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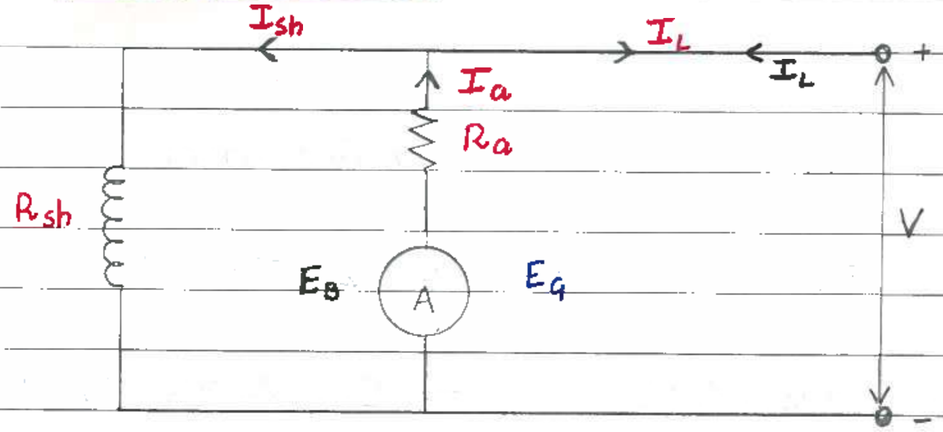
Page 1

DC MACHINES

→ There are 3 types of DC machines, viz.

i) Shunt
ii) Series
iii) Compounded :- a) Short shunt
b) Long shunt

1) SHUNT MACHINES



For Motor,

→ $I_L = I_A + I_{sh}$

or $I_A = I_L - I_{sh}$

→ $I_{sh} = \frac{V}{R_{sh}}$

But, $V = E_B + I_a R_a$

→ $\therefore E_B = V - I_a R_a$

For Generator,

→ $I_A = I_L + I_{sh}$

→ $I_{sh} = \frac{V}{R_{sh}}$

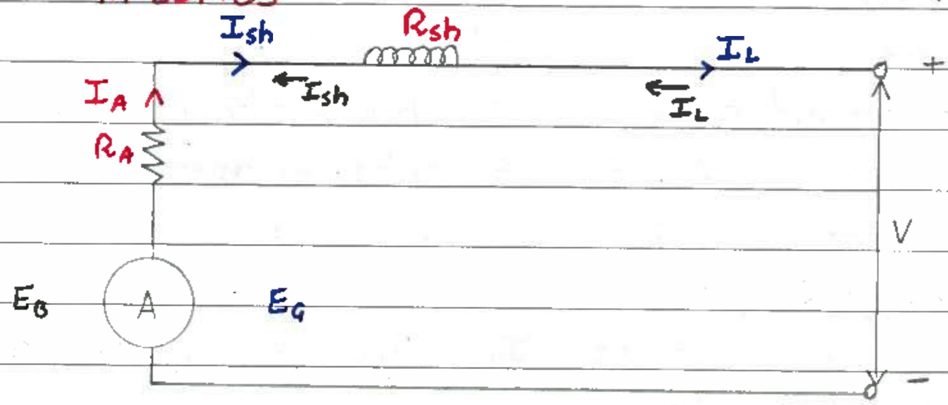
But, $V = E_G - I_a R_a$

→ $\therefore E_G = V + I_a R_a$

* Shunt machines means, the armature is in parallel with the field coiling

I) SERIES MACHINES

* Here the armature & field coil are connected in series



For Motor,

→ $I_A = I_{sh} = I_L$

→ $E_B = V - I_A(R_A + R_{sh})$

For Generator,

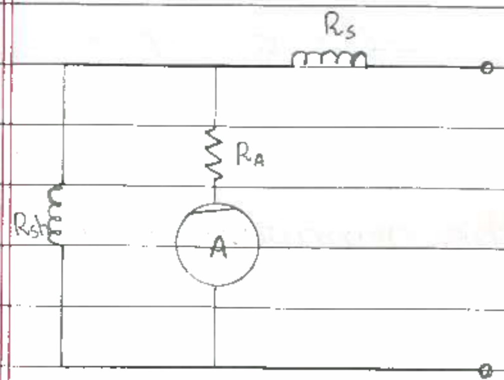
→ $I_A = I_{sh} = I_L$

→ $E_G = V + I_A(R_A + R_{sh})$

II) COMPOUNDED MACHINES

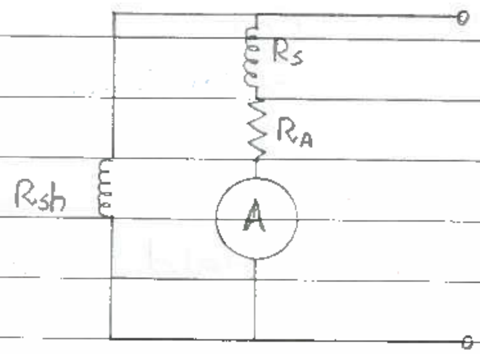
A) SHORT SHUNT

* As the shunt is connected only across the armature



B) LONG SHUNT

* As the shunt is connected across the armature + the load



⇒ EMF EQUATION FOR DC MACHINES

P → No. of Poles
N → Speed in rpm
ϕ → Flux lines per pole in Wb (10^8 flux lines = 1 Wb)
A → No. of Parallel Paths
i) For Lap wound : A = P (For more current)
ii) For Wave wound : A = 2 (For less current)
Z → No. of Conductors

* Flux cut by one conductor per revolution = Flux per pole × No. of Poles

$$= \phi \times P \text{ Wb}$$

* Time for one revolution $= \frac{1}{N}$ minute

$$= \frac{60}{N} \text{ secs}$$

∴ EMF Developed $= \frac{\text{Flux cut}}{\text{Time for 1 rev.}}$

$$= \frac{\phi P N}{60}$$

i.e. EMF Developed per conductor $= \frac{\phi P N}{60}$ Volts

Total EMF, = Avg. EMF per conductor × No. of conductors per parallel paths

$$E = \frac{\phi P N}{60} \times \frac{Z}{A}$$

$\therefore$ Total EMF, $E = \frac{\phi Z N}{60} \times \frac{P}{A}$ Volts

⇒ <u>TORQUE</u> (* Only for Motor)

$F = BIL$ Newton

where,

$F \rightarrow$ Force in N

$B \rightarrow$ Flux Density

$I \rightarrow$ Armature Current

$L \rightarrow$ Length of Armature

* $r \rightarrow$ radius of shaft

Now,

Torque, $T = F \times r$ N-m

$\therefore$ Total Torque, $T = \frac{1}{2\pi} \times \phi Z \times \frac{P}{A} \times I_a$

$= 0.159 \times \phi Z \times \frac{P}{A} \times I_a$ N-m

Power developed at the armature,

$$E_B \times I_a = \frac{2\pi N}{60} \times T$$

⇒ ~~Ef~~ EFFICIENCY

$$\text{Input Power} \xrightarrow{A} \boxed{\text{Stator}} \xrightarrow{B} \boxed{\text{Rotor}} \xrightarrow{C} \boxed{\text{Mechanical}} \xrightarrow{D} \text{Final mech. output}$$

- Stator: Core + Cu loss
  - Cu loss is negligible as Stator is made of Iron
- Rotor: Core + Cu loss
  - Core loss is negligible as Rotor is made of rotating Cu bars
- Mechanical: Rotational loss
  - Frictional loss + Winding loss

$$\eta = \frac{\text{output}}{\text{input}} \times 100\ \%$$

OR

$$\eta = \frac{\text{output}}{\text{output} + \text{Losses}} \times 100\ \%$$

Also,

$$\eta_{Electrical} = \frac{\text{Electric power o/p to Armature}}{\text{Same o/p} + \text{Losses}}$$

$$= \frac{C}{A} \longrightarrow \text{i)}$$

$$\eta_{Mechanical} = \frac{D}{C} \longrightarrow \text{ii)}$$

$$\eta_{\substack{overall \\ OR \\ commercial}} = \frac{\text{Final mech. output}}{\text{Electrical power input}}$$

$$= \frac{D}{A} \longrightarrow \text{iii)}$$

⇒ Speed Regulation of DC Motors

We know,

$$E_B = \frac{\phi Z N}{60} \times \frac{P}{A} \qquad \text{(As per total EMF)}$$

$$E_B \propto \phi N$$

OR

$$E_B = K \phi N \qquad \text{where } K \text{ is a constant}$$

$$E_B = V - I_A R_A \qquad \text{For a DC shunt machine}$$

$$\therefore \quad K\phi N = V - I_A R_A$$

$$N = \frac{V - I_A R_A}{K\phi}$$

i.e. $N \propto \dfrac{V - I_A R_A}{\phi}$

∴ Speed regulation is available as many parameters can be varied such as V, I_A, R_A & ϕ

* Also a series machine cannot be started at no load

⇒ APPLICATIONS OF DC MOTORS

1) SHUNT MOTORS : Used for constant speed applications
Ex. Drilling machines, Compressors, Pumps, Machine Tools

2) SERIES MOTORS : Used where large starting torque is required
Ex. Deck machineries

Q. A DC motor takes an armature current of 110 A at 480 V. The resistance of the armature ~~coil~~ ckt. is 0.2 Ω. The machine has 6 poles & the armature is lap connected with 864 conductors. The flux per pole is 0.05 Wb. Calculate the

i) Speed

ii) Gross Torque developed by the armature.

GIVEN DATA:

$I_A = 110$ A $\quad R_A = 0.2\,\Omega \quad Z = 864$

$V = 480$ V $\quad P = 6 \quad \phi = 0.05$ Wb

$A = P = 6$ .... Lap wound

Sol^n.

$$E_B = V - I_A R_A$$
$$= 480 - 110 \times 0.2$$
$$= 458 \text{ V}$$

Now,

$$E_B = \frac{\phi Z N}{60} \times \frac{P}{A}$$

$$458 = \frac{0.05 \times 864 \times N}{60} \times \frac{6}{6}$$

$$\therefore \underline{N = 636 \text{ rpm}} \longrightarrow \text{i)}$$

Alternatively can use $E_B \times I_A = \frac{2\pi N}{60} \times T$

$$\text{Total Torque} = 0.159 \times \phi Z \times \frac{P}{A} \times I_A$$

$$= 0.159 \times 0.05 \times 864 \times \frac{6}{6} \times 110$$

$$\therefore \underline{T = 755.568 \text{ N-m}} \longrightarrow \text{ii)}$$

Q. A 100 kW, 460 V shunt generator was run as a motor on no load at its rated voltage & speed. The total current taken was 9.8 A, including a shunt current of 2.7 A. The resistance of the armature ckt. at normal working temp. was 0.11 Ω. Calculate the efficiencies at
i) Full Load ii) Half Load

GIVEN DATA:

Power = 100 kW $\qquad I_L = 9.8\,A \qquad R_A = 0.11\,\Omega$

V = 460 V $\qquad I_{sh} = 2.7\,A$

Sol^n.

As a Generator,

$$\text{Full Load Current} = \frac{\text{Power rating in Watts}}{\text{Voltage}}$$

$$I_{FL} = \frac{100 \times 10^3}{460}$$

$$I_{FL} = 217.4 \text{ Amp}$$

Also,

$$I_A = I_{FL} + I_{sh}$$
$$= 217.4 + 2.7$$
$$= 220.1\,A$$

$$\text{Full Load Cu loss} = I_A^2 R_A$$
$$= (220.1)^2 \times 0.11$$
$$= 5329\,W$$

$$\text{Cu loss in shunt coil} = I_{sh}^2 R_{sh}$$
$$= 2.7^2 \times \frac{460}{2.7}$$
$$= 1242\,W$$

As a Motor,

$$I_A = I_L - I_{sh}$$
$$= 9.8 - 2.7$$
$$= 7.1\ A$$

Power supplied to the armature, $= V \times I_A$
$$= 460 \times 7.1$$
$$= 3266\ W$$

No load Cu loss $= I_A^2 R_A$
$$= 7.1^2 \times 0.11$$
$$= 5.545 W$$

Iron loss = Power supplied − No load Cu loss
$$= 3266 - 5.545$$
$$= 3260.455\ W$$

Full load losses $= 5329 + 1242 + 3260$
$$= 9831\ W$$

$$\eta_{FL} = \frac{o/p}{o/p + losses} \times 100\%$$
$$= \frac{100 \times 10^3}{100 \times 10^3 + 9831} \times 100\%$$

$$\therefore \quad \eta_{FL} = 91.05\% \quad \longrightarrow \text{i)}$$

Now,

$$o/p \text{ current @ } HL = I_{FL}/2$$
$$= 108.7 \text{ A}$$

Also

$$I_A = I_{HL} + I_{sh}$$
$$= 108.7 + 2.7$$
$$= 111.4 \text{ A}$$

$$\text{Cu loss @ } HL = I_A^2 R_A$$
$$= 111.4^2 \times 0.11$$
$$= 1365 \text{ W}$$

$$\text{Half Load losses} = 1365\text{ W} + 1242\text{ W} + 3260\text{ W}$$
$$= 5867 \text{ W}$$

$$\eta_{HL} = \frac{o/p}{o/p + \text{losses}} \times 100\%$$

where,

$$o/p = \frac{o/p \text{ @ } FL}{2}$$
$$= 50 \text{ kW}$$

$$\therefore \eta_{HL} = \frac{50 \times 10^3}{50 \times 10^3 + 5867} \times 100\%$$

$$\therefore \eta_{HL} = 89.49\%$$ → ii)

Q. A 440 V shunt motor takes an armature current of 30 A at 700 rev/min. The armature resistance is 0·7 Ω. If the flux is suddenly reduced by 20 %, to what value will the armature current rise momentarily? Assuming unchanged resisting torque to motion, what will be the new steady value of speed & armature current? Sketch graphs showing armature current & speed as functions of time, during the transition from initial to final steady state conditions.

GIVEN DATA:

$V = 440\ V$ $\quad N = 700\ rpm$

$I_A = 30\ A$ $\quad R_A = 0{\cdot}7\ \Omega$

Sol^{n}:

For a shunt motor,

$$E_B = V - I_A R_A$$
$$= 440 - 30 \times 0{\cdot}7$$
$$\therefore E_B = 419\ V$$

As the flux reduces by 20%, assume initial flux to be ϕ_1

$$\therefore \phi_2 = \phi_1 - 0{\cdot}2\phi_1$$
$$= 0{\cdot}8\,\phi_1\ Wb$$

Momentarily assuming no change in speed,

$$\frac{E_{B_1}}{E_{B_2}} = \frac{\phi_1}{\phi_2} \qquad \rightarrow \text{As } E_B \propto \phi N$$

$$\therefore E_{B_2} = 0{\cdot}8\,E_{B_1} = 0{\cdot}8 \times 419$$

i.e. $E_{B_2} = 335.2\ V$

Now,

$$E_{B_2} = V - I_A R_A$$

$$335.2 = 440 - I_A \times 0.7\ \Omega$$

$$\therefore I_A = 149.7\ A \longrightarrow \text{i)}$$

Armature current will momentarily rise to 149.7 A

We know,

$$T \propto \phi I_A$$

But, we know that the torque is unchanged

$$\therefore T_1 = T_2$$

$$\phi_1 I_{A_1} = \phi_2 I_{A_2}$$

$$\phi_1 \times 30 = 0.8\,\phi_1 \times I_{A_2}$$

$$\therefore I_{A_2} = 37.5\ A$$

Now,

$$E_{B_{New}} = V - I_{A_2} R_A$$

$$= 440 - 37.5 \times 0.7$$

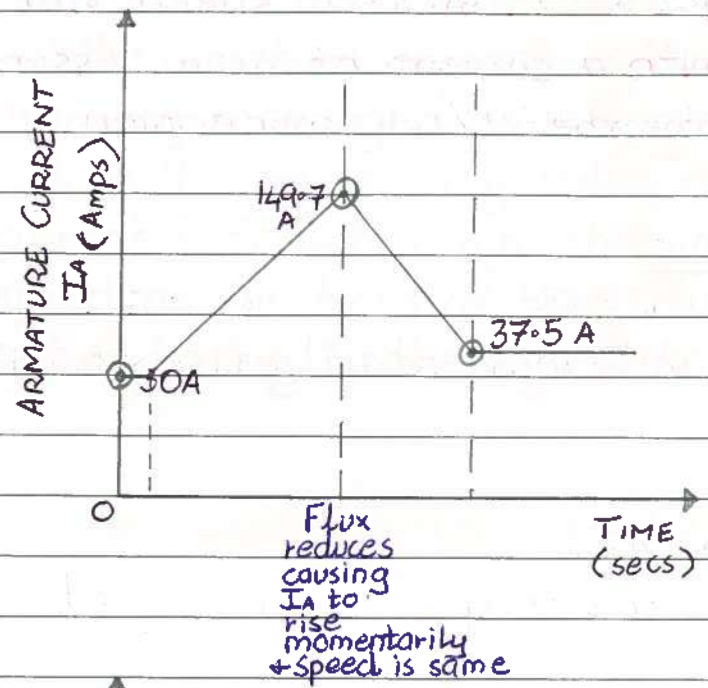
$$E_{B_{New}} = 413.75\ V$$

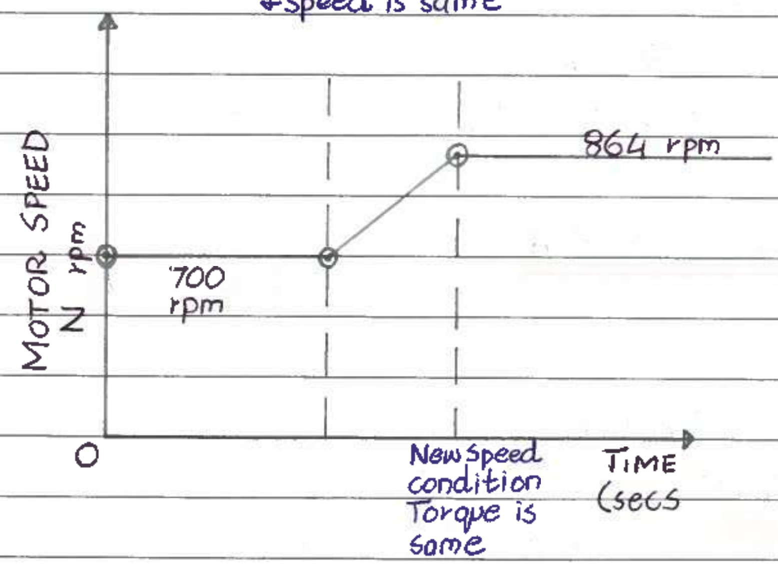
$$\frac{E_{B_{New}}}{E_{B_1}} = \frac{\phi_N \times N_N}{\phi_1 \times N_1}$$

As $E_B \propto \phi N$
$(\phi_N = \phi_2 = 0.8\,\phi_1)$

$$\frac{413.75}{419} = \frac{0.8\,\phi_1}{\phi_1} \times \frac{N_N}{700}$$

$\therefore$ $\underline{N_N = 864 \text{ rpm}}$ $\longrightarrow$ ii)





Q. A shunt motor runs at 900 rpm when connected to a 440 V supply, the armature current being 60 A & the armature resistance 0.4 Ω. At what speed will it run on a 220 V supply with a current of 40 A. Assume 60% reduction in flux for the 220 V connection.

GIVEN DATA:

$N_1 = 900$ rpm $I_{A_1} = 60$ A $V_2 = 220$ V

$V_1 = 440$ V $R_{A} = 0.4\,\Omega$ $I_{A_2} = 40$ A

Sol^n.

Let the initial flux be ϕ_1 wb

$$\phi_2 = \phi_1 - 0.6\phi_1$$
$$= \phi_1 \times 0.4$$

We know,

$$\cancel{E_B \propto \phi N}$$

$$N \propto \frac{V - I_A R_A}{\phi}$$

$$\therefore \frac{N_1}{N_2} = \frac{V_1 - I_{A_1} R_A}{\phi_1} \times \frac{\phi_2}{V_2 - I_{A_2} R_A}$$

$$\therefore \frac{900}{N_2} = \frac{(440 - 60 \times 0.4)}{\phi_1} \times \frac{0.4\phi_1}{(220 - 40 \times 0.4)}$$

$$\therefore \underline{\underline{N_2 = 1103 \text{ rpm}}}$$

Q. A 230 V DC shunt motor runs at 1000 rpm & takes 5 A. The armature resistance of the motor is 0·025 Ω & shunt field resistance is 230 Ω. Calculate the drop in speed when the motor is loaded & takes a line current of 41 A. Neglect armature reaction.

GIVEN DATA:

$V = 230\ V$ $I_{L_1} = 5\ A$ $R_{sh} = 230\ \Omega$

$N = 1000\ rpm$ $R_A = 0{\cdot}025\ \Omega$ $I_{L_2} = 41\ A$

Sol^n.

