module - II

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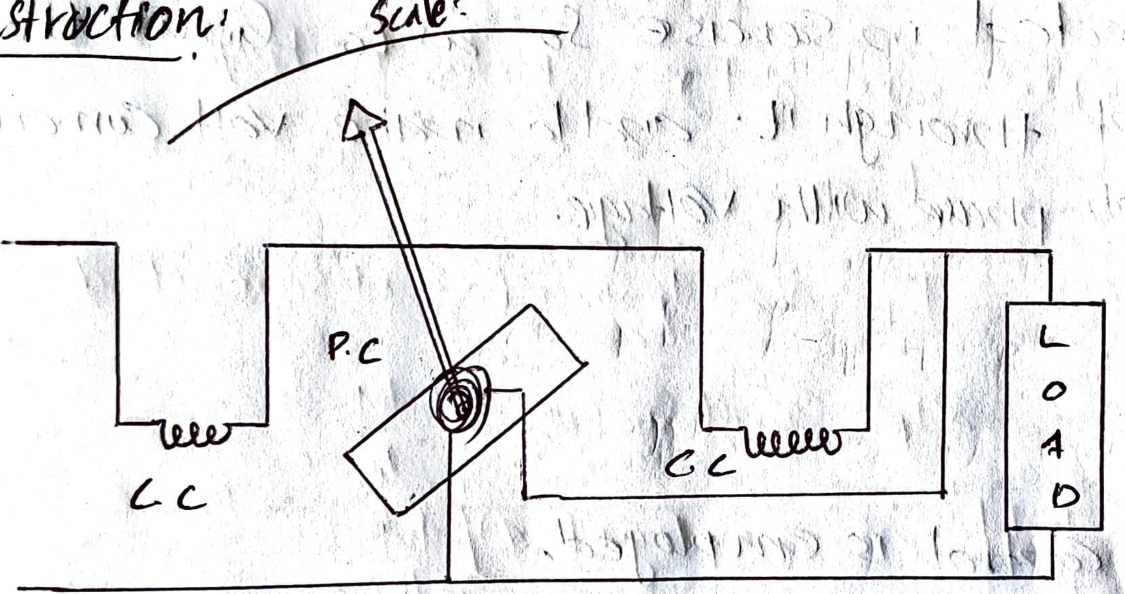
Electrodynamometer Wattmeter

An electrodynamometer - type watt meter is similer in design and construction with the analog electrodynamometer - type Ammeter and Voltmeter.

Construction:



fixed Coil:

* It has 2 Coils Connected in different ways to the same ckt of which power is to be measured.
* fixed coils are Connected in sereise.
* pressure coils are connected in parallel with the supply.
* The magnetic feild is produced by these fixed coils.
* These Coil is devided into 2 Sections so as to provide uniform magnetic feild.

Moving Coil

* Connected acceross the load. Carries ~~to~~ current proportional to load current.
* Also called as pressure coils.
* Mounted on a pivoted spindle.
* A high value non-inductive fixed ~~to~~ resistance is. Connected in sereise so as to limit the current through it. and to make ~~volt~~ current as inph phase with voltage.

Control

* Spring control is employed.

Damping

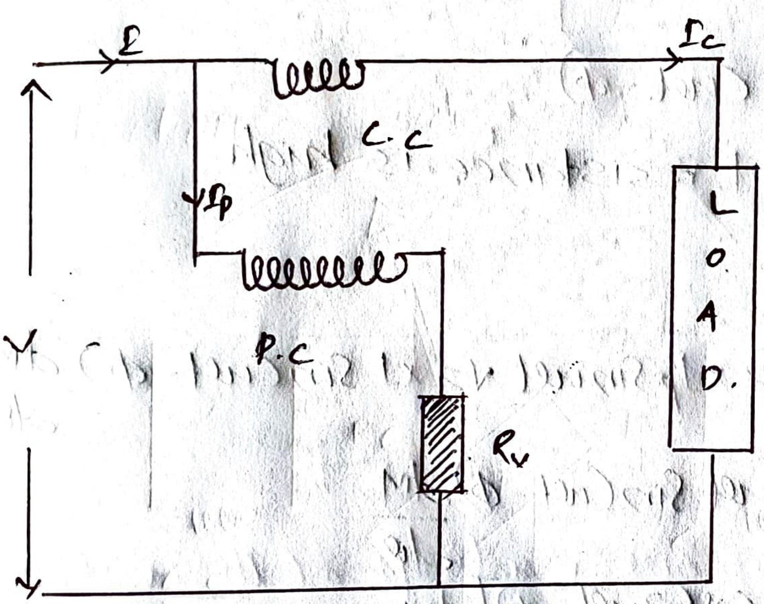
Air friction damping is used.

Sheilding System

* The operating feild produced by the fixed coils are comparitively lower in electrodynamometer type instruments as compared to other instruments.
* So it is essential to sheild the instrument from effects of stray magnetic feild.

- So enclosure is made of alloys with high permiability to restrict penetration of external stray magnetic feild into the instrument.

<u>Working:</u>



V → Voltage.
I → Current
C.C → Current Coil
P.C → pressure Coil.
i_p → Voltage coil I_{inst}
i_c → Current coil I_{inst}
R_v → external resistance with pressure Coil.
R_p → pressure Coil resistance.

M → mutual inductance b/w Current Coil and pressure Coil.
θ → angle of deflection of the moving system
w → Angular frequency
ϕ → phase angle. lag of current w.r.t voltage.

The instantaneous torque of electrodynamometer w/m is.

$$T_i = i_p i_c \frac{dM}{d\theta}$$

Instantaneous value of voltage across the pressure Coil circuit is

$$V_p = \sqrt{2} V \sin wt$$

If the pressure coil resistance is assumed to be high.
The current i_p in the pressure coil thus, can be assumed to in phase with the voltage V_p, and instantaneous value

$$i_p = v_p / R_p = \sqrt{2} V / R_p \sin \omega t = \sqrt{2} I_p \sin \omega t$$

where $I_p = V/R_p$ is the rms value of current in pressure coil.

$$i_c = \sqrt{2} \times I \sin(\omega t - \phi)$$

Since pressure coil resistance is high

Instaneous torque

$$T_i = \sqrt{2} \times I_p \sin \omega t \sqrt{2} \times I \sin(\omega t - \phi) \frac{dM}{d\theta}$$

$$= 2 I_p I \sin \omega t \sin(\omega t - \phi) \frac{dM}{d\theta}$$

$$= I_p I [\cos\phi - \cos(2\omega t - \phi)] \frac{dM}{d\theta}$$

$$T_d = 1/T \int_0^T T_i \, d\omega t = 1/2\pi \int_0^{2\pi} I_p I (\cos\phi - \cos(2\omega t - \phi)) \frac{dM}{d\theta} \, d\omega t$$

$$\frac{I_p I}{2\pi} [\omega t \cos\phi]_0^{2\pi} \frac{dM}{d\theta} = I_p I \cos\phi \frac{dM}{d\theta} = \frac{V}{R_p} I \cos\phi \frac{dM}{d\theta}$$

Thus,

$$T_d = \frac{V I \cos\phi}{R_p} \frac{dM}{d\theta}.$$

with a Spring Constant k, the controlling torque is provided by the spring for a final steady-state deflection of θ is given by

$$T_c = \cancel{k\theta} \, k\theta.$$

* Under Steady State Condition, the avg: deflecting torque will be balanced by the controlling torque provided by the Spring.

