

Module 2 : Current and Voltage Transformers

Lecture 6 : CT Tutorial

Objectives

In this lecture we will solve some tutorial problems on CT and analyse:

- The performance of a class C CT based on standard excitation curve.
- Maximum limit for secondary burden of a CT.
- Accuracy limit of a class C CT based on IEEE standards.

Example 1:

A 1200/5, C400 CT with excitation curves shown on above fig 5.7, is connected to a $2.0\ \Omega$ burden. Based on the accuracy classification, what is the maximum symmetrical fault current that may be applied to this CT without exceeding a 10% ratio error?

Answer:

CT ratio = 1200/5

Secondary resistance = $0.61\ \Omega$

Relay burden = $2\ \Omega$

For 20 times rated secondary current, i.e., 100A

Secondary voltage = $100 \times (2 + 0.61) = 261$ Volts which is less than knee point of the CT. Since this voltage is less than 400V, from electrical perspective, linearity will not be lost at even higher currents.

Approximate limit on secondary current is given by $I_{\max} = \frac{400}{2.61} = 153A$. Hence maximum symmetrical

fault current = $153 \times \frac{1200}{5} = 36720A$.

More exact calculation requires usage of fig 5.7. This would involve 'cut and try' approach.

Example 2:

A 1200/5, C400 CT is connected on the 1000/5 tap. What is the maximum secondary burden that can be used and we can maintain rated accuracy at 20 times rated symmetrical secondary current?

Answer:

The secondary voltage V_s corresponding to the tap 1000/5, $V_s = \frac{1000}{1200} \times 400 = 333V$

Secondary current $I_s = 20 \times 5 = 100A$

$$V_s = I_s(R_s + R_B)$$

$R_s = 0.51\ \Omega$, from calibration curve.

$$333 = 100(0.51 + R_B)$$

Secondary burden = $3.33 - 0.51 = 2.72\ \Omega$

Example 3:

Assume that secondary burden of a 300:5 class C CT is $5\ \Omega$. The relay setting is 2A and the CT ratio is 300/5. Using fig 5.7, calculate the primary current required to operate the relay?

Answer:

Secondary burden = $5\ \Omega$

Secondary resistance for 300/5 CT = 0.15

Relay setting, $I_s = 2A$

$$V_s = 2 \times (5 + 0.15) = 10.3V$$

Corresponding exciting current = 0.04A

$$\text{Total secondary current} = 2 + 0.04 = 2.04A$$

Note that, strictly, phasor addition of currents has to be done. However, algebraic addition simplifies work and usually leads to conservative estimate of voltages. Hence, this practice is considered acceptable.

$$\text{Primary current to operate the relay} = \frac{300}{5} \times 2.04 = 122A$$

Example 4:

A relay is expected to operate for 7000A primary current. The class C CT ratio is 600/5 (see fig 5.7). Secondary burden is 3.5 Ω . Will the CT saturate at this burden? Also, comment on the ratio error.

Answer:

$$\text{Secondary current } I_s = \frac{7000}{600} \times 5 = 58.33A$$

$$V_s = 58.33 (3.5 + 0.31) = 222.25V.$$

From the excitation curve (fig. 5.7) of 600/5 CT, we can see that the CT will be in deep saturation and % ratio error will exceed the limits.

Example 5:

What will be the approximate % error if a 500:5 class C CT is connected to a secondary burden of 2.5 Ω and the secondary current is 68A.

Answer:

For a 500/5 CT, secondary resistance $R_s = 0.25 \Omega$

$$\text{Secondary burden } R_B = 2.5 \Omega$$

$$V_s = I_s (R_B + R_s)$$

$$V_s = 68(2.5 + 0.25) = 187V$$

Corresponding exciting current $I_E = 6A$ (fig 5.7) (approximate)

$$\begin{aligned} \text{\% ratio error} &= \frac{I_E}{I_s} \times 100 = \frac{6}{68} \times 100 \\ &= 8.82\% \end{aligned}$$

Example 6:

If a 300:5 class C CT (fig 6.1) is connected to a meter with resistance $R_T = 1\Omega$ and secondary current in the CT is 4.5A find out the primary current, voltage developed across the meter and % ratio error. Lead wire resistance $R_L = 0.02\Omega$ secondary resistance R_s of a 300:5 CT = 0.15 Ω

Answer:

$$R_T = 1\Omega, R_L = 0.02\Omega, R_s = 0.15\Omega, I_s = 4.5A$$

$$\begin{aligned} \text{Total secondary resistance } R_T &= R_T + R_L + R_s \\ &= 1.17\Omega \end{aligned}$$

