MODULE :3

Extension Of Instrument Ranges

Range :

Range of an electrical instrument means amount of currents that can be safely passed through its coil.

* Range extension is mainly done to measure large currents or voltages with low range Ammeter & voltmeter.

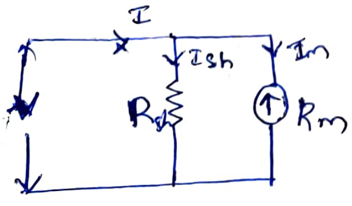
* There are four methods for range extension of Ammeter & voltmeter

1. By using shunts to increase range of d.c ammeter
2. By using multipliers to increase range of d.c voltmeter
3. By using C.T to increase range of a.c ammeter
4. By using P.T to increase range of a.c voltmeter

Shunts :

"Shunt is a very low resistance connected in parallel with d.c ammeter to extend its range".

Shunts for DC ammeter



R_{sh} = Shunt resistance

R_m = meter resistance

I_m = meter current

I_{sh} = shunt current

I = total current

w.k.That from circuit dia

$V = I_{sh} R_{sh} = I_m R_m$

$I = I_{sh} + I_m$ (or) $I_{sh} = I - I_m$

$\therefore (I - I_m) R_{sh} = I_m R_m$

$$R_{sh} = \frac{I_m R_m}{I - I_m}$$

÷ Num & denominator by I_m

$$R_{sh} = \frac{R_m}{\frac{I}{I_m} - 1}$$

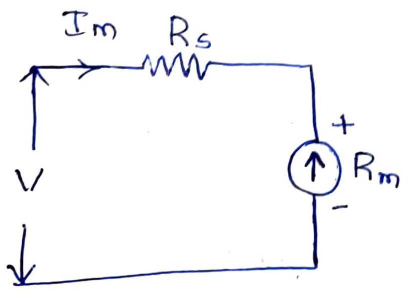
let $\frac{I}{I_m} = m$

$$\therefore R_{sh} = \frac{R_m}{m-1}$$

$$\boxed{m = \frac{R_m}{R_{sh}} + 1}$$

∴ To increase the range of ammeter m times the shunt must have Resistance $R_{sh} = \frac{1}{N-1}$ times the resistance of ammeter.

Multipliers for DC voltmeters



I_m = meter current

R_s = Series multiplier resist

R_m = meter Resistance

V = Full voltage to be measured.

BY KVL

$V - I_m R_s - I_m R_m = 0$

$V - I_m (R_s + R_m) = 0$

$V = I_m (R_s + R_m) \longrightarrow (1)$

(or) $\boxed{\frac{V}{I_m} - R_m = R_s}$

~~in eqn 1~~

voltage drop across meter $v = I_m R_m$

& the multiplying factor 'm' is the ratio of full range voltage (V) & voltage drop across meter (v)

$$\therefore m = \frac{V}{v}$$

put V & v values

$$m = \frac{I_m (R_s + R_m)}{I_m R_m}$$

$$\boxed{m = \frac{R_s + R_m}{R_m}} \quad \text{or} \quad \frac{R_s}{R_m} + 1 = m$$

$$\text{or} \quad \boxed{R_s = (m-1) R_m}$$

$\therefore$ To increase the range of voltmeter 'm' times the series resistance required is $(m-1)$ times of basic meter resistance.

INSTRUMENT TRANSFORMERS.

" Transformers used in conjunction with measuring instrument is called instrument transformers".

They are used to extend the range of AC instruments.

* Instrument transformers are generally classified into 2 groupe

1. current transformers
2. Potential transformers.

