Power System Protection

EE454

Lecture ppt. # 3

- **Note:**

  The materials in this presentation are only for the use of students enrolled in this course in the specific campus; these materials are for purposes associated with this course and may not be further disseminated or retained after expiry of the course.

Contents
Lect. File 3 – Mainly **Chapter 3** of PS Relaying


بسم الله الرحمن الرحيم

3

Current and voltage transformers

Figure 3 – Current transformers for outdoor operation. They transform high current into standardized values for meters, measuring and protection devices. (photo credit:

Free Standing CT

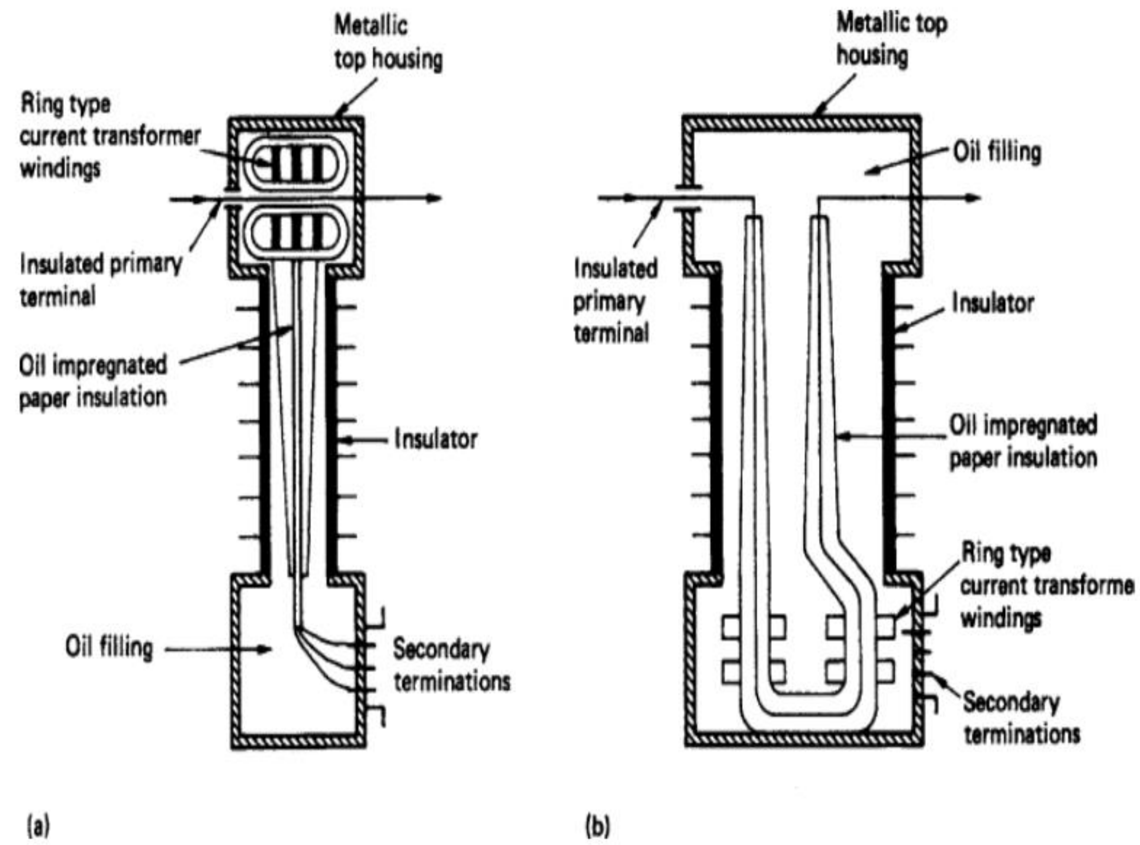
Dead-Tank Circuit Breaker with Bushing-Type CTs

Bushing CT

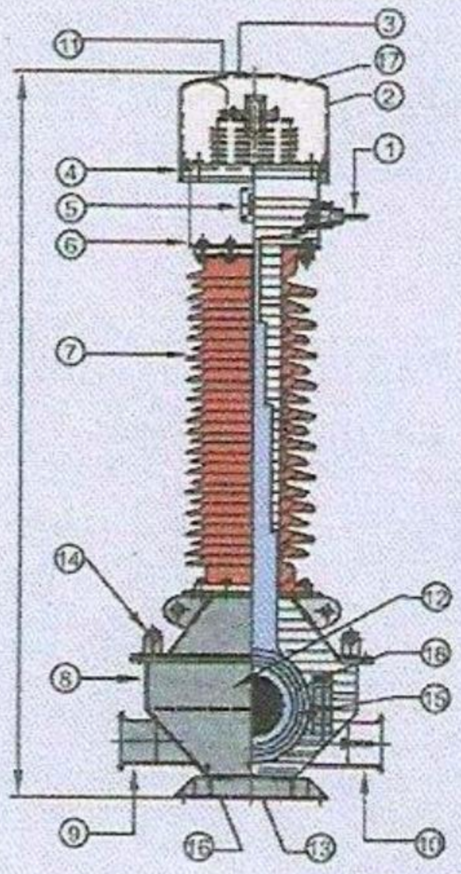
GE DIGITAL ENERGY
Learning & Development | Training Module

FMPR
Fundamentals of Modern Protective Relaying

FMPR-103 Power System Protection



Cross-section of (a) live-tank and (b) dead-tank current transformers



Sr. No.	DESCRIPTION
1	PRIMARY TERMINAL
2	S. S. BELLOW
3	PRESSURE RELEASE DEVICE
4	HOOD
5	OIL LEVEL INDICATOR
6	OIL EXPANSION CHAMBER
7	BUSHING
8	OIL TANK WITH COVER
9	SECONDARY TERMINAL BOX
10	EARTHING TERMINAL BOX
11	OIL FILLING PLUG
12	NAME & RATING PLATE
13	OIL DRAIN PLUG
14	LIFTING LUG 25
15	SECONDARY WINDING
16	PRIMARY WINDING
17	BELLOW INDICATOR

132 KV P.T. DETAILS

Free standing CTs can further be live tank or dead tank – and they can have multiple secondaries

Parts of a PT

High Voltage Instrument Transformers

Instrument Transformers are an essential link for the safe and efficient operation of transmission networks. They provide accurate and reliable current and voltage measurements for secondary equipment such as meters, protections relays, bay computers and other devices.

GE has manufactured tens of thousands high voltage instrument transformers. Our customers recognize our top-of-the-line products for their long term robustness, safety and reliability.

GE offers a comprehensive range of instrument transformers up to 1,200 kV including Current Transformers, Magnetic Voltage Transformers, Combined Metering Units, Capacitor Voltage Transformer, GIS Voltage Transformers and Power Voltage Transformers.

https://www.gegridsolutions.com/hvmv_equipment/catalog/hv_instrumenttransformers.htm

OSKF

Oil-Insulated Current Transformers up to 800 kV

GE's OSKF have been designed for a 30 year lifetime and, thanks to the profound technical concepts, many well out-live this service life. The oil is hermetically sealed from the air by a stainless steel diaphragm assembly and all external parts are of corrosion-resistant material.

Customer Benefits

- Special accuracy classes for protection: TPS, TPX, TPY, PR

OTEF

Oil-Insulated Voltage Transformers up to 550 kV

GE manufactures a complete range of high voltage oil-filled voltage transformers (VTs). The OTEF is a tank-type potential transformer with post insulator. Thousands voltage transformers are in service worldwide, in all types of climates and under the most severe conditions.

Customer Benefits

- Extensive field experience

3.1 Introduction

The function of current and voltage transformers (collectively known as transducers) is to transform power system currents and voltages to lower magnitudes, and to provide galvanic isolation between the power network and the relays and other instruments connected to the transducer secondary windings.

current transformer secondary windings are rated for 5 A, while in Europe a second standard of 1 A secondary is also in use. Voltage transformer secondary windings are rated at 120 V for phase-to-phase voltage connections, or, equivalently, at 69.3 V for phase-to-neutral connections.

Thus, current transformers are designed to withstand fault currents (which may be as high as 50 times the load current) for a few seconds, while voltage transformers are required to withstand power system dynamic overvoltages (of the order of 20 % above the normal value) almost indefinitely, since these types of overvoltage phenomena may last for long durations.

