Selecting Current Transformers Part 1

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Introduction:

As engineers, we are aware that electrical power systems have grown. How much have they grown? When was the last time you specified a 2400-volt system, a 4160-volt 250 MVA system, a 15 kV 500 MVA system or specified a 2000-amp 480-volt system? An industrial plant now requires a larger and more complex system than was required just a few years ago. The 2400-volt systems have all but disappeared; 4160-volt systems have expanded from 350 MVA to 63 kA (equivalent to 500 MVA). The 15 kV systems also have expanded to 63 kA (equivalent to 1500 MVA). Has all of the electrical system expanded?

In order to monitor and to protect the power system we must measure the energy flow. To connect a meter, relay or other current sensing device in series with a large current source would be impractical. The industry has a device that has been around for a long time and will allow the engineer to monitor the electrical power system. The current transformer is an engineer’s main measuring device to determine current flow in a power system. Engineers tend to think of a current transformer as an ideal device; however, it is ideal only up to a point.

Ideal Current Transformer

An ideal current transformer would proportionally scale down the value of the power system current to a useable known value. Second, the scale-down output should faithfully reproduce the power system current waveform. An ideal current transformer should perform these two tasks over the range of a few amps up through tens of thousands amps. The ideal current transformer should be able to meet these requirements. In reality, a current transformer has limitations.

Today’s current transformer hasn’t changed since it was developed more than 80 year ago. A current transformer consists of the following components:

- A laminated steel core
- A secondary winding around the core
- Insulating material

When current travels through a current caring device, such as a cable or bus duct it develops a magnetic field at right angles to the flow of current. The strength of the magnetic field varies as the current magitude changes during all operating conditions. As learned in transformer theory, when a magnetic field strikes a wire, it will cause a current to flow in the wire. By using the strength of the magnetic field and knowing the turns ratio, we can obtain a value of current that is useable for meters, relays and other current sensing device.

In order to scale a value of high current flowing in a conductor, the engineer needs to introduce a specific number of uniformally distributed turns of wire around the core to scale down the system current. This will ensure that the output current is always proportional to the current flowing in the conductor. The current-caring conductor is referred to as the primary or H1 and the ends of the wire surrounding the core are referred to as the secondary or X1 and X2 for single winding current transformer. Remember, on multi-ratio current transformers there are several secondary outputs.

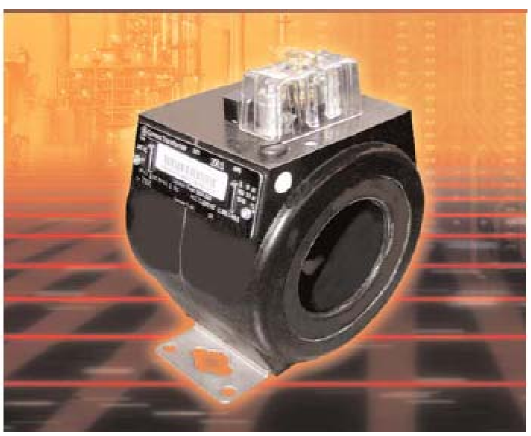
The current transformer can provide a constant current or voltage output. This paper will cover only current transformers that provide a current output.

In the past, there were two main values of secondary current typically used in measuring current. In the United States, engineers typically use a 5-amp output. Other countries have adopted a 1-amp output. With the advent of microprocessor meters and relays, the industry is seeing the 5-amp or 1-amp secondary being replaced with a mA secondary. Typically, devices with mA output are called "current sensors," as opposed to current transformers.

Type of Current Transformers
Current transformers are available in several different styles. Engineers can choose from the following:

- Bushing type, Window or Donut
- Wound type
- Bar type

By far, the most common one is the wound type current transformer. The wound type provides excellent performance under a wide operating range. Typically, the wound type is insulated to only 600 volts. The bushing type is typically used around the bushing on circuit breakers and transformers and may not have a hard protective outside cover. Bar types are available with higher insulation levels and are usually bolted to the current caring device.



Typical Donut Type Current Transformer

Donut type current transformers are typically insulated for 600 volts. To ensure accuracy, the conductor should be positioned in the center of the current transformer opening.

Typical Bar Type Current Transformer

Bar type current transformers are insulated for the operating voltage of the system.

Current transformers are applied in two very different functions, metering and/or protection.

