by

$$P(t) = vi = Cv(t)\frac{dv(t)}{dt}$$

- The energy stored in the capacitor is given by

$$W = \frac{1}{2}Cv^2(t)\text{joules}$$

Q.2. (b) Derive the quality factor Q_0 of the series RLC circuit at reasonance. Discuss the expression of Q_0 in terms of energy.

Ans. Q-Factor of Series R-L-C Circuit

At series resonance, the p.d. across L or C (the two drops being equal and opposite) builds up to a value many times greater than the applied voltage V. This voltage magnification produced by resonance is termed as Q-factor of the series resonant circuit (Q stands for quality) *i.e.*

$$Q\text{-factor} = \frac{\text{Voltage across L or C}}{\text{Applied voltage}}$$

$$= \frac{I_r X_L}{I_r R} = \frac{X_L}{R}$$

$\therefore$ $$Q\text{-factor} = \frac{\omega_r L}{R} \qquad \text{...(i) where } \omega_r = 2\pi f_r$$

The Q-factor of a series resonant circuit can also be expressed in terms of L and C.

We know, $$f_r = \frac{1}{2\pi\sqrt{LC}} \text{ or } 2\pi f_r = \frac{1}{\sqrt{LC}}$$

or $$\omega_r = \frac{1}{\sqrt{LC}}$$

Substituting the value of ω_r in eq., (i), we get,

$$Q\text{-factor} = \frac{1}{R}\sqrt{\frac{L}{C}} \qquad \text{...(ii)}$$

The value of Q-factor depends entirely upon the design of oil (*i.e.* R-L part of the R-L-C circuit) because resistance arises in this rather in a capacitor. With a well designed coil, the quality factor can be 200 or more.

Physical meaning of Q-factor. Let us now turn to the physical meaning of Q-factor. The Q-factor of a series circuit indicates how many times the p.d. across L or C is greater than the applied voltage at resonance. For example, consider a R-L-C series circuit connected to a 240 V source. If Q-factor of the coil is 20, then voltage across the coil or a capacitor will be $20 \times 240 = 4800$ volts at resonance *i.e.*,

Q.2. (c) Derive the relationship between line current, phase current, line voltage and phase voltage in a 3-phase star-connected and delta-connected circuits.

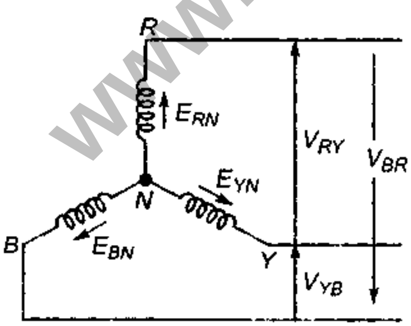
Ans. Voltages and currents in Balanced Y-Connection

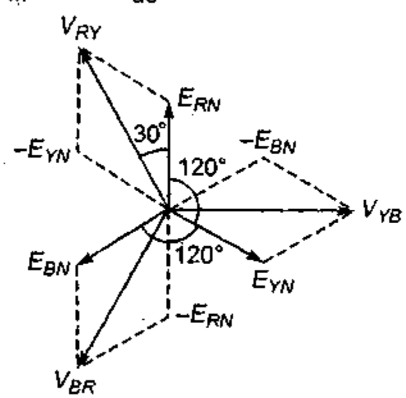
Fig. shows a balanced 3-phase Y-connected system in which the r.ms. values of the emf.s generated in the three phases are E_{RN}, E_{YN} and E_{BN}. It is clear from the circuit diagram (See Fig.) that p.d. between any two line terminals (i.e. line voltage) is the phasor difference between the potentials of these terminals *w.r.t.* neutral point *i.e.*,

P.D. between lines R and Y, $\quad {}^*V_{RY} = E_{RN} - E_{YN}$ ... phasor difference

P.D. between lines Y and B, $\quad V_{YB} = E_{YN} - E_{BN}$ ... —do—

P.D. between lines B and R, $\quad V_{BR} = E_{BN} - E_{RN}$ ... —do—





1. Relation between line voltage and phase voltage

Considering the lines R and Y, the line voltage V_{RY} is equal to the phasor difference of E_{RN} and E_{YN}. To substrate E_{YN} from E_{RN}, reverse the phasor E_{YN} and find its phasor sum with E_{RN} as shown in the phasor diagram in Fig. The two phasors E_{RN} and $-E_{YN}$ are qual in magnitude $(= E_{ph})$ and are 60° apart.

$$V_{RY} = 2E_{ph} \cos(60°/2) = 2E_{ph} \cos 30 = \sqrt{3}\, E_{ph}$$

Similarly, $V_{YB} = E_{YN} - E_{BN} = \sqrt{3}\, E_{ph}$ ... *phasor difference*

and $V_{BR} = E_{BN} - E_{RN}$ ...*phasor difference*

$= \sqrt{3}\, E_{ph}$

Hence in a balanced 3-phase Y-connection,

(i) Line voltage, $V_L = \sqrt{3}\, E_{ph}$

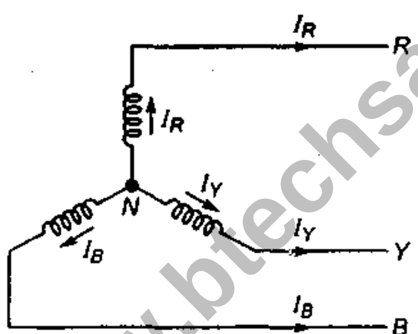
(ii) All line voltages are equal in magnitude (*i.e.*, $= \sqrt{3}\, E_{ph}$) but displaced 120° apart from one another (see the phasor diagram in Fig.).

(iii) Line voltages are 30° ahead of their respective phase voltages.

2. Relation between line current and phase current

In Y-connection, each line conductor is connected in series to a separate phase as shown in Fig. Therefore, current in a line conductor is the same as that in the phase to which the line conductor in connected.

$\therefore$ Line current, $I_L = I_{ph}$



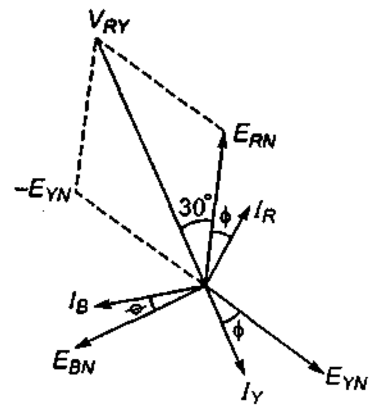


Fig. shows the phasor diagram for a balanced lagging load; the phase angle being ϕ Hence in a balanced 3-phase Y-connection :

(i) Line current, $I_L = I_{ph}$

(ii) All the line currents are equal in magnitude (*i.e.* $= I_{ph}$) but displaced 120° from one another.

(iii) The angle between the line currents and the corresponding line voltages is $30 \pm \phi$; + if p.f. is lagging and - if it is leading.