* Thus, at balanced condition $T_c = T_d$.
* Steady State deflection θ is thus found to be an indication of the power P to be measured.

$$K\theta = \frac{VI\cos\phi}{R_p}\frac{dM}{d\theta}$$

$$\theta = \frac{VI\cos\phi}{KR_p}\frac{dM}{d\theta} \qquad \theta = K_1\left[\frac{dM}{d\theta}\right]P.$$

Blondel's Theorom

If a network is supplied through 'n' conductors, the total power is measured by summing the reading of 'N' w/m.

By taking one line as common, we can measure the power by using (n-1) w/m

3ϕ Power Measurement

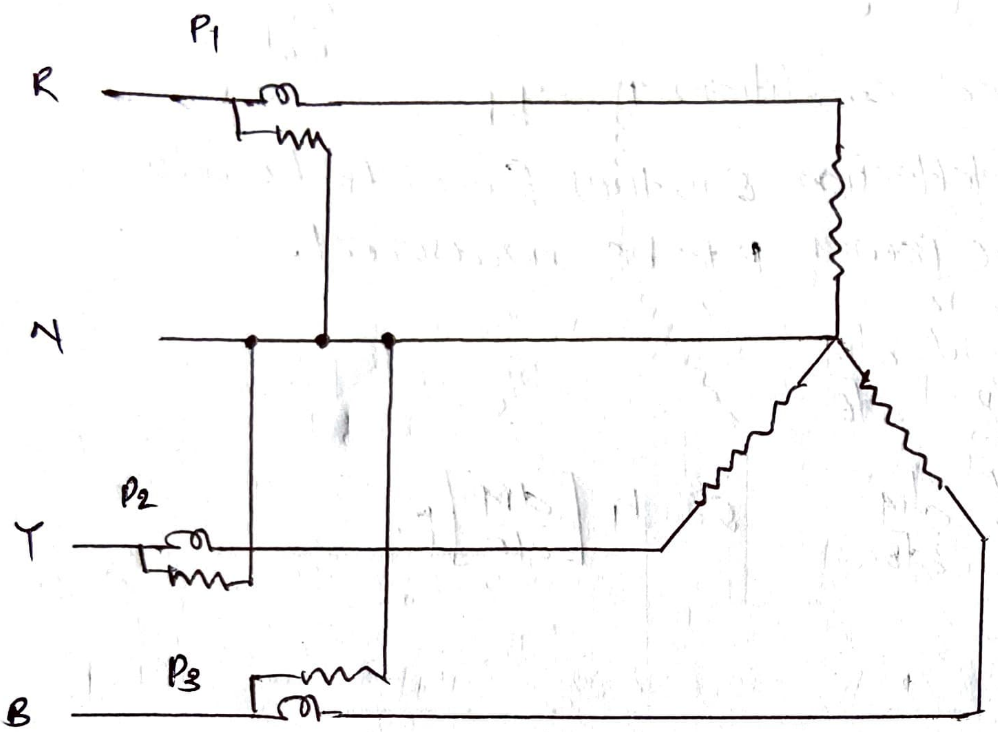
Can be done by 3 methods.

a) Single w/m method.

b) 2 w/m method

c) 3 w/m method.

3w/m Method



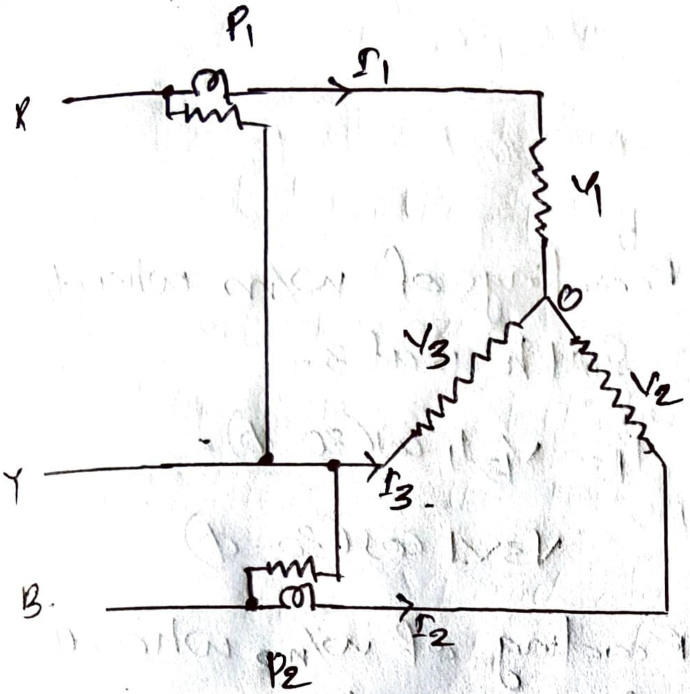
Sum of the instaneous readings of the wattmeter

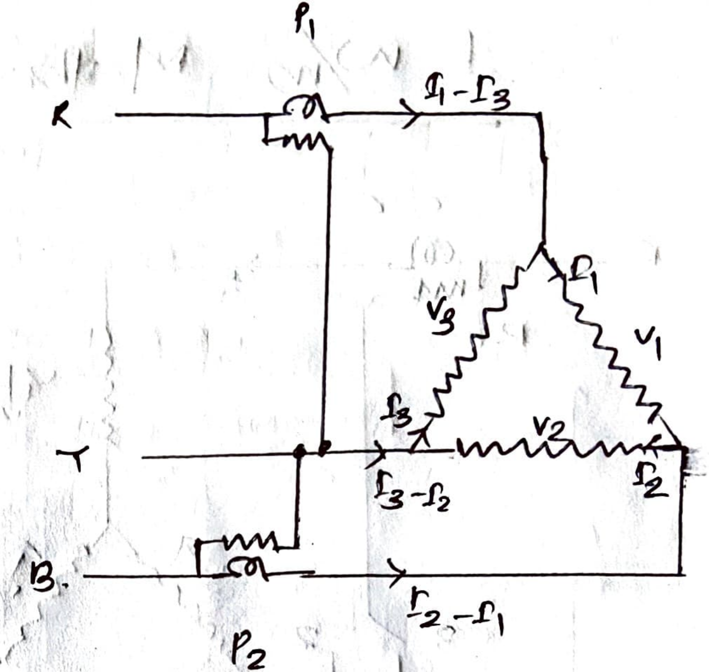
$P = P_1 + P_2 + P_3 = V_1 i_1 + V_2 i_2 + V_3 i_3$ → Instaneous Load.

* Applied 3ϕ 4 wire system.
* ~~Res~~ current coils are connected to respective phases.
* pressure coils are connected to a common line

2w/m Method

* Applied to 3ϕ 3 wire system.
* Can be used in both balanced and unbalanced system.





