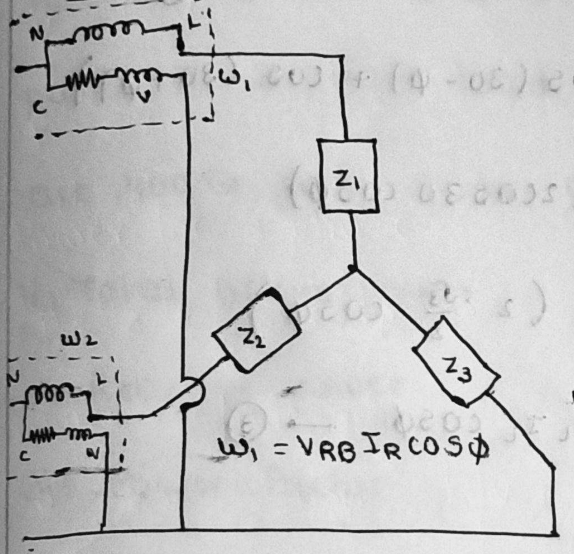
Unit 5

Two wattmeter method:



m = main

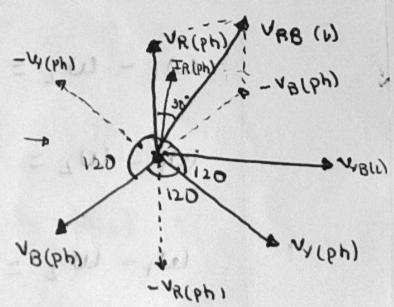
L = Load

c = common

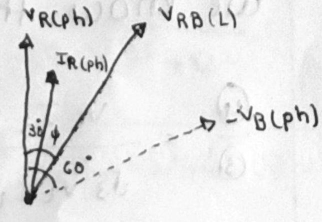
v = voltage

wattmeter consists of two coils called as currrent coil in series and voltage coil..

Vector representation of voltages →



* By vector representations, we determine the ~~volts~~ powers of both wattmeters W_1 & W_2

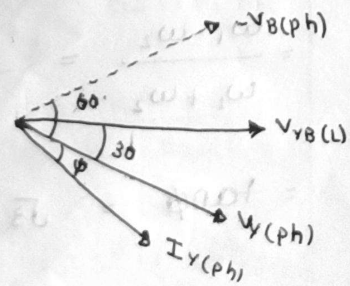


$W_1 = V_{RB} I_R \cos\phi$

$W_1 = V_L I_L \cos(30-\phi)$ → (1)

$W_2 = V_{YB} I_Y \cos\phi$

$W_2 = V_L I_L \cos(30+\phi)$ → (2)



* Generally loads are 3 types

1) Resistive (Power factor 1)
2) Inductive (Power factor lag)

3) capacitive (Power factor lead)

* From equations ① & ② i.e ① + ②

$$w_1 + w_2 = V_L I_L (\cos(30-\phi) + \cos(30+\phi))$$

$$w_1 + w_2 = V_L I_L (2\cos 30 \cos\phi)$$

$$w_1 + w_2 = V_L I_L \left(2 \cdot \frac{\sqrt{3}}{2} \cdot \cos\phi\right)$$

$$w_1 + w_2 = \sqrt{3} V_L I_L \cos\phi \longrightarrow ③$$

now ① - ②

$$w_1 - w_2 = V_L I_L (\cos(30-\phi) - \cos(30+\phi))$$

$$w_1 - w_2 = V_L I_L (2\sin 30 \sin\phi)$$

$$w_1 - w_2 = V_L I_L \left(2 \cdot \frac{1}{2} \cdot \sin\phi\right)$$

$$w_1 - w_2 = V_L I_L \sin\phi \longrightarrow ④$$

we know that $Q = \sqrt{3} V_L I_L \sin\phi = \sqrt{3}(w_1 - w_2)$

$$\frac{④}{③} = \frac{V_L I_L \sin\phi}{\sqrt{3} V_L I_L \cos\theta} = \frac{w_1 - w_2}{w_1 + w_2}$$

$$= \frac{w_1 - w_2}{w_1 + w_2} = \frac{\tan\phi}{\sqrt{3}}$$

$$= \tan\phi = \sqrt{3}\left(\frac{w_1 - w_2}{w_1 + w_2}\right)$$

$$= \phi = \tan^{-1}\left(\sqrt{3}\left(\frac{w_1 - w_2}{w_1 + w_2}\right)\right)$$

Power factor $\cos\phi = \cos\left[\tan^{-1}\left(\sqrt{3}\,\frac{w_1 - w_2}{w_1 + w_2}\right)\right]$

$S^2 = P^2 + Q^2$

Q Two wattmeter method is used to measure the power in 3 phase load the wattmeter readings are 400 w and -35 w. calculate

(i) Total active power

(ii) Reactive power

(iii) Power factor

(iv) Apparent power.

A Given $W_1 = 400\,W$, $W_2 = -35\,W$

(i) $P = W_1 + W_2$

$P = 400 - 35$

$P = 365\,W$

(ii) $Q = \sqrt{3}\,(W_1 - W_2)$

$= \sqrt{3}\,(400 + 35)$

$= 753.42$ VAR

(iii) P.F = $\cos\phi$

$\tan\phi = \sqrt{3}\,\dfrac{W_1 - W_2}{W_1 + W_2}$

$= \dfrac{753.42}{365}$

$= 2.064$

$\phi = \tan^{-1}(2.064) = 64.14°$

$\cos\phi = \cos(64.14) = 0.436$

(iv) $S = \sqrt{P^2 + Q^2}$

$S = \sqrt{365^2 + (753.42)^2}$

$S = 837.17$ VA

2) Two watt meter method is used to measure power in 3-ϕ Load. The load is 10 kw at 0.8 PF. Find

the individual at readings of watt meters

A $P = 10kw$

$PF = 0.8$

$\cos\phi = 0.8$

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

$= 36.86$

$\sin\phi = 0.6$ & $\tan\phi = 0.74$

$P = W_1 + W_2 = 10\ kw \rightarrow (1)$

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

$$0.74 = \frac{\sqrt{3}(W_1 - W_2)}{10 \times 10^3}$$

$$\frac{0.74 \times 10^4}{\sqrt{3}} = W_1 - W_2$$

$W_1 - W_2 = 4272.39 \rightarrow (2)$

$W_1 = 7136.19 = 7.136kw$

$W_2 = 2863.80 = 2.863\ kw$

3) A balanced star connected load of $4+j3\Omega$ for phase is connected to a balanced $3-\phi$ 400V supply. The phase current is 12A. Find

(i) Total active power

(ii) Reactive power

(iii) Total apparent power

λ balanced load

$V_L = 400V$

$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 230.9V$

$I_{ph} = 12 = I_L$

$Z_L = (4+j3)\,\Omega$ $\{R = 4$ & $X = 3\}$

$Z_L = 5\angle 36.86$

$\cos\phi = \cos(36.86) = 0.8$

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

$= \sqrt{3}(400)(12)(0.8)$ $= \sqrt{3}(400)(12)(0.6)$

$= 6651.07\, W$ $= 4988.30\, VAR$

$S = \sqrt{P^2 + Q^2} = \sqrt{(6651.07)^2 + (4988.30)^2}$

$= 8313.78\, VA$

4) A balanced delta connected load of $2+j3\,\Omega$ for phase is connected to a balanced $3-\phi$ 440V supply. The phase current is 10A. Find

(i) Total active power

(ii) Reactive power

(iii) Apparent power in ckt

A Δ - balanced load

$Z_L = (2+j3) = 3.60\angle 56.30$ $\{R = 2$ & $X = 3\}$

$\phi = 56.30$

$\cos\phi = \cos(56.30) = 0.5$

$\sin\phi = \sin(56.30) = 0.83$

$V_L = 440V = V_{ph}$

$I_{ph} = 10A$

$I_L = \sqrt{3}\, I_{ph} = \sqrt{3}(10) = 17.32$

$P = \sqrt{3}\, V_L I_L \cos\phi = \sqrt{3}(440)(17.32)(0.5)$

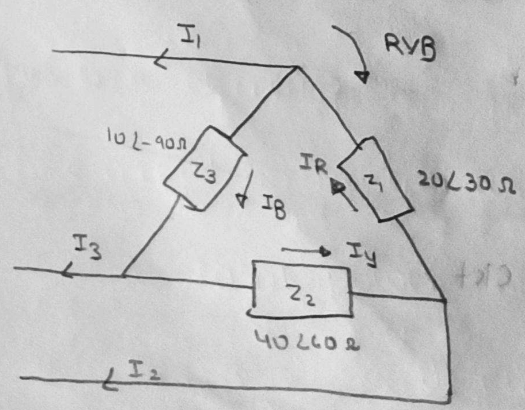
$= 6599.80\ W$

$Q = \sqrt{3}\, V_L I_L \sin\phi = \sqrt{3}(440)(17.32)(0.83)$

$= 10955.67\ \cancel{VA}\ VAR$

$S = \sqrt{3}\, V_L I_L = 13199.61\ VA$

5) 3 impedances $Z_1 = 20\angle 30^\circ$, $Z_2 = 40\angle 60$, $Z_3 = 10\angle -90\ \Omega$ are in delta connected to 400V 3-ϕ phase system. Determine i) phase currents ii) Line currents iii) Total power consumed by load.



