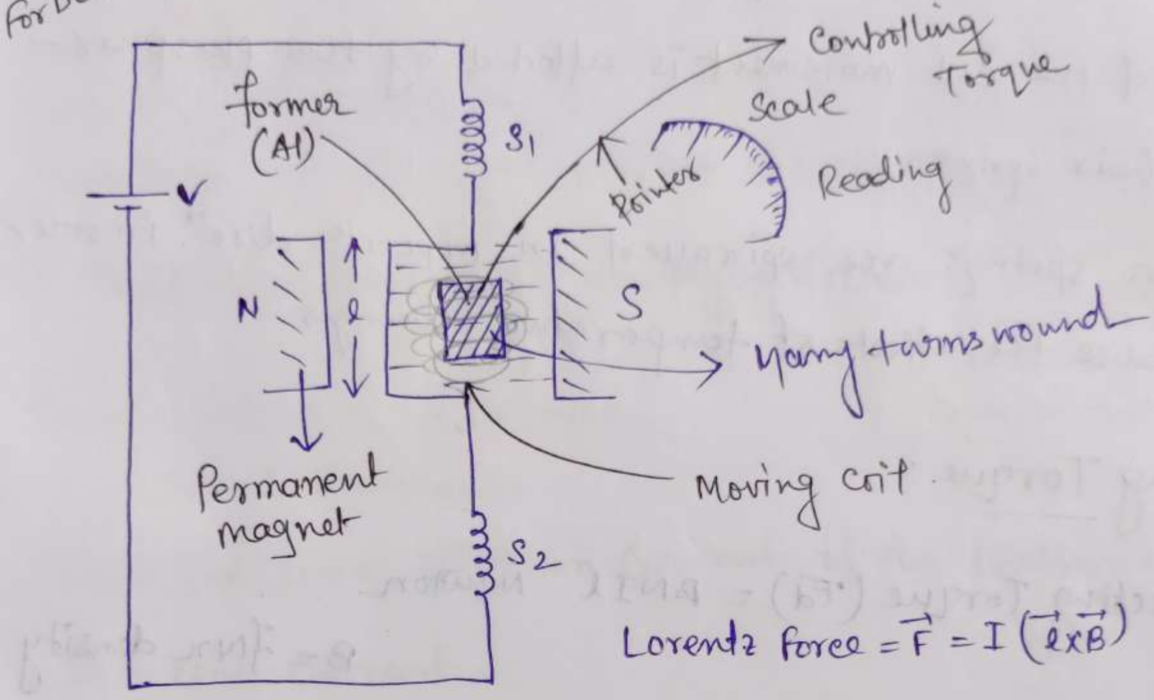
ELECTRICAL MEASUREMENT

PMMC (Permanent Magnetic Moving Coil) (Pawan chandani)

For DC



Lorentz force $= \vec{F} = I(\vec{l} \times \vec{B})$

→ Principle:

when a current carrying conductor is placed in a magnetic field and a force acted upon it which tends to move it to one side and out of the field.

→ Permanent magnet is made of Alnico and has soft iron end pole pieces.

→ Between the magnetic poles is fixed a soft iron cylinder whose function —

(i) To make the field radial and uniform.

(ii) To decrease the reluctance of the air path b/w the poles and hence increase the magnetic flux.

→ Al frame not only provides support for the coil but also provides damping by eddy currents induced in it.

→ Control of the coil movement is affected by two phosphor-Bronze hair springs.

→ The two springs are spiralled in opposite dirⁿ in order to neutralize the effects of temperature changes.

Deflecting Torque :

Deflecting Torque (T_d) = BNIl Newton

B = flux density
l = length of coil
b = breadth of coil
N = no. of Turns

$\therefore T_d = F_d \times$ perpendicular dist.

$= NBIl \times b$

$= NBIA$

$= BINA$

if B is constant Then $\boxed{T_d \propto I}$.

Such Instruments are invariable Spring Controlled so that $T_c \propto$ deflection θ.

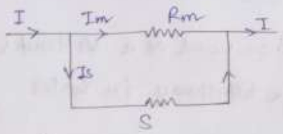
Since, the final deflected position $T_d = T_c$

$\therefore \boxed{\theta \propto I}$

Advantage & Disadvantage of PMMC from B.L. Theraja Book.

Extension of Range :

① As Ammeter :



→ Here low resistance shunt is connected in parallel of the Instrument and provides a bypath for extra Current.

→ Multiplying power or multiplying factor = $\dfrac{\text{maximum Current with Shunt}}{\text{full scale deflection current without Shunt}}$

R_m = instrument Resistance

S = Shunt Resistance

I_m = full scale deflection Current of the Instrument.

