Instrument Transformer

- In power system, the currents and voltages are very large
  - Therefore, their direct measurements are not possible.
- It might appear that the extension of range could be conveniently done by the use of shunts for currents and multiplier for voltage measurement, as in DC.
  - But this method is suitable only for small values of current and voltage.
    - Difficult to achieve accuracy with a shunt on AC
    - Capability of having shunt of large range is not possible
    - The power consumed by multipliers become large as the voltage increases
    - The measuring circuit is not isolated electrically from the power circuit
- The solution is to step-down these currents/voltages with the help of Instrument Transformer
  - So that, they could be metered with instruments of moderate size

Current Transformer (C.T.):

- Transformers used for current measurement
- Steps down the current to the level of ammeter.

Voltage Transformer (V.T. or P.T.):

- Transformers used for voltage (Potential) measurement
- Steps down the voltage to the level of voltmeter.

- Used in AC system for the measurement of current, voltage, power and energy.

- Finds a wide application in protection circuits of power system
  - Ex. over current, under voltage, earth fault, etc.

Advantages of Instrument Transformer:

- Their reading do not depend upon circuit constant such as R, L & C
  - As in the case of shunts and multipliers
- Possible to standardize the instrument around their ratings.
  - This makes the replacement of instrument transformer very easy.
- The measuring circuit is isolated from the power circuit
- Low power consumption in the metering circuit
- Several instrument can be operated from a single instrument transformer

Ratios of Instrument Transformer:

Transformation Ratio, $R = I_{Pri} / I_{Sec}$ for a C.T.

and $R = V_{Pri} / V_{Sec}$ for a P.T.

Nominal Ratio, K_n = Rated I_{Pri} / Rated I_{Sec} for a C.T.

= Rated V_{Pri} / Rated V_{Sec} for a P.T.

Turns Ratio, $n = N_{sec} / N_{Pri}$ for a C.T.

$= N_{Pri} / N_{Sec}$ for a P.T.

Ratio Correction Factor (RCF) = Transformation Ratio/*Nominal Ratio*=R/K_n

or $R = RCF \times K_n$

– The ratio marked on the transformer is their nominal ratio

– **What is the meaning of KVA reading on the Transformer**

Current Transformer:

- Primary winding is connected in series with line carrying the current to be measured
  - Therefore, I_{Pri} α Load
- Primary winding consist of very few turns
  - Therefore, no appreciable voltage drop across it
- Secondary winding has larger number of turns
  - Exact number is being determined by the turn ratio

Relationship in a C.T.:

- r_s and x_s = resistance and reactance of secondary winding
- r_e and x_e = resistance and reactance of external burden
- E_p and E_s = primary and secondary winding induced voltage
- N_p and N_s = number of primary and secondary winding turns
- V_s = voltage at secondary winding terminals
- I_p and I_s = primary and secondary winding currents
- Φ = working flux of the transformer
- θ = phase angle of transformer (angle between I_s reversed and I_p)
- δ = angle between E_s and I_s
- Δ = phase angle of secondary winding load circuit
- I_o = exciting current
- I_m and I_e = magnetizing and loss component of I_o
- α = angle between I_o and Φ

– **Expression for Transformation Raito is derived on board**

Errors in C.T.:

- The secondary winding current is not a constant fraction of the primary winding current
  - depend upon magnetizing and loss component of exciting current
  - this introduces considerable errors into current measurements

$$\text{ratio error} = (K_n - R)/R$$

- It is necessary that the phase of I_s shall be displaced exactly by 180^0 from I_p.
  - but, it is displaced by an angle θ.

Characteristic of C.T.:

- *Effect of change of I_p*
  - If I_p changes, I_s also changes proportionally
  - At low values of I_p, the current I_m and I_e are a great portion of I_p
    - Therefore, errors are greater
  - As the I_p increases, I_s increases and results in decrement of R.

- *Effect of change of I_s*
  - Increment in I_s means increase in Volt-Ampere rating
  - This increases the secondary winding induced voltage
    - Therefore, I_m and I_e are increased
  - Thus, the errors will be increased.

- *Effect of change of Frequency*
  - Increase in frequency will result in proportionate decrease in flux density

Means to reduce the error in C.T.:

- Ideally, R=n and θ=0
  - But, as a result of physical limitations inherent in electric and magnetic circuit, the ideality will be lost and errors are induced

- The expression of R and θ indicates that
  - Both depend upon the I_e and I_m respectively
    - Thus, they are chosen small.
  - Specific design feature will help in minimization of the errors

Core:

- Core must have a low reluctance and low core loss
- Reduction of reluctance flux path can be done by
  - using materials of high permeability
  - short magnetic path
  - large cross section of core
  - Low value of flux density
- The number of joints in building up core should be minimum
  - because joints produce air gape
    - which offer path of high reluctance for the flux
- Core loss is reduced by choosing materials of low hysteresis and low eddy current losses

Effect of secondary winding open

- C.T. are always used with the secondary winding closed
  - Never open the secondary windings circuit of a C.T. while its primary winding is energized
  - Failure to this may lead to serious consequences for both
- In case of P.T., the current flowing in the primary winding is largely the reflection of that flowing in the secondary circuit.
  - whereas, in case of a C.T., the primary winding is connected in series with the line whose current is being measured
  - This current is in no ways controlled or determined by the condition of secondary winding circuit
- Under normal operating conditions, both primary and secondary windings produces ***mmf***, which act against each other
  - The secondary *mmf* is slightly less than the primary *mmf*
    - Thus, the resultant *mmf* is small

- The resultant *mmf* maintains the flux in core and supply the iron losses
  - since the resultant *mmf* is small, the flux density is also quite low
  - hence, a small voltage is induced in the secondary winding
- If the secondary winding is open-circuited when the primary winding is carrying current
  - the primary *mmf* remains same while the open secondary *mmf* reduces to zero
    - therefore, the resultant *mmf* is very large (i.e., equal to primary *mmf* $=I_pN_p$)
  - this large *mmf* produces a large flux in core till it saturates
  - this large flux linking the turn of secondary winding would induce a high voltage in the secondary winding which could be dangerous
    - to the transformer insulation and to the person operating it
  - Also, the eddy current and hysteresis loses would be very high under this condition
    - thus the transformer may be overheated and completely damaged
    - Even if this does not happen, the core may become permanently magnetized and give erroneous results.