Star (wye) Connection

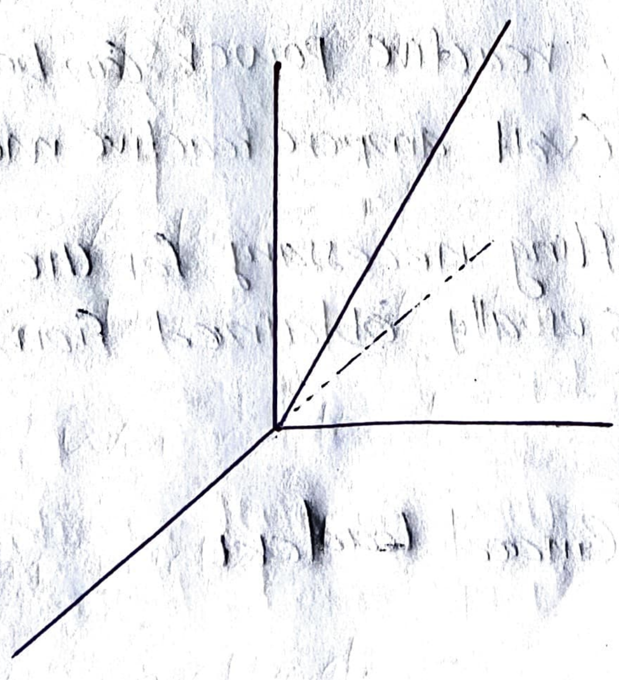
Sum of Instantaneous readings of 2 w/m.

$$P_1+P_2 = i_1(v_1-v_3)+i_2(v_2-v_3)$$
$$= v_1i_1+v_2i_2-v_3(i_1+i_2)$$
$$= v_1i_1+v_2i_2+v_3i_3$$

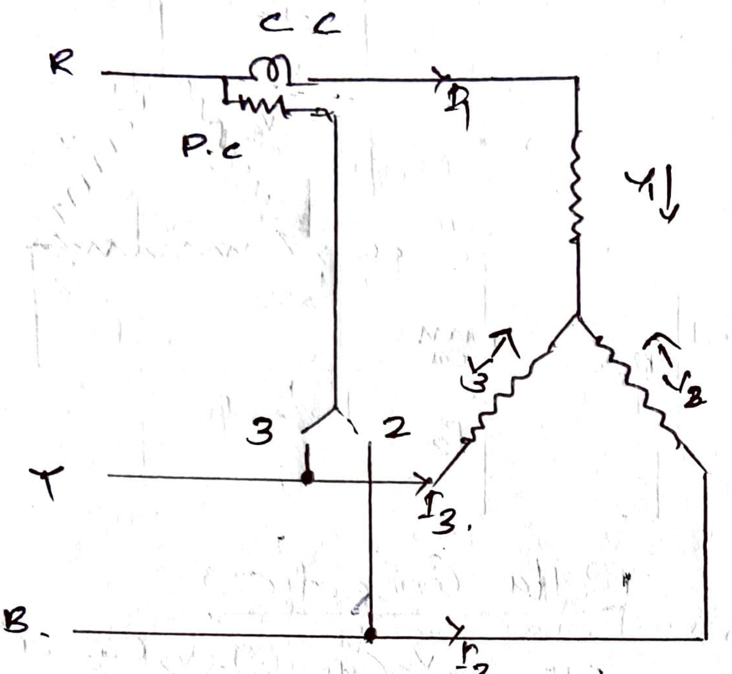
Delta Connection

$$P_1+P_2 = -v_3(i_1-i_3)+v_2(i_2-i_1)$$
$$= v_2i_2+v_3i_3-i_1(v_2+v_3)$$
$$= v_1i_1+v_2i_2+v_3i_3.$$

The sum of the 2 w/m reading is equal to the power consumed by the load. This is irrespective of whether the load is balanced or unbalanced.



1 W/m Method



Readings of w/m when the Switch is at 3.

$P_1 = V_{13} I_1 \cos(30-\phi) =$

$\sqrt{3} VI \cos(30-\phi)$

Reading of w/m when the Switch is at 2

$P_2 = V_{12} I_1 \cos(30+\phi) = \sqrt{3} VI \cos(30+\phi)$

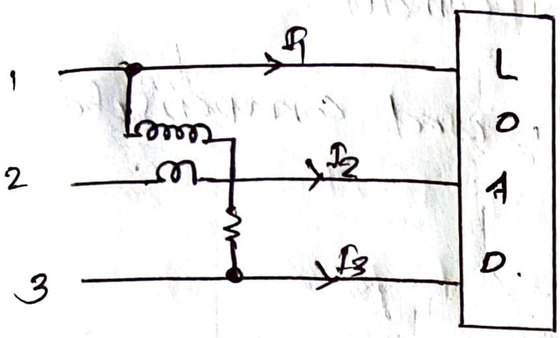
Total power $= P_1 + P_2 = \sqrt{3} VI \cos(30-\phi) + \sqrt{3} VI \cos(30+\phi)$.

$= \sqrt{3} VI [\cos(30-\phi) + \cos(30+\phi)]$

$= 3VI \cos\phi$.

Measurement of Reactive Power

* In a Single phase ckt, reactive power can be measured by a Varmeter. (Volt-ampere reactive meter).
* In 3ϕ ckts phase shifting necessary for the measurement of reactive power is usually obtained from phase shifting transformers.
* In case of 3ϕ balanced load ckt



Reading of w/m $= V_{13} I_2 \cos(90+\phi)$.

$= \sqrt{3} VI \sin\phi$.

Total reactive Volt-ampere of the ckt

$= 3VI \sin\phi$

$\phi = \tan^{-1}(Q/P)$.

LPF W/M (electrodynamometer type).

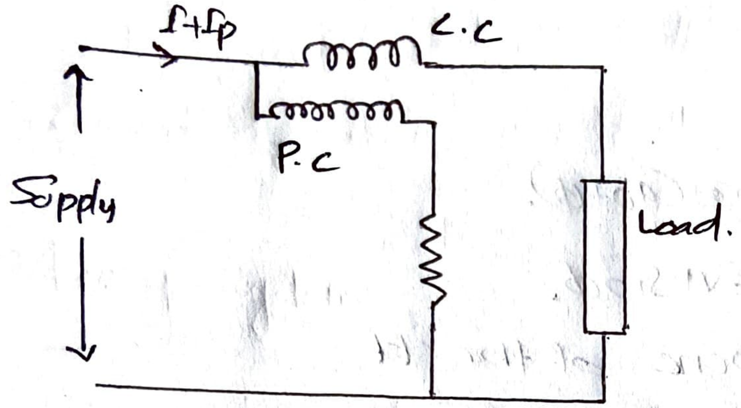
* Measurement of power with low p.f is difficult with ordinary w/m due to
  - a) T_d is small even at full excitation.
  - b) Errors due to inductance of P.c ckt is large at low p.f
* Special features are added to make a LPF w/m from ordinary w/m.

Pressure Coil Current

Pressure coil ckt is designed to have low value of resistance so current through it is increased and there by the torque (upto 10 times more current).

Compensation for pressure Coil Current

in Lpf w/m. Compensation Coil is used compensate error caused by power loss.



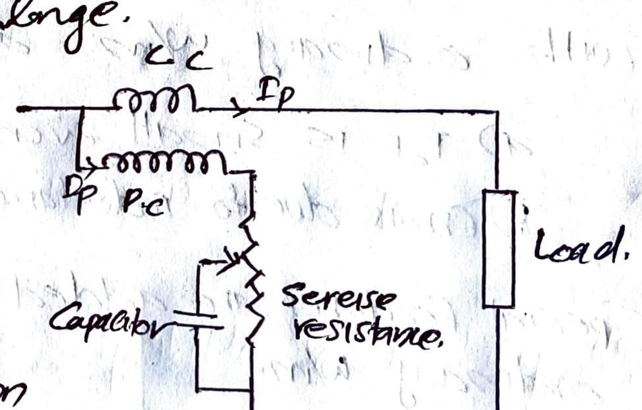
Compensation for Inductance of pressure Coil

The error caused by pressure coil inductance

$\approx I \sin\phi \tan\beta$

with low p.f, the value of ϕ is large and therefore the error, is correspondingly large.

