It is common in the submetering market to use simple terms to express the accuracy of electric energy meter, but the reality is very complicated. This article summarizes the common meter and current transformer (CT) accuracy standards, as well as overall system accuracy. It explains how the system accuracy (meter with CTs) can be much worse than just the meter accuracy or even the naïve addition of the meter and CT accuracies (a 0.2% meter with 0.3% CTs may not result in 0.5% accuracy).

Meter, CT, and System Accuracy

Broadly speaking, manufacturers can make accuracy claims about any of the following meter configurations:

- **Direct meter:** this refers to meters with built-in current measurement and no external sensors. In this case, the meter and system accuracies are the same.
- **Meter with CTs:** this refers to meters with external CTs that are tested as a system, so the results are the system accuracy.
- **Meter without CTs:** it is common for submeter manufacturers to claim a meter accuracy without including the effect of the necessary external CTs. For example, they might claim a meter accuracy of 0.2% excluding CTs.

For the first two cases, the quoted and system accuracies are the same, but in the third case, it can be difficult to determine the system accuracy.

Accuracy Effects of CTs

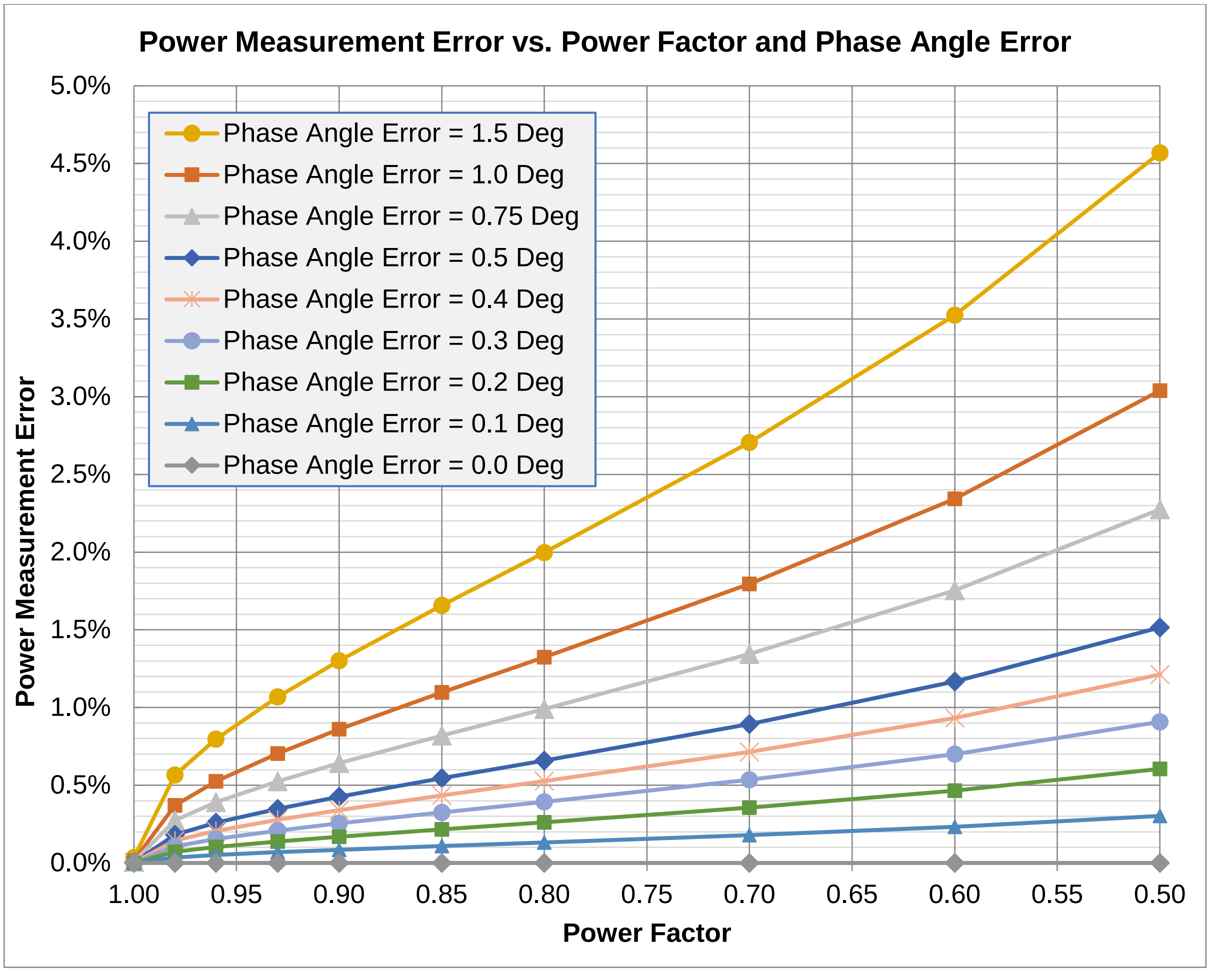
When combining a meter with external CTs, it seems intuitive that combining a 0.2% meter with 0.3% CTs should yield a 0.5% system accuracy, or more precisely a system accuracy that would meet the accuracy class 0.5 requirements for a direct meter. This is not always true for the following two reasons:

