How to Measure Current and Make Power Measurements

Overview
Learn how to measure current using transformers, transducers, and data acquisition devices. See how to use current measurements as part of a power quality analysis or power monitoring system.

Table of Contents
1. Current Transformers and Transducers
2. Measurements Needed
3. Suggested Components for a Three Phase System
4. Next Steps

1. Current Transformers and Transducers

Safely measuring large currents in a laboratory or production setting presents many challenges not associated with typical signal acquisition. Measuring the voltage across small burden resistors placed in the circuit is often impractical, and can be potentially dangerous. Common instruments such as digital multimeters can typically measure currents on the order of a few amperes, but these generally have limits on the length of time that can be observed, and significant care must be taken to avoid damaging equipment or causing injury. More importantly, however, many users need to measure currents considerably larger than can be safely measured through such direct connections.

To measure high currents safely, the typical practice is to use a special purpose Current Transformer (CT) or transducer which reduces the magnitude of the current in the circuit to a more manageable level. As with other sensing technologies, there are a variety of types of these sensors suited for different applications.

Split Core vs. Solid Core

Current transformers may be split core (open) or solid core (closed). Current transformers use inductance to measure current, and as such the circuit must pass through the sensor at least once, though multiple turns can be used to multiply the current output. When installing CT's in existing circuitry, split core CT's are often seen as advantageous, as they can be opened and placed around existing wires without disrupting the circuit. Solid core CT’s, on the other hand, require the circuit to be rewired in order to pass through the core. Because installation costs can easily exceed the price of the sensors themselves, split core sensors, though more expensive to purchase, may actually reduce the total cost of implementation. Solid core transformers may be preferred, however, in situations where extremely precise current measurements are needed, as they are generally more accurate than similarly priced split core devices.

Output and Integration with Measurement Systems

Care must be taken when integrating current sensors into a measurement system, as different sensors outputs differ significantly. Connecting the wrong sensor to your equipment, or connecting a sensor improperly can damage both the measurement equipment and the sensor, and can present a significant safety hazard to personnel. It is essential to know which type of sensor you are purchasing and how that sensor interfaces with instrumentation.

Current transformers broadly come in two different output configurations: current outputs and voltage outputs. Sensors which output voltage signals proportional to the current on the primary of the transformer are often rated in volts per primary ampere, e.g. 0.1V per amp. These sensors typically contain a precise burden resistor internally which allows the secondary current to be measured as a voltage. Sensors which output directly to a voltage can be connected to most standard equipment, so long as the expected voltage does not exceed the ratings of the equipment. The signals produced by these sensors are low energy and may safely be connected and disconnected without damaging the sensor. Because they are low energy signals, however, they are subject to interference and signal degradation, and are not always suitable when leads must be run over extended distances between the sensor and measurement equipment.

Other current transformers output current waveforms at their secondary terminals. These sensors produce high energy signals which can produce significant safety hazards if not properly handled. The secondary terminals of these transformers are generally constructed to output a nominal 5 ampere AC (AAC) or 1 AAC signal, and cannot be directly connected to most standard equipment. A 500:5 CT, for example, would produce 5 AAC of secondary current when 500AAC passed through its primary. It is extremely important that the secondary terminals of these CT’s not be in an open circuit configuration if current is passing through the primary coils, as dangerous voltages will occur across the secondary, and the sensor could sustain permanent damage. For this reason, CT
secondary circuits which output currents should never be fused. In order to use these sensors with measurement equipment that does not accept current inputs, an external burden resistor is necessary. In order to preserve signal integrity, this resistor is generally placed as close to the measurement equipment as is practical. Contact the manufacturer of your test or control equipment if you are uncertain of whether it accepts voltage or current inputs.

Basic current sensors and current transformers will not perform any form of computation or analysis on a power circuit. Measurements such as RMS, power factor, power, peak-peak, phase and many others are fairly common and require more expensive sensors or can be calculated with output from a basic current sensor/transformer and software. For test systems used in design or manufacturing test, it is often preferred to have a system perform the calculations in software due to the specific and unique requirements that come with product design and validation.

**Current Sensor and Transformer Vendors**

The following 3rd party companies have either current measurement transformers, and/or transducers in their catalog.

- MAGNELAB
- CR Magnetics
- LEM

2. Measurements Needed

The fundamental power measurements, as seen in figure 2, are represented in what is known as the power triangle. Using the three measurements of voltage, current, and the phase offset between the V and I waveforms, the entire triangle can be computed.