Voltages and Currents in Balanced Δ Connection

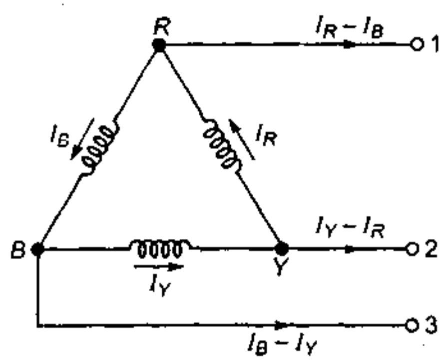
We shall now investigate the characteristics of balanced Δ-connection.

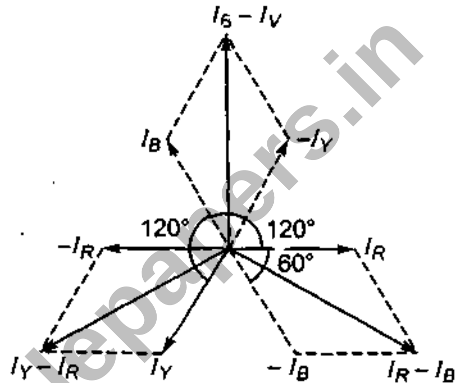
(i) Line voltage and phase voltage : Since the system is balanced, the three phase voltages are equal in magnitude (say each equal to V_{ph}, the phase voltage) but displaced 120° from one another. An examination of Fig. shows that only one phase winding is included between any pair of lines. Hence in Δ connection, the line voltage is equal to the phase voltage *i.e.*

$$V_L = V_{ph}$$

Since the phase sequence is RYB, the line voltage V_{RY} is 120° ahead of V_{YB} and 240° ahead of V_{BR}. Incidentally, these are also the phase voltages.

(ii) Line current and phase current : Since the system is balanced, the three phase currents I_R, I_Y and I_B are equal in magnitude say each equal to I_{ph}, the phase current) but displaced 120° from one another is shown in the phasor diagram in Fig. An examination of the circuit diagram in Fig. shows that current in any line is equal to the phasor difference of the currents in the two phases attached to that line. Thus :





Current in Line 1, $\quad I_1 = I_R - I_B$ ...*phasor difference*

Current in line, 2, $\quad I_2 = I_Y - I_R$ ... *phasor difference*

Current in line, 3, $\quad I_3 = I_B - I_Y$ ... *phasor difference*

The current I_1 in line 1 is the phasor difference of I_R and I_B. To subtract I_B from I_R, reverse the phasor I_B and find its phasor sum with I_R as shown in Fig. The two phasors I_R and $-I_B$ are equal in magnitude ($=I_{ph}$) and are 60° apart.

$\therefore \quad I_1 = 2I_{ph} \cos(60°/2) = 2I_{ph} \cos 30° = \sqrt{3}\, I_{ph}$

Similarly, $\quad I_2 = I_Y - I_R$ ... *phasor difference*

$= \sqrt{3}\, I_{ph}$

and $\quad I_3 = I_B - I_Y$ ... *phasor difference*

$= \sqrt{3}\, I_{ph}$

The three line currents, I_1, I_2 and I_3 are equal in magnitude; each being equal to $\sqrt{3}\, I_{ph}$.

Hence in a balanced Δ connection :

(a) Line current, $I_L = \sqrt{3}\, I_{ph}$

(b) All the line currents are equal in magnitude ($=\sqrt{3}\, I_{ph}$) but displaced 120° from one another as seen from Fig.

(c) Line currents are 30° behind the respective phase currents.

Q.2. (d) A 100 k VA, 1100/220 V, 60 Hz transformer has a high-voltage winding resistance of 0.1 Ω and a leakage reactance of 0.3 Ω. The low-voltage winding resistance is 0.004 Ω and the leakage reactance is 0.012 Ω. The source is applied to high-voltage side :

(i) Find the equivalent winding resistance and reactance referred to the high-voltage side and low-voltage side.

(ii) Compute the equivalent resistance and equivalent reactance drops in volts and in percent of the rated winding voltages expressed in terms of the primary quantities.

(iii) Calculate equivalent leakage impedances of the transformer referred to the primary and secondary sides.

$$kVA = \frac{V_1 I_1}{1000}$$

$$100 = \frac{1100 \times I_1}{1000}, I_1 = 91\,\text{A}$$

Also,

$$kVA = \frac{V_2 I_2}{1000}$$

$$100 = \frac{200 I_2}{1000}, I_2 = 455\,\text{A}$$

$$R_1 = 0.1\Omega, x_1 = 0.3\Omega$$

$$R_2 = 0.004\,\Omega, X_2 = 0.012\Omega$$

$$a = \frac{T_1}{T_2} = \frac{V_1}{V_2}$$

$$= \frac{1100}{220} = 5$$

(a) Equivalent resistance referred to high voltage side

$$R_{e_1} = R_1 + R_2\left(\frac{T_1}{T_2}\right)^2$$

$$= 0.1 + 0.004\left(\frac{1100}{220}\right)^2 = 0.2\Omega$$

Equivalent reactance referred to high voltage side

$$X_{e_1} = X_1 + X_2\left(\frac{T_1}{T_2}\right)^2$$

$$= 0.3 + 0.012\left(\frac{1100}{220}\right)^2 = 0.6\Omega$$

Equivalent resistance refereed to low-voltage side

$$R_{e_2} = R_2 + R_1\left(\frac{T_2}{T_1}\right)^2$$

$$= 0.004 + 0.1\left(\frac{1}{5}\right)^2 = 0.008\Omega$$

Equivalent reactance referred to low-voltage side

$$X_{e_2} = X_2 + X_1\left(\frac{T_2}{T_1}\right)^2$$

$$= 0.012 + 0.3\left(\frac{1}{5}\right)^2 = 0.024\Omega$$

(b) Equivalent resistance drop referred to the high-voltage side

$$= I_1 R_{e_1}$$

$$= 91 \times 0.2 = 18.2 \text{ V}$$

Percent equivalent resistance drop referred to the high-voltage side

$$= \frac{I_1 X_{e_1}}{V_1} \times 100$$

$$= \frac{91 \times 0.6}{11000} \times 100 = 4.95\%$$

(d) Equivalent leakage impedance referred to the high voltage side

$$Z_{e_1} = R_{e_1} + jX_{e_1} = 0.2 + j0.6$$

$$= 0.634 \angle 71.6° \Omega$$

Equivalent leakage impedance referred to the low-voltage side

$$Z_{e_2} = R_{e_2} + 0.008 + j0.024$$

$$= 0.0253 \angle 71.6° \Omega$$

Alternatively

$$Z_{e_2} = Z_{e_1} \left(\frac{T_2}{T_1}\right)^2$$

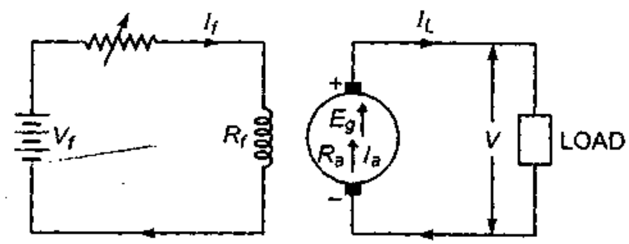
$$= (0.634 \angle 71.6°)\left(\frac{220}{1100}\right)^2$$

$$= 0.0253 / 71.6° \text{C}$$

Q. 2. (e) Describe the difference between the separately excited shunt generator and the self-excited one. Explain the process of voltage built up in self-excited shunt generation.