3.2 Steady-state performance of current transformers

Two types of CTs

i. Metering CT

Should give accurate measurement during steady state operation

But during a fault, the output may not be accurate

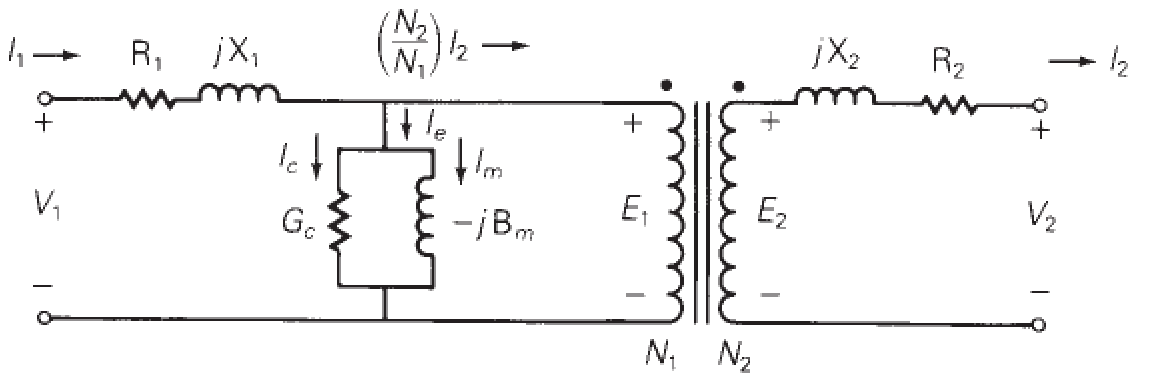
i. Protection CT

Vice Versa of Metering CT.

FIGURE 3.5

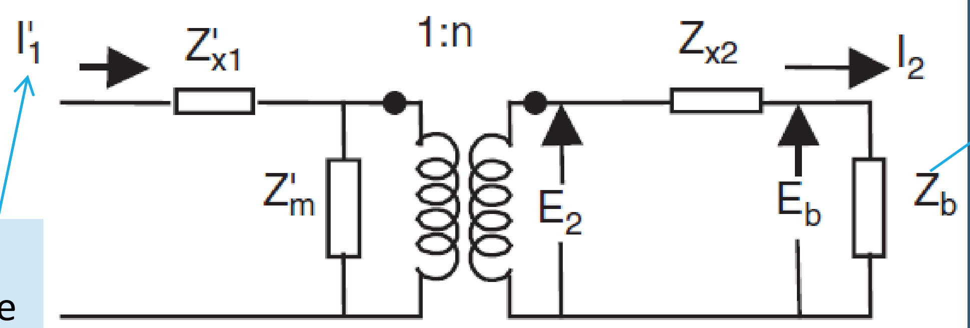
Equivalent circuit of a practical single-phase two-winding transformer

PSA by Glover



The burden may be specified in Zb ohms or as I^2Zb volt-amps, which becomes 25Zb VA for 5A rated secondary output.

Fig. 3.1 (a) CT equivalent Cct.



Primary current i.e. the line current

Zb i.e. burden impedance includes total impedance of relays/meters as well as connecting leads

Transformer basic formulae

$$E_1 = \left(\frac{N_1}{N_2}\right) E_2$$

$$I_1 = \left(\frac{N_2}{N_1}\right) I_2 =$$

Any load impedance Z_2 on 2ndry side, when referred to primary, it becomes:

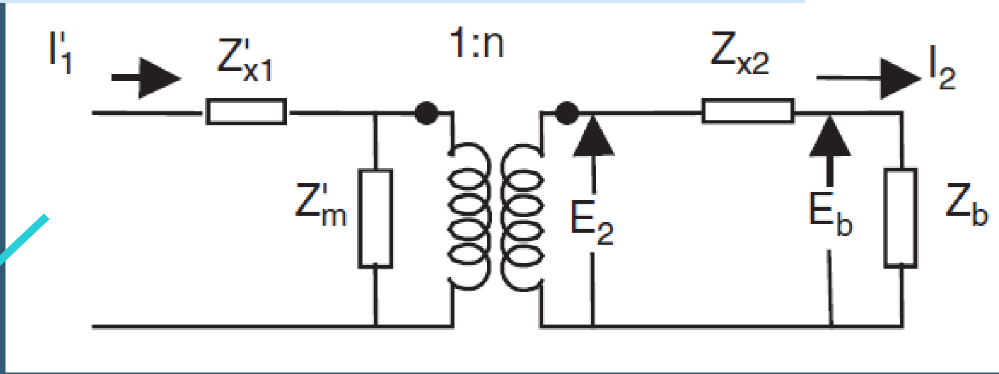
$$Z_2' = \frac{E_1}{I_1} = \frac{a_t E_2}{I_2/a_t} = a_t^2 Z_2 = \left(\frac{N_1}{N_2}\right)^2 Z_2$$

Now for the CT, using 1:n turns ratio

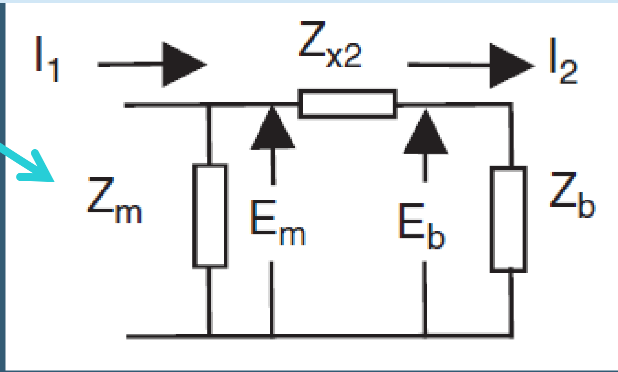
$$I_1 = \frac{I_1'}{n} \qquad (3.1)$$

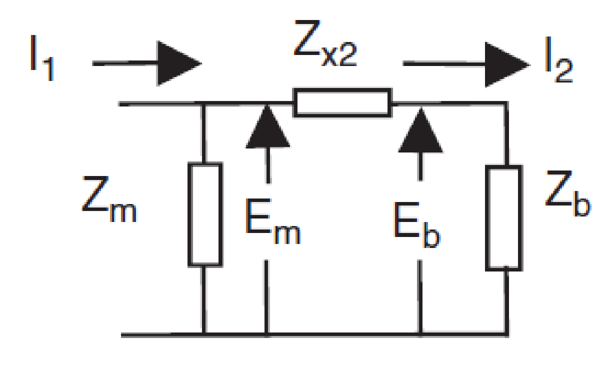
$$Z_\mathrm{m} = n^2 Z_\mathrm{m}' \qquad (3.2)$$

CT equivalent cct. - original



CT equivalent cct. - referred to secondary





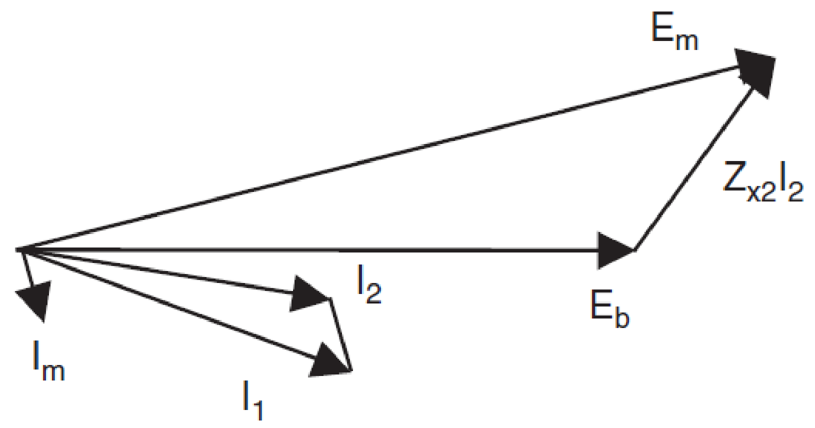


Figure 3.2 CT phasor diagram

$$E_{\mathrm{m}} = E_{\mathrm{b}} + Z_{\mathrm{x2}} I_2 \quad (3.3)$$

$$I_{\mathrm{m}} = \frac{E_{\mathrm{m}}}{Z_{\mathrm{m}}} \quad (3.4)$$

$$I_1 = I_2 + I_{\mathrm{m}} \quad (3.5)$$

$$\varepsilon = \frac{I_1 - I_2}{I_1} = \frac{I_{\mathrm{m}}}{I_1} \quad (3.6)$$

CT error

More often, the CT error is presented in terms of a ratio correction factor R instead of the per unit error E discussed above. **The ratio correction factor R is defined as the constant by which the name plate turns ratio n of a current transformer must be multiplied to obtain the effective turns ratio.**

$$R = \frac{1}{1 - \varepsilon} \qquad (3.7)$$

Although $\in$ and R are complex numbers, it is sometimes necessary to use the error and the ratio correction factor as real numbers equal to their respective magnitudes. This is approximate, but not excessively so.

