Achieve Accurate Metering in Modern Nonsinusoidal Power System Conditions

Sri Lakshmi Nalla

Overview

Modern power systems are experiencing an increasing number of distorted waveforms caused by fast-switching circuits and nonlinear elements. These distorted waveforms decrease the efficiency of systems and end equipment and can also negatively affect revenue metering accuracy. The most important function of revenue meters is accurate metering under all system conditions, but not all revenue-grade meters can accurately and precisely measure the full spectrum of energy consumption in all conditions.

Some meters may lose accuracy in nonsinusoidal conditions if they are not designed to measure different types of waveforms. To evaluate the accuracy performance of revenue meters for modern power system conditions, nonsinusoidal waveforms were added to the most-recent version of the American National Standards Institute (ANSI) C12.20 standard, ANSI C12.20-2015. This revision also added a new 0.1 accuracy class, becoming the industry's most stringent accuracy standard. This paper discusses how the SEL-735 Power Quality and Revenue Meter exceeds the nonsinusoidal test requirements for ANSI 0.1 accuracy class compliance. It also illustrates why the SEL-735 is highly qualified for revenue metering applications in today's challenging power system conditions.

Introduction

Various applications, such as intertie metering, tariff metering, energy bill verification, and submetering, require high-accuracy energy measurement. Qualified revenue meters must accurately account for energy use and losses under the most demanding power system conditions. This results in fair billing and an accurate understanding of power system losses.

Traditionally, power systems were dominated by linear loads and synchronous power generation. The waveforms were almost perfectly sinusoidal with very little distortion. Today, power systems supply an increasing number of switching and nonlinear loads that cause measurable waveform distortion. For example, more consumers are adopting energy-efficient fluorescent and LED lighting systems, which use switched-mode power supplies. Nonconventional sources of energy generation, such as wind farms, solar farms, fuel cells, and batteries, are also becoming more common. These sources do not generate ideal sinusoidal signals because they use nonlinear elements to convert dc power to ac. Meters that are characterized and tested using sinusoidal waveforms may not meet the same level of accuracy under nonsinusoidal waveform conditions. Therefore, it is very important to understand a meter's accuracy in both sinusoidal and nonsinusoidal conditions to ensure that it is suitable for the chosen application.

Metering Challenges When Measuring Waveforms From Switching and Nonlinear Loads

Today, most of the waveforms that meters see are nonsinusoidal because of modern load types. For example, Figure 1 illustrates a three-phase current draw associated with a commercial office building that is equipped with LED lighting, printers, copy machines, computers, HVAC systems, and other non-constant-impedance loads.

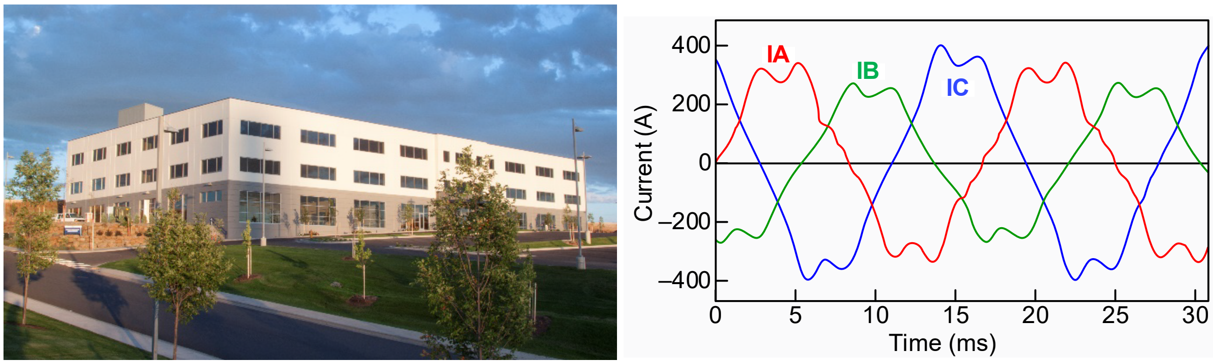

Figure 1 Three-Phase Current Draw of an Office Building

Figure 2 through Figure 4 demonstrate that fluorescent lighting, battery chargers, and variable frequency drives cause nonsinusoidal waveforms. Slight voltage distortions also result from the current distortion.