Small Control Torque



low p.f w/m are designed with to have a small control torque So that they give full scale deflection for p.f as low as 0.1

Electrical Energy meter

A device that measure the amount of electrical energy Consumed by electrically powered device.

unit → kwh.

Types of Energy Meter

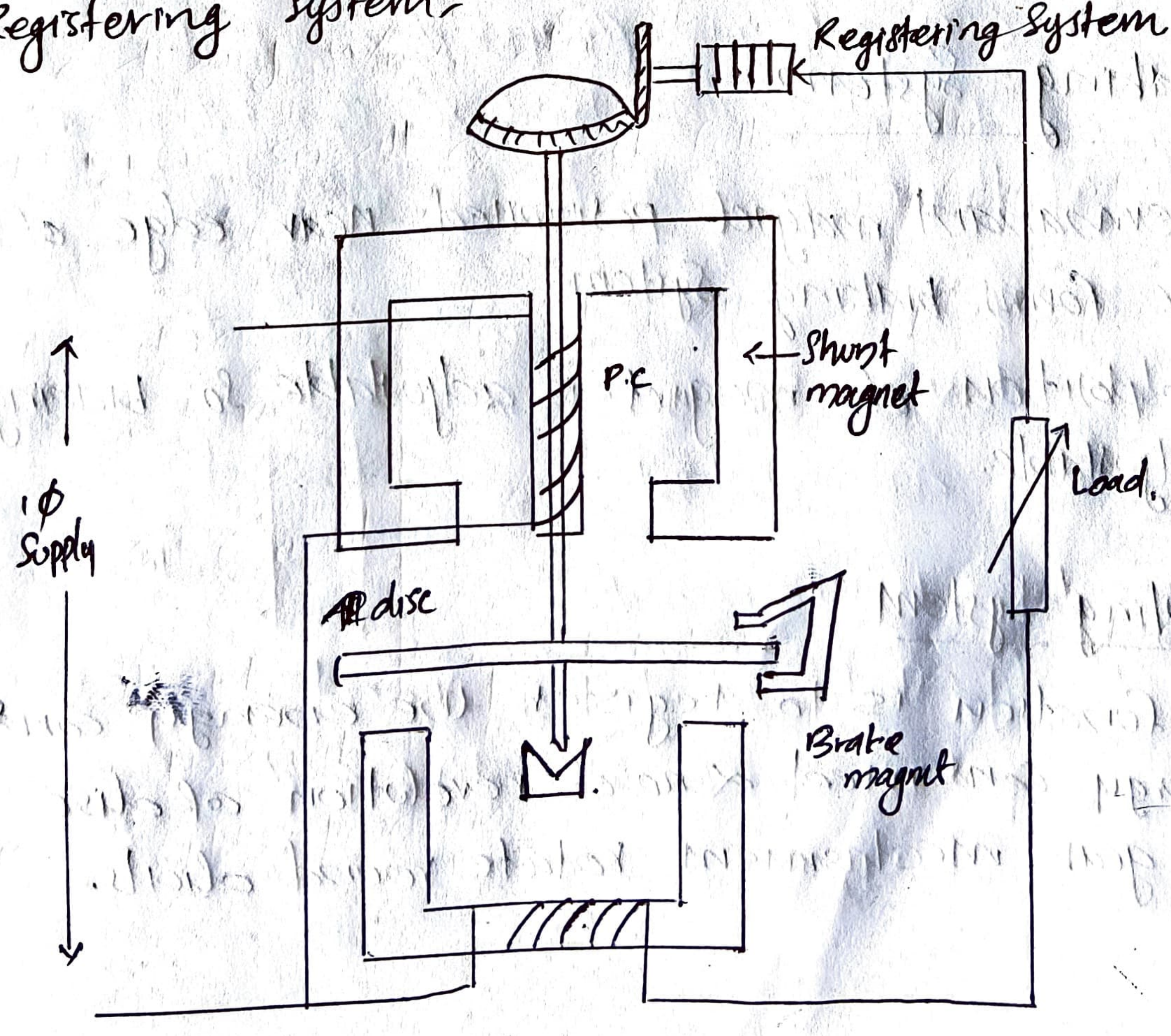
* Electromechanical induction type meter
* electronic meter.

Electro Mechanical Energy Meter.

* Measure energy by counting revelation of a rotating disc.
* The disc is non-magnetic but electrically conductive.
* no. of revelation ∝ ~~propotional~~ energy usage.

Construction:

* Driving System
* Moving System
* Braking System
* Registering System



Driving System

* consists of 2 electromagnets.
* The core laminated with Si steel.
* one current coil and other voltage coil
* Electromagnets are called Sereise and Shunt magnets.

Moving System

* This consists of an 'Al' disc mounted on a light alloy Shaft
* Disc is mounted b/w Sereis and Shunt magnets.
* The pivot is supported by jewel bearings.
* A gear mechanism is connected to the shaft

Braking System

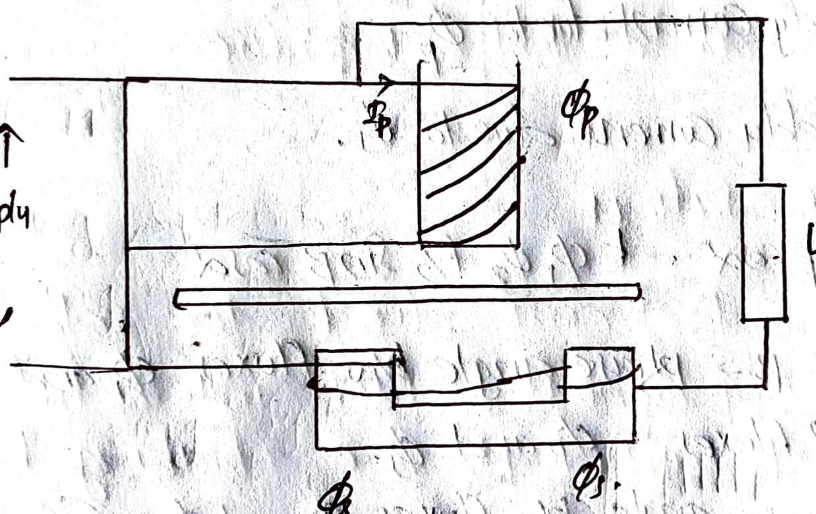
* A permanant magnet positioned near edge of the Al disc forms braking system
* The position of magnet is adjustable so braking also adjustable

Counting System

* The function is to register the energy consumed.
* Energy consumed ∝ no: of revelution of disc
* The gear mechanism rotate round dials.

Single phase Induction Type Energy Meter

* Supply voltage is applied accross the pressure coil.
* pressure coil winding is highly inductive, reluctance to the magnetic ckt is small.
* current through pressure coil $I_p \propto$ Supply Voltage and lags few degree lesthan $90°$.
* The lag is due to resistance and iron loss.