1. Unless the CT accuracy is specified from 1% to 100% of rated current, the CT may be less accurate below 10%, resulting in a system accuracy that does not meet the C12.1 or C12.20 requirements.

   For example, the U.S. standard IEEE C57.13 only specifies CT accuracy down to 10% of rated current and allows the error to be twice as large at 10%. A class 0.3 CT could have a 0.3% error at 100% of rated current, a 0.6% error at 10% of rated current, and an arbitrarily large error at 1% of rated current.

   Even the IEC standards IEC 61869-2 and IEC 60044-1 for CTs are not perfect. The accuracy classes 1, 0.5, 0.2, and 0.1 only specify the accuracy down to 5% of rated current and allow an error 3.0 to 4.0 times larger at 5% of rated current. The IEC standards have 0.2S and 0.5S accuracy classes that extend down to 1% of rated current, but also allow 3.0 to 3.75 times larger errors at 1%. By comparison, the C12.1 and C12.20 standards are much more stringent and only allow the metering error to be 2.0 times larger at 1%.

2. Current transformers have a phase error (also called phase displacement) that is a phase shift between the actual current and the secondary output signal (current or voltage) generated by the CT. These phase angle errors cause measurement errors that increase as the power factor gets lower. At power factors around 0.5, the error due to the CT phase angle will generally dominate as shown on the graph below.



The allowable phase angle errors are limited by standards like IEEE C57.13, IEC 61869-2, and IEC 60044-1, but these limits are not always sufficient to provide a system accuracy that meets ANSI C12 requirements, especially below 10% of rated current.

As an example, C57.13 class 0.3 allows a phase angle error of 0.25 degrees (15 minutes) at 10% of rated current (more precisely, it allows a TCF of 0.6). Uncorrected, this phase angle error will cause a 0.75% error at a power factor of 0.5, which exceeds the 0.6% maximum error allowed by C12.20 accuracy class 0.5. Many CTs have phase angle errors of 0.5 degrees or more, which can cause 1.5% or higher errors.

See https://ctlsys.com/measurement_errors_due_to_ct_phase_shift/ and https://ctlsys.com/ct_accuracy_standards/ for more information.

Note: *to address these concerns, all revenue-grade CTs provided by CCS have gain accuracy and phase angle error specifications that extend down to 1% of rated current. Furthermore, the CT gain accuracy and phase angle specifications are tight enough to ensure that when combined with our meters, the system accuracy can meet the appropriate ANSI C12 accuracy class.*

Accuracy Standards

ANSI C12.1-2014 and C12.20-2010

The ANSI C12 standards are the most widely used metering standards in the U.S.A.

Older versions of C12.1 only covered accuracy class 1, while the 2014 edition includes two accuracy classes: accuracy class 1.0 and accuracy class 0.5. C12.20 includes accuracy class 0.5 and accuracy class 0.2.

