A Maxim Integrated Products Brand

AN_661x_021   April 2010

Introduction

This application note describes using current transformers (CT) with the Teridian 78M661x family in a measurement system. The following topics are discussed:

- Current Transformer Background
- Burden Resistor Selection
- Phase Error and Compensation
- Selecting a Current Transformer
- System Calibration
- Measurement Results

A design example is included to itemize the design process followed with calibration considerations and performance test data.

Current Transformer Background

A current transformer is a device that produces a reduced current in its secondary winding accurately proportional to the current flowing in its primary winding. The secondary (output) current flows into the secondary load, usually called the burden resistor. The primary winding is usually the primary (input) current conductor passing through an aperture in the current transformer core. Other implementations utilize two or more turns of the primary circuit wound on the core together with the secondary winding. CTs are used when the current in the circuit is too high to directly apply to the measuring instrument.

There are two basic CT construction types. The first type is commonly referred to as a "ring" type or solid core CT because the core is usually annular. These tend to be more accurate and compact. The second type, usually known as a "wound primary" type, split core or clamp on CT, which has core designs with square or rectangular shapes. These can be installed without interrupting the circuit.
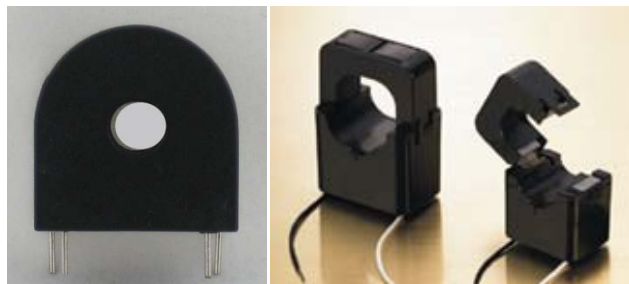

Figure 1: Examples of CT Construction Types

The primary and secondary currents are expressed as a ratio such as 500:1, 1000:1, etc. With a 500:1 ratio CT, 5 A flowing in the primary winding will result in 10 mA flowing in its secondary winding. Similarly, for lesser primary currents, the secondary currents are proportionately lower.

The principal requirements of a measuring CT are that, for primary currents up to 125% of its rated current, its secondary current is proportional to the exciting primary current. The specified accuracy and specified maximum phase angle displacement applies up to a maximum load current. Load currents above this maximum value will "saturate" the core resulting in non-linear transfer characteristics.

Increasing the value of the burden resistor (across the secondary winding of the CT) will result in an increase in the CT's secondary output voltage. This behavior is used to calculate the value of the burden resistor for an optimum current-to-voltage relationship. Conversely, a reduction in the value of the burden resistor results in a reduction in the CT's secondary output voltage. This rise in secondary voltage output with an increase in burden resistor value means that, theoretically, with an open circuit secondary, an infinitely high voltage appears across the secondary terminals. For practical reasons, this voltage is not infinitely high, but can be high enough to cause a breakdown in the insulation between the primary and secondary windings or between either or both windings and the core.

An open circuit secondary winding presents a high voltage safety condition. The secondary leads must be connected to the burden resistor at all times when current flows through the primary.

For this reason, primary current should never be allowed to flow with no load or with a high resistance load connected across the secondary winding.
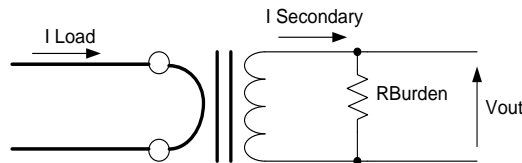

Figure 2: CT with Burden Resistor

The general specifications for a CT are:

RATIO: input / output current ratio.
VA: burden resistor value.
CLASS: Accuracy required for operation.
DIMENSIONS: maximum and minimum limits.

CT Classes:

- 0.1 or 0.2 for precision measurements.
- 0.5 for high grade kilowatt hour meters for commercial grade kilowatt hour meters.
- 3 for general industrial measurements.
- 3 or 5 for lower accuracy commercial measurements.

Teridian recommends use of class 0.5 or better for energy measurement.

Burden Resistor Selection

A CT with a turns ratio of 2000:1 yields a secondary current of 1/2000 of the primary current. In a typical application, the secondary current is applied to a resistor (usually defined as the "burden resistor") of a few ohms in order to generate a voltage signal (see Figure 2).

Following Ohm's law, the resulting voltage V across the burden resistor R is:

$$Vout = \frac{ILoad}{N} RBurden$$

In this formula, N is the turns ratio and ILoad is the primary load current.

