Deploying Current Transformers in Applications Greater Than 200 A

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Step-down Current Transformers (CTs) are common, and useful, in large motor applications. They provide isolation between the high-current conductors and the overload relay. One of the increasing uses of CTs in industrial motor control applications is with motors larger than 200 A. Because many manufacturers no longer develop direct-mount overload relays above 200 A, CTs paired with smaller-frame overload relays are a popular choice when the current cannot be measured directly.

Benefits of Using Step-down CTs

The use of external CTs provides you with many benefits such as saving panel space by reducing the footprint of the overload relay that helps protect the motor, and reducing the cost of the overload relay. For retrofit applications, you can place split-core CTs around each phase conductor and mount the overload relay elsewhere in the panel, providing flexibility and time savings because the power conductors do not need to be disconnected.

How CTs Work

CTs work to transform or change the magnitude of AC current (50…400 Hz) in a system, typically from a higher current value to a lower current value. The transformation, or amount of change, is dependent on the number of turns of both the primary and secondary conductors. As shown in Figure 1, a CT consists of three main components: a primary winding, a core, and a secondary winding.

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Figure 1 - Construction and Symbol Representation for a Current Transformer
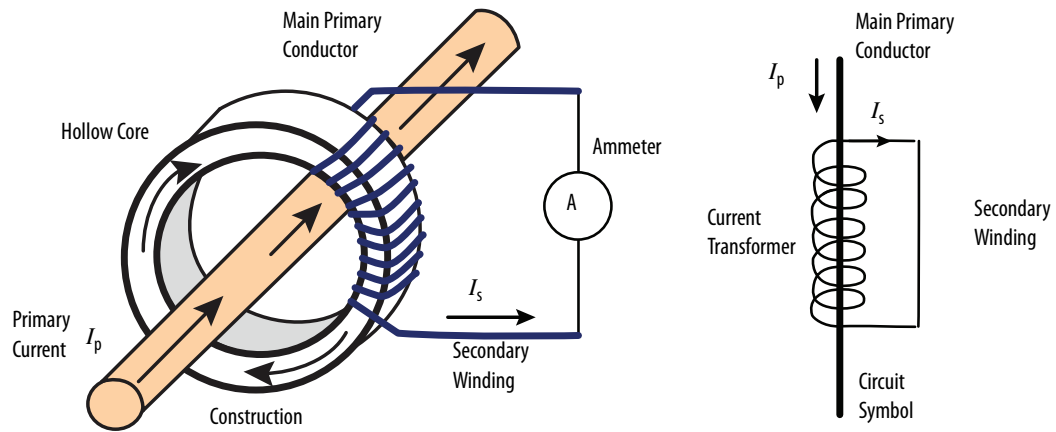
The relationship, or ratio, between the number of turns in the primary and secondary windings is responsible for reducing or 'stepping down' the current in a system to a value that is usable to the current-monitoring device, such as an overload relay or power monitoring product. The following formula demonstrates how the ratio between the windings can lower the current:

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

I_p = Primary Current N_p = Number of turns in the primary winding

I_s = Secondary Current N_s = Number of turns in the secondary winding

When you rearrange the equation and solve for secondary current:

$$I_s = I_p \times \frac{N_p}{N_s}$$

Because external current transformers are typically used on motor loads greater than 200 A, this example uses a 400 A motor load with a 600:5 CT ratio (where 600 is the secondary winding and 5 is the primary winding). To determine the secondary current, we use the rearranged equation with actual numbers:

$$I_s = 400 \times \frac{5}{600} = 3.3 \text{ A}$$

The Current Transformer ratio is specified with the assumption that the primary conductor passes through the window once, but it is possible to modify the ratio by looping the primary conductor through the opening additional times. Figure 2 shows an example where one loop through the window maintains the 300:5 ratio that is specified on the CT nameplate. Introducing two loops decreases the 300:5 ratio by a factor of two, yielding a 150:5 ratio, and three loops provides a decrease by a factor of three, or 100:5.