Note: Figure 2 through Figure 4 were captured in real time using the SEL-735 Wave View feature that displays the signals in both the time and frequency domains.

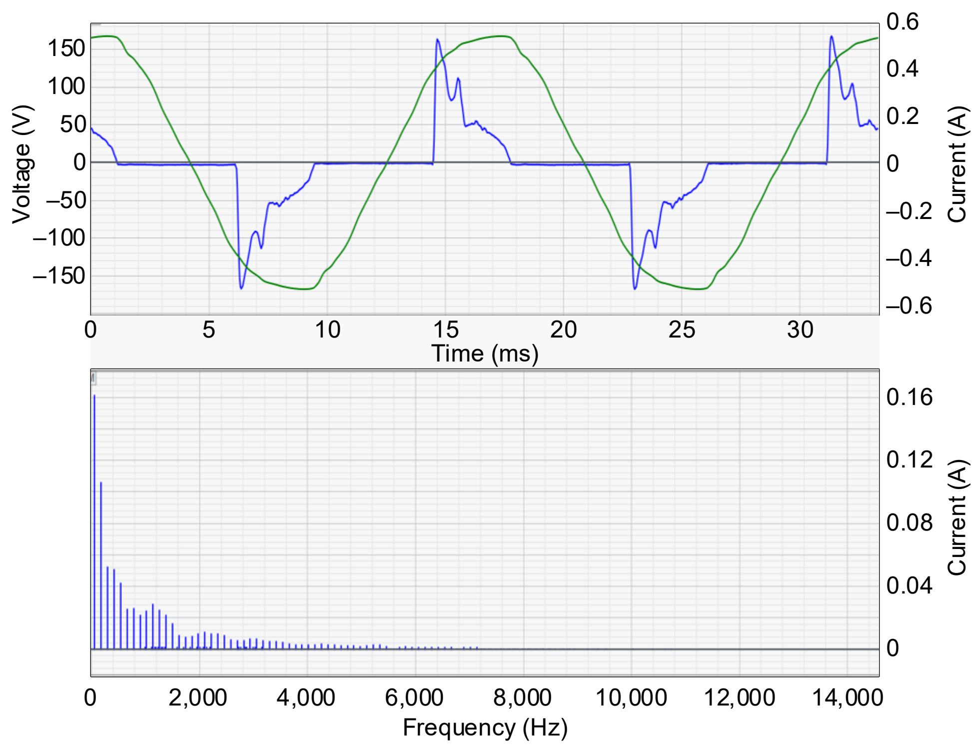

Figure 2 Fluorescent Lighting Waveform

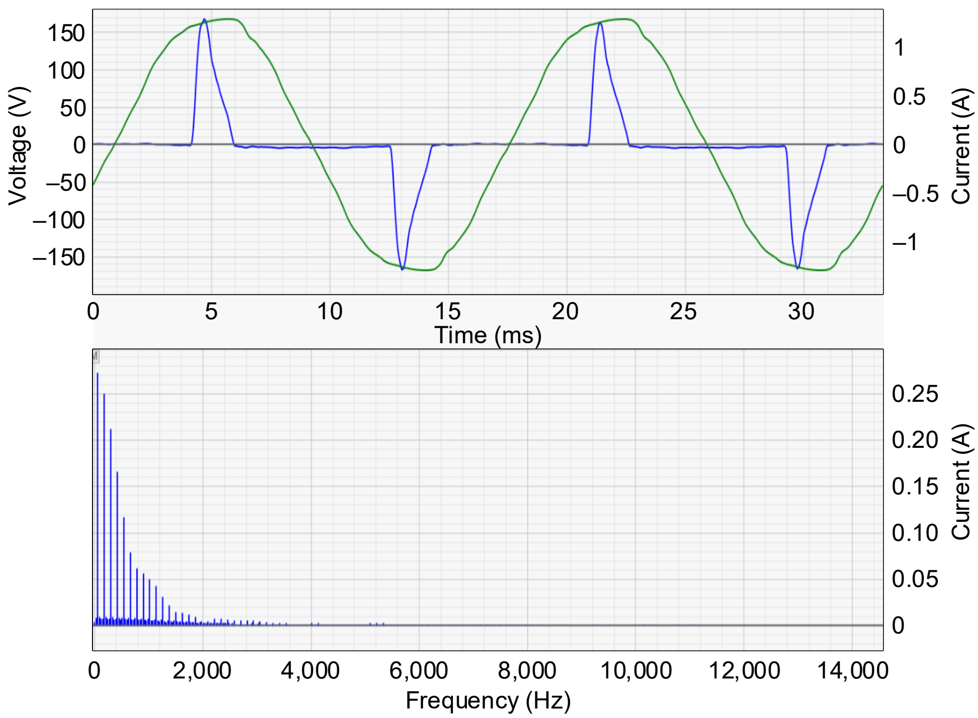

Figure 3 Battery Charger Waveform

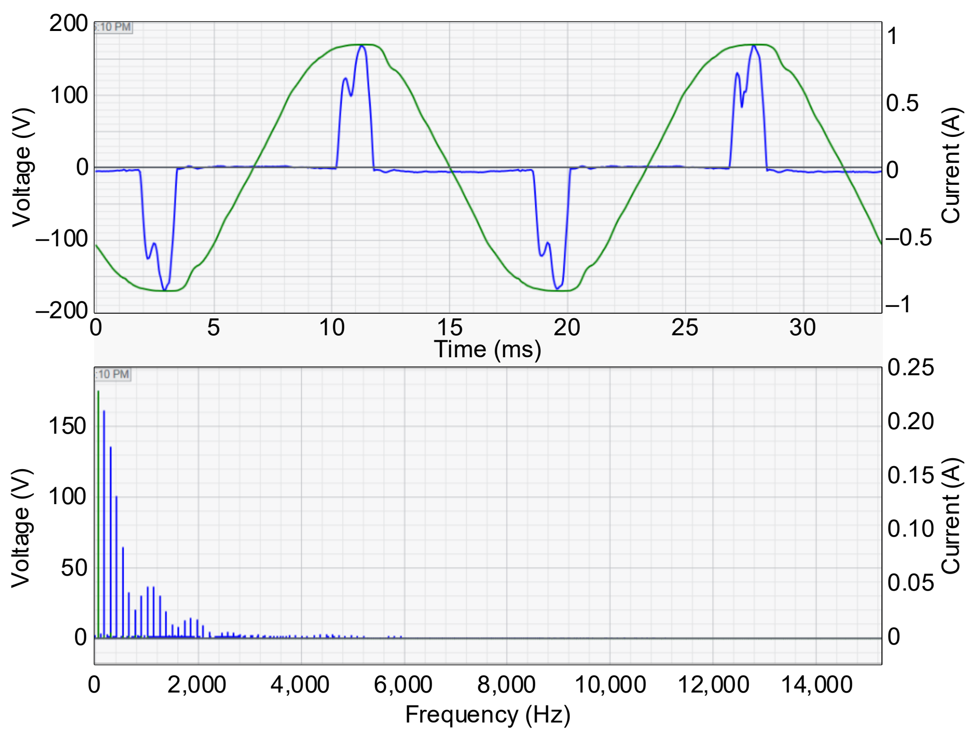

Figure 4 Variable Frequency Drive Waveform

Switching and nonlinear loads result in waveforms with the following characteristics:

- A rapid rising edge.
- Multiple zero crossings.
- Distortions in voltage and/or current.

Many meters are not designed to measure these types of waveforms and only provide accurate measurements when the applied voltages and currents are sinusoidal. A qualified revenue meter guarantees accurate performance under all system conditions by complying with the most stringent accuracy class for all test conditions specified in the most-recent ANSI revenue metering standard, including nonsinusoidal conditions.

ANSI C12.20-2015 Requirements for Revenue Meters

ANSI C12.20 is a well-defined North American revenue metering standard. Prior to the release of ANSI C12.20-2015, ANSI C12.20 only specified revenue metering accuracy requirements under sinusoidal conditions with 0.2 and 0.5 accuracy class performance levels.

ANSI C12.20-2015 (released April 2017) includes revisions to ensure that solid-state meters provide reliable and highly accurate metering under all power system conditions. The revisions include the following:

- Expanded test conditions that include meter performance under nonsinusoidal conditions.
- A new 0.1 accuracy class with more stringent accuracy requirements than the previous 0.2 accuracy class.

Accurate measurement of nonsinusoidal signals, especially with milliampere-level currents, requires high-speed sampling rates, wide-range resolution, and sophisticated metering algorithms. Figure 5 shows how the sampling rate can affect energy measurement. Accurately measuring the current waveform of an LED light bulb requires a meter that samples at a rate of at least 8 kHz.