$Z_1 = 20\angle 30 = (\underset{R_1}{17.32} + j\underset{X_1}{10})\ \Omega$

$Z_2 = 40\angle 60 = (\underset{R_2}{20} + j\underset{X_2}{34.64})\ \Omega$

$Z_3 = 10\angle -90 = (\underset{R_3}{0} - j\underset{X_3}{10})\ \Omega$

$V_L = 440V = V_{ph}$

$V_R = 400\angle 0$

$V_Y = 400\angle -120$

$V_B = 400\angle -240$

phase currents

$$I_R = \frac{V_R}{Z_1} = \frac{400\angle 0}{20\angle 30} = 20\angle -30\ A = (17.32 - j10)\ A$$

$$I_Y = \frac{V_2}{Z_2} = \frac{400\angle -120}{40\angle 60} = 10\angle -180\ A = (-10 + j0)\ A$$

$$I_B = \frac{V_B}{Z_3} = \frac{400\angle -240}{10\angle -90} = 40\angle -150 = (-34.64 - j20)\ A$$

Line currents

$I_1 = I_R - I_B$

$= (17.32 - j10) - (-34.64 - j20)$

$= (51.96 + j10)\ A$

$= 51.91\angle 10.89$

$I_2 = I_Y - I_R$

$= (-10 + j0) - (17.32 - j10)$

$= -27.32 + j10$

$= 29.09\angle 159.89$

$I_3 = I_B - I_Y$

$= (-34.64 - j20) - (-10 + j0)$

$= -24.64 - j20$

$= 31.73 \angle -140.93$

Power :: $P_R = I_R^2 R_1 = (20)^2 (17.32)$

$= 6928 W.$

$P_y = I_y^2 R_2 = (10)^2 (20) = 2000 W$

$P_B = I_B^2 R_3 = (40)^2 (0) = 0$

Total Power consumed by load $= P_R + P_B + P_y$

$= 8928 W$

$Q_R = I_R^2 X_1 = (20)^2 (10) = 4000$

$Q_Y = I_y^2 X_2 = (10)^2 (34.64) = 3464$

$Q_B = I_B^2 X_3 = (40)^2 (-10) = -16000$ VAR

$Q_{Total} = -16000$ VAR $+ 3464 + 4000 = -8536$ VAR

c) An unbalanced 4-wire star connected load has a balanced voltage of 400V The loads are $Z_1 = 4 + j8 \Omega$, $Z_2 = 3 + j4 \Omega$, $Z_3 = 15 + j20 \Omega$. Calculate

(i) line currents

(ii) Current in neutral wire

(iii) The total power consumed

$Z_1 = (4 + j8) \Omega = 8.94 \angle 63.43$

$Z_2 = (3 + j4) \Omega = 5 \angle 53.13$

$Z_3 = (15+j20)\ \Omega = 25\angle 53.13$

$V_L = 400V$

$V_{ph} = \frac{400}{\sqrt{3}} = 230.9V$

$V_R = 230.9\angle 0\ V$

$V_Y = 230.9\angle -120\ V$

$V_B = 230.9\ \angle -240\ V$

$I_R = \frac{V_R}{Z_1} = \frac{230.9\angle 0}{8.94\angle 63.43} = 25.82\ \angle -63.43$

$= (11.54 - j23.09)\ A$

$I_Y = \frac{V_Y}{Z_2} = \frac{230.9\angle -120}{5\angle 53.13} = 46.18\ \angle -173.13$

$= (-45.84 - j5.52)\ A$

$I_B = \frac{V_B}{Z_3} = \frac{230.9\ \angle -240}{25\ \angle 53.13} = 9.236\ \angle -293.13\ A$

$= (3.62 + j8.4)\ A$

$I_N = -[(I_R + I_Y + I_B)]$

$= -(11.54 - 45.84 + 3.62)$

$= -(-30.68)$

$= 30.68 + j20.21$

$= 36.73\ \angle 33.37$

Power $P_R = I_R^2 (R_1) = (25.82)^2 (4) = 2666.68\ W$

$P_Y = I_Y^2 (R_2) = (46.18)^2 (3) = 6397.77\ W$

$P_B = I_B^2 (R_3) = (9.236)^2 (5) = 1269.6\ W$

$P_T = P_R + P_Y + P_B$

$= 2666.68 + 6397.77 + 1269.6$

$= 10334.05 W$

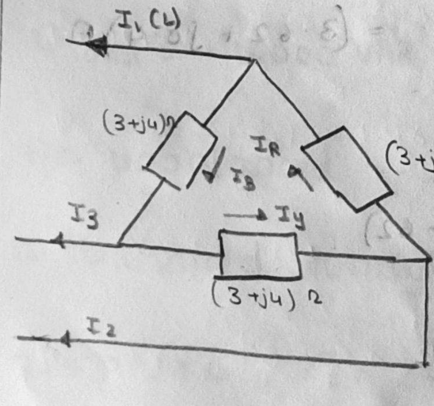
$Q_R = I_R^2 (X_1) = (25.82)^2 (8) = 5333.37$ VAR

$Q_Y = I_y^2 (X_2) = (46.18)^2 (4) = 8530.36$ VAR

$Q_Z = I_B^2 (X_3) = (9.236)^2 (20) = 1692.8$ VAR

$Q_T = 5333.37 + 8530.36 + 1692.8 = 15556.5$ VAR

7) A 3-ϕ delta connected RYB with an effective voltage of 400V has a balanced load with impedances (3+j4)Ω. Calculate the phase currents line currents, power in each phase.



$Z_1 = 3 + j4\ \Omega = 5 \angle 53.13$

$\phi = 53.13°$

$\cos\phi = \cos(53.13) = 0.60$

$V_L = 400V = V_{ph}$

$V_R = 400 \angle 0 \qquad V_y = 400 \angle -120 \qquad V_B = 400 \angle -240$

$I_R = \frac{V_R}{Z_1} = \frac{400 \angle 0}{5 \angle 53.13} = 80 \angle -53.13 = (48 - j63.99)$

$I_y = \frac{V_y}{Z} = \frac{400 \angle -120}{5 \angle 53.13} = 80 \angle -173.13 = (-79.42 - j9.56)$

$I_B = \frac{V_B}{Z} = \frac{400 \angle -240}{5 \angle 53.13} = 80 \angle -293.13 = (31.42 + j73.56)$

$I_1 = I_R - I_B$

$= 48 - j63.99 - (31.42 + j73.56)$

$= 16.58 - j137.55$

$= 138.52 \angle -83.12$

$I_2 = I_y - I_R$

$= (-79.42) - j9.56) - (48 - j63.99)$

$= -127.42 + j54.43$

$= 138.55 \angle 156.86$

$I_3 = I_B - I_y$

$= (31.42 + j73.56) - (-79.42 - j9.56)$ A

$= 110.84 + j83.12$

$= 138.54 \angle 36.86$ A

$P_R = I_R^2 (R_1) = (80)^2 (3) = 19200$ W

$P_R = P_Y = P_B = 19200$ W

$P_T = 3 \times 19200 = 57600$

8) A 3-ϕ star connected RYB with an effective voltage of 400V has a balanced load with impedance $(\cancel{3}3 + 4j)$. Calculate phase currents, line currents, total power.

$Z = (3 + j4) = 5 \angle 53.13$

$V_L = 400\,V$

$V_{ph} = \frac{400}{\sqrt{3}} = 230.9V$

$V_R = 230.9 \angle 0$

$V_Y = 230.9 \angle -120$

$V_B = 230.9 \angle -240$

$I_L = I_{ph} \qquad I_R = \frac{V_R}{Z}$

$I_R = \frac{230.9 \angle 0}{5 \angle 53.13} = 46.18 \angle -53.13$

$I_Y = \frac{230.9 \angle -120}{5 \angle 53.13} = 46.18 \angle -173.13$

$I_B = \frac{230.9 \angle -240}{5 \angle 53.13} = 46.18 \angle -293.13$

Power

$P_R = I_R^2 (R_1) = (46.18)^2 (3)$

$= 6397.77\omega$

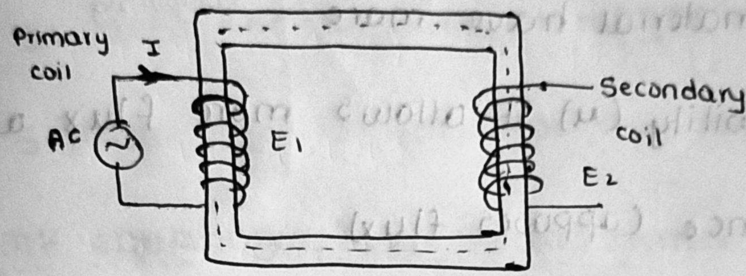
$P_R = P_Y = P_B = 6397.77\,\omega$

$P_T = 3 \times 6397.77$

$P_T = 19193.33$ watts.