Figure 2 - Ways to Change the CT Ratio
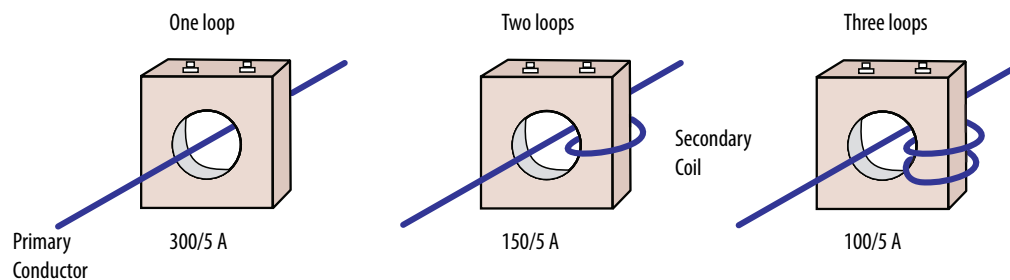
Types of Current Transformers

There are a number of different types of current transformers, each facilitating the step down and metering of current, but the manner in how that is accomplished can be different. The following explains the characteristics of three main types of current transformers.

- Wound Current Transformer – The primary winding is physically connected in series with the conductor that carries the measured current flowing in the circuit. The magnitude of the secondary current is based on the ratio of the current transformer.
- Toroidal Current Transformer – This type of transformer does not contain a primary winding. Instead, the line that carries the current flowing in the circuit passes through a window or hole in the toroidal transformer. Some current transformers have a "split-core", which allows them to be opened, installed, and closed without disconnecting the circuit to which they are attached.
- Bar-type Current Transformer – This type of current transformer uses the actual cable or busbar of the main circuit as the primary winding, which is equivalent to one turn. They are fully insulated from the high operating voltage of the system and are usually bolted to the current carrying device.

This publication focuses on Toroidal Current Transformers. The 193-CT-UL-300A and 193-CT-UL-600A, 193-CT-CE-300A, and 193-CT-CE-400A are all solid-core transformers.

Selecting a Current Transformer Ratio

Table 1 lists the approximate Amperes/Horsepower and applies to three-phase AC induction type, squirrel-cage and wound rotor motors over 200 Hp.

Table 1 - Ampere/Horsepower Values for Motors

Voltage	208V AC	240V AC	480V AC	600V AC	2300V AC	4160V AC
Amperes/Hp	2.75	2.4	1.2	0.96	0.24	0.133

To find the appropriate current transformer rating, it is important to multiply the Full Load Amperes (FLA) by a factor of 1.25. The factor of 1.25 locates the FLA above 2/3 full scale of the CT, which allows the CT to measure overload conditions. See Table 1 to calculate the CT ratio for a 300 Hp, 480V AC motor in the following example:

- Horsepower = 400 Hp
- Voltage = 480V AC

The chart value of 1.2 A/Hp multiplied by 400 Hp = 480 A. Multiply 480 A by the scaling factor of 1.25 = 600 A. Use the 193-CT-UL-600A (600:5) current transformer.

If the calculation does not produce a standard CT ratio, select the closest offering.
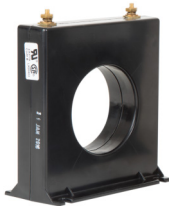
Selecting the correct current transformer ratio is important to confirm that the primary current is accurately captured. Ideally, the secondary current that leaves the CT equals the primary current divided by the CT ratio. However, this does not hold true when a CT saturates and can no longer represent the primary current. CT saturation can interfere with the functionality of protective relays because the spikes in primary current go undetected and do not contribute to the motor heating. If the CT is used for indication purposes only, CT saturation may be tolerable.

A typical direct-on-line starter (DOL) has an inrush current approximate to 6x FLA. This inrush current, while short in duration, can contribute to the heating of the motor, especially if the motor has a high duty cycle. It is important that the CT can detect the current spikes if a jam or stall condition occurs so that the overload relay can properly help protect the motor.

Proper Installation and Implementation of Current Transformers

Rockwell Automation® offers two overload current transformer kits (for North American and European markets) that can be easily installed in applications above 200 A. Table 2 provides information about the available current transformers.

Table 2 - Current Transformer Technical Data

	Core Type	Certifications	Current Ratio	Accuracy (60 Hz)	Burden [VA]	Pkg. Qty.	Catalog Number
	Solid	• UL • c-UL Recognized • CSA	300:5	± 1%	8.0	3	193-CT-UL-300A
	Solid	• UL • c-UL Recognized • CSA	600:5	± 1%	30.0	3	193-CT-UL-600A
	Solid	• CE • IEC 61869	300:5	± 1%	1.5	3	193-CT-CE-300A
	Solid	• CE • IEC 61869	400:5	± 1%	1.5	3	193-CT-CE-400A

demonstrates the use of external current transformers and the connection to the overload relay. Each power conductor passes through a current transformer and the primary (X1) and secondary (X2) studs are connected to the line and load side of the overload relay, respectively.