* The flux ϕ_p goes through aluminum disc and hence is responsible for production of driving torque.
* $\phi_p \propto I$ and is in phase with I
* $\therefore$ flux $\phi_p \propto$ Voltage and lags by an angle few degrees lessthan $90°$ since flux ϕ_p is alternating in nature.
* load current I flows through current coil ~~current~~ produces flux ϕ_s.
* $\phi_s \propto I_L$ and inphase with I_L
* eddy current I_{es} interact with both ϕ_p and ϕ_s for producing different torques.

* These torques are oppose in direction, So the resultant is the difference of these

let

V = applied Voltage

I = load current.

ϕ = phase angle load

E_{ep} = eddy current by ϕ_p

f = frequency

I_{ep} = eddy current due to ϕ_p

I_{es} = eddy current due to ϕ_s.

$I_p \rightarrow$ pressure coil current

Δ = phase angle b/w V and ϕ_p

z = impedence of I_{es} path

E_{es} = eddy current by ϕ_s

α = phase angle of eddy current path

$T_d \propto \phi_1 \phi_2 \frac{f}{z} \sin\beta \cos\alpha = k \phi_1 \phi_2 \frac{f}{z} \sin\beta \cos\alpha$

$k_1 \rightarrow$ constant $\beta \rightarrow$ phase angle b/w fluxes ϕ_1 and ϕ_2

In our cases 2 fluxes ϕ_p and ϕ_s

β = phase angle b/w fluxes ϕ_p and ϕ_s = $(\Delta - \phi)$

driving torque $T_d = k_1 \phi_p \phi_s \frac{f}{z} \sin(\Delta - \phi) \cos\alpha$

$\phi_p \propto V$ and $\phi_s \propto I$

$T_d = k_2 VI \frac{f}{z} \sin(\Delta - \phi) \cos\alpha$

if f, z, α are constant.

$T_d = k_3 VI \sin(\Delta - \phi)$

At steady state and steady speed.

$kVI \sin(90 - \phi) = kVI \cos\phi$

$= k \times$ power

Since, Speed of rotation $\propto$ power.

Δ Should be $= 90°$. Hence ϕ_p must be made lag the Supply voltage by exactly $90°$.

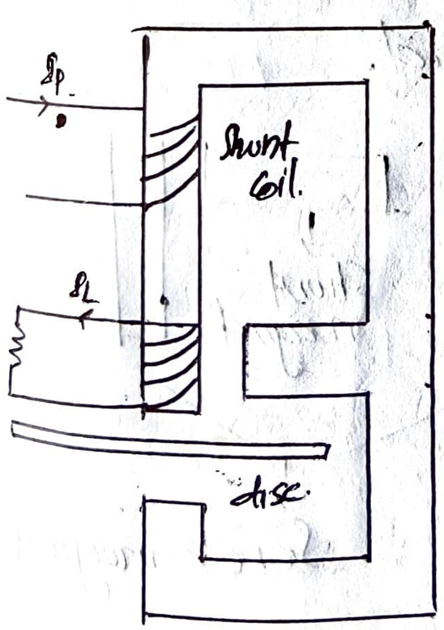
no. of revelution $= \int N dt = k\int VI \sin(\Delta - \phi) dt$

$= \int VI \cos\phi \, dt$

$= k\int (\text{power}) \, dt = \underline{k \times \text{energy}}$

Lag Adjustment Devices

* The meter will read only if angle Δ is made equal to $90°$.
* Thus the angle b/w shunt megnet flux ϕ_p and Supply voltage V should be equal to $90°$.
* So the pressure coil should be highly inductive, and has low resistance, iron and core losses are small.



* By introducing a magnetic shunt ckt, it is possible to introduce an mmf
* The flux ϕ_p in the disc air gap will be created by the combined action of the main mmf.
* Thus flux ϕ_p will be in phase with resultant mmf AT_p.

Creeping

* In some meters a slow but continuous rotation is obtained even when there is no current in pressure coil. This is called creeping.

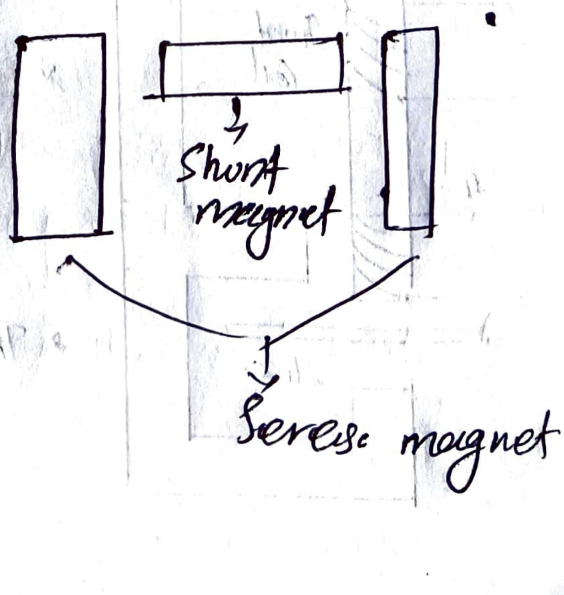
* The major cause for creeping is over-compensation for friction.

* In order to prevent creeping, a diametrically opposite holes are drilled in the disc.

Overload Compensation

* Dynamically included emf due to the rotation of the disc causes eddy current which interacts with sereis magnet feild to produce a braking torque.

* Overload compensating device takes the form of a magnetic shunt for the sereis magnet core whose permiability decreases at overload.