Transformers :

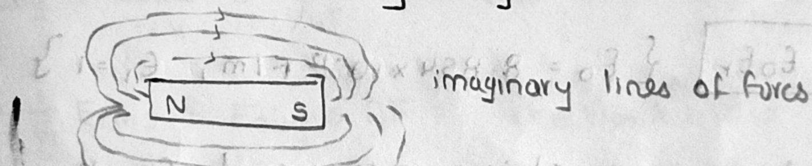
Transformer is a static device which transfers electrical energy into others without change in its frequency.



$I \propto \phi$ (flux)

flux units = weber

1weber = 10^8 imaginary lines of forces



* whenever a changing flux linked with coil, it induces EMF

* The amount of induced EMF in coil

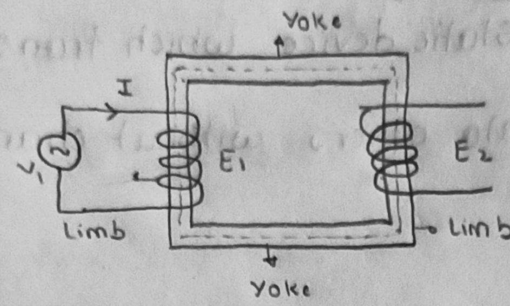
$|E| \propto \frac{d\phi}{dt}$ (AC)

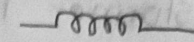
* primary & secondary coils are separated electrically but linked magnetically.

* Core ty

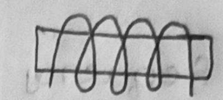
* Construction

1) <u>Core type transformer</u>:





air core medium



iron core medium
(supporting)

* If a material have more permeability (μ) it allows more flux and low reluctance (apposes flux)

$$\boxed{\mu = \mu_0 \mu_r}$$

$\{ \mu_0 = 4\pi \times 10^{-7}$ H/m & $\mu_r = 1 \}$

* For air, $\mu = 4\pi \times 10^{-7}$ H/m

$\boxed{\epsilon = \epsilon_0 \epsilon_r}$ $\{ \epsilon_0 = 8.854 \times 10^{-12}$ F/m, $\epsilon_r = 1 \}$

→ steel or iron strips are used for the preparation of core. (laminated core) (0.35mm x 0.5mm)

→ Flux and current are same

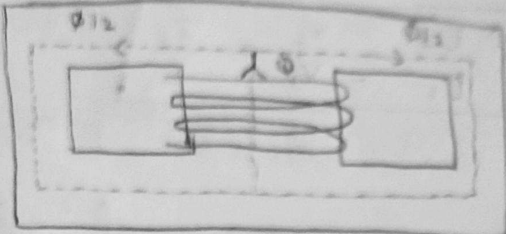
Flux in the series magnetic circuit is same

1) Core type transformer is also acts as series magnetic circuit

2) windings surrounds the core

3) Windings are placed at limbs

4) Shell type transformer.



1) winding placed at center limb.

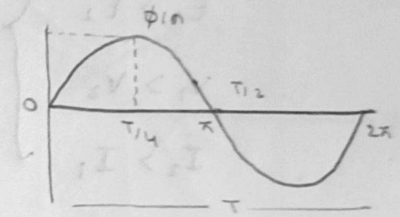
2) core surrounded the winding

3) It acts like a parallel magnetic circuit

4) Silicon steel is used for the manufacture of core

* EMF equation of the transformer:

$|E| \propto \frac{d\phi}{dt}$



$E = \frac{d\phi}{dt}$

$E_{avg} = \frac{\phi_m}{T/4} = \frac{\phi_m}{1/4f} = 4f\phi_m$

$T = \frac{1}{f}$ $E_{rms} = E_{avg} \times FF = 4f\phi_m \times 1.111 = 4.44 f \phi_m$ {form factor}

{for single turn}

for N turns $E = 4.44 f \phi_m N$

$E_1 = 4.44 f \phi_m N_1$ volts.

$E_2 = 4.44 f \phi_m N_2$

Transformation Ratio (K):-

$E_1 = 4.44 f \phi_m N_1$

$E_2 = 4.4 f \phi_m N_2$

$\frac{E_2}{E_1} = \frac{4.44 f \phi_m N_2}{4.44 f \phi_m N_1} = \frac{N_2}{N_1}$

$$\boxed{K = \frac{N_2}{N_1} = \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2}}$$

(i) $N_2 > N_1$

$E \propto N$

$E_2 > E_1$

$V_2 > V_1$

$I_1 > I_2$

These are the conditions satisfied by step up transformer $(K>1)$

(ii) $N_1 > N_2$

$E_1 > E_2$

$V_1 > V_2$

$I_2 > I_1$

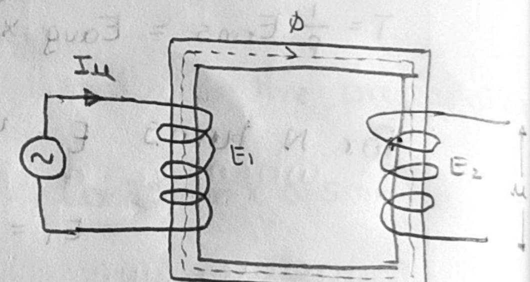
These are the conditions satisfied by step down transformer $(K<1)$

* Ideal transformer :-

1) winding resistance of ideal transformer is '0'.

2) $I^2R = 0$ (loses are 0)

3) Core permeability is ∞

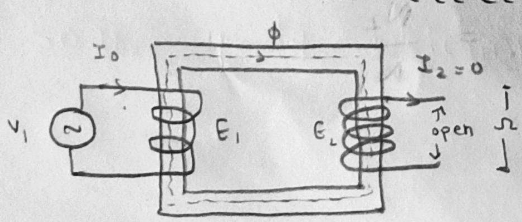


The purpose of I_μ is to generate flux in the transformer is constant.

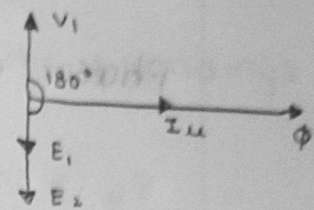
* Practical transformer :

① No load transformer :

$$I_0 = \vec{I_w} + \vec{I_\mu}$$



A transformer is said to be no load transformer if its secondary coil is open.

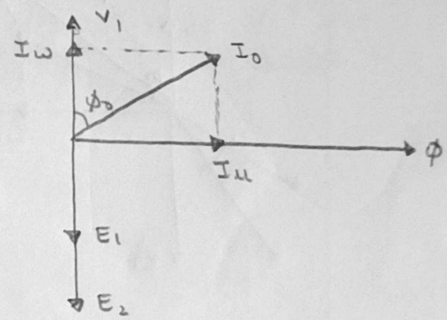


$I_0 = \vec{I_w} + \vec{I_u}$ where

$\vec{I_w} \rightarrow$ loss current, active current, Real current wattfull current, iron loss, true current

$\vec{I_u} \rightarrow$ useful current, imaginary current, magnetizing current, reactive current, wattless current.

$\cos\phi_0 = \frac{I_w}{I_0}$



$\boxed{I_w = I_0 \cos\phi_0}$

$\sin\phi_0 = \frac{I_u}{I_0}$

$\boxed{I_u = I_0 \sin\phi_0}$

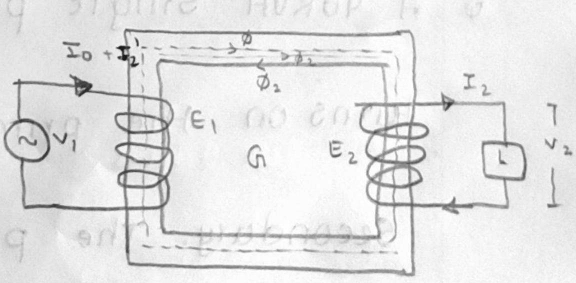
$I_0 = \sqrt{I_w^2 + I_u^2}$

The phase angle difference of input voltage and E_1, E_2 is 180°

* ON load transformer :

$I_2 \rightarrow$ secondary current

$I_2' \rightarrow$ Secondary current refference to primary side



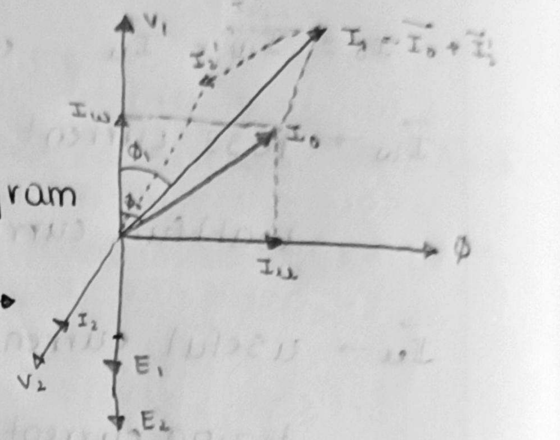
magnitude of ϕ_2 and ϕ_2' are equal but directions are different

Phasor diagram for resistive load (unity power factor)