Example 3.1

Consider a current transformer with a turns ratio of 500 : 5, a secondary leakage impedance of $(0.01 + j0.1)\ \Omega$ and a resistive burden of $2.0\ \Omega$. If the magnetizing impedance is $(4.0 + j15)\ \Omega$, then for a primary current (referred to the secondary) of I_l

$$E_m = \frac{I_1(0.01 + j0.1 + 2.0)(4.0 + j15.0)}{(0.01 + j0.1 + 2.0 + 4.0 + j15.0)} = I_1 \times 1.922\angle 9.62^\circ$$

and

$$I_m = \frac{I_1 \times 1.922\angle 9.62^\circ}{(4.0 + j15.0)} = I_1 \times 0.1238\angle - 65.45^\circ$$

Im = Em/ Zm

Thus, if the burden impedance and the magnetizing impedance of the CT are constant, the per unit CT error

$$\varepsilon = \frac{I_m}{I_1} = 0.1238\angle - 65.45^\circ$$

is constant, regardless of the magnitude of the primary current. However, the error does depend upon the magnitude and phase angle of the burden impedance. Thus, in this example, for a burden of $1.0\ \Omega$, $\in$ is $0.064\angle - 66^\circ$, and for an inductive burden of j2 ohms, $\in$ is $0.12\angle 12.92^\circ$. The corresponding ratio correction factor can be found for each of these burdens:

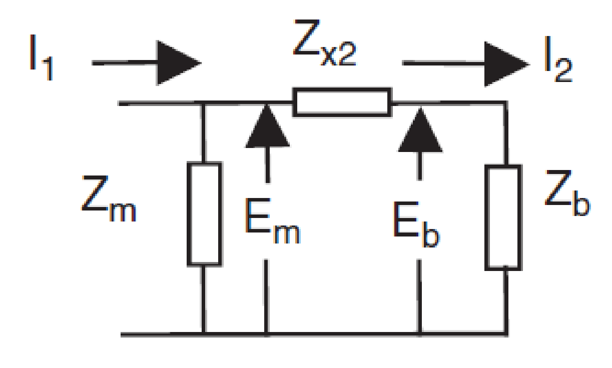
$$R = \frac{1}{(1.0 - 0.1238\angle - 65.45^\circ)} = 1.0468\angle - 6.79^\circ \quad \text{for } Z_b = 2 \text{ ohms}$$

$$R = 1.025\angle - 3.44^\circ \quad \text{for } Z_b = 1 \text{ ohm}$$

and

$$R = 1.13\angle 1.73^\circ \quad \text{for } Z_b = j2 \text{ ohms}$$

Em = I1 * (Zm || (Zx2 + Zb)



$$\varepsilon = \frac{I_1 - I_2}{I_1} = \frac{I_m}{I_1} \qquad (3.6)$$

$$R = \frac{1}{1 - \varepsilon} \qquad (3.7)$$

So the effective turns ratio is not 500:5, rather it is 500*(1.0468):5 ≈ 523:5
i.e. for Ip = 523 Amps, Is is 5 Amps.

Since the magnetizing branch of a practical transformer is nonlinear, Z_m is not constant, and the actual excitation characteristic of the transformer must be taken into account in determining the factor R for a given situation.

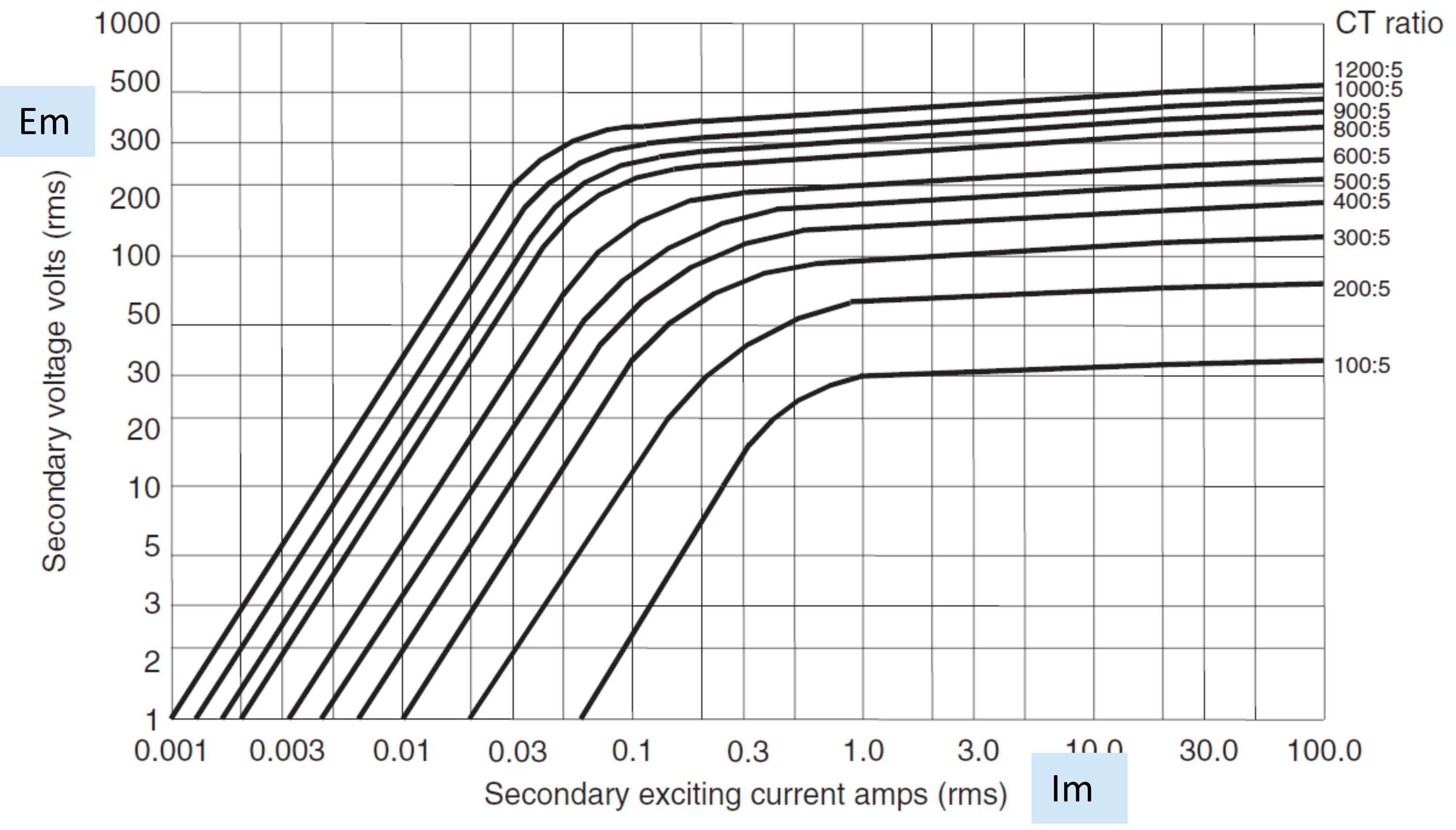


Figure 3.3 Magnetizing characteristic of a typical CT

Table 3.1 Standard current transformer multiratios (MR represents multiratio CTs)

600 : 5 MR	1200 : 5 MR	2000 : 5 MR	3000 : 5 MR
50 : 5	100 : 5	300 : 5	300 : 5
100 : 5	200 : 5	400 : 5	500 : 5
150 : 5	300 : 5	500 : 5	800 : 5
200 : 5	400 : 5	800 : 5	1000 : 5
250 : 5	500 : 5	1100 : 5	1200 : 5
300 : 5	600 : 5	1200 : 5	1500 : 5
400 : 5	800 : 5	1500 : 5	2000 : 5
450 : 5	900 : 5	1600 : 5	2200 : 5
500 : 5	1000 : 5	2000 : 5	2500 : 5
600 : 5	1200 : 5		3000 : 5

Example 3.2

Consider a CT with a turns ratio of 600 : 5, and the magnetizing characteristic corresponding to this ratio in Figure 3.3. It is required to calculate the current in its secondary winding for a primary current of 5000 A, if the total burden impedance is $(9 + j2)\ \Omega$ and the secondary leakage impedance is negligible. The impedance angle of the magnetizing branch is 60°. Since the magnetizing branch is nonlinear, we may consider the equivalent circuit to be made up of a linear part consisting of a current source of $5000 \times 5/600 = 41.66$ A in parallel with the burden, and connected across the nonlinear impedance Z_m, as shown in Figure 3.4. The corresponding Thévenin equivalent consists of a voltage source of $41.66 \times (9 + j2) = 384.1\angle 12.53°$ volts, in series with the burden. Since the impedance angle of Z_m is known to be 60°, the magnetizing current I_m and the secondary voltage E_2 can be expressed in terms of the magnitude of Z_m with the Thévenin voltage as the reference phasor:

$$I_m = \frac{384.1}{[|Z_m| \times (0.5 + j0.866) + (9.0 + j2.0)]}$$

$$E_2 = I_m Z_m$$

These two equations may be solved to produce values of E_2 and I_m in terms of $|Z_m|$ as the parameter (Table 3.2). Plotting the curve of these values on Figure 3.3, it is found to intersect the magnetizing characteristic at $I_m = 17$ A, $E_2 = 260$ V. Finally, reworking the equations to find the phase angles of the currents, the various currents are: $I_1 = 41.66\angle 0°$ (in that case, $E_{th} = 384.1\angle 12.53°$), $I_m = 17\angle -29.96°$ and $I_z = 28.24\angle 17.51°$. The error $\in$ is therefore $0.408\angle -29.96°$ and the ratio correction factor $R = 1.47\angle -17.51°$.

