Module 2 : Current and Voltage Transformers

Lecture 5 : Introduction to CT

Objectives

In this lecture we will

- Introduce CT.
- Derive equivalent circuit of CT.
- Discuss classifications of CTs.

5.1 Introduction

Practically all electrical measurements and relaying decisions are derived from current and voltage signals. Since relaying hardware works with smaller range of current (in amperes and not kA) and voltage (volts and not kV), real life signals (feeder or transmission line currents) and bus voltages have to be scaled to lower levels and then fed to the relays. This job is done by current and voltage transformers (CTs and VTs). CTs and VTs also electrically isolate the relaying system from the actual power apparatus. The electrical isolation from the primary voltage also provides safety of both human personnel and the equipment. Thus,

- CT and VTs are the sensors for the relay.
- CT and VT function like ‘ears' and the ‘eyes' of the protection system. They listen to and observe all happening in the

external world. Relay itself is the brain which processes these signals and issues decision commands implemented by circuit breakers, alarms etc.

Clearly, quality of the relaying decision depends upon ‘faithful' reproduction on the secondary side of the transformer. In this module, we will learn a lot more about these devices. In particular, we will answer the following questions:

- How is a CT different from the normal transformer?
- How to decide the CT specifications?
- How to ascertain that CT is functioning as desired i.e., performance analysis?

5.2 Equivalent Circuit of CT

To begin with, equivalent circuit of a CT is not much different from that of a regular transformer (fig 5.1). However, a fundamental difference is that while regular power transformers are excited by a voltage source, a current transformer has current source excitation. Primary

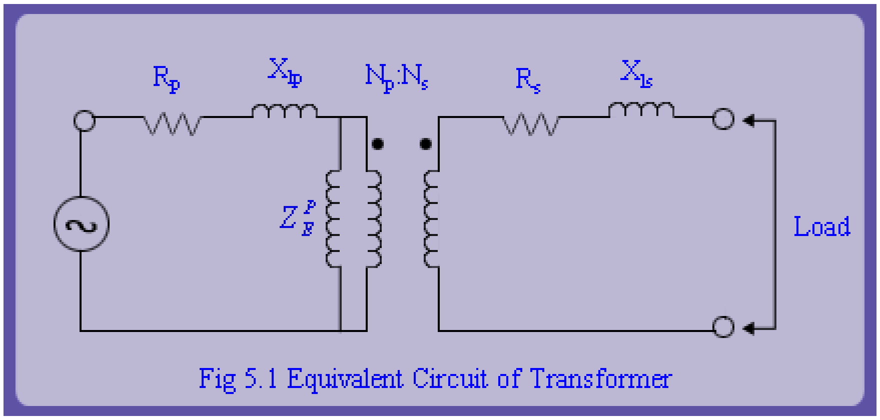

Fig 5.1 Equivalent Circuit of Transformer

winding of the CT is connected in series with the transmission line. The load on the secondary side is the relaying burden and the lead wire resistance.

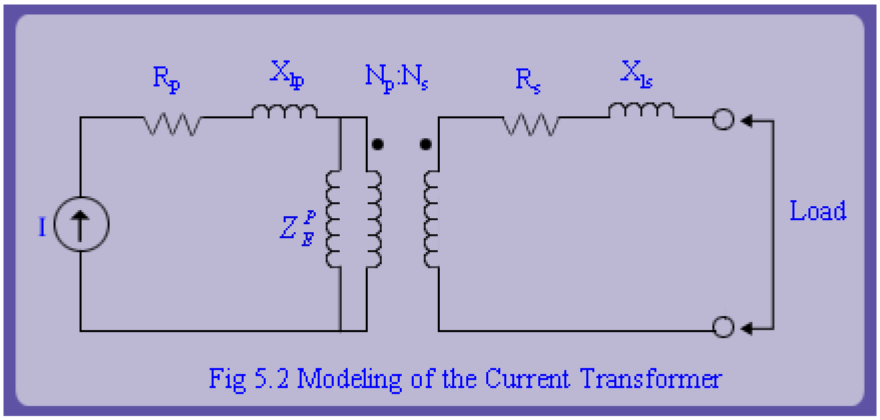

Fig 5.2 Modeling of the Current Transformer

Total load in ohms that is introduced by CT in series with the transmission line is insignificant and hence, the connection of the CT does not alter current in the feeder or the power apparatus at all. Hence from modeling perspectives it is reasonable to assume that CT primary is connected to a current source. Therefore, the CT equivalent circuit will look as shown in fig 5.2. The remaining steps in modeling are as follows:

