Exploring Current Transformer Applications

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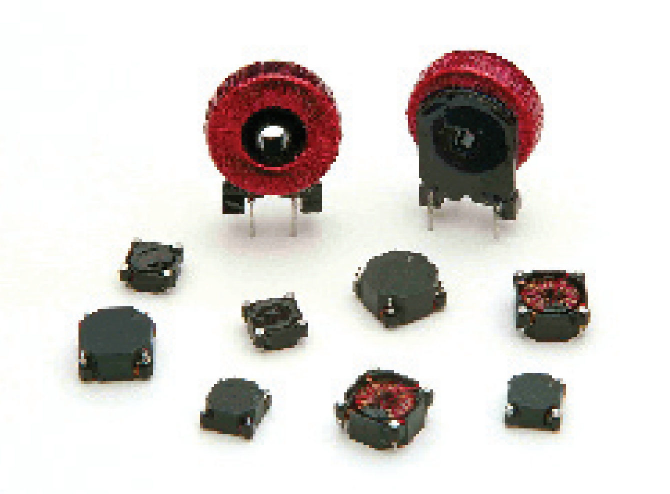
For a variety of applications, current transformers are an efficient way to sense current with minimum insertion loss. Let's see how we can use knowledge and a current transformer to produce something useful.

Current transformers can perform circuit control, measure current for power measurement and control, and perform roles for safety protection and current limiting. They can also cause circuit events to occur when the monitored current reaches a specified level. Current monitoring is necessary at frequencies from the 50 Hz/60 Hz power line to the higher frequencies of switchmode transformers that range into the hundreds of kilohertz.



Current transformers come in many shapes and sizes.

The object with current transformers is to think in terms of current transformation rather than voltage ratios. Current ratios are the inverse of voltage ratios. The thing to remember about transformers is that P_{out} = (P_{in} – transformer power losses). With this in mind, let's assume we had an ideal loss-less transformer in which $P_{out} = P_{in}$. Since power is voltage times current, this product must be the same on the output as it is on the input. This implies that a 1:10 step-up transformer with the voltage stepped up by a factor of 10 results in an output current reduced by a factor of 10. This is what happens on a current transformer. If a transformer had a one-turn primary and a ten-turn secondary, each amp in the primary results in 0.1A in the secondary, or a 10:1 current ratio. It's exactly the inverse of the voltage ratio—preserving volt times current product.

How can we use this transformer and knowledge to produce something useful? Normally, an engineer wants to produce an output on the secondary proportional to the primary current. Quite often, this output is in volts output per amp of primary current. The device that monitors this output voltage can be calibrated to produce the desired results when the voltage reaches a specified level.

A burden resistor connected across the secondary produces an output voltage proportional to the resistor value, based on the amount of current flowing through it. With our 1:10 turns ratio transformer that produces a 10:1 current ratio, a burden resistor can be selected to produce the voltage we want. If 1A on the primary produces 0.1A on the secondary, then by Ohm's law, 0.1 times the burden resistor will result in an output voltage per amp.

Many voltage transformers have adjusted ratios that produce the desired output voltage and compensate for losses. The turns-ratios or actual turns aren't the primary concern of the end-user. Only the voltage output and possibly regulation and other loss parameters may be of concern. With current transformers, the user must know the current ratio to use the transformer. The knowledge of amps in per amps out is the basis for use of the current transformer. Quite often, the end users provide the primary with a wire through the center of the transformer. They must know what secondary turns are to determine what their output current will be. Generally, in catalogues, the turns of the transformers are provided as a specification for use.

With this knowledge, the user can choose the burden resistor to produce their desired output voltage. The output current of 0.1A for a 1A primary on the 1:10 turns ratio transformer will produce 0.1 V/A across a 1Ω burden resistor, 1V per amp across a 10Ω burden and 10V per amp across a 100Ω burden resistor.

Fig. 1, on page 33, shows an ideal transformation ratio. In this analysis, the secondary dc resistance (R_{DCR}) doesn't become part of the calculation. When considering the secondary current, only the actual current affects V. How well that current can be determined controls the accuracy of the prediction of V. The secondary dc resistance is best analyzed by reflecting it to the primary by R_{DCR}/N^2.

When choosing the burden resistor, the engineer can create any output voltage per amp, as long as it doesn't saturate the core. Core saturation level is an important consideration when specifying current transformers. The maximum volt-microsecond product specifies what the core can handle without saturating. The burden resistor is one of the factors controlling the output voltage. There's a limit to the amount of voltage that can be achieved at a given frequency. Since frequency = 1/cycle period, if the frequency is too low (cycle period too long) so that voltage-time product exceeds the core's flux capacity, saturation will occur. The flux that exists in a core is proportional to the voltage times cycle period. Most specifications provide a maximum volt-microsecond product that the current transformer can provide across the burden resistor. Exceeding this voltage with too large a burden resistor will saturate the transformer and limit the voltage.