Figure 3 - Proper Installation of Current Transformers
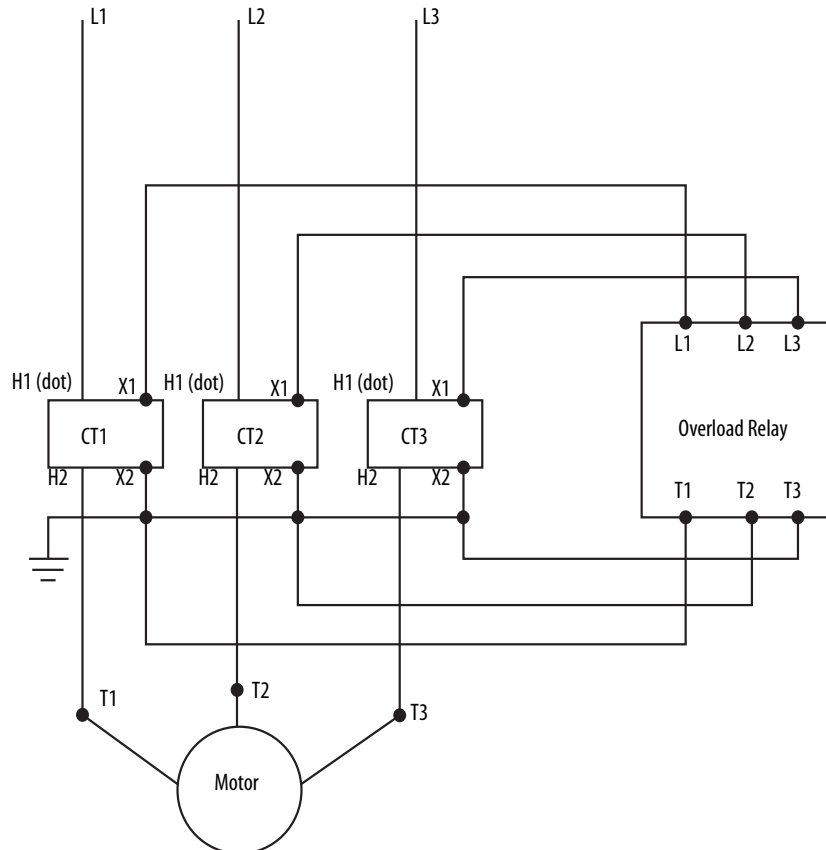
The overload relay is then programmed with the primary and secondary current ratio so that the primary current can be calculated based on what it senses on the secondary side of the current transformer.

For accuracy and consistent readings, install the primary conductor so that it is centered in the air core.

Polarity is an important aspect to consider when installing and connecting CTs for an application. The polarity of a CT is determined by the direction that the coils are wound around the core of the CT (clockwise or counterclockwise) and by the way the leads are brought out of the transformer case. All current transformers are subtractive polarity and typically have the designations to guide proper installation: (H1) primary current, line-facing direction; (H2) primary current, load-facing direction; and (X1) secondary current. Failure to account for polarity during installation can cause inaccurate measurements.

Core-balanced Current Transformers for Ground Fault Detection

The use of Core-Balanced Current Transformers (CBCT) for Ground Fault detection differs from relay CTs that are used for current monitoring and protection. The core balanced method, often referred to as a zero-sequence sensor, is based on the flux summation of the phase currents. This method uses one current transformer for all three phases (and a Neutral conductor if one exists), rather than a separate CT for each phase.

During normal operation, the flux summation of the currents that flow through the CBCT is zero, but when current flows through the ground wire, it creates an imbalance in the CBCT secondary winding. The overload relay or other protection device detects the imbalance and triggers a Ground Fault Trip.

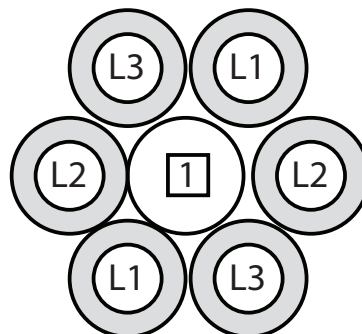## Power Cable Installation Requirements and Considerations

1. All power cables (including the Neutral if one exists) must pass through the sensor window. The equipment ground conductor (the conductor used to carry the non-current-carrying metal parts of the equipment, as defined by Article 100 of the NEC) must not pass through the sensor window.

