Increasing Metering Accuracy by Optimizing the Analog-to-Digital Converter Characteristics

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***Abstract*—Accuracy is perhaps the most important attribute of high-end metering. The overall accuracy of a metering installation is dependent on a combination of the accuracy of the meter and the instrumentation transformers. Optimization of the analog-to-digital converter (ADC) resolution and the time averaging period in the root mean square (rms) calculation can improve meter accuracy. This paper shows that appropriately changing either of these characteristics can increase the overall metering accuracy.**

I. Introduction

Today, a number of electric utilities expect high-end meters to deliver accuracy that exceeds the ANSI C12.20 0.2 accuracy class specification—in some cases by more than four times. This transition has taken the "industrial grade" electric meter to the realm of precision laboratory equipment. Is this major shift in precision warranted? If so, should ANSI C12.20 reflect this shift?

II. Instrumentation Transformer Accuracy

Instrumentation transformers are not 100% accurate and contribute to the total system error in any revenue metering system. Assuming a Gaussian distribution (a bell curve), the transformer error is:

$$\varepsilon PT = \sqrt{\varepsilon VT^2 + \varepsilon CT^2} \tag{1}$$

Where:

- εVT is the error of the voltage transformer
- εCT is the error of the current transformer
- εPT is the transformer error (combined measurement error of the voltage and current transformer pair)

Consider the typical meter installation where both the current and voltage instrument transformers have an error of 0.1%. By Equation 1, the transformer error, εPT, is:

$$\varepsilon PT = \sqrt{0.1\%^2 + 0.1\%^2}$$

$$\varepsilon PT = 0.141\%$$

III. Meter Accuracy Effects on System Accuracy

Using the same principle outlined above, the total system error is:

$$\varepsilon S = \sqrt{\varepsilon M^2 + \varepsilon PT^2} \tag{2}$$

Where:

- εS is the error of the system
- εM is the measurement error of the meter

Consider a meter with a measurement error, εM, of 0.2% and transformer error, εPT, of 0.141% from the example above. The system error, εS, is then:

$$\varepsilon S = \sqrt{0.2\%^2 + 0.141\%^2}$$

$$\varepsilon S = 0.245\%$$

Notice that the total system error is greater than the error of any one component but statistically less than the sum of the parts. If we assume a wholesale price of $0.03/kWh, a 10 MW load, and a system error of 0.245% from the previous example, an equivalent dollar value of the measurement error is:

$$10\ \text{MW} \bullet \frac{\$0.03}{\text{kWh}} \bullet 0.245\% = \frac{\$6438}{\text{yr}}$$

Now consider a meter with a measurement error of 0.05%, similar to today's high-end meters, installed at the same location. The total system error of the extraprecision meter is:

$$\varepsilon S_{EP} = \sqrt{0.05\%^2 + 0.141\%^2}$$

$$\varepsilon S_{EP} = 0.140\%$$

Where:

- εS_{EP} is the total system error with the extraprecision meter combined with the 0.141% transformer error

The equivalent dollar value of the extraprecision system is:

$$10\ \text{MW} \bullet \frac{\$0.03}{\text{kWh}} \bullet 0.150\% = \frac{\$3942}{\text{yr}}$$

The difference of $2496 is enough to justify the purchase of an extraprecision meter with a payoff of approximately one year.

This begs the question, "Do further increases in accuracy produce favorable results?" Assume an ultraprecision meter with an error of 0.02%. The total system error is:

$$\varepsilon S_{UP} = \sqrt{0.02\%^2 + 0.141\%^2}$$

$$\varepsilon S_{UP} = 0.142\%$$

Where:

- εS_{UP} is the total system error with the ultraprecision meter combined with the 0.141% transformer error

Notice that the difference between the system error and the transformer error is only 0.001%, yielding a difference of only $200 per year between a system with an extraprecision meter and one with an ultraprecision meter.

One could argue that the difference is $2000 on a 100 MW load and, therefore, the increased precision is justifiable. However, no vendors presently offer a 0.02% revenue meter, and if such a device were available, it would cost at least twice as much as the extraprecision meters available today. Additionally, in order to test this new 0.02% meter, the utility would need to invest in a watt-hour standard with at least 0.002% accuracy: a required investment of approximately $35000.

Perhaps the ANSI C12.20 committee should consider a 0.05% accuracy class. It has a noticeable impact on system accuracy and is readily available. However, accuracies beyond 0.05% are of little practical significance.

IV. Analog-to-Digital Conversion in High-End Electric Meters

Most electronic meters use analog-to-digital converters (ADCs) to change the analog voltage and current waveforms that are present at the meter terminals into digital values that represent the waveform magnitudes at a given point in time.

Meter vendors often capitalize on the perception that more is better and convince utilities that meters with higher-resolution ADCs outperform meters with lower-resolution devices. High-resolution ADCs have more quantization levels, or counts, than do lower-resolution counterparts. However, these counts do not directly relate to watt-hour measurement accuracy.

