High Voltage Instrument Transformers

An Online Continuing Education Course for Engineers

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High Voltage Instrument Transformers

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INTRODUCTION

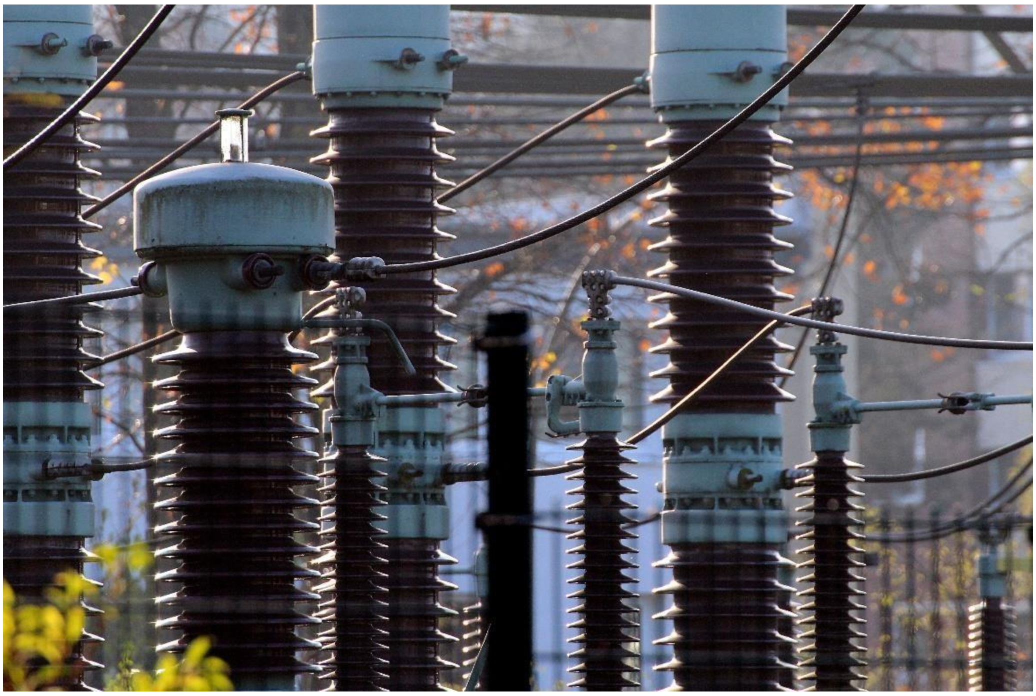
In the electrical industry, **current** and **voltage** transformers are collectively called **instrument transformers**. Electrical instrument transformers are used in power systems to transform high-magnitude currents and voltages to lower-magnitude, easy-to-handle values. These are then used for system monitoring, control, protection, and **measurement** purposes.

The main function of instrument transformers is to provide protection and metering devices with **representative current** and **voltage signals** that accurately (lower magnitude) reproduce the corresponding **primary quantities** according to the specified **transformation ratio**.

If instrument transformers are not used in high-voltage grid systems, then the protection, control, and metering devices would require an infeasible amount of electrical insulation and thermal robustness, leading to an astronomical increase in their cost and complexity.

Instrument transformers, by virtue of their construction, also provide **galvanic isolation** to the protection relay or metering devices (connected to the secondary windings) from the primary high-voltage network.

Furthermore, since the current and voltage ratings of the secondary windings of instrument transformers are **standardized**, inter-changeability between different manufacturer’s relays and meters is possible.