At No load,

$$I_{sh} = V/R_{sh} = 230/230 = 1\ A$$

For a DC Shunt motor

$$I_A = I_L - I_{sh}$$

$$\therefore I_{A_1} = 5 - 1 = 4\ A$$

Now,

$$E_{B_1} = V_1 - I_{A_1} R_A = 230 - 4 \times 0{\cdot}025 = \cancel{230\ V}\ 229{\cdot}9\ V$$

At Full Load,

$$I_{A_2} = I_{L_2} - I_{sh} = 41 - 1$$

$$I_{A_2} = 40\ A$$

$$E_{B_2} = V - I_{A_2} R_A$$
$$= 230 - 40 \times 0.025$$
$$= 229 \text{ V}$$

Neglecting armature reaction,

$$\frac{E_{B_2}}{E_{B_1}} = \frac{N_2}{N_1}$$

As ϕ is constant & $E_b \propto \phi N$

$$\frac{229}{229.9} = \frac{N_2}{1000}$$

$$\therefore \quad N_2 = 996 \text{ rpm}$$

Drop in speed $= N_1 - N_2$
$= 1000 - 996$

$\therefore$ Drop in Speed = 4 rpm

Q. A 220V DC shunt motor has an armature resistance of 0.5Ω & an armature current of 40 A on full load. Determine the reduction in flux necessary for a 50% reduction in speed. The torque for both conditions can be assumed to remain constant.

GIVEN DATA:

$R_A = 0.5\,\Omega$ $\quad N_2 = 0.5 N_1$ $\quad V = 220\ V$

$I_A = 40\ A$ $\quad T_1 = T_2$

Sol^n

$$E_{B_1} = V - I_{A_1} R_A$$
$$= 220 - 40 \times 0.5$$
$$= 200\ V$$

We know,

$$T \propto \phi I_a$$

& as Torque remains constant

$$\phi_1 I_{A_1} = \phi_2 I_{A_2} \longrightarrow ①$$

$$E_{B_2} = V - I_{A_2} R_A$$
$$= 220 - 0.5 I_{A_2}$$

Now,

$$\frac{E_{B_2}}{E_{B_1}} = \frac{\phi_2}{\phi_1} \times \frac{N_2}{N_1} \qquad \text{As } E_B \propto \phi N$$

$$\frac{E_{B_2}}{E_{B_1}} = 0.5 \frac{\phi_2}{\phi_1} \longrightarrow ② \qquad \because N_2 = 0.5 N_1$$

From ① & ②

$$\frac{220 - 0.5 I_{A2}}{200} = 0.5 \times \frac{I_{A1}}{I_{A2}}$$

$$\therefore \quad 220 I_{A2} - 0.5 I_{A2}^2 - 4000 = 0$$

$$\text{i.e.} \quad 0.5 I_{A2}^2 - 220 I_{A2} + 4000 = 0$$

$$I_{A2}^2 - 440 I_{A2} + 8000 = 0$$

$$\because \quad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$I_{A2} = 421 \text{ A} \quad \text{OR} \quad 19 \text{ A}$$

As we have to determine the reduction in flux, we need to discard the value of 19 Amps.

$$\therefore \quad I_{A2} = 421 \text{A}$$

$$\phi_1 \times 40 = \phi_2 \times 421$$

$$\therefore \quad \phi_2 = 0.095 \phi_1$$

Hence, for a 50% reduction in speed, the reduction in flux necessary is 9.5% of the original flux, ϕ_1.

Q. A shunt motor supplied at 230 V runs at 900 rpm. When the armature current is 30 A, the resistance of the armature ckt. is 0.4 Ω. Calculate the resistance required in series with the armature ckt. to reduce the speed to 500 rpm. Assume the armature current is 25 A.

GIVEN DATA:

$V = 230\ V$ $\quad I_{A_1} = 30\ A$ $\quad N_2 = 500\ rpm$

$N_1 = 900\ rpm$ $\quad R_A = 0.4$ $\quad I_{A_2} = 25\ A$

Sol^n

$$E_{B_1} = V - I_{A_1} R_A$$
$$= 230 - 30 \times 0.4$$
$$= 218\ V$$

We know that $\quad E_B \propto \phi N$

$\therefore$ At constant ϕ $\quad E_B \propto N$

$$\frac{E_{B_1}}{E_{B_2}} = \frac{N_1}{N_2}$$

$$\therefore\ E_{B_2} = \frac{218 \times 500}{900}$$
$$= 121.11\ V$$

For a long shunt ~~series~~ DC Motor,

$$E_B = V - I_A (R_A + R_S)$$
$$121.11 = 230 - 25 (0.4 + R_S)$$

$$\therefore\quad \underline{R_S = 3.956\ \Omega}$$

Q. A shunt motor has an armature resistance of 0·2 Ω with an armature current of 120 A runs at 750 rpm of a 400 V supply. Calculate the speed & armature current of the motor, if the flux per pole is reduced to 75% of its initial value, the total torque remaining unaltered.

GIVEN DATA:

$R_A = 0{\cdot}2\,\Omega$ $\quad N = 750$ rpm $\quad \phi_2 = 0{\cdot}75\,\phi_1$

$I_A = 120\,A$ $\quad V = 400\,V$

Sol^{n}.

We know, $\quad T \propto \phi I_A$

But as the total torque is unaltered,

$$\phi_1 I_{A_1} = \phi_2 I_{A_2}$$

$$\therefore \quad \phi_1 \times 120 = 0{\cdot}75\,\phi_1 I_{A_2}$$

$$\therefore \quad \underline{\underline{I_{A_2} = 160\ A}} \longrightarrow \text{i)}$$

$E_{B_1} = V - I_{A_1} R_A$

$= 400 - 120 \times 0{\cdot}2$

$= 376\ V$

$E_{B_2} = V - I_{A_2} R_A$

$= 400 - 160 \times 0{\cdot}2$

$= 368\ V$

$$\frac{E_{B_1}}{E_{B_2}} = \frac{\phi_1 \times N_1}{\phi_2 \times N_2} \qquad \because E_B \propto \phi N$$

$$\therefore \quad \frac{376}{368} = \frac{\phi_1 \times 750}{0{\cdot}75\,\phi_1 \times N_2}$$

$$\therefore \quad \underline{\underline{N_2 = 978{\cdot}72\ \text{rpm}}} \longrightarrow \text{ii)}$$

Q. A 230 V motor which normally develops 10 kW at 1000 rpm with an efficiency of 85% is to be used as a generator. The armature resistance is 0·15 Ω & shunt field resistance is 220 Ω. If it is driven at 1080 rpm & field current is adjusted to 1·1A by means of a shunt regulator, what output in kW could be expected as a generator, if the armature copper loss was kept down to that when running as a motor.

GIVEN DATA:

$V = 230\ V$ $\quad \eta = 85\%$ $\quad N_2 = 1080$ rpm

$o/p = 10\ kW$ $\quad R_A = 0{\cdot}15\ \Omega$ $\quad I_{sh_2} = 1{\cdot}1\ A$

$N_1 = 1000$ rpm $\quad R_{sh} = 220\ \Omega$

Sol^n:

As a motor,

$$\eta = \frac{o/p}{i/p}$$

$$\therefore\ i/p = o/p / \eta$$

$$= 10 \times 10^3 / 0{\cdot}85$$

$$= 11765\ W$$

Input current from supply, $I_L = \frac{\text{Power } i/p}{V}$

$$= 11765 / 230$$

$$= 51{\cdot}15\ A$$

$$I_{sh_1} = \frac{V}{R_{sh}}$$

$$= \frac{230}{220}$$

$\therefore I_{sh_1} = 1.045A$

Now,

$$I_A = I_L - I_{sh}$$

$$= 51.15 - 1.045$$

$$= 50.1 \ A$$

$$E_B = V - I_A R_A$$

$$= 230 - 50.1 \times 0.15$$

$$= 222.48 \ V$$

As a Generator,

Speed is increased & flux is also increased proportional to the shunt field current.

i.e. $E \propto \phi N$ But, $\phi \propto I_{sh}$

$\therefore E \propto I_{sh} N$

Now,

$$\frac{E_B}{E} = \frac{I_{sh_1} \times N_1}{I_{sh_2} \times N_2}$$

$$\therefore E = \frac{222.48 \times 1.1 \times 1080}{1.045 \times 1000}$$

$$\therefore E = 252.92 \ V$$

As the armature losses are the same for motor + generator, armature current I_a will be the same.

i.e. $I_A = 50.1 \text{ A}$

$$E_G = V + I_A R_A$$

$$\cancel{= 230 + 50.1 \times 0.15}$$

$$\cancel{= 237.52 \text{ V}}$$

$$\therefore V = E_G - I_A R_A$$

$$= 252.92 - 50.1 \times 0.15$$

$$= 245.4 \text{ V}$$

$$I_A = I_L + I_{sh}$$

$$50.1 = I_L + 1.1$$

$$\therefore I_L = 49 \text{ A}$$

Power o/p ~~of~~ as Generator $= V \times I_L$

$$= \cancel{230 \times 49} \; 245.4 \times 49$$

$\therefore$ Power o/p as Generator $= \cancel{11.27} \; 12.024$ kW

Q. A 200 V long shunt compound wound generator has a full load o/p of 20 kW. The various resistances are as follows

i) armature (incl. brush contact) 0·15 Ω
ii) series field 0·025 Ω
iii) interpole field 0·028 Ω
iv) shunt field (incl. field regulator resistance) 115 Ω.

The iron losses at full load are 780 W & the friction & windage losses are 590 W. Calculate the Full load efficiency.

GIVEN DATA:

$V = 200$ V

Power $o/p_{FL} = 20$ kW

$R_A = 0{\cdot}15\ \Omega$

Iron $loss_{FL} = 780$ W

$R_s = 0{\cdot}025\ \Omega$

$R_{if} = 0{\cdot}028\ \Omega$

$R_{sh} = 115\ \Omega$

Rotation loss $= 590$ W

Solⁿ

At Full Load,

Line current, $I_L = \dfrac{\text{Power o/p}}{V}$

$= 20 \times 10^3 / 200$

$\therefore\ I_L = 100$ A

$I_{sh} = \dfrac{V}{R_{sh}}$

$I_{sh} = 200/115$

$\therefore\ I_{sh} = 1{\cdot}74$ A

Now, $I_A = I_L + I_{sh}$
$= 100 + 1.74$
$\therefore I_A = 101.74\ A$

Cu Loss in Armature $= I_A^2 R_A$
$= 101.74^2 \times (0.15 + 0.025 + 0.028)$
$= 2101.26\ W$

Cu loss in Shunt field $= I_{sh}^2 R_{sh}$
$= 1.74^2 \times 115$
$= 348.17\ W$

Total Cu loss $= 2101.26 + 348.17$
$= 2449.4\ W$

Total Losses $= 2449.4 + 780 + 590$
$= 3819.4$

Now,

$$\eta_{FL} = \frac{o/p}{o/p + \text{Total losses}} \times 100\%$$

$$= \frac{20 \times 10^3}{20 \times 10^3 + 3819.4} \times 100\%$$

$$\therefore \quad \underline{\eta_{FL} = 83.96\%}$$

AC FUNDAMENTALS

I) For a Sinusoidal wave,

$v_i = V_{max} \sin \omega t$ & $i_i = i_{max} \sin \omega t$

where, $\omega t \longrightarrow$ Angular Velocity

II) Frequency, $f = \dfrac{P \times N}{120}$ Hz

where, $P \rightarrow$ No. of Poles

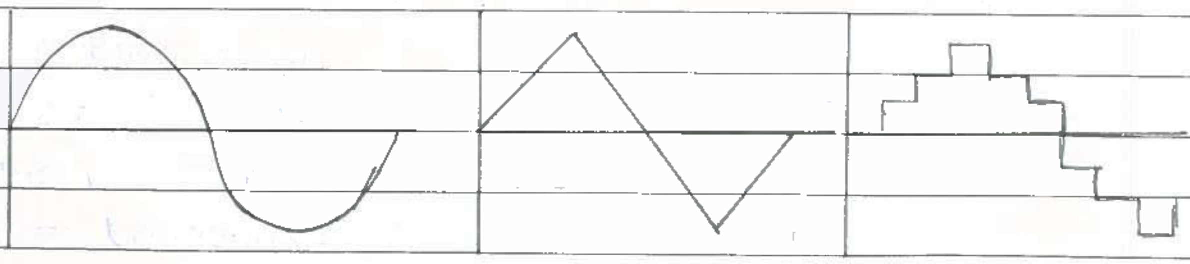
$N \rightarrow$ RPM

III) Time Period, $T = \dfrac{1}{f}$ secs

& also $f = \dfrac{1}{T}$ Hz

IV) DEFITUITIONS / TERMINOLOGIES

A) WAVEFORM: The shape of the curve obtained by plotting the instantaneous values of voltage or current as an ordinate against time as an abscissa.



B) An ALTERNATING CURRENT or VOLTAGE is one, the circuit direction of which reverses at regularly recurring intervals.

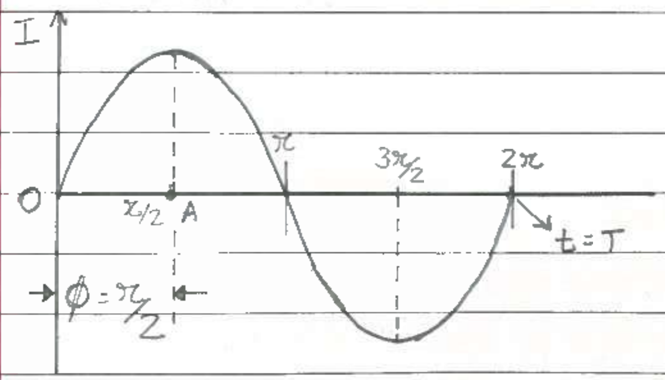
C) CYCLE: One complete set of +ve & -ve values of an alternating quantity is known as a cycle.
A cycle, may also be, sometimes specified in terms of angular measure. In that case, one complete cycle is said to spread over 360° or 2π radians.

D) TIME PERIOD: The time taken by an alternating quantity to complete on cycle is called its time period 'T'.

E) FREQUENCY: The no. of cycles per second is called the frequency of the alternating quantity.

F) AMPLITUDE: The max. value, +ve or -ve, of an alternating quantity is known as its amplitude.

G) PHASE: By phase of an alternating current, it is meant the fraction of the time period of that AC that has elapsed since it last passed through the zero position of reference.



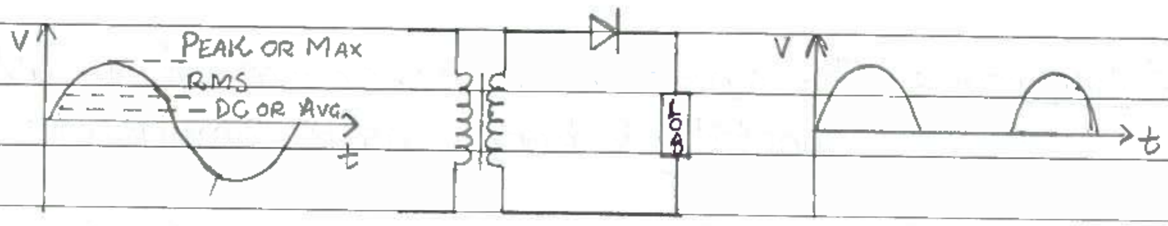
Ex. The phase of the current, I, at point A is $T/4$ secs, where T is the time period or when expressed in terms of an angle, it is $\pi/2$ radians.

H) **ROOT MEAN SQUARE (RMS) VALUE** : The rms value of an AC is given by that steady DC which when flowing through a given circuit for a given time produces the same heat as produced by the AC when flowing through the same circuit for the same time.

It is also known as effective or virtual value of AC, with the former term being used more extensively.

I) RECTIFICATION (Converting AC to DC)

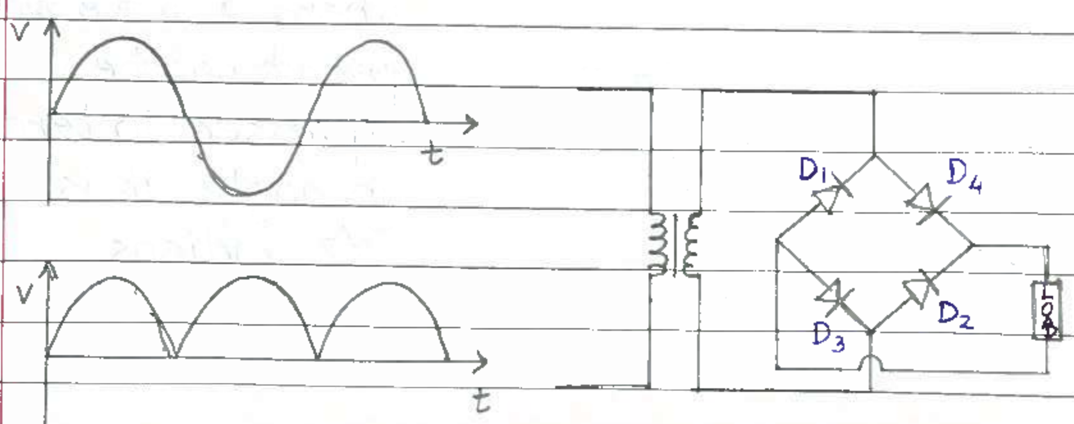
A) HALF WAVE RECTIFIER



$$V_{RMS} = \frac{V_{MAX.}}{2} \qquad I_{RMS} = \frac{I_{MAX}}{2}$$

$$V_{DC\ OR\ AVG.} = \frac{V_{MAX.}}{\pi} \qquad I_{\cancel{MAX}\ DC} = \frac{I_{MAX}}{\pi}$$

B) FULL WAVE RECTIFIER



$$V_{RMS} = \frac{V_{MAX}}{\sqrt{2}} \qquad I_{RMS} = \frac{I_{MAX}}{\sqrt{2}}$$

$$V_{DC\ or\ AVG.} = \frac{2 \times V_{MAX}}{\pi} \qquad I_{DC\ or\ AVG.} = \frac{2 \times I_{MAX}}{\pi}$$

V)

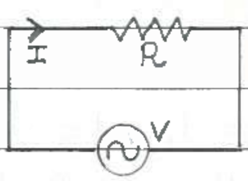
A) **Peak / Amplitude Factor or Crest:**

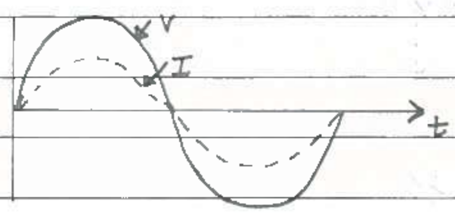
$$K_p = \frac{\text{Max. value}}{\text{rms value}}$$

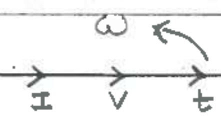
B) **Form Factor:**

$$K_f = \frac{\text{rms value}}{\text{avg. value}}$$

VI) **AC Through a Pure Ohmic Resistance Only:**



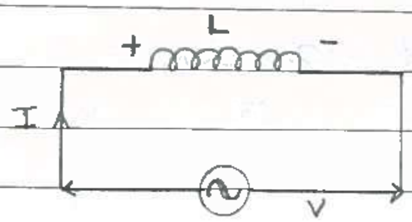


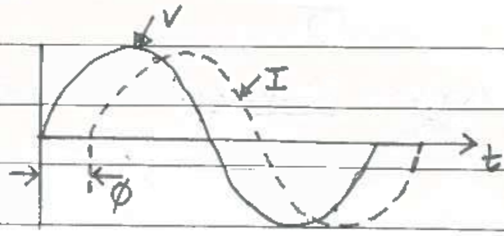


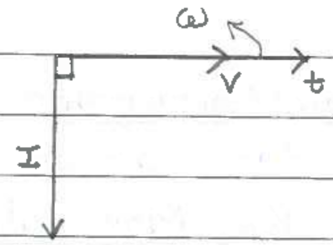
V & I are in-phase
i.e. phase angle, $\phi = 0$
$\therefore$ power factor, $\cos\phi = 1$

where,
$\omega \longrightarrow$ Angular Velocity in rad/sec.

VIII) AC Through Inductance Only







$$\frac{V}{I} = Z = X_L$$

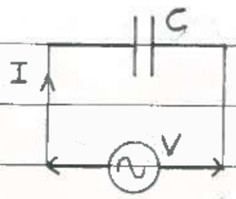
$$X_L = 2\pi f L = L\omega$$

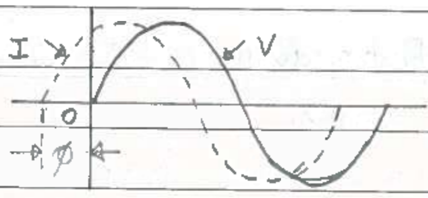
where,

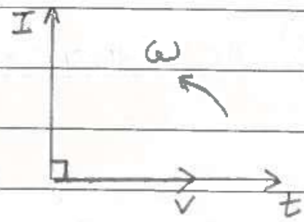
$X_L \longrightarrow$ Induct~~ance~~ive Reactance

I lags behind V, thus, p.f., $\cos\phi$ = lagging

IX) AC Through Capacitance Alone:







$$\frac{V}{I} = Z = X_C$$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{\omega C}$$

where,

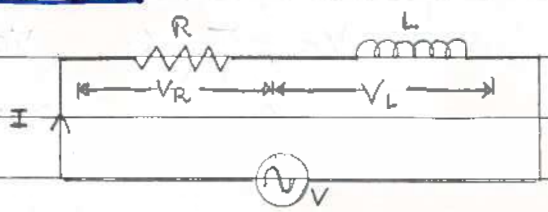
$X_C \longrightarrow$ Capacitive Reactance

I leads V,

$\therefore$ p.f., $\cos\phi$ = leading

SERIES AC CIRCUITS

I) R-L CIRCUIT

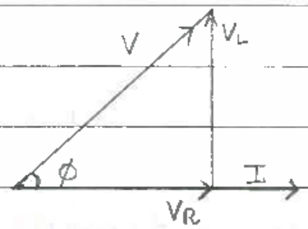


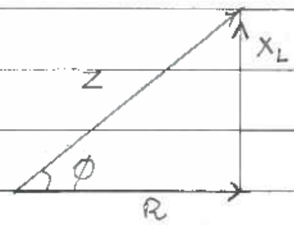
$V_R = I \times R$ Volts $\qquad V_L = I \times X_L$ Volts

$X_L = 2\pi f L$

$= \omega L \quad \Omega$

$\overline{V} = \overline{V_R} + \overline{V_L}$





IMPEDANCE TRIANGLE

where,

$R \rightarrow$ Active Component

$X_L \rightarrow$ Reactive Component

$Z \rightarrow$ Impedance of the ckt.