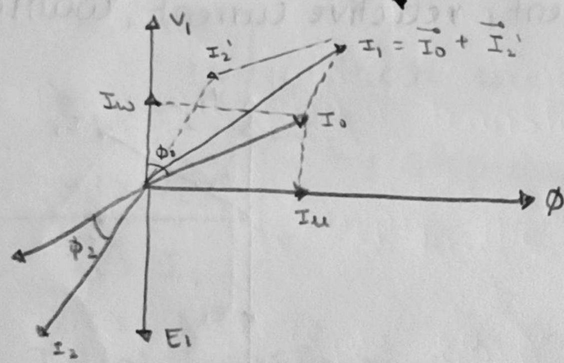
E_2 is source for V_2

This is phasor diagram

for resistive load →

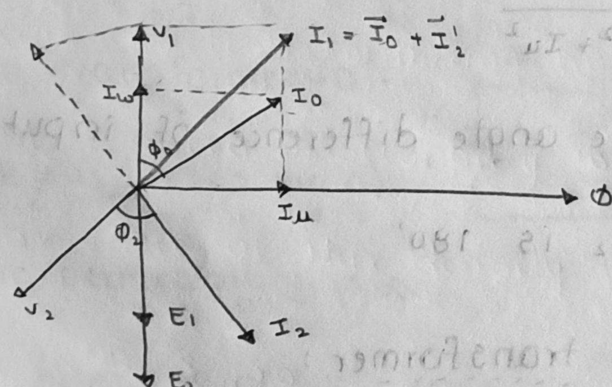


Inductive load →



(lag)

capacitive load (lead) →



Q A 40KVA single phase transformer has 400 turns on the primary and 100 turns on the secondary. The primary is connected to 2000V, 50 Hz supply. Determine

1) The secondary voltage on open circuit

2) The current flowing through the 2 windings on full load.

3) max value of flux.

A (i) for no load

$V_1 = E_1$ and $V_2 = E_2$

$$K = \frac{N_2}{N_1} = \frac{100}{400} = 0.25$$

$$K = \frac{V_2}{V_1} \rightarrow V_2 = kV_1 = 0.25 \times 2000 = 500V$$

$$\text{(ii) } I_1 = \frac{KVA}{V_1} = \frac{40 \times 10^3}{2000} = 20A$$

$$I_2 = \frac{KVA}{V_2} = \frac{40 \times 10^3}{500} = 80\,A$$

$$\text{(iii) } E_1 = 4.44 f \phi_m N_1$$

$$\phi_m = \frac{E_1}{4.44 f N_1} = \frac{2000}{4.44(50)(400)} = 0.0225\ wb$$

Q The no load ratio required in a single ø 50Hz transformer is 6600/600V. If the max value of flux in the core is to be about 0.08 wb. Find the no. of turns in each winding

A $V_1 = 6600V$ $V_2 = 600V$

$$k = \frac{V_2}{V_1} = \frac{600}{6600} = 0.09\ V$$

for no load

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

$$N_1 = \frac{E_1}{4.44 f \phi_m} = \frac{6600}{4.44(50)(0.08)}$$

$$= 372 \text{ turns}$$

$$N_2 = k N_1 = 0.09(372)$$

$$= 34 \text{ turns}$$

Q A single phase transformer is connected a 230V 50Hz supply. The net cross sectional area of core is $60 cm^2$. The no. of turns in the primary is 500. And in secondary is 100. Determine 1) Transformation Ratio

2) EMF induced in secondary winding

3) max value of flux density in the core

A 1) $K = \frac{N_2}{N_1} = \frac{100}{500} = 0.2$

2) $E_2 = k E_1$

for no load, $E_1 = V_1 = 230$

$$E_2 = (0.2) 230$$

$$= 46$$

3) $E_2 = 4.44 f \phi_m N_2$

$$\phi m = \frac{E_2}{4.44 f N_2} = \frac{46}{4.44 \times 50 \times 100}$$

$$= 2.07 \times 10^{-3}$$

$$= 2.07 \text{ mwb}$$

$$\text{flux density } (B_m) = \frac{\text{flux}}{\text{area}}$$

$$= \frac{2.07 \times 10^{-3}}{60 \times 10^{-4}}$$

$$= 0.345 \text{ wb/m}^2 \text{ (or) T}$$

Q 3300/300V, single phase 300 kVA transformer has 100 primary turns. Find

1) transformation ratio

2) secondary no. of turns

3) voltage for turn

A 1) $K = \frac{V_2}{V_1} = \frac{300}{3300} \doteq 0.09$

2) $N_2 = KN_1 = (0.09)(1100)$

$= 100$ turns

3) voltage / turn $= \frac{V_1}{N_1}$ or $\frac{V_2}{N_2}$

$$= \frac{3300}{1100}$$

$$= \underline{\underline{3\text{v}}}$$

→ For the same above problem. Calculate the second-ary current when it supplies a load of 200 kw at lagging Power factor.

A $P_2 = 200\,kW$

$\cos\phi_2 = 0.8$ lag

$P_2 = V_2 I_2 \cos\phi_2$

$$I_2 = \frac{P_2}{V_2 \cos\phi_2}$$

$$= \frac{200 \times 10^3}{300 (0.8)}$$

$I_2 = 833.33\,A$

Q The voltage for turn of a single phase trans-former is 1.1V. when the primary winding is connected to a 220V, 50Hz AC supply. The secondary voltage found to be 550V find

1) Primary & secondary turns

2) The core area if B_m is 1.1T

A Voltage/turn = 1.1V

$f = 50\,Hz$

$V_1 = 220\,V$ $\qquad B_m = 1.1\,T$

$V_2 = 550\,V$

$$\text{(i) } \frac{\text{voltage}}{\text{turn}} = \frac{V_1}{N_1} = \frac{220}{N_1} = 1.1$$

$N_1 = 200$ turns

$$1.1 = \frac{550}{N_2}$$

$$N_2 = \frac{550}{1.1}$$

$N_2 = 500$ turns

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

$$= \frac{220}{4.44(50)(200)}$$

$= 0.00495$ wb

$= 4.95$ mwb

$$A = \frac{\phi_m}{B_m} = \frac{4.95 \times 10^{-3}}{1.1}$$

$$= 4.5 \times 10^{-3}$$

$$= 4.5 \, mm^2$$

Q. A 3300/300v single phase transformer gives 0.6A and 60 W as Ammeter and wattmeter readin-gs when supply is given low voltage side and the high voltage winding is kept open. Find

(i) Power factor of no load current

(ii) magnetizing component current

(iii) Iron loss component current.

$V_1 = 300V, \quad V_2 = 3300V$

$I_o = 0.6A, \quad P_o = 60W$

(i) $P_o = V_1 I_o \cos\phi_o$

$$\cos\phi_o = \frac{P_o}{V_1 I_o} = \frac{60}{300 \times 0.6} = 0.33 \text{ lag}$$

(ii) $I_\mu = I_m = I_o \sin\phi_o$

$\cos\phi_o = 0.33$

$\phi_o = \cos^{-1}(0.33)$

$= 70.7°$

$\sin\phi_o = \sin(70.7)$

$= 0.94$

$I_\mu = 0.6(0.94) = 0.564A$

(iii) $I_w = \sqrt{I_o^2 - I_m^2} \quad | \quad I_w = I_o \cos\phi_o$

$= 0.6(0.33) = 0.198A.$

Find) i) Active & reactive component of no load current (ii) no load current of 440/220V single phase transformer if the power input on no load to high voltage winding is 80W. And the power factor of no load current is 0.3 lagging

$V_1 = 440V \quad V_2 = 220$

A

$P_0 = 80W, \cos\phi = 0.3$ lagg

i) $P_0 = V_1 I_0 \cos\phi_0$

$P_0 = V_1 I_w$

$I_w = \frac{P_0}{V_1} = \frac{80}{440} = 0.18$

(ii) $I_w = I_0 \cos\phi_0$

$I_0 = \frac{I_w}{\cos\phi_0}$

$= \frac{0.18}{0.3} = 0.606\ A$

$I_m = I_\mu = \sqrt{I_0^2 - I_\mu^2}$

$= \sqrt{0.606^2 - 0.18^2}$

$= 0.57\ A$

Q 3300/220 V, 30 kVA single phase transformer take a no load current 1.5 A when the low voltage is kept open. The iron loss component is equal to 0.4A. Find (i) The no load input power (ii) magnetizing component current & PF of no load current.

A 3300/220 V

$V_1 = 3300V$ & $V_2 = 220V$

30 kVA

$I_0 = 1.5A$

$I_w = 0.4A$

$P_o = V_1 I_0 \cos\phi_0$

$= V_1 I_w$

$P_o = 3300 (0.4) = 1320 V$

(ii) $I_\mu = I_0 \sin\phi_0 \ / \ \sqrt{I_0^2 - I_w^2}$

$= \sqrt{1.5^2 - 0.4^2}$

$= 1.44$

P.F of no load current

$\cos\phi_0 = \frac{I_w}{I_0} = \frac{0.4}{1.5} = 0.266$ lag.

Q A 230/115V, single phase transformer takes a no load current of 2A at PF of 0.2 lagging with a low voltage winding is kept open. If the open low voltage winding is known loaded to take a current of 15 A at 0.8 PF lag. Find 1) The current taken by high voltage winding.