I = line Current.

$I = I_m + I_s$

$\therefore I_m \times R_m = S I_s$

$\Rightarrow I_m R_m = S(I - I_m)$

$\Rightarrow S = \dfrac{I_m R_m}{I - I_m}$

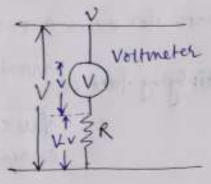
$\therefore \dfrac{I}{I_m} = \left(1 + \dfrac{R_m}{S}\right)$

$\therefore$ multiplying power $= \left(1 + \dfrac{R_m}{S}\right)$.

$\therefore$ Lower the value of Shunt Resistance, greater its multiplying power.

(II) As Voltmeter:

→ When used as a Voltmeter can be increased by using High Resistance in Series.



I_m = Full scale deflection current

R_m = Instrument Resistance.

$V = R_m I_m$ = full scale p.d accross it

R = Series Resistance Required.

The the Voltage drop across R is $V - v$.

$$R = \frac{V - v}{I_m}$$

$$\Rightarrow R \cdot I_m = V - v$$

Dividing both Sides by v we get,

$$\frac{R I_m}{v} = \frac{V}{v} - 1$$

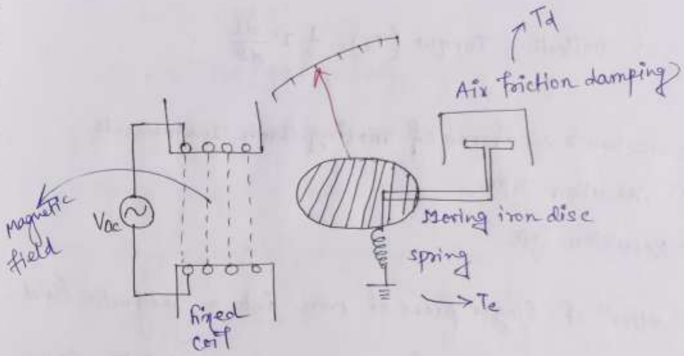
$$\Rightarrow \frac{R \cdot I_m}{I_m R_m} = \frac{V}{v} - 1$$

$$\Rightarrow \frac{V}{v} = \left(1 + \frac{R}{R_m}\right)$$

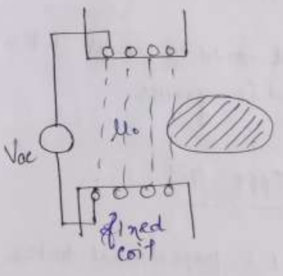
∴ Voltage multiplication = $\left(1 + \frac{R}{R_m}\right)$

∴ Larger the Value of R, greater the Voltage multiplication or range.

Moving Iron-Meter (Both AC and DC)



We use electromagnet for generating magnetic field



$\mu_0 \rightarrow$ Relative permeability

When disc enters to the magnetic field μ_0 change to $\mu_r \mu_0$.

$$\mu_0 \rightarrow \mu_0 \mu_r$$

$$\boxed{L = \frac{\mu_0 \mu_r N^2 A}{l}}$$

When position of moving iron changes → Inductance Chan

θ changes → L changes.

$$\boxed{T = \frac{dU}{d\theta}}$$

$dU \rightarrow$ potential Energy.

- In a Conductor energy stored is $- U = \frac{1}{2} L I^2$

$$\Rightarrow \frac{dU}{d\theta} = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

$\therefore$ Deflecting Torque $(T_d) = \frac{1}{2} I^2 \frac{dL}{d\theta}$

There are two basic forms of moving Iron Instruments

(I) Attraction Type

(II) Repulsion Type

Attrac^n: attra^n of single piece of Iron into a magnetic field.

Repl^n: Two adjacent pieces of iron magnetised by the same Magnetic field.

→ The Amount of deflection produced would be greater when the Current producing the magnetic field is greater.

Deflecting Torque for Attractive Type M.I:

The Magnetization of Iron disc is proportional to the component of H acting along the axis of disc $= H \sin(\theta + \phi)$

ϕ = subtend an angle ϕ ~~rotor~~ when iron disc in zero pos^n

θ = deflection produced be θ Corresponding to a Current I through the Coil.