The accuracy class provides a nominal accuracy, but there are many cases where the actual accuracy may be worse. For example, an accuracy class 1.0 meter should be 1% accurate under a narrow range of conditions, but may have a 2% error at 1% of rated current and a 2% error from 75%-100% of rated current. It may have an additional 2% error under certain conditions of current and power factor. Added errors are allowed for variations in the line frequency, line voltage, unbalanced loads, due to internal heating, and due to ambient temperature variations. Under the right conditions the total allowed error could easily exceed 5%.

The C12 standards only deals minimally with meters that use external current transformers, by saying that they must use CTs that have been tested to conform to IEEE C57.13. But C57.13 only requires accuracy down to 10% of rated current, while C12.1 and C12.20 include accuracy tests down to 1.5% or 1% of rated current. This could result in a situation where the system accuracy with CTs is far worse at light loads than for meters without CTs or meters tested as a system with the CTs.

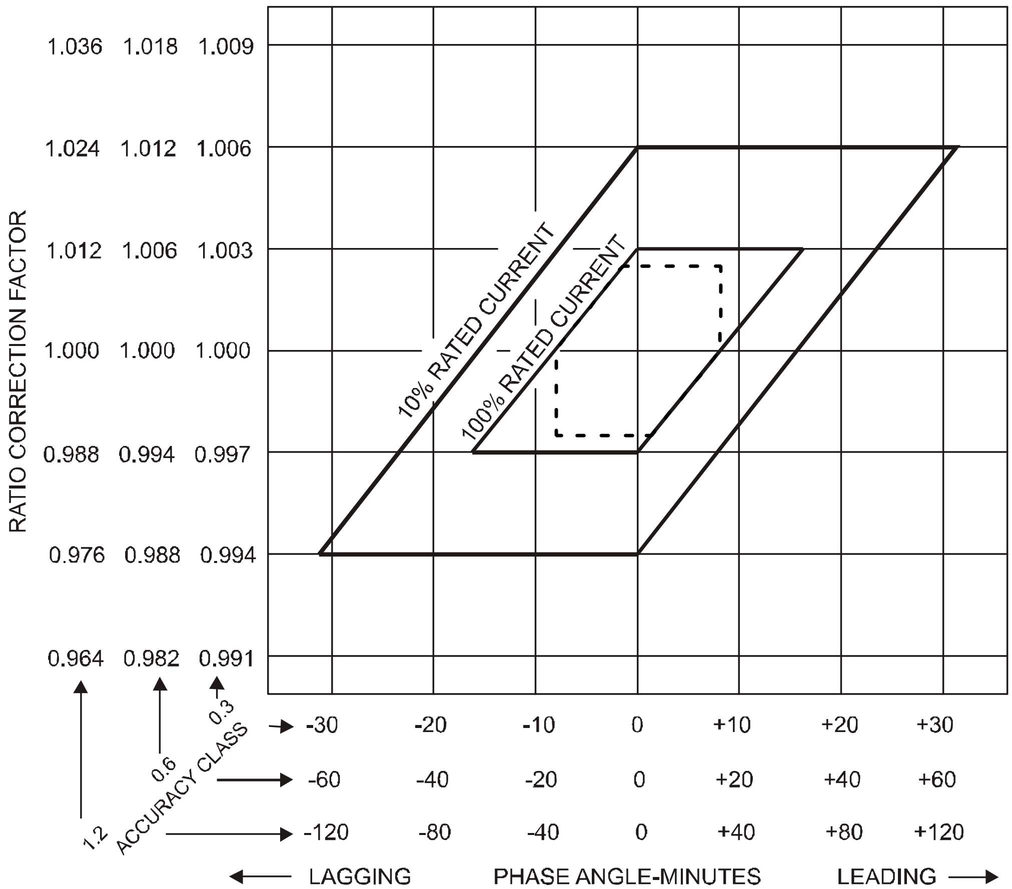
In practice, when it comes to submeters, formal laboratory C12 testing is commonly performed with the external CTs connected, so the entire system accuracy is tested.