A 230/115 V

$V_1 = 230V$, $I_0 = 2A$ $I_2 = 15A$

$V_2 = 115V$, $\cos\phi_0 = 0.2$ lag $\cos\phi_2 = 0.8$ lag

$$K = \frac{V_2}{V_1} = \frac{115}{230} = 0.5$$

$$I_2' = K I_2 = (0.5)(15) = 7.5A$$

$$I\phi = \overrightarrow{I_1} + \overrightarrow{I_2'}$$

$$\phi_0 = 78.46$$

$$\phi_2 = 36.86$$

$$\phi_1 = 78.46 - 36.86$$

$$= 41.6^\circ$$

$$I_1 = \sqrt{I_0^2 + I_2'^2 + 2 I_0 I_2' \cos(41.6)}$$

$$I_1 = \sqrt{4 + 7.5^2 + 2(4)(7.5)(0.747)}$$

$$I_1 = 9.09A.$$

D.C Machines :

* Generally machine has two important parts. They are 1) Conductor 2) magnetic field.

* There are 2 types of DC mahines.

1) DC Generator (mechanical energy to electrical)

2) DC Motor (Electrical energy to mechanical energy)

* A DC machine is an electro - mechanical energy conversion device.

* DC Generator :

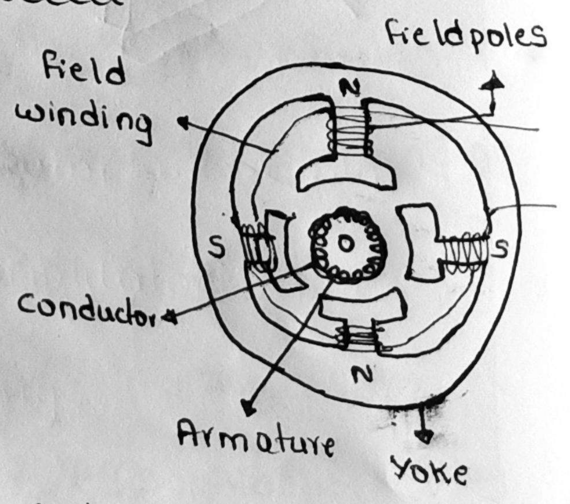
A DC generator is a rotating machine that suppli -es an electrical output with unidirectional voltage and current. or A device which converts mechanical energy to electrical energy.

Construction of DC machine :

→ Yoke → outerframe of the machine

→ choice of metal :-

Steel, Nylon, Haudral

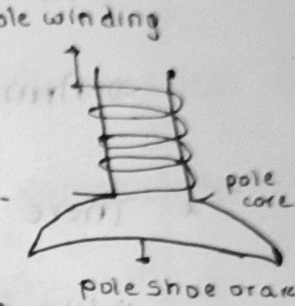


* Armature → rotating part.

* To utilize the maximum forces of the flux gener-ated we can use either steel or Hydratylon.

* In machines we go with general use of electro-magnetic field.

* we use laminated core, that is formed of by lamination and comb-ination of many sheets of steel.



1)→ magnetic field poles:

The pole of the DC machine is an electromagnet with the field winding, winded among the pole. whenever field winding is energized, then the pole gives magnetic flux.

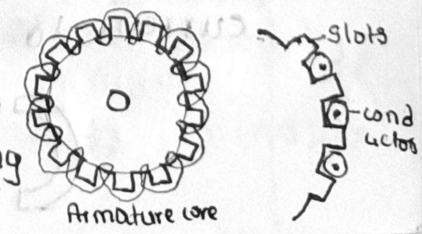
* DC machines have commonly 2 basic parts.

Stator → Stationary part → Yoke, Field poles.

Rotar → Rotating part

2)* Armature: Armature of a DC motor is a cylin-der of magnetic laminations that are insulated from one another.

* We use the conductor like winding



placed in the armature.

* Armature has 3 parts:

1) Armature core

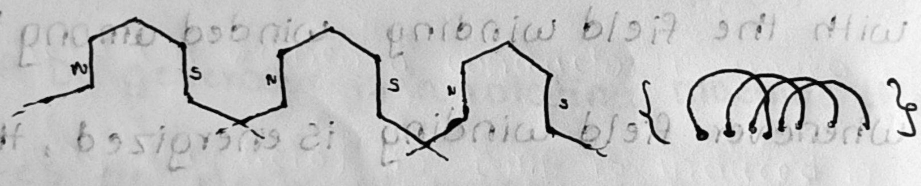
2) Armature slot

3) Armature winding.

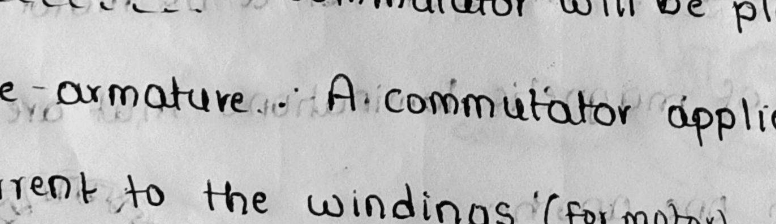
* There are 2 popular windings in armature.

1) Wave winding: It is used for getting high voltage and low current.

- No of parallel paths [A] = 2



2) Lap winding: It is used for getting high current and low voltage.

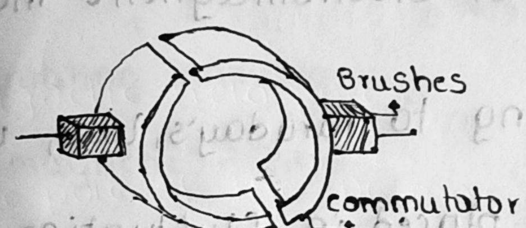


3) Commutator: commutator will be placed on the armature. A commutator applies an electric current to the windings. (for motor).


commutator segments

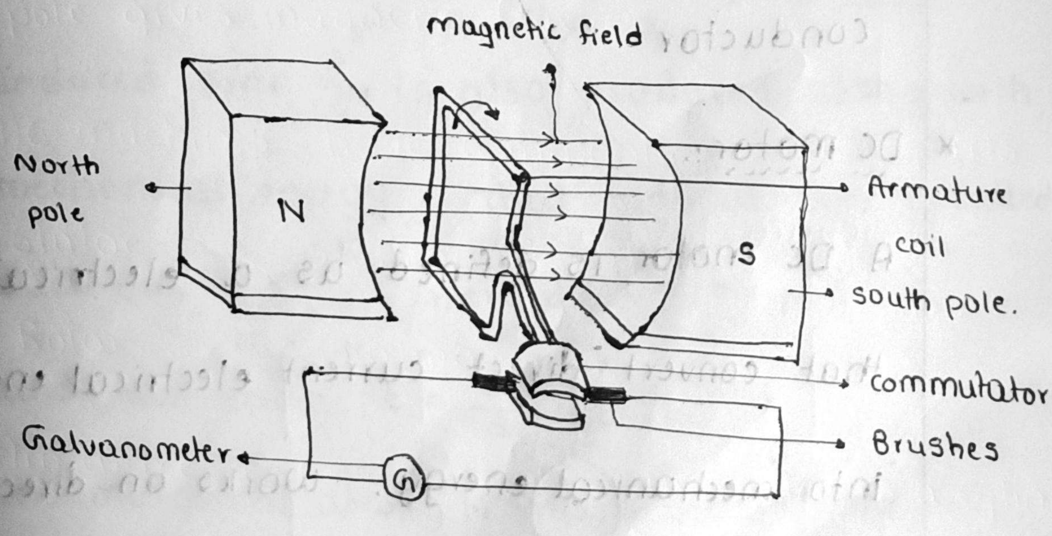
* **Brushes**: Brushes are normally used in dc generators to collect the generated power from rotating armature. In motor, the brushes make physical contact with the commutator.

when DC voltage is applied to brushes, the voltage is transferred into commutator which, in turn, powers the windings.



* **Shaft**: Device used to transfer mechanical work.

* **Principle of operation of DC Generator**



* Due to mechanical energy, armature coil rotates and cuts magnetic Flux continuously created by magnetic field poles which leads to induce

EMF. Induced EMF generated in generator is called Generated EMF (E / E_g)

$$\boxed{E \propto \frac{d\phi}{dt}}$$

* Direction of induced EMF can be found by Flemmings Right Hand Rule
* A DC generator operates on the principle of "Faraday's law of electromagnetic induction."