As impedance in series with the current source can be neglected, we can neglect the primary winding resistance and

leakage reactance in CT modeling.

- For the convenience in analysis, we can shift the magnetizing impedance from the primary side to the secondary side of

  the ideal transformer.

5.2 Equivalent Circuit of CT

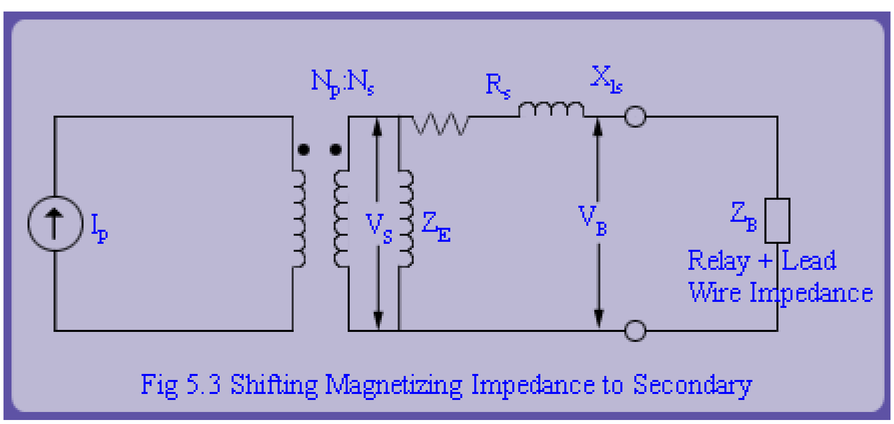

Fig 5.3 Shifting Magnetizing Impedance to Secondary

After application of the above steps, the CT equivalent circuit is as shown in the fig 5.3. Note that the secondary winding resistance and leakage reactance is not neglected as it will affect the performance of CT. The total impedance on the secondary side is the sum of relay burden, lead wire resistance and leakage impedance of secondary winding. Therefore, the voltage developed in the secondary winding depends upon these parameters directly.

The secondary voltage developed by the CT has to be monitored because as per the transformer emf equation, the flux level in the core depends upon it. The transformer emf equation is given by,

$$E_2 = 4.44 f N_2 \phi_m$$

where ϕ_m is the peak sinusoidal flux developed in the core. If B_m corresponding to this flux is

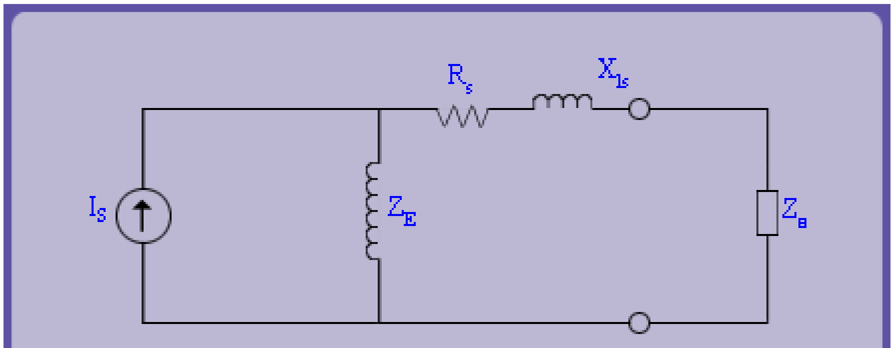

Fig 5.4 Final Equivalent Circuit of CT

above the knee point, it is more or less obvious that the CT will saturate. During saturation, CT secondary winding cannot replicate the primary current accurately and hence, the performance of the CT deteriorates.