Metering Accuracy
The accuracy class of a current transformer is expressed as the percent error for a known burden, current and power factor. ANSI C57.13-1993 Table 11 defines the standard burdens for current transformers with 5-amp secondary. The standard percent error expressed in Table 11 are 0.3, 0.6, and 1.2, and the standard metering burdens are 0.1, 0.2, 0.5, 0.9 and 1.8 ohms at 60 Hz, 90% power factor lagging. In order to study the full range of normal operation, engineers should determine the accuracy at 10% and 100% load conditions.

As an example, a current transformer with a meter accuracy of 0.6B0.5 would indicate a standard burden of 0.5 ohms and a load power factor between 0.6 and 1.0. First, at 100% primary current the error in the meter reading due to the current transformer will be less than +/- 0.6%. Second, at 10% primary current the error in the meter reading due to the current transformer will be less than +/- 1.2%. The code allows the error at 10% primary current to be no more than twice the error at 100% primary current.

Relay Accuracy
For relay classification engineers rely on the secondary terminal voltage, which the current transformer can maintain at 20 times rated secondary current without exceeding 10% ratio correction. For a 5-amp current transformer secondary, that would be 100-amps. ANSI C57.13-1993 offers the following standard terminal voltage ratings as 10, 20, 50, 100, 200, 400, and 800 volts. ANSI C57.13 only indicated the current transformer is capable of supplying the value indicated. A current transformer with a 50-volt rating will supply at least 50 volts but is not capable of supplying 100 volts. It may very well be able to supply 95 volts. Always calculate the actual voltage capability for the current transformer in use.

In addition to voltage classification, ANSI C57.13 assigns a letter to precede the voltage classification. It uses a “C” or “T” to define the manner in which the rating is established. When the leakage reactance is low and does not have an appreciable effect on the ratio the standard assigns a “C” for calculated value. Bar-type and window-type current transformers, which typically have fully distributed windings, are a good example of these types of current transformers.

When the leakage reactance has an appreciable effect on the ratio, the standard assigns a “T”. The accuracy of these current transformers can only be determined by testing. Typically, wound-primary current transformers which have non-distributed windings fit in this category.

The ability of a current transformer to produce the necessary voltage classification is directly determined by the current transformer ratio. A GE ITI 780-301 300:5 current transformer is rated as a C20. This current transformer has a core thickness of just over three inches. It would be considered a standard accuracy current transformer. Another selection might be a GE ITI 785-301 300:5 current transformers is rated as a C100. This current transformer has a core thickness of about 6.5 inches. In a switchgear application, one could install two 780-301 300:5 on each phase of the switchgear; although, only one 785-301 300:5 current transformer could be installed on each phase.

Many times when engineers read a specification that requires a 100:5 current transformer and states, “all current transformers shall have a minimum of C200 rating,” they are puzzled as how to proceed. When the specification requires a supplier to furnish one set of current transformers for each of the functions shown below, it may not be possible to provide C200 rated current transformers for each function:

- Transformers differential
- Bus differential
- Phase over current protection
- Metering

Burden
The burden can be expressed in two ways. The burden can be expressed as the total impedance in ohms of the circuit or the total volt-amperes and power factor at a specified value of current or voltage and frequency. The engineer can convert a volt-amperes value to total impedance in ohms by dividing the volt-amperes by the square of the secondary amperes. A typical calculation would be to convert 50 volt-amperes to total impedance in ohms. Dividing 50 volt-amperes by 5^2 (25) would be an impedance of 2 ohms.

To determine the total impedance, both active and reactive, one must sum the burden of the individual devices connected to the current transformer. The individual devices may only be the current transformer, a short run of wire and a meter. In contrast, the circuit may have the current transformer, a lone run of wiring, a relay, a meter, an auxiliary current transformer and a transducer. While the latter configuration would not be used today, one may be required to make this calculation on an existing system. All manufacturers can supply the burden of their individual devices.

Although not used very often these days, induction disk over-current devices always gave the burden for the minimum tap setting. To determine the impedance of the actual tap setting being used, first square the ratio of minimum divide by the actual tap setting used and, second multiply this value by the minimum impedance. A GE IFC 51 time over-current relay (50/51 device) has an impedance of 1.47 + 5.34j at the 1-amp tap. To apply the relay at the 4-amp tap the engineer would multiply the impedance at the 1-amp tap setting by $(1/4)^2$. The impedance at the 4-amp tap would be 0.0919 + 0.3338j or 0.3462 Z at 96.4 power factor.