Force $(F) = H^2 \sin(\theta + \phi)$

$H \alpha I, \quad F \alpha I^2$

$T_d = F l \cos(\theta + \phi)$

So, $T_d \propto I^2 \sin(\theta + \phi) \times l \cos(\theta + \phi)$

$\Rightarrow T_d \propto I^2 \sin 2(\theta + \phi) = K I^2 \sin 2(\theta + \phi)$

If spring control is used then $T_c = K' \theta$

In the steady pos^n of deflection, $T_d = T_c$

$K I^2 \sin 2(\theta + \phi) = K' \theta$

$\boxed{\theta \propto I^2}$

If A.C used

$\theta \propto I^2_{rms}$

Source of Error

Deflecting Torque in Terms of change in Self-Induction

When I current passes through the Instrument, the deflection is θ, inductance L.

Further, when current changes from I to $(I + dI)$ deflection changes from θ to $(\theta + d\theta)$ and L changes to $(L + dL)$

Then the increase in energy stored in the magnetic field $(dE) = d\left(\frac{1}{2} LI^2\right)$

$$= \frac{1}{2} L \cdot 2I\,dI + \frac{1}{2} I^2 dL$$

$$= LI\,dI + \frac{1}{2} I^2 dL \text{ Joule.}$$

If $T\frac{1}{2}$ N-m is the Controlling torque for deflection θ, then extra energy stored in the Control system is $T \times d\theta$ J.

Total Increased in the stored Energy of the system is

$$= LI\,dI + \frac{1}{2} I^2 dL + T \times d\theta \quad \text{—— (1)}$$

The Induced emf is $(e) = \frac{d}{dt}(LI)$

The energy drawn from Supply to overcome this back emf is

$$= e \cdot I dt = \frac{d}{dt}(LI) \cdot I dt = I \cdot d(LI) = I\,(L \cdot dI + I \cdot dL)$$

$$= LI\,dI + I^2 dL \quad \text{— (2)}$$

Equating (1) & (2). we get,

$$LI\,dI + \frac{1}{2} I^2 dL + T d\theta = LI\,dI + I^2 dL$$

$$\Rightarrow T = \frac{1}{2} I^2 \cdot \frac{dL}{d\theta} \text{ N.m}$$

Ammeter and As Voltmeter from Book)

Controlling Torque:- The deflection of moving System would be indefinite if there were no controlling or restoring Torque. This Torque oppose the deflecting Torque and increase with the deflection of the moving System. The pointer is brought to Rest at a position where the two opposing torques are equal. The deflecting Torque ensures that the currents of different magnitude shall produced deflection of the moving system in proportion to their size. Without such a Torque, the pointer would swing over to the maximum deflected position

DC MACHINE

E.M.F Equation of DC Generator

Let P = Number of poles of generator

ϕ = Flux produced by each pole (wb)

N = Speed of the armature of generator (rpm)

Z = Total no. of Conductors in armature

A = No. of parallel paths in which conductors are distributed

e = Rate of Cutting the flux.

$e = \frac{d\phi}{dt}$ — as per faraday's law of electromagnetic Induction.

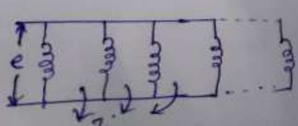
Total flux = Flux produced by each pole x no. of poles

$(\phi) = \phi \times P$

Time required for Conductor to Complete one revolution

$= \frac{60}{N}$

$\therefore \quad e = \frac{\phi P}{\left(\frac{60}{N}\right)} = \frac{\phi P N}{60}$ [only for one Conductor]



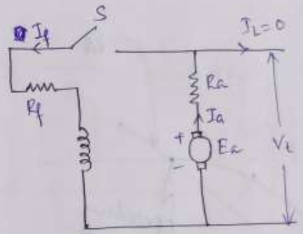
Z conductors are distributed in A parallel paths

Effectively $\frac{Z}{A}$ conductors need to be Multiplied with emf induced in one ~~conductor~~ path

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

Total emf induced in DC generator.

Voltage Build up in a DC Shunt Generator



E_{ar} = Residual emf

No load, $N \rightarrow$ Constant speed

(1) Switch open. $I_f = 0$

$$\boxed{E_a = E_{ar}\ (2 \text{ to } 4V)}$$

(2) Switch closed.

$E_a = V_t + I_a R_a$.

No-load $\Rightarrow I_a$ = Small

$I_a R_a$ = Very small (Neglect)

$\boxed{E_a = R_f \cdot I_f}$ $\rightarrow$ $(y = mx)$.

