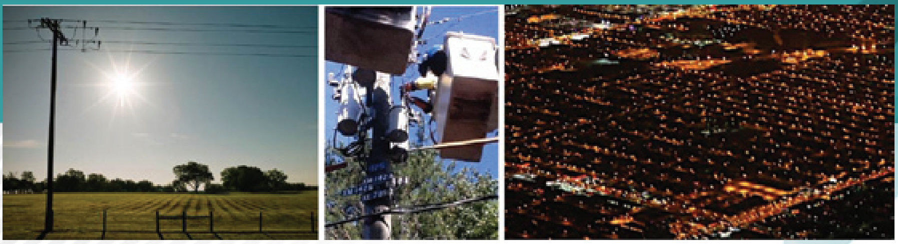
Why Accuracy Matters!

Factors that Influence the Accuracy of Metering Data & why they Matter

By Jon Bickel, PE



Why Accuracy Matters

There are over 6.2 million miles (10 million kilometres) of three-phase and single-phase distribution circuits in the United States and metering data provides utilities with the only ‘real-time eyes and ears’ into the performance of their systems.

Accurate measurements of electrical signals are essential to:

- improve reliability
- increase energy efficiency and conservation
- manage operations
- promote asset management
- identify cost savings opportunities and solve problems

Two components (sensors and intelligent electronic devices) are required to gather data from medium voltage distribution systems. Each component introduces inaccuracies as the primary signal is converted into a digital signal. It is important to select metering components that minimize or eliminate potential inaccuracies. This will provide more confidence in decisions that are made based on metering system data. This article identifies factors that can influence the accuracy of metering data as it is transformed into digital information – and explains why they matter.

The Significance of Accuracy

Accuracy seems to be a straightforward term and is frequently employed in the world of distribution system sensors and metering. **Accuracy is the degree of closeness that the meter can achieve with respect to the true value of the measured quantity.** While accuracy is commonly accepted at face value, it is far too important a concept, and has too many repercussions, for insufficient consideration.

The primary objective of electric metering devices, such as sensors and Intelligent Electronic Devices (IEDs), is to accurately capture and reproduce data from a primary signal (e.g., magnitudes and phase angles) so that the best decisions can be subsequently made. While accurate metering data can facilitate system improvements, inaccurate data can produce ineffectual or even counterproductive results.

Consequences of Inaccurate Metering Data

The existence of one or more of these issues can negate the potential value of a high-quality, well-designed distribution metering system.

- **Loss of confidence in distribution system:** If metering data is conflicting or historically inaccurate, operators may not know what is correct and ignore the metering system data.
- **Decreased reliability and efficiency:** Inaccurate meter data veils the actual operating parameters and reduces the ability to optimally operate the system.
- **Higher direct costs:** Inaccurate consumption readings at meter results in billing errors and impacts revenue.
- **Higher indirect costs:** Erroneous assumptions based upon inaccurate metering data can influence decisions to increase spending on nonexistent problems.
- **Misallocation of resources:** In the process of measuring and converting the primary signal into a digital signal, valuable information may be lost – resulting in erroneous conclusions and time lost in trying to identify root causes.
- **Safety concerns:** Overloaded conductors or service equipment may not be identified – resulting in electrical or fire hazards.

When measuring a signal and communicating its parameters to the end user, there are several factors that can introduce inaccuracies into the data. These inaccuracies can lead to problems for the end user – from misallocating resources by pursuing faulty assumptions to unwittingly forfeiting beneficial opportunities.

Because the sensor and IED are discrete components that are typically designed, manufactured, and sold independently, each receives its own accuracy rating from the manufacturer. This is a very important consideration when pairing a sensor with an IED because the accuracy of either component can adversely impact the combination of the two.

Metering System Components: Sensors and Intelligent Electronic Devices

Two primary components make up the core of data collection on utility systems: sensors and intelligent electronic devices (IEDs) – as shown in Figure 1.