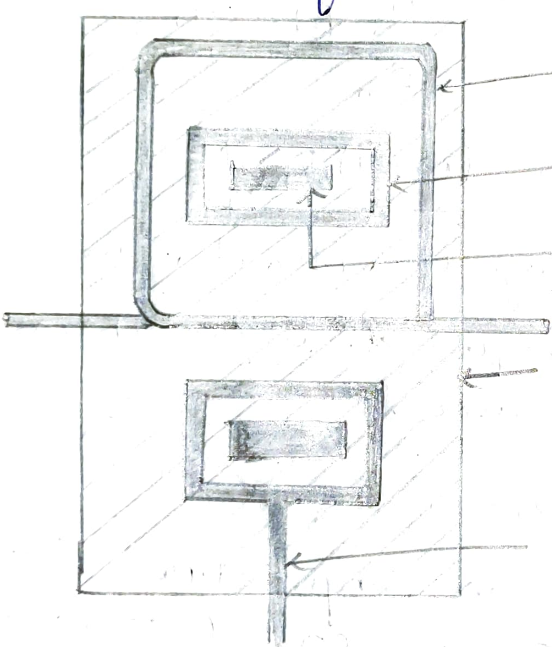
Construction of current transformers

"Transformers used for the measurement of large current with normal low range instrument" is called C.T".

* Their are 2 types of C.T
  1. wound type C.T
  2. Bar type C.T

1. wound type C.T :

In this primary is wound for more than one full turn on core.



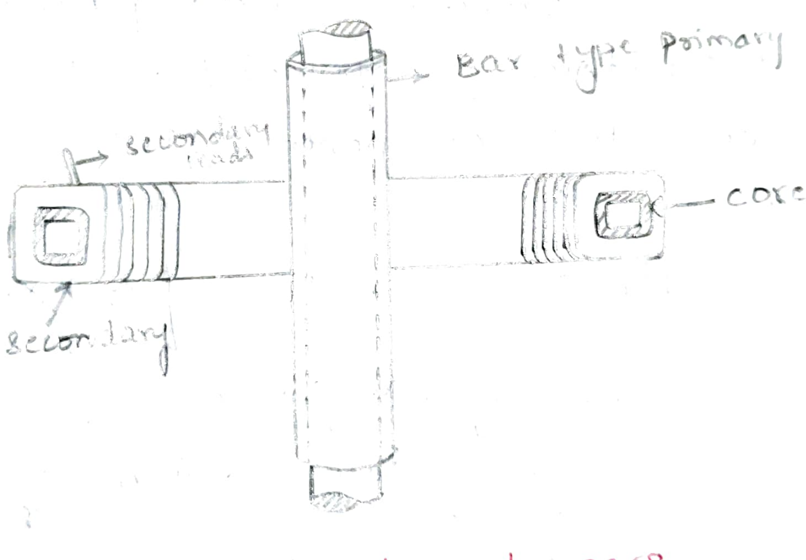
* In a low voltage wound type C.T secondary winding is wound on bakelite former. heavy primary winding is wound on secondary winding with suitable insulation in between or primary some times wound separately & then lapped with secondary leads.
* core material is nickel-iron alloy or electrical steel.
* Their are 3 types of wound type C.T ① Rectangular ② Ring ③ Stadium

2. BAR TYPE C.T :-

In this type C.T Primary winding

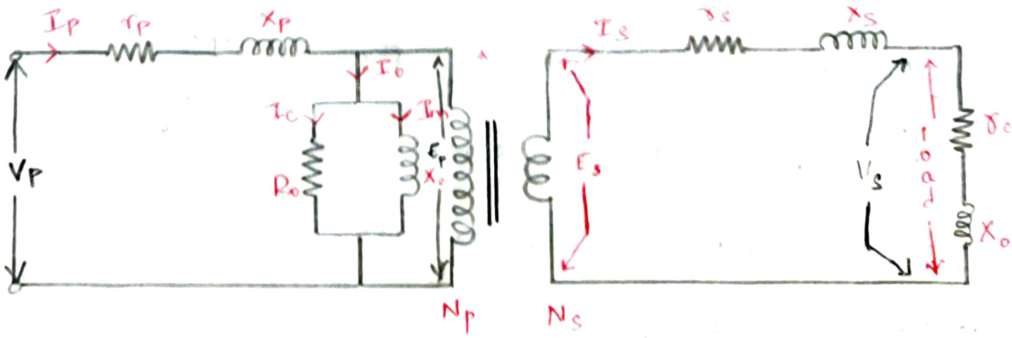
is nothing but bar of suitable size.

* Bar type primary is integral part of C.T & core & secondary windings are same in bar type transformer.
* Insulation for primary bar is provided by laminations is bakelized paper tube. & it should have high cross-sectional area than ordinary transformers.
* These windings are placed very close to each other to reduce leakage reactance.
* external diameter of ~~bar~~ tube is kept large to avoid corona effect.