The number of counts, or output values, of an n-bit ADC is:

$$\text{Counts}_n = 2^n \tag{3}$$

By Equation 3, the number of counts of a 12-bit ADC and 16-bit ADC is:

$$\text{Counts}_{12} = 2^{12}$$

$$\text{Counts}_{12} = 4096$$

$$\text{Counts}_{16} = 65536$$

Given a CL20 revenue meter with a current measurement range of 0–22 A rms, the quantization error with a 12-bit ADC is:

$$\begin{aligned} \varepsilon Q_{12} &= \frac{1}{2} \bullet \frac{22\text{ A}}{\text{Counts}_{12} - 1} \\ \varepsilon Q_{12} &= 2.69\text{ mA} \end{aligned} \tag{4}$$

Where:

εQ_{12} is the quantization error of a 12-bit ADC.

This means that every output value, or count, of the ADC has an incremental value of 2.69 mA. Although the highest measurement point of ANSI C12.20 is 20 A, Equation 4 assumes a design margin of 10%. Equation 4 uses a multiplier of 0.5 because the analog waveform is always between quantization levels, and the ADC will round up or down accordingly. That is, the error is never one full count but half a count.

Similarly, the quantization error of a CL20 revenue meter with a 16-bit ADC is:

$$\begin{aligned} \varepsilon Q_{16} &= \frac{1}{2} \bullet \frac{22\text{ A}}{\text{Counts}_{16} - 1} \\ \varepsilon Q_{16} &= 168\ \mu\text{A} \end{aligned} \tag{5}$$

Resolution is improved 16 times between the 16- and 12-bit devices. How might this affect meter registration? The registration of any single measurement point at a test current of 2.5 A for the 12- and 16-bit systems, respectively, is:

$$\varepsilon I_{12} = \left| \frac{2.5\text{ A} - \varepsilon Q_{12}}{2.5\text{ A}} \right| \bullet 100\%$$

$$\varepsilon I_{12} = 99.8926\%$$

$$\varepsilon I_{16} = \left| \frac{2.5\text{ A} - \varepsilon Q_{16}}{2.5\text{ A}} \right| \bullet 100\%$$

$$\varepsilon I_{16} = 99.9933\%$$

Where:

εI_{12} is the instantaneous registration of a 12-bit ADC

εI_{16} is the instantaneous registration of a 16-bit ADC

Upon first inspection, the difference in registration appears substantial—greater than 0.1%. However, it is important to note that revenue meters do not calculate watt-hours directly from instantaneous measurements. Revenue meters calculate energy values from time-averaged rms measurements. During the rms measurement (or averaging), some quantization errors will be positive and some will be negative. Statistically, the root sum square provides a method for determining the effects of quantization errors for averaged values.

Assume a one-second average of 8,000 samples. The registration of the averaged 12-bit system is:

$$\varepsilon A_{12} = \frac{\sqrt{\varepsilon I_{12}{}^2}}{\sqrt{8000}} = 99.9988\%$$

The registration of the averaged 16-bit system is:

$$\varepsilon A_{16} = \frac{\sqrt{\varepsilon I_{16}{}^2}}{\sqrt{8000}} = 99.9999\%$$

The difference in accuracy between the 12- and 16-bit time-averaged systems is 0.0011%. Today's watt-hour standards cannot measure such differences, and the minimum demand interval is typically greater than one minute. Therefore, ADC resolution is not an indication of watt-hour measurement accuracy.

V. Conclusions

This paper illustrates that several factors influence metering system accuracy. The metering system accuracy is a function of both the accuracy of the meter itself and the accuracy of the instrumentation transformers. Increasing the meter accuracy far beyond the accuracy of the instrumentation transformers produces diminishing returns.

The combination of ADC resolution and the number of samples in the time-averaged rms period affects meter accuracy. It is not simply a function of the ADC resolution. Changing these characteristics can improve the accuracy of the meter installation to an extent.

Finally, increasing meter accuracy beyond 0.05% requires the use of ultraprecision watt-hour standards for verification. The cost of such watt-hour standards is often prohibitive.

VI. Biographies

Travis Mooney received his B.S. in Electrical Engineering from Gonzaga University in 1995. He joined SEL upon graduation as an electronics engineer in the Research and Development Division, where he designed many protective relay and communications products. In 2003 he joined the SEL Meter Systems Division as an electronics engineer, where he provides systems engineering, electronics engineering, and customer support for revenue metering products. He holds two patents in data acquisition and measurement techniques.

Dick Martin graduated from Iowa State University with a B.S. in Electrical Engineering. He joined SEL in 2004 as the product manager for the Meter Systems Division. Prior to joining SEL, he worked with Telemetric Corporation, T&D Technologies Corporation, ESCA, and Westinghouse Electric in various sales and application positions.

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