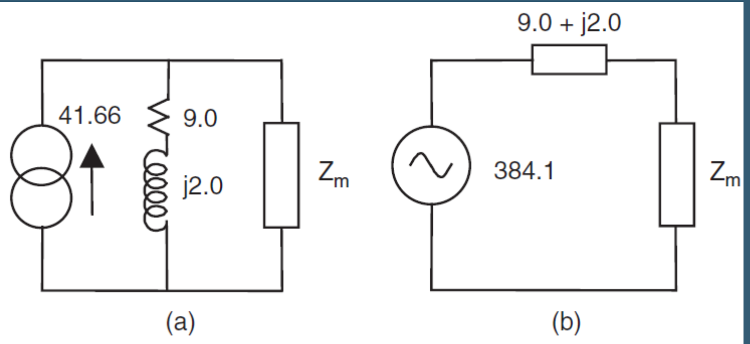


Figure 3.4 Calculation of CT performance in Example 3.2

Table 3.2 Values of secondary voltage E_2 and magnetizing current I_m in terms of magnetizing impedance Z_m as the parameter

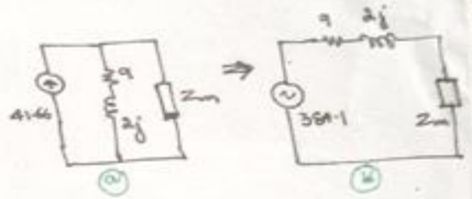
$\lvert Z_m \rvert$	$\lvert I_m \rvert$	$\lvert E_2 \rvert$
∞	0	384.1
100	3.61	361.0
10	21.82	218.2

Clearly, this CT is in severe saturation at this current and at the burden chosen. In practice, it must be used with much smaller burdens to provide reasonable accuracies under faulted conditions.

Example 3.2 (PSP)

CT turns ratio 600:5 — magnetizing xtic → given in fig 3.3. $I_p = 5000A$ $I_s = ?$ $Z_b = (9+2j)\Omega$ $Z_m = |Z_m| \angle 60°$

Ignore 2ndy leakage reactance.



Solution

1. Calculate current transformed according to 600:5 ratio $\Longrightarrow$ $5000 \times 5/600 = 41.66A$

2. To model the equivalent cct. assume a current source of 41.66A supplying I to parallel branches of $9+2j$ & Z_m — see fig 3.2(b) for this -

3. Convert I source to V source. $V = 41.66 \times (9+2j) = 384.1 \angle 12.53°$

   Take this as the reference voltage - $\therefore$ $V = 384.1 \angle 0$ for the cct. of fig (b)

4. $I_m = (384.1) / \left[|Z_m| (\cos 60° + j\sin 60°) + (9+2j) \right] \rightarrow ①$ & $E_2 = I_m Z_m \Rightarrow ②$

5. Plot a graph of $E_M = I_m Z_m$ starting with $Z_m = \infty$ & then 100, 10 . . . — This meets magnetic xtic at $(E_M, I_m) = (260, 17)$

   put Z_m in ① to get I_m → put in ② to get E_2; $E_2 = E_m$ (graph)

   So $|Z_m| = E_m / I_m = 260/17 = 15.29$ $\therefore$ $Z_m = 15.29 \angle 60°$

   (see below) This is the only pt on the graph that will satisfy both eq ① & ② —

6. $I_m = (384.1 \angle 12.53) / [15.29 (\cos 60° + j\sin 60°) + 9 + 2j] = 17 \angle -29.9°$

   Here angle of V is taken so that 41.66 is $41.66 \angle 0°$ i.e. the primary side current (transformed) is the reference.

   $I_2 = 41.66 - I_m = 41.66 \angle 0° - 17 \angle -29.9° = 28.24 \angle 17.51°$

   This is the current that the burden gets while actually it should be getting the full 41.66

7. $\epsilon = I_m / I_1 = 0.408 \angle -29.9°$ $R = 1/1-\epsilon = 1.47 \angle -17.51$

8. So the effective turns ratio is $R \times 600 = (1.47 \angle -17.51)(600) : 5$

   $= 882 \angle -17.51 : 5$

   using this ratio; we see for $I_p = 5000$ $I_s = I_2 = 5000 \times 5 / 882 \angle -17.51$

   $\approx 28.3 \angle 17.51$

The CT is in severe saturation.
It must be used with a smaller burden
i.e. higher Z_b -

3.2.1 Standard class designation

The equivalent circuit method of calculating the performance of a CT depends upon the availability of the magnetizing characteristic. When this is not readily available, an approximate assessment of the CT performance may be made through its standard class designation[3] as defined by the American National Standards Institute (ANSI) and the Institute of Electrical and Electronics Engineers (IEEE). The ANSI/IEEE class designation of a CT consists of two integer parameters, separated by the letter 'C' or 'T': for example, 10C400 or 10T300. The first integers describe the upper limit on the error made by the CT when the voltage at its secondary terminals is equal to the second integer, while the current in the transformer is 20 times its rated value. As most CT secondary windings are rated at 5 A secondary, this corresponds to a secondary current of 100 A. The 10C400 CT, for example, will have an error of less than or equal to 10 % at a secondary current of 100 A for burden impedances which produce 400 V or less at its secondary terminals.

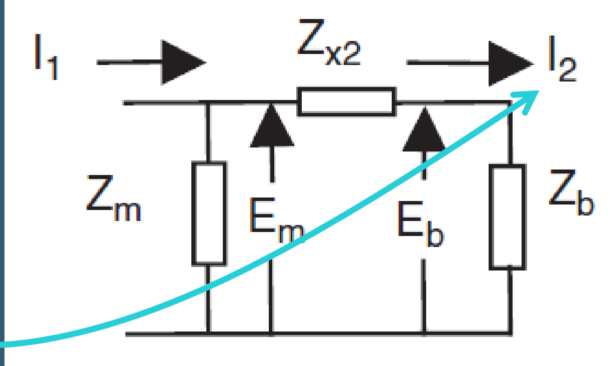
If the magnetizing impedance is assumed to be linear, the error made will be approximately proportional to the developed voltage. The letter 'C' in the class designation implies that the transformer design is such that the CT performance can be calculated, whereas the letter 'T' signifies some uncertainties in the transformer design, and the performance of the CT must be determined by testing the CT.

Example 3.3

Consider a 600 : 5 turns ratio CT of the class 10C400. The 10C400 CT will provide 100 A in the secondary with no more than 10 % error at 400 V secondary. Thus the magnitude of the magnetizing impedance is approximately $400/(0.1 \times 100) = 40\ \Omega$. With a primary current of 5000 A, the nominal secondary current will be $5000 \times 5/600 = 41.66$ A.

10% of 100A = 0.1 x 100

i.e. as per name plate ratio, I2 is 41.66A



With a maximum error of 10 %, this will allow a magnetizing current of about 4 A. At this magnetizing current, it may have a maximum secondary voltage of $4.16 \times 400/10$, or 167 V. Since the primary current is 41.66 A, the maximum burden impedance which will produce 167 V at the secondary is $167/(41.66 - 4.16) = 4.45\ \Omega$. All burdens of a smaller magnitude will produce smaller errors.

b/c smaller Zb will give smaller Em and hence smaller Im

Procedure is based on assumptions – apparently, Zx2 is also ignored.

In the above calculation, we have assumed that the magnetizing current is in phase with the secondary current and the current in the burden. Considering all other approximations made in this procedure (such as the assumed linearity of the magnetizing characteristic), this approximation is justifiable. We should remember that calculations such as these give us a limit for safe operation; oftentimes the errors will be much under those limits, and the approximations will not matter.

3.2.2 Polarity markings on CT windings

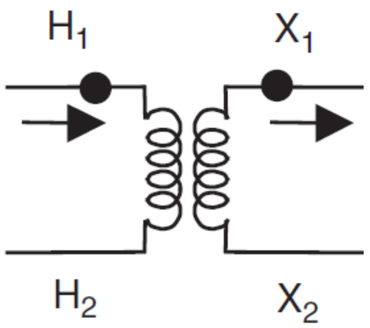


Figure 3.5 Polarity markings of a CT

Example 3.4

Consider the CTs shown in Figure 3.6(a). If the primary current is 1000 A, and the two CT ratios are 1000 : 5 and 1000 : 5 respectively, the current in the burden impedance Z_L is 10 A. If the CT secondaries are connected as shown in Figure 3.6(b), the burden current becomes zero. In reality, because of CT errors, the burden current in the first case will be less than 10 A, and in the second case it will be small, but not equal to zero. If the magnetizing characteristics of the two CTs are taken into account, the current in the burden must be calculated iteratively. One of the problems at the end of the chapter will illustrate this case.