Compare the GE IFC 51 over-current relay, which has only two functions with the GE SR-750 Feeder Protection Relay with 16 current related functions. The SR750 relay has a burden of only 0.20 VA at 5-amp input. The SR750 burden of 0.008 ohms is 43.3 times lower than the 0.3462 for the two function GE IFC51 relay.

Side Bar Note

The modern microprocessor relay takes the analog waveform from the current transformer and digitalizes the data before processing. To compensate for current transformer saturation the microprocessor relays utilized many algorithms to identify a saturation condition. Few power engineers are familiar with terms like Discrete Fourier transform, cosine filters, Digital Signal Processing, Finite Impulse Response, and MIMIC filters, just to name a few. These terms are used to explain the operation of the microprocessor relay under saturated current transformer conditions. Because the microprocessor digitalizes the input current signal, and employees a host of filters and algorithms the microprocessor relay have a very small burden. In addition, the burden does not vary with relay tap setting.

In order to determine the correct current transformer for the application, the engineer must sum the impedances of all the devices connected in series with the current transformer. Engineering studies have shown that a sufficiently accurate value can be obtained by adding the individual device impedances arithmetically, which allows for the power factor to be ignored. If using these procedures yields a borderline result, it is recommended that application be avoided.

The resistance of the terminal connection may be neglected in calculating burden. In applications where the wiring is confined to the inside of a switchgear cubical, the engineer may neglect lead resistances. However, on long switchgear lineups applying bus differential and application involving outdoor switchgear lead length (lead resistance) should not be neglected.

Unless a study involves the use of the current transformer excitation curve, it is acceptable to delete the current transformer internal resistance. The use of ANSI accuracy rating has already factored in the internal resistance of the current transformer.

Auxiliary Current Transformers:

Because of the advent of microprocessor relays and meters, the use of auxiliary current transformers may not be needed. In the event an auxiliary current transformer is required, the lowest ampere-rated auxiliary current transformer that meets the circuit thermal requirement should be selected. By selecting the lowest ampere rating, a smaller wire can be applied, thereby allowing many more turns to occupy the same space. This will result in a higher output voltage before the current transformer becomes saturated.

To illustrate this point, when the main current transformer is over sized and a 2-to-1 step-up of current is required, the auxiliary current transformer should be rated 2.5 to 5 amps. This is different than the 5:10 amps one would expect. The use of auxiliary current transformers should be studied completely before applying in the secondary of a current transformer.

Relay Accuracy Calculation
Engineers are required to demonstrate the suitability of their system in order to provide personal and equipment safety. When it comes to relay accuracy calculation, three avenues are offered. As an engineer involved only with industrial power systems, I am not familiar with "T" rated current transformer application; therefore, my discussion will be limited to "C" rated current transformers.

One method, which utilizes over-current ratio-correction curves, applies only to "T" rated current transformers. Should additional information on this subject be required, please contact the local GE sales office for a list of names and telephone numbers.

The remaining two methods are as follows. One method will involve the comparison of current transformer accuracy rating with the secondary terminal voltages the current transformer can produce under all expected operating conditions. Another method available to the engineering community requires the current transformer secondary excitation curves to calculate the actual ratio correction the current transformer will experience for a given condition. The first function that must be performed in any of the methods is to determine the total burden on the current transformer. The total ohmic burden must include all relays, meters, transducers and wiring resistance, when appropriate.

Using ANSI Accuracy Classification
The current transformer manufactures will supply the burden impedance, the ANSI accuracy classification and ratio. Typically, data from a manufactures would be GE ITI 780-302, 3000:5, C200, 1.105 ohms at 75 deg C.

Using the ANSI accuracy classification assigned to a current transformer alone with the circuit burden impedance will offer an approximate check on the selection of a current transformer. This is due to the fact that the ANSI accuracy classification is based on a single current value. The standard has selected 20 times secondary current (100 amps for a 5 amp secondary) with standard burdens. The following steps will outline a systematic approach to validate the current transformer selection.

ANSI Accuracy Classification Step 1
Use the maximum short circuit current available from the short circuit study as a starting point. Depending on the type of grounding, the ground fault current may be different than the phase-to-phase short circuit current. In most cases, knowledge of the instantaneous and time over-current values is required.

ANSI Accuracy Classification Step 2
Determine the impedance of all devices connected in the current transformer circuit at the ideal current transformer value. The ideal secondary current is the primary current divided by the current transformer ratio. In older induction disk relays, the impedances of the instantaneous and time over-current function will be different. Typically, on older induction disk relays the calculation should be preformed for instantaneous, time over-current and ground fault settings. As described earlier, microprocessor relays have a single impedance value, which applies over the complete range of operation. This greatly simplifies the number of calculations required to verify the suitability of the current transformer in question.

