EE493 Protection of Power Systems I

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- Slides 2-10 are from chapter 4 of “Protection of Electricity Distribution Networks”, 3rd Edition, 2011, by Juan Gers

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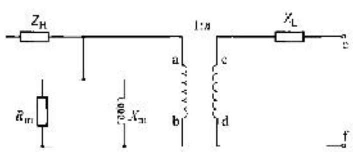
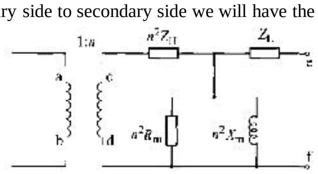
Modeling CTs

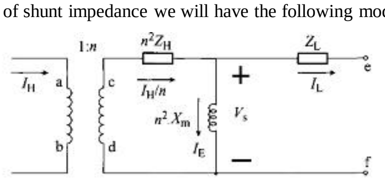
Current Transformers can be modeled as follows where Z_H is primary impedance, and Z_L is secondary impedance. Rm and Xm represent the losses and the excitation of the core.



If we bring impedances of primary side to secondary side we will have the following model:



If we ignore the resistive part of shunt impedance we will have the following model for CT



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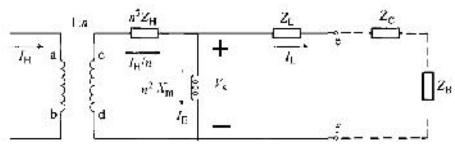
If the relay with equivalent impedance of ZB is connected to the CT through a cable with impedance of ZC we will have the following circuit:



$$V_s = I_L(Z_L + Z_C + Z_B)$$

where:
Vs = r.m.s voltage induced in the secondary winding;
I_L = maximum secondary current in amperes (this can be determined by dividing the maximum fault current on the system by the transformer turns ratio selected);
ZB = external impedance connected (impedance of the relay);
ZL = impedance of the secondary winding;
Zc = impedance of the connecting wiring (cable between CT and the relay).

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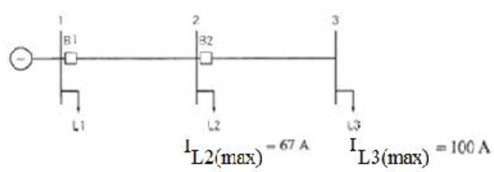
Selection of CTs

When we want to select a CT for protective relays, we should determine two things (1) CT ratio and (2) CT type.
(1) To determine CT ratio we should determine the maximum current that flows at CT location in normal condition of the network and then pick up a standard CT ratio accordingly. For example in the following network, for the CT installed at B1

I_{B1}=67+100=167 A



According the following table that shows standard CT ratios, 167 A is between 150 and 200. Therefore, we should select a CT with ratio of 200/5.

Standard CT ratios

Current Ratios						
50 : 5	100 : 5	150 : 5	200 : 5	250 : 5	300 : 5	400 : 5
450 : 5	500 : 5	600 : 5	800 : 5	900 : 5	1000 : 5	1200 : 5
1500 : 5	1600 : 5	2000 : 5	2400 : 5	2500 : 5	3000 : 5	3200 : 5
4000 : 5	5000 : 5	6000 : 5				

(2)When selecting a CT type, it is important to ensure that the fault level and normal load conditions do not result in saturation of the core and that the errors do not exceed acceptable limits. There are three methods that we can use to determine the CT type:
1) Using the formula;
2) Using the magnetization curve ;
3) Using CT classes of accuracy.

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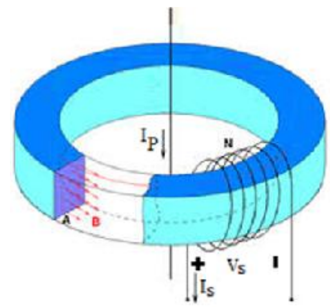
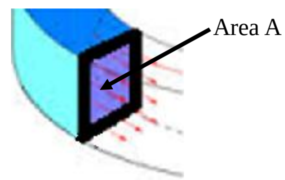
1) Use of the formula





$$V_s = 4.44\, f\, A\, N\, B_{max}\, 10^{-8} \text{ volts}$$

where:
f = frequency in Hz;
A = cross-sectional area of core (in^2);
N = number of turns which is equal to CT ratio;
B_{max} = flux density (lines/in^2).