The optimum burden resistor value is specified by the CT manufacturer. If the burden resistor value is too high, the output becomes non-linear. When used with a 78M661x energy measurement device, it is important to dimension the burden resistor value for optimum signal magnitude. At maximum load current (IMAX), the voltage built up across the burden resistor should not exceed 176 mVrms (±250 mVpp). It is useful to provide a voltage margin in order to accommodate transients above IMAX. For various systems considerations, it may be necessary to select a burden resistor value lower than the manufacturer's recommended value. For most CTs, this will not pose a problem.

Phase Error and Compensation

All current transformers include an inherent phase shift relative to the current measurement. This phase shift introduces an error in the power measurement.

The error in the power measurement introduced by phase error is illustrated with the following equations.

Power is calculated as

$$P = V\,I\,cos\theta$$

Where V is the LINE voltage, I is the load current and $cos\theta$ is the power factor.

The measured power is calculated from

P*meas* = (V * Kv) * (I*Ki) * cos($\theta + \alpha$)

Where Kv is the scaling factor for voltage and Ki is the scaling factor for current.

The power measurement error introduced by the phase error is:

$$Error = \ 1 - \frac{Pmeas}{P} = 1 - \frac{\cos\,(\theta + \alpha)}{cos\theta}$$

When the power factor is high (close to 1), the influence of phase error to the measurement is almost negligible; however, a phase error of 1 degree at a power factor of 0.5 ($\theta = 60°$) introduces a power measurement error of 3%. The resultant phase error is generally unacceptable in energy measurement systems. Figure 3 shows the effects of phase error on measurement error across varying power factor.
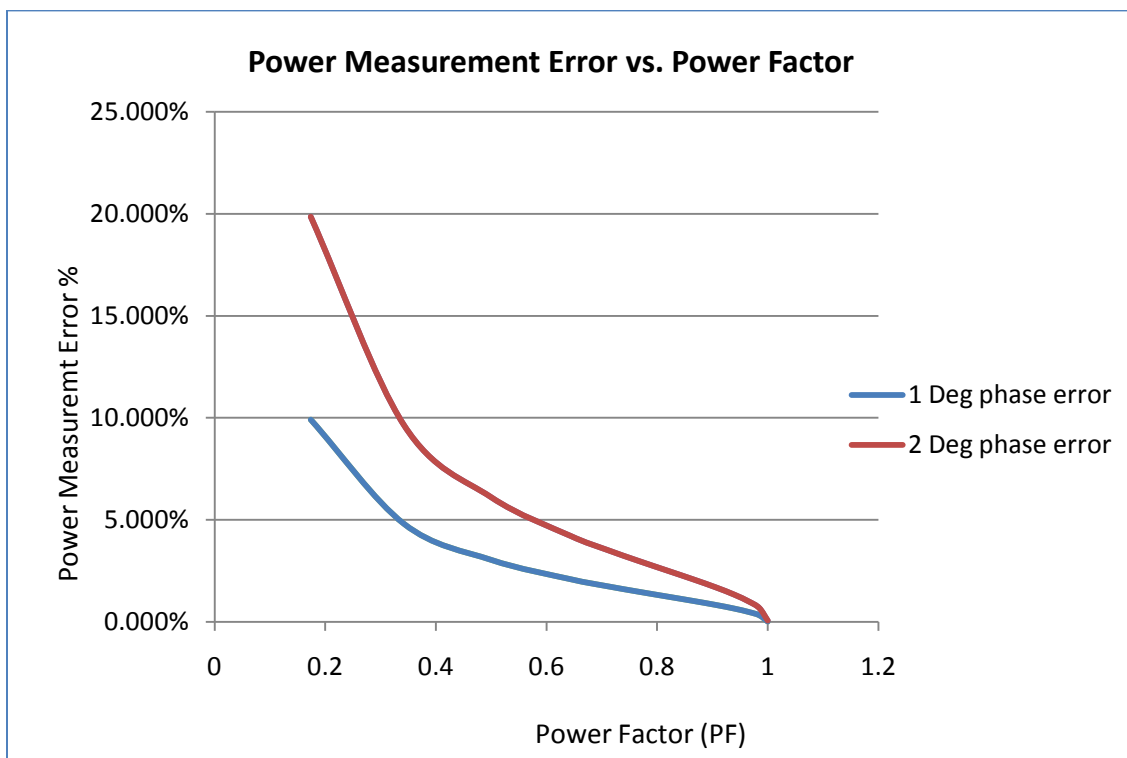

Figure 3: Power Measurement Error versus Power Factor

Current Transformer Selection

The selection of a current transformer includes factors such as range of current being measured, turns ratio and the class. The resultant accuracy depends on these parameters. Subjecting a current transformer to load currents above the manufacturer's rated current specification will saturate the core and may cause mechanical failures due to an excessive temperature rise. On the other hand, a current transformer that is rated much higher than the target load current might be restrictively too large and too expensive for its purpose. A typical rule of thumb is to select a current transformer which is rated approximately 20% above the expected maximum load current.