ANSI Accuracy Classification Step 3

Utilize the ANSI classification assigned to the current transformer. These data are available from the current transformer manufacturer.

ANSI Accuracy Classification Step 4
Depending on the type of relay selected the process will involve one or more calculations. First, determine the total burden impedance (Z_b) for the current transformer secondary circuit. Second, calculate the current transformer secondary voltage (V'_t).

$V'_t = (I_p/N) * Z_b$

I_p = Primary current
N = Current transformer turn ratio
Z_b = Total burden impedance

Finally, compare V'_t to the current transformer rating. If the voltage rating is greater than or equal to the calculated secondary voltage, the current transformer is acceptable for the application. If V'_t is greater than the ANSI classification, additional calculations should be performed before rejecting the current transformer.

Using Excitation Curves
Engineers have another method to determine the suitability of a selected current transformer, which method requires the use of the current transformer excitation curve. The method provides a more accurate assessment of the performance by calculating the actual secondary current for given primary current and burden impedance. As stated earlier, this method applies only to "C" classified current transformer.

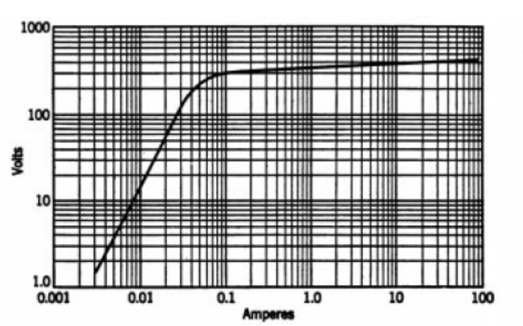


Fig. 3 Secondary-excitation characteristic. Frequency, 60; internal resistance, 1.08 ohms; secondary turns, 240.

Typical Secondary Excitation Curve
The secondary-excitation curve shown is for a 600:5, C200 current transformer.

Secondary-excitation curves are available from the current transformer manufacturer.

Using this method will require the engineer to obtain the actual burden impedance and actual primary current magnitude that the current transformer will measure. As a result, this method is more complex than applying the ANSI classification for a single fixed current magnitude. This method can indicate a current transformer is suitable for the application when the ANSI classification method demonstrated it was not suitable. Follow the four-step method to apply the secondary excitation curve calculations.

Step 1: Secondary-excitation
Ascertain the maximum primary fault current for the system under investigation. In the absence of a completed short circuit study, a quick method to obtain a system's short circuit is to sum the transformer full load amps divided by the transformer impedance (transformer contribution), plus the transformer full load amps divided by .017 (motor contribution). This will represent the maximum expected short circuit value for that system. Using this method will provide a more realistic short circuit value as opposed to using the equipment bracing value.

Step 2: Secondary-excitation
After determining all the devices that will be connected in series with the current transformer, obtain the impedance for each device and then total the impedance for this circuit.

Step 3: Secondary-excitation
From the current transformer manufacturer, secure the secondary excitation curve and secondary winding resistance.

Step 4: Secondary-excitation
Use the conditions identified in Step 1 to determine the current transformer ratio correction using the steps below:

4.a Calculate the total burden impedance Z_t seen by the current transformer.

4.b Determine the primary current measured by current transformer, which is labeled as I_s. First, in order to proceed with the calculation a value for I_e must be assumed. A good starting point would be to assume I_e is equal to zero. Based on I_e equals zero, the equation $I_s = I_p/N$ becomes valid.

4.c Use the equation $E_s = I_s * Z_t$ to calculate the current transformer secondary voltage

4.d Use the value for E_s and the secondary excitation curve to identify a value for I_e.

4.e Calculate the percent excitation current using the equations $\%I_e = (I_e/I_s) * 100$.

If the percentage of I_e is negligible the assumption of $I_e = 0$ in step 4.b is acceptable.

Should the calculated value prove not to be negligible, return to 4.b and select another value for I_e and follow the same procedure again.

Summary
This paper has offered a window into the complexity of selecting the correct current transformer for the application. It will provide a basis to go deeper into the selection procedure. The following references list many publications that can be used to broaden one's knowledge.

The following papers explore in greater details the art of selecting the correct current transformers.

Reference:

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