Example:
Assume that a CT with a ratio of 2000/5 is available, having a steel core of high permeability, a cross-sectional area of 3.25 in^2, and a secondary winding with a resistance of 0.31 Ω. The impedance of the relays, including connections, is 2 Ω. Determine whether the CT would be saturated by a fault of 35000 A at 50 Hz. Assume that B of the CT is equal to 100000 lines/in^2

Solution
If the CT is not saturated, then the secondary current, I_L, is 35000×5/2000 = 87.5 A.
N = 2000/5 = 400 turns, and Vs=87.5 × (0.31 + 2) = 202.1 V.
According to

$$V_s = 4.44\, f\, A\, N\, B_{max}\, 10^{-8} \text{ volts}$$

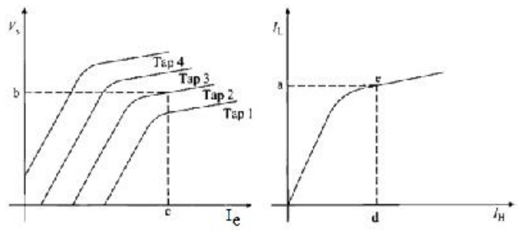
B_{max} can now be calculated:

$$B_{max} = \frac{202.1 \times 10^8}{4.44 \times 50 \times 3.25 \times 400} = 70\,030 \text{ lines/in}^2$$

Since the transformer in this example has a steel core of high permeability(B of the CT is equal to 100000 lines/in^2) above B_{max} does not result in saturation.

2) Using the magnetization curve

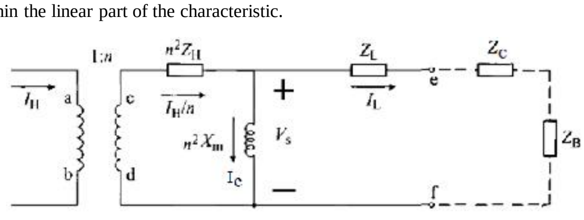
Typical CT excitation curves, which are supplied by manufacturers, state the r.m.s. current obtained on applying an r.m.s, voltage to the secondary winding, with the primary winding open-circuited. The curves give the magnitude of the excitation current required in order to obtain a specific secondary voltage. The method consists of producing a curve that shows the relationship between the primary and secondary currents for one tap and specified load conditions, such as shown in the following figure.



Starting with any value of secondary current, and with the help of the magnetisation curves, the value of the corresponding primary current can be determined. The process is summarised in the following steps:

(a) Assume a value for I_L.
(b) Calculate Vs in accordance with $Vs=I_L(Z_L+Z_C+Z_B)$
(c) Locate the value of Vs on the curve for the tap selected, and find the associated value of the magnetisation current, Ie.
(d) Calculate I_H/n (which according to CT model as shown bellow is equal to I_L + Ie) and multiply this value by n to refer it to the primary side of the CT.
(e) This provides one point on the curve of I_L versus I_H. The process is then repeated to obtain other values of I_L and the resultant values of I_H. By joining the points together the curve of I_L against I_H is obtained.

After constructing the curve it should be checked to confirm that the maximum primary fault current is within the transformer saturation zone. If not, then it will be necessary to repeat the process, changing the CT tap until the fault current is within the linear part of the characteristic.



3) Accuracy classes established by the ANSI/IEE standards

The American National Standards Institute (ANSI) and the Institute of Electrical and Electronics Engineers (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 20×5=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.

The C designator applies to a current transformer which has fully distributed secondary windings, and in which the leakage reactance (or, leakage flux in the core) is very low. In turn, this means that the relaying accuracy can be calculated (hence, "C").
The T designator applies to a current transformer in which there is a high leakage reactance that impacts the relaying accuracy, so that the accuracy must be determined by test (hence, "T").

These accuracy classes are only applicable for complete windings. When considering a winding provided with taps, each tap will have a voltage capacity proportionally smaller, and in consequence it can only feed a portion of the load without exceeding the ten percent error limit. Therefore, the maximum voltage at terminal of the CT for which the error of CT stays in the acceptable range is defined as

$V = Np \times Vc$

where

Np is the fraction of the total number of turns being used, and Vc is the ANSI/IEEE voltage capacity for the complete CT.

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Example

The maximum fault current in a given circuit is 12000A. The nominal CT ratio is 1200/5 and the CT is to be used with a tap of 800/5. The CT class is 10C200, the resistance of the secondary is 0.2 Ω, the total secondary load(impedance of the relay + impedance of the cable between the relay and CT) is 2.4 Ω. Determine if, on the occurrence of a fault, the error will exceed ten percent (i.e. is 10C200 CT good enough or we should change the CT?)

Solution

For a fault with 12000A, the CT's secondary current is

$I_L = 12000 \times (5/800) = 75$ A.

Then, the voltage at CT terminal is:

$Vs = I_L(Z_L+Z_C+Z_B)$

$Vs = 75\times (0.2+2.4) = 195$ volt

So, when a fault of 12000A occurs, the voltage at CT terminal is Vs=195. As we use 10C200 type CT, if the nominal CT ratio (in this case 1200/5) is used the CT has 10% error or less for secondary terminal voltage of 200 volts or less. However, the used CT has several taps. In this case, we used CT tap with ratio of 800/5 which means we are using 800/1200 portion of the secondary winding. So, the maximum secondary voltage that causes 10% error or less is

V(the maximum secondary voltage that causes 10% error or less)= (800/1200) ×200= 133.3 volts

Since the fault causes Vs=195 volts which is more than the maximum permissible voltage of 133.3 volts, the error could exceed ten percent during a fault of 12000 A. Consequently, it is necessary to reduce the load by using a cable with less impedance, or increase the current transformer tap, or use another CT of a higher class.

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