2. The power cables through the sensor window should be straight, tightly bundled, centered in the window, and perpendicular to the sensor for a length equal to or greater than six times the cable diameter (including insulation) from the sensor.

3. All other conductors with available fault currents in excess of 1,000 A should be placed a distance equal to or greater than six times the cable diameter (including insulation) from the sensor, which is shown in Figure 4.

Figure 4 - Proper Installation of Core Balanced Current Transformer

90°

6x

Core Balance Ground Fault Sensor   Power Cables

6x
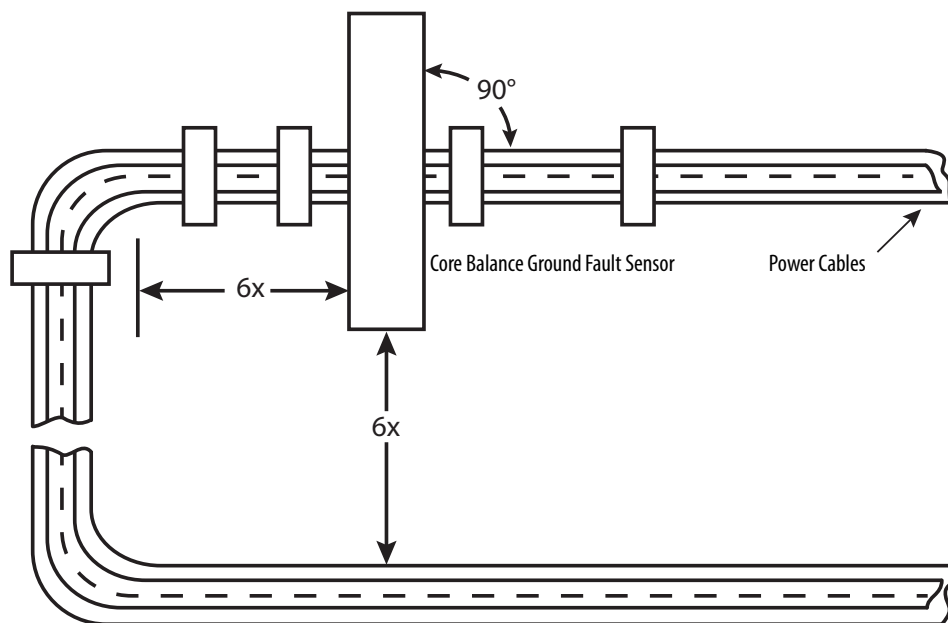
1. The power system can be solidly grounded or grounded through an impedance at its source as long as the impedance allows a magnitude of current to flow that is within the 20 mA…5 A operational range of the Overload Relay.

2. For applications with two conductors per phase, a spacer must be added to the center of the cable bundle. The spacer must be at least ten times the cable diameter in length, without connections to any terminals, as shown in Figure 5.

Figure 5 - Proper Spacing of Conductors in Applications with Two Conductors Per Phase

L3   L1

L2   1   L2

L1   L3

Table 3 provides installation details such as maximum current rating and maximum cable sizes for the Bulletin 193-CBCT products.

Table 3 - CBCT Installation Requirements

Catalog Number	Maximum Current	Frequency	Turns Ratio	Sensor Window Inner Diameter	Maximum Recommended Cable Size (at 600V)	IEC Contactor Size	NEMA Contactor Size
193-CBCT1	45 A	50/60 Hz	1000:1	19.1 mm (0.75 in.)	8 AWG (10 mm^2)	100-C09…100-C37	00…2
193-CBCT2	90 A	50/60 Hz	1000:1	39.6 mm (1.56 in.)	2 AWG (35 mm^2)	100-C09…100-C85	00…3
193-CBCT3	180 A	50/60 Hz	1000:1	63.5 mm (2.50 in.)	250MCM (120 mm^2)	100-C09…100-E146	00…4
193-CBCT4	420 A	50/60 Hz	1000:1	82.3 mm (3.25 in.)	350MCM (185 mm^2)	100-C09…100-E400	00…5

Conclusion

Rockwell Automation offers a wide range of current transformers that you can apply to motor protection applications for both overcurrent and ground fault current detection. The 193-CT-UL and 193-CT-CE kits cover North American and European markets and provide easy ordering and installation. The kits are compatible with E1 Plus™, E3 Plus™, E300™, and Bimetallic overload relays for applications above 200 A.

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