Now,

$$V = \sqrt{V_R^2 + V_L^2}$$

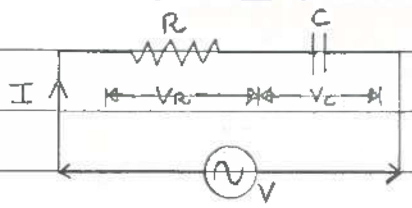
i.e. $V = I\sqrt{R^2 + X_L^2}$

$\because \quad V/I = Z$

$$Z = \sqrt{R^2 + X_L^2} \qquad \longrightarrow i)$$

p.f., $\cos\phi = \dfrac{R}{Z}$ lagging $\longrightarrow$ ii)

1) R-C CIRCUIT :



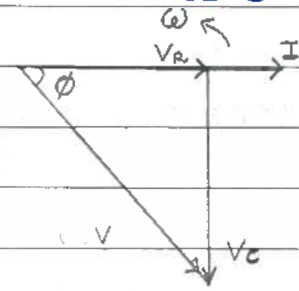
$V_R = I \times R$ Volts

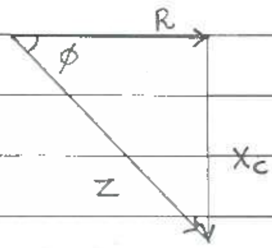
$V_C = I \times X_C$ Volts

where,

$$X_C = \frac{1}{2\pi f C}$$

$$= \frac{1}{\omega C} \quad \Omega$$





$$\bar{V} = \bar{V_R} + \bar{V_C}$$

$$V = \sqrt{V_R^2 + V_C^2}$$

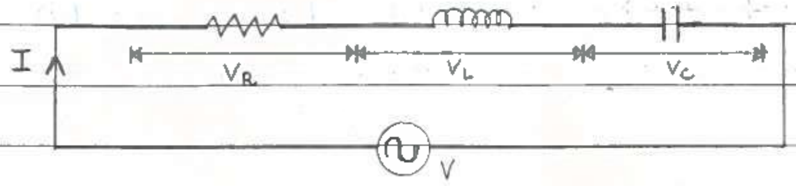
$$= I\sqrt{R^2 + X_C^2}$$

$\because \quad V/I = Z$

$$Z = \sqrt{R^2 + X_C^2} \qquad \longrightarrow \text{i)}$$

p.f., $\cos\phi = \dfrac{R}{Z}$ Leading $\longrightarrow$ ii)

II) RLC CIRCUIT



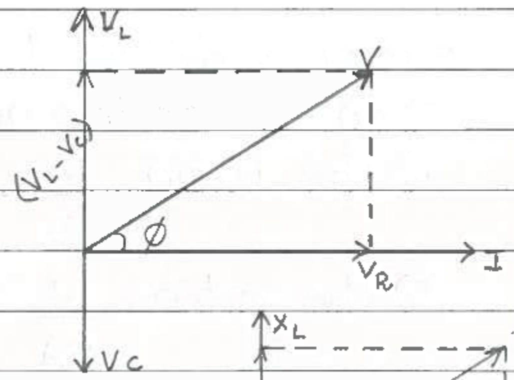
$V_R = I \times R$ Volts

$V_L = I \times X_L$ Volts where, $X_L = 2\pi f \times L = \omega L \ \Omega$

$V_C = I \times X_C$ Volts where, $X_C = 1/2\pi f \times C = 1/\omega \times C \ \Omega$

Now, let us assume that the inductive component is greater than the capacitive component.

i.e. $X_L > X_C$

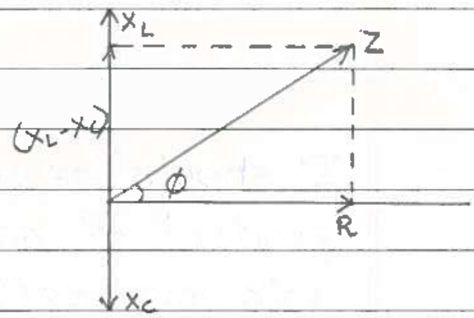


$$\therefore \quad V^2 = V_R^2 + (V_L - V_C)^2$$

$$V^2 = I^2 [R^2 + (X_L - X_C)^2]$$

$$V = I\sqrt{R^2 + (X_L - X_C)^2}$$

$$\because \quad V/I = Z$$



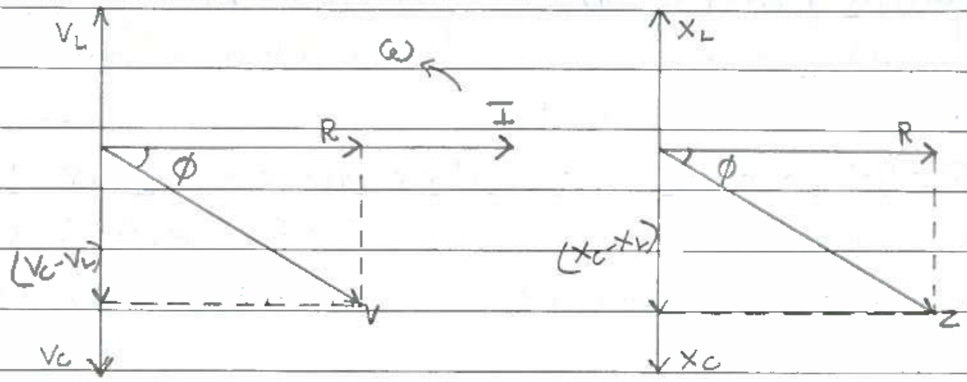
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

p.f., $\cos\phi = \dfrac{R}{Z}$ lagging if $X_L > X_C$
leading if $X_C > X_L$

* when $X_L = X_C$, the circuit is said to be a 'Resonant circuit'

If $X_L < X_C$, then

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$



11) POWER FACTOR

- It may be defined as
  i) cosine of the angle of lead or lag
  ii) the ratio $\frac{R}{Z} = \frac{\text{Resistance}}{\text{Impedance}}$
  iii) the ratio $\frac{W}{VA} = \frac{\text{Watt}}{\text{Volt-Amperes}}$

- It should be remembered that in an AC circuit the product of rms volts & rms amperes gives volt amperes (VA) & not true power (W)

- True Power = Volt-Amperes × Power factor

i.e. $W = VA \times \cos\phi$

OR

$KW = KVA \times \cos\phi$

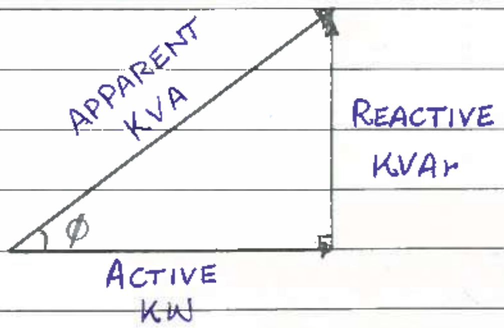
- Power factor is defined as the ratio of real power to apparent power.
- Power factor is a simple way to describe how much of the current contributes to real power in the load.
- A p.f. of unity (one or 1.0) indicates that 100% of the current is contributing to power in the load while a p.f. of zero indicates that none of the current contributes to power in the load.

1) ACTIVE + REACTIVE COMPONENTS OF CURRENT

i) Active Component: is that which is in phase with the applied voltage i.e. $I \cos \phi$.
- Also known as 'Wattful' component.

ii) Reactive Component: is that which is in quadrature with the applied voltage i.e. $I \sin \phi$.
- Also known as 'Wattless' or 'Idle' component

POWER TRIANGLE



APPARENT POWER = $V_{RMS} \times I_{RMS}$

p.f. $\cos \phi$ = KW/KVA

$KVA = \sqrt{KW^2 + KVAr^2}$

$KW = KVA \times \cos\phi$

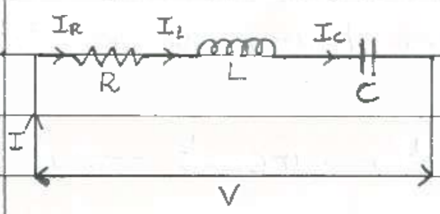
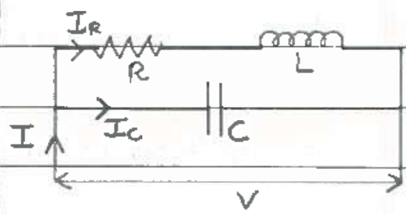
KW → True / Active / Wattful / In-phase Power

$KVA_r = KVA \times \sin\phi$

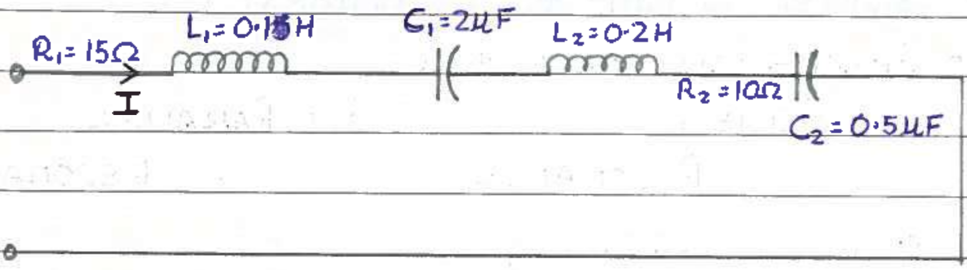
KVA_r → Wattless / Reactive / Out of phase Power

Q. Compare the Series & Parallel Resonance circuits. Find the frequency at which the following circuit resonates.

ANS.

	SERIES RESONANCE	PARALLEL RESONANCE
Circuit		
Resonant condition	At Resonance, $X_L = X_C$. $\therefore$ Net Reactance is zero	At Resonance, $L/C = Z^2$. $\therefore$ Net Susceptance is zero.
Current	$I = V/R$ & is Maximum	$I = \frac{V}{L/CR}$ & is Minimum
Impedance	$Z = R$ & is Minimum. $\therefore$ Admittance is Maximum	$Z = L/CR$ & is Maximum Admittance = Conductance
Power Factor	Unity	Unity
Resonant Frequency	$f_0 = \frac{1}{2\pi\sqrt{LC}}$	$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$
	Acceptor circuit	Rejector circuit
Peculiar Features	Voltage across the coil is more than voltage across the capacitance due to resistance. $\therefore$ Voltage resonance + Voltage magnifier	Current circulating between the 2 branches is many times greater than the line current from supply. $\therefore$ Current resonance + Current magnifier

- Quality Factor, $Q = L\omega/R$ is same for both the circuits



Total Inductance in the circuit $\longrightarrow L$

$$L = L_1 + L_2$$
$$= 0.1 + 0.2$$
$$L = 0.3 \text{ H}$$

Total Capacitance in the circuit $\longrightarrow C$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$
$$= \frac{C_1 + C_2}{C_1 C_2}$$
$$\therefore \quad C = \frac{C_1 C_2}{C_1 + C_2} = \frac{2 \times 0.5}{2 + 0.5}$$

$$C = 0.4 \mu F$$

At Resonant Conditions, $X_L = X_C$

$$\therefore \quad 2\pi f L = \frac{1}{2\pi f C}$$

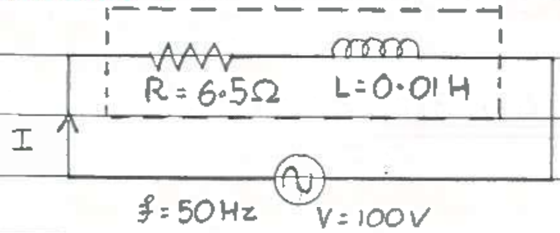
$$\therefore f^2 = \frac{1}{(2\pi)^2 LC}$$

Resonant Frequency, $f_0 = f = \dfrac{1}{2\pi\sqrt{LC}}$

$$\therefore f_0 = \frac{1}{2\pi\sqrt{0.3 \times 0.4 \times 10^{-6}}}$$

$$f_0 = 459.44 \text{ Hz}$$

Q. A heater unit of inductance has a resistance of 6.5 Ω & is intended for use with 100 V mains. For what 50 Hz voltage would it be suitable when placed in series with an isothermal apparatus of negligible resistance having an inductance of 0.01 H. If the frequency rises by 5% & this voltage remains constant, what would be the resulting change of voltage at the heater terminals?



Sol^n.

Resistance of the Heater, $R = 6.5\ \Omega$
Working voltage, $V = 100\ V$

∴ Max. current permissible through the heater,

$$I = V/R = 100/6.5$$
$$\therefore \quad I = 15.38 \text{ Amps}$$

Inductive Reactance, $X_L = 2\pi f L$
$$= 2\pi \times 50 \times 0.01$$
$$\therefore \quad X_L = 3.14\ \Omega$$

Impedance, $Z = \sqrt{R^2 + X_L^2}$
$$= \sqrt{6.5^2 + 3.14^2}$$
$$= \sqrt{52.1096}$$

$$\therefore Z = 7.22\ \Omega$$

Max. Applicable Voltage, $V_{app} = I \times Z$

$= 15.38 \times 7.22$

$\therefore \quad \underline{V_{app} = 111.04 \text{ V}}$

Hence, the applied voltage should be 111.04 V to give 100 V to the heater.

$\because$ Frequency rises by 5%

The new frequency, $f_1 = f + 5\% \text{ of } f$

$= 50 + 0.05 \times 50$

$= 52.5$ Hz

$\therefore$ New Inductive Reactance, $X_{L_1} = 2\pi f_1 L$

$= 2\pi \times 52.5 \times 0.01$

$= 3.299\ \Omega$

New Impedance, $Z_1 = \sqrt{R^2 + X_{L_1}^2} = \sqrt{6.5^2 + 3.299^2} = \sqrt{53.13}$

$\therefore \quad Z_1 = 7.289\ \Omega$

New Heater current, $I_1 = V_{applied}/Z_1 = 111.04/7.289$

$\therefore \quad I_1 = 15.23$ Amps

New Voltage @ Heater Terminal, $V_1 = I_1 \times R = 15.23 \times 6.5$

$\therefore \quad V_1 = 98.99$ V

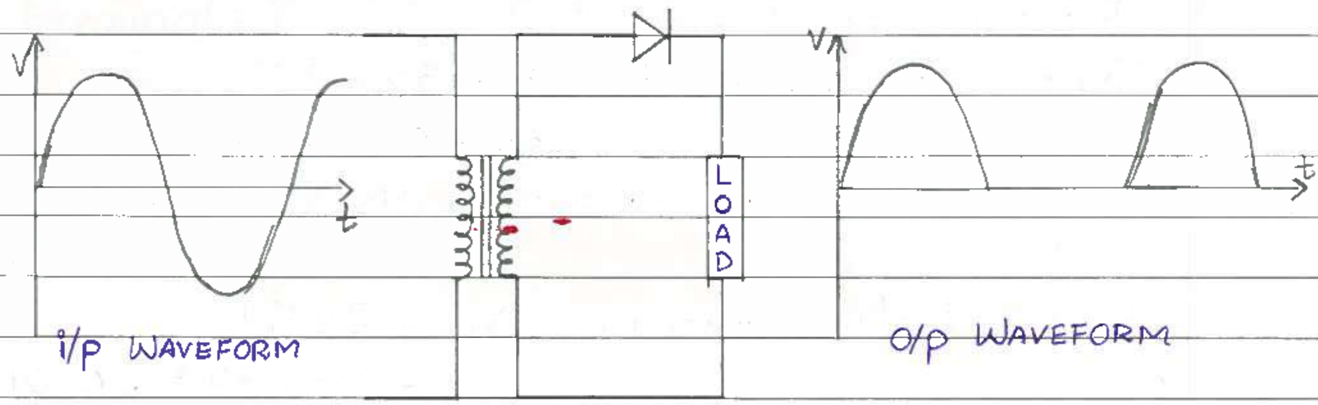
$\therefore$ Change in Voltage $= V - V_1$

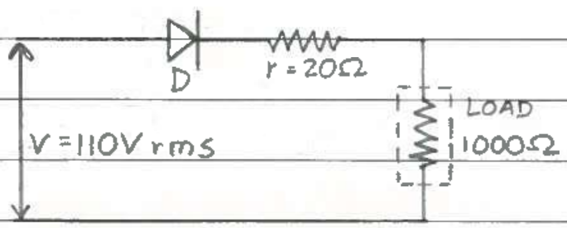
$= 100 - 98.99$

$= \underline{1.01 \text{ V}}$

Q. Draw the circuit of Half wave rectifier & its output waveform. A diode whose internal resistance is 20Ω is to supply power to 1000 Ω load from 110V (rms) source.
Calculate:
i) Peak Load current
ii) DC Load current
iii) AC Load current

Soln





i) Peak Load current, $I_{MAX.} = \dfrac{V_{MAX.}}{R + r}$

where, $V_{MAX.} = V_{RMS} \times \sqrt{2}$
$= 110 \times \sqrt{2}$
$= 155.56 \text{ V}$

$\therefore I_{Max.} = \dfrac{155.56}{1000 + 20}$
$= 152.51 \text{ mA}$

$\underline{I_{MAX} = 152.51 \text{ mA}}$

ii) DC Load current, $I_{DC} = \frac{I_{MAX}}{\pi}$

$$I_{DC} = 152.51/\pi$$

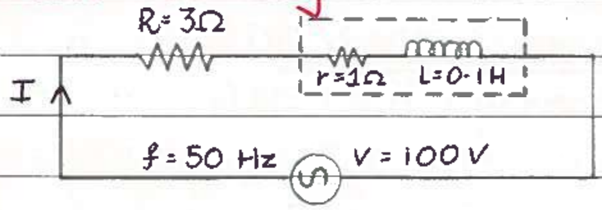
$$\underline{\underline{I_{DC} = 48.54\ mA}}$$

iii) AC Load current, $I_{AC} = \frac{I_{MAX}}{2}$

$$\therefore I_{AC} = 152.51/2$$

$$\therefore \underline{\underline{I_{AC} = 76.25\ mA}}$$

Q. A resistor of ohmic value of 3Ω is connected in series with a coil of inductance 0.1 H & resistance 1Ω. If 100 V at frequency of 50 Hz is applied to the circuit, find the current flowing.



Sol^n.

Total Resistance, $R_T = R + r$

$$= 3 + 1$$

$$= 4\,\Omega$$

$$X_L = 2\pi f L$$

$$= 2\pi \times 50 \times 0.1$$

$$= 31.42\,\Omega$$

Now,

$$Z = \sqrt{R_T^2 + X_L^2}$$

$$= \sqrt{4^2 + 31.42^2}$$

$$= \sqrt{1003.22}$$

$$\therefore\ Z = 31.67\,\Omega$$

But, $Z = V/I$

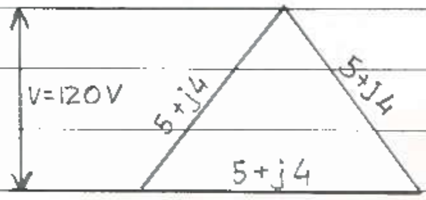
$$\therefore\ I = V/Z$$

$$= 100/31.67$$

$$\therefore\ \underline{I = 3.158 \text{ Amps}}$$

Q. Three impedances, $Z = 5 + j4$ are connected in the form of a delta to the three loads of the balanced 3 phase circuit. The line voltage is 120 Volts. Find:

a) Phase current
b) Power factor
c) Volt-Ampere in circuit
d) Line current.



*Note: $5 \oplus j4$
Inductive Load
Resistance
X_L

$5 \ominus j4$
Capacitive Load
Resistance
X_C

Sol^n:

Since, the load is an inductive load,

$$\text{Impedance, } Z = \sqrt{R^2 + X_L^2}$$
$$= \sqrt{5^2 + 4^2}$$
$$Z = 6.40\ \Omega$$

$$I_{ph} = V/Z = 120/6.40$$

$$\therefore \underline{I_{ph} = 18.75\ A}$$

$$I_L = \sqrt{3}\ I_{ph}$$
$$= \sqrt{3} \times 18.75$$
$$\underline{I_L = 32.48\ A}$$

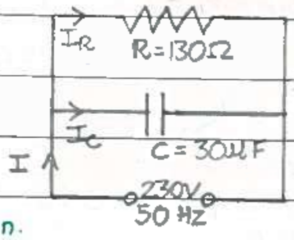
$$\cos\phi = R/Z$$
$$= 5/6.40$$

$$\therefore \underline{\cos\phi = 0.78 \text{ lagging}}$$

Total VA = 3 x VI of Individual phase
$$= 3 \times 120 \times 18.75$$

$$\therefore \underline{\text{Total VA} = 6750\ VA}$$

Q. A resistance of 130 Ω & a capacitor of 30 μF are connected in Parallel across a 230 Volt, 50 Hz supply. Find the current in each component, total current, phase angle & the power consumed.