Thus, we conclude that in practice, while selecting a CT we should ascertain that it should not saturate on the sinusoidal currents that it would be subjected to.

Use of numerical relays due to their very small burden vis-a-vis solid state and electromechanical relays, improves the CT performance. CT is to be operated always in closed condition. If the CT is open circuited, all the current I_p/N, would flow through X_m. This will lead to the development of dangerously high level of voltage in secondary winding which can even burn out the CT.

We can further, simplify the equivalent circuit of a CT by transferring the current source (through the ideal transformer) to the secondary side. Thus, the equivalent circuit of the CT is as shown in fig 5.4.

5.2 Equivalent Circuit

5.2.1 Equivalent circuit of saturated CT

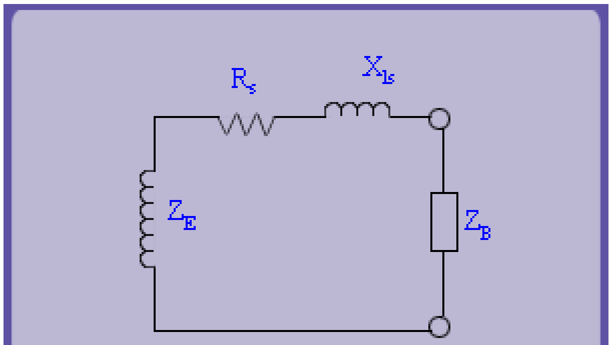

Fig 5.5 CT Equivalent Circuit during Saturation

One of the major problems faced by the protection systems engineer is the saturation of CT on large ac currents and dc offset current present during the transient. When the CT is saturated, primary current source cannot be faithfully reflected to the secondary side. In other words, we can open circuit the current source in fig 5.4. Also, the magnetizing impedance falls down during saturation. Then the transformer behaves more like air core device, with negligible coupling between the primary and secondary winding. The high reluctance due to the air path implies that the magnetizing impedance (inductance) falls down. The corresponding equivalent circuit is shown in fig 5.5.

5.3 Classification of CTs

The CTs can be classified into following types:

- Measurement CTs
- Protection CTs

A measurement grade CT has much lower VA capacity than a protection grade CT. A measurement CT has to be accurate over its complete range e.g. from 5% to 125% of normal current. In other words, its magnetizing impedance at low current levels. (and hence low flux levels) should be very high. Note that due to non-linear nature of B-H curve, magnetizing impedance is not constant but varies over the CT's operating range. It is not expected to give linear response (secondary current a scaled replica of the primary current) during large fault currents.

In contrast, for a protection grade CT, linear response is expected up to 20 times the rated current. Its performance has to be accurate in the range of normal currents and upto fault currents. Specifically, for protection grade CT's magnetizing impedance should be maintained to a large value in the range of the currents of the order of fault currents.

When a CT is used for both the purposes, it has to be of required accuracy class to satisfy both accuracy conditions of measurement CTs and protection CTs. In other words, it has to be accurate for both very small and very large values of current. Typically, CT secondary rated current is standardized to 1A or 5A (more common).

However, it would be unreasonable to assume that the linear response will be independent of the net burden on the CT secondary. For simplicity, we refer to the net impedance on the secondary side (neglecting magnetizing impedance) as the CT burden. It is quite obvious that the driving force (E_2) required to drive the primary current replica will increase as this burden increases. If this voltage exceeds the designer's set limits, then the CT core will saturate and hence linear response will be lost. Hence, when we say that a CT will give linear response up to 20 times the rated current, there is also an implicit constraint that the CT burden will be kept to a low value. In general, name-plate rating specifies a voltage limit on the secondary (e.g., 100 V) up to which linear response is expected. If the CT burden causes this voltage to be exceeded, CT saturation results.