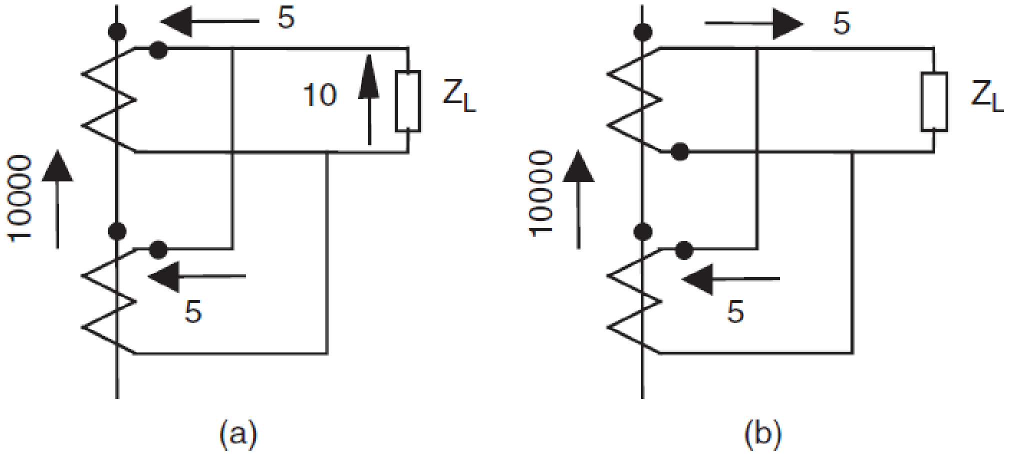


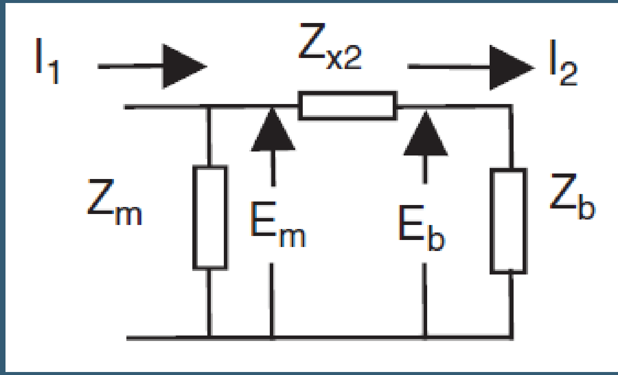
Figure 3.6 CT connections for Example 3.4

3.3 Transient performance of current transformers

When faults occur, the current magnitudes could be much larger, the fault current may have substantial amounts of DC components and there may be remanence in the CT core. All of these factors may lead to saturation of the CT core, and cause significant distortion of the secondary current waveform.

Consider the CT equivalent circuit shown in Figure 3.1(b), with the total impedance in the secondary circuit – i.e. the sum of the secondary leakage impedance, lead impedance and load impedance – given by $Z_b = (R_b + j\omega L_b)$. In Laplace domain, $Z_b = (R_b + sL_b)$.

Assume further that the magnetizing impedance Z_m is a parallel combination of the core loss resistance R_c and the magnetizing inductance L_m (Figure 3.7).



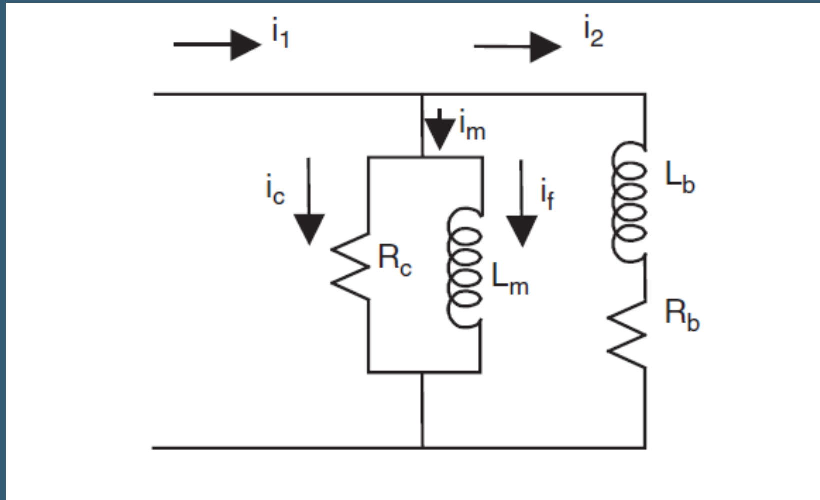


Figure 3.7 CT equivalent circuit for transient analysis

The primary current $i_1(t)$ (as reflected in the secondary), containing an exponentially decaying DC offset, is given by

$$\begin{aligned} i_1(t) &= I_{\max}[\cos(\omega t - \theta) - \varepsilon^{-t/T}\cos\theta] \quad \text{for } t > 0 \\ &= 0 \quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\;\; \text{for } t < 0 \end{aligned}$$

where $I_{\max}$ is the peak value of the sinusoidal steady-state fault current, T is the time constant of the primary fault circuit and θ is the angle on the voltage wave where the fault occurs;

In Laplace domain, the authors give i1(s) as:

$$i_1(s) = I_{\max}\cos\theta\left(\frac{s}{s^2+\omega^2} + \frac{T}{1+sT}\right) + I_{\max}\sin\theta\left(\frac{\omega}{s^2+\omega^2}\right) \tag{3.9}$$

$$v_2(s) = R_c i_c = sL_m i_f = i_2(R_b + sL_b) \tag{3.10}$$

and the flux linkages λ of the core are given by $L_m i_f$.

$$i_2 = i_1 - (i_f - i_c) \tag{3.11}$$

This will be +

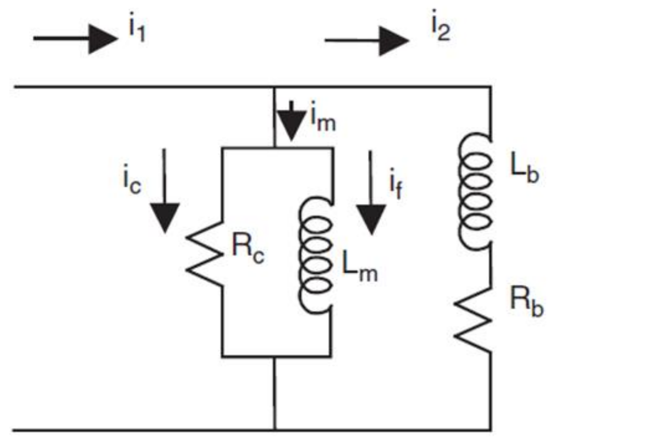


Figure 3.7 CT equivalent circuit for transient analysis

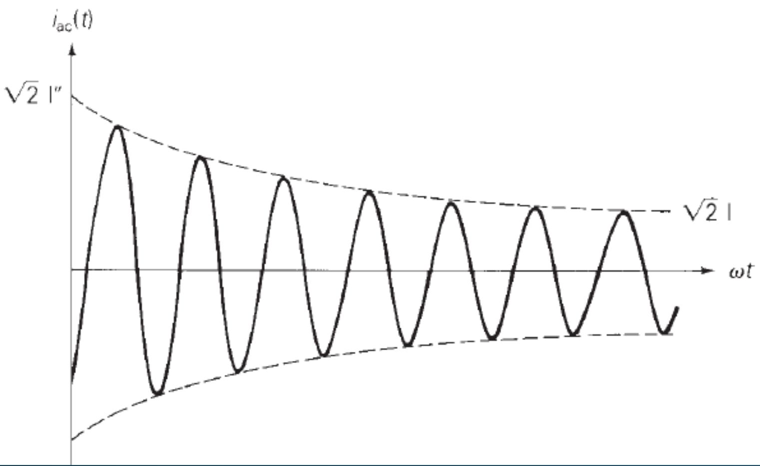
Slide #4 – from PSA ODL week 7:

7

SYMMETRICAL FAULTS

FIGURE 7.2

The ac fault current in one phase of an unloaded synchronous machine during a three-phase short circuit (the dc offset current is removed)



A physical explanation for this phenomenon is that . . . . See Glover Topic 7.2, Pg. 386