Ans. Separately Excited Dc. Generators

A d.c. generator whose field magnet winding is supplied from an independent external d.c. source (e.g. a battery etc) is called a separately excited generator. Fig. shows the connections of a separately excited generator. The voltage output depends upon the speed of rotation of armature and the field current ($E_g = P\phi ZN / 60A$). The greater the speed and field current, greater is the generated e.m.f. It may be noted that separately excited d.c. generators are rarely used in practice. The d.c. generators are normally of self-excited type.



Armature current, $I_a = I_L$

terminal voltage, $V = E_g - I_a R_a$

Electric power developed $= E_g I_a$

Power delivered to load $= I_g I_a - I_a^2 R_a = I_a (E_g - I_a R_a) = VI_a$

A d.c. generator whose field magnet winding is supplied current from the output of the generator itself is called a **self-excited generator*. There are three types of self-excited generator.

(i) shunt,

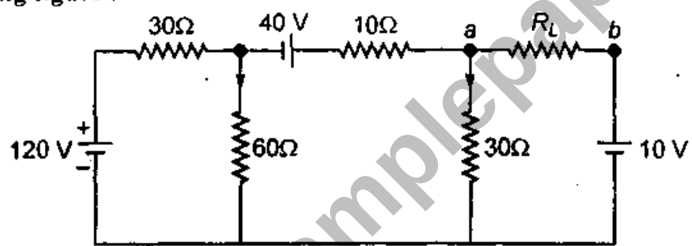
(ii) series,

(iii) compound.

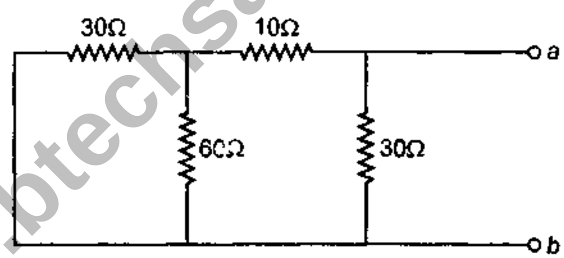
* When the armature is rotated, a small voltage is induced in the armature winding due to residual flux in the poles. This voltage produces a small field current in the field winding and causes the flux per pole to increase. The increased flux increase the induced voltage which further increases the field current. These events take place rapidly and the generator builds up to the rated generated voltage.

Q.3. Attempt any two parts of the following : **10×5=50**

Q.3. (i) Apply Norton's theorem to find the Norton equivalent circuit as seen by R_L in the circuit shown in the following figure :



Ans.

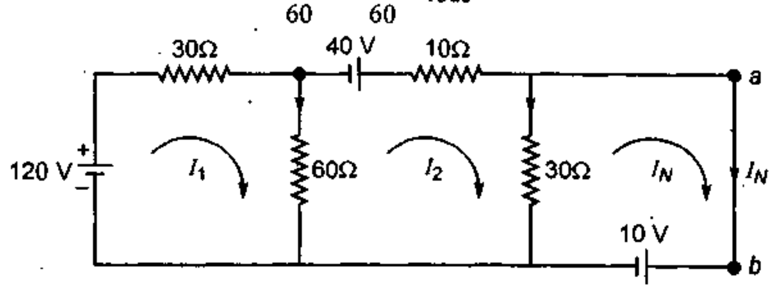


$$R_N = \left(\frac{30 \times 60}{90} + 10\right) || 30$$

$$= \left(\frac{1800}{90} + 10\right) || 30$$

$$R_n = 30 || 30$$

$$= \frac{30 \times 30}{60} = \frac{900}{60} = 15\Omega$$



KVL in first loop

$$30I_1 + 60(I_1 - I_2) = 120$$

$$3I_1 - 2I_2 = 4 \quad ...(1)$$

KVL in second loop

$$10I_2 + 30(I_2 - I_N) + 60(I_2 - I_1) = 40$$

$$100I_2 - 60I_1 - 30I_N = 40$$

$$10I_2 - 6I_1 - 3I_N = 4 \quad ...(2)$$

Now KVL in Third loop

$$-10 + 30(I_N - I_2) = 0$$

$$3I_2 - 3I_N = 1$$

$$3I_N = 3I_2 - 1 \quad ...(3)$$

Equation (3) put in equation ...(4)

$$10I_2 - 6I_1 - (3I_2 - 1) = 4$$

$$7I_2 - 6I_1 = 3 \quad ...(4)$$

Equation (1) multiplied by 2 and add in equation (4)

$$6I_1 - 4I_2 = 8$$

$$-6I_1 + 7I_2 = 3$$

$$3I_2 = 11$$

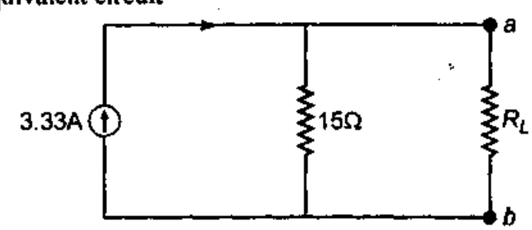
$$I_2 = \frac{11}{3}\text{ A}$$

Value of I_2 put in equation (3)

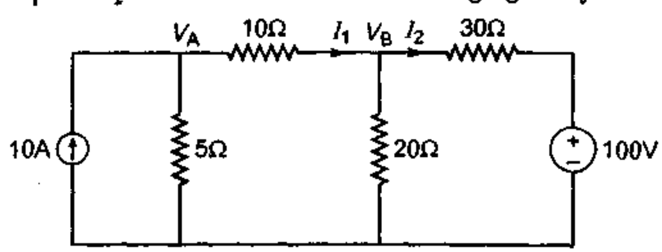
$$3I_N = 3 \times \frac{11}{3} - 1$$

$$I_N = \frac{10}{3} = 3.33\text{ A}$$

Now draw Norton's equivalent circuit



Q.3. (ii) Solve for I_1 and I_2 of the network of the following figure by nodal analysis.