This design example has a maximum load current of 20 Arms and utilizes the Oswell CT020P2A current transformer. This CT has a 1000:1 turns ratio terminated with a recommended burden resistor of 5 Ω.

The higher the turns ratio (TurnRatio = Nsecondary/Nprimary), the higher the resolution of the load current measurement. Too high a turns ratio increases the distributed capacitance and leakage inductance reducing the current transformer's accuracy and capability to operate at higher frequencies. If the number of turns is too low, the output signal may distort or "droop" (for positively sloped unipolar input signal). Such distortion may cause measurement inaccuracies.
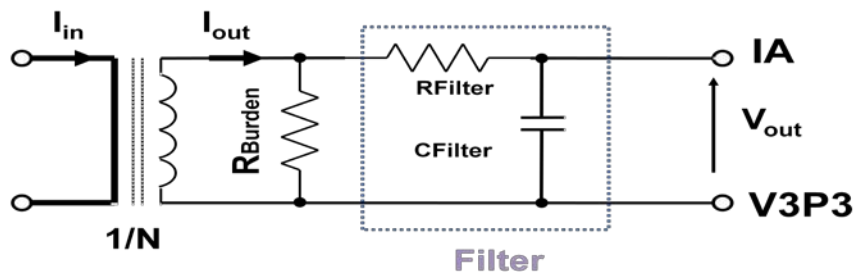

Figure 4: Current Transformer (CT) Basic Connections

The 78M661x input signal range is +/- 250 mVpp. The CT's secondary output voltage (Vout) must swing within this range. At the maximum load current of 20 A rms (28.28 A pk), a 1000:1 turns ratio current transformer will produce a secondary current of 28.3 mApp. Using the following equation, the Oswell CT020P2A produces 141.1 mVpp when attached to the recommended 5 Ω burden resistor.

$$RBurden = \frac{Vout}{Iout}$$

This nominal maximum signal swing provides sufficient margin for transients while producing adequate signal swing at the minimum load current of 10 mA.

System Calibration

Any measurement system will achieve the highest accuracy levels by employing in-system calibration. The in-system calibration compensates for the CT's parasitic losses and phase error, LINE input voltage divider resistor network, current sensor tolerances, and 78M661x tolerances.

The following table shows different accuracies depending on the type of calibration. The Current Only Calibration compensates for CT parasitic losses, the burden resistor tolerance and 78M661x tolerances. The Full Calibration compensates for the voltage divider plus the CT's parasitic losses and phase error plus the burden resistor tolerance.

Calibration	Time per Outlet	Accuracy
Full Calibration	< 11 s	< 0.5 %
Current Only Calibration [1]	< 4 s	< 1.0 %
No Calibration (fixed coeff.) [1] [2]	0	< 3 %

Notes:
1. Use 0.1% tolerance resistors voltage divider.
2. Use 1% tolerance burden resistor.

Accuracy Results

The following table shows different accuracies depending on the type of calibration.

Max Current (RMS)	Load Watts at 120Vrms	Burden Resistor (ohms)	Volts Pk-pk across Rburden	% of Input Range	Full Calibration	Current Only Calibration	No Calibration
22	2640	4.99	0.15525	62 %	-0.13%	-1.05 %	±3 %
20	2400	4.99	0.14114	56 %	-0.15 %	-1.06 %	±3 %
18	2160	4.99	0.12702	51 %	-0.12 %	-1.04 %	±3 %
16	1920	4.99	0.11291	45 %	-0.11 %	-1.02 %	±3 %
10	1200	4.99	0.07057	28 %	-0.09 %	-1.01 %	±3 %
5	600	4.99	0.03528	14 %	-0.05 %	-0.98 %	±3 %
2	240	4.99	0.01411	5.6 %	-0.04 %	-0.94 %	±3 %
1	120	4.99	0.00706	2.8 %	-0.04 %	-0.96 %	±3 %
0.5	60	4.99	0.00353	1.4 %	-0.02 %	-0.99 %	±3 %
0.2	24	4.99	0.00141	0.56 %	+0.004 %	-0.92 %	±3 %
0.1	12	4.99	0.00071	0.28 %	+0.02 %	-0.91 %	±3 %
0.05	6	4.99	0.00035	0.14 %	-0.02 %	-0.96 %	±3 %
0.044	5.28	4.99	0.00031	0.12 %	+0.1 %	-0.72 %	±3 %
0.022	2.64	4.99	0.00016	0.06 %	+0.1 %	-0.99 %	±3 %
0.011	1.32	4.99	0.00008	0.03 %	+0.03 %	-0.58 %	±3 %

Revision History

Revision	Date	Description
1.0	4/2/2010	First publication.