Sol^n.

$I_R = V/R = 230/130$

$\therefore$ $\underline{I_R = 1.77\ A}$

$I_c = V/X_c$ where, $X_c = 1/2\pi f C = 1/2\pi \times 50 \times 30 \times 10^{-6}$

$\therefore$ $X_c = 106.1\ \Omega$

$\therefore$ $I_c = 230/106.1$

$\therefore$ $\underline{I_c = 2.17\ A}$

Vector Sum, $I = \sqrt{I_R^2 + I_c^2}$

$= \sqrt{1.77^2 + 2.17^2}$

$\therefore$ $\underline{I = 2.8\ A}$

$\cos\phi = I_R / I = 1.77/2.8$

$\therefore$ $\cos\phi = 0.632$

$\phi = \cos^{-1}(0.632)$

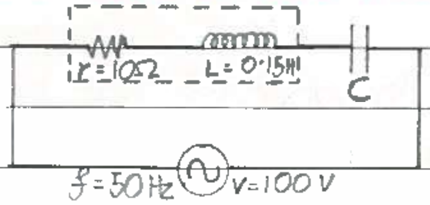
$\therefore$ $\underline{\phi = 50.80}\ ^\circ$

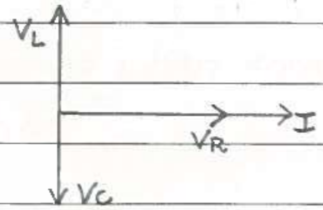
Power $= VI \times \cos\phi$

$= 230 \times 2.8 \times 0.632$

$\therefore$ $\underline{\text{Power} = 407\ W}$

Q. A coil having a resistance of $10\,\Omega$ & an inductance of 0.15 H is connected in series with a capacitor across a 100 V, 50 Hz supply. If the current & voltage are in phase, what will be the value of the current in the circuit & the voltage drop across the coil?





Sol^n.

In a R-L-C circuit, when the current & voltage are in-phase, it is said to be in resonant condition.

At resonant condition, $X_L = X_C$

Now,

$$Z = V/I = \sqrt{R^2 + (X_L - X_C)^2}$$

$$\therefore \quad Z = \sqrt{R^2}$$

$$\text{i.e.} \quad Z = 10\,\Omega$$

Thus, $I = V/Z = 100/10$

$$\therefore \quad \underline{\underline{I = 10\ A}}$$

$$X_L = 2\pi f L$$
$$= 2\pi \times 50 \times 0.15$$

$$\therefore X_L = 47.12\,\Omega$$

Date

Page

Impedance of the coil, $Z_{coil} = \sqrt{R^2 + X_L^2}$

$= \sqrt{10^2 + 47.12^2}$

$= \sqrt{2320.29}$

$\therefore \quad Z_{coil} = 48.17\ \Omega$

Voltage drop across the coil $= I \times Z_{coil}$

$= 10 \times 48.17$

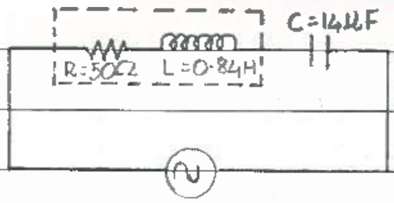
$= 481.7\ V$

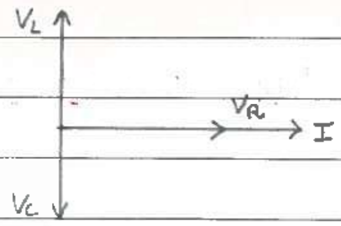
$V_{coil} = 481.7\ V$

Q. A coil of 0·84 H inductance & 50Ω resistance is connected in series with a capacitor of $14\ \mu F$ capacitance.

i) Find the frequency for resonance & the potential difference across the capacitor, across the coil & across both when a current of 5 A at this frequency is flowing.

ii) Find the 3 potential differences when same current flows at 60 Hz & the supply voltage.





Sol$^{n.}$

For a series R-L-C circuit

i)

Resonating frequency, $f_o = \dfrac{1}{2\pi\sqrt{LC}}$

$$\therefore \quad f_o = \frac{1}{2\pi\sqrt{0{\cdot}84 \times 14 \times 10^{-6}}}$$

$$\therefore \quad \underline{f_o = 46{\cdot}41\ Hz} \qquad \longrightarrow \ a)$$

$$X_L = 2\pi f_o L$$

$$= 2\pi \times 46{\cdot}41 \times 0{\cdot}84$$

$$\therefore \quad X_L = 244{\cdot}95\ \Omega$$

Now,

Voltage drop across the inductive coil $= I \times X_L$

$V_{L_0} = 5 \times 244.95$

$\therefore V_{L_0} = 1224.75 \text{ V}$

Voltage drop across resistance, $V_{R_0} = I \times R$

$= 5 \times 50$

$\therefore V_{R_0} = 250 \text{ V}$

Voltage drop across the coil $= \sqrt{V_{R_0}^2 + V_{L_0}^2}$

$= \sqrt{250^2 + 1224.75^2}$

$V_{coil} = 1250 \text{ V} \longrightarrow$ b)

Voltage drop across capacitor $= I \times X_C$

But, $X_L = X_C$

$\therefore V_{C_0} = I \times X_L$

i.e. $V_{C_0} = 1224.75 \text{ V} \longrightarrow$ c)

Voltage drop across coil & capacitor = Voltage drop across resistance

$V_{coil + capacitor} = 250 \text{ V} \longrightarrow$ d)

ii) At $f = 60$ Hz + $I = 5A$

$X_L = 2\pi \times f \times L$

$= 2\pi \times 60 \times 0.84$

$\therefore X_L = 316.67 \, \Omega$

Voltage drop across the inductive reactance coil,

$$V_L = I \times X_L$$
$$= 5 \times 316.67$$
$$\therefore \quad V_L = 1583.35 \text{ V}$$

Voltage drop across the resistance, $V_R = I \times R$

$$= 250 \text{ V}$$

Voltage drop across the coil, $V_{coil} = \sqrt{V_L^2 + V_R^2}$

$$= \sqrt{1583.35^2 + 250^2}$$
$$V_{coil} = 1602.96 \text{ V} \longrightarrow a)$$

Voltage drop across the capacitor,

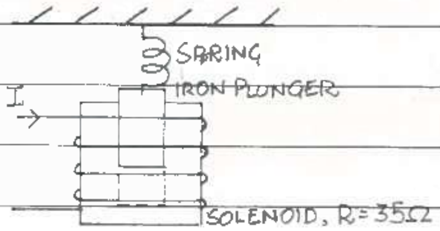
$$V_{capacitor} = I \times X_c$$
$$= I \times \frac{1}{2\pi f C}$$
$$= 5 \times \frac{1}{2\pi \times 60 \times 14 \times 10^{-6}}$$
$$\therefore \quad V_{capacitor} = 947.35 \text{ V} \longrightarrow b)$$

Voltage drop across coil & capacitor, $= V_L - V_c$

$$= 1583.35 - 947.35$$
$$V_{coil+capacitor} = 636 \text{ V} \longrightarrow c)$$

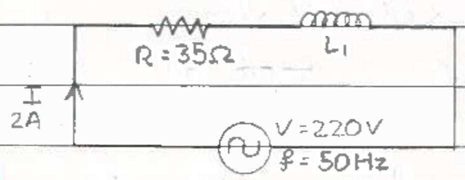
$$\therefore \text{ Supply Voltage} = \sqrt{636^2 + 250^2}$$
$$V_{supply} = 683.37 \text{ V} \longrightarrow d)$$

Q. The low voltage release of an AC motor starter consists of a solenoid into which an iron plunger is drawn against a spring. The resistance of the solenoid is $35\,\Omega$. When connected to a 220 V, 50 Hz AC supply, the current taken at first is 2 A & when the plunger is drawn into its 'full-in' position the current falls to 0·7 A. Calculate the inductance of the solenoid for both positions of plunger & the maximum value of flux-linkages in weber-turns for the 'full-in' pos^{n} of the plunger.



Sol^{n}

i) PLUNGER FULL OUT POS^{N}



$$Z = V/I_{OUT}$$

$$\therefore \quad Z = 220/2$$

i.e. $Z = 110\,\Omega$

ALSO,

$$Z = \sqrt{R^2 + X_L^2}$$

$$Z^2 = R^2 + X_L^2$$

$$\therefore \quad X_L = \sqrt{Z^2 - R^2}$$

$$= \sqrt{110^2 - 35^2}$$

$$\therefore \quad X_L = 104{\cdot}28\,\Omega$$

NOW,

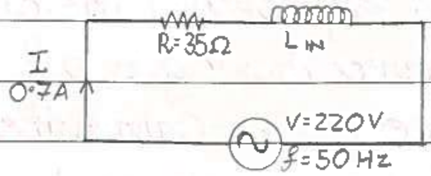
$$X_L = 2\pi f L_{OUT}$$

$$\therefore \quad L_{OUT} = X_L / 2\pi f$$

$$= 104{\cdot}28 / 2\pi \times 50$$

$$\therefore \quad \underline{\underline{L_{OUT} = 0{\cdot}332\ H}}$$

ii) PLUNGER FULL IN POS$^{N.}$



$$Z = V/I_{IN}$$
$$\therefore Z = 220/0.7$$
$$\therefore Z = 314.28\ \Omega$$

We know,

$$Z = \sqrt{R^2 + X_L^2}$$
$$\therefore X_L = \sqrt{Z^2 - R^2}$$
$$= \sqrt{314.28^2 - 35^2}$$
$$X_L = 312.32\ \Omega$$

But,

$$X_L = 2\pi f \times L_{IN}$$
$$\therefore L_{IN} = X_L / 2\pi f$$
$$= 312.32 / 2\pi \times 50$$
$$\therefore \underline{L_{IN} = 0.994\ H}$$

iii)

We know,

$$L = N\phi / I$$

where,

$L \rightarrow$ Flux linkage/ampere

$N \rightarrow$ No. of turns

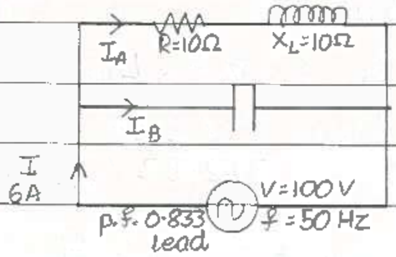
$\phi \rightarrow$ Flux in Wb

$\therefore$ Max. flux-linkage current = Inductance $\times$ Peak value of current

$$= L_2 \times I_{MAX}$$
$$= L_{IN} \times I_{RMS} \times \sqrt{2}$$
$$= 0.994 \times 0.7 \times \sqrt{2}$$

$\therefore$ <u>Max. flux linkage = 0.984 Wb-Turns</u>

Q. A resistance of 10Ω & inductive reactance of 10Ω in series are connected in parallel with a capacitor. The circuit is supplied by a 100 V, 50 Hz source having a p.f. of 0.833 leading. Current from the source is 6A. Calculate the value of capacitance.



Sol^{n}.

$$Z_A = \sqrt{R^2 + X_L^2}$$
$$= \sqrt{10^2 + 10^2}$$
$$= 14.14\,\Omega$$

$$I = \sqrt{I_A^2 + I_R^2}$$

But,

$$I_A = I \times \cos\phi$$
$$= 6 \times 0.833$$
$$= 4.998\text{ A}$$

$$\therefore I_R = \sqrt{I^2 - I_A^2}$$
$$= \sqrt{6^2 - 4.998^2}$$
$$= 3.32\text{ A}$$

For Branch A,

$$I_1 = V/Z_A = 100/14.14$$
$$\therefore I_1 = 7.07\text{ A}$$

Now,

$$I_R = -I_1 \sin \phi_A + I_2 \sin \phi_B$$

$$\therefore\ 3.32 = -7.07 \times X_L/Z + I_2$$

$$\text{i.e. } I_2 = 3.32 + 7.07 \times 10/14.14$$

$$= 8.32\ A$$

For Branch B,

$$X_c = V/I_2 = 100/8.32$$

$$\therefore\ X_c = 12.02\ \Omega$$

But,

$$X_c = \frac{1}{2\pi f C}$$

$$\therefore\ C = \frac{1}{2\pi f \times X_c} = \frac{1}{2\pi \times 50 \times 12.02}$$

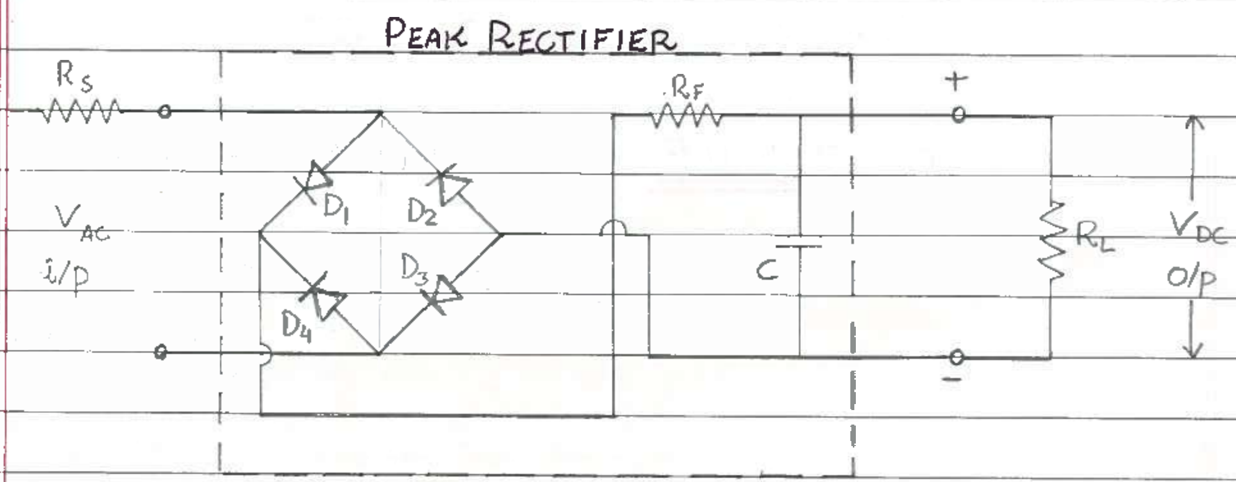
$$\therefore\ \underline{C = 265\ \mu F}$$

Q. A) By means of a schematic circuit diagram illustrate a peak rectifier. If the supply voltage is $v(t) = V_m \sin \omega t$, What is the voltage across the load resistor ?

B) A Battery charging ckt. is shown below in fig. The forward resistance of the diode can be considered negligible & the reverse resistance infinite. The internal resistance of the battery is negligible. Calculate the necessary value of the variable resistance, R, so that the battery charging current is 1.0 A.

Sol^n.

A) PEAK RECTIFIER

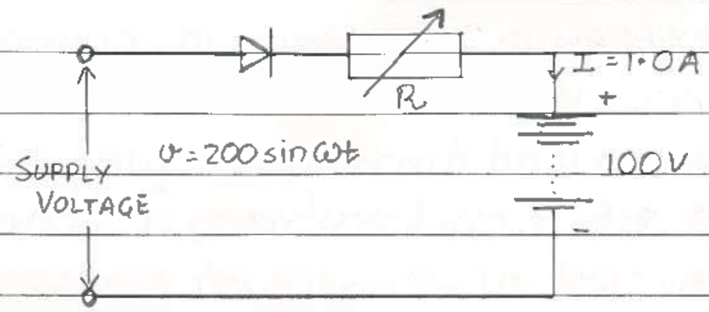


- A rectifier along with a capacitor filter is a peak rectifier.
- It can be either a full wave or half wave rectifier but nowadays all peak rectifiers are full wave rectifiers.

- Supply voltage, $v(t) = V_m \sin \omega t$
- Voltage across the load resistor, R_L, will be

$$V_{DC} = V_M - I_{DC} \times \frac{1}{4fC} - I_{DC}(R_s + R_f)$$

B)



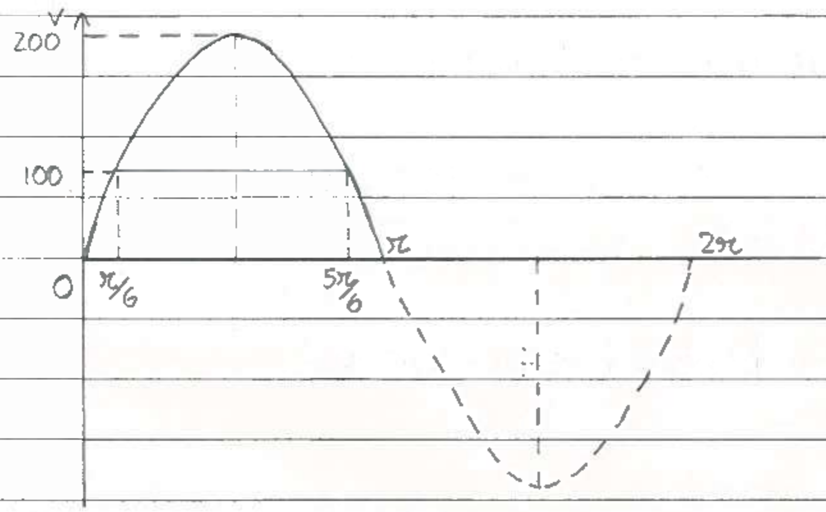
$v_i = V_m \sin \omega t$

$100 = 200 \sin \omega t$

$\therefore \sin \omega t = 0.5$

$\omega t = \sin^{-1}(0.5)$

$\therefore \omega t = \pi/6$



* Charging current will be present only in the region
$\pi/6 < \omega t < 5\pi/6$

* Only when the voltage is above the battery voltage, will the circuit conduct.

During conduction, $V = 200 \sin \omega t$

$$I = \frac{V - 100}{R}$$

i.e. $I = \dfrac{200 \sin \omega t - 100}{R}$

Charging current, $I = 1\,A$ → Given

Assume $\omega t = \theta$

$$\therefore \quad 1 = \frac{200 \sin \theta - 100}{R}$$

$$1\, d\theta = \frac{1}{R} (200 \sin \theta - 100)\, d\theta$$

→ Multiplying both sides with $d\theta$

Now, Integrating for 1 complete cycle

$$\int_0^{2\pi} 1\, d\theta = \frac{1}{R} \int_{\pi/6}^{5\pi/6} (200 \sin \theta - 100)\, d\theta$$

$$\therefore [\theta]_0^{2\pi} = \frac{1}{R} \left[-200 \cos \theta - 100\, \theta\right]_{\pi/6}^{5\pi/6}$$

$$2\pi - 0 = \frac{1}{R} \left[\left(-200 \cos 5\pi/6 - 100 \times 5\pi/6\right) - \left(-200 \cos \pi/6 - 100 \times \pi/6\right)\right]$$

$$2\pi R = \left[-200 \times (-\sqrt{3}/2) - 500\, \pi/6 + 200 \times (\sqrt{3}/2) + 100\, \pi/6\right]$$

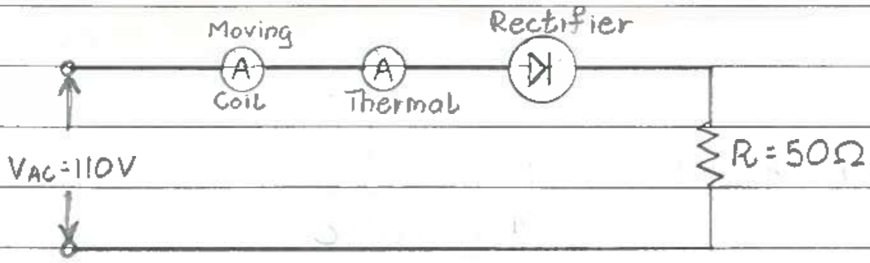
$$\therefore 2\pi R = \left[200 \times \sqrt{3} - 400\, \pi/6\right]$$

$$\therefore R = \frac{100 \times \sqrt{3}}{\pi} - \frac{200}{6}$$

$$\therefore \underline{\underline{R = 21.8\, \Omega}}$$

Q. A moving coil ammeter, a thermal ammeter & a rectifier are in series with a resistor across a 110V sinusoidal AC supply. The circuit has a resistance of 50Ω to current in one direction & due to rectifier, an infinite resistance to current in the reverse direction.
Calculate: i) Readings on the Ammeters
ii) Form & Peak factors of the current wave.

Sol^{n}.