$E_{ar} \rightarrow I_{f_1}$

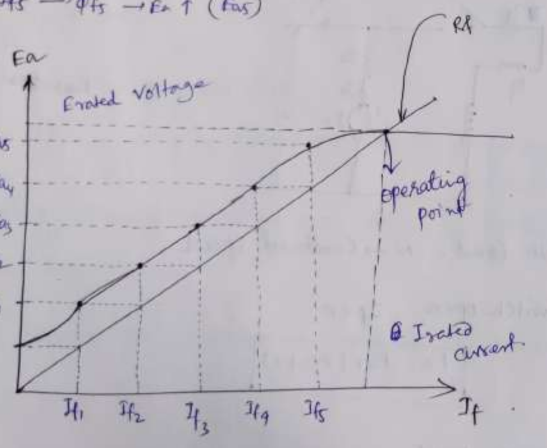
$I_{f_1} \rightarrow \phi_{f_1} \rightarrow E_a \uparrow \; (E_{a_1})$

$E_{a_1} \rightarrow I_{f_2} \rightarrow \phi_{f_2} \rightarrow E_a \uparrow \; (E_{a_2})$

$E_{a_2} \rightarrow I_{f_3} \rightarrow \phi_{f_3} \rightarrow E_a \uparrow \; (E_{a_3})$

$E_{a_3} \rightarrow I_{f_4} \rightarrow \phi_{f_4} \rightarrow E_a \uparrow \; (E_{a_4})$

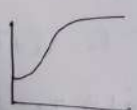
$E_{a_4} \rightarrow I_{f_5} \rightarrow \phi_{f_5} \rightarrow E_a \uparrow \; (E_{a_5})$



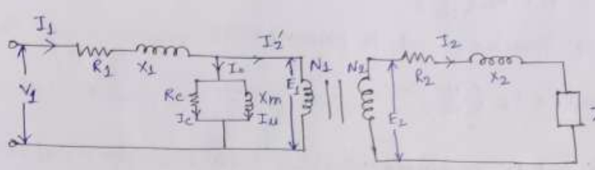
$\propto \phi$

Saturate

Constant



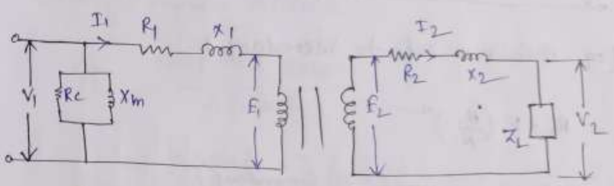
Equivalent Circuit of Single Phase Transformer

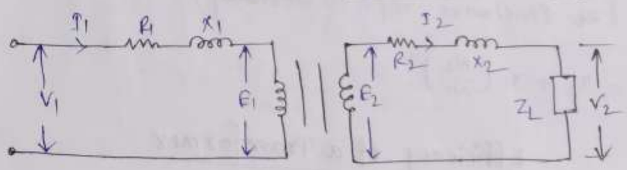


$\overline{I_1} = \overline{I_0} + \overline{I_2'}$

$\hookrightarrow$ No load Primary Current, Very low (5-10% of full load Current)

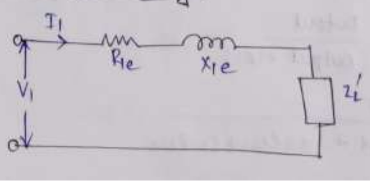
$\Rightarrow \overline{I_1} \simeq \overline{I_2'}$





Equivalent Circuit diagram of 1ϕ transformer

(a) Referred to Primary :-



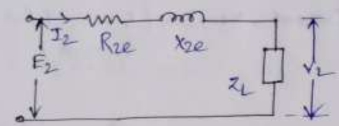
R_{1e} (eqn Resistance ref. to primary)

$$R_{1e} = R_1 + R_2 \left(\frac{N_1}{N_2}\right)^2$$

X_{1e} (eq. Reactance ref. to primary)

$$X_{1e} = X_1 + X_2 \left(\frac{N_1}{N_2}\right)^2$$

(b) Referred to Secondary :-



R_{2e} (eq. Resistance ref. to Secondary)

$$R_{2e} = R_2 + R_1 \left(\frac{N_2}{N_1}\right)^2$$

X_{2e} (eq. Reactance ref. to Secondary)

$$X_{2e} = X_2 + X_1 \left(\frac{N_2}{N_1}\right)^2$$

Efficiency of a Transformer

$$\text{Efficiency} = \frac{\text{Output}}{\text{input}}$$

$$\text{Efficiency } (\eta) = \frac{\text{Output}}{\text{Output} + \text{loss}}$$

$$\eta = \frac{\text{Output}}{\text{Output} + \text{Iron loss} + \text{Cu loss}}$$

$$\eta = \frac{\text{Input} - \text{Losses}}{\text{Input}} = 1 - \frac{\text{Losses}}{\text{Input}}$$