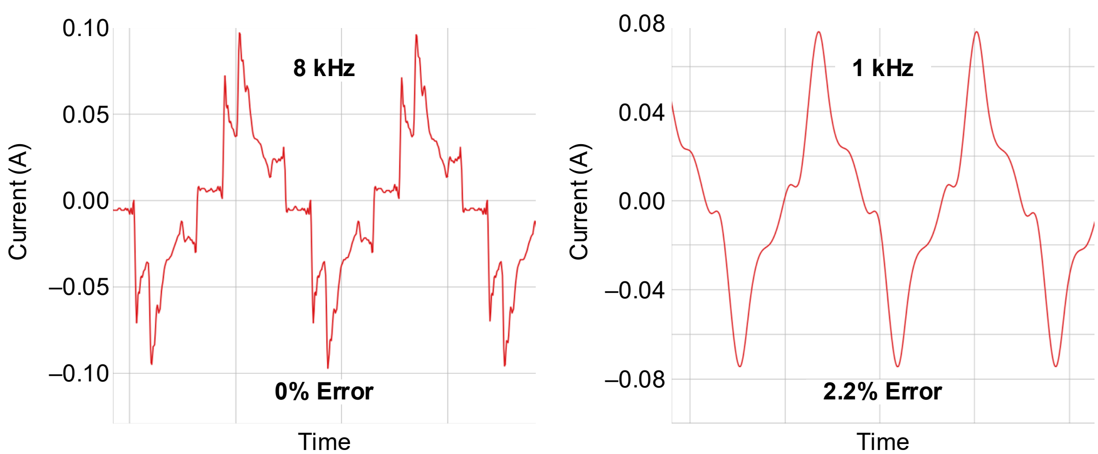

Figure 5 Higher Sampling Rates Increase Precision

The SEL-735 complies to the ANSI 0.1 accuracy class across a wide current range, under all system conditions, including nonsinusoidal waveforms. The SEL-735 also exceeds the requirements of the international revenue metering standard, IEC 62053-22, which lists the 0.2 accuracy class as the most stringent accuracy class.

ANSI C12.20-2015 specifies 44 separate tests that a meter must pass to claim compliance. These tests account for a wide range of influences, including changes in load current, power factor, temperature, harmonic distortion, and environmental conditions like surge and radio frequency interference.

Figure 6 through Figure 11 show the six newly added nonsinusoidal test conditions in ANSI C12.20-2015 that replicate real-world load conditions. Users can have confidence that meters compliant to this standard will perform accurately even under nonsinusoidal conditions.