Theory of current transformers

* Equivalent circuit of C.T as shown below.



where

$$n = \text{turns ratio} = \frac{\text{secondary turns}}{\text{Primary turns}} = \frac{N_s}{N_p}.$$

r_p = resistance of primary winding
r_s = resistance of secondary winding
x_p = reactance of primary winding
x_s = reactance of secondary winding
r_e = resistance of load on secondary
x_e = reactance of load on secondary
E_p = primary induced voltage
E_s = Secondary induced voltage
V_s = secondary terminal voltage
I_p = Primary current
I_s = secondary current
I_o = No load current or exciting current
I_m = magnetising component of I_o ie $I_o \sin\phi_o$
I_c = core loss component of I_o ie $I_o \cos\phi_o$.
ϕ = flux
δ = Angle b/w E_s & I_s $= \tan^{-1}\left[\frac{x_s + x_e}{r_s + r_e}\right]$
θ = Phase angle of transformer
Δ = phase angle of load $= \tan^{-1}\frac{x_e}{r_e}$
α = angle b/w I_o & ϕ.

Derivation of Actual ratio
(or)
Phasor diagram of C.T

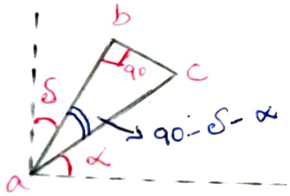
* In this transformer has lagging p.f
* From phasor diagram

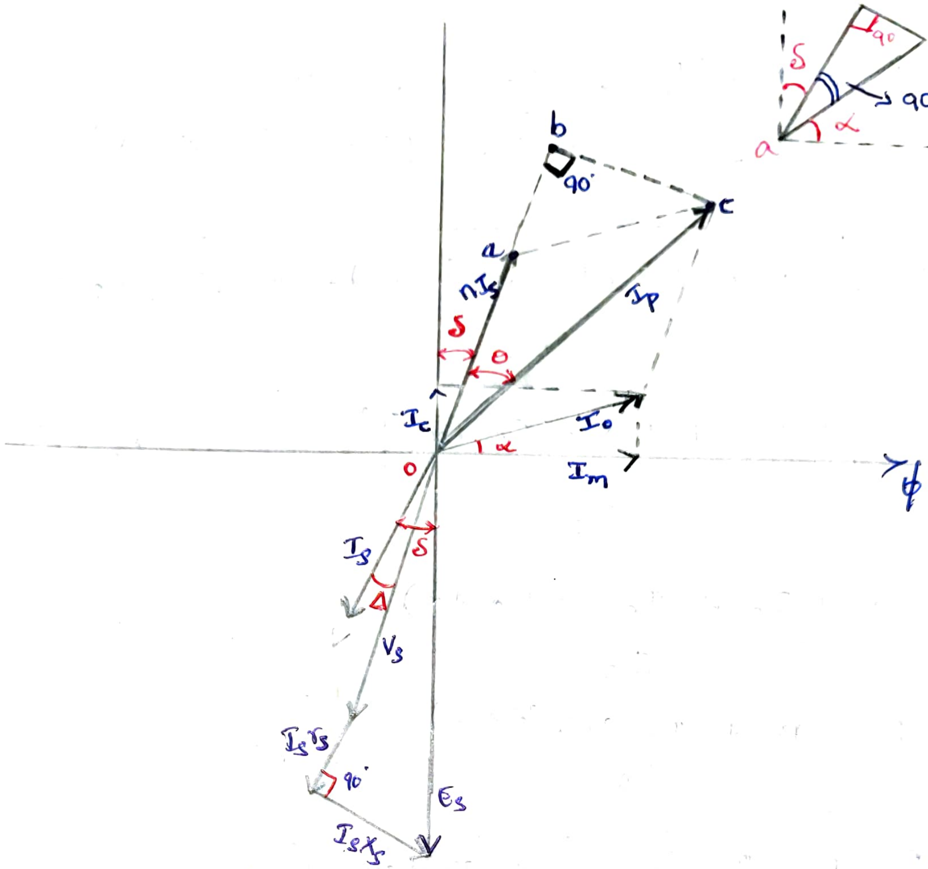
① $\angle bac = 90° - \delta - \alpha$

$oa = nI_s$ $ac = I_o$
$oc = I_p$ & $bc = ac \sin(90 - \delta - \alpha)$
$ab = ac \cos(90 - \delta - \alpha)$