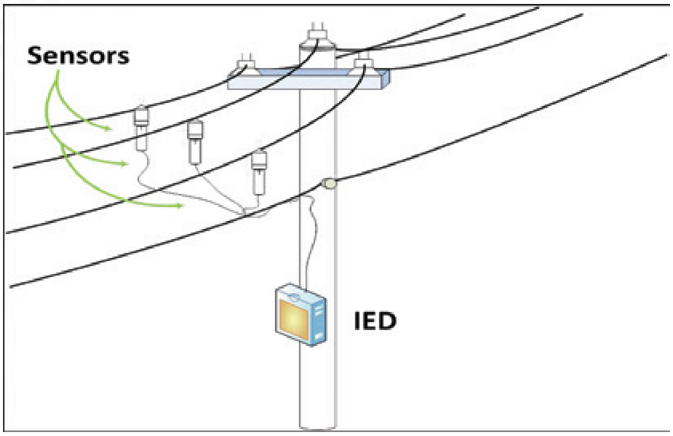


Figure 1

The purpose of a sensor is to safely and accurately reduce a primary signal's magnitude while keeping its characteristic qualities intact. The IED then converts the representative analog sensor signal into digital data, which is then easier to analyze, manipulate, communicate, and store.

There is a conversion that occurs in each of these two components and the representative signal is degraded to some extent as it is passed through the sensor and IED.

As the primary signal passes through the sensor, a change is induced in the sensor. A representative analog signal, which is proportional to the primary signal, is produced.

It is impossible to generate a perfect characteristic correlation between the primary signal and the sensor's representative signal, so the resulting sensor output signal is modified to some degree. Sensors often introduce inadvertent filtering, noise, phase shifts, and magnitude imprecisions into their output signals. External factors such as temperature, humidity, and burden can produce additional influences.

After the sensor output signal is acquired from the primary signal, the sensor output signal must be converted into a digital format by an IED. The post-conversion benefits of converting analog signals, such as voltages and currents, into digital formats or signals include easy storage, simple reproducibility, higher noise immunity, and increased flexibility.

Similar to the process of creating the sensor output signal, the process of creating a digital representation of that signal (and by extension, the primary signal) produces some degree of alteration or degradation in the resulting signal.

Since a digital representation is produced by discrete samples of the analog signal (Figure 2), it is evident that a loss of information occurs in the period between samples (the inter-sample interval) during the transformation into a digital signal.

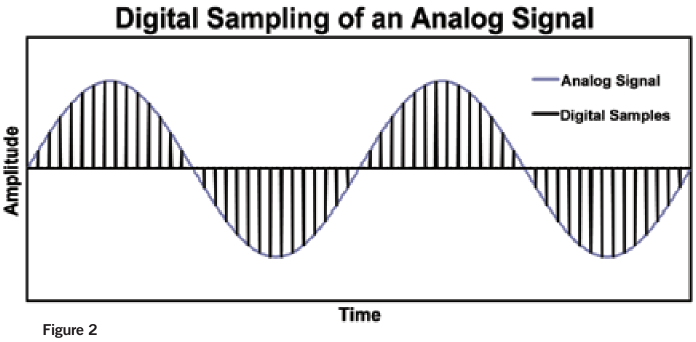


Figure 2

Sensor Technologies

Two broad sensor technologies – conductive sensors and optical sensors – are employed to capture voltage and current characteristics from medium voltage distribution systems and convert them into representative analog signals for the IEDs.

- Conductive sensors use voltage or current as the representative analog output signal to be passed to the IEDs.
- Optical sensors use light as a representative analog output signal to be passed to the IEDs.

It is important to consider the influence that each of these technologies can have on the primary signal.

Figure 3: GE Voltage & Current Transformer (PT/CT)

Although there are several other conductive sensor technologies available (e.g., Rowgoski coils, voltage dividers), the most prevalent types of conductive sensor technologies used in medium voltage distribution systems are instrument potential transformers (PTs or VTs) and instrument current transformers (CTs) (Figure 3). Instrument transformers have long been used to measure ac power parameters, and their performance and accuracy depend on correctly using them in a metering system.

Conventional Instrument Transformers

Because instrument transformers use current flow through windings to produce a ratio of the primary signal to a secondary signal, they are subject to the physical constraints of those elements.

The primary and secondary windings of voltage transformers share a common core, similar to a standard service transformer, and the output of the secondary windings are proportional to the primary windings.