KCL at node A

$$10 = \frac{V_A - V_B}{10} + \frac{V_A}{5}$$

$$100 = V_A - V_B + 2V_A$$

$$\boxed{100 = 3V_A - V_B} \quad (1)$$

KCL at node B

$$\boxed{\frac{V_B - V_A}{10} + \frac{V_B - 100}{30} + \frac{V_B}{20} = 0} \quad (2)$$

$$\frac{6V_B - 6V_A + 2V_B - 200 + 3V_B}{60} = 0$$

$$-6V_A + 11V_B = 200$$

or $$\boxed{V_B = \frac{200 + 6V_A}{11}} \quad (3)$$

Put equation (3) in equation (1)

$$100 = 3V_A - \left(\frac{200 + 6V_A}{11}\right)$$

$$1100 = 33V_A - 200 - 6V_A$$

$$1300 = 27V_A$$

$$\boxed{V_A = 48.1 \text{ Volts}}$$

So, $$V_B = \frac{200 + 6 \times 48.1}{11}$$

$$\boxed{V_B = 44.4 \text{ Volts}}$$

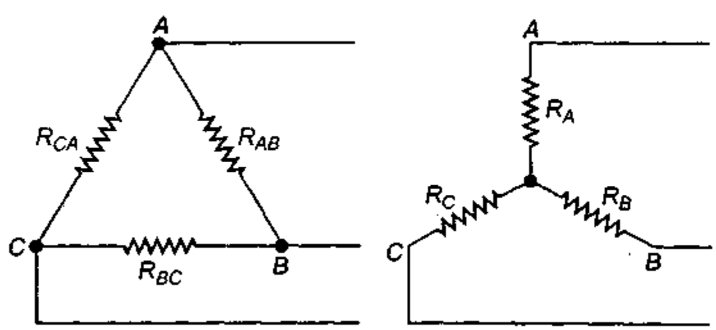
∴ $$\boxed{I_1 = .37 \text{ Amps}}$$

and $$\boxed{I_1 = 1.85 \text{ A}}$$

Q.3. (iii) When is the Δ-Y transformation useful in network reduction ? Illustrate.

Ans. Delta/Star and Transformation

There are some networks in which the resistances are neither in series nor in parallel. A familiar case is a three terminal network e.g. delta network or star network. In such situations, it is not possible to simplify the



(i) (ii)

network by series and parallel circuit rules. However, converting delta network into star and vice-versa often simplifies the network and makes it possible to apply series-parallel circuit techniques.

Delta/Star Transformation : Consider three resistors R_{AB}, R_{BC} and R_{CA} connected in delta to three terminals A, B and C as shown in Fig (i). It is desired to replace these three delta-connected resistors by three resistors R_A, R_B and R_C connected in star [See Fig. (ii)] so that the two networks are electrically equivalent. The two arrangements will be electrically equivalent if resistance between any two terminals of one network is equal to the resistance between the corresponding terminals of the other network.

Referring to Delta network shown in Fig. (i),

Resistance between A and B $= R_{AB} \,||\, (R_{BC} + R_{CA})$

$$= \frac{R_{AB}\,(R_{BC} + R_{CA})}{R_{AB} + R_{BC} + R_{CA}} \qquad ...(i)$$

Referring to star network shown in Fig. (ii).

Resistance between A and $B = R_A + R_B$

Since the two arrangements are electrically equivalent,

$$\therefore \quad R_A + R_B = \frac{R_{AB}\,(R_{BC} + R_{CA})}{R_{AB} + R_{BC} + R_{CA}} \qquad ...(iii)$$

Similarly it can be shown that between terminals B and C and terminals C and A.

$$R_B + R_C = \frac{R_{BC}\,(R_{CA} + R_{AB})}{R_{AB} + R_{BC} + R_{CA}} \qquad ...(iv)$$

and

$$R_C + R_A = \frac{R_{CA}\,(R_{AB} + R_{BC})}{R_{AB} + R_{BC} + R_{CA}} \qquad ...(v)$$

Subtracting eq (iv) from eq (iii) and adding the result to eq (v),

$$R_A = \frac{R_{AB} R_{CA}}{R_{AB} + R_{BC} + R_{CA}} \qquad ...(vi)$$

Similarly,

$$R_B = \frac{R_{BC} R_{AB}}{R_{AB} + R_{BC} + R_{CA}} \qquad ...(vii)$$

and

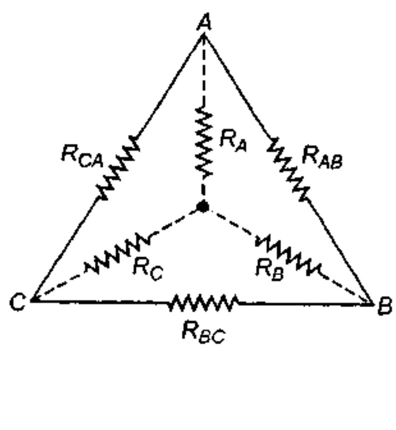
$$R_C = \frac{R_{CA} R_{BC R_{AB} + R_{BC} + R_{CA}}}{R_{AB} + R_{BC} + R_{CA}} \qquad ...(viii)$$

How to remember ? There is an easy way to remember it. Referring to Fig. star-connected resistances R_A, R_B and R_C are electrically equivalent to delta connected resistances R_{AB}, R_{BC} and R_{CA}. We have seen above that :

$$R_A = \frac{R_{AB} R_{CA}}{R_{AB} + R_{BC} + R_{CA}}$$

i.e. Any arm of star connection

$$= \frac{\text{Product of two Adjacentarms of } \Delta}{\text{Sum of arms of } \Delta}$$



Q.4. Attempt any two parts of the following :

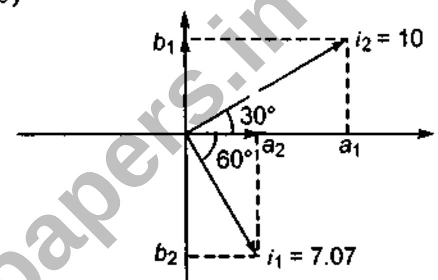
Q.4. (i) A voltage source of $e(t) = 141 \sin 377\ t$ is applied to two parallel branches. The time expression for the current in the first branch is $i_1(t) = 7.07 \sin(\omega t - \pi/3)$. In the second branch it is $i_2(t) = 10 \sin \omega t + \pi/6)$. Compute the total power supplied by the source.