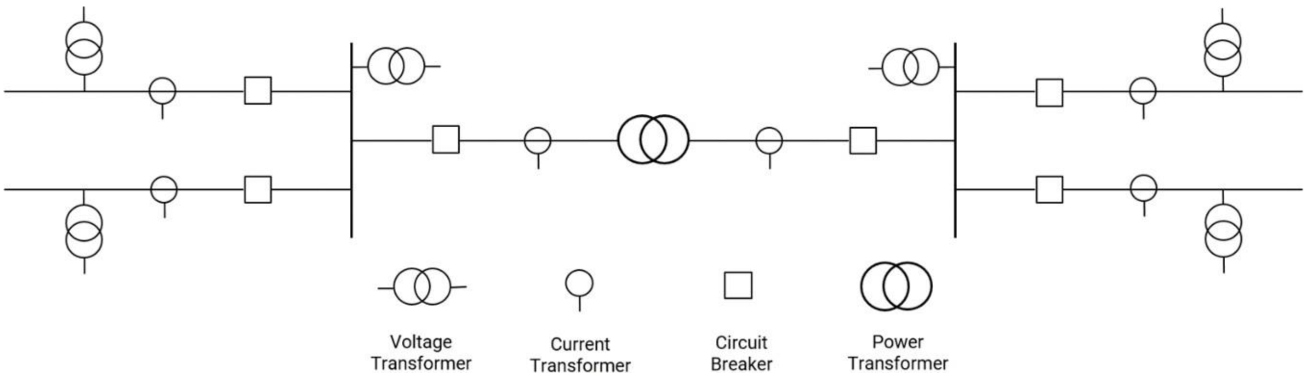


Current Transformers in a High Voltage Substation

Location of Instrument Transformers in Substations

Instrument transformers are used to supply measured quantities of current and voltage in an appropriate form to controlling and protective apparatus, such as energy meters, indicating instruments, protective relays, fault locators, fault recorders, and synchronizers. Instrument transformers are thus installed when it is necessary to obtain measuring quantities for the purposes mentioned above. Typical points of installation are **switch bays for lines**, **feeders**, **transformers**, **bus couplers**, and **busbars**.

The figure below shows an example of a suitable location for a current transformer (CT) and voltage transformer (VT) in a typical substation arrangement.



Instrument Transformers in a Typical Substation

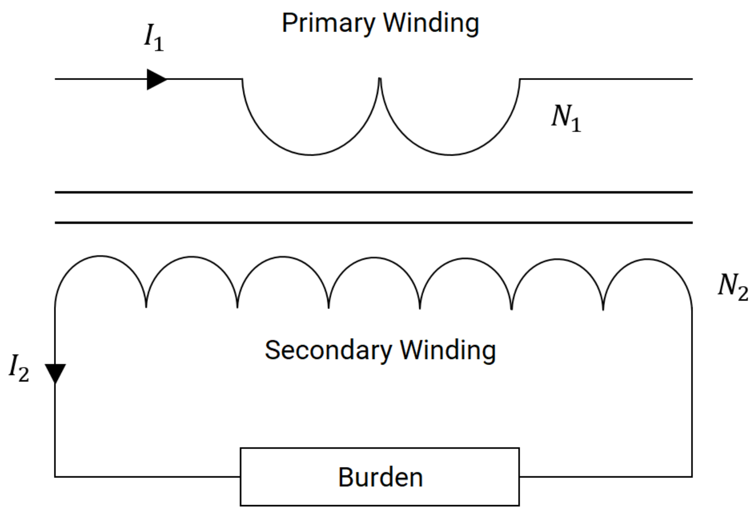
The next sections discuss the working principles, construction, components, and design aspects of instrument transformers applied in high-voltage air-insulated substations (AIS). Part I deals with current transformers, whereas Part II covers voltage transformers.

PART 1: CURRENT TRANSFORMER (CT)

Basic Concepts and Operating Principles

A **current transformer (CT)** is connected in series to carry the full-rated load (and short circuit current) of the system. In its simplest form, a CT consists of a **magnetic core** and two windings, commonly designated as the **primar**y and **secondary windings,** which are insulated from each other. Alternating current (AC) flowing in the primary produces a **magnetic flux** that is coupled or linked to the secondary winding through the CT core, thereby **inducing** an MMF (magnetomotive force) and current in the secondary winding. In many ways, a CT is similar to a single-phase power transformer except that the current in its primary winding is stiff, i.e., it's controlled by the primary network.

Note: In a power transformer, the current in the primary winding is controlled by the load connected to the secondary winding.



Schematic of a Current Transformer

The figure above shows the simplified schematic of a CT. In the case of an **ideal** current transformer, the magnetomotive force (MMF) in the primary must be the same as the magnetomotive force in the secondary, in which case the following equation applies:

$$I_1 N_1 = I_2 N_2$$

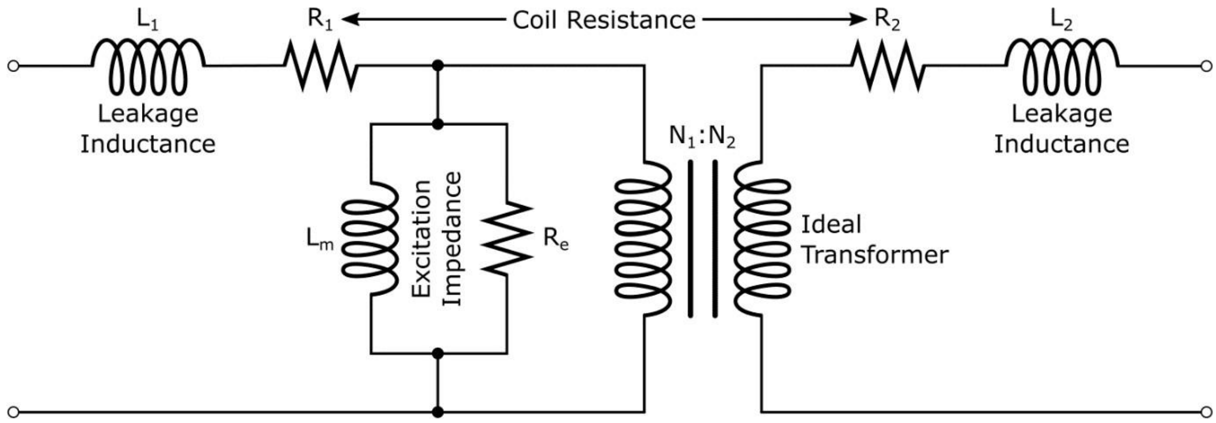
Or by rearranging,

$$\frac{I_1}{I_2} = \frac{N_2}{N_1}$$

Where,
I_1 is the current in the primary winding (the line current)
I_2 is the current induced in the secondary winding
N_1 is the number of turns of the primary winding
N_2 is the number of turns of the secondary winding

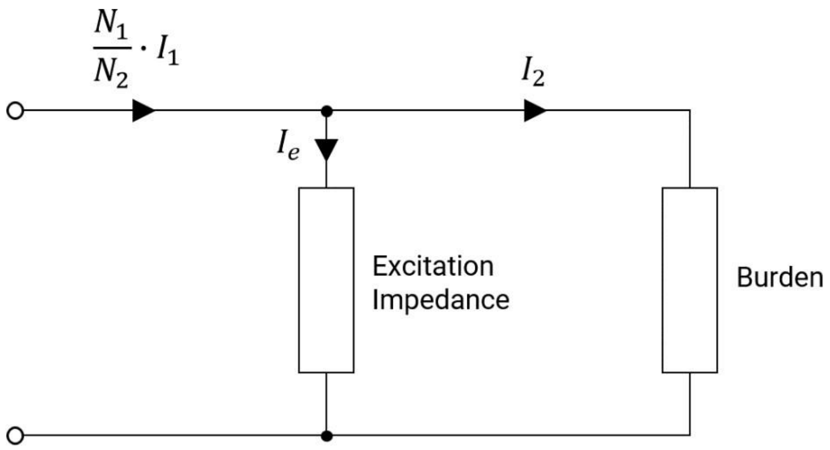
The ratio N_1/N_2 is known as the transformer ratio. The specified ratio N_2/N_1 is referred to as the **current transformation ratio**. The standard values for rated secondary current are 1 A or 5 A. For high voltage grid applications, the current transformation ratio is usually high, for example, 2000:1. This means 2000 turns of secondary winding around the magnetic core to 1 primary single-turn conductor. As a result, 2000 A flowing in the primary circuit would translate into 1 A flowing in the secondary output of the current transformer. Protection and control equipment can then use this output signal as required to monitor and execute the safe operation of the substation equipment and associated network.

In reality, the current transformer is a transformer and must be modeled by the equivalent circuit of "The Real Transformer," which is displayed below.



Equivalent Circuit for a Real Transformer

In the case of a current transformer, the coil resistance of both the primary and secondary is extremely small. The primary is usually a busbar that goes straight through the CT once, and the secondary winding is constructed using a heavy gauge (diameter). The secondary coil is a toroid, resulting in very little leakage inductance. Therefore, R_1 & R_2 may be neglected. Thus, all the inaccuracies may be attributed to the excitation impedance. Since the currents are related by the inverse of the turns ratio of the transformer, the following equivalent circuit referred to the secondary side may be used.



Equivalent Circuit of a Current Transformer Referred to the Secondary Side

Here, the load impedance is commonly known as the **burden** on the CT and is specified in units of ohms (Ω). The load impedance or burden includes the impedance of the **relays** and **meters** connected to the secondary winding of the CT as well as the **leads** (physical wires & cables) connecting the secondary winding terminals of the CT (installed in the outdoor switchyard) with the protection and metering equipment (installed in the indoor control house building).

The diagram shows that not all primary current is transformed (transferred) to the secondary circuit because some part of it is consumed by the CT core in the form of **excitation** or **magnetizing current** (I_e). The relationship between the primary and secondary currents of a CT is therefore modified as follows:

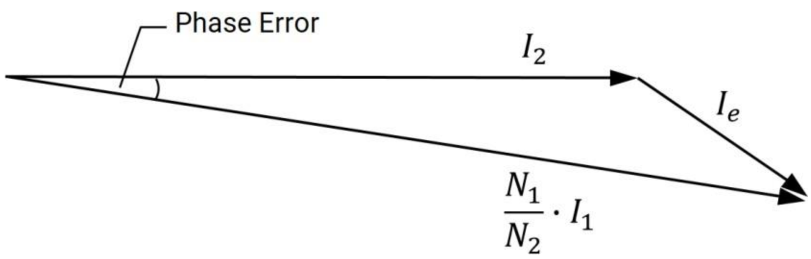
$$I_2 = \frac{N_1}{N_2} I_1 - I_e = I'_1 - I_e$$

The equation above corresponds to the CT equivalent circuit r**eferred to the secondary side**. Therefore, the quantity I'_1 is the primary current referred to the secondary side.

This means that the primary current is not reproduced exactly, which introduces an error both in magnitude and phase. The error in **amplitude** called the **current** or **ratio error** (**ε**) is defined as:

$$\varepsilon = \frac{I'_1 - I_2}{I'_1} = \frac{I_e}{I'_1}$$

The error in phase is called the **phase error** or **phase displacement**. It can be visualized by examining the phasor diagram below. In an ideal transformer, the vector angle between the primary and secondary is zero.



Phasor Diagram of Currents in a CT

The error of the CT directly depends on the size (magnitude) of the connected burden. For smaller burdens, the excitation current I_e is small. Therefore, current transformers work best when they are connected to low-impedance burdens. When applying current transformers in substations, it is important to take into account the amplitude and phase displacement errors.

Metering and Protection Application

The requirements expected from a current transformer can vary depending on whether it is intended for a metering or protection application. To meet the varied requirements (as briefly explained below), typically, a single high-voltage current transformer unit houses multiple **metering** and **protection cores** (up to five in total) made from different materials to provide the requisite characteristics. Normally, one or two cores are specified for metering purposes, and two to four cores for protection purposes.

Metering Cores

When used for **metering/revenue billing** purposes, current transformers should provide current signals that are very accurate representations of the primary line values for **steady-state** and **overload** conditions. Furthermore, the secondary output from the current transformer should **saturate** in the event of a short circuit fault or system transient to protect the metering devices connected to it from being damaged by high currents during the fault conditions.