IEEE C57.13

The IEEE C57.13 standard is the most popular standard in the U.S.A. for current transformers. It defines the required accuracy at 100% and 10% of rated current. It allows double the gain accuracy error and phase angle error at 10% that is allowed at 100%. It has no accuracy requirements below 10% of rated current.

C57.13 does not directly specify the required gain accuracy or phase angle error. Instead, it specifies the TCF (transformer correction factor) which is based on the RCF (ratio correction factor) and the phase angle error. This can be translated into gain and phase angle errors, which results in a parallelogram-shaped region of allowable gain (ratio correction factor) and phase angle errors as shown in the following diagram from the standard (Figure 2 from “IEEE C57.13-2008”).

See https://ctlsys.com/ct_accuracy_standards/ for more details.



Unfortunately, the C57.13 standard was not written in coordination with the ANSI C12 standards to ensure the complete system accuracy, so using IEEE C57.13 accurate CTs is no guarantee that the system accuracy will meet C12.1 or C12.20 limits.

Note: *CCS revenue-grade CTs meet stricter limits than required by IEEE C57.13.*

- *The tighter 100% gain limit is applied from 120% to 1% of rated current*
- *The 10% phase angle (TCF) limit is applied down to 1% of rated current*
- *The gain accuracy is limited to 1% (instead of 1.2%) for class 1.2.*
- *The gain accuracy is limited to 0.5% (instead of 0.6%) for class 0.6*
- *Where C57.13 allows larger phase angle errors (the upper-right and lower-left quadrants of the parallelograms), CCS cuts off the corners. The tighter CCS limits are shown with the dashed lines.*

IEC 60044-1 and IEC 61869-2

The IEC current transformer standards are more commonly uses outside the U.S.A. They are far less complex, since they specify just the gain error and phase displacement (phase angle error). They do not use concepts like RCF and TCF. They have the advantage of specifying accuracy down to 5% or 1% of rated current. However, they allow significantly higher errors at low currents. As with the C57.13 standard, using an IEC rated CT is no guarantee of overall system accuracy.

CCS ANSI Testing

CCS has successfully passed formal laboratory testing (MET Laboratories) on three of our WNC series meter models to the ANSI C12.1 accuracy class 1.0 requirement. This was performed with three models of our Accu-CTs, ensuring the system accuracy meets the accuracy class 1.0 requirements.

CCS has successfully passed formal laboratory testing (MET Laboratories) on one WND series meter to the ANSI C12.20 accuracy class 0.5 requirements with the TCL-B-100 current transformer.

We have developed an automated internal test system that can perform the ANSI C12 accuracy tests (accuracy classes 1.0, 0.5, or 0.2) using NIST traceable test equipment. This allows us to validate the system accuracy of meters with CTs much more quickly and economically than using an external laboratory for cases where formal certification is not required. This system can generate high-quality formal reports of the results.

Our internal test system cannot perform all the electromagnetic compatibility (EMC) and external influence tests, but it can perform the following ANSI C12 tests:

- Test 1: No Load
- Test 2: Starting Load
- Test 3: Load Performance
- Test 4: Power Factor
- Test 5: Voltage Variation
- Test 6: Frequency Variation
- Test 7: Equality of Current Circuits
- Test 11: Effect of Internal Heating
- Test 13: Stability of Performance
- Test 14: Independence of Elements
- Test 15: Insulation
- Test 16: Voltage Interruptions
- Test 19: Temperature Variation

Conclusion

It is easy to be misled by accuracy claims for meters or for CTs in isolation. There are realistically only two ways to determine the system accuracy of a meter and external CTs:

- Measure the system accuracy using a C12 test suite that includes tests at varying loads, power factors, temperatures, etc.
- Use detailed accuracy data for the meter and current transformer, with algebra and trigonometry to estimate the combined accuracy at the relevant C12 test points. This approach is not practical, due to its complexity and because few manufacturers provide detailed current transformer accuracy information from 1% to 100% of rated current.

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