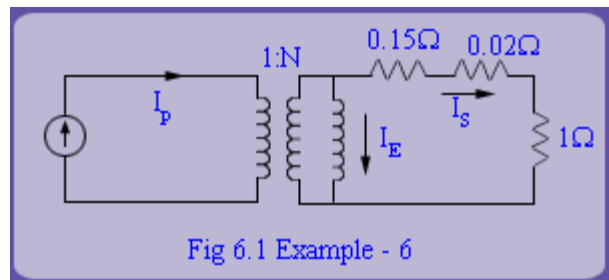
$$\begin{aligned} \text{Secondary voltage} &= I_s \times R_T \\ &= 4.5 \times 1.17 \\ &= 5.265V \end{aligned}$$

From Fig 5.7,

$$\begin{aligned} \text{Exciting current } I_E \text{ for } 5.265V \\ &= 0.03A \text{ (approximate)} \end{aligned}$$

$$\text{Turns ratio } N = 300/5 = 60$$

$$\begin{aligned} I_p &= N(I_s + I_E) \\ &= 60(4.5 + 0.03) \end{aligned}$$



$$= 271.8A$$

$$\begin{aligned} \text{Voltage across meter} &= I_g \times R_f \\ &= 4.5 \times 1 = 4.5V \end{aligned}$$

$$\begin{aligned} \text{Ratio error} &= \frac{I_E}{I_S} \times 100 = \frac{0.03}{4.5} \times 100 \\ &= 0.67\% \end{aligned}$$

Review Questions

Note: Use fig 5.7 wherever necessary.

- A circuit has a 1200:5 C 400 CT with characteristics as shown in fig 5.7. The maximum symmetrical fault for which the associated relays are to operate is 17,800 Amp. Find out the approximate % error if the secondary burden is:
 - 2Ω
 - 4Ω
- The secondary burden in a relay circuit is 4Ω . The overcurrent relay set to pick up at 3 Amp and CT ratio is 400:5. Calculate the minimum primary current to just operate the relay?
- Find out the maximum secondary burden that can be used and still maintain rated accuracy at 20 times rated symmetrical secondary current if a 1200:5 C 400 CT is connected on 800/5 tap.
- If the secondary burden of 1200:5 C 400 CT connected to 300:5 tap is 2Ω , find out. Find out the maximum symmetrical fault current that may be applied to this CT without exceeding 10% ratio error.
- Let the primary fault current in the primary side of a CT be given by

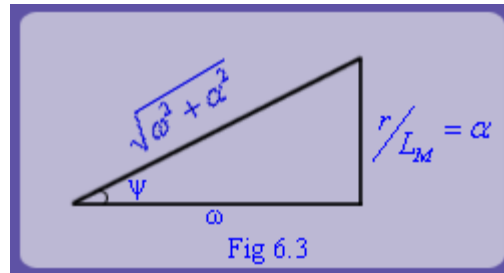
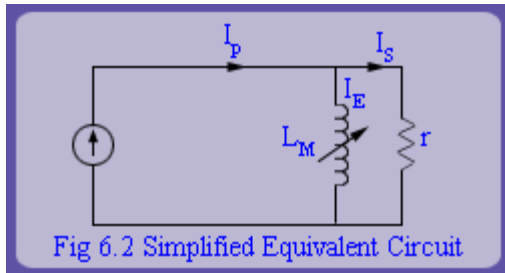
$$i_p = [I' \sin(\omega t + \delta) - I' \sin \delta e^{-\gamma t}] u(t)$$

(a) Show that this equation can be rearranged as follows.

$$i_p = [I' \sin \delta (\cos \omega t + e^{-\gamma t}) + I' \cos \delta \sin \omega t] u(t)$$

For $u(t)$ where $u(t)$ is the unit step function.

(b) Consider the simplified equivalent circuit of CT as shown in fig 6.2



Let ψ be the angle as shown in fig 6.3 and $1/\alpha = \frac{L_M}{r}$. Then show that secondary reflected current components for the primary are given by

	Primary Fault current	Secondary reflected current
1)	$I' \cos \delta \sin \omega t$ (Sine Component)	$I' \cos \delta [-e^{-\alpha t} \sin \psi \cos \psi + \cos \psi \sin(\omega t + \psi)]$
2)	$I' \sin \delta \cos \omega t$ (Cosine Component)	$I' \sin \delta [-e^{-\alpha t} \sin^2 \psi + \cos \psi \cos(\omega t + \psi)]$
3)	$-I' \sin \delta e^{-\gamma t}$ (d c component)	$-\frac{I' \sin \delta}{\alpha - \gamma} (\alpha e^{-\alpha t} - \gamma e^{-\gamma t})$

Recap

In this lecture we have learnt the following by solving the tutorial problems:

- Ratio error of a CT can be worked out from its excitation curve.
- The ratio error in a class C CT should not exceed 10%.
- Ratio error increases with secondary burden and there is a maximum limit for secondary burden of a CT.