Voltage Compensation

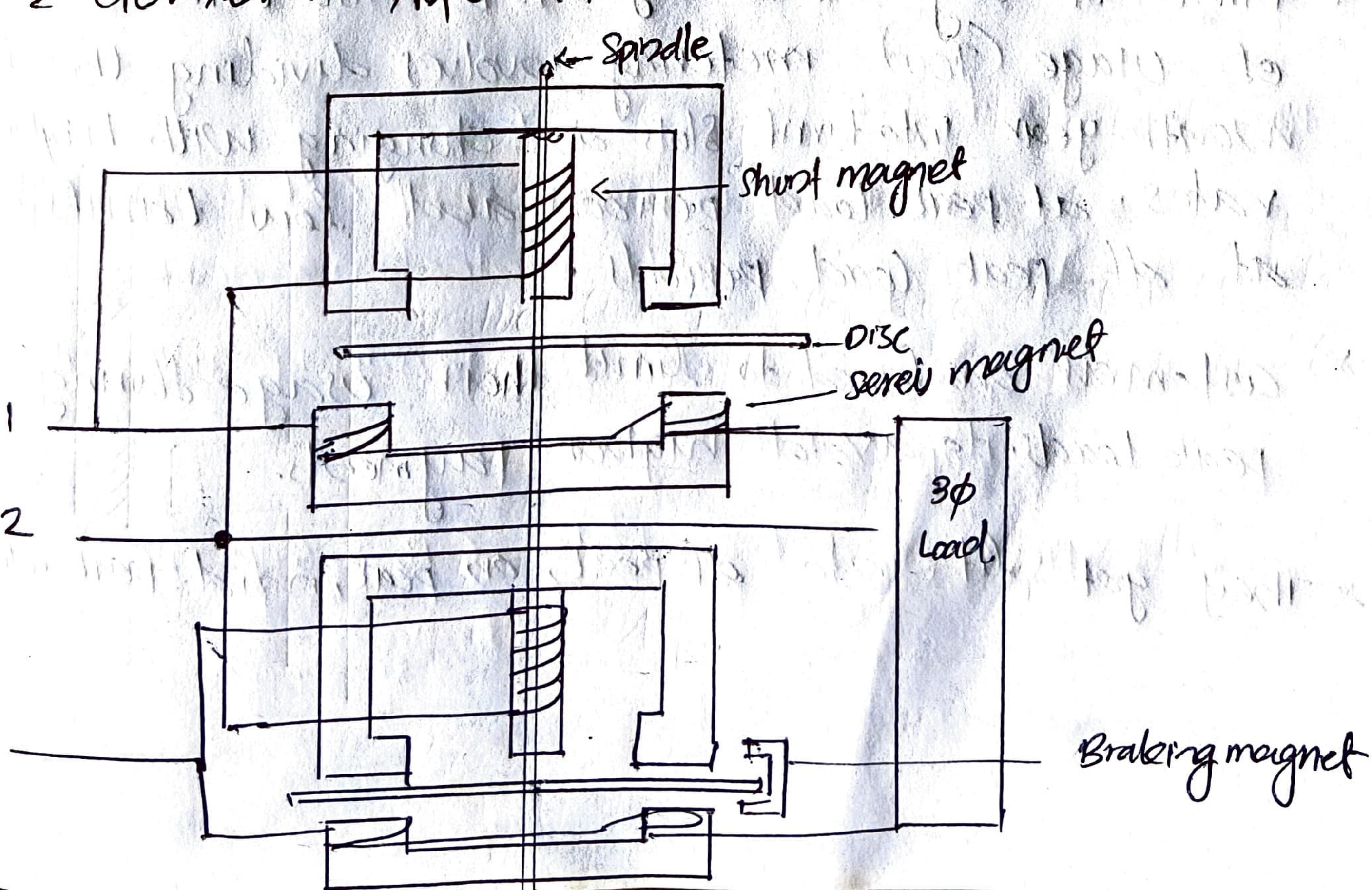
The compensation for voltage variations can be conviniently provided by the increasing the reluctance of the side limbs of the shunt magnet which is done by providing holes in the side limbs.

Polyphase Energy Meter

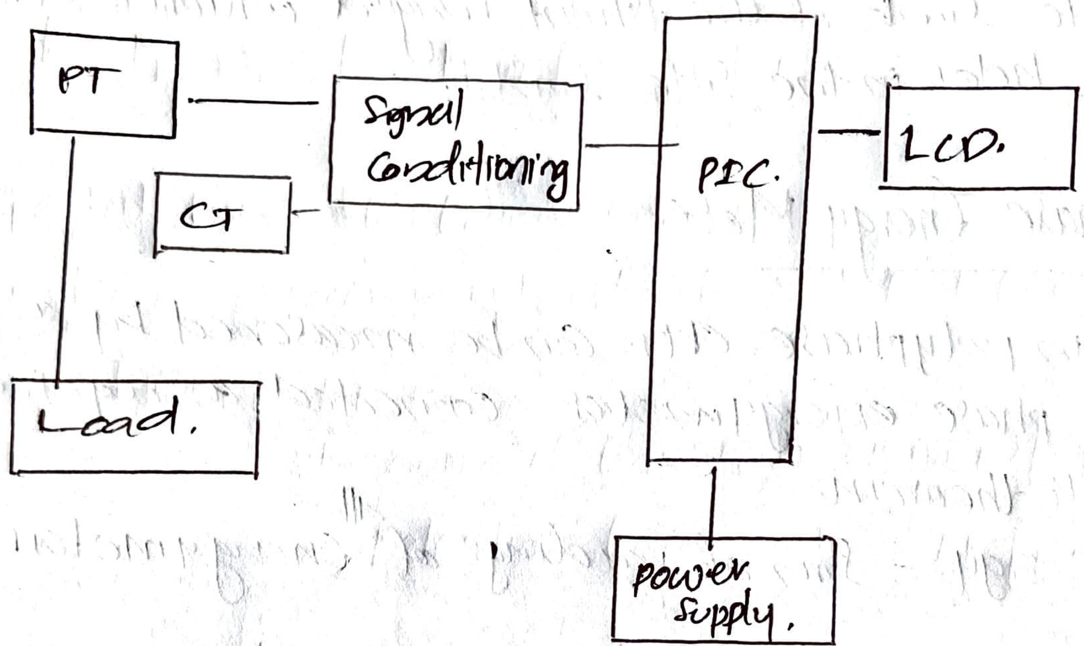
- Energy in polyphase ckts. can be measured by a group of single phase energymeter connected as required by Blondel's theorom.
- Total energy = Sum of readings of all energymeters

2 Element Energy Meter

2 element E/M used for 3ϕ 3 wire system.



Digital Energy Meter



TOD Meter

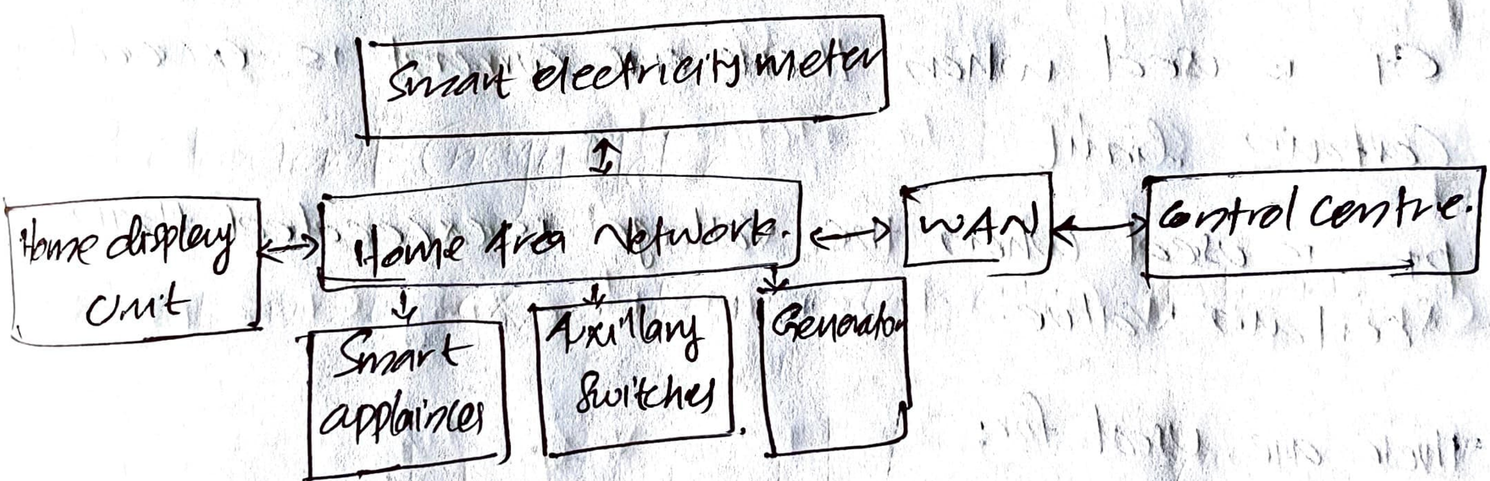
* Time of day metering (TOD) also known as time of usage (TOU) metering involves dividing the day, month, year into tarrif slots and charging with higher rates at peak load periods and low tarrif's rates at off-peak load periods.