5.3 Classification of CTs

5.3.1 ANSI / IEEE classification

ANSI/IEEE standards classify CTs into two types:

- Class T CT
- Class C CT

5.3.1.1 Class T CTs

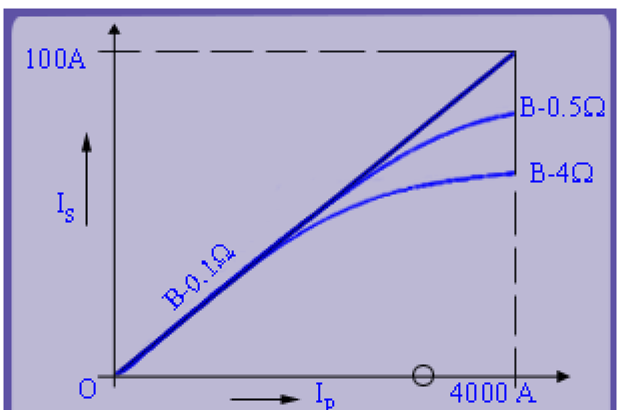

Fig 5.6 Performance Curve for Class T 200:5 CT

Typically, a class T CT is a wound type CT with one or more primary turns wound on a core. It is associated with high leakage flux in the core. Because of this, the only way to determine it's performance is by test. In other words, standardized performance curves cannot be used with this types of CTs.

Figure 5.6 shows one such experimentally calibrated curve for a CT. The letter 'B' indicates the burden in ohms to which the CT is subjected. It is seen that when burden is less than say 0.1 ohms, CT meets the linear performance criterion. However, as the burden increases to 0.5 ohms, the corresponding linearity criteria is not met till the end. At 4 ohms burden, there is significant deviation from the linear response. **A general rule of thumb is that, one should try to keep the CT burden as low as possible.**

Ratio Error: CT performance is usually gauged from the ratio error. The ratio error is the percentage deviation in the current magnitude in the secondary from the desired value. In other words, if the current measured in the secondary is I_s, true or actual value is I_p/N, where N is nominal ratio (e.g. N for a 100:5 CT is 20) and I_p is the primary current then ratio error is given by $\frac{\left|\frac{I_P}{N}\right| - |I_S|}{|I_S|} \times 100$. When the CT is not saturated ratio error $\frac{\frac{I_P}{N} - I_S}{I_S} \times 100$ is a consequence of magnetizing current I_E since $\frac{I_P}{N} - I_S = I_E$. Therefore, % ratio error is equal to $\frac{I_E}{I_S} \times 100$.

When the CT is saturated, coupling between primary and secondary is reduced. Hence large ratio errors are expected in saturation. The current in the secondary is also phase shifted. For measurement grade CTs, there are strict performance requirements on phase angle errors also. Error in phase angle measurement affects power factor calculation and ultimately real and reactive power measurements. It is expected that the ratio error for protection grade CTs will be maintained within $\pm 10\%$.