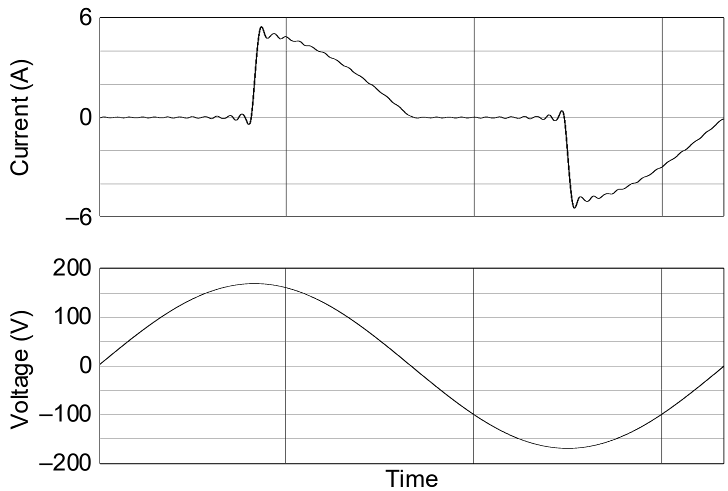

Figure 6 Test 39: 90-Degree Phase-Fired Waveform

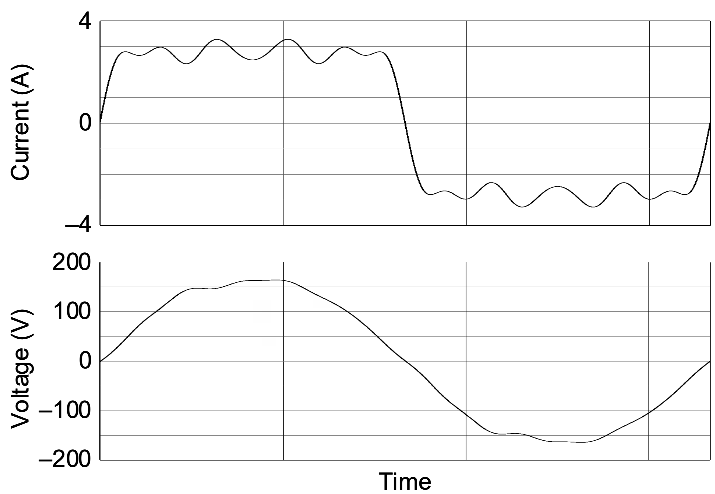

Figure 7 Test 40: Quadriform Waveform

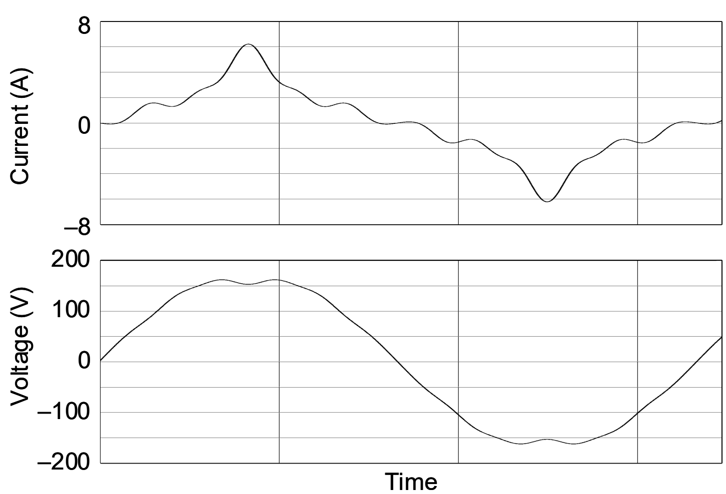

Figure 8 Test 41: Peaked Waveform

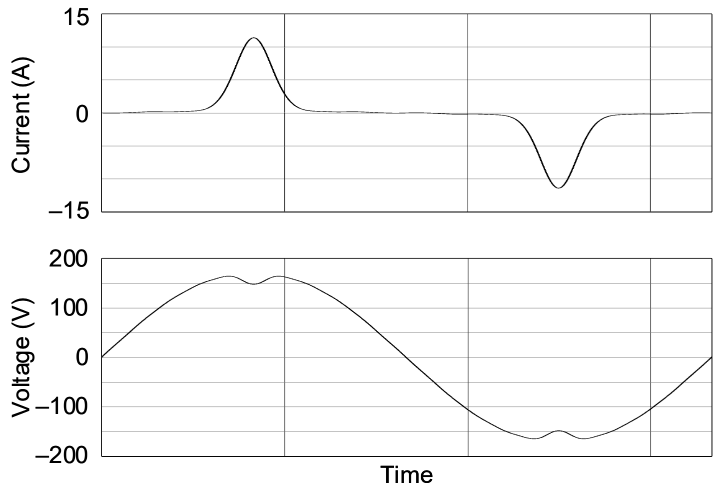

Figure 9 Test 42: Pulse Waveform

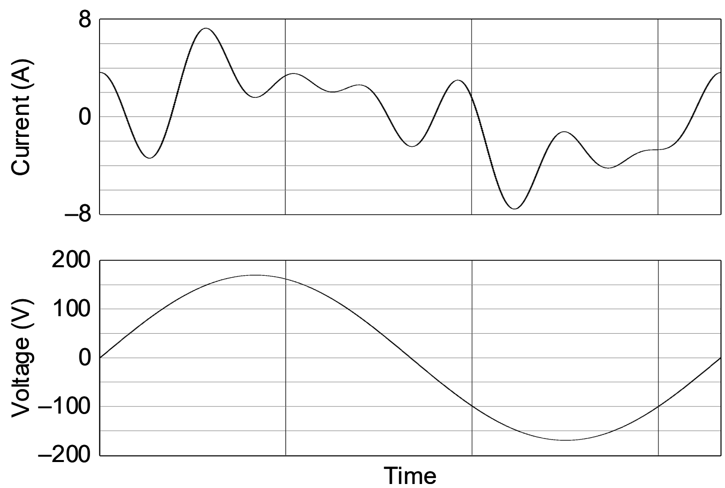

Figure 10 Test 43: Multiple Zero Crossing Current Waveform

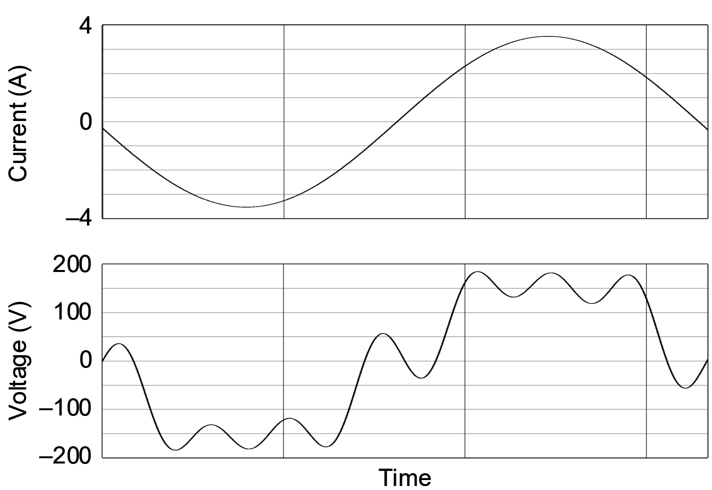

Figure 11 Test 44: Multiple Zero Crossing Voltage Waveform

SEL-735 Provides Exceptional Metering Accuracy

ANSI C12.20-2015 defines meter performance requirements for different current classes. The SEL-735 exceeds the new nonsinusoidal requirements for the ANSI 0.1 accuracy class. For example, Table 1 illustrates that the SEL-735 reports an error of just 0.006 percent when tested with peaked waveform distortion. The SEL-735 complies with the ANSI 0.1 and IEC 0.2 accuracy classes for current classes CL2, CL10, and CL20 at 50 and 60 Hz.

Table 1 SEL-735 Exceptional Performance With Peaked Waveform Distortion

Voltage Waveform	Current Waveform	0.1 Accuracy Class Reference Performance (%)	SEL-735 Measured Error (%)
Sinusoidal	Sinusoidal	±0.05	0.003
Sinusoidal	Peaked	±0.2	0.006
Peaked	Peaked	±0.3	0.006

Figure 12 through Figure 14 show ANSI accuracy class 0.1 test results for the SEL-735 and two other high-end meters under nonsinusoidal conditions, power factor variation, and the influence of harmonics.