* Customers are forced to limit their usage during peak loads, to avoid higher payments.

* They got split into off-peak, on-peak, mid-peak etc.

Smart Metering

- A smart metering system is built with smart meters, control devices and communication link.
- The key element is combination of metering and intelligence
- They are introduced for better energy saving, demand management and energy efficiency.
- It will read, max. demand, P.f, Voltage, current, energy consumption etc.
- It can enable 2 way communication.
- The communication may be wired or wireless.



- Consumer can use the collected data from smart meter to adjust their load, and save electricity bill.
- The utilities can use this data to monitor the electricity usage of each customer.
- In home display unit is a touch screen device that communicates with smart meter, that shows a summary of energy usage over the day, week, month.

* WAN is used for communication b/w premises and control centre

Instrument Transformer

* Special type of transformers.
* Used for measurement of V, I, P, P.F etc.
* 2 types:
  1. Current transformer (CT) [Series t/f].
  2. potential transformer (PT) [parallel t/f].

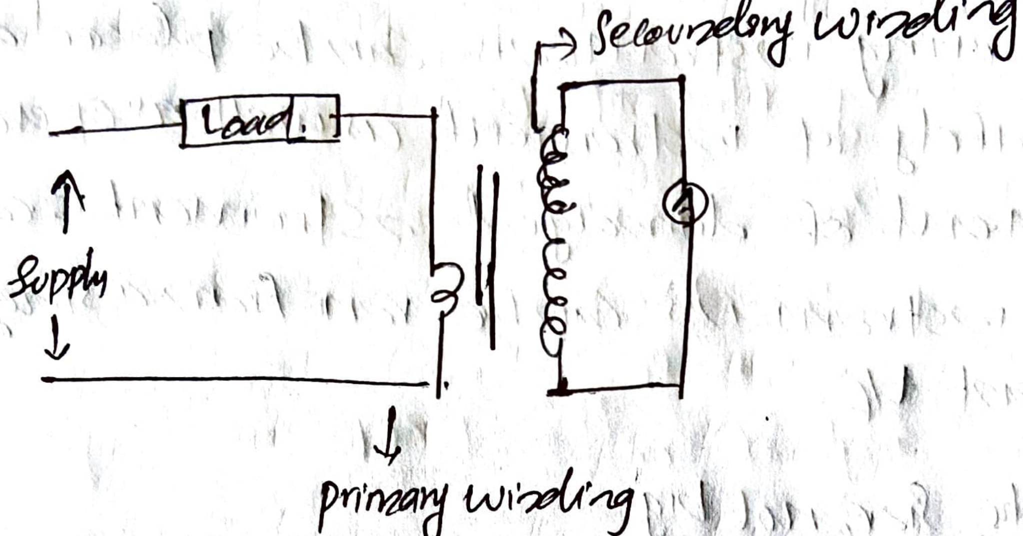
CT is used when ~~there are~~ current is exceeding certain limit

PT is used when the voltage is exceeded than certain value.

These are used for:

* ~~CT~~ To Isolate measuring ckt from high voltage so as to protect measuring ckt
* To make possible of measuring high values of voltage and current.
* Also used to actuate C.B, relays etc.

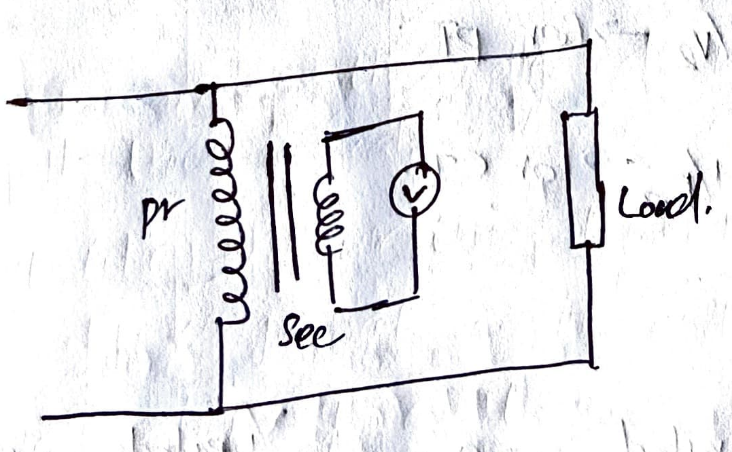
Measurement By CT



- The primary winding is connected to ckt where the Current is needed to be measured.
- Secoundary winding is connected to ammeter.
- The function of CT is to reduce the current.

Measurement By PT

Primary winding is connected to the voltage side to be measured and Secoundary to the Voltmeter.



Advantages of Instrument Transformers

* The measuring instruments can be placed anywhere for the safety of instrument as well as operator.
* Replacement of damaged instrument is easy.
* Several instruments can be run from a single instrument t/f.

* Moderate size, not big.
* Measuring ckt is isolated from power ckt
* power loss in instrument t/f is very small.

Disadvantages

* Cannot used for DC networks.

Expression for Measurement using CT & PT :

Transformation ratio (R) = V_2/V_1 = I_1/I_2

→ $\cancel{V_2/V_1}$ V_1/V_2 → for PT.

I_1/I_2 → for CT;

Nominal ratio (K_n)

$$= \frac{I_1 \text{ rated}}{I_2 \text{ rated}} \rightarrow \text{for CT} \cdot \frac{V_1 \text{ rated}}{V_2 \text{ rated}} \rightarrow \text{for PT}$$

Turns ratio (n)

$= N_2/N_1 \rightarrow$ for CT.

$N_1/N_2 \rightarrow$ for PT.

Ratio Correction factor :

$$\frac{\text{Transformation ratio}}{\text{nominal ratio}} = R/K_n \rightarrow \text{for CT \& PT}$$

Total sec: burden =

$$\frac{(\text{Sec induced voltage})^2}{\text{impedence of sec: ckt} \times \text{induced impedence in sec: wdg}}$$

Let

$n \rightarrow$ turns ratio.

$R_s \rightarrow$ resistance to sec: winding.

$x_s \rightarrow$ reactance to " "

$R_p \rightarrow$ resistance to primary winding.

$X_p \rightarrow$ reactance to " "

$E_p \rightarrow$ primary induced voltage

$E_s \rightarrow$ secondary " "

$N_p \rightarrow$ ~~p~~ no: of primary windings.

$N_s \rightarrow$ no: of secondary " "

$V_s \rightarrow$ Voltage of " "

$I_s \rightarrow$ secoundary winding current

$I_p \rightarrow$ primary "

$\phi \rightarrow$ working flux of t/f

$\delta \rightarrow$ angle b/w E_s and I_s.

$$= \tan^{-1}\left(\frac{x_s + x_e}{R_s + R_e}\right).$$

$\Delta \rightarrow$ phase angle of sec. load ckt

$I_0 \rightarrow$ exciting current

$I_e \rightarrow$ loss component of exciting current.

$\alpha \rightarrow$ angle b/w I_0 and ϕ

$\theta \rightarrow$ phase angle of t/f

Transformation Ratio $(R) = I_p / I_s$.

$$= \frac{\left[n^2 I_s^2 + 2n I_s I_0 \sin(\delta+\alpha) + I_0^2\right]^{1/2}}{I_s}$$

$I_0 << nI_s$ and $I_p = nI_s$.

$$R = \frac{\left[n^2 I_s^2 + 2n I_s \sin(\delta+\alpha) + I_0^2 \sin^2(\delta+\alpha)\right]^{1/2}}{I_s}$$

$$R = n + I_0/I_s \sin(\delta+\alpha)$$

expanding, $R = n \pm \dfrac{I_m \sin\delta + I_e \cos\delta}{I_s}$.

where $I_m = I_0 \cos\alpha$ and $I_e = I_0 \sin\alpha$.