A Constellation Energy Company

Baltimore Gas and Electric

(BGE), a subsidiary of Exelon Corporation, serves more than 1.2 million electric and more than 650,000 gas customers in Central Maryland. Its distribution system includes 24,000 miles (38,600 kilometers) of electricity transmission and distribution lines and more than 7,000 miles (11,260 kilometers) of gas main.

“Having accurate field data is extremely important when making decisions that are critical to customers and the business,” says Aleksander Vukojevic, Engineering Consultant for Smart Grid Distribution Automation and Technology with BGE.

“For Conservation Voltage Reduction (CVR), we need accurate voltage measurements from all capacitor bank controllers, and other field sensors,” Vukojevic notes.

“Voltage range for residential customers in the U.S. is small (114 V to 126 V), and the objective of CVR is to keep the voltage within the lower portion of the range in order to minimize energy consumption.

“BGE capacitor bank controllers use voltage from 1 kV potential transformer as a reference. Moving forward, before we can roll out any device on our system full scale, we must have the confidence that we have very accurate voltage and current readings, which will enable us to use the CVR algorithms more efficiently to help meet our CVR objective.”

Unlike the voltage transformer, the current transformer is connected in series with the phase conductor and produces an output current that is proportional to the flow of current through the conductor. A conventional voltage transformer produces a known secondary signal that is typically either 115 or 120 volts at the rated primary voltage. Likewise, the conventional current transformer typically produces five amperes in the secondary signal when the rated current is flowing through the conductor.

Several factors can influence theaccuracy of PTs and CTs including burden, temperature variation, signal range, and frequency components present. Instrument transformers are selected for specific purposes, such as metering or protection, and the misapplication of instrument transformers can distort or attenuate important information contained within the primary signal.

Even the best instrument transformer will experience ever-increasing attenuation of high frequency components, such as harmonics, due to their increasing impedance at higher frequencies ($X_L = 2\pi fl$). In short, it is necessary that the instrument transformer’s design, intended application, interacting equipment, and environmental constraints be well understood for a successful deployment.

Optical Sensors

Optical sensors use a different method to produce a representative analog signal from the primary signal and convey it to the IED: light.

Light waves are electromagnetic waves that have both electric and magnetic fields that oscillate at right angles to each other. As polarized light is passed through the electromagnetic (EM) fields that surround conductors, it is rotated by an angle that corresponds to the magnitude of the field. The rotation of the polarized light will vary as the EM field varies so that a representative signal can be derived by measuring the degree of rotation as a function of time.

Fig.ure 4: Optisense MV Optical Current & Voltage Sensors attached to 3 Phase Distribution Lines

Factors that can influence the accuracy of optical sensors include the light's wavelength, transmission medium, temperature variations, and neighboring EM fields. In most cases, design considerations can mitigate a significant portion of any potential signal degradation in the conversion to a representative analog signal. Calibration of the sensors over the operational temperature range also improves the veracity of the representative signal. Using a technology that measures the degree of rotation in polarized light allows a wider operating range without experiencing saturation.

Intelligent Electronic Devices (IEDs)

The analog (continuous-time) signals produced by the sensors are sampled and converted into a digital (discrete-time) signal by an IED. Any inaccuracies introduced by the sensors are passed into the IEDs where additional inaccuracies are introduced.

Analog-to-digital converters (ADC) are hardware components used in IEDs to transform the analog input voltage and current signals into approximate digital representations. The ADC takes discrete samples or measurements of the analog input signal. This provides an approximate magnitude of the signal at the point the sample was taken. The ADC takes these samples at a pre-determined periodicity called the sample rate (samples/second) or sample frequency (1/sample rate).

Both the vertical (magnitude of the signal) and horizontal (sample rate over a period) dimensions must be considered when attempting to accurately convert an analog waveform into a digital waveform. An ADC can provide a fixed number of values, determined by the ADC's resolution, over the range of the analog signal's values. Higher resolution ADCs will more accurately represent the analog signal's real value.

For example, an 8-bit ADC provides 2^8 (256) different values over the analog signal's range. Obviously, a higher resolution ADC will provide more values (and better accuracy) over a given range.