Ans.

$$e(t) = 141 \sin 377t$$

$$i_1(t) = 7.07 \sin(\omega t - \pi/3)$$

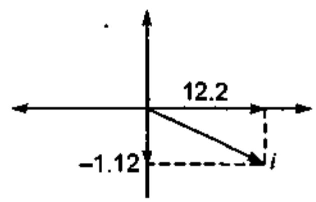
$$i_2(t) = 10 \sin(\omega t + \pi/6)$$



X-component
$$= a_1 + a_2$$
$$= 10 \cos 30 + 7.07 \cos 60°$$
$$= 8.66 + 3.54$$
$$= 12.20$$

Y-component
$$= b_1 - b_2$$
$$= 10 \sin 30 - 7.07 \sin 60$$
$$= 5 - 6.12$$
$$= -1.12$$

$$i = \sqrt{12.2^2 + (-1.12)^2}$$
$$= 12.25\ \text{A}$$



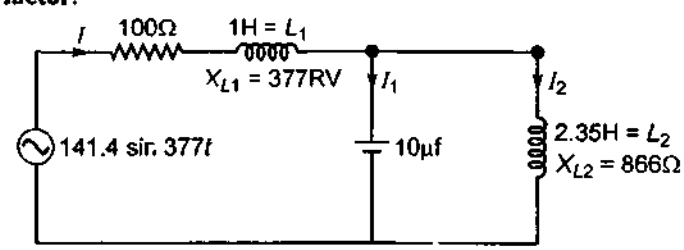
$$\theta = \tan^{-1}\left(\frac{-1.12}{12.2}\right)$$
$$\theta = -5.25°$$
$$i(t) = 12.25 \sin(\omega t - 5.25)$$
$$e(t) = 141 \sin(\omega t)$$

RMS voltage
$$E = \frac{141}{\sqrt{2}} = 100\ \text{V}$$

RMS current
$$I = \frac{12.25}{\sqrt{2}} = 8.66\ \underline{|-5.25°}\ \text{A}$$

Total power,
$$P = 100 \times 8.66 \times \cos(5.25)$$
$$= 866 \times 0.9958$$
$$= 862\ \text{Watt Ans.}$$

Q.4 (ii) Refer to the circuit shown in the following figure. Find (a) rms line current (b) power dissipated (c) power factor.



Ans. $Z_{R-L} = (100 + j377)\Omega$

$$Z_C = \frac{-j10^6}{10 \times 377}\Omega = -j265.2\Omega$$

$$Z_L = j2.35 \times 377$$

$$\boxed{= j885.9\Omega}$$

$$Z_P = \frac{Z_L \times Z_C}{Z_L + Z_C} = \frac{234940.68}{j620.7}$$

$$Z_P \boxed{= -j378.5\Omega}$$

$$Z_{Total} = Z_{R-L} + Z_P = 100 + j377 - j378.5$$

$$\boxed{= 100 - j1.5\Omega}$$

$$\boxed{Z_{Total} = 100 \angle -.859^\circ\ \Omega}$$

(a) $$I_{rms} = \frac{141.4}{\sqrt{2}} \times \frac{1}{100} \angle -.859^\circ\ \Omega$$

$= .99 \angle .859^\circ$ Amp's

(b) Power dissipated $= VI\cos\theta$ | I^2R

$=97.99$ Wats | 98.01 W

(c) $\cos\theta = \cos(.85^\circ)$

$\boxed{\simeq .99}$ Ans.

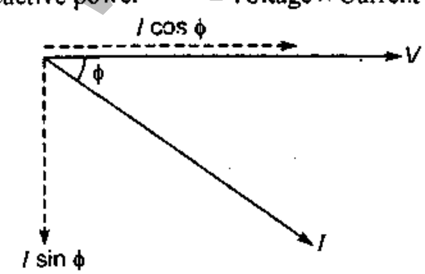
Q.4 (iii) What are active and reactive powers ? Why is the term 'reactive power' not encountered when d-c sources are used in an electric circuit ?

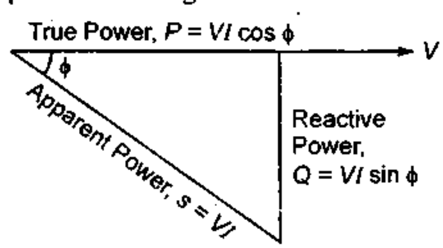
Ans. Active power and Reactive Power

We have already seen in the previous chapter that power is consumed only in resistance since neither pure inductor nor the capacitor consumes any active power. The power consumed (or true power) in L and C is zero because all the power received from the source in a half-cycle is returned to the source in the next half-cycle. This circulating power is called the **reactive power** and does no useful work in the circuit. The reader may recall that current and voltage are in phase in a resistance whereas they are 90° out of phase in L or C. Therefore, we come to the conclusion that current in phase with voltage produces true or active power whereas current 90° out of phase with voltage contributes to reactive power *i.e.*

True/power = Voltage × Current in phase with voltage

Reactive power = Voltage × Current 90° out of phase with voltage





Consider an inductive circuit in which current I lags behind the applied voltage V by $\phi°$. The phasor diagram of the circuit is shown in Fig. The current I can be resolved into two rectangular components viz. (i) $I\cos\phi$ in phase with V and (ii) $I\sin\phi$, 90° out of phase with V.

$\therefore$ True power, $P = V \times I \cos\phi = VI\cos\phi$ watts or kW

Reactive power, $Q = V \times I \sin\phi = VI\sin\phi$ VAR or kVAR

Apparent power, $S = V \times I = VI$ VA or kVA

(i) The component $I\cos\phi$ is called the in phase component or wattful component. It is this component of total current which contributes to true power (i.e. $VI\cos\phi$).

(ii) The component $I\sin\phi$ is called the reactive component and contributes to reactive power (*i.e.* $VI\sin\phi$). The reactive power is neither consumed in the circuit or it does any useful work. It merely flows back and forth in both directions in the circuit. A wattmeter does not measure the reactive power.

(iii) The produce of voltage (V) and actual current (I) in the circuit is called the apparent power (*i.e.* VI). To avoid confusion, it is measured in volt-amperes (VA).

Q.5. Attempt any two parts of the following :

Q.5 (i) A balanced delta-connected load of impedance 16 + j 12 Ω/ phase is connected to a 3-phase 400 V supply. Find the phase current, line current, power factor, power, reactive VA and total VA.

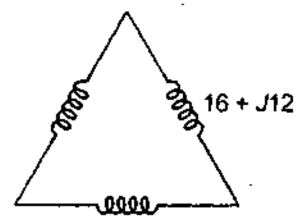
Ans. $Z = 16 + J\,12\Omega$ /phase

$V_L = 400$ V

$|Z| = \sqrt{16^2 + 12^2}$

$= \sqrt{256 + 144}$

$|Z| = 20\Omega$



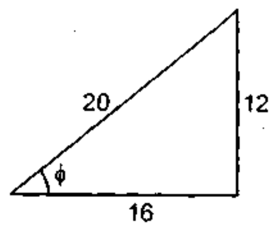
In care of delta,

$V_P = V_L = 400$ V

$I_P = \dfrac{V_P}{|Z|} = \dfrac{400}{20} = 20$ A Ans.

$I_L = \sqrt{3}\,I_P = \sqrt{3} \times 20 = 34.64$ A Ans.