Condn for Maximum Efficiency :-

Cu loss $= I_1^2 R_{01}$ or $I_2^2 R_{02} = W_{cu}$

Iron loss = Hysteresis loss + Eddy current loss

$= W_h + W_e = W_i$

Considering primary side,

Primary Input $= V_1 I_1 \cos\phi_1$

$$\eta = \frac{V_1 I_1 \cos\phi_1 - \text{losses}}{V_1 I_1 \cos\phi_1}$$

$$= \frac{V_1 I_1 \cos\phi_1 - I_1^2 R_{01} - W_i}{V_1 I_1 \cos\phi_1}$$

$$= 1 - \frac{I_1 R_{01}}{V_1 \cos\phi_1} - \frac{W_i}{V_1 I_1 \cos\phi_1}$$

Diff. wrt I_1

$$\Rightarrow \frac{d\eta}{dI_1} = 0 - \frac{R_{01}}{V_1 \cos\phi_1} + \frac{W_i}{V_1 I_1^2 \cos\phi_1}$$

for maxm η, $\frac{d\eta}{dI_1} = 0$

$$\Rightarrow \frac{R_{01}}{V_1 \cos\phi_1} = \frac{W_i}{V_1 I_1^2 \cos\phi_1}$$

$$\Rightarrow W_i = I_1^2 R_{01} \text{ or } I_1^2 R_{02}$$

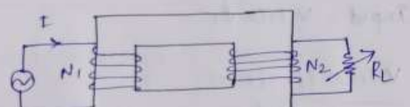
Working & Principal Operation of Transformer

① $E = N.\frac{d\phi}{dt}$ ② $E = N\omega\phi_m \times \cos\omega t$ ③ $E_{max} = N\omega\phi_{max}$

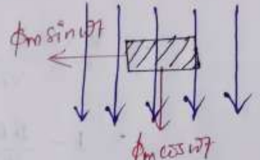
④ $E_{rms} = \frac{N\omega}{\sqrt{2}}\phi_m = \frac{2\pi}{\sqrt{2}} \cdot f N\phi_m$ ⑤ $E_{rms} = 4.44 f N\phi_m$

$f \rightarrow$ freq N = No. of coil windings, ϕ = flux.

Emf eqn of a single Phase Transformer:



We know that, induced emf in coil of 'N' no. of turns will be –



$E = -N.\frac{d\phi}{dt}$

$\phi = \phi_m \sin\omega t$

$E = -N.\frac{d}{dt}(\phi_m \sin\omega t)$

$E = N\omega\phi_m \cos\omega t$.

We can say that,

$E_m = N\omega\phi_m$.

Emf in rms form of Representation

$E_{rms} = \frac{E_m}{\sqrt{2}}$

$\therefore E_{rms} = \frac{N\omega\phi_m}{\sqrt{2}}$ $\omega = 2\pi f$

$E_{rms} = \sqrt{2}N\pi f\phi_m$

$\Rightarrow \boxed{E_{rms} = 4.44 f\phi_m N}$

This is the rms value of emf induced in a Single phase Transformer.

Voltage Transformation ratio

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

$K \rightarrow$ Voltage Transformation ratio.

(i) $K > 1 \rightarrow$ step up

(ii) $K < 1 \rightarrow$ step down.

Principal of Operation of Single Phase Transformer:–

(a) Faraday's Law of Electromagnetic Induction.

(b) On the basis of mutual Induction.

* Emf induced in primary side using (a) and emf flow from primary to secondary side using (b).

* Transformer Core = Silicon-steel. (Reduce Hysterisis loss, lamination for reduce eddy current loss.

Reluctance ↓ μ_r ↑ $S = \frac{l}{A\mu_0\mu_r}$

$S \propto \frac{1}{\mu_r}$

(c) Reluctance should be less and relative permeability should be high.

Faraday① if There will be a relative motion between a set of conductors and uniform magnetic field then emf will be induced in the conductor.

Faraday② The induced emf will be directly proportional to the amount of magnetic flux linked with the system.

$$e = -N \cdot \frac{d\phi}{dt}$$

Working :-

- When the primary of a Transformer is connected to an a.c supply, the current flows in the coil and the Magnetic field builds up.

- The cond^n is known as mutual inductance and the flow of current is as per Faraday's law of electromagnetic induction.

- As the current increases from zero to its maximum value the Magnetic field strengthens and is given by $d\phi/dt$.

- The electromagnet forms the Magnetic lines of force and expands outwards from the coil forming a path of magnetic flux.

$$\phi_T = \phi_u + \phi_e.$$

- The ~~coil~~ Turns of both windings get linked by this magnetic flux.