Analog signals provided by the sensors are likely to have multiple frequencies embedded in the signal (in addition to the 60 Hz signal) due to the arbitrary nature of medium voltage distribution systems (e.g., load types, operational parameters).

For example, events such as capacitor switching produce additional frequency components or ringing (Figure 5). In order to accurately capture the embedded high frequency components in the digital format, the sample rate of the ADC must be greater than twice the highest frequency of interest.

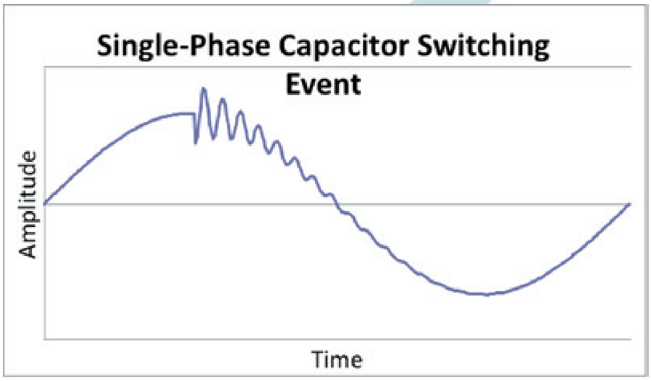


Figure 5: Single Phase Capacitor Switch Event

If the 15th harmonic is the highest frequency of interest, the ADC must sample at a rate greater than 1800 Hz (2 x 15th x 60 Hz). The sample rate of the ADC determines the highest harmonic that can be captured by an IED. Conversely, not sampling the analog signal at a high enough rate (under-sampling) results in lost information and inaccurate data from the IED.

Aliasing

Under-sampling analog signals in the conversion process also produce an error known as aliasing. Aliasing occurs when there are frequencies in the analog signal that are greater than half the sample rate of the ADC. An illustration of the consequences of under-sampling is the wagon wheel effect. In old movies, an optical illusion occurs when the wheels of a rapidly moving wagon appear to be turning slowly forwards or backwards. This effect is produced by having a slower camera frame rate compared to the high speed of the wagon wheel.

Aliasing in IEDs can be mitigated by incorporating a low pass filter on the input to eliminate frequencies above the useful range of the ADC, or by increasing the sample rate of the ADC to at least twice the highest frequency present on the analog signal. Additional factors can generate inaccuracies in digital data. Some of the factors are:

- non-synchronous sampling
- algorithm errors
- noise
- blind sampling
- component aging
- stability of the reference

Aliasing

A signal is synchronously evaluated by two IEDs. The first IED ("IED$_{16}$") has a sample rate of 16 samples per cycle; the second IED ("IED$_{32}$") has a sample rate of 32 samples per cycle. A large magnitude 9th order harmonic is injected into the signal and a waveform is captured by both IEDs. Figures 6 and 7 below illustrate the waveforms from IED$_{16}$ and IED$_{32}$ respectively.

The waveforms are noticeably different due to the respective IED sample rates and the presence of the 9th harmonic component. Figures below demonstrate a textbook example of the aliasing effect. What is measured correctly as a 9th order harmonic component by IED$_{32}$ incorrectly determined to be a 7th order harmonic component by IED$_{16}$. Under-sampling the 9th order harmonic component by IED$_{16}$ permits it to be aliased down to a 7th order harmonic component. In most cases, different load types produce the 7th order and 9th order harmonic components, so troubleshooting the problem and locating the harmonic source would be difficult because of IED$_{16}$'s sample rate.