$\cos\phi = \dfrac{16}{20} = 0.8$ Ans



$P = \sqrt{3}\,V_L I_L \cos\phi$

$= \sqrt{3} \times 400 \times 34.64 \times 0.8$

$= 19199.44$ W

$= 19.2$ KW Ans

Reactive VA

$Q = \sqrt{3}\,V_L I_L \sin\phi$

$= \sqrt{3} \times 400 \times 34.64 \times 0.6$

$= 14399.58$ VAr

$= 14.4$ KV Ar

Total VA

$S = \sqrt{3}\,V\,I$

$= \sqrt{3} \times 400 \times 34.64$

$= 23999.29$ VA

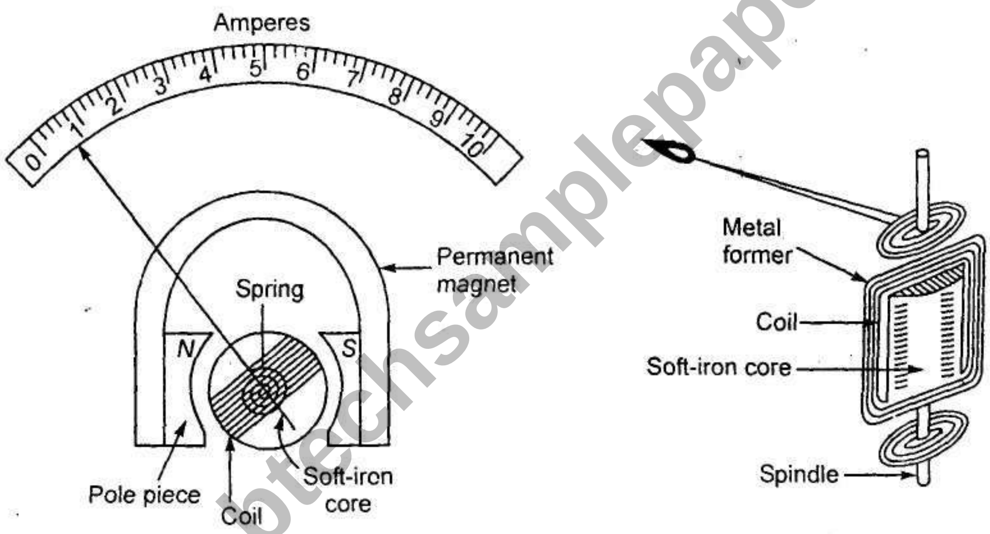
$= 24$ KVA Ans.

Q.5. (ii) Discuss the principle, construction and operation of PMMC type measuring instruments.

Ans. Permanent-Magnet Moving Coil Instruments

These instruments are used either as ammeters or voltmeters and are suitable for d.c. work only. This type of instrument is based on the principle that when a current carrying conductor is placed in a magnetic field, mechanical force acts on the conductor.

Construction. Fig. shows the various parts of a permanent-magnet moving coil instrument. It consists of a light rectangular coil of many turns of fine wire wound on an aluminum former inside which is an iron core as shown in Fig. (i). The coil is delicately pivoted upon jewel bearings and is mounted between the poles of a permanent horseshoe magnet. Attached to these poles are two soft-iron pole pieces which concentrate the magnetic field. The current is led into and out of the coil by means of two control hair springs, one above and the other below the coil, as shown in Fig. (ii). These springs also provide the controlling torque. The damping torque is provided by eddy currents induced in the aluminum former as the coil moves from one position to another.



(i) (ii)

Working : When the instrument is connected in the circuit to measure current or voltage, the operating current flows through the coil. Since the coil is carrying current and is placed in the magnetic field of the permanent magnet, a mechanical force acts on it. As a result, the pointer attached to the moving system moves in a clockwise direction over the graduated scale to indicate the value of current or voltage being measured. If the current in the coil is reversed, the deflecting torque will also be reversed sinece the direction of the field of the permanent magnet is the same. Consequently, the pointer will try to deflect below zero. Deflection in this direction *i. e,* reverse direction) is prevented by a spring "stop". Since the deflecting torque reverses with the reversal of current in the coil, such instruments can be used to measure direct current and voltage *only.

Q.5. (iii) A single phase energy meter has a constant of 1200 revolutions/kWh. When a load of 200 W is connected, the disc rotates at 4.2 revolutions/minute. If the load is on for 10 hours, how many units are recorded as an error ? Also find percentage error.

Ans. A single-phase energy meter has a constant of 1200 revolutions/kWh. When a load of 200 W is connected, the disc rotates at 4.2 revolutions per minute. If the load is on for 10 hours, how many units are recorded as error. Also find the percentage error.

Actual energy consumed b the load in 10 hours $= \text{power} \times \text{time} = 200 \times 10$ Wh

$$= 200 \times 10 \times 10^{-3} \text{ kWh} = 2 \text{kWh}$$

Disc speed = 4.2 revolutions/mixture = 4.2×60 revolutions/hour

Number of revolutions made by the disc in 10 hours $= 4.2 \times 60 \times 10 = 2520$

Energy recorded by the meter

$$= \frac{2520}{1200} = 2.1 \text{kWh}$$

Energy meter error = observed reading - correct reading

$$= 2.1 - 2.0 = 0.1 \text{kWh}$$

Hence the meter records 0.1 kWh more than the correct reading.

Per unit error

$$= \frac{\text{observed reading - correct reading}}{\text{correct reading}}$$

$$= \frac{21 - 20}{20} = 0.05 \text{ pu}$$

Percentage error $= 0.05 \times 100 = 5\%$

Q.6. Attempt any two parts of the following :

Q.6. (i) Draw single line diagram of a power system between generating station and end user. Mention the different voltage levels.

Ans. At the generating station,an electrical power is generated with the help of three phase alternators running in parallel. In the scheme shown, the voltage level is 11 kV but the voltage level may be 6.6 kV, 22 k V