- The strength of a magnetic field generated in the core depends on the number of the turns in the winding and the amount of current.

- The Magnetic flux and current are directly proportional to each other.

D.C generator

→ Convert Mech to elect.

→ principal of the production of

DC MOTOR

Force = BIL newton.

Back emf :-

When the motor armature rotates, the conductor also rotates and hence cut the flux. In accordance with the laws of electromagnetic induction, emf is induced in them whose direction, as found by Fleming's Right hand rule, is in opposition to applied voltage. Because of its opposing direction, it is reffered to as counter emf of back emf E_b.

V has to drive I_a against the opposition of E_b. The power required to overcome this opposition is $E_b I_a$.

Voltage eqn of a motor:-

The Voltage V applied across the motor armature has to,

(a) Overcome the back Emf E_b, and

(b) Supply the armature ohmic drop $I_a R_a$.

Hence ⇒ $\boxed{V = E_b + I_a R_a}$ → Voltage eqn of DC motor

Now, Multiplying both sides by I_a.

$$V I_a = E_b I_a + I_a^2 R_a$$

$V I_a$ → Electrical power input to the armature

$E_b I_a$ → Electrical equivalent of mechanical power developed in the armature.

$I_a^2 R_a$ = Copper loss in the armature.

Condn for maximum Efficiency:-

The gross mechanical power developed by motor is

$$P_m = V I_a - I_a^2 R_a$$

Differentiating both side with respect to I_a and equating the Result to zero, we get

$$\frac{dP_m}{dI_a} = V - 2 I_a R_a = 0$$

$$\Rightarrow I_a R_a = V/2$$

As, $V = E_b + I_a R_a$

$$\Rightarrow E_b = V - \frac{V}{2} = V/2$$

$$\therefore \boxed{E_b = \frac{V}{2}}$$

⇒ The gross mechanical power developed by a motor is maximum when back emf is equal to half the supply Voltage.

Torque:

Consider a pulley of radius r meter acted upon by a Circumferential force of F N which Causes it to rotate at N r

Then Torque $(T) = F \times r$ N.m

Work done by this force in one revolution

= Force × dist.

= $F \times 2\pi r$ Jule.

Power developed = $F \times 2\pi r \times N$ Joule/sec or Watt

$= (F \times r) \times 2\pi n \quad W$

$= (F \times r) \times \omega \quad W$ $\qquad 2\pi n = \omega$, $F \times r = T$

$= T\omega \quad W$

if N is in rpm then.

$$\omega = \frac{2\pi N}{60} \text{ rad/s}$$

$$\therefore \boxed{P = \frac{2\pi N}{60} \times T = \frac{NT}{9.55}}$$

Armature Torque of a motor:-

Let Ta be the Torque develope by a armature of a motor running at N rps. If Ta is in N-m, then power developed = $T_a \times 2\pi N$ Watt.

We also know that electrical power converted into mechanical power in the armature = $E_b I_a$ W

Comparing above eq^n,

$$T_a \times 2\pi N = E_b I_a$$

if N is rps then $\boxed{T_a = \frac{E_b I_a}{2\pi N}}$

if N is rpm, Then, $T_a = \frac{E_b I_a}{2\pi \times N/60} = \boxed{9.55 \times \frac{E_b I_a}{N}}$

also, $T_a = 0.159\, \phi Z I_a \times (P/A)$ N-m.

Shaft Torque:-

The whole armature Torque is not available for doing useful ~~Torque~~ work, because of iron and friction losses in the motor. The Torque which is available for doing useful work is Known as Shaft Torque T_{sh}. The motor output is given by —

Output = $T_{sh} \times 2\pi N$ watt $\quad$ N rps.

$$\Rightarrow T_{sh} = \frac{\text{Output}}{2\pi N}$$

if N is rpm then

$$T_{sh} = \frac{\text{Output}}{2\pi N/60} = 9.55 \times \frac{\text{Output}}{N}$$

$$\boxed{T_{sh} = 9.55 \times \frac{\text{Output}}{N}}$$

Speed Control of DC motor:

The expression of Speed Control dc motor is

$$N = \frac{V - I_a R_a}{Z\phi}\left(\frac{A}{P}\right) = K \cdot \frac{V - I_a R_a}{\phi} \text{ rps.}$$

$R_a \rightarrow$ Armature Resistance.