- Moving coil meter reads DC (Avg. value) & has a linear scale
- Thermal ammeter reads AC (RMS value) & has a non-linear scale.

$$V_{RMS} = \frac{V_{MAX}}{\sqrt{2}}$$

$$\therefore V_{MAX.} = V_{RMS} \times \sqrt{2}$$
$$= 110 \times \sqrt{2}$$
$$= 155.56 \text{ V}$$

Now, $I_{MAX} = \frac{V_{MAX}}{R}$

$$\therefore I_{MAX} = \frac{155.56}{50}$$
$$= 3.11 \text{ A}$$

i) Reading on Moving coil Ammeter,

$$I_{DC} = \frac{2 \times I_{Max.}}{\pi} = \frac{2 \times 3.11}{\pi}$$

But, this DC meter does not conduct during the -ve half cycle of the i/p signal

$$\therefore I_{DC} = \frac{1}{2} \times \frac{2 \times 3.11}{\pi}$$

$$\therefore \underline{I_{DC} = 0.99\,A} \longrightarrow a)$$

Reading on Thermal Ammeter,

$$I_{RMS} = \frac{I_{MAX}}{2} = \frac{3.11}{2}$$

$$\therefore \underline{I_{RMS} = 1.56\ A} \longrightarrow b)$$

ii)

Form factor, $K_f = \frac{\text{RMS value}}{\text{Avg. value}}$

$$K_f = \frac{1.56}{0.99}$$

$$\underline{K_f = 1.57} \longrightarrow c)$$

Peak factor, $K_p = \frac{\text{Max. value}}{\text{RMS value}}$

$$\therefore K_p = \frac{3.11}{1.56}$$

$$\therefore \underline{K_p = 1.99} \longrightarrow d)$$

TRANSFORMERS

I)

- A Transformer is a static (or stationary) piece of apparatus by means of which electric power in one circuit is transformed to electric power of the same frequency in another circuit.
- It can raise or lower the voltage in a circuit but with a corresponding decrease or increase in current.
- The physical basis of a transformer is mutual induction between two circuits linked by a common magnetic flux.

II)

- EMF (Electro Motive Force) is for current
- MMF (Magneto Motive Force)

V/I = Resistance $\qquad$ mmf/ϕ = Reluctance (S)

- Flux density, $B = \phi/A$ $\quad Wb/m^2$ or Tesla

III) PERMEABILITY

- It is the property of the magnetic material to allow magnetic flux to pass through.

Absolute Permeability = Relative Permeability × Permeability of Free Space

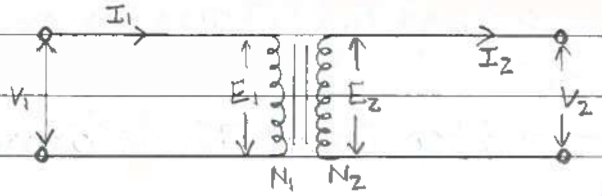
$$\mu = \mu_R \times \mu_0$$

* For Air, Vacuum, $\mu_0 = 4\pi \times 10^{-7}$ H/m

$$\mu = B/H \quad H/m$$

$$H = mmf/l = N \times I / l$$

4) **EMF EQUATION OF A TRANSFORMER**



$N_1 \rightarrow$ No. of turns in Primary
$N_2 \rightarrow$ No. of turns in Secondary
$\phi_m \rightarrow$ Max. flux in the core in webers

$$\phi_m = B \times A \quad Wb$$

$f \rightarrow$ Frequency input of AC in Hz.

$$E_{1RMS} = 4.44 f N_1 \phi_m = 4.44 f N_1 B_m A$$

$$E_{2RMS} = 4.44 f N_2 \phi_m = 4.44 f N_2 B_m A$$

* For an ideal transformer on no load

$V_1 = E_1$ & $V_2 = E_2$
where, $V_2 \rightarrow$ Terminal voltage

4) VOLTAGE TRANSFORMATION RATIO

$$\frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = K$$

$K \longrightarrow$ constant known as Voltage Transformation Ratio

i) If $N_2 > N_1$, $K > 1$ $\longrightarrow$ Step Up Transformer

ii) If $N_1 > N_2$, $K < 1$ $\longrightarrow$ Step Down Transformer

Again for an ideal transformer,

Input VA = Output VA

$$I_1 V_1 = I_2 V_2$$

$$\therefore \frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{1}{K}$$

Also,

$$\frac{I_1}{I_2} = \frac{V_2}{V_1} = \frac{N_2}{N_1} \qquad \therefore \frac{I_1}{I_2} = \frac{N_2}{N_1}$$

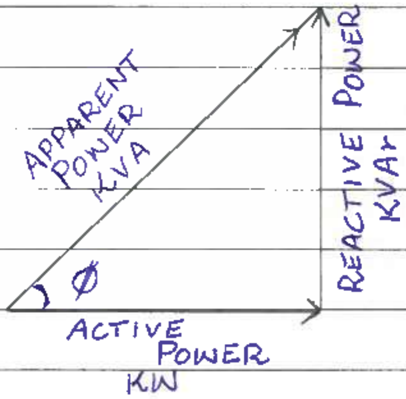
&

$$\frac{E_2}{N_2} = \frac{E_1}{N_1}$$

i.e. emf / turn of secondary = emf / turn of primary

V) RATING OF TRANSFORMER

* Rated in MVA / KVA or VA



From Power Triangle,

$KW = KVA \cdot \cos\phi$

But,

$\cos\phi$ is unknown

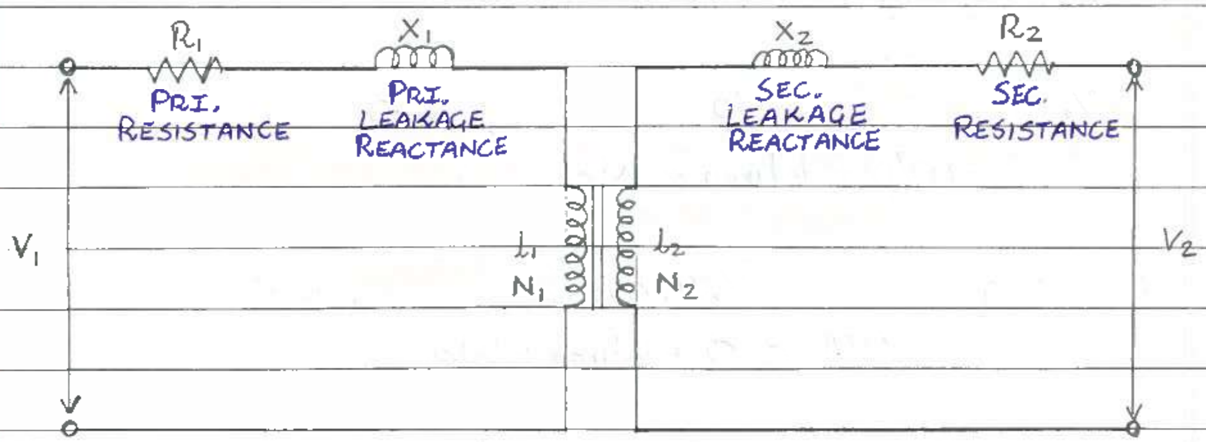
∴ Transformers are rated in KVA & not KW

VI) LOSSES IN A TRANSFORMER

1) Core loss or Iron Loss
   a) Flux loss (Leakage loss + Hysteresis loss)
   b) Eddy loss

2) Copper loss
   a) Primary
   b) Secondary

VII) EQUIVALENT CIRCUIT OF A TRANSFORMER



A) PRIMARY

$$R_{01} = R_1 + R_2' [N_1/N_2]^2$$

$$X_{01} = X_1 + X_2' [N_1/N_2]^2$$

$$\therefore \quad Z_{01} = \sqrt{R_{01}^2 + X_{01}^2}$$

B) SECONDARY

$$R_{02} = R_2 + R_1' [N_2/N_1]^2$$

$$X_{02} = X_2 + X_1' [N_2/N_1]^2$$

$$\therefore \quad Z_{02} = \sqrt{R_{02}^2 + X_{02}^2}$$

IX) EFFICIENCY OF A TRANSFORMER

$$\% \eta = \frac{o/p}{i/p} \times 100$$

$$= \frac{o/p}{o/p + \text{losses}} \times 100$$

$$\% \eta = \frac{o/p}{o/p + W_{iron} + W_{cu}} \times 100$$

$$\text{F.L. } \% \eta = \frac{KVA \cos\phi}{KVA \cos\phi + W_{iron} + W_{cu}} \times 100$$

$$\text{H.L. } \% \eta = \frac{(1/2) KVA \cos\phi}{(1/2) KVA \cos\phi + W_{iron} + W_{cu}/4} \times 100$$

'x' load % $\eta = \dfrac{x \times KVA \cos\phi}{x \times KVA \cos\phi + W_{iron} + x^2 \times W_{cu}} \times 100$

where,

$x \rightarrow$ Loading factor (RANGE : 0 to 1, i.e. 0 to 100%)

All day % $\eta = \dfrac{\text{o/p in kWh in 24 hrs.}}{\text{i/p in kWh}} \times 100$

~~X~~) REGULATION

% Regulation $= \dfrac{V_{NL} - V_{FL}}{V_{FL}} \times 100$

Q. In a 25 KVA, 3300/233 V single phase transformer, the iron & full load Cu. losses are 350 & 400 W respectively. Calculate the efficiency at half-load, 0.8 power factor.

GIVEN:

Step Down Transformer 3300/233 V

KVA = 25 KVA $\quad W_{iron_{FL}} = 350$ W $\quad W_{Cu_{FL}} = 400$ W

Sol^{n}:

Loading factor, $x = 0.5$

We know,

Iron loss remains the same. $\therefore W_{iron_{HL}} = 350$ W

$= 0.35$ KW

Half load Cu loss, $W_{Cu_{HL}} = x^2 \times W_{Cu_{FL}}$

$$= \frac{1}{4} \times 400$$

$= 100$ W or 0.1 KW

$$HL \% \eta = \frac{x \times KVA \cos\phi}{x \times KVA \cos\phi + W_{iron_{HL}} + W_{Cu_{HL}}} \times 100$$

$$\therefore \% \eta_{HL} = \frac{0.5 \times 25 \times 0.8}{0.5 \times 25 \times 0.8 + 0.35 + 0.1} \times 100$$

$$\therefore \underline{\% \eta_{HL} = 95.69 \%}$$

Q. The following results were obtained on a 50 KVA Transformer

Open circuit test : Primary voltage = 3300 V
Secondary voltage = 415 V
Primary power = 430 W

Short circuit test: Primary voltage = 124 V
Primary current = 15·3 A
Primary Power = 525 W
Secondary current = full load value.

Calculate:

i) The efficiencies at full load & half load for 0·7 p.f.

ii) The voltage regulations for p.f. 0·7 a) Lagging
b) Leading

iii) The secondary terminal voltages corresponding to ii) a) + b)

Sol^n.

For an open ckt. test, primary power = Iron loss

$\therefore W_{iron} = 430\ W = 0.43\ KW$

For a short ckt. test, primary power = Cu. loss

$\therefore W_{cu} = 525\ W = 0.525\ KW$

* For a short ckt. test, the supply voltage is very low, so iron losses are very small as the flux produced is very small, thus, primary power is equal to Cu. loss

$$\%\ \eta_{FL} = \frac{KVA \cos\phi}{KVA \cos\phi + W_{iron} + W_{cu}} \times 100$$

$$\therefore \%\ \eta_{FL} = \frac{50 \times 0.7}{50 \times 0.7 + 0.43 + 0.525} \times 100$$

$\therefore \%\eta_{FL} = 97.34\%$ $\longrightarrow$ i) full load

Now,

$$\%\eta_{HL} = \frac{x \times KVA \cos\phi}{x \times KVA \cos\phi + W_{iron} + x^2 \times W_{Cu}} \times 100$$

where,

$x \longrightarrow$ loading factor & is 1/2 or 0.5

$$\therefore \%\eta_{HL} = \frac{0.5 \times 50 \times 0.7}{0.5 \times 50 \times 0.7 + 0.43 + 0.5^2 \times 0.525} \times 100$$

$\therefore \%\eta_{HL} = 96.89\%$ $\longrightarrow$ ii) half load

Now,

From short ckt. test,

$$Z_{01} = V_1 / I_1$$
$$= 124/15.3$$
$$\therefore Z_{01} = 8.1\,\Omega$$

$$R_{01} = \frac{\text{Pri. Power}}{I_1^2}$$ $\because$ Pri. Power = Cu loss = I^2R

$$\therefore R_{01} = 525/15.3^2$$
$$= 2.24\,\Omega$$

Thus,

$$X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$$
$$= \sqrt{8.1^2 - 2.24^2}$$

$$\therefore X_{01} = 7.78\,\Omega$$

Also,

$\cos\phi = 0.7$

$\therefore \phi = \cos^{-1}(0.7)$

$\therefore \phi = 45.57^\circ$

Thus,

$\sin\phi = \sin(45.57)$

$= 0.714$

For lagging p.f. 0.7

$$\% \text{ Voltage Regulation} = \frac{I_1(R_{01} \times \cos\phi + X_{01}\sin\phi)}{V_2} \times 100$$

$$\therefore \% VR = \frac{15.3(2.24 \times 0.7 + 7.78 \times 0.714)}{3300} \times 100$$

$\therefore$ % V.R. = 3.3 % down $\longrightarrow$ ii) a) lagging

For leading p.f. 0.7

$$\% VR = \frac{I_1(R_{01}\cos\phi - X_{01}\sin\phi)}{V} \times 100$$

$$\therefore \% VR = \frac{15.3(2.24 \times 0.7 - 7.78 \times 0.714)}{3300} \times 100$$

$\therefore$ % VR = - 1.8 % up $\longrightarrow$ ii) b) leading

-ve sign indicates leading p.f.

Now,

From open ckt. test, the secondary terminal voltages are

a) For lagging p.f.,

$$\text{Terminal voltage} = 415 - (415 \times 0.033)$$
$$= 401.3 \text{ V}$$

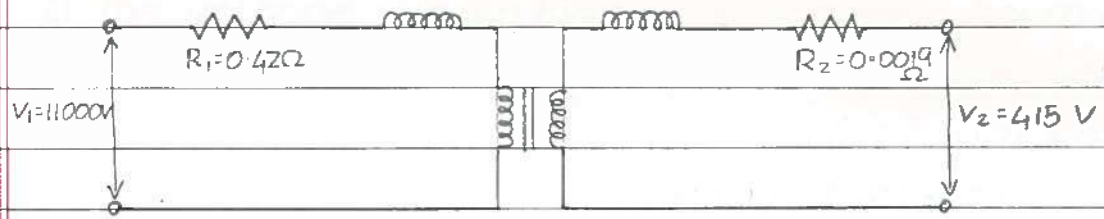
b) For leading p.f.,

$$\text{Terminal voltage} = 415 - (415 \times -0.018)$$
$$= 422.47 \text{ V}$$

Q. The primary & secondary windings of a 500 KVA transformer have resistances of 0·42Ω & 0·0019Ω resp. The primary & secondary voltages are 11000V + 415V resp. & the core loss is 2·9 KW, assuming the p.f. of the load to be 0·8. Calculate the efficiencies on

i) full load

ii) half load



GIVEN:

$KVA = 500$ | $W_{iron} = 2\cdot9$ KW | p.f., $\cos\phi = 0\cdot8$

$R_1 = 0\cdot42\Omega$ | $V_1 = 11000V$

$R_2 = 0\cdot0019\Omega$ | $V_2 = 415 V$

Solⁿ.

For determining, the total resistance of the primary, we know,

$$R_{01} = R_1 + R_2'(N_1/N_2)^2$$

But,

$$\frac{I_1}{I_2} = \frac{V_2}{V_1} = \frac{N_2}{N_1}$$ → From Voltage Transformatⁿ ratio

$$\therefore R_{01} = R_1 + R_2 \cdot (V_1/V_2)^2$$
$$= 0\cdot42 + 0\cdot0019 \times (11000/415)^2$$

$$\therefore R_{01} = 1\cdot75\ \Omega$$

Also, for an ideal transformer

$$i/p\ VA = o/p\ VA$$

$$\therefore I_1 V_1 = 500\ KVA$$

$$\therefore I_1 = \frac{500 \times 10^3}{11000}$$

$$\therefore I_1 = 45.45\ A$$

Now,

$$W_{Cu_{FL}} = I_1^2 R_{01}$$

$$= 45.45^2 \times 1.75$$

$$\therefore W_{Cu_{FL}} = 3614.98\ W$$

$$= 3.615\ KW$$

$$\% \eta_{FL} = \frac{KVA \times \cos\phi}{KVA \cos\phi + W_{iron} + W_{Cu_{FL}}} \times 100$$

$$= \frac{500 \times 0.8}{500 \times 0.8 + 2.9 + 3.615} \times 100$$

$$\therefore \% \eta_{FL} = 98.39\ \% \longrightarrow i)$$

And

$$\% \eta_{HL} = \frac{x \times KVA \cos\phi}{x \times KVA \cos\phi + W_{iron} + x^2 W_{Cu_{FL}}} \times 100$$

where

$x = 1/2$ or $0.5 \longrightarrow$ Loading factor

$W_{iron} \longrightarrow$ remains same

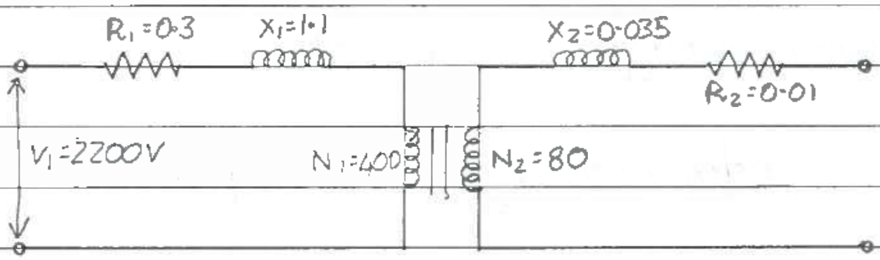
$$\therefore \% \eta_{HL} = \frac{0.5 \times 500 \times 0.8}{0.5 \times 500 \times 0.8 + 2.9 + 0.5^2 \times 3.615} \times 100$$

$$\therefore \% \eta_{HL} = 98.13\ \% \longrightarrow ii)$$

Q. A 100 KVA transformer has 400 turns on the primary & 80 turns on the secondary. The primary & secondary resistances are 0.3 Ω & 0.01 Ω respectively & the corresponding leakage reactances are 1.1 Ω & 0.035 Ω resp. The supply voltage is 2200 V. Calculate:

i) The equivalent impedance referred to the primary ckt.

ii) The voltage regulation & secondary terminal voltage for full load having a p.f. of 0.8 a) Lagging b) Leading



Solⁿ.

For Impedance referred to the primary, we need to determine the resistance & reactance referred to the primary. Thus,

$$R_{01} = R_1 + R_2 \cdot (N_1/N_2)^2 = 0.3 + 0.01\,(400/80)^2$$

$$X_{01} = X_1 + X_2 \cdot (N_1/N_2)^2 = 1.1 + 0.035\,(400/80)^2$$

$\therefore$ $R_{01} = 0.55\,\Omega$ $\quad$ $X_{01} = 1.975\,\Omega$

Now,

$$Z_1 = \sqrt{R_{01}^2 + X_{01}^2} = \sqrt{0.55^2 + 1.975^2}$$

$\therefore$ $\underline{Z_1 = 2.05\,\Omega}$ $\longrightarrow$ Equivalent Impedance referred to Primary

Now, from Voltage Transformation Ratio we know that,

$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

$$\therefore E_2 = \frac{N_2}{N_1} \times E_1$$

$$= \frac{80}{400} \times 2200$$

$\therefore$ Secondary voltage, $E_2 = 440$ V

This is the secondary voltage for an open circuit.

But,

$$KVA = I_f \times V$$

where,

$I_f \longrightarrow$ Full Load current

$$\therefore \quad 100 \times 10^3 = I_f \times 2200$$

$$\therefore I_f = 45.45 \text{ A}$$

Also,

$$\cos\phi = 0.8$$

$$\therefore \phi = \cos^{-1}(0.8)$$

$$= 36.87°$$

Now,

$$\sin\phi = \sin(36.87)$$

$$= 0.60$$

ii)
a) For lagging p.f. of 0.8

$$\%\text{ Voltage Regulation} = \frac{I_f (R_{01} \cos\phi + X_{01} \sin\phi)}{V} \times 100$$

$$\therefore \%\ V.R. = \frac{45.45 (0.55 \times 0.8 + 1.975 \times 0.6)}{2200} \times 100$$

$$\therefore \%\ V.R. = 3.36\ \%\ \text{down}$$

And

$$\text{Sec. Terminal voltage} = 440 - 440 \times 0.0336$$
$$= 425.22\ V$$

b) For leading p.f. of 0.8

$$\%\text{ Voltage Regulation} = \frac{I_f (R_{01} \times \cos\phi - X_{01} \sin\phi)}{V} \times 100$$

$$\therefore \%\ V.R. = \frac{45.45 (0.55 \times 0.8 - 1.975 \times 0.6)}{2200} \times 100$$

$$\therefore \%\ V.R. = -1.54\ \%\ \text{up}$$

-ve sign indicates leading p.f.

And

$$\text{Sec. Terminal Voltage} = 440 - 440 \times -0.0154$$
$$= 446.78\ V$$

Q. A 550 KVA, 50 Hz, single phase transformer has 1875 & 75 turns in the primary & secondary windings resp. If the secondary voltage is 220V. Calculate
i) Primary voltage
ii) Primary & Secondary currents
iii) Max. value of flux.

GIVEN:
KVA = 500 KVA
$f = 50$ Hz
$N_1 = 1875$ $\quad N_2 = 75$
$V_2 = 220$ V

Sol^n.