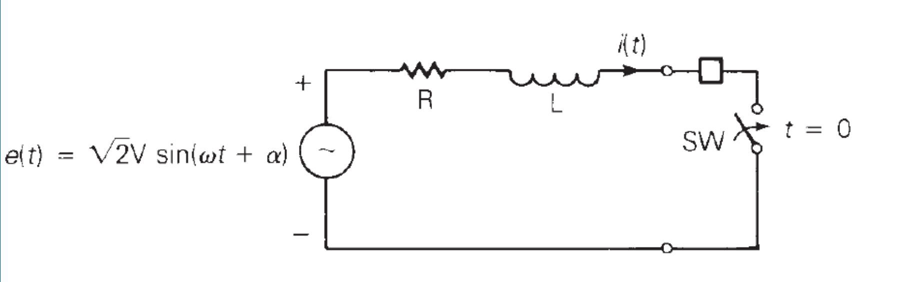
X''_d = direct axis subtransient reactance

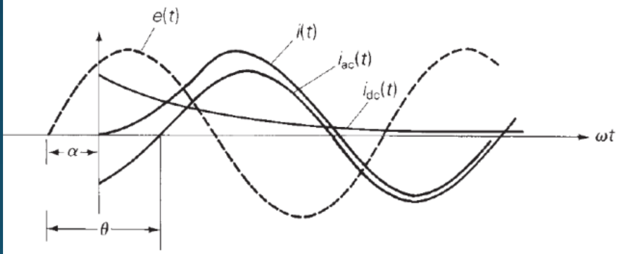
X'_d = direct axis transient reactance

X_d = direct axis synchronous reactance

Machine reactances X''_d, X'_d, and X_d as well as time constants T''_d, T'_d, and T_A are usually provided by synchronous machine manufacturers.

Concept of dc off-set





$$\frac{L\,di(t)}{dt} + Ri(t) = \sqrt{2}V\,\sin(\omega t + \alpha) \qquad t \geqslant 0 \qquad (7.1.1)$$

The solution to (7.1.1) is

$$i(t) = i_{ac}(t) + i_{dc}(t)$$

$$= \frac{\sqrt{2}V}{Z}\left[\sin(\omega t + \alpha - \theta) - \sin(\alpha - \theta)e^{-t/T}\right] \quad \text{A} \qquad (7.1.2)$$

Carrying on the derivation, the authors derive final results (with their conditions) to be

$$\lambda = I_{\max}\cos\theta\frac{R_c R_b}{R_c + R_b}\left\{\varepsilon^{-t/\tau}\left[-\frac{\tau T}{\tau - T} + \tau(\sin\varphi\cos\varphi\tan\theta - \cos^2\varphi)\right]\right.$$
$$\left. + \varepsilon^{-t/T}\left(\frac{\tau T}{\tau - T}\right) + \tau\frac{\cos\varphi}{\cos\theta}\cos(\omega t - \theta - \varphi)\right\} \tag{3.15}$$

$$i_2 = \frac{1}{B_b}\frac{\mathrm{d}\lambda}{\mathrm{d}t}$$
$$= I_{\max}\cos\theta\frac{R_c}{R_c + R_b}\left\{\varepsilon^{-t/\tau}\left[-\frac{T}{\tau - T} + (\sin\varphi\cos\varphi\tan\theta - \cos^2\varphi)\right]\right.$$
$$\left. - \varepsilon^{-t/T}\left(\frac{\tau}{\tau - T}\right) - \omega\tau\frac{\cos\varphi}{\cos\theta}\sin(\omega t - \theta - \varphi)\right\} \tag{3.16}$$

where $\tan\varphi = \omega\tau$.

Example 3.5

Consider the case of a purely resistive burden of 0.5 Ω being supplied by a current transformer with a core loss resistance of 100 Ω, and a magnetizing inductance of 0.005 H. Let the primary current with a steady-state value of 100 A be fully offset. Let the primary fault circuit time constant be 0.1 s. For this case $\theta = \pi,\ R_c = 100,\ R_b = 0.5,\ T = 0.1\ \text{s}$

$$i_1(t) = I_{\max}[\cos(\omega t - \theta) - \varepsilon^{-t/T}\cos\theta] \quad \text{for } t > 0$$

cos(ωt – 180) = - cos (ωt), and cos (180) = -1; also, 1/T = 10 so i1 becomes:

$$i_1 = 141.4 \times \epsilon^{-10t} - 141.4\cos(\omega t)$$

hence

$$\tau = \frac{(100 + 0.5) \times 0.005}{100 \times 0.5} = 0.01005$$

$$\omega\tau = 377 \times 0.01005 = 3.789$$

and

$$\varphi = tan^{-1}(3.789) = 75.21^\circ = 1.3127 \text{ rad}$$

As in book

$$\tau = \frac{R_c L_m + R_b L_m}{R_b R_c} \qquad (3.14)$$

Also,

$$\tan\varphi = \omega\tau.$$

Substituting these values in equations (3.15) and (3.16) gives

$$\lambda = -0.7399\varepsilon^{-99.5t} + 0.786\varepsilon^{-10t} - 0.1804\cos(\omega t - 1.3127)$$

$$i_2 = 147.24\varepsilon^{-99.5t} - 15.726\varepsilon^{-10t} + 136.02\sin(\omega t - 1.3127)$$

These expressions for i_1, i_2 and λ have been plotted in Figure 3.8. When the burden is inductive, L_b cannot be neglected, and the expressions for i_2 and λ are far more complicated. Essentially, additional time constants are introduced in their expressions. It is usual to solve such circuits by one of the several available time-domain simulation programs.

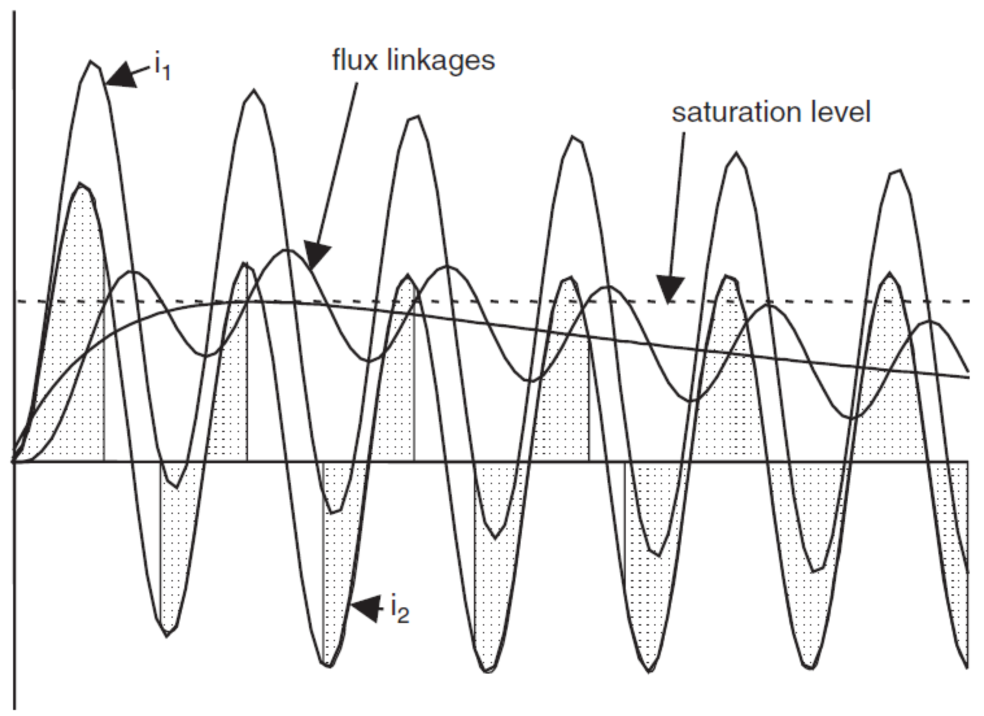
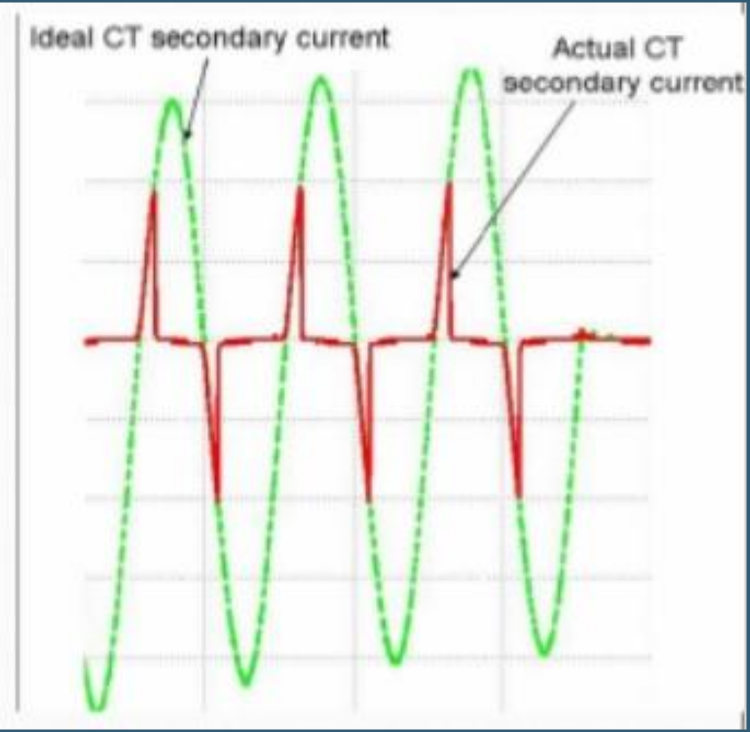


Figure 3.8 Primary and secondary currents and core flux linkages of a CT



3.4 Special connections of current transformers

Topic 3.4 was covered in lectures - from book directly, consult book for preparing this topic.
Further, study 3.5 from book as well.