$bc = I_0 \cos(\delta + \alpha)$

$ab = I_0 \sin(\delta + \alpha)$





(2) consider Δ^{le} obc

$(oc)^2 = (ob)^2 + (bc)^2$ (By plythogorous theorem)

$I_p^2 = [n I_s + I_0 \sin(\alpha + \delta)]^2 + [I_0 \cos(\delta + \alpha)]^2$

$ob = oa + ab \longrightarrow (1)$

$= nI_s + I_0 \sin(\delta + \alpha)$

$= nI_s + I_0 \sin(\delta + \alpha)$

$\because bc = I_0 \cos(\delta + \alpha)$

$(a+b)^2 = a^2 + 2ab + b^2$

$= n^2 I_s^2 + 2n I_s I_0 \sin(\alpha + \delta) + I_0^2 \sin^2$

$= n^2 I_s^2 + 2n I_s I_0 \sin(\alpha + \delta) + I_0^2 \sin^2(\alpha + \delta) + I_0^2 \cos^2(\delta + \alpha)$

$= n^2 I_s^2 + 2n I_s I_0 \sin(\alpha + \delta) + I_0^2 [\underbrace{\sin^2(\alpha + \delta) + \cos^2(\delta + \alpha)}_{1}]$

$\sin^2\alpha + \cos^2\alpha = 1$

$I_p^2 = n^2 I_s^2 + 2n I_s I_0 \sin(\alpha + \delta) + I_0^2$

$I_p = \sqrt{n^2 I_s^2 + 2n I_s I_0 \sin(\alpha + \delta) + I_0^2}$

(3) Actual ratio $= R = \dfrac{I_p}{I_s}$

$$\therefore R = \frac{\sqrt{n^2 I_s^2 + 2nI_sI_0\sin(\alpha+\delta) + I_0^2}}{I_s}$$

(4) Practically $I_0 << nI_s$ so

I_0^2 becomes $I_0^2\sin^2(\delta+\alpha)$

$$\therefore R = \frac{\sqrt{n^2 I_s^2 + 2nI_sI_0\sin(\alpha+\delta) + I_0^2\sin^2(\delta+\alpha)}}{I_s}$$

$$= \frac{\sqrt{[nI_s + I_0\sin(\delta+\alpha)]^2}}{I_s} \quad = (a+b)^2 \text{ formula}$$

$$= \frac{nI_s + I_0\sin(\delta+\alpha)}{I_s}$$

$$R = n + \frac{I_0}{I_s}\sin(\delta+\alpha)$$

$$R = n + \frac{I_0}{I_s}[\sin\delta\cos\alpha + \sin\alpha\cos\delta]$$

$\sin(a+b) = \sin a\cos b + \cos a\sin b$

From fig $\sin\alpha = \frac{I_c}{I_0}$ $\cos\alpha = \frac{I_m}{I_0}$

(2) $\leftarrow I_0\sin\alpha = I_c$ $I_0\cos\alpha = I_m \rightarrow$ (3)

$$\therefore R = n + \frac{I_m}{I_s}\sin\delta + \frac{I_c}{I_s}\cos\delta$$

or

$$\boxed{R = n + \frac{I_m\sin\delta + I_c\cos\delta}{I_s}}$$

Phase Angle (θ):

$$\tan\theta = \frac{bc}{ob} = \frac{bc}{oa + ab} = \frac{I_0\cos(\delta+\alpha)}{\underbrace{nI_s + I_0\sin(\delta+\alpha)}_{\text{from (1)}}}$$

$\tan\theta \approx \theta$

$$\theta = \frac{I_0\cos(\delta+\alpha)}{nI_s + I_0\sin(\delta+\alpha)}$$

Neglecting I_0 as $I_0 << nI_s$ &

$$\cos(a+b) = \cos a \cos b - \sin a . \sin b$$

$$\therefore \quad \theta = \frac{I_0(\cos\delta \cos\alpha - \sin\delta + \sin\alpha)}{nI_s}$$

from 2 & 3

$$\theta = \frac{I_m \cos\delta - I_c \sin\delta}{nI_s}$$ radians

$$\boxed{\theta = \frac{180}{\pi}\left[\frac{I_m \cos\delta - I_c \sin\delta}{nI_s}\right] \text{ degrees}}$$

θ is +ve if I_s leads I_p

θ is -ve if I_s lage I_p.