$= (F \times r) \times 2\pi n$ W

$= (F \times r) \times \omega$ W $\quad 2\pi n = \omega$, $F \times r = T$

$= T\omega$ W

if N is in rpm then.

$$\omega = \frac{2\pi N}{60} \text{ rad/s}$$

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$$T_a \times 2\pi N = E_b I_a$$

if N is rps then $\boxed{T_a = \frac{E_b I_a}{2\pi N}}$

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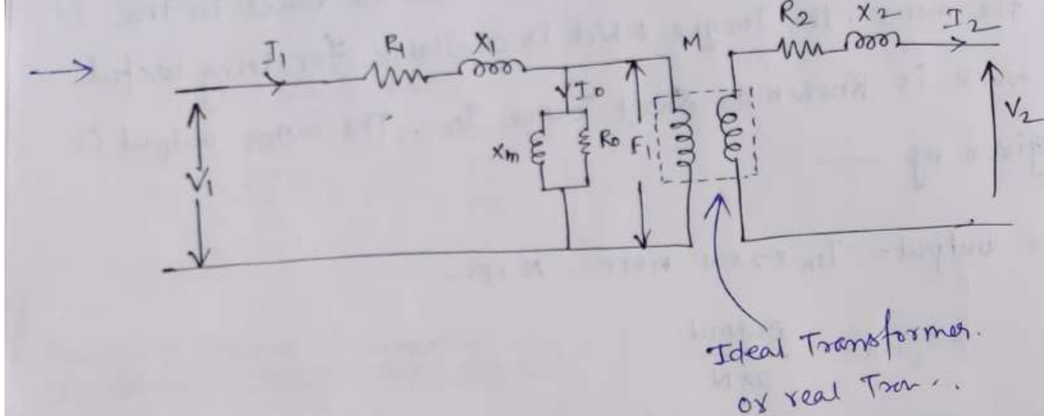
The expression of Speed Control dc motor is

$$N = \frac{V - I_a R_a}{Z\phi}\left(\frac{A}{P}\right) = K \cdot \frac{V - I_a R_a}{\phi} \text{ rps.}$$

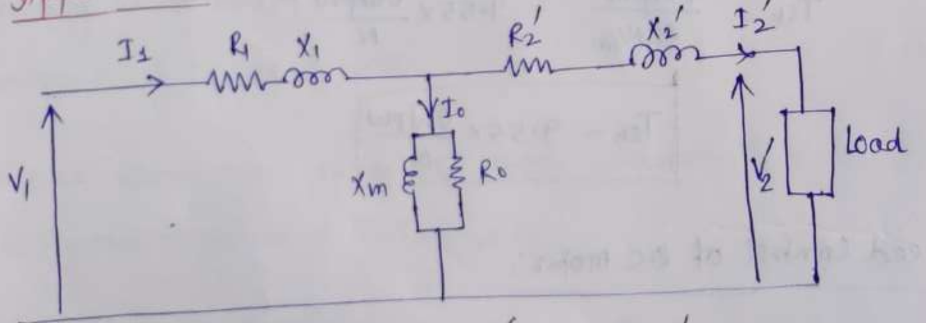
$R_a \rightarrow$ Armature Resistance.

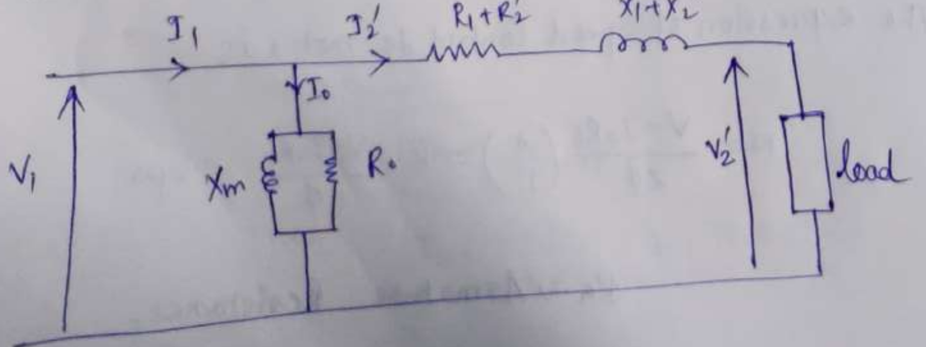
Q[24] Draw the exact equivalent circuit of a real single phase Transformer with load? How do you obtain the approximate equivalent circuit of the Transformer from the real equivalent circuit?