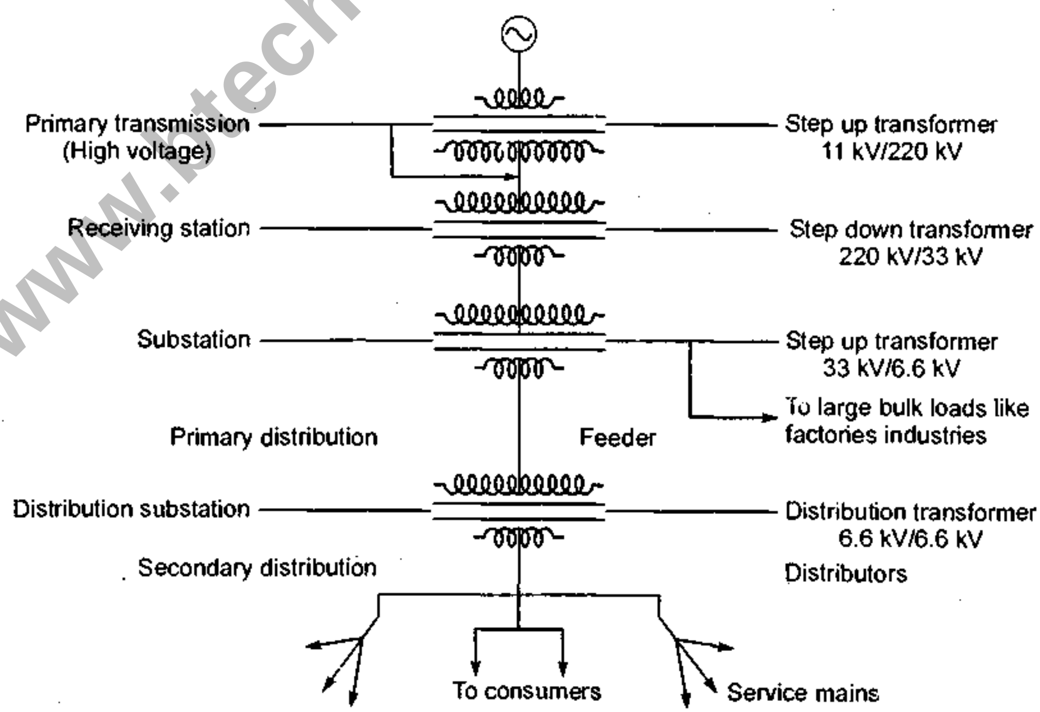


Fig. Line diagram of a typical transmission distribution scheme

to 33 kV depending upon the capacity of the generating station. After the generating station, actual transmission and distribution starts. The overall scheme can be divided into four sections which are :

1. Primary transmission : It is basically with the help of overhead transmission lines. For the economic aspects. the voltage level in increased to 132 kV, 220 kV or more, with the help of step up transformer. Hence this transmission is also called high **voltage transmission**. The primary transmission used 3 phase 3 wire system.

2. Secondary transmission : The primary transmission line continues via transmission towers till the receiving stations. At the receiving stations, the voltage level is reduced to 22 kV or 33 kV using the step down transformer. There can be more than one receiving stations. Then at reduced voltage level of 22 kV or 33 kV, the power is then transmitted to various substations using overhead 3 phase 3 wire system. This is secondary transmission. The conductors used for the secondary transmission are called feeders.

3. Primary distribution : At the substation the voltage level is reduce to 6.6 kV, 3.3 kV or 11 kV with the help of step down transformer. It used three phase three wire underground system. And the power is further transmitted to the local distribution centers. This is primary distribution , also called high voltage distribution. For the large consumers like factories and industries, the power is directly transmitted to such loads from a substation. Such big loads have their own substations.

4. Secondary distribution : At the local distribution centers, there are step down distribution transformers. The voltage level of 6.6 kV, 11 kV is further reduced to 400 V using distribution transformers. Sometimes it may be reduced to 230 V. The power is then transmitted using distributors and service mains to the consumers. This is secondary distribution, also called low voltage distribution. This uses 3 phases 4 wire system. The voltage between any two lines is 400 V while the voltage between any of the three lines and a natural is 230 V. The single phase lighting loads are supplied using a line and neutral while loads like motors are supplied using three phase lines.

Q.6. (ii) The total core loss (hysteresis plus eddy-current) for a specimen of magnetic sheet steel is found to be 1800 W at 60 Hz. If the flux density is kept constant and the frequency of the supply increased 50%, the total core loss is found to be 3000 W. Compute the separate hysteresis and eddy-current losses at both frequencies.

Ans. We know that total core loss is $P_C = K_h f B_m^x + K_e f^2 B_m^2$

For constant flux density $P_C = k_h f + k_e f^2$

Where $k_h = K_h B_m^x$

and $k_e = K_e B_m^2$

At 60 Hz $1800 = k_h f + k_e f^2$

$$1800 = k_h 60 + k_e (60)^2 \quad (1)$$

and at 90 Hz $3000 = k_h 90 + k_e (90)^2 \quad (2)$

Now, $1800 = k_h 60 + k_e 3600 \quad (3)$

and $3000 = k_h 90 + k_e 8100 \quad (4)$

from equation (3) $\dfrac{1800 - k_e 3600}{60} = k_h \quad (5)$

Put equation (5) in euqation (4)

$$3000 = \frac{90(1800 - k_e 3600)}{60} + k_e 8100$$

$$= 2700 - k_e 5400 + k_3 8100$$
$$= 2700 + k_e 2700$$

$\therefore$ $\boxed{k_e = .11}$

$\therefore$ $\boxed{k_n = 23.4}$

Thus at 60 Hz; hysteresis loss $= k_n \times f$

$$= 23.4 \times 60$$
$$\boxed{= 1404 \text{ W}}$$

Eddy current loss $= k_e f^2$

$$= .11 \times 60^2$$
$$\boxed{= 396 \text{ W}}$$

At 90 Hz; $P_n = k_n \times f = 23.4 \times 90$

$$\boxed{= 2106 \text{ W}} \text{ Ans.}$$
$$P_e = k_e \times f^2 = .11 \times 8100$$
$$\boxed{= 891 \text{ Watts}} \text{ Ans.}$$

Q.6. (iii) Develop the equivalent circuit of a single phase transformation on no-load and 'one-load conditions.

Ans. Equivalent Circuit of Transformer

The term equivalent circuit of a machine means the combination of fixed and variable resistances and reactances, which exactly simulates performance and working of the machine.

For a transformer, no load primary current I_0 has to components,

$$I_m = I_0 \sin\phi_0 = \text{Magnetising component}$$
$$I_c = I_0 \cos\phi_0 = \text{Active component}$$

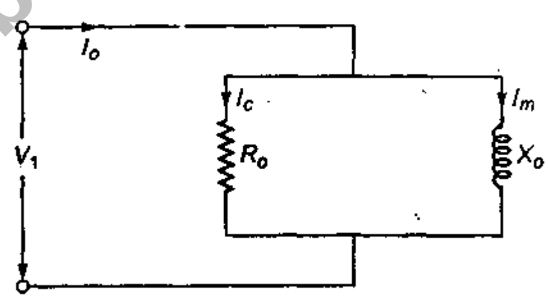


Fig. No load equivalent circuit

I_m produces the flux and is assumed to flow through reactance X_0 called no load reactance while I_c is active component representing core losses hence is assumed to flow through the resistance R_0. Hence equivalent circuit on no load can be shown as in the Fig. This circuit consisting of R_0 and X_0 in parallel is called exciting circuit. From the equivalent circuit we can write, and