As θ is small, and I_0 is very small compared nI_s.

phase angle, $\theta = \frac{I_0 \cos(\delta + \alpha)}{nI_s}$ rad.

$\theta = 180/\pi \left[\frac{I_m \cos\delta - I_e \sin\delta}{nI_s} \right]$ degree

Errors in Instrument Transformer

a) Ratio Error:

$$\% \text{ ratio} = \frac{\text{Nominal ratio} - \text{Actual ratio}}{\text{Actual ratio}} \times 100.$$

for normal operation of these instrument t/f, the current transformation ratio should be constant within the limits.

b) phase Angle Error:

$$\text{phase angle error}, \theta = \frac{180}{\pi} \left[\frac{I_m \cos\delta - I_e \sin\delta}{nI_s} \right] \text{degree.}$$

phase angle error is due to the no load current or exciting current. this is the angle by which the secondary current when reversed, differs in phase from primary current.

Methods to minimise Error (CT).

Ratio error mainly depends upon the working component of current and phase angle error. depends upon magnetising component of the current.

1. In order to minimise these errors (I_w and I_m) needed to be minimised. This could be only done by materials of having high permiability, short magnetic path and large cross-section area.

we can use.

Hot rolled Si

CRGO ~~Steel~~ Si Steel.

Ni iron alloys.

The construction of core has min: no: of joints. for that we just made cores as the shape of either

a) Ring

b) Spiral

2) By providing suitable turn ratio of the secondary can be reduced by one or two turns.

3. Leakage reactance should also increases the ratio error. Therefor a windings should be placed as close as can.

4. If the current on the secondary is too large, it should be reduced by putting a shunt either of side. It also reduces phase angle error.

Application of CT

* CT's are used in panel boards of ~~subst~~ power stations and sub stations to measure very high current
* CT are widely used in power measuring ckts.
* Also used as an actuator in C.B, relays etc.

Application of PT

* used to measure high voltage by meas of low range V/m.
* used in over to voltage protectons to actuate the ckt

PT

a) Construction:

* Basically PT is a 2 winding t/f. primary is conncted to H.v and secoundary is connected to L.v.
* core is shell type.
* Insulation is provided b/w Lv and H.v winding.
* Dry type P.T s are used upto 6.6kv and for much we will use immersed type.

b) Features:

* output of PT is very small and size is large, no problem of temperature
* Size of core is larger compared to power t/f
* material of core should be highly permiable to reduce iron loss and ratio erro, phase angle error.
* primary and secoundary are co-axial to reduce leakage reactance.

Difference b/w CT and PT

* CT is also called series t/f, secoundary of CT is virtually short ckted. when primary is energised.
* PT is also called parallel t/f, and secoundary is open

* Under normal condition, V_L of PT is constant. Flux density and the exciting current of PT varies b/w small range where I_p and excitation of primary varies by a wide range

* Current in CT is indepent of load condition while on PT is depent on the secondary load burden

* primary of PT is connected to full line voltage, while of CT there is a small voltage

Methods to Minimise Error in PT.

1. In order to minimise the error, no load componab I_m and I_w must kept very low.

2. By reducing winding resistance and leackage reactance (X_L).

3. By providing suitable turn ratio

Q A CT has a single turn on primary and 200 turns on secondary winding. The secondary winding of 5A is passing through a secondary burden of 1Ω resistance. The required flux is set up in the core by emf of 80 . The frequency is 50 Hz and net cross-sectional area. Calculate the ratio and phase angle And also the flux density.

Ans. $N_1 = 1$ $N_2 = 200$.

$Z_2 = 1\Omega$ turn ratio $= N_2/N_1 = 200/1 = 200$.

Voltage induced in secondary, $E_2 = I_2 Z_2 = 5V$.

also, $I_1 = K \cdot I_2$.

The working component of no load current is negleted, $I_w = 0$.

Now, magnetizing component of no load current is negleted. $I_w = 0$.

Now magnetizing component of no load current

= mmf/primary turn. $I_m = 80/1 = 80A$

Secondary winding current, $I_2 = 5A$

Secondary reverse current, $I_1 = K \cdot I_2 = 200 \times 5 = 1000A$

Now primary current

$$I_1 = [(I_m^2) + (I_1^2)]^{1/2}$$

$$= [80^2 + 1000^2]^{1/2}$$

$$= \underline{\underline{1003.2A}}$$

Actual transformation ratio $= 1003.2/5 = 200.64$

phase angle $\phi = \tan^{-1}(I_m/I_1) = \tan^{-1}(80/1000) = 4°34'$

from emf eqn: $E = 4.44 f \phi_{max} N_2$

$25 = 4.44 \times 50 \times \phi_m \times 200.$

$25 / 4.44 \times 50 \times 200 = \phi_m \rightarrow 0.1126 \times 10^{-3}$ wb.

Now area of core, $A = 1000$ mm²

$= 1000 \times 10^{-6}$ m² $= 10^{-3}$ m² //

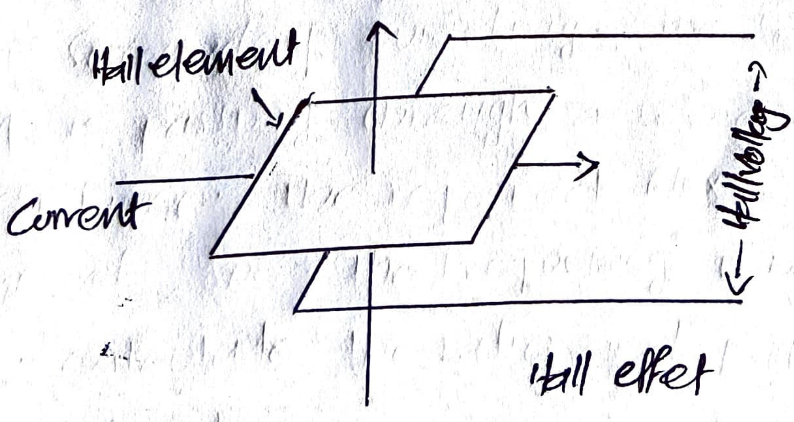
$B_{max} = \phi_{max} / \text{area}.$

$= 0.1126 \times 10^{-3} / 1000 \times 10^{-6}$

$= 0.1126$ wb/m²

Hall Effect Multiplier

- The current is passed through the current coil which produces a magnetic feild propotional to the current i, This feild is ⊥r to the hall effect element
- A current ip is propotional to the voltage passed through hall element in a direction ⊥r to feild which is limited by the multiplier resistance R_s.



The o/p Voltage of the Hall effect multiplier.

$$V_H = R_H \times \frac{i_v B}{t}$$

$R_H \rightarrow$ Hall co-efficient; V-m/A - wb m²

$B \rightarrow$ flux density : wb/m²

$t \rightarrow$ tickness of hall element

now $B \propto i$ and $i_p = V/R_s \propto V$. Hence $V_H \propto V_{i}$

* o/p Voltage of Hall effect multiplier is $\propto P_{inst}$