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Current transformer relaying accuracies – IEEE compared to IEC

In today's business atmosphere, we can no longer consider only the current transformer standard common in the U.S., principally the IEEE C57.13 standard for instrument transformers. Many multi-national firms now wish to design facilities that can be constructed in any geographic area, not simply in the U.S. or Canada. Outside North America, the most common standards for current transformers are the IEC 61869-1 and 61869-2 standards (replacement for the old IEC 60044-series), the first specifying common characteristics for instrument transformers, and the second specifying characteristics pertinent to current transformers.

The IEEE and IEC standards developed independently, and the resulting standards are quite different. However, the fundamental physics underlying current transformers are the same. This issue of TechTopics discusses the relaying or protection accuracy classifications of current transformers to the two differing standards' philosophies, and provides an example of the accuracy of one particular current transformer to both of the standards.

A word of caution: The discussion is highly simplified so as to illustrate the basic principles.

Metering accuracy will not be addressed in this discussion. Historically, separate current transformers were often specified for metering purposes and for protection (relaying) purposes, but this is seldom required with modern switchgear. Current transformers with relaying accuracy as well as excellent metering accuracy can generally serve both purposes.

This discussion will deal primarily with current transformers having a rated secondary current of 5 A. A supplementary discussion of current transformers with rated secondary current of 1 A is also included.

IEEE C57.13 CT relaying accuracy classes

IEEE defines two fundamental relaying accuracy designations, one headed by a "C" and the other by a "T" designator. The C and T leading designators signify the type of construction of the current transