

Application Note

AN0305

Introduction to Current Transformers

Summary

Current transformers are devices used to scale large primary currents to a smaller, easy to measure, secondary currents. Like a traditional voltage transformer, the ratio of the windings determines the relation between the input and output currents. Current transformers of various shapes and sizes are used as an interfacing solution between high currents and instrumentation devices.

Current transformers (CTs) are an indispensable tool to aid in the measurement of AC current. They provide a means of scaling a large primary (input) current into a smaller, manageable output (secondary) current for measurement and instrumentation.

A CT utilizes the strength of the magnetic field around the conductor to form an induced current on its secondary windings. This indirect method of interfacing allows for easy installation and provides a high level of isolation between the primary circuit and secondary measurement circuits.

CTs are available in various sizes, designs and input ranges and output signal types. This application note will attempt to address many of the common CT types, and how to select the correct CT for a particular installation.

Basics

A CT is useful for measurements made on AC waveforms. It acts just like a regular voltage transformer, but typically has only one primary winding (the wire carrying the current to be measured). Unlike a regular voltage transformer, there is no physical connection made to the measured line. The CT uses magnetic fields generated by the AC current flowing through the primary wire to induce a secondary current. The ratio of the number of secondary turns to the number of primary turns determines the amplitude

of the current on the output. The output of a CT acts as a current *source*.

CT Core Material and Types

The core on which the secondary wire is wound plays a significant part in the performance of a CT. Core types include silicon steel, nickel alloy, or ferrite. The type of core determines price and accuracy. Accuracy is comprised by the actual input to output transfer ratio, as well as linearity and phase shift. While phase shift is of little significance for current measurements, in the measurement of power, an uncompensated phase shift will lead to large errors in measurement of real power and power factor.

CT cores can be of a solid (closed) or split (open) type. The solid/split core defines how the CT core is designed, and how it can be installed. Solid core CTs feature a closed loop, which the primary conductor must be passed through. Split core CTs can be temporarily opened to facilitate easier installation. When using a split core CT, the primary conductor need not be disconnected to install the CT, and in most cases, the conductor can continue to carry current while the CT is being installed. Split core CTs have a large advantage in installations where shutdowns are not practical or economical. However, because of the added manufacturing complexity, split core CTs carry a large price premium. Likewise, because of the inherent "gap" associated with the CT opening mechanism, split

core CTs tend to have lower accuracy and worse phase shift performance compared to a similar solid core CT.

CT Output Types

5A Output CTs

Traditionally, CTs were designed to have a full scale output of 5A for a given full scale primary current. Typical full scale input currents ranged from 50 to 2000 amps. This would be represented as 50:5 or 2000:5. In a 2000:5 CT, 5A flows in the secondary winding when 2000A is flowing through the primary winding. By changing the number of secondary windings, the CT manufacturer defines the input full scale.

5A is a considerable amount of current, and it was designed to be used with electromagnetic meters, to provide the power to move the magnetic needles or power protective relays. This style of CT has advantages in that the metering equipment is all configured for a 5A input. The appropriate CT can therefore be chosen to determine the full scale measurement range of the metering equipment. As far as the meter is concerned, it will see a range between 0-5A, since the CT is chosen for the proper maximum primary current. Many measurement and monitoring devices support 5A CT inputs, as this has become a defacto standard in the metering industry, especially for large building or sub-metering installations.

However, due to the relatively large (5A) current requirement, these CTs require a larger, heavier core, and a larger wire gauge. This translates to a larger, heavier final product and higher costs.

Moreover, these CTs can be extremely dangerous because of the large voltages that are induced when the CT secondaries are not shorted. Since a CT acts as a current source, following Ohm's law, $V=IR$. If the resistance is increased (a very high value when open circuited), the induced voltage becomes very high. Many of these CTs have enough power to cause large arcing across open secondary wires.

Special shorting blocks are required to ensure that the CTs remain shorted, even if disconnected from the meter. The induced voltages are large enough to cause serious injury or even death if the appropriate precautions are not taken to prevent

open circuiting the output. The added cost and burden of the shorting blocks and their installation must be considered when using these CTs.

5A CTs are available in solid and split core varieties, however, typical 5A split core CTs are quite large, and extremely expensive. It is not unusual for a 5A split core CT to exceed the price of the metering device. In some installations however, such as large bus-bars, the use of these CTs is unavoidable.

mA Output CTs

With the advent of digital metering, the need for a large output current became unnecessary. To reduce the size and cost of CTs, manufacturers began utilizing smaller, lower cost variants. Working under the same principle as a 5A CT, the number of secondary windings is increased to effectively lower the secondary output current. Because the output current is lower, the core and the winding wire may be significantly smaller and less expensive. Depending on the actual number of turns, the output current is proportionately scaled. For example, a CT rated for up to 100A input, with 2500 turns will output only 0.04A (40mA).

In this case, the metering equipment must be configured and calibrated such that a 40mA measurement is interpreted as a 100A full scale. The advantage of these CTs is the smaller size and cost, as well as much safer conditions when the CTs are not shorted. Many models have built in voltage suppression devices that will limit the output voltage to a low level (typically around 20V) when opened.

As with most types of CTs, the mA output types are available in solid and split core variants. The solid core CTs can have extremely high precision due to the higher quality core and windings that are available. Accuracy, including linearity and phase shift can actually exceed the revenue grade 5A output CTs. Split core varieties tend to have lower accuracy, however their small size and extremely easy wiring makes them ideal for many installations. A mA output split core CT can cost 1/3 that of a 5A output split core CT.

The main disadvantage of these CTs is that the metering equipment is tied to the CT type, and the full scale is defined by the calibration within the metering equipment.

mV Output CTs

Using the same hardware as the mA output CTs, mV CTs contain an internal burden resistor that converts the mA signal into mV ($V=IR$). The resistor can be chosen such that a pre-determined output voltage is generated when a full scale current is flowing. Typical full scale output voltages include 333mV and 1V. For example, a CT can be defined to output 333mV when 100A is flowing through the primary wire. The added advantage of this type of CT is that the output voltage always remains safe, regardless of the connection of the secondary wires. Also, because the full scale current is defined by the burden resistor inside the CT, the metering hardware can be universal (as with 5A CTs), and changing the full scale input current is determined by the CT chosen. However, mV CTs face disadvantages. Specifically, the accuracy of the CT is greatly determined by the size of the burden resistor.

Typically, manufacturers do not trim each CT, and therefore the tolerance of the resistor plays a large role in determining accuracy. Moreover the difference in calculated resistor value and actual resistor value (resistors do not come in an infinite array of values, so the manufacturer must choose the closest value available) influences overall accuracy. To complicate matters further, typical resistor values are small, and as such the resistance of the secondary wires plays a role in influencing the signal. When using mV output CTs, lead length should be kept to a minimum to avoid errors due to introduced resistance, as well as noise issues due to pickup. 5A and mA output CTs have the added advantage of higher noise immunity because of their characteristics as a current source.

CT types must never be mixed, and only CTs designed for the metering apparatus should be used with the device. ***Use of the incorrect CT Output type may cause severe damage to the equipment, and create a potential hazardous situation.***

CT Installation

During CT installation care should be taken in the placement of the CT primary wire. Ideally, the wire should be placed in the middle of the CT to obtain the best performance. When using split core CTs, the wire should be placed either in the middle, or as

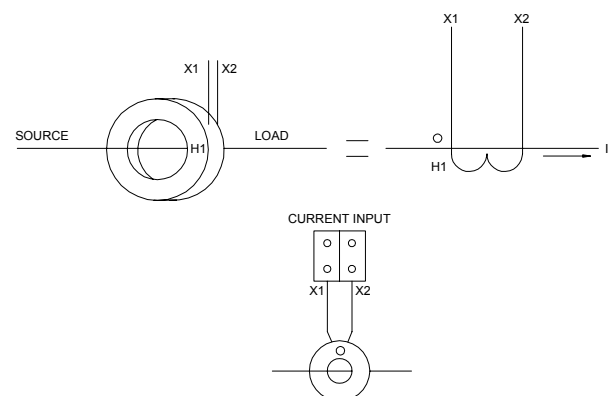
far away from the opening mechanism as possible. The air gap created by the opening mechanism induces error in the magnetic field and therefore the output accuracy.

A quick method to change the CT turns ratio is to add multiple primary turns. For example, if the primary wire is passed through a 2000 turn CT 4 times, the effective ratio becomes 4:2000, (1:500). This method in effect decreases the effective full scale of the CT, and has the added advantage of increasing accuracy by increasing the effective performance of the core.

CT Labeling

For many AC current measurement applications, the direction of the CT, and the polarity of the output windings is irrelevant. However, for applications requiring power measurements, the polarity of the CT must be taken into account to avoid phase reversal situations. The voltage and current measurements must have the same polarity to keep the power factor and direction of power flow measurements accurate and consistent.

Most CTs are labeled with a means that shows which side of the CT should face either the source or the load. Alternatively, a dot (or the label "H1") defines the direction as flowing into the CT (ie: the dot should face the "source" side). The output wires are typically designated with the labels "X1" and "X2". X1 corresponds to H1, or the input. The figure below shows various CT wiring notations.



Care must always be taken with both the physical orientation of the CT, as well as the wiring polarity. Instructions must always be followed as per the metering manufacturer's manual and labeling.

CT Type Comparison

	5A Output	mA Output	mV Output
Pros	<ul style="list-style-type: none"> • Industry Standard • Widely Available • Large Input Range • Low Cost (Solid Core) • Revenue Grade Available • Accepted by most metering manufacturers • Universal output 	<ul style="list-style-type: none"> • Highest Accuracy (solid core) • Low Cost • Small size • Not limited to predefined current ranges • Safe outputs 	<ul style="list-style-type: none"> • Low Cost • Universal output • Safe outputs
Cons	<ul style="list-style-type: none"> • High Cost (Split Core) • Large Size • Heavy • Requires Shorting Block for safety • Limited Ranges for small currents (<50A) 	<ul style="list-style-type: none"> • Full scale stays with metering equipment • Poor phase shift performance (split core) • Limited size of wire window for large current conductors 	<ul style="list-style-type: none"> • Susceptible to noise • Lower Accuracy • Poor Phase Shift Performance • Typically available in Split Core varieties only. • Fixed ranges

Conclusions

CT selection can play a large roll in determining installation options, accuracy and performance of the metering system. The type of metering system and the desired performance characteristics must be taken into consideration when selecting the type of CT to be used. Metering equipment must be considered depending on the type of CT inputs available.

Elkor Technologies Inc. manufactures current and power transducers that are capable of interfacing to any of the discussed current transformers.