Neglecting I_0 as $I_0 << nI_s$ &

$\cos(a+b) = \cos a \cos b - \sin a . \sin b$

$$\therefore \theta = \frac{I_0(\cos\delta \cos\alpha - \sin\delta + \sin\alpha)}{nI_s}$$

$$\theta = \frac{I_m \cos\delta - I_c \sin\delta}{nI_s} \text{ radians}$$

from (2) & (3)

$$\boxed{\theta = \frac{180}{\pi}\left[\frac{I_m \cos\delta - I_c \sin\delta}{nI_s}\right] \text{ degrees}}$$

θ is +ve if I_s leads I_p

θ is -ve if I_s lags I_p.

Errors in P.T (or) Errors in Instrument T

(or)

Errors in Current Transformers

In C.T i) the transformation ratio = turns ratio

& ii) phase angle of secondary turns must be displaced exactly by 180° from primary turns.

when these are affected the following two errors occur.

1. Ratio error
2. phase Angle error.

i) Ratio error :-

* practically transformation ratio I_2/I_1 is not equal to N_1/N_2 turns ratio because of i) magnetizing & core loss components of exciting current.
ii) & due to secondary current & its power factor.

* In case of P.T V_2/V_1 is not equal to N_1/N_2

so it is concluded that transformation

ratio depends on load current, power factor of load & exciting current. due to this large error is introduced in instrument transformers. this error is called ratio error.

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

ie $\boxed{\% \text{ ratio error} = \frac{K_n - R}{R} \times 100}$

ii) Phase Angle error:

* In ~~Both~~ C.T & ~~P.T~~ the secondary current must be displaced by 180° from primary current

* In P.T the secondary voltage must be displaced by 180° from primary voltage But in practical it is not true thus occuring error is called phase Angle error denoted by θ.

$$\theta = \frac{180}{\pi}\left[\frac{I_m \cos\delta - I_c \sin\delta}{n I_s}\right] \text{deg}$$

Characteristics of C.T

1. Effect of power factor of secondary circuit.

* Secondary circuit power factor depends on p.f of burden on secondary ie mainly affects following errors

then flux & flux density decreases
thus I_m & I_c reduces hence errors are reduces.

Potential Transformers

* " Potential transformers are used to measure high voltage when used with low range voltmeter".

* Also used for energising relays, potential coils & low range wattmeters.

Construction.

In P.T their are 2 types
① shell type ② core type
• shell type is used for low voltage &
• core type is used for high voltage transformers

* ~~Secon~~ P.T have 2 windings, Primary & secondary.
• secondary windings will be wound on the core. These are low voltage windings.
• Primary windings are wound on secondary & for low voltage P.transformer it is a single coil & for high voltage P.transformer primary is divided into number of small sections to reduce need of insulation.

* Both primary & secondary windings are insulated by cotton tape & varnish cambric.

* For oil filled P.T their will be two oil filled bushings.

theory
characteristics

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a) Ratio error: (angle b/w E_s & I_s)

* In C.T ① for all inductive loads, δ is +ve & sin $(\delta+\alpha)$ becomes Positive hence 'R' is greater than turns ratio 'n'.

② for capacitive loads, δ is '-ve' & R is less than 'n'.

b) phase angle error:

when is load	inductive	inductive	capacitive
δ	small	90°	negative
θ	Positive	negative.	positive.

② Effect of change in I_p.

* I_p & I_s are directly related so as I_p changes I_s also changes.
* If the I_p values are low then I_o values will dominate I_p thus as I_m & I_c are components I_o they also dominate I_p thus errors are higher.
* As I_p increases I_o I_m & I_c becomes insignificant thus errors are Less.