3.5 Linear couplers and electronic current transformers

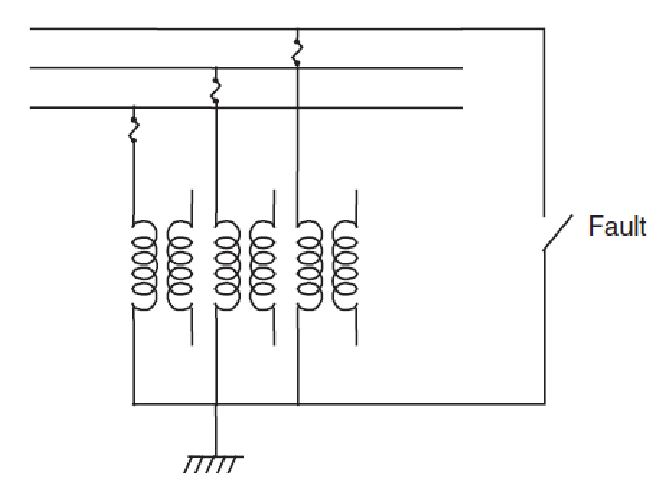
3.6 Voltage transformers

with one or more secondary windings rated at the standard voltage of 69.3 V for phase-to-neutral voltages or 120 V for phase-to-phase voltages. Their performance, equivalent circuit and phasor diagrams are similar to those of a power transformer. The error of transformation of such a transformer is negligible for all practical purposes in its entire operating range – from zero to about 110 % of its normal rating. We may consider such transformers to be error-free from the point of view of relaying. Voltage transformers are rather expensive, especially at extra high voltages: 345 kV or above. Consequently, they are usually found on low-, medium- and high-voltage systems.

Further, see video of GE (as mentioned in slide 5) for PT details and its accuracy classes.

At extra high voltages, capacitive voltage transformers, to be described in the next section, are the more usual sources for relaying and metering.

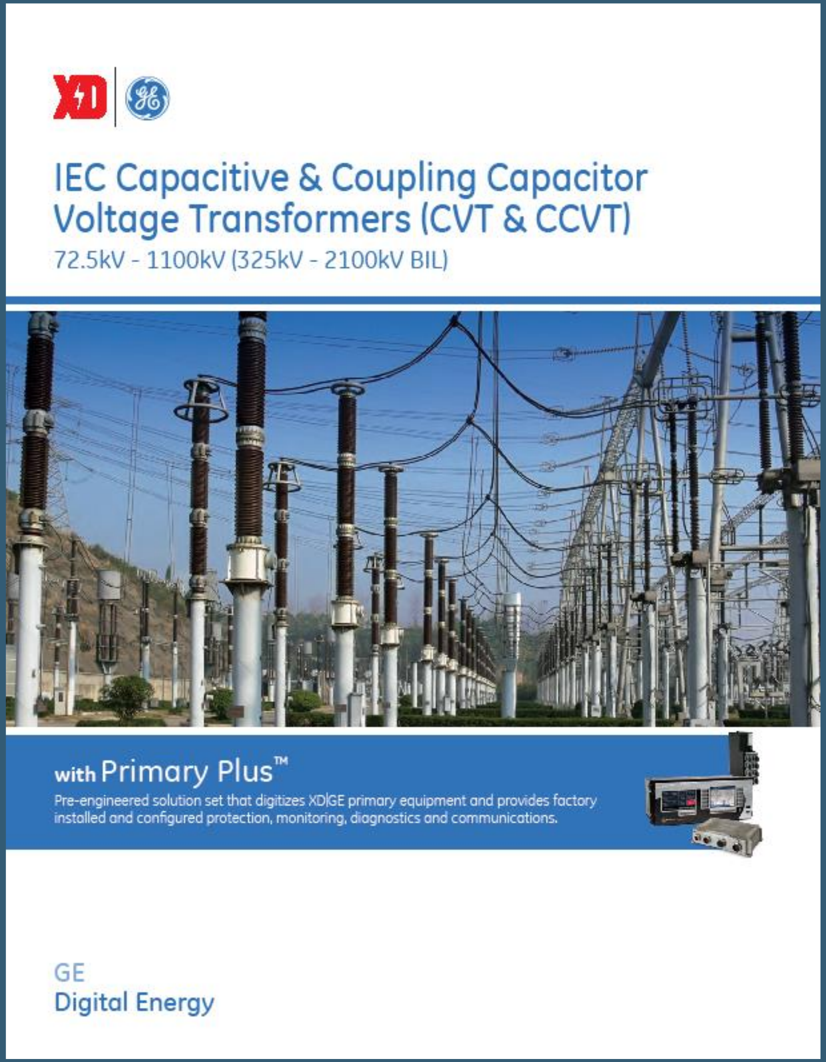
In passing, we may mention a possible problem with voltage transformers when used on ungrounded (or high-impedance grounded) power systems.[9] As shown in Figure 3.14, when a ground fault occurs on such a system, the voltage transformers connected to the unfaulted phases are subjected to a voltage equal to the phase-to-phase voltage of the power system. This usually drives one of the transformers well into saturation, and, because of the excessive magnetizing current drawn by this transformer, may blow the protective fuse.



3.7 Coupling capacitor voltage transformers

For Voltage Transformer as the Primary Voltage increases N1 increases as V2=V1*(N2/N1) V2=110 V and the turns ratio N1:N2 increases and transformer becomes bulky.

To cut down the VT size and cost, a capacitance potential divider is used Thus, a reduced voltage is fed to primary of the transformer. This reduces the size of VT. This leads to development of coupling capacitor voltage transformers (CCVT).



See pg 5 for section view of CVT

$$E_{th} = E_{pri} C_1/(C_1 + C_2),$$

$$E_2 = E_{th} - I_1 \left[j\omega L + \frac{1}{j\omega(C_1 + C_2)} \right] \quad (3.17)$$