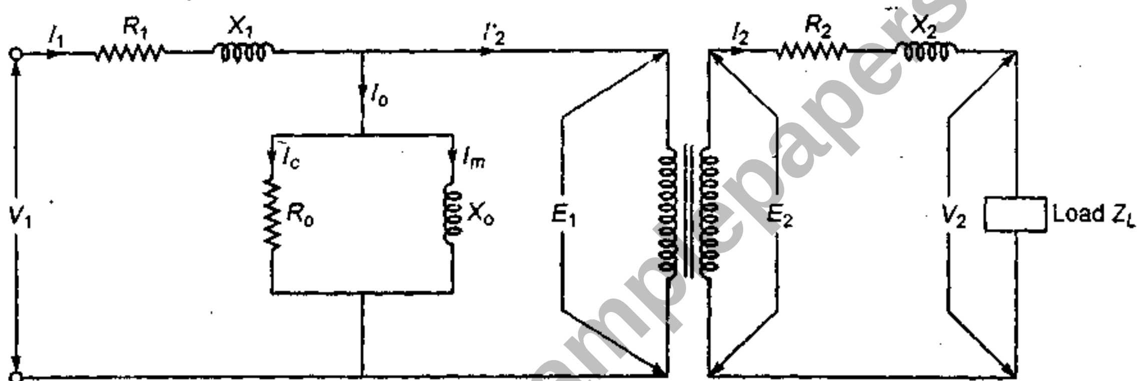
$$R_o = \frac{V_1}{I_c}$$

and
$$X_o = \frac{V_1}{I_m}$$

When the load is connected to the transformer then secondary current I_2 flows. This causes voltage drop across R_2 and X_2. Due to I_2, primary draws an additional current.

$I'_2 = I_2 / K$. Now I_1 is the phasor addition of I_0 and I'_2. This I_1 causes the voltage drop across primary resistance R_1 and reactance X_1.

Hence the equivalent circuit can be shown as in the Fig.



But in the equivalent circuit, winding are not shown and it is further simplified by transferring all the values to the primary or secondary. This makes the transformer calculations much easy.

So transferring secondary parameters to primary we get,

$$R'_2 = \frac{R_2}{K^2};$$

$$X'_2 = \frac{X_2}{K^2},$$

$$Z'_2 = \frac{Z_2}{K^2}$$

while
$$E'_2 = \frac{E_2}{K}, I'_2 = KI_2$$

where
$$K = \frac{N_2}{N_1}$$

Q.7. Attempt any two parts of the following :

Q.7. (i) A 4-pole, lap-wound armature has 144 slots with two coil sides per slot, each coil having two turns. If the flux per pole is 20 mWb and the armature rotates at 720 rpm, what is the induced voltage ?

Ans.

Substitute $p = a = 4, n = 720, \phi = 0.020$, and $z = 144 \times 2 \times 2 = 576$ in the emf equation to obtain.

$$E = \frac{(0.020)(720)(576)}{60}\left(\frac{4}{4}\right) = 138.24 \text{ V}$$

Q.7. (ii) Define slip in 3-phase induction motor. What is its value at starting and at synchronous speed ? A 60 Hz induction motor has 2 poles and runs at 3510 rpm. Calculate (a) the synchronous speed and (b) the percent slip.

Ans. Slip : Change in speed of induction motor from no-load to full load is known as slip of induction motor. It is represented by S. percentage slip of induction motor can be expresed by the following expression :

$$\%S = \frac{N_s - N_r}{N_s} \times 100$$

Where,

N_s = synchronous speed in r.p.m

N_r = rotor speed in r p.m

At starting

$$N_r = 0, \text{ then,}$$

$$S = \frac{N_s - 0}{N_s}$$

$$S = 1$$

At synchronous speed :

$$N_r = N_s, \text{ then}$$

$$S = 0$$

$$f = 60\,\text{Hz},$$

$$P = 2$$

$$N_r = 3510\,\text{rpm}$$

Synchronous speed

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

$$= \frac{120 \times 60}{2}$$

$$= 3600 \text{ r.p.m. Ans.}$$

Percentage, slip,

$$\%\text{age } S = \frac{N_S - N_r}{N_S} \times 100$$

$$= \frac{3600 - 3510}{3600} \times 100$$

$$= 2.5\%$$

Q.7. (iii) Discuss the principle of operation of a three-phase synchronous machine. Give the various applications of a 3-phase synchronous motor.

Ans.

Operation of Basic Machine types

Synchronous Machine : Fig. show a synchronous machine with a round rotor. The rotor is initially stationary with fixed north-south poles created by dc excitation. Let the 3-phase winding of the stator be connected to a 3-phase supply of fixed voltage V (line) and fixed frequency f. As s result, 3-phase currents flow in the stator winding creating a rotating magnetic field rotating at synchronous speed n_s $(= 120 f / p)$ in

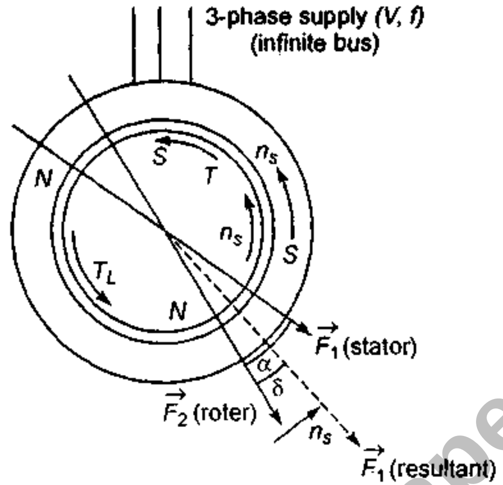


Fig. Torque production in synchronous machine (motoring)

the counter-clockwise direction (say) Since the rotor is stationary and cannot pickup speed instantaneously (inertia effect), the two fields move relative to each other resulting in zero average torque. As such the motor is non-self-starting.

Consider now that the rotor is run by auxiliary means to a speed close to synchronous in the direction of rotation of the stator field. The two fields now have the opportunity of locking into each other or, in other words, the rotor pulls into step with the starter field and then on runs at exactly synchronous speed. It is easily seen from Fig. that the electromagnetic torque developed (T) acts on the rotor in the direction of rotation of rotor and balances the load torque. T_L. The mechanical power therefore flows to the load (motoring action) and, by the principle of conservation of energy, and equal amount of electrical power (plus losses in the device) are drawn from the electric supply. It is also seen from Fig. that for a given T_L, the rotor field lags behind the stator field by an angle α . And rotor move in the direction or rotation of stator field.

Applications of Synchronous Motors

(i) Synchronous motors are particularly attractive for low speeds (< 300 r.p.m.) because the power factor can always be adjusted to unity and efficiency in high.

(ii) Over-excited synchronous motors can be used to improve the power factor of a plant while carrying their rated loads.

(iii) They are used to improve the voltage regulation of transmission lines.

(iv) High-power electronic converters generating very low frequencies enable us to run synchronous motors at ultra-low speeds. Thus huge motors in the 10 MW range drive crushers, rotary kilns and variable-speed ball mills.