What happens if the burden resistor is left off or opens during operation? The output voltage will rise trying to develop current until it reaches the saturation voltage of the coil at that frequency. At that point, the voltage will cease to rise and the transformer will add no additional impedance to the driving current. Therefore, without a burden resistor, the output voltage of a current transformer will be its saturation voltage at the operating frequency.

There are factors in the current transformer that affect efficiency. For complete accuracy, the output current must be the input current divided by the turns ratio. Unfortunately, not all the current is transferred. Some of the current isn't transformed to the secondary, but is instead shunted by the inductance of the transformer and the core loss resistance. Generally, it's the inductance of the transformer that contributes the majority of the current shunting that detracts from the output current. This is why it's important to use a high-permeability core to achieve the maximum inductance and minimize the inductance current. Accurate turns ratio must be maintained to produce the expected secondary current and the expected accuracy. **Fig. 2**, on page 33, shows the current transformed is smaller than the input current by:

$$I_{TRANSFORMED} = I_{INPUT} - I_{CORE} - jI_{MAG} \qquad (1)$$

What about the effect the transformer will have on the current it's monitoring? This is where the term burden enters the picture. Any measuring device alters the circuit in which it measures. For instance, connecting a voltmeter to a circuit causes the volt-

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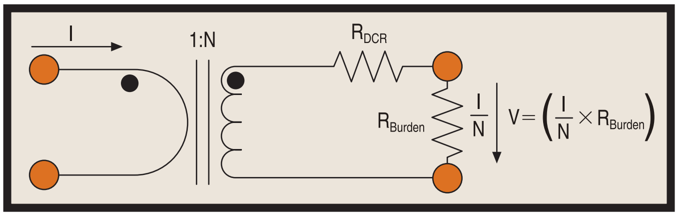

Fig. 1. *Ideal current transformer circuit.*

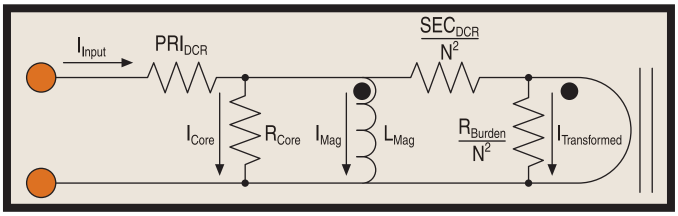

Fig. 2. *Current transformer loss components.*

age to change from what it was before the meter was attached. However minuscule this effect may or may not be, the voltage you read isn't the voltage that existed before attaching the meter. This is also true with a current transformer. The burden resistor on the secondary is reflected to the primary by ($1/N^2$), which provides a resistance in series with the current on the primary. This usually has minimal effect and is usually only important when you are concerned about the current that would exist when the transformer isn't in the circuit, such as when it's used as a temporary measuring device.

Notice the four loss components in the circuit of **Fig. 2**. The resistance of the primary loop (PRI_{DCR}), the core loss resistance (R_{CORE}), the secondary DCR (R_{DCR}) is reduced by $1/N^2$, and the secondary burden resistor R_{BURDEN} is also reduced by a factor of N^2. These are losses that affect current source (I). The resistances have an indirect effect on the current transformer accuracy. It's their effect on the circuit that they are monitoring that alters its current. The primary dc resistance (PRI_{dcr}) and the secondary DCR/N^2 (R_{DCR}/N^2) don't detract from the I_{input} that is read or is affecting the accuracy of the actual current reading. Rather, they alter the current from what it would be if the current transformer weren't in the circuit. With the exception of the burden resistor, these loss resistors are the components that contribute to the loss in the transformer and heating.

This wasted energy is usually small compared with the power in the circuit it's monitoring. Usually, the design of the transformer and choice of the burden resistor will be within the maximum energy loss the end user can allow. As battery-operated devices come into wider use and power consumption contributes to the energy crisis—even this power may be of concern. Under these circumstances, it may require special design attention to power consumption.

Current transformers are an efficient way to measure current. Since the burden resistor is reflected to the primary by $1/N^2$, the resistance seen in the circuit being monitored can be very small. This allows a larger voltage to be created on the output with minimal effect on the circuit being measured. A simpler and lower-cost method to measure current is to use a sense resistor connected in series with the current. However, this method can only be used when power consumption is of secondary concern. With the more frequent use of battery-powered devices and the prevailing need to reduce power consumption, the extra expense of a current transformer can soon be recovered with use. Also, with high current or when a voltage of any magnitude is required, a sense resistor would be impractical. **PETech**

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