From Voltage Transformation Ratio, we know that

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$\therefore V_1 = V_2 \times \frac{N_1}{N_2}$$

$$= 220 \times \frac{1875}{75}$$

$\therefore$ Primary Voltage, $V_1 = 5500$ V $\longrightarrow$ i)

Assuming an ideal Transformer,

$$i/p\ VA = o/p\ VA \longrightarrow a)$$

$$\therefore I_1 \times V_1 = 550 \times 10^3$$

$$\therefore I_1 = \frac{550 \times 10^3}{5500}$$

$\therefore$ Primary Current, $I_1 = 100\ A$ $\longrightarrow$ ii) a)

Also, a) can now be written as

$$I_1 \times V_1 = I_2 \times V_2$$

$$\therefore I_2 = I_1 \times \frac{V_1}{V_2}$$

$$= 100 \times \frac{5500}{220}$$

$\therefore$ Secondary Current, $I_2 = 2500\ A$ $\longrightarrow$ ii) b)

Now,

$$E_1 = 4{\cdot}44\, f\, N_1\, \phi_m$$

$$\therefore \phi_m = \frac{E_1}{4{\cdot}44 \times f \times N_1}$$

$$= \frac{5500}{4{\cdot}44 \times 50 \times 1875}$$

$\therefore$ Max. flux in the core, $\phi_m = 0{\cdot}0132\ Wb$ $\longrightarrow$ iii)

Q. The no-load current of a transformer is 5 A & p.f. 0.25, when supplied at 235 V, 50 Hz. The turns on the primary winding are 200. Calculate:
i) Max. value of flux in the core
ii) The core loss

GIVEN:

$I_{NL} = 5\ A$ $V_1 = 235\ V$ $N_1 = 200$

p.f., $\cos\phi = 0.25$ $f = 50\ Hz$

Sol^{n}.

At no load condition,

$$V_1 = E_1 = 4.44\, f N_1 \phi_m$$

$$\therefore \phi_m = \frac{V_1}{4.44 \times f \times N_1}$$

$$= \frac{235}{4.44 \times 50 \times 200}$$

$\therefore$ Max. flux in core, $\phi_m = 5.29\ mWb$

Also, at no load, primary power is equal to Core ~~Cu~~ loss

$$\therefore W_{\cancel{Cu}\ Iron} = V_1 I_0 \cos\phi$$

$$= 235 \times 5 \times 0.25$$

$$\therefore W_{Iron\ \cancel{Cu}} = 293.75\ W$$

Q. A 3 phase transformer has 560 turns on the primary & 42 turns on the secondary. The primary windings are connected to a line voltage of 6·6 kV. Calculate the secondary line voltage when the transformer is connected as i) Star - Delta
ii) Delta - Star

Sol^{n}:

From Voltage Transformation Ratio,

$$K = \frac{N_1}{N_2} = \frac{V_1}{V_2}$$

$$\therefore \quad K = 560/42$$

$$\therefore K = 13 \cdot 33$$

1) For a Star-Delta Transformer : Primary → Star
Secondary → Delta

Pri. voltage/phase, $V_{P_1} = V_L/\sqrt{3} = 6600/\sqrt{3} = 3810 \cdot 5\ V$

Sec. voltage/phase, $V_{P_2} = V_L/K \times \sqrt{3} = 6600/13 \cdot 33 \times \sqrt{3} = 285 \cdot 86\ V$

For a Delta connection, Line voltage = Phase voltage

$\therefore$ Sec. Line voltage $= V_{P_2}$

$= \underline{285 \cdot 86\ V}$

1) For a Delta-Star Transformer : Primary → Delta
Secondary → Star

Pri. voltage/phase, V_{P_1} = Line voltage

$= 6600\ V$

Sec. voltage/phase, $V_{P_2} = V_L/K = 6600/13.33 = 495.12\ V$

For a Star connection,

$\therefore$ Sec. Line Voltage, $V_L = \sqrt{3} \times V_{P_2}$

$= \underline{857.57\ V}$

Q. A single phase transformer, 50 Hz has a core with a square cross section, each side being 270 mm. The transformation ratio is 3500 V/440 V & flux density in the core is not to exceed 1.4 T. Find the nos. of turns of windings required if frequency is 50 Hz.

Sol$^{n.}$

We know,

$$\phi_m = B \times A \quad Wb$$

where,

$B \rightarrow$ Flux Density (T) or (Wb/m^2)

$A \rightarrow$ Area (m^2)

$$\therefore \phi_m = 1.4 \times 0.27^2$$

$\because$ core has a square cross section

$$\therefore \phi_m = 0.1021 \ Wb$$

Also,

$$V_1 = 4.44 f N_1 \phi_m$$

$$\therefore N_1 = \frac{V_1}{4.44 f \phi_m}$$

$$= \frac{3500}{4.44 \times 50 \times 0.1021}$$

$\therefore N_1 = 154$ turns of Primary winding

From Voltage Transformation Ratio, we know

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$\therefore N_2 = N_1 \times {}^{V_2}/_{V_1} = 154 \times {}^{440}/_{3500}$$

$\therefore N_2 = 19$ turns of Secondary winding

Q. A 20 KW transformer has an ordinary efficiency of 95% on full load for 6 hrs/day. Find the all day efficiency if the full load losses are equally divided between copper & iron losses.

Sol^n.

As the $\% \eta = 95\%$, the losses are expected to be 5%

i.e. losses = 5% of Power

$= 0.05 \times 20$

Total loss @ F.L. $= 1$ kW

$\because$ it is given that the FL losses are equally divided between copper (W_{cu}) & iron (W_{iron}) losses

$W_{cu} = \text{Loss @ FL}/2 = W_{iron}$

$\therefore$ $W_{cu} = 0.5$ KW $\qquad W_{iron} = 0.5$ KW

- The Cu. loss takes place only when the transformer is fully or partially loaded whereas Fe loss occurs all the time the transformer is energized.
- As it is unknown whether transformer is loaded or unloaded for remaining 18 hrs., we assume it to be unloaded but energized for that 18 hrs. period.

Now,

Total o/p for 6 hrs $= 6 \times 20$

$= 120$ KW-hr.

Iron loss for 24 hrs. $= 0.5 \times 24$

$= 12$ KW-hr

Cu. loss for 6 hrs. $= 0.5 \times 6$

$= 3$ KW-hr

$\therefore$ Total i/p = Total o/p + losses

$= 120 + 12 + 3$

$= 135$ KW-hr

Now,

$$\text{All day } \% \eta = \frac{\text{Total o/p}}{\text{Total i/p}} \times 100$$

$$\therefore \% \eta_{\text{All Day}} = \frac{120}{135} \times 100$$

$$\therefore \% \eta_{\text{All Day}} = 88.89 \%$$

Q. A transformer has a 1000 V supply connected to its primary. The resistance & reactance of the primary are 0.15 Ω & 0.8 Ω resp. Find the primary induced EMF (back emf) if the primary current is 60 A & p.f. of 0.8.

Sol^n

$$\cos\phi = 0.8$$

$$\therefore \phi = \cos^{-1}(0.8) = 36.87^\circ$$

Thus,

$$\sin\phi = \sin 36.87 = 0.6$$

Now,

E_1 = Back emf + Drop across R_1 & X_1

Drop across $R_1 = I_0 R_1 \cos\phi = 60 \times 0.15 \times 0.8 = 7.2\ V$

Drop across $X_1 = I_0 X_1 \sin\phi = 60 \times 0.8 \times 0.6 = 28.8\ V$

$\therefore$ BACK EMF $= E_1 - [\text{Drop across } R_1 + \text{Drop across } X_1]$
$= 1000 - (7.2 + 28.8)$

$\therefore$ BACK EMF $= 964\ V$

ALTERNATORS

I) FREQUENCY

Frequency of generated emf, $f = \frac{P \times N}{120}$ Hz

$P \rightarrow$ No. of Rotor Poles
$N \rightarrow$ Rotational speed of the Rotor in rpm

Basically,

Frequency = No. of cycles per revolution × No. of revolutions per second

i.e. $f = \frac{P}{2} \times \frac{N}{60}$

$\therefore \quad f = PN/120$

- N is the synchronous speed as it is the speed at which the alternator must run in order to generate an emf of the required frequency.

II) EQUATION OF INDUCED EMF

Let, $Z \rightarrow$ No. of Conductors or coil sides in series
& $Z = 2T$ where T is the no. of coils or turns
$P \rightarrow$ No. of Rotor poles
$f \rightarrow$ Frequency of the induced EMF in Hz
$\phi \rightarrow$ Flux per pole in Wb
$N \rightarrow$ Rotation speed of the Rotor in rpm

Avg. EMF induced per conductor $= \frac{d\phi}{dt} = \frac{\phi P}{60/N}$

But, $N = 120f/P$

$\therefore$ Avg. EMF per conductor $= \frac{\phi P}{60} \times \frac{120 f}{P}$

$= 2 f \phi$ Volts

If there are Z conductors in series per phase, then

Avg. EMF per phase $= 2 f \phi \times Z$

$= 4 f \phi T$ Volts $\quad \because Z = 2T$

RMS value of EMF per phase $= 1.11 \times 2 f \phi Z$

$= 2.22 f \phi Z$ OR

$= 4.44 f \phi T$ Volts

* If the alternator is star connected, then the line voltage is $\sqrt{3}$ times the phase voltage

III) VOLTAGE REGULATION (V.R.)

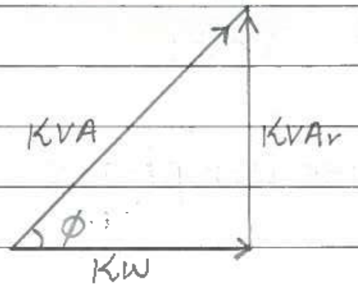
- V.R. of an alternator is defined as the rise in voltage when full-load is removed divided by the rated terminal voltage.

% Regulation 'up' $= \frac{E - V}{V} \times 100$

IV) Breadth Factor or Distribution Factor (K_D)

$$K_D = \frac{\text{EMF in distributed winding}}{\text{EMF in concentrated winding}}$$

V) Power Triangle



$$KW = KVA \times \cos\phi$$

$$KVA_r = KVA \times \sin\phi$$

$$KVA = \sqrt{KW^2 + KVA_r^2}$$

VI) A) Synchronous Impedance

$$Z_s = \frac{\text{Open ckt. voltage}}{\text{Short ckt. current}}$$

B) Synchronous Reactance

$$X_s = \underbrace{X_A}_{\text{Armature Reactance}} + \underbrace{X_L}_{\text{Leakage Reactance}}$$

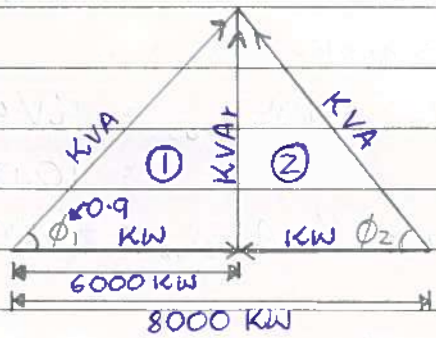
VII) Induced EMF

No load EMF, $E_0 = \sqrt{(V_P\cos\phi + IR_a)^2 + (V_P\sin\phi + IX_{as})^2}$

Internal EMF, $E_A = \sqrt{(V_P\cos\phi + IR_A)^2 + (V_P\sin\phi + IX_L)^2}$

Q. A total load of 8000 KW at 0.8 p.f. is supplied by two alternators in parallel. One alternator supplies 6000 KW at 0.9 p.f.. Find the KVA rating of the other alternator & the p.f.

Soln.



For Alternator 1,

$$KVA_1 = KW_1 / \cos\phi_1$$
$$= 6000 / 0.9$$

$\therefore KVA_1 = 6667$ KVA (Actually 6666.6667 KVA, but rounding upto 6667 KVA)

$$KVAr_1 = KVA_1 \times \sin\phi_1$$

$\because \cos\phi_1 = 0.9$
$\phi_1 = \cos^{-1}(0.9)$
i.e. $\phi_1 = 25.84°$

$\therefore KVAr_1 = 6667 \times \sin 25.84$
$\therefore KVAr_1 = 2905.87$ KVAr
i.e. $KVAr_1 = -2906$ KVAr

For Alternator 2,

$$KW_2 = KW_{Total} - KW_1$$
$$= 8000 - 6000$$
$$= 2000 \text{ KW}$$

$$KVA_{Total} = KW_{Total} / \cos\phi_{Total}$$
$$= 8000 / 0.8$$

$\therefore KVA_{Total} = 10,000$ KVA

$$\cos\phi_{Total} = 0.8$$

$$\therefore \phi_{Total} = \cos^{-1}(0.8)$$

$$= 36.87^\circ$$

$$\therefore \sin\phi_{Total} = \sin 36.87$$

$$= 0.6$$

Now,

$$KVAr_{Total} = KVA_{Total} \times \sin\phi_{Total}$$

$$= 10{,}000 \times 0.6$$

i.e. $KVAr_{Total} = -6000 \text{ KVAr}$

Thus, $KVAr_2 = KVAr_{Total} - KVAr_1$

$$= -6000 - (-290\cancel{7}6)$$

$$= -3094 \text{ KVAr}$$

Now,

$$KVA_2 = \sqrt{KW_2^2 + KVAr_2^2}$$

$$= \sqrt{2000^2 + (-3094)^2}$$

$$\therefore \underline{\underline{KVA_2 = 3684.133 \text{ KVA}}} \rightarrow \underline{\text{KVA rating}}$$

Also,

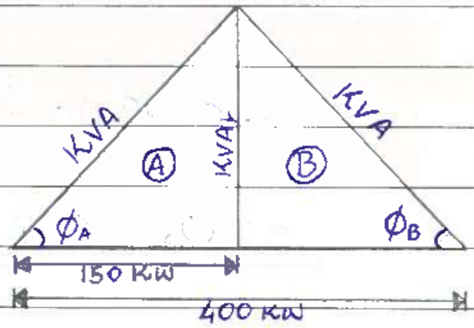
$$\cos\phi_2 = KW_2 / KVA_2$$

$$\therefore \cos\phi_2 = 2000 / 3684.133$$

$$\underline{\underline{\cos\phi_2 = 0.543}} \rightarrow \underline{\text{p.f.}}$$

Q. A 440 V load of 400 KW at 0.8 (lagging) p.f. is jointly supplied by 2 alternators A & B. The KW load on A is 150 KW & the KVAr load on B is 150 KVAr (lagging). Determine the KW load on B, the KVAr load on A, the p.f. of operation on each machine & the current loading on each machine.

Sol^n.



$KW_{Total} = 400$ KW

p.f., $\cos\phi_{Total} = 0.8$

$\therefore \phi_{Total} = \cos^{-1}(0.8)$

$= 36.87°$

Now,

$\sin\phi_{Total} = \sin 36.87$

$= 0.6$

$KVA_{Total} = KW_{Total} / \cos\phi_{Total}$ $\quad$ $KVAr_{Total} = KVA_{Total} \times \sin\phi_{Total}$

$KVA_{Total} = 400/0.8$ $\quad$ $KVAr_{Total} = 500 \times 0.6$

$= 500$ KVA $\quad$ $= -300$ KVAr

For Alternator 'A', $KW_A = 150$ KW

$\therefore KW_B = KW_{Total} - KW_A$

$= 400 - 150$

$\underline{KW_B = 250 \text{ KW}}$

For Alternator 'B', $KVAr_B = -150$ KVAr

$\therefore KVAr_A = KVAr_{Total} - KVAr_B$

$= -300 - (-150)$

$\underline{KVAr_A = -150 \text{ KVAr}}$

Now,

$$KVA_A = \sqrt{KW_A^2 + KVAr_A^2}$$
$$= \sqrt{150^2 + (-150)^2}$$

$\therefore$ $KVA_A = 212.13$ KVA

Hence,

p.f. for 'A' $\rightarrow$ $\cos\phi_A = KW_A / KVA_A$

$$\cos\phi_A = 150/212.13$$

$\therefore$ $\cos\phi_A = 0.707$ lagging $\rightarrow$ p.f.

Similarly,

$$KVA_B = \sqrt{KW_B^2 + KVAr_B^2}$$
$$= \sqrt{250^2 + (-150)^2}$$

$\therefore$ $KVA_B = 291.55$ KVA

Hence,

p.f. for 'B' $\rightarrow$ $\cos\phi_B = KW_B / KVA_B$
$= 250/291.55$

$\therefore$ $\cos\phi_B = 0.857$ lagging $\rightarrow$ p.f.

Now,

$$KW = \sqrt{3} \times VI \times \cos\phi$$

$\therefore$ $KVA = \sqrt{3}\, VI$ $\quad\because KVA = KW/\cos\phi$

$\therefore$ $I_A = KVA_A / \sqrt{3} \times V$
$= 212.13 \times 10^3 / \sqrt{3} \times 440$

$I_B = KVA_B / \sqrt{3} \times V$
$= 291.55 \times 10^3 / \sqrt{3} \times 440$

$I_A = 278.35$ A

$I_B = 382.56$ A

Q. Find the synchronous impedance + reactance of an alternator in which a given field current produces an armature current of 200 A on short ckt. & an EMF of 50 V on open ckt. The armature resistance is 0·1Ω. To what induced voltage must the alternator be excited if it is to deliver a load of 100A at a p.f. of 0·8 lagging with a terminal voltage of 200 V.

Sol^n.

$$Z_s = \frac{\text{Open ckt. voltage}}{\text{Short ckt. current}}$$

$$\therefore \quad Z_s = \frac{50}{200}$$

i.e. Synchronous Impedance, $Z_s = 0·25\ \Omega$

Now,

$$X_s = \sqrt{Z_s^2 - R_A^2}$$
$$= \sqrt{0·25^2 - 0·1^2}$$

$\therefore$ Synchronous Reactance, $X_s = 0·229\ \Omega$

$\cos\phi = 0·8$

$\therefore \phi = \cos^{-1}(0·8)$

$= 36·87°$

$\sin\phi = \sin 36·87$

$= 0·6$

Now,

$$E_o = \sqrt{(V \times \cos\phi + I R_A)^2 + (V \sin\phi + I X_s)^2}$$
$$= \sqrt{(200 \times 0·8 + 100 \times 0·1)^2 + (200 \times 0·6 + 100 \times 0·229)^2}$$

$$\therefore E_o = \sqrt{170^2 + 142·9^2}$$

$\therefore$ Induced Voltage, $E = 222·1\ V$

Q. In a 50 KVA, star connected, 440 V, 3 phase, 50 Hz, alternator, the effective armature resistance is 0.25 Ω/phase. The synchronous reactance is 3.2 Ω/phase & leakage reactance is 0.5 Ω/phase. Determine at rated load & unity p.f. the following:

i) Internal EMF, E_A

ii) No load EMF, E_0

iii) % Regulation on Full Load

iv) Value of Synchronous reactance which replaces armature reaction.

Sol^{n}.

Alternator is star connected,

$\therefore \quad V_L = \sqrt{3} \times V_P \qquad\qquad I_L = I_P$

i.e. $V_P = V_L/\sqrt{3}$

$\therefore \quad V_P = 440/\sqrt{3}$

$= 254.03\ V$

Internal EMF, E_A, is the vector sum of the pure voltage IR_A & IX_L

$P = VI \times \sqrt{3} \times \cos\phi$

i.e. $KW = VI \times \sqrt{3} \times \cos\phi \qquad$ But $KVA = KW/\cos\phi$

$\therefore \quad KVA = \sqrt{3} \times VI$

where, I is the full load current at unity p.f.

$$\therefore \quad I = \frac{KVA}{\sqrt{3} \times V_L} = \frac{50 \times 10^3}{\sqrt{3} \times 440} = 65.61\ A$$

Now,

$$E_A = \sqrt{(V_P \cos\phi + IR_A)^2 + (V_P \sin\phi + IX_L)^2}$$

$$\therefore E_A = \sqrt{(254.03 \times 1 + 65.61 \times 0.25)^2 + (254.03 \times 0 + 65.61 \times 0.5)^2}$$

$\because \cos\phi = 1$

$\phi = 0$

$\therefore \sin 0 = 0$

$$E_A = \sqrt{270.43^2 + 32.81^2}$$

$\therefore$ Internal EMF, $E_A = 272.41$ V $\longrightarrow$ i)

No-Load EMF, E_0 is the vector sum of the pure voltage drop IR_A & IX_s.