③ Effect of change in burden on secondary

* The secondary winding circuit as burden increases means volt-ampere rating increases thus secondary current increases also secondary flux increases thus induces more voltage on secondary thus I_m & I_c increases to keep flux constant. Thus errors also increases.
i.e more secondary burden means more error

④ Effect of change in frequency:

* As frequency is increased in constant supply voltage

Ratios of Instrument Transformers

1. **Transformation Ratio (R) (or) Actual Ratio.**

It is the ratio of magnitude of primary phasor to secondary phasor.

$$\text{Transformation Ratio } R = \frac{|\text{Primary phasor}|}{|\text{secondary phasor}|}$$

for C.T $\quad R = \dfrac{\text{Primary winding current}}{\text{Secondary winding current}}$.

for P.T $\quad R = \dfrac{\text{Primary winding voltage}}{\text{Secondary winding voltage}}$.

2. **Nominal Ratio (K_n) :-**

It is the ratio of rated primary winding current or voltage to rated secondary winding current or voltage.

K_n for C.T $= \dfrac{\text{rated primary winding current}}{\text{rated secondary winding current}}$

K_n P.T $= \dfrac{\text{rated primary winding voltage}}{\text{rated secondary winding voltage}}$.

3. **Turns ratio : (n)**

It is defined as the ratio of number of turns of ~~pri~~ secondary winding to number of turns of primary winding.

for both C.T & P.T

$$n = \frac{\text{Number of turns of secondary winding}}{\text{Number of turns of primary winding}}$$

Ratio correction factor (RCF)

It is the ratio of transformation ratio to nominal ratio.

$$RCF = \frac{R}{K_n} = \frac{\text{Transformation ratio}}{\text{nominal ratio}}$$

Comparision of C.T and P.T

C.T	P.T
1. It can be treated as series transformer under virtual short circuit conditions	1. It can be treated as Parallel transformer under open circuit secondary.
2. Secondary must be always shorted	2. Secondary is nearly under open circuit conditions
3. A small voltage exists across its terminals as connected in series	3. Full line voltage appears across its terminals.
4. The winding carries full line current	4. The winding is impressed with full line voltage.
5. The primary current & excitation varies over a wide range	5. The line voltage is almost constant hence exciting current & flux density
6. The primary current is independent of the secondary circuit conditions	6. Primary current depends on the secondary circuit conditions.
7. Needs one bushing as two ends of primary winding are brought out to same insulator so there is saving in cost	7 Two bushings are required when neither side of the line.

Reduction of Errors in Instrument Transformers.

* errors can be minimized by following methods

① Reducing the core loss and magnetising components of I_0.

② Reduction of resistance & leakage reactance.

③ Providing turns compensation :-

In P.T

$$R = n + \frac{\frac{I_s}{n}\left[R_{1e}\cos\Delta + X_{1e}\sin\Delta\right] + I_c r_p + I_m x_p}{V_s}$$

at no load $I_s = 0$

$$\therefore R = n + \frac{\frac{I_s}{n}\times 0 + I_c r_p + I_m x_p}{V_s}$$

$$\Rightarrow R = n + \frac{I_c r_p + I_m x_p}{V_s}$$

thus on no load actual ratio exceeds by $\frac{I_c r_p + I_m x_p}{V_s}$ so remedy is to reduce the primary turns or increase secondary turns thus at particular load actual ratio is (R) equal to nominal ratio (n) this reduces the ratio error this is called turns compensation

* turns compensation does not affect 'θ' phase angle.

* For C.T

$$R = n + \frac{I_c}{I_s}$$

Actual ratio is more than nominal ratio by $\frac{I_c}{I_s}$ so remedy is reducing turns ratio.