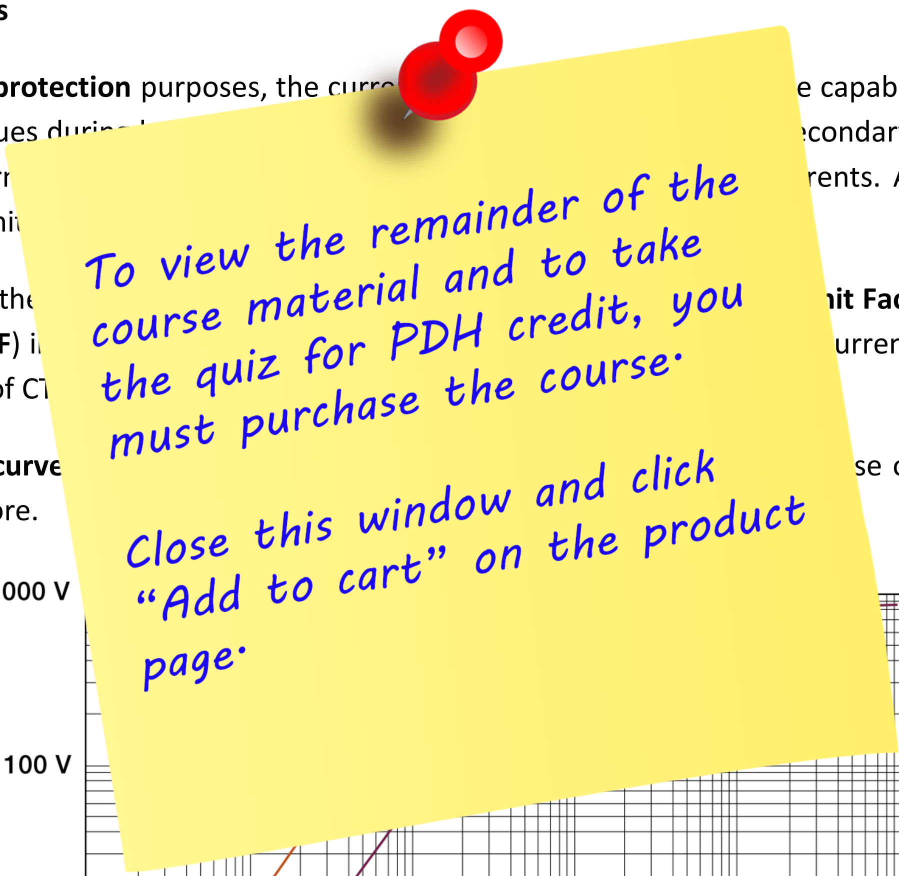
An important factor for the metering core of a current transformer is the **Instrument Security Factor** (FS). The rated FS indicates the overcurrent as a multiple of the rated primary current at which the metering core will saturate (the primary current limit). Thus, the secondary current is limited to FS times the rated current. The safety of the metering equipment is greatest when the value of FS is small. Typical FS factors are 5 or 10.

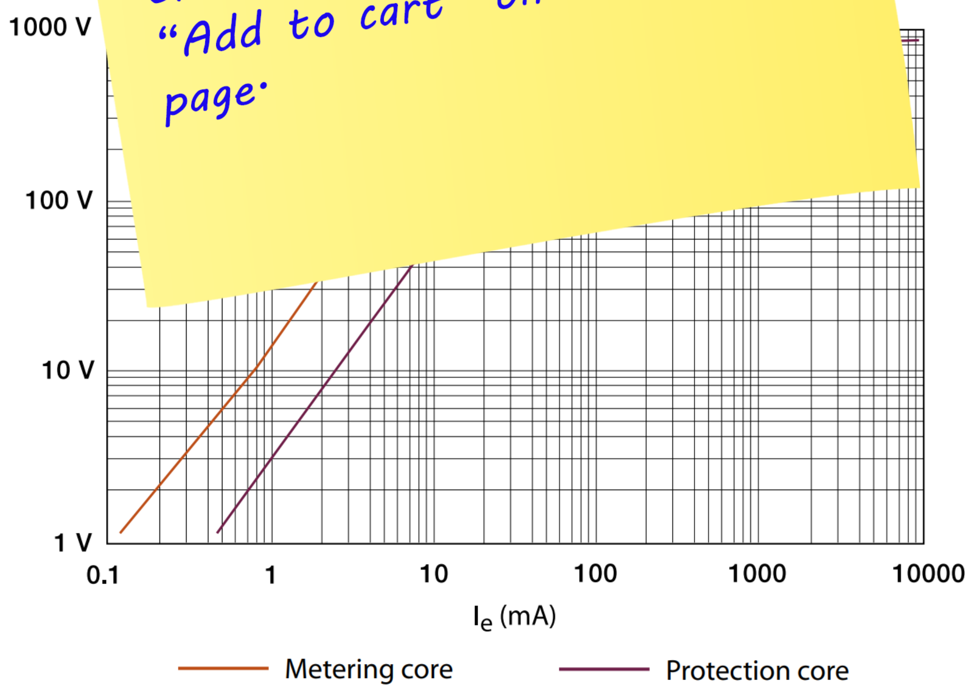
Protection Cores

When used for **protection** purposes, the curr... e capable of transforming primary line values durin... condary output from the current transfor... rents. As a result, lower accuracy is permi...

A key factor for the... it Factor. The Accuracy Limit Factor (**ALF**) i... urrent up to which the rated accuracy of CT...

The **excitation curve**... se of a metering and protection CT core.





Typical Excitation Curve for Protective and Metering Cores (Source: ABB)

To summarize:

Current Transformers for Metering

- Designed to operate at rated steady-state current
- Saturation typically commences at 1.2 – 1.5 x primary rated current