5.3 Classification of CTs

5.3.2Class C CT

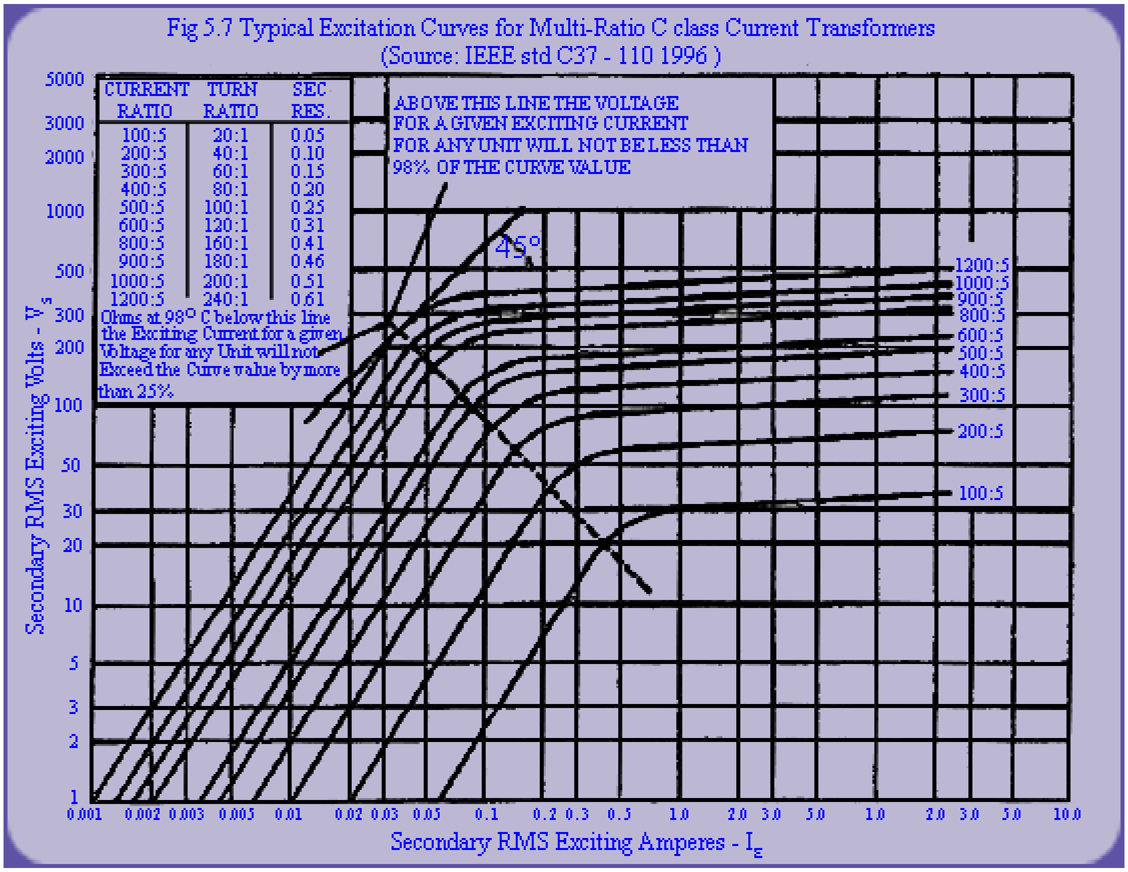

Fig 5.7 Typical Excitation Curves for Multi-Ratio C class Current Transformers
(Source: IEEE std C37 - 110 1996)

Letter designation 'C' indicates that the leakeage flux is negligible. Class C CTs are the more accurate bar type CTs. In such CTs, the leakage flux from the core is kept very small. For such CTs, the performance can be evaluated from the standard exciting curves. Also, the ratio error is maintained within $\pm 10\%$ for standard operating conditions. For such CTs, voltage rating on the secondary is specified up to which linear response is guaranteed. For example, a class C CT specification could be as follows: 200:5 C 100. The labeling scheme indicates that we are dealing with a 200:5 class C CT which will provide linear response up to 20 times rated current provided the burden on the secondary is kept below $(100/(5 \times 20) = 1)$ ohm. Similarly, a corresponding class T CT may be labeled as 200:5 T 100.

For class C CTs, standard chart for E_2 versus excitation current (I_e) on the secondary side is available. This provides the protection engineer data to do more exact calculations (refer fig 5.7). e.g., in determining relaying sensitivity.

Review Questions

1. What are the functions of a CT?

2. Derive equivalent circuit of a CT.

3. What are the consequences of CT saturation on large AC current? How can it be avoided?

4. What are the differences between:

   (a) Measurement CTs and Protection CTs.

(b) Class T CTs and class C CTs.

5. By mistake someone has interchanged the terminals of measurement CT and protection CT. Both CT are at the same

place and having same current ratings. What will happen in normal condition and abnormal condition?

Recap

In this lecture we have learnt the following:

- Functions of CT and VT.
- Equivalent circuits of CT.
- Classifications of CTs .