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*, \( R = \frac{I_{Pri}}{I_{Sec}} \) for a C.T.

and \( R = \frac{V_{Pri}}{V_{Sec}} \) for a P.T.

*Nominal Ratio*, \( K_n = \frac{\text{Rated } I_{Pri}}{\text{Rated } I_{Sec}} \) for a C.T.

\( = \frac{\text{Rated } V_{Pri}}{\text{Rated } V_{Sec}} \) for a P.T.

*Turns Ratio*, \( n = \frac{N_{sec}}{N_{Pri}} \) for a C.T.

\( = \frac{N_{Pri}}{N_{Sec}} \) for a P.T.

*Ratio Correction Factor (RCF)* = \( \frac{\text{Transformation Ratio}}{\text{Nominal Ratio}} = \frac{R}{K_n} \)

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, $I_{\text{Pri}} \propto \text{Load}$

- Primary winding consists of very few turns
  - Therefore, no appreciable voltage drop across it

- Secondary winding has a 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
- $\Phi$ = working flux of the transformer
- $\theta$ = phase angle of transformer (angle between $I_s$ reversed and $I_p$)
- $\delta$ = angle between $E_s$ and $I_s$
- $\Delta$ = phase angle of secondary winding load circuit
- $I_o$ = exciting current
- $I_m$ and $I_e$ = magnetizing and loss component of $I_o$
- $\alpha$ = angle between $I_o$ and $\Phi$

- 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

\[
\text{ratio error} = \left(\frac{K_n}{R}\right) - \frac{R}{R}
\]

• It is necessary that the phase of \(I_s\) shall be displaced exactly by 180° from \(I_p\).
  – but, it is displaced by an angle \(\theta\).
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 \( \theta=0 \)
  – 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 \( \theta \) indicates that
  – Both depend upon the \( I_c \) 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 \textit{mmf} maintains the flux in core and supply the iron losses
  • since the resultant \textit{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 \textit{mmf} remains same while the open secondary \textit{mmf} reduces to zero
    • therefore, the resultant \textit{mmf} is very large (i.e., equal to primary \textit{mmf} = I_p N_p)
  – this large \textit{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.