Thus,

$$E_0 = \sqrt{(V_P \cos\phi + IR_A)^2 + (V_P \sin\phi + IX_s)^2}$$

$$\therefore E_0 = \sqrt{(254.03 \times 1 + 65.61 \times 0.25)^2 + (254.03 \times 0 + 65.61 \times 3.2)^2}$$

$$= \sqrt{270.43^2 + 209.95^2}$$

$\therefore$ No Load EMF, $E_0 = 342.36$ V $\longrightarrow$ ii)

Now,

Line Voltage, $V_{L_1} = \sqrt{3} \times V_P = \sqrt{3} \times E_0$

$\therefore V_{L_1} = \sqrt{3} \times 342.36$

$= 592.98$ V

Now,

$$\% \text{ V.R. @ F.L.} = \frac{E_0 - V_{L_s}}{V_{L_s}} \times 100$$

$$\therefore \quad \% \text{ V.R.}_{FL} = \frac{342.36 - 254.03}{254.03} \times 100$$

% Voltage Regulation @ F.L. = 34.77 % → iii)

Now,

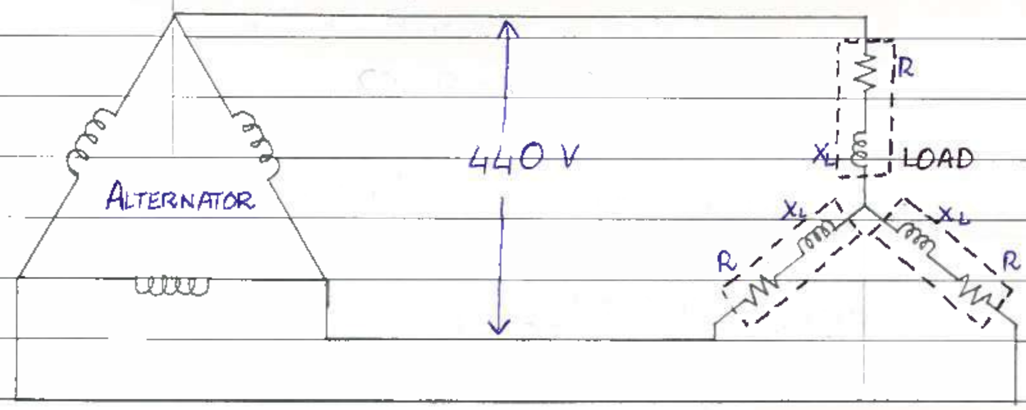
$$X_A = X_S - X_L$$
$$= 3.2 - 0.5$$
$$= 2.7\ \Omega \text{ per phase}$$

Synchronous Reactance which replaces armature reaction is $2.7\ \Omega$ / phase

→ iv)

Q. A 12 pole, 3-phase Delta connected alternator runs at 600 rpm & supplies a balanced star connected load. Each phase of the load is a coil of resistance of 35Ω & inductive reactance of 25Ω. The line terminal voltage is 440 V. Determine:

i) Frequency of supply
ii) Current in each coil
iii) Current in each phase of the alternator
iv) Total power supplied to the load.



GIVEN:

Delta Connected Alternator; Star Connected Load

$P = 12$ $\quad R = 35\Omega$ $\quad V_L = 440\text{ V}$

$N = 600\text{ rpm}$ $\quad X_L = 25\Omega$

Sol^n.

For the Delta Connected Alternator,

$$\text{Frequency, } f = \frac{P \times N}{120} = \frac{12 \times 600}{120}$$

$$\therefore \underline{f = 60\text{ Hz}} \longrightarrow \text{i)}$$

For Star Connected Load, as it is balanced

$V_{L\lambda} = \sqrt{3}\ V_{P\lambda}$ $\qquad$ $I_{L\lambda} = I_{P\lambda}$

$\therefore V_{P\lambda} = V_{L\lambda}/\sqrt{3}$

$= 440/\sqrt{3}$

$V_{P\lambda} = 254.03\ V$

Impedance per coil, $Z = \sqrt{R^2 + X_L^2}$

$= \sqrt{35^2 + 25^2}$

$\therefore Z = 43.01\ \Omega$

Current in each coil, $I = V_P/Z$

$\therefore I = 254.03/43.01$

$\therefore$ $I_{coil} = 5.91$ A per coil $\longrightarrow$ ii)

For the Delta Connected Alternator,

$I_L = \sqrt{3}\ I_P$ $\qquad$ $V_L = V_P$

$\therefore I_P = I_L/\sqrt{3}$

From fig. we know $I_L = I_{coil}$

$\therefore I_P = 5.91/\sqrt{3}$

$\therefore$ Current in each phase of the alternator, $I_P = 3.41$ A

Now we know,

$$\cos\phi = R/Z$$

i.e. $\cos\phi = 35/43.01$

$= 0.81$ lagging

Total Power supplied to the load,

$$P = \sqrt{3}\, V_{L\lambda} \times I_{coil} \times \cos\phi$$

$\therefore P = \sqrt{3} \times 440 \times 5.91 \times 0.81$

$= 3648.26$ W OR 3.65 KW

$\therefore$ Total Power supplied to the Load, $P = 3.65$ KW

Q. 3 conductors fitted side by side in the stator of a salient pole alternator, each generates a max. voltage of 200 V (sinusoidal). The angle subtended at the center of the stator between adjacent conductors is 20 electrical degrees. If the 3 conductors are connected in series, then find:

i) the rms value of effective voltage

ii) the breadth factor

Using the theory that is the basis of this problem, give one reason why 3-phase current has been introduced.

Sol^n.

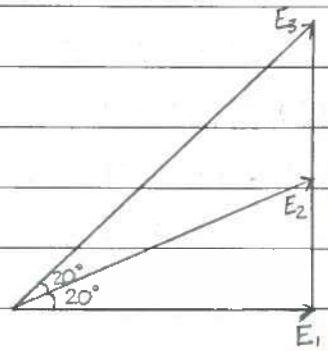
Since, the coils are distributed, the individual EMF's have a phase difference of 20° with each other. Their vector sum is given by,

$E_H = E_1 + E_1 \cos 20 + E_1 \cos 40 \qquad E_V = E_1 \sin 20 + E_1 \sin 40$

$\therefore E_H = 2.71 E_1 \qquad E_V = 0.98 E_1$

Now,

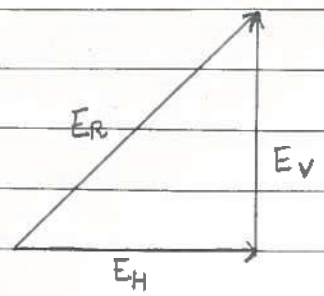
$$E_R = \sqrt{E_H^2 + E_V^2}$$
$$= \sqrt{(2.71 E_1)^2 + (0.98 E_1)^2}$$



$\therefore E_R = 2.882 E_1$

Theus, Max. Voltage is

$$E_R = 2.882 \times 200$$
$$= 576.4 \text{ V}$$



$$V_{RMS} = \frac{V_{MAX}}{\sqrt{2}}$$
$$= 576.4/\sqrt{2}$$

$\therefore$ RMS value of effective voltage, $V_{RMS} = 407.58$ V $\rightarrow$ i)

Now,

$$\text{Breadth Factor} = \frac{\text{EMF in Distributed winding}}{\text{EMF in Concentrated winding}}$$

$$\therefore K_D = \frac{576.4}{3 \times 200}$$

$\therefore$ Breadth Factor, $K_D = 0.96$ $\longrightarrow$ ii)

- In case of a single phase system, where all the conductors are connected in series, all conductors are spread over all slots per pole in the stator. In that case, the breadth factor will be reduced, thus, reducing the effective voltage,

$$E_{\text{per phase}} = 4.44\, K_P \times K_D \times f \phi T \quad \text{Volts}.$$

- In case of a 3 phase system, the spreading of conductors is in small number of slots i.e. slots/pole/phase, improves the breadth factor.
- This is one reason for introduction of 3 phase system.

Q. A 3000 KVA, 6-pole alternator runs at 1000 rpm in parallel with other machines on 3300 V bus bars. The synchronous reactance is 25%. Calculate the synchronizing power for one mechanical degree of displacement & the corresponding synchronizing torque.

Sol^{n}.

- Here the alternator is working in parallel with many machines, hence, it may be considered to be connected to infinite bus bars.

Now,

$$1 \text{ Pole-pitch} = 180° \text{ electrical} = \frac{360°}{P} \text{ mechanical} = \frac{360°}{6}$$

$$\therefore \ 1 \text{ Pole-pitch} = 60° \text{ mechanical}$$

$$\therefore 1 \text{ Mechanical degree}, \alpha = 180°/\text{Pole-Pitch} = 180/60$$

$$\therefore \ \alpha = 3° \text{ electrical degree}$$

OR $\alpha = 3 \times \pi/180 = \pi/60$ electrical radian

$$I_L = I = KVA/\sqrt{3} \times V_L$$

$$\therefore \ I = \frac{3000 \times 10^3}{\sqrt{3} \times 3300}$$

$$I = 524.86 \text{ A}$$

Now,

$$V_P = V_L/\sqrt{3} = 3300/\sqrt{3}$$

$$\therefore \ V_P = 1905.26 V$$

$I \times X_s = 25\%$ of V_P → Given

$$\therefore \ X_s = \frac{0.25 \times 1905.26}{524.86}$$

$\therefore X_s = 0.907\,\Omega$

Synchronizing Power, $P_{syn} = \dfrac{3 \times \alpha \times E^2}{X_s}$

where $E = V_P$

$\therefore \quad P_{syn} = 3 \times \dfrac{\pi}{60} \times \dfrac{1905.26^2}{0.907}$

$\therefore P_{syn} = 628667.62\ W$

OR

$P_{syn} = 628.67\ KW$

Also,

$P_{syn} = \dfrac{2\pi N_s \times T_{syn}}{60}$

where T_{syn} = Synchronous Torque

$\therefore T_{syn} = \dfrac{628.67 \times 10^3 \times 60}{2\pi \times 1000}$

$\therefore T_{syn} = 6003.36\ N\text{-}m$

Synchronizing Power = 628.67 KW

Synchronizing Torque = 6003.36 N-m

Q. If an alternator supplies the following loads :
a) 200 KW Lighting load @ unity p.f.
b) 400 KW Induction motor load @ 0.8 lagging p.f.
c) 200 KW Synchronous motor load.
Find the p.f. of the synchronous motor load to give an overall p.f. of 0.97 (lagging).

Sol^{n}

For the Lighting Load,

$KW_L = 200\ KW$ & $\cos\phi = 1$

$\therefore \phi = 0°$

$KVA_L = KW_L / \cos\phi$

$= 200\ KVA$

$KVAr_L = KVA_L \times \sin\phi$

$= 0$ $\because \sin 0 = 0$

For the Induction Motor Load,

$KW_I = 400\ KW$

$\cos\phi = 0.8$ lagging

$\therefore \phi = \cos^{-1}(0.8) = 36.82$

$\sin 36.82 = 0.6$

$KVA_I = KW_I / \cos\phi$

$= 400 / 0.8$

$= 500\ KVA$

$KVAr_I = KVA_I \sin\phi$

$= 500 \times 0.6$

$= 300\ KVAr$

For the Synchronous Motor Load,

$$KW_s = 200\ KW$$

Now, Total Active power supplied by the Alternator,

$$KW_{TOT} = KW_L + KW_I + KW_s$$
$$= 200 + 400 + 200$$
$$= 800\ KW$$

$$KVA_{TOT} = KW_{TOT} / \cos\phi_{TOT}$$
$$= 800 / 0.97$$
$$= 824.74\ KVA$$

$$\cos\phi_{TOT} = 0.97$$
$$\therefore \phi_{TOT} = \cos^{-1}(0.97)$$
$$= 14.07^\circ$$

$$\sin\phi_{TOT} = \sin 14.97$$
$$= 0.258$$

$$\therefore KVAr_{TOT} = KVA_{TOT} \times \sin\phi_{TOT}$$
$$= 824.74 \times 0.258$$
$$= 212.78\ KVAr$$

Thus, the lagging KVAr is reduced by $300 - 212.78$
$= 87.22\ KVAr$

This is the reactive power of the Synchronous Motor Load.

i.e. $KVAr_s = 87.22\ KVAr$

Now,

$$KVA_s = \sqrt{KW_s^2 + KVAr_s^2}$$
$$= \sqrt{200^2 + 87.22^2}$$
$$\therefore KVA_s = 218.19\ KVA$$

$$\cos \phi_s = \frac{KW_s}{KVA_s}$$

$$\therefore \cos \phi_s = \frac{200}{218.19}$$

$$= 0.92$$

i.e. p.f. of Synchronous Motor Load is 0.92

Q. A 2000 KVA, 3 phase, 8 pole alternator runs at 750 rpm in parallel with other machines on 6000 V bus bars. Find the synchronizing power on full load 0.8 p.f. lagging per mechanical degree of displacement & the corresponding synchronizing torque. The synchronous reactance is 6 Ω per phase.

Sol^n.

* Here the Alternator is working in Parallel with many other machines, hence, it may be considered to be connected to infinite bus-bars.

Now,

1 Pole-pitch $= 360°/P$ (mechanical)

$= 360°/8$

$= 45°$ mechanical

1 Mechanical degree, $\alpha = 180/\text{Pole Pitch}$

$= 180/45$

$\therefore$ $\alpha = 4°$ electrical degree OR $\alpha = 4 \times \pi/180$

$= \pi/45$ electrical radians

$V_P = V_L/\sqrt{3}$

$= 6000/\sqrt{3}$

$\therefore$ $V_P = 3464.1$ V

$$P_{syn} = \frac{3 \times \alpha \times E^2}{X_s}$$

where $E = V_P$

$$\therefore P_{syn} = \frac{3 \times \pi/45 \times 3464.1^2}{6}$$

$\therefore$ $P_{syn} = 418878.63$ W

i.e. $P_{syn} = 418 \cdot 88$ KW

Also,

$$P_{syn} = \frac{2\pi N_s \times T_{syn}}{60}$$

$$\therefore T_{syn} = \frac{418 \cdot 88 \times 10^3 \times 60}{2\pi \times 750}$$

$$= 5333 \cdot 34 \text{ N-m}$$

Synchronizing Power, $P_{syn} = 418 \cdot 88$ KW

Synchronizing Torque, $T_{syn} = 5333 \cdot 34$ N-m

Induction Motors

I) Synchronous Speed (N_s)

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

where,

$f \rightarrow$ Frequency of the stator AC supply

$P \rightarrow$ No. of Motor Poles

II) Slip (S)

$$\% \text{ Slip}, S = \frac{N_s - N}{N_s} \times 100$$

where,

$(N_s - N) \rightarrow$ Slip Speed

$N \rightarrow$ Actual Speed of the Rotor

III) Rotor to Stator Relationships

A) Frequency

Rotor Frequency = Supply Frequency x ~~F~~ Slip

$$f_R = f \times S \quad \text{Hz}$$

Since,

$$f_R = \frac{\text{Slip Speed} \times P}{120} = \frac{(N_s - N) \times P}{120}$$

i.e. $$f_R = \frac{S N_s P}{120}$$

$$\therefore \quad f_R = f \times S$$

B) ~~R~~ EMF

Rotor induced EMF at any speed = Standstill EMF × Slip

i.e. $E_2' = E_2 \times S$ Volts

C) REACTANCE

Rotor Reactance at any speed = Standstill Reactance × Slip

i.e. $X_2' = X_2 \times S$ Ω

* Rotor frequency (f_R), EMF (E_2') & Reactance (X_2') are due to relative speed between stator & rotor i.e. slip speed.

→ Rotor Impedance, $Z_2' = \sqrt{R_2^2 + (SX_2)^2}$ Ω

→ Rotor Current, $I_2' = \dfrac{E_2'}{Z_2'} = \dfrac{E_2 S}{\sqrt{R_2^2 + (SX_2)^2}}$ Amps

→ Rotor Phase Angle, $\cos \phi_2' = \dfrac{R_2}{Z_2'} = \dfrac{R_2}{\sqrt{R_2^2 + (SX_2)^2}}$

4) Relationship Between Rotor Loss, Input Power + Output

Stator O/p = Rotor i/p

OR

= Stator i/p − Stator losses

OR

= Rotor o/p + Rotor Cu. loss

i.e. Rotor Cu. Loss = Rotor i/p − Rotor o/p

= Stator o/p − Rotor o/p

$$= \frac{2\pi T (N_1 - N_2)}{60}$$

where,

$T \rightarrow$ Torque (N-m)

$N \rightarrow$ Speed (rpm)

Now,

$$\frac{\text{Rotor Cu. loss}}{\text{Rotor input}} = \frac{2\pi T (N_1 - N_2)}{60} \times \frac{60}{2\pi N_1 T}$$

$$= \frac{N_1 - N_2}{N_1}$$

$$= S$$

$$\therefore \text{Slip, } S = \frac{\text{Rotor Cu. loss}}{\text{Rotor i/p}} \longrightarrow a)$$

From above, we see that,

$$S = \frac{N_1 - N_2}{N_1}$$

$$\therefore SN_1 = N_1 - N_2$$

$$\therefore N_2 = N_1(1 - S)$$

Now,

$$\frac{\text{Rotor Cu. loss}}{\text{Rotor o/p}} = \frac{N_1 - N_2}{N_2}$$

$$= \frac{N_1 - N_1(1-S)}{N_1(1-S)}$$

$$= \frac{S}{1-S}$$

$$\therefore \frac{\text{Rotor Cu. loss}}{\text{Rotor o/p}} = \frac{S}{1-S} \longrightarrow b)$$

From Equations a) & b), we get

Rotor i/p : Rotor Cu. loss : Rotor o/p = $1 : S : (1-S)$ $\longrightarrow$ c)

4) TORQUE

$$T \propto \frac{SR_2}{R_2^2 + (SX_2)^2}$$

* For max. Torque, $R_2 = SX_2$

VI) Power Stages in an Induction Motor

Motor i/p to Stator	Stator Losses Cu + Iron	Rotor i/p	Rotor Cu. Loss	Mech. Power Developed in Rotor or Gross Torque	Mechanical Losses Windage + Friction	Rotor o/p
P_1		P_2		P_M or T_G		P_{OUT}

Now, Eqⁿ: c) from IV) can also be written as,

$$P_2 : I^2R : P_{\cancel{out}\,M} = 1 : S : (1-S)$$

where,

$$P_{OUT} = P_M - \text{Mech. losses}$$

Q. A 3 phase Induction motor is wound for 4 poles & is supplied by a 50 Hz system. Calculate:
i) Synchronous Speed
ii) Speed of the Rotor when the slip is 4%.
iii) Rotor frequency when the speed of the rotor is 600 rpm

Sol^{n}

We know,

$$N_s = \frac{120 \times f}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

Synchronous Speed, $N_s = 1500$ rpm $\longrightarrow$ i)

We also know,

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

$$\therefore 0.04 = \frac{1500 - N}{1500}$$

$$\therefore N = 1440 \text{ rpm}$$

Speed of the Rotor, $N = 1440$ rpm $\longrightarrow$ ii)

Now,

$$f_R = f \times S$$

But, $S = N_s - N / N_s$ where $N = 600$

$$\therefore \% S = 1500 - 600/1500 \times 100$$

$$\therefore \% S = 60\%$$

$$\therefore f_R = 50 \times 0.6 = 30 \text{ Hz}$$

Rotor frequency, $f_R = 30$ Hz $\longrightarrow$ iii) classmate

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Q. The star connected rotor of an induction motor has a standstill reactance of 4.5Ω per phase & a resistance of 0.5Ω per phase. The motor has an induced EMF of 50 V between the slip rings at standstill on open ckt. when connected to its normal supply voltage. Find the current in each phase & the p.f. at start when the slip rings are short circuited.

Solⁿ:

- The rotor is star connected & voltage across the slip rings is given as 50 V.

i.e. $E_L = 50\ V$

- As we know for a star connection,

$$E_L = \sqrt{3} \times E_P$$

$$\therefore E_P = E_L/\sqrt{3}$$

$$= 50/\sqrt{3}$$

$$\therefore E_P = 28.87\ V$$

i.e. $E_2 = E_P = 28.87\ V$

$$Z_2 = \sqrt{R_2^2 + X_2^2}$$

$$= \sqrt{0.5^2 + 4.5^2}$$

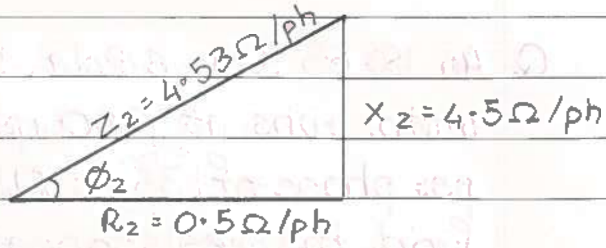
$$\therefore Z_2 = 4.53\ \Omega$$

$$I_2 = E_2/Z_2 = 28.87/4.53$$

$$\therefore I_2 = 6.37\ A$$

Current in each phase, $I_2 = 6.37\ A$

$$\cos \phi_2 = R_2/Z_2$$
$$= 0.5/4.53$$
$$= 0.1104$$



p.f. at start, $\cos \phi_2 = 0.1104$

Q. An 18·65 KW, 6 Pole, 50 Hz, 3 phase slip ring Induction motor runs at 960 rpm on full load with a rotor current per phase of 35 A. Allowing 1 KW for mechanical losses, find the resistance per phase of the 3-phase rotor winding.

Sol^{n}.

$$P_M = P_{OUT} + \text{Mech. losses}$$
$$= 18.65 + 1$$
$$= 19.65 \text{ KW}$$

Now,

$$N_s = \frac{120 \times f}{P} = \frac{120 \times 50}{6}$$
$$\therefore N_s = 1000 \text{ rpm}$$

Thus,

$$\%\text{ Slip, } S = \frac{N_s - N}{N_s} \times 100$$
$$\therefore \%\, S = \frac{1000 - 960}{1000} \times 100$$
$$\%\, S = 4\,\%$$

We know,

$$P_2 : \text{Rotor Cu Loss} : P_{OUTM} = 1 : S : (1-S)$$
$$\therefore \frac{\text{Rotor Cu. loss}}{P_{OUTM}} = \frac{S}{1-S}$$

i.e. $\text{Rotor Cu. loss} = \frac{0.04}{1-0.04} \times P_{OUTM}$

$$= 0.042 \times \overset{19}{\cancel{18}}.65$$

$\therefore$ Rotor Cu. Loss = 0.8253 KW

Also,

Rotor Cu. Loss = $I_2^2 R_2$

$\therefore$ $0.8253 \times 10^3 = 35^2 \times R_2$

$\therefore$ $R_2 = 0.674\ \Omega$ ~~per phase~~

Now,

Resistance per phase = $R_2/3$ As it is a 3 ϕ rotor

$= 0.674/3$

$= 0.225\ \Omega$

Resistance per phase is $0.225\ \Omega$

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Q. A 50 Hz, 4 pole Induction motor has an EMF in the rotor. The frequency of the rotor current is 2 Hz. Determine the following:
i) Synchronous Speed
ii) Slip
iii) Speed of the Motor.