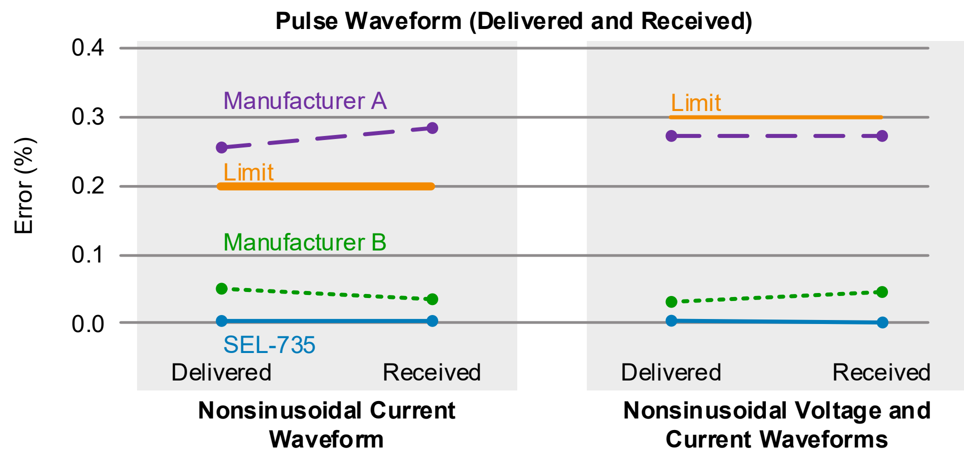

Figure 12 SEL-735 Accurate Performance Under Nonsinusoidal Conditions

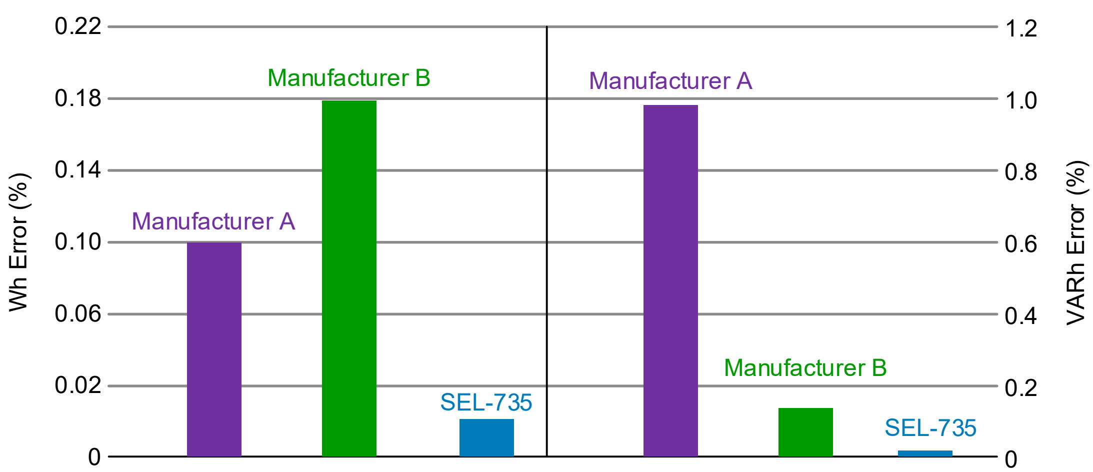

Figure 13 SEL-735 Reliable Performance at 0.025 A and 0.5 Power Factor

Some meters can lose significant accuracy when the measured signal includes harmonics, as shown in Figure 14.

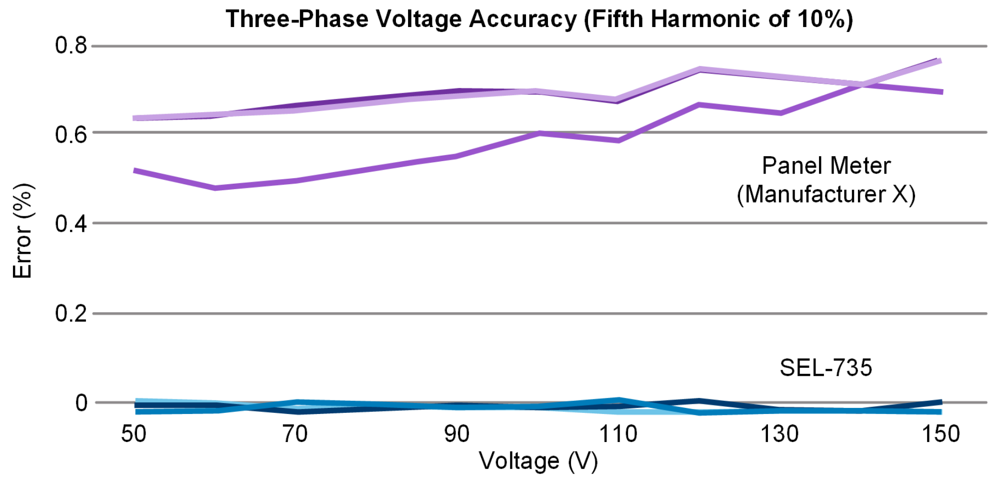

Figure 14 SEL-735 High-End Performance Compared With Low-End Meters Under the Influence of Harmonics

Better Accountability With Higher Accuracy Metering Installation

Vast amounts of energy pass through a transmission metering installation each day. Installing precise meters and instrument transformers ensures accurate accounting of energy transactions and losses. This accurate accounting also leads to a fair return on investments.

Table 2 shows, as an example, that a transmission utility benefits from decreased measurement error when their metering installation incorporates high-accuracy measuring instruments, such as an ANSI 0.1 accuracy class meter and a IEEE 0.15 transformer.