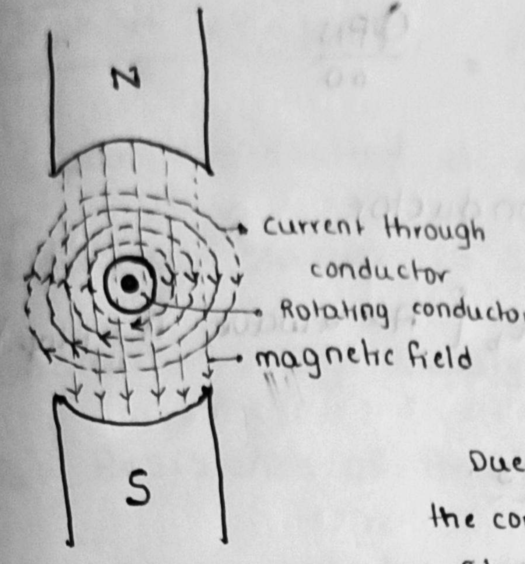
According to Faraday's law, whenever a conductor is placed in fluctuating magnetic field (or when a conductor is moved in a magnetic field) an EMF is induced in the conductor

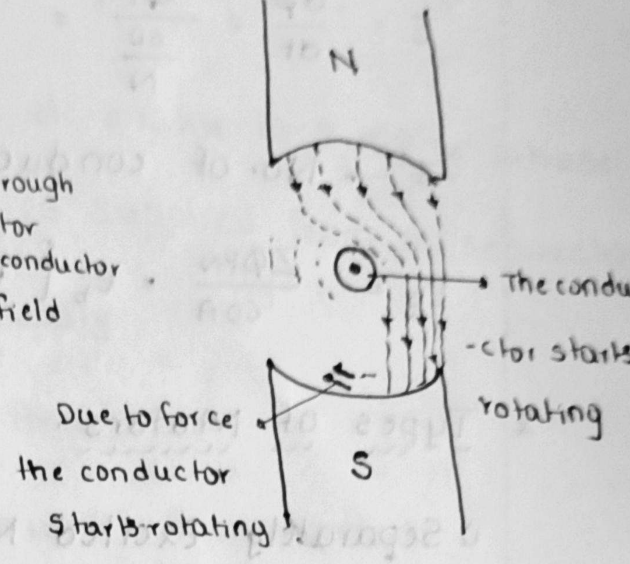
* DC motor:

A DC motor is defined as a electrical motor that convert direct current electrical energy into mechanical energy. works on directr current.

* Working principle of DC motor:

* Principle of operation of DC motor:





* Rotating conductor in magnetic field

* To determine the direction of force, we can use "Flemmings Left hand Rule"

* Force produced in a motor by using BIL sinθ

* Induced EMF ~~pr~~ is also produced along with mechanical energy. That induced EMF is called "Back EMF" (E_B) Here $d\phi = \phi P \rightarrow (1)$

and we know $E = \frac{d\phi}{dt} \rightarrow (2)$

let motor rotates N revolutions per time

$N \rightarrow$ RPM i.e $\frac{N}{60} \rightarrow$ RPS $\left(\frac{rev}{time}\right)$

$dt = \frac{60}{N} \rightarrow (3)$

Substitute ① ③ in ②

$$E = \frac{d\phi}{dt} = \frac{\phi P}{\frac{60}{N}} = \frac{\phi PN}{60}$$

'Z' → No. of conductor

$$E_g = \frac{Z\phi PN}{60A} = E_b \left\{ A = 2 \text{ wave}, \ A = P \text{ lap.} \right)$$

* Types of Motors:

1) Separately Excited Motor

2) Self Excited Motor.

a) Series Motor

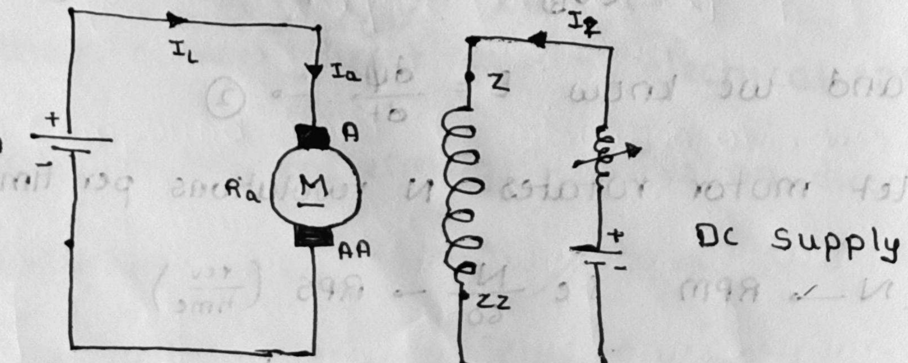
b) Shunt motor

c) Compound motor

(i) long shunt

(ii) Short shunt

1) Separately Excited Motor:



$I_L = I_a$ $\{ v - I_a R_a =$ Drop in armature $\}$

$V - I_a R_a - E_b = 0$

$$\boxed{E_b = V - I_a R_a}$$

* A separately excited dc motor is a motor whose field circuit current is supplied from a separately constant-voltage supply

R_a = Resistance of Armature

I_L = line current (current from source)

I_a = Armature current

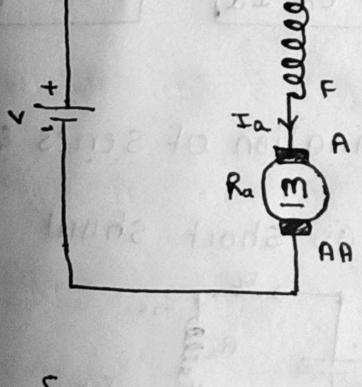
V = voltage (supply)

I_z = field current

E_b = back EMF

2) Self excited motor :-

a) Series motor :



In series DC motor, the field winding and the armature coil are connected in series to the power supple. So, Then

$$I_L = I_{SC} = I_a$$

{ I_L = line current, I_{SC} = Series current

I_L = line current }

Voltage drop

$$V - I_{sc} R_{sc} - I_a R_a - E_b = 0$$

$$E_b = V - I_{sc}(R_a + R_{sc})$$

$$\boxed{E_b = V - I_{Ra}(R_a + R_s)}$$

$\{P_a = E_b \cdot I_a\}$

$\{I_{sc} = I_a\}$

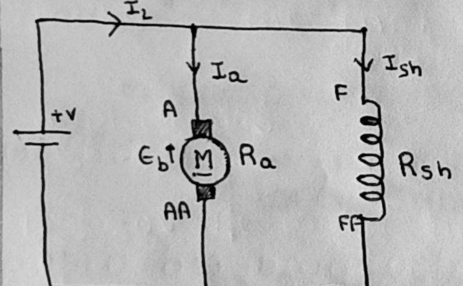
R_{sc} = conductor ~~or~~ coil resistance

R_a = Armature resistance

E_b = Back EMF.

P_a = Power {Armature}

b) Shunt motor :-



The field winding is connected in parallel with firmware.

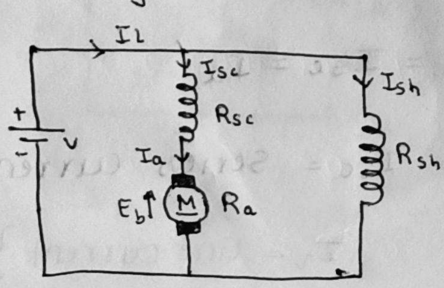
$$I_L = I_a + I_{sh}$$

$$= V - I_a R_a - E_b = 0$$

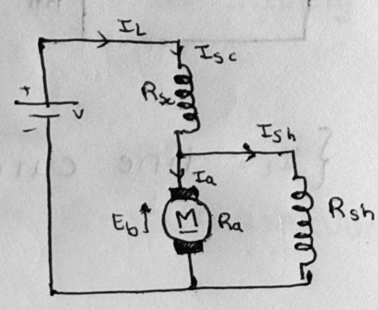
$$= \boxed{E_b = V - I_a R_a} \ \& \ \boxed{P_a = E_a \cdot I_a} \quad \boxed{I_{sh} = \frac{V}{R_{sh}}}$$

c) Compound motor: (combination of series & shunt)

(i) Long shunt



(ii) Short shunt



Shunt field connected across both series field wind & armature	Shunt field connected across only armature
* $I_L = I_{sc} + I_{sh}$	* $I_L = I_{sc} = I_a + I_{sh}$
* $I_{sc} = I_a$	* $I_{sc} = I_a + I_{sh}$
* $V - I_{sc} R_{sc} - I_a R_a - E_b = 0$	* $V - I_{sc} R_{sc} - I_a R_a - E_b = 0$
* $E_b = V - I_a (R_a + R_{sc})$	* $E_b = V - I_{sc} R_{sc} - I_a R_a$
* $P_a = E_b \cdot I_a$	* $P = E_b \cdot I_a$
* $I_{sh} = V / R_{sh}$	

* Flux of series field wind & flux of shunt field winding are in same direction then it is cummulatively compound, if windings are in different direction, then it is differentially compound.

⊙ Applications of DC shunt :- (motor)

1) Used in lake machines
2) Used in drilling machines
3) Used in grinders, blowers
4) Used as compressors

⊙ Applications of DC series :- (motor)

1) Used in electric tractors
2) Used in hoists and lifts
3) Used in cranes.

4) Used in rolling mills.

5) Can be used in conveyers

Applications of cumulatively compound:

1) Used in elevators

2) Used in rolling mills

3) Used in punching machinaries

4) In the planers.

Applications of differential compound:

The speed of these motors increases with increase in load which leads to unstable operation of motor ∴ we can't use this motor for any practical applications.

Q A 220V DC motor has an armature resistance of 0.75 Ω, it is drawing an armature current of 30A at certain load. Calculate induced EMF in motor under this condition.

A $V = 220V$, $I_a = 30A$

$R_a = 0.75\,\Omega$

voltage equation for shunt motor

$V - I_a R_a - E_b = 0$

$E_b = V - I_a R_a = 220 - 30(0.75) = \boxed{197.5V}$

Q A four pole DC shunt has lap connected armature winding. The flux/pole is 30 mWb. The no. of armature conductors is 250. When connected to 230 V DC supply it draws an armature current of 40 A. Calculate E_b & speed with which motor is running. Assume the armature resistance is 0.6Ω.