![Power Triangle Diagram](image)

**Measuring Voltage**

NI offers a wide selection of voltage measurement modules but for waveform power measurements the suggested modules will be the NI 9239 for 10V measurements, the NI 9229 for 60V measurements, and the NI 9225 for up to 300 Vrms measurements. All three of these modules are simultaneously sampled which is needed for phase measurement and have 600 Vrms CAT II channel-to-channel isolation for safety. Though it is most convenient to have a direct connection to the module for voltage measurements, for voltages above 300 Vrms a power transformer (PT) can be used to step down the voltage similar to the current transformers that have been discussed earlier in this paper.

**Measuring Current**

Since many current sensors can output voltages proportional to the current flowing through their secondary, there are several NI products that can be used to measure currents with high amperage. For a 10V output sensor, use the NI 9239. For a current transformer that outputs 1A or 5A, use the NI 9227. These modules operate on the same architecture as the NI 9225 making them the ideal choice for synchronization. Selection of an analog input module for current measurement will depend on the particular current sensor chosen, as well as the maximum current expected on the measured circuit. While NI hardware meets all industry standards for voltage isolation and withstand, improper selection of analog input modules can result in measurement saturation or damage to the module if the sensor output voltage exceeds the module’s rating. When calculating the maximum sensor voltage output, remember that many industrial machines may have startup transient currents many times their normal load rating. It is not uncommon to see transient currents which are four to ten times rated load current. Check the datasheet for the individual module you are considering to determine whether it is appropriate for your application.
Measuring Phase Offset

To make a phase offset measurement between voltage waveforms and current waveforms, you need to synchronize the channels. You synchronize the channels by using the two modules, such as the NI 9225 for voltage and NI 9239 for current, in the same CompactDAQ or CompactRIO chassis. These backplanes run all of the channels on the same internal clocks that provide synchronous data. With this synchronous data, phase offset can be computed in software. Many software packages have built in functions for measuring phase offset, the easiest of which is to install the NI LabVIEW Electrical Power Suite from the [NI LabVIEW Electrical Power Suite Download Page](#) and use the RMS VI and the Fundamental Vector VI. For more information on phase see the [Phase Modulation](#) tutorial.

**RMS.vi**

Calculates the RMS value of a voltage or current signal

**Fundamental Vector.vi**

Calculates the fundamental vector of a voltage or current signal for a single channel or N channels

The Vector Diagram is included with the NI LabVIEW Electrical Power Suite

3. Suggested Components for a Three Phase System

- **1 NI CompactDAQ chassis (cDAQ-9178) or CompactRIO chassis (many options available)**
- **1 NI 9225 – 300Vrms Analog Input module for voltage measurement**
- **1 NI 9229 (60V p-p), NI 9239 (10V p-p), or NI 9227 (5A RMS) Analog Input module (connected to a current sensor)**
- **Current Sensor (one per phase)**

This recommended system can measure a single-phase two-wire, single-phase three-wire, or three-phase three-wire system. The NI 9225, NI 9229 and NI 9239 use 24-bit resolution analog-to-digital converters (ADC) to acquire data at 50 kS/s/ch, which is important if you need to calculate transients and harmonics. The modules not only have simultaneous sampling (one ADC per channel), but are automatically synchronized within the backplane, which is critical for measuring the phase angle between the current and voltage on a single line.

Software Calculations for a Flexible, Expandable Test or Control System

The NI LabVIEW Electrical Power Suite provides analysis functions for all of the fundamental power calculations discussed in this paper and is available for download online. The following analysis functions are included with the Full version of the NI LabVIEW Electrical Power Suite and conform to the IEC 61000-4-30:2008 standard:

- Power frequency
- Magnitude of the supply voltage
- Flicker
- Supply voltage dips and swells
- Voltage interruptions
• Supply voltage unbalance
• Voltage harmonics
• Mains signaling voltage on the supply voltage
• Rapid voltage changes (RVC)
• Measurement of underdeviation and overdeviation parameters

The following analysis functions conform to the EN 50160:2007 standard:
• Power measurement
• Energy measurement
• Aggregation (demand)

A complete USB-based system using the NI 9225 and NI 9227 modules for power measurements can be found in the Electrical Power Measurement System.

4. Next Steps
Watch the Power Quality Monitoring and Analysis Webcast

In this webcast, you will learn power monitoring basics, including required hardware measurements and software analysis functions. The applications for power monitoring can range from grid consumption to green product design, but the measurement fundamentals are the same. Discover how new tools and technologies will help make tomorrow’s grid smarter and tomorrow’s products greener.