→



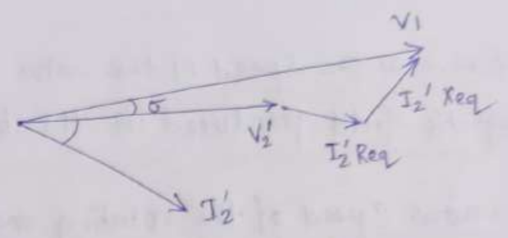
□) Approximate:



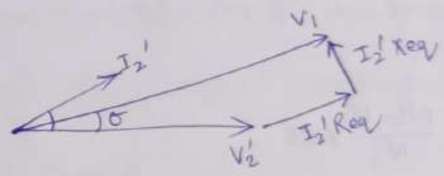


Q Draw Phasor Diagram of single phase Transformer for lagging power factor load with proper explaination.

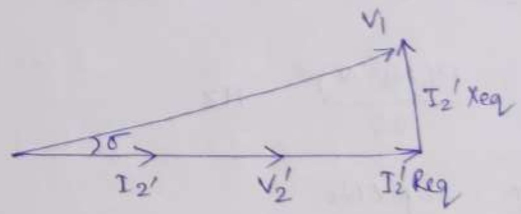
→



lagging power factor



leading power factor



Unity Power factor

Three Phase Induction Motor

Slip

→ The sleip is defined as the speed of the rotor relative to the rotating) magnetic field produced in the stator.

N_s = synchronous speed of the rotating magnetic field in rpm

N = Speed of Rotor in rpm.

$$\text{Slip } (S) = N_s - N$$

$$\text{percentage slip}, S = \frac{N_s - N}{N_s} \times 100$$

* At stand still, slip is equal to one or 100%.

Frequency of Rotor Emf and Current

$$f_r = \frac{P(N_s - N)}{120} \text{ Hz}$$

But, $N_s - N = \text{slip} \times N_s$

Thus $f_r = \text{slip} \times \frac{PN_s}{120}$

Supply frequency to the stator $f = \frac{PN_s}{120}$

$\therefore$ Rotor frequency = slip × Stator freq

$$f_r = sf$$

$$\Rightarrow \boxed{s = \frac{f_r}{f}}$$

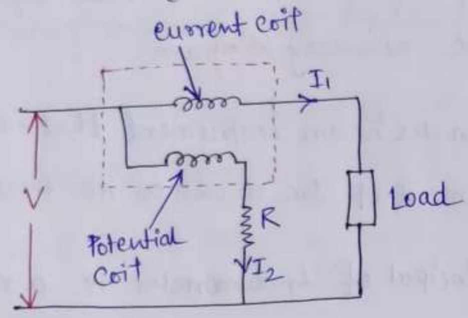
Q Explain the principal of operation of Electrodynamometer type instrument with necessary diagram.

→ An Electrodynamometer is an instrument that is universally used for the measurement of DC as well as AC electric power.

It works on the principal of dynamometer i.e. a mechanical force acts b/w two current carrying conductors.

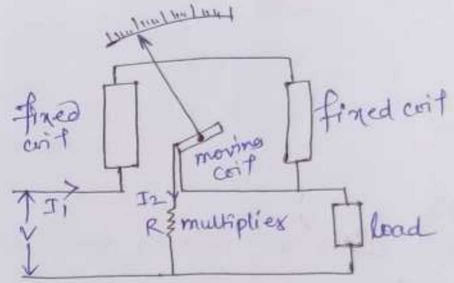
Principal of operation:

When electrodynamometer Wattmeter is connected in the ckt to measure the electric power. The current coil carries the load current and the potential coil carries a current ~~potential~~ proportional to the load voltage. Because of the current in the two coils, a mechanical force acts b/w them due to which the moving coil (Potential coil) moves and hence the pointer attached to it. The pointer comes to rest at a position where the deflecting Torque and Controlling Torque become equal. When the current is reversed in the circuit, the reversal of current takes place in both the current coil and potential coil so that the direction of the deflecting Torque remains unchanged. Hence the electrodynamometer wattmeter can be used for the measurement of DC as well as AC power.



Construction:-

The electrodynamometer wattmeter has a fixed coil divided into two parts and is connected in series with a load and carries a load current (I_1). The moving coil is connected across the load through a series multiplier resistance R and carries a current (I_2) proportional to the load voltage. The fixed coil is called current coil and the moving coil is called as potential coil. The controlling Torque is provided by two spiral springs. Air friction damping is provided in electrodynamometer wattmeter. A pointer is attached with the moving coil.



Deflecting Torque:

The Torque (Force) required for the deflection of the pointer is called deflecting Torque. The system which provides the deflecting Torque, when the current is passed through it is called a deflecting system. Every instrument will have a deflecting system that converts the electric energy into mechanical Energy and thus providing the necessary and sufficient deflecting Torque.

In general deflecting Torque is nothing but the movement of the pointer in a measuring instrument.