Sol$^{n.}$

We know,

$$N_s = \frac{120 \times f}{P} = \frac{120 \times 50}{4}$$

$$\therefore \quad N_s = 1500 \text{ rpm}$$

Synchronous Speed, $N_s = 1500$ rpm → i)

Now,

$$f_R = f \times S$$

$$\therefore \; 2 = 50 \times S$$

$$\therefore \; S = 0.04$$

Slip is 0.04 or 4 % → ii)

Since,

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

$$0.04 = \frac{1500 - N}{1500}$$

$$\therefore \quad N = 1440 \text{ rpm}$$

Speed of the Motor, N = 1440 rpm → iii)

Q. A 4 Pole, 3 phase Induction Motor operates from a supply whose frequency is 50 Hz. Calculate:
i) Speed at which the magnetic field of the stator is rotating,
ii) Speed of the rotor when the slip is 0.04
iii) Frequency of the rotor current when the slip is 0.03.

Sol^n.

We know,

$$N_s = \frac{120 f}{P} = \frac{120 \times 50}{4}$$

$$\therefore \quad N_s = 1500 \text{ rpm}$$

Synchronous Speed, $N_s \longrightarrow 1500$ rpm

Also,

$$\text{Slip} = \frac{N_s - N}{N_s}$$

$$0.04 = \frac{1500 - N}{1500}$$

$$\therefore \quad N = 1440 \text{ rpm}$$

Speed of the Rotor, $N = 1440$ rpm

And,

$$f_R = f \times S$$

$$= 50 \times 0.03$$

$$= 1.5 \text{ Hz}$$

Frequency of Rotor Current, $f_R = 1.5$ Hz

BASIC ELECTRICAL ENGINEERING

1) OHM'S LAW

- The ratio of the potential difference (V) between any 2 points of a conductor to the current (I) flowing between them is constant, provided the temperature of the conductor does not change.

$$V/I = \text{constant}$$

where, $R = \text{constant}$ $R \rightarrow$ Resistance of the conductor between the 2 points considered.

- In other words, as long as 'R' is kept constant, current (I) is directly proportional to the P.D. across the conductor.

* $V = IR$ (Volts)   * $R = V/I$ (Ohms)
* $I = V/R$ (Amperes)

- Also, Power $(P) = V \times I = V^2/R = I^2R$

2) TEMPERATURE CO-EFFICIENT OF RESISTANCE

- It is defined as the fractional change in resistance per degree change in temperature from 0° Celsius.

$$R_T = R_0 \, \cancel{(1+\alpha t)} \, [1+\alpha(T-T_0)] \quad \Omega$$

where, $R_T \rightarrow$ Resistance @ temp. T

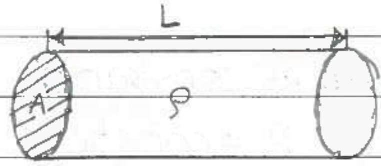
$R_0 \rightarrow$ Resistance @ 0° Celsius

$\alpha \rightarrow$ Temp. co-efficient of resistance for a particular conductor material.

III) Specific Resistance or Resistivity:

- At a fixed temp., the amount of resistance offered in the flow of current by a conductor having unit length & unit cross section is called its specific resistance or resistivity of the conductor.
- It is an intrinsic property.

$$R = \rho \times \frac{L}{A}$$



$$\therefore \rho = \frac{R \times A}{L}$$

where,

$\rho \rightarrow$ Specific Resistance / Resistivity (Ω-m)
$R \rightarrow$ Resistance of the conductor (Ω)
$L \rightarrow$ Length of the Conductor (m)
$A \rightarrow$ Cross-sectional Area of the conductor (m^2)

'R' is an extrinsic property depending on L, A & material

$R \propto L$ & $R \propto 1/A$

$$\rho = 1/\sigma$$

where,

$\sigma \rightarrow$ Conductivity of the material (S/m $\rightarrow$ Siemens/metre)

- If ρ is $\uparrow$, σ is $\downarrow$ & vice-versa

IV) Insulation Resistance

- The AC resistance between 2 electrical conductors/ systems of conductors separated by an Insulating material.

$$I.R. = \rho \times \frac{D}{L} \quad \Omega$$

where, $D \rightarrow$ Thickness

V) Resistances Connected in

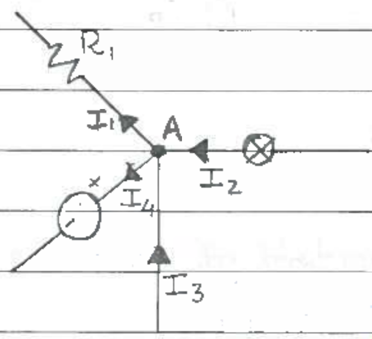
Series	Parallel
$R_s = R_1 + R_2\ R_3$	$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

VI) Kirchoff's Current Law / First Law / Point or Junction or Nodal Rule (KCL)

- The current entering any junction is equal to current leaving that junction.

OR

- The algebraic sum of currents in a network of conductors meeting at a point/node/junction is zero.



At pt. A,

$$(-I_1) + I_2 + I_3 + (-I_4) = 0$$

entering currents $\longrightarrow$ +ve
exiting currents $\longrightarrow$ -ve

VI) KIRCHOFF'S VOLTAGE LAW / SECOND LAW / LOOP OR MESH RULE (KVL)

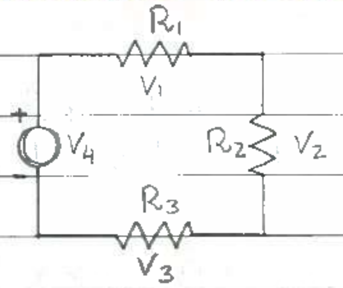
- The sum of all voltages around a loop is equal to zero.

OR

- The sum of the EMF's in any closed loop is equivalent to the sum of potential drops in that loop.

OR

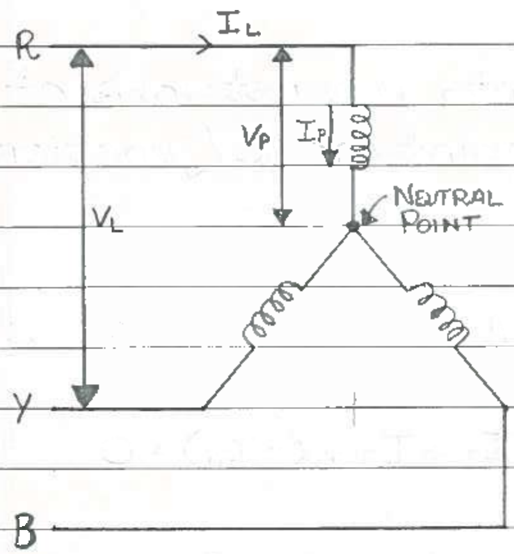
- The algebraic sum of the products of the resistances of the conductors & the currents in each of them in a closed loop is equal to the total emf ~~in the~~ available in the loop concerned.



$$V_1 + V_2 + V_3 + V_4 = 0$$

VII) CONNECTIONS

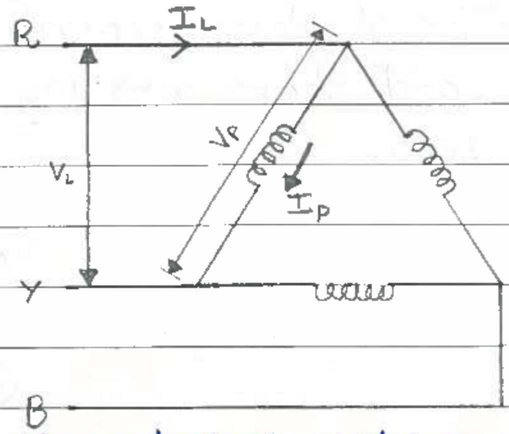
STAR



$I_L = I_{PH}$

$V_L = \sqrt{3}\, V_{PH}$

DELTA



* No neutral pt. as it is a closed loop

$V_L = V_{PH}$

$I_L = \sqrt{3}\, I_{PH}$

OTHER SALIENT TOPICS TO COVER

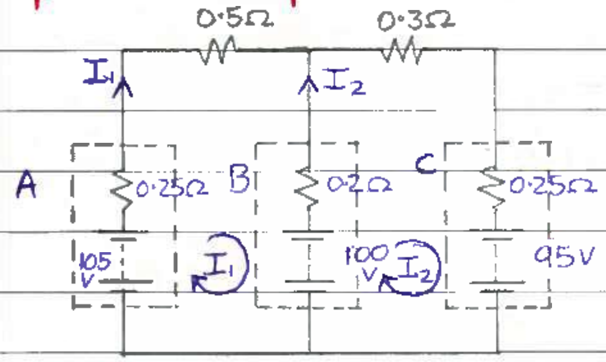
1. Wheatstone Bridge
2. Mesh Currents
3. Loop Currents
4. Superposition Theorem
5. Thevenin's Theorem
6. Norton's Theorem

NETWORK ANALYSIS

Q. 3 Batteries A, B & C have their -ve terminals connected together. Between the +ve terminals of A + B, there is a resistor of $0.5\,\Omega$ & between B + C there is a resistor of $0.3\,\Omega$. Specification of the 3 Batterie is

i) Bat. A 105 V, internal resistance $0.25\,\Omega$
ii) Bat. B 100V, " " $0.2\,\Omega$
iii) Bat. C 95V, " " $0.25\,\Omega$

Determine the current values in the 2 resistors & the power dissipated in them.



Sol$^{n.}$

Applying KVL in loops ① & ②, we get

For loop ①,

$$105 = 0.25I_1 + 0.5I_1 + 0.2(I_1 - I_2) + 100$$

$$0.25I_1 + 0.5I_1 + 0.2I_1 - 0.2I_2 = 105 - 100$$

$$0.95I_1 - 0.2I_2 = 5 \longrightarrow (a)$$

For loop ②,

$$100 = 0.2(I_2 - I_1) + 0.3I_2 + 0.25I_2 + 95$$

$$0.2I_2 - 0.2I_1 + 0.3I_2 + 0.25I_2 = 100 - 95$$

$$-0.2I_1 + 0.75I_2 = 5 \longrightarrow (b)$$

$$0.7125I_1 - 0.15I_2 = 3.75 \rightarrow (c)$$ X ing Eq^n (a) with 0.75

&

$$-0.04I_1 + 0.15I_2 = 1 \longrightarrow (d)$$ X ing Eq^n (b) with 0.2

Now, Adding Eq$^{ns.}$ © & ⓓ

$$0.7125 I_1 - 0.15 I_2 = 3.75$$
$$+ \quad \underline{(-0.04 I_1) + 0.15 I_2 = 1}$$

$$\therefore \quad 0.6725 I_1 = 4.75$$
$$\therefore \quad I_1 = 7.06 \text{ A}$$

Substituting value of I_1 in Eq^{n} ⓑ

$$-0.2 \times 7.06 + 0.75 I_2 = 5$$
$$\therefore \quad 0.75 I_2 = 5 + 1.412$$
$$\therefore \quad I_2 = 8.55 \text{ A}$$

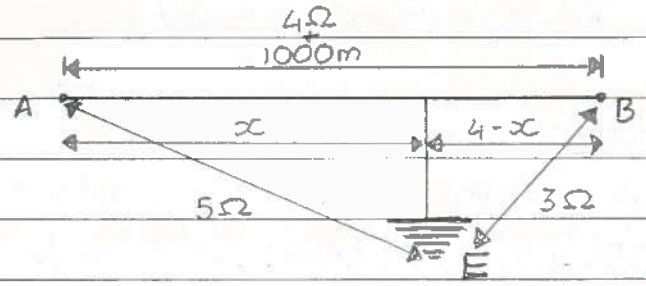
Power Dissipated in Resistors $= I^2 R$

$\therefore \quad P_{0.5} = I_1^2 R \qquad\qquad P_{0.3} = I_2^2 R$

$P_{0.5} = 7.06^2 \times 0.5 \qquad\qquad P_{0.3} = 8.55^2 \times 0.3$

$\therefore \quad P_{0.5} = 24.92$ W $\qquad\qquad P_{0.3} = 21.93$ W

Q. A section of a supply cable AB, 1 km long has a fault to earth such that when end B is disconnected the resistance measurement from end A to earth is 5Ω. When end A is disconnected, the resistance reading from end B to earth is 3 Ω. The length of cable AB has a resistance of 4Ω when intact. Find the distance of the fault from end A.



Solⁿ.

l(section of supply cable AB) = 1 km = 1000 m

- For the given length, the resistance of the cable is 4Ω.
- Let the fault be at pt. E & 'x' be the resistance of the cable till pt. E.

Now,
When B is disconnected, resistance between pts. A+E is 5Ω

$$\therefore x + R = 5\Omega \longrightarrow (1)$$

When A is disconnected, resistance between pts. B & E is 3Ω.

$$\therefore (4-x) + R = 3 \longrightarrow (2)$$

But, from eqⁿ (1), it can be said $R = (5-x)\ \Omega$
Substituting this value of R in eqⁿ (2)

$$\therefore 4 - x + (5-x) = 3$$

$\therefore \quad 9 - 2x = 3$

$\therefore \quad 2x = 6$

$x = 3\ \Omega$

Resistance of the cable from pt. A till fault point is 3Ω.

Now,

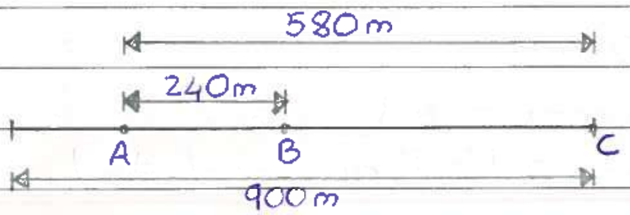
$$\frac{1000}{4} = \frac{l_A}{3}$$

where l is distance from pt. A to fault pt.

$\therefore \quad l_A = 750\ m$

Distance of the fault from end A, $l_A = 750\ m$

Q. A ring main 900m long is supplied at pt. A at a P.D. of 220 V. At pt. B, 240 m from A, a load of 45 A is drawn from the main & at pt. C 580m from A measured in the same direction, a load of 78 A is taken from the main. If the resistance of the main is 0·25 Ω per km, calculate the current which will flow in each direction, round the main from the supply pt. A & the P.D. across the main, at the load where it is the lowest.



Sol^n.

$l(AB) = 240m$ Given

$l(BC) = l(AC) - l(AB)$

$= 580 - 240$

$= 340$ m

$l(AC) = 580m$ Given

Total load drawn from the main = Load drawn at pt. B + Load drawn at pt. C

$= 45 + 78$

$= 123$ A

Let,

current in section AC be 'I' Amps,

then, current in section AB, $I_{AB} = (123 - I)$ Amp

&, current in section BC, $I_{BC} = 123 - I - 45$

$= (78 - I)$ Amp

Resistance of the main = $0.25\,\Omega$ per km

$\therefore$ Resistance of the main for 0.9 km is x

$$\frac{x}{0.9} = \frac{0.25}{1}$$

$$\therefore x = 0.225\,\Omega$$

Resistance of ~~section AC~~ the main till pt. A, $R_{Main-A} = \frac{0.25}{1000} \times (900-580)$

$$= 0.08\,\Omega$$

Similarly,

Resistance of section AB, $R_{AB} = \frac{0.25}{1000} \times 240$

$$= 0.06\,\Omega$$

Resistance of section BC, $R_{BC} = \frac{0.25}{1000} \times 340$

$$= 0.085\,\Omega$$

As per KVL, the voltage drop at either section of the main feeding the load at C are equal.

$$\therefore I \times 0.08 = (123 - I)\,0.06 + (78 - I) \times 0.085$$

$$0.08I = 7.38 - 0.06I + 6.63 - 0.085I$$

$$0.08I = 14.01 - 0.145I$$

$$\therefore 0.225I = 14.01$$

$$\therefore I = 62.26 \text{ Amps}$$

i.e. Current in section AC, $I = 62.26$ A

$\therefore$ Current in section AB, $I_{AB} = 123 - 62.26$

$$= 60.74 \text{ A}$$

& Current in section BC, $I_{BC} = 78 - 62{\cdot}26$
$= 15{\cdot}74$ A

P.D. at pt. C $= V - IR_{Main-A}$
$= 220 - 62{\cdot}26 \times 0{\cdot}08$
$= 215{\cdot}02$ V

P.D. at pt. B $= V - I_{AB} \times R_{AB}$
$= 220 - 60{\cdot}74 \times 0{\cdot}06$
$= 216{\cdot}36$ V

P.D. at pt. C is the lowest $\rightarrow$ 215·02 V

Q. An electrical supply systems has the following tariff in force at a time ; Rs. 100 per KVA of maximum demand plus 5p per unit. A consumer installs a phase advancing plant inorder to improve the p.f. of his installation. The cost of the plant is Rs. 40 per KVA. Assuming the interest & depreciation as 10%, Calculate the most economical p.f. to which it should be improved.

Solⁿ.

Optimal p.f. for most economical operation is given by,

$$\cos\phi = \sqrt{1 - \left(\frac{B \times P}{A}\right)^2}$$

where, A → Cost/KVA @ max. demand

B → Cost/KVA of p.f. advancing equipment

P → Interest & Depriciation

From the given data, we get

$A = \text{Rs.} (100 + 0.05) / \text{KVA}$

$= \text{Rs. } 100.05 / \text{KVA}$

$B = \text{Rs. } 40 / \text{KVA}$

$P = 10\%$

$= 0.1$

Now,

$$\cos\phi = \sqrt{1 - (40 \times 0.1 / 100.05)^2}$$

$$= \sqrt{1 - 1.598 \times 10^{-3}}$$

$$\therefore \cos\phi = \sqrt{0.998}$$

$$\therefore \underline{\cos\phi = 0.999}$$

Most economical p.f. to which the system should be improved is 0.999.

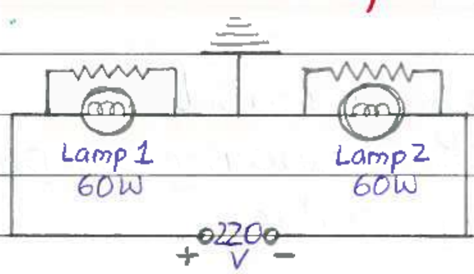
Q. The earth lamps on a main switch board comprise of 2 240V, 60 W lamps connected in the usual manner. The P.D. at the busbars is 220 V. Damage by sea water occurs to a distribution cable so that the Insulation resistance to earth is reduced to 16Ω & 6Ω for the 2 cables respectively. Find

a) which of the 2 lamps burns the brighter &

b) the additional load on the generators occasioned by the fault.

The resistance of the cables & ships structure may be neglected & that of the lamps taken as constant at the value corresponding to the 60 W rating.

Sol^n.



We know that,

Power (P) = V×I Watts

∴ Current taken by 1 lamp, $I = P/V$

i.e. $I = \frac{60}{240}$

∴ $I = 0.25$ A

Now,

Resistance of 1 lamp, $R = V/I$

∴ $R = \frac{240}{0.25}$

∴ $R = 960\ \Omega$

Let R_A be the resistance between the +ve terminal & earth

$$\frac{1}{R_A} = \frac{1}{960} + \frac{1}{16}$$

$\therefore R_A = 15.74\,\Omega$

Let R_B be the resistance between the -ve terminal & earth,

$$\frac{1}{R_B} = \frac{1}{960} + \frac{1}{6}$$

$\therefore R_B = 5.96\,\Omega$

Now,

Total Resistance between the +ve & -ve lines is

$$R_T = R_A + R_B$$
$$= 15.74 + 5.96$$
$$= 21.7\,\Omega$$

Current flowing between the +ve & -ve lines is,

$$I = V/R_T$$
$$= 220/21.7$$
$$\therefore I = 10.14\text{ A}$$

Voltage drop across +ve line & earth $= I \times R_A$
$= 10.14 \times 15.74$
$= 159.6\text{ V}$

Voltage drop across -ve line & earth $= I \times R_B$
$= 10.14 \times 5.96$
$= 60.43\text{ V}$

Thus, the lamp connected across the +ve terminal & earth will burn brighter. $\longrightarrow$ a)

Now,

Initial Load = $V \times I$

As resistance offered by each lamp is 960Ω

$$I = V/R$$

$$= \frac{220}{960+960}$$

$$\therefore I = 0.1146 \text{ A}$$

Thus,

$$\text{Initial Load} = 220 \times 0.1146$$
$$= 25.21 \text{ W}$$

$$\text{Additional Load} = \text{New Load} - \text{Initial Load}$$
$$= 220 \times 10.14 - 25.21$$
$$= 2230.8 - 25.21$$
$$= 2205.6 \text{ W} \quad \underline{\text{OR}} \quad 2.2 \text{ KW}$$

Additional Load = 2.2 KW $\longrightarrow$ b)