Table 2 Benefits of High-Accuracy Metering Installation on a 10 MW Load

Meter Accuracy Class	ANSI 0.2	New ANSI 0.1
Transformer Accuracy Class	IEEE 0.3	IEEE 0.15
Meter Measurement Error (M)	0.2%	0.1%
Total PT and CT Measurement Error (IT)[a]	0.735%[b]	0.367%[c]
Total System Error[d] (S_{error})	0.762%	0.381%
Yearly Cost of Measured Error (Using $0.10[e] /kWh)[f]	$67,000	$33,000

a Error calculation is based on the ratio correction factor values provided in IEEE C57.13 at PF = 1 and the SEL technical paper, "Increasing Metering Accuracy by Optimizing the Analog-to-Digital Converter Characteristics."

b For 0.3% error CTs and PTs; the total instrument transformer error is $\sqrt{\left(3 \cdot \text{CTerror\%}^2\right) + \left(3 \cdot \text{PTerror\%}^2\right)}$.

c For 0.15% error CTs and PTs; the total instrument transformer error is $\sqrt{\left(3 \cdot \text{CTerror\%}^2\right) + \left(3 \cdot \text{PTerror\%}^2\right)}$.

d Total system error is a combination of meter accuracy error and total instrument transformer error: $\sqrt{(\text{M\%})^2 + (\text{IT\%})^2}$.

e Average retail price in the United States according to the U.S. Energy Information Administration (https://www.eia.gov/electricity/state/).

f The equivalent dollar value for a 10 MW load is $(10\text{ MW} \cdot 365 \cdot 24) \cdot \frac{\$0.10}{\text{kWh}} \cdot \frac{\text{Serror\%}}{100}$ *(rounded to an integer value).*

Accurate and Precise Metering

The accuracy of a meter is how closely the measurement agrees with a reference, and the precision is the consistency of repeated measurements. An accuracy test of approximately 1,000 SEL-735 meters reports a maximum error of 0.025 percent, with a standard deviation (precision) of 0.006 percent, as shown in Figure 15. This demonstrates the exceptionally precise and accurate performance of the SEL-735.

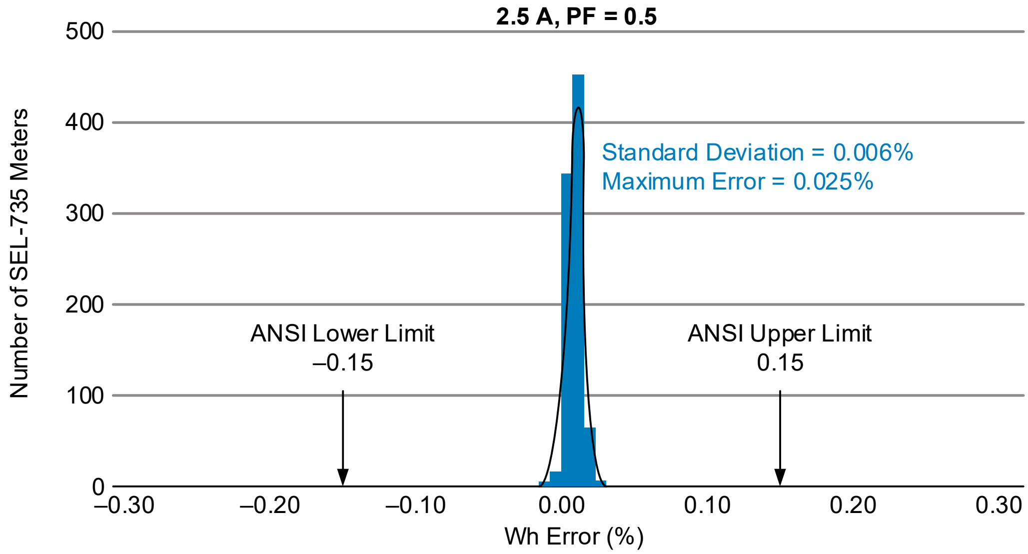

Figure 15 Statistical Data Validates SEL-735 Accuracy and Precision

Conclusion

Metering accuracy is a crucial factor for revenue metering applications. In today's power system, where the expected sinusoidal waveform can be highly distorted, selecting the right meter for accurate energy measurements is very important. Selecting a revenue-grade meter, like an SEL-735, that meets all ANSI-specified system conditions and exceeds the industry's most stringent accuracy class requirements (ANSI 0.1) helps ensure accurate and precise metering of energy consumption and losses.

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Schweitzer Engineering Laboratories, Inc.
Tel: +1.509.332.1890 | Email: info@selinc.com | Web: www.selinc.com

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