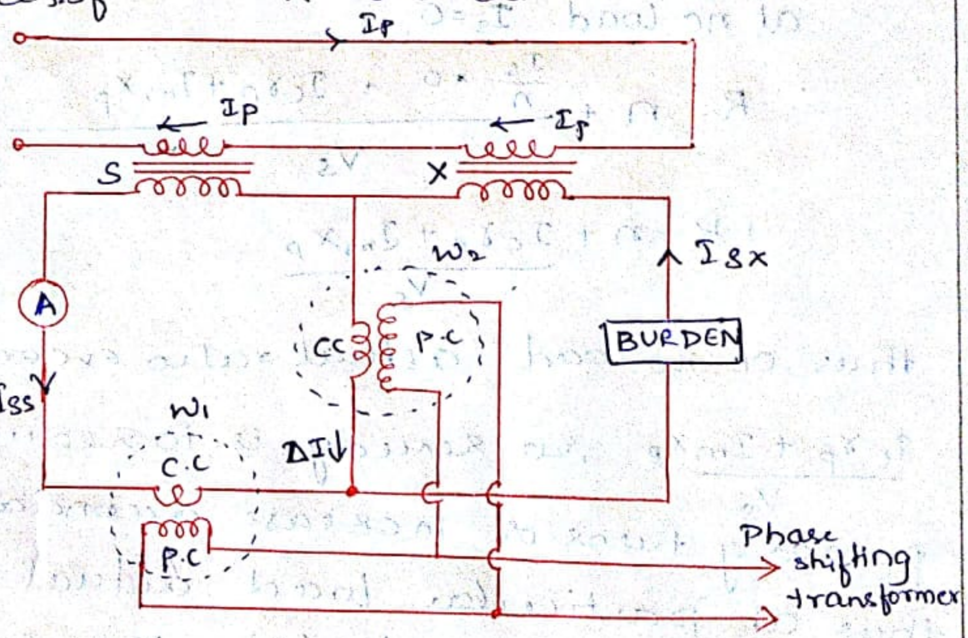
by reducing secondary winding turns thus actual ratio will be equal to nominal ratio this is turns compensation for C.T

TESTING OF CURRENT TRANSFORMERS

1. Silsbee's Method:

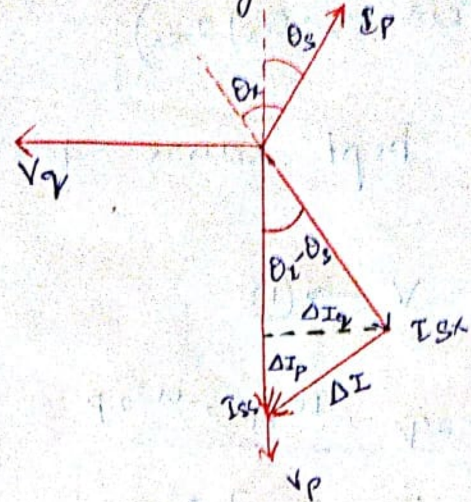
* In Silsbee's method their are 2 types
  1. Deflectional method
  2. Null method.

Here deflectional method is explained here. In this method ratio & phase angle of test transformer -X are determined.



* Two transformers (X & S) primaries are connected in series.
* Adjustible burden is put in secondary circuit of X transformer.
* Ammeter is connected in series with secondary of 'S' transformer.
* W_1 wattmeter is connected such that current coil of W_1 carries secondary current of 'S' transformer

* W_2 carries ΔI which is the difference of x transformer & S transformer
* W_1 & W_2 wattmeters pressure coil are connected in parallel to phase shifting transformer at constant voltage V.



* <u>Case 1</u>: phase of voltage is adjusted such that $W_1 = 0$

thus voltage V_q becomes in quadrature with current I_{ss}.

• Reading of wattmeter 1, $W_{1q} = V_q I_{ss} \cos 90° = 0$.

• Reading of wattmeter 2, $W_{2q} = V_q \times$ current component of ΔI in phase with V_q

$$= V_q \times \Delta I_q$$

$$= V_q \times I_{sx} \sin(\theta_x - \theta_s)$$

where θ_x = phase angle of x tran

θ_s = phase angle of S tran

consider ΔAOB

$\sin \theta_x - \theta_s = \frac{\Delta I_q}{I_{sx}}$

$\therefore \Delta I_q = \sin(\theta_x - \theta_s) \times I_{sx}$

<u>Case 2</u>: phase of voltage is shifted 90°

thus V_p becomes in phase with I_{ss}

• Reading of wattmeter 1 $W_{1p} = V_p I_{ss} \cos 0 = V_p I_{ss}$

• Reading of wattmeter 2 $W_{2p} = V_p \times$ current component of ΔI in phase with V_p