A

$E_b = V - I_a R_a$

$= 230 - (40)(0.6)$

$= 206\,V$

$E_b = \dfrac{Z N \phi P}{60 A}$

$N = \dfrac{E_b \times 60 \times A}{Z \times \phi \times P}$

$= \dfrac{206 \times 60 \times 4}{250 \times 30 \times 10^{-3} \times 4} = \underline{\underline{1648\ RPM}}$

$P = 4$

$\phi = 30\,mWb$

$Z = 250$

$V = 230\,V$

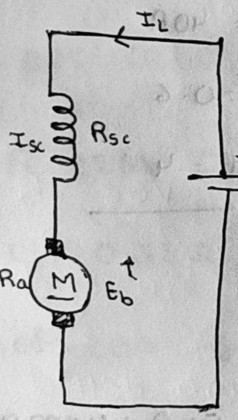
$I_a = 40\,A$

$R_a = 0.6$

$A = P = 4$

Q A four pole DC motor takes a 50 A armature current. The armature has lap connected 480 conductors. The flux for pole is 20 mWb. Calculate gross torque.

Q A four pole 250V DC Series motor has wave connected armature with 200 conductors. The flux for pole is 25 mWb, when the motor is drawing 60A. from the Supply, the armature resistance is 0.15 Ω, while the series field winding resistance is 0.2 Ω. Calculate the speed under this condition.



$P = 4$, $V = 250V$, $Z = 200$, $\phi = 25 mWb$

$I_L = 60A$, $R_a = 0.15 \Omega$, $R_{sc} = 0.2 \Omega$

$V - I_a R_a - I_{sc} R_{sc} - E_b = 0$

for series motor

$I_L = I_a = I_{sc} = 60A$

$E_b = 250 - 60(0.15 + 0.2)$

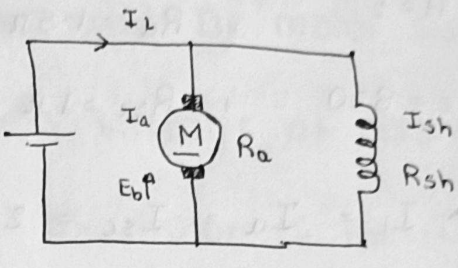
$= 229 V$

$E_b = \frac{Z N \phi P}{60 A}$; $N = \frac{E_b \times 60 \times A}{Z \times \phi \times P} = \frac{229 \times 60 \times 2}{200 \times 25 \times 10^{-3} \times 4}$

$= 1374$ RPM

Q A 250V DC shunt motor takes a line current of 20 A. The resistance of shunt field winding is 200Ω. And the resistance of armature is 0.3 Ω. Find the armature current and back EMF?

A $V = 250\ V$



$I_L = 20A$

$R_{sh} = 200\Omega$

$R_a = 0.3\Omega$

$I_L = I_a + I_{sh}$

$I_a = I_L - I_{sh}$

$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{200} = 1.25\ A$

$I_a = I_L - I_{sh}$

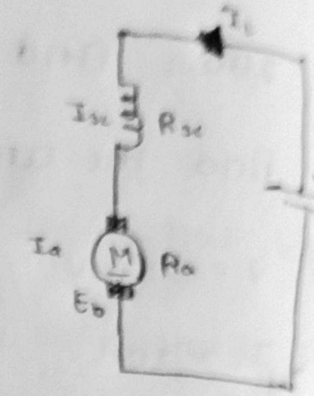
$= 20 - 1.25 = 18.75\ A$

$E_b = V - I_a R_a$

$E_b = 250 - (18.75)(0.3)$

$= 244.37\ \Omega$.

Q A four DC series motor has 820 wave connected armature conductors. The flux for pole is 35 mwb. And the Armature drawing a current of 20A. Calculate the current taken by motor. And the speed of motor when applied a voltage 500V. the armature resistance is 1.5Ω and series field winding resistance is 1Ω



A $V = 500v$, $\phi = 35mwb$

$P = 4$, $I_a = 20A$

$A = 2$, $R_a = 1.5Ω$

$z = 820$, $R_{se} = 1Ω$

* $I_L = I_a = I_{se} = 20A$

$E_b = V - I_a R_a - I_{se} R_{se}$

$= V - I_a(R_a + R_{se}) = 500 - 20(1.5 + 1)$

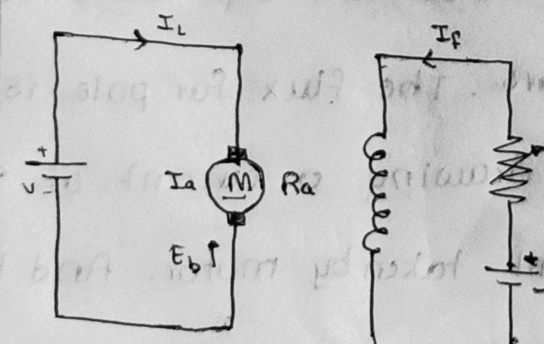
$= 450v.$

$E_b = \frac{ZN\phi P}{60A}$; $N = \frac{E_b \times 60 \times A}{Z \times \phi \times P} = \frac{450 \times 60 \times 2}{820 \times 35 \times 10^{-3} \times 4}$

$= \underline{\underline{471 \text{ RPM}}}$

Q A 250v, 10kW separately excited DC motor has an back EMF of 245v at full load. If the brush drop is 2v for brush, calculate R_a for the motor.

A



$V = 250V$

$P = 10kW$

$E_b = 245v$ (below supply voltage)

$B \cdot D = 2v/brush$

Total $B \cdot D = 4V$

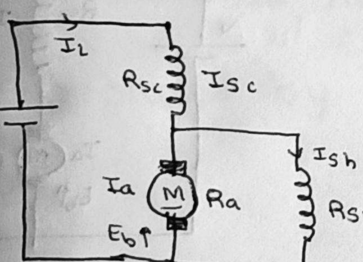
$I_L = \frac{P}{V} = \frac{10 \times 10^3}{250} = 40A$

$E_b = V - I_a R_a - B.D$

$250 - 40 R_a - 245 - 4 = 0$

$\boxed{R_a = 0.025 \Omega}$

Q. A shaot shunt compound DC motor supplies a current of 75 A at a voltage of 255V. Calcul -ate the back EMF of motor if the resistances of armature , shunt field & series field win -dings are 0.04 Ω, 90Ω, 0.02Ω respectively



$I_L = 75 A$

$V = 255 V$

$R_a = 0.04 \Omega$

$R_{sh} = 90 \Omega$

$R_{sc} = 0.02 \Omega$

* $V - I_{sc} R_{sc} - I_a R_a - E_b = 0$

* $E_b = V - I_{sc} R_{sc} - I_a R_a$

And also $V - I_{sc} R_{sc} - I_{sh} R_{sh} = 0$

$225 - 75(0.02) - I_{sh}(90) = 0$

$\frac{225 - 75(0.02)}{90} = I_{sh}$

$I_{sh} = 2.48 A$

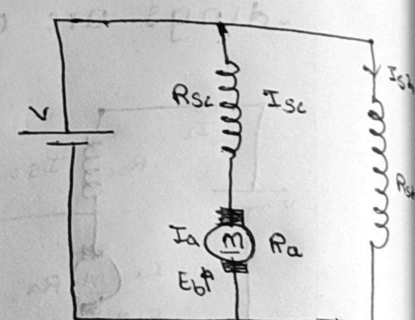
$I_a = I_L - I_{sh} = 75 - 2.48 = \underline{72.5 A}$

$E_b = V - I_{sc} R_{sc} - I_a R_a$

$= 225 - 75(0.02) - 72.5(0.04)$

$= 220.6$

Q A four pole lap wound long shunt compound motor has 1200 armature conductors. The armature, series field & shunt resistances are 0.1Ω, 0.15Ω and 200Ω respectively. If the flux for pole is 0.075 wb. Calculate speed of the motor at 50 kw, 500V



A $P = 4 = A$

$Z = 1200$, $R_a = 0.1$

$R_{sc} = 0.15$, $R_{sh} = 200$

$V = 500$, $P = 50\ kW$

* $V - I_{sc} R_{sc} - I_a R_a - E_b = 0$

* $E_b = V - I_{sc} R_{sc} - I_a R_a$

$P = V \cdot I_L$

$I_L = P/V = \dfrac{50 \times 10^3}{500} = 100A$

$I_{sh} = \dfrac{V}{R_{sh}} = \dfrac{500}{200} = 2.5A$

$I_a = I_L - I_{sh}$

$= 100 - 2.5 = 97.5\ A$

$E_b = 500 - 97.5\,(0.1 + 0.15)$

$= 475.62\ V$

$$E_b = \frac{ZN\phi P}{60A}$$

$$N = \frac{E_b \times 60 \times A}{Z \times \phi \times P} = \frac{475.62 \times 60 \times 4}{1200 \times 0.075 \times 4} = \underline{318\ Rpm}$$

Q A four pole lap wound DC motor has a useful flux of 0.07 wb for pole. Calculate E_b generated in motor when it is rotated at a speed of 900 RPM. The armature consists of 440 conductors. Also calculate the E_b if lap wound armature is replaced by wave wound armature.