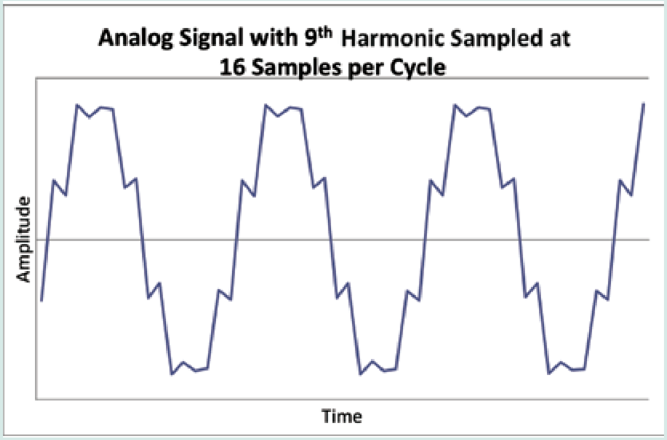


Figure 6: IED$_{16}$

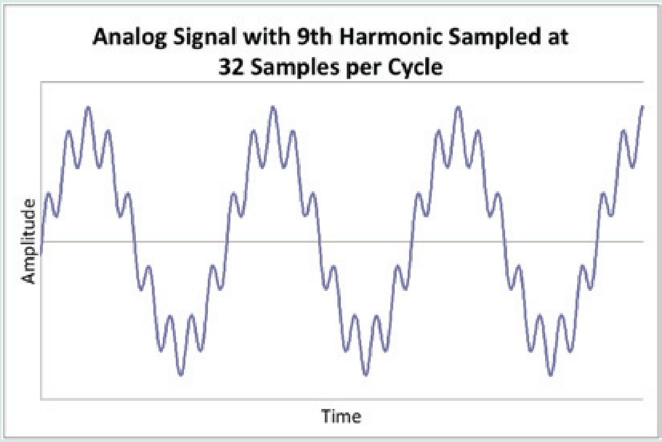


Figure 7: IED$_{32}$

It is important to understand the sources of inaccuracies in metering systems so that steps may be taken to reduce their effects. The conversion of an analog signal into a digital signal typically produces inaccuracies by omitting, creating, repositioning, or eliminating data. Because data from every digital meter includes some degree of inaccuracy, the end user must determine their acceptable level.

Accuracy Effects of Combining Sensors and IEDs

Because the sensor and IED are typically designed, manufactured, and sold independently, each component receives its own accuracy rating from the manufacturer. This is a very important consideration when pairing a sensor with an IED, because the accuracy of either component can adversely impact the combination of the two.

Table 1: Combined Accuracy of Sensor and IED

Sensor Accuracy	IED Accuracy				
	±0.2%	**±0.3%**	**±0.5%**	**±1%**	**±2%**
±0.2%	0.28%	0.36%	0.54%	1.02%	2.01%
±0.3%	0.36%	0.42%	0.58%	1.04%	2.02%
±0.5%	0.54%	0.58%	0.71%	1.12%	2.06%
±1%	1.02%	1.04%	1.12%	1.41%	2.24%
±2%	2.01%	2.02%	2.06%	2.24%	2.83%

Table 1 illustrates the effects of combining sensors and IEDs with differing accuracies. For example, choosing a sensor with ±1% accuracy to interface with a ±0.2% accurate IED will result in a combined accuracy of ±1.02% for the pair. Choosing a sensor with ±0.5% accuracy to interface with a ±0.5% accurate IED will produce a combined accuracy of approximately 0.71%.

Ultimately, the accuracy with which a primary voltage or current signal can be digitally reproduced (through both the sensor and IED) is determined by a combined accuracy that is worse than that of either individual component.

While a few manufacturers sell total metering hardware solutions that provide combined accuracy for sensors and IEDs, the majority do not. Therefore, it is important for the end-user to account for the combined effects on accuracy of *both* the sensor and IED when selecting a metering system.

Conclusion

Accurate measurements of electrical signals are essential to pinpoint energy savings opportunities, improve reliability, and identify and solve problems. The two components (sensors and IEDs) are required to gather data from medium voltage distribution systems. However, each component introduces inaccuracies as the primary signal is converted into a digital signal. It is important to select metering components that minimize or eliminate potential inaccuracies. Doing so provides more confidence in the decisions that are made based on data provided by the metering system.

About the author

Jon Bickel is a professional engineer, IEEE Senior Member, and Senior Edison Expert with a specialization in Power Quality and Reliability Metering Instruments. Formerly with TXU and Schneider Electric, Jon is the holder of more than 30 patents. Currently Jon serves as Vice President of Product Management with Optisense Network, LLC, a designer and producer of medium voltage technologies for Smart Grid applications.

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Figure 2: http://cnx.org/content/m15655/latest/

GE PT/ CT
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