$$= V_p \times \Delta I_p$$

$I_{ss} - \Delta I_p = \cos(\theta_x - \theta_s) \times I_{sx}$

$I_{ss} - \cos(\theta_x - \theta_s) I_{sx} = \Delta I_p.$

$\therefore w_{2p} = V_p (I_{ss} - \cos(\theta_x - \theta_s) I_{sx})$

consider AOC

$\cos(\theta_x - \theta_s) = \frac{OB}{OA}$

$= \frac{OC - BC}{OA}$

$= \frac{I_{ss} - \Delta I_p}{I_{sx}}$

* If voltage is kept same for both 'x' & 's' transformers

ie $V_p = V_q = V \rightarrow$ (1)

$\therefore$ put (1) in w_{2q}, w_{1p}, w_{2p}.

ie $\boxed{w_{2q} = V[\sin(\theta_x - \theta_s)] I_{sx}}$

$\boxed{w_{1p} = V I_{ss}} \longrightarrow$ (2)

$w_{2p} = V [I_{ss} - \cos(\theta_x - \theta_s) I_{sx}]$

$\boxed{w_{2p} = V I_{ss} - V\cos(\theta_x - \theta_s) I_{sx}}$

$\therefore$ putting w_{1p} value in w_{2p}

$\therefore w_{2p} = w_{1p} - V\cos(\theta_x - \theta_s) I_{sx}$

* As $\theta_x - \theta_s$ is very small it is takes 0

$\cos 0 = 1$

$\therefore w_{2p} = w_{1p} - V I_{sx} \rightarrow$

(or)

$V I_{sx} = w_{1p} - w_{2p} \rightarrow$ (3)

case 3:- Derivation of ratio of 'X' transfor-mer

• Actual ratio of 'x' tran $R_x = \frac{I_p}{I_{sx}}$

. Actual ratio of 's' tran $R_s = \frac{I_p}{I_{ss}}$

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* Divide $\frac{R_x}{R_s} = \frac{I_p / I_{sx}}{I_p / I_{ss}} = \frac{I_p}{I_{sx}} \times \frac{I_{ss}}{I_p} = \frac{I_{ss}}{I_{sx}}$

* multiply Numerator & denominator by V.

$$\frac{R_x}{R_s} = \frac{I_{ss}}{I_{sx}} \times \frac{V}{V}$$

$$= \frac{W_{1p}}{W_{1p} - W_{2p}} = \frac{1}{1 - \frac{W_{2p}}{W_{1p}}}$$

$$\frac{R_x}{R_s} \simeq 1 + \frac{W_{2p}}{W_{1p}} \quad \text{or} \quad \boxed{R_x \simeq \left[1 + \frac{W_{2p}}{W_{1p}}\right] R_s}$$

<u>case 4</u>: Derivation of phase angle of X'tran

w.k.T

$$W_{2q} = V I_{sx} \sin(\theta_x - \theta_s)$$

or

$$\frac{W_{2q}}{V I_{sx}} = \sin(\theta_x - \theta_s)$$

$$W_{2p} = W_{1p} - V.I_{sx} \cos(\theta_x - \theta_s)$$

$$\therefore \cos(\theta_x - \theta_s) = \frac{W_{1p} - W_{2p}}{V I_{sx}}$$

So by dividing $\frac{\sin\theta}{\cos\theta} = \tan\theta$

$$\frac{\sin(\theta_x - \theta_s)}{\cos(\theta_x - \theta_s)} = \frac{W_{2q}/V I_{sx}}{W_{1p} - W_{2p}/V I_{sx}} = \frac{W_{2q}}{W_{1p} - W_{2p}}$$

$$\therefore \tan(\theta_x - \theta_s) = \frac{W_{2q}}{W_{1p} - W_{2p}}$$

Assume $\tan(\theta_x - \theta_s)$ as $\theta_x - \theta_s$ & ω_{2p} is very small $\therefore$ ω_{2p} is neglected

$$\theta_x - \theta_s = \frac{\omega_2 q V}{\omega_{1p}}$$

$$\therefore \boxed{\theta_x = \frac{\omega_2 q V}{\omega_{1p}} + \theta_s}$$