A $P = 4$

$\phi = 0.07\ wb$

$N = 900\ RPM$

$Z = 440$

Lap connected

$A = P = 4$

$$E_b = \frac{Z\phi PN}{60A}$$

$$= \frac{440 \times 900 \times 4 \times 0.07}{60 \times 4}$$

$= 462V$

$$E_b = \frac{ZN\phi P}{60A}$$

$$E_b = \frac{440 \times 900 \times 0.07 \times 2}{60 \times 4}$$

$= \boxed{924\ V}$

Losses of DC Motor:

While converting energy from one form to another form there will be some energy losses.

∴ Here, converting electrical to mechanical energy

Types of losses:

Magnetic loss: (or) core loss or Iron loss:

Armature windings & field windings are placed in core and magnetic field also at the place of core.

There will be two losses here

(i) Hysteresis loss

(ii) Eddy current loss

(i) Hysteresis loss:

As we increase the current in magnetic field the flux increases till its maximum value behind that even if we increase current it's value will be saturated.

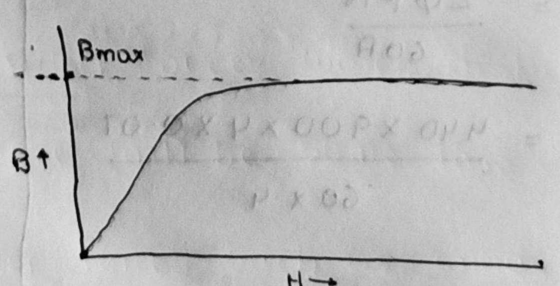
$\phi \propto I$

$B \propto H$

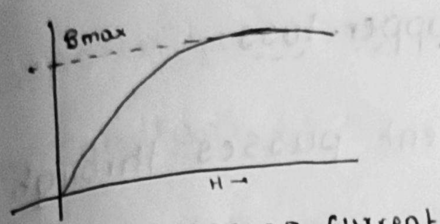
$B = \frac{\phi}{A}$

$B = \mu H$

$H = \frac{NI}{l}$

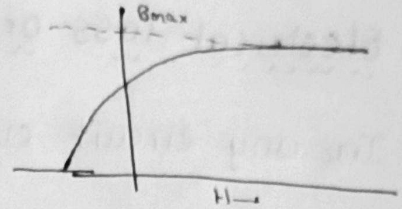


By increasing current, flux increases.



By decreasing current

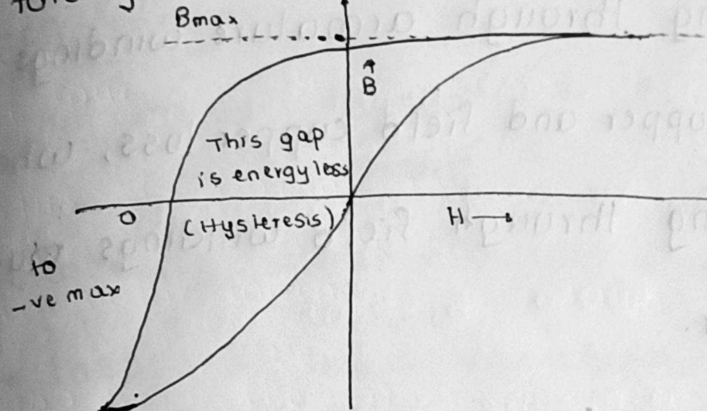
(for ideal)



By decreasing current

(for practical).

totally

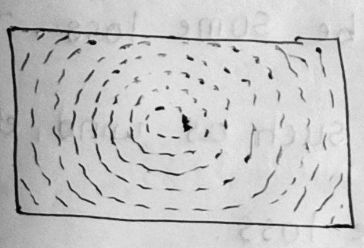


loss of energy due to reversal of magnetic field. It happens in magnetic field

To reduce the hysteresis loss, we make core with silica steel strips.

(ii) Eddy current loss:

As flux links with core an induced emf will be produced in the core. Due to this induced voltage there will be current but it is discontinuous. The direction of current in the eddy formation in the core.



* Eddy currents loss can be minimized by using properly laminated core.

2) Electrical loss or copper loss:

In any circuit current passes through any conductor there will be I^2R lose | Electrical loss There will be Armature copper loss when current is passing through armature windings made up of copper and field copper loss, when current is passing through field windings made up of copper.

3) Mechanical loss:

There will be two losses

(i) Frictional loss:

Armature will rotate with the support of shaft when we fix armature on the shaft using bearings there will be some losses this loss is called frictional loss.

(ii) Windiage loss:

When something is mechanaically working there will be other forces which disturbs its speed then there will be some loss. This lose is due to other forces such as wind, etc, so it is called as windage loss.

* Generally losses of DC motor are of two types

(i) Constant loss (ii) Variable loss

- magnetic losses - Electrical losses.

- mechanical losses

* Efficiency :

$\eta = \cancel{\frac{Input}{output}} \; \frac{output}{Input}$

Generally, input = output + losses.

* losses = $\underbrace{W_c}_{\text{constant losses}}$ + $\underbrace{\text{Variable losses}}_{I^2R}$

* $\eta = \frac{E_b \cdot I_a}{E_b \cdot I_a + W_c + I_a^2 R_a}$

* $I/p = VI_L$ { I/p = input }

* $O/p = I/p - \text{losses}$ { O/p = output }

- Interms of I/p :

$\eta = \frac{I/p - \text{losses}}{I/p}$

* If the denominator is zero, then efficiency is maximum, $D = 1 + \frac{W_c}{E_b \cdot I_a} + \frac{I_a \cdot R_a}{E_b}$

* $\frac{dD}{dI_a} = 0 - \frac{W_c}{E_b \cdot I_a^2} + \frac{R_a}{E_b} = 0$

$\rightarrow \frac{W_c}{\cancel{E_b} \cdot I_a^2} = \frac{R_a}{\cancel{E_b}}$

* $W_c = I_a^2 R_a$

* $\boxed{I_a = \sqrt{\frac{W_c}{R_a}}}$

Efficiency is maximum if constant loss (W_c) and variable loss ($I_a^2 R_a$) is equal.

Q: A 10 kW DC shunt motor has the following losses at fall load. mechanical = 300 W, Iron loss = 400 W. ~~Ku~~ shunt field copper losses are 100 W, armature copper losses are 100 W. calculate the full load efficiency of motor and the armature current corresponding to max efficiency. if armature resistance is 0.25 Ω

A Mechanical loss = 300 W

Iron loss = 400 W

shunt field 'W' loss = 100 W

Armature 'Cu' loss = 500 W

$R_a = 0.25\ \Omega$

Constant loss = W_c = 300 + 400 + 100 = 800 W

Variable loss = 500 W

$$\text{Efficiency} = \frac{O/P}{O/P + W_c + \text{variable loss}}$$

$$= \frac{10 \times 10^3}{10 \times 10^3 + 800 + 500} \times 100$$

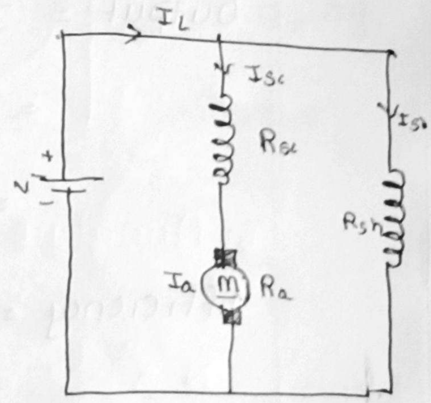
$$= 88.49 \%$$

$$I_a = \sqrt{\frac{W_c}{R_a}} = \sqrt{\frac{800}{0.25}} = 56.56 A$$

Q A 250 V DC long shunt compound motor takes a current of 82 A at a full load. Calculate output power and efficiency for given details. Armature resistance is 0.09 Ω, shunt field resistance is 125 Ω, series field resistance is 0.04 Ω total all other loss are 750 W

A $V = 250 V$

$I_L = 32 A$



$R_a = 0.09 \Omega$

$R_{sc} = 0.04 \Omega$

$R_{sh} = 125 \Omega$

Total other losses $= 750 W$

$$I_{sc} = I_a = I_L - I_{sh}$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{125} = 2A$$

$$\therefore I_a = I_L - I_{sh} = 82 - 2 = 80 A$$

$$I_a = I_{sc} = 80A$$

Armature 'cu' loss $= I_a^2 R_a = (80)^2 (0.09)$

$$= 576 W$$

* Series field 'Cu' loss $= I_{sc}^2 R_{sc} = (80)^2 (0.04)$

$= 256 W$

* Shunt field 'Cu' loss $= I_{sh}^2 R_{sh} = (2)^2 (125)$

$= 500 W$

Other losses $= 750 W$

Total losses $= 576 + 256 + 500 + 750$

$= \underline{2082 W}$

Input power $= V I_L$

$= (250)(82)$

$= \underline{20500 W}$

Output = Input − losses

$= 20500 - 2082$

$= \underline{18418 W}$

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} \times 100$$

$$= \frac{18418}{20500} \times 100$$

$= \underline{89.84\%}$