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Current-Sense Transformer Application Design Guidelines

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The standard for precise current measurement in instrumentation and other high reliability equipment applications has been the current sense transformer. They are accurate, easy to implement, and reliable under harsh environmental and thermal conditions. In electronic systems applications such as switch-mode power supplies, current transformers are generally used for control, circuit-protection, and monitoring features. With the increasing availability of OTS (Off-The-Shelf) current transformers, a simple guideline can greatly help in the selection of proper and cost-effective components for many applications.

Figure 1. is a simple chart for the selection process

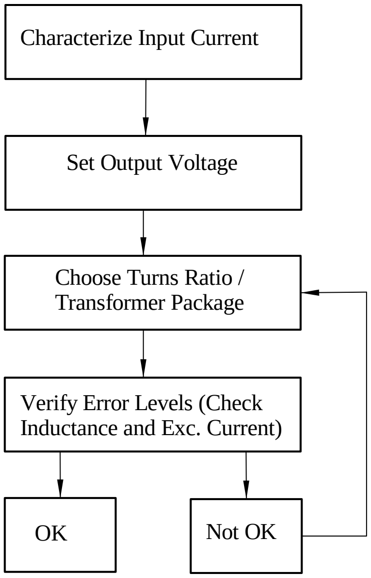

Figure 1: OTS current transformer selection flow chart

The Input Specifications

The selection of a current transformer must begin with the definition and verification of certain factors such as size, frequency, function, and the range of current being sampled – the accuracy and effectiveness will essentially be dependent on these parameters. Aside from the possibility of compromising the transformer's accuracy, using a current transformer above the manufacturer's rated current specification may saturate the transformer and may cause circuit failures due to an uncontrolled rise in operating temperature. On the other hand, a current transformer that is rated much higher than the "sample current" might be restrictively too large and expensive for its purpose. Typically, selecting a current-transformer that is rated approximately 30% above the expected maximum of the "sample current" is a prudent starting point.

The Primary/Secondary Turns Ratio

Off the shelf current-transformers commonly have turns ratios ranging from 1:10 to 1:1000. The higher the turns ratio ($r = N_{sec}/N_{pri}$), the higher the resolution of the current measurement. However, care must be taken as too high of a turns ratio will necessitate an increase in distributed capacitance and leakage inductance which may decrease the transformer's accuracy and capability to operate at higher frequencies (due to self-resonance). However, if the number of turns is too low (lower inductance), the output signal may distort or "droop" (in positively sloped unipolar input signal) which may also cause instability in the control circuit and inaccuracies in measurements.

Inductance and Excitation Current

The current transformer's secondary inductance will determine the fidelity of the output signal. The value of inductance is inversely proportional to the excitation current – which is then subtracted to the "sensed current."

The excitation current should be several times less than the magnitude of the sample current (a maximum of 10% is ideal for most SMPS applications) – this will ensure the maximum error tolerance of the transformer. For instance, if a circuit has to maintain a maximum of 10% loss for a sample current of 1 A to 20 A at 100 kHz, the excitation current must be set to a maximum of 100 mA (10% of the minimum sample current value). A 1 A sample current will yield an error of 10% while a 20 A sample will yield an error of 0.5%.

In case the excitation current is not specified in the manufacturer's data sheet, it can be calculated with the equation:

$$e = -L\frac{dI}{dt};$$

$$\left|\frac{dI}{dt}\right| = \frac{e}{L}$$

Where *e* is the set output voltage (V), L is the inductance (H), and $\left|dI/dt\right|$ is the excitation current w/ respect to time (A/s).

The Output Voltage and "Burden Resistor"

The output voltage (Vo) should be set as low as practically possible to minimize the insertion loss. Assuming 0.5 V is the optimum secondary output voltage in a circuit and the output current is 20 A, a 1:100 ratio transformer will yield a secondary current of ≅ 200 mA. Per Figure 2, the burden resistor should be:

$$Ro = \frac{Vo}{Is} = \frac{0.5}{0.200} = 2.5\ \Omega$$

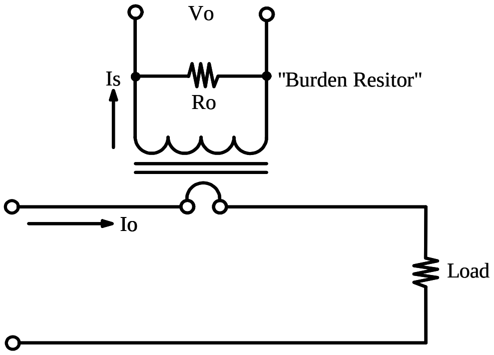

Figure 2: Current Sense Circuit

Practical Example

<u>Definition of Requirements:</u>
Input Current: 100 kHz, 1A – 5A
Output Voltage: 0.1 V → 1 A
0.5 V → 5 A
@ 10% accuracy
Package: low-profile, surface-mount

<u>Part Selection:</u>
Using Datatronics' standard OTS catalog on their website, the CT317-100 current transformer satisfies the input current and package requirements – only the accuracy level and burden resistance are left to be determined.

<u>Error Level Approximation:</u>
For 10% Error (neglecting coupling losses), the primary excitation current must be less than 10% of the minimum input current – a maximum of 100 mA in this case;

$$I_{exc\ (SEC)} \cong 1/f * e/L$$
$$\cong 1/100\ kHz * 0.1/(2.5\ mH)$$
$$\cong 0.4\ mA$$

This yields an approximate current of 40 mA on the primary, 60 mA less than the 100 mA maximum.

Burden Resistor Calculation:

$$R_o = V_o/I_{sec} = 0.1V / (1A/100) = 10\Omega$$

For the given requirement, the Datatronics CT317-100 is an acceptable selection.

Conclusion

OTS components are inexpensive and instantly available, but as discussed in this article, there are functional limitations on their usage. There are applications where specific recommendations or even full customization may be required. It is therefore advisable to procure these components from reputable manufacturers that have strong engineering, manufacturing, and customer service capabilities.

References

Billings, Keith H., *Switchmode Power Supply Handbook – 2nd ed.*, McGraw-Hill, New York, 1999.

McLyman, Colonel Wm. T., *Transformer and Inductor Design Handbook*, Marcel Dekker, New York, 1978.