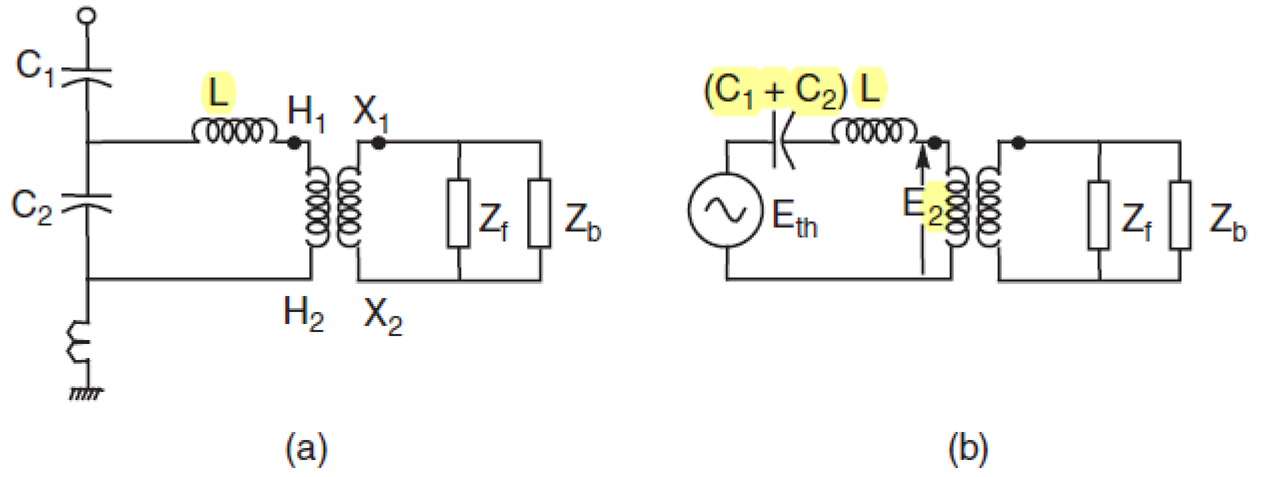


Figure 3.15 CCVT connections and equivalent circuit

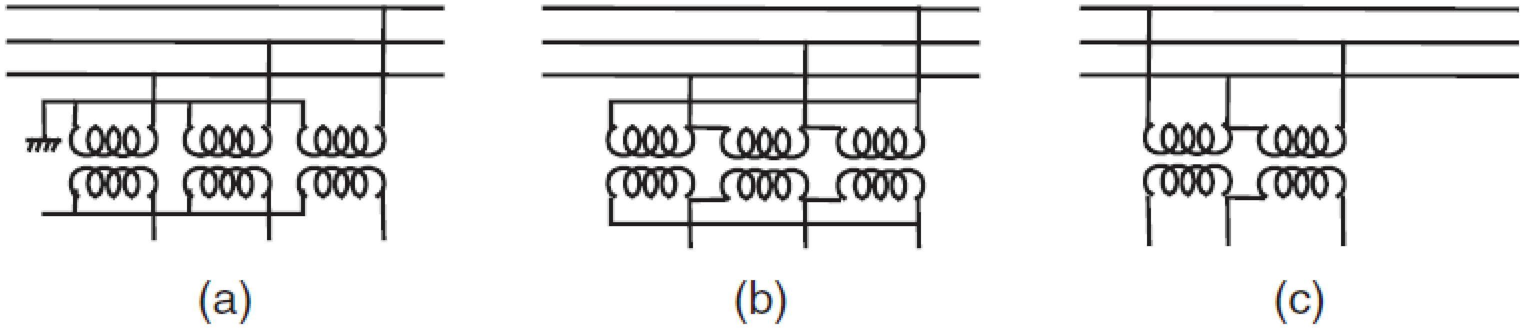


Figure 3.16 CCVT connections: (a) wye; (b) delta; (c) open delta

$$L = \frac{1}{\omega^2} \frac{1}{(C_1 + C_2)}$$

Example 3.7

Consider the three voltage transformers connected in delta on the primary and secondary sides as shown in Figure 3.17(a). Assume that each of the three transformers has a leakage impedance of $(1 + j5)\ \Omega$. Let the burden impedances (also connected in a delta) be $50\ \Omega$. If the primary voltage is 69 kV and the turns ratio of each of the transformers is $69\,000/120 = 575$ the burden currents (which are the same as the secondary delta winding currents) can be found from the equivalent circuit shown in Figure 3.17(a):

$$I'_a = \frac{E_{ab}}{Z_b} = \frac{E_{ab0} - I'_a Z_x}{Z_b}$$

where E_{ab} and E_{ab0} are the burden and source voltages, respectively. Solving for E_{ab} gives

$$E_{ab} = E_{ab0}\frac{Z_b}{Z_x + Z_b} = E_{ab0}\frac{50}{50 + 1 + j5} = E_{ab0} \times 0.976\angle 5.6^\circ$$

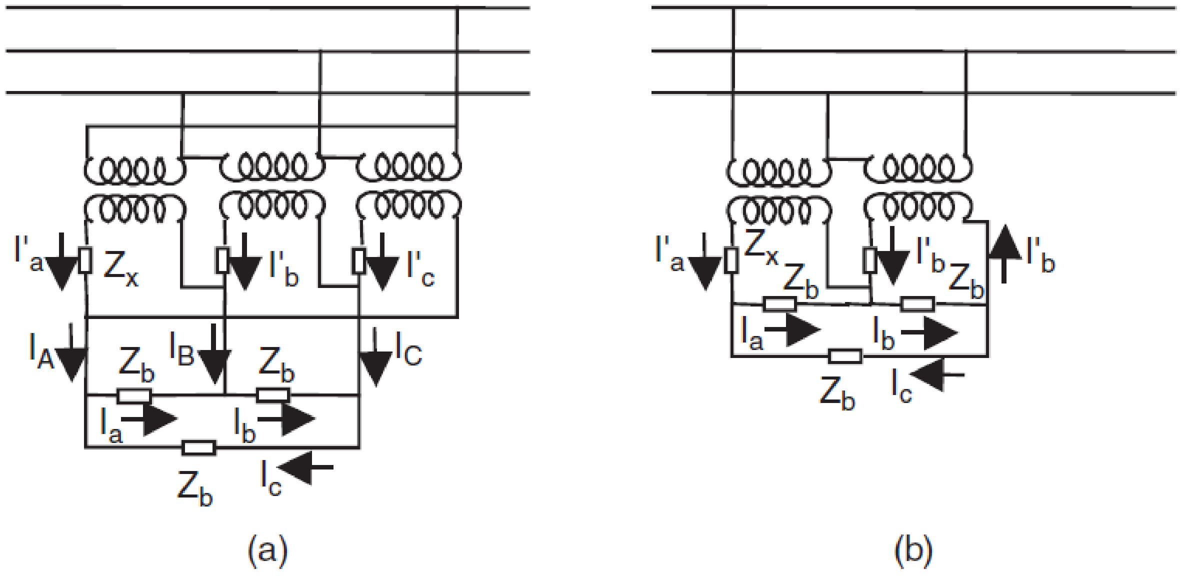
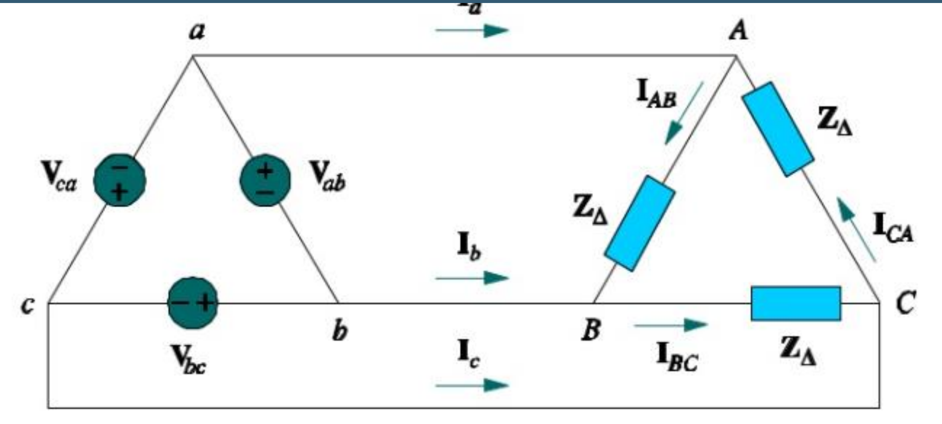


Figure 3.17 Connections for Example 3.7: (a) delta connection; (b) open delta connection

Thus, the ratio correction factor for this voltage transformer at this burden is $0.976\angle 5.6^\circ$. The voltages across the three burdens are of course balanced and symmetric.



Transient performance of CCVTs

For the transient performance of CVT, consult the resource - pages 3,4 and 5.

Capacitive Voltage Transformers:
Transient Overreach Concerns and
Solutions for Distance Relaying

Daqing Hou and Jeff Roberts
Schweitzer Engineering Laboratories, Inc.

Revised edition released October 2010

Previously presented at the
1996 Canadian Conference on Electrical and Computer Engineering, May 1996,
50th Annual Georgia Tech Protective Relaying Conference, May 1996,
and 49th Annual Conference for Protective Relay Engineers, April 1996

Previous revised edition released July 2000

Originally presented at the
22nd Annual Western Protective Relay Conference, October 1995

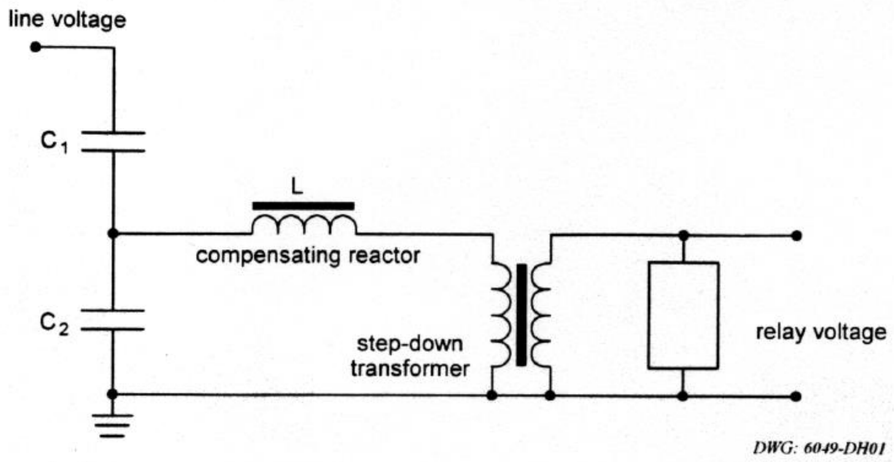


Figure 1 Generic CVT Structure

When a fault suddenly reduces the line voltage, the CVT secondary output does not instantaneously represent the primary voltage. This is because the energy storage elements, such as coupling capacitors and the compensating reactor, cannot instantaneously change their charge or flux. These energy storage elements cause the CVT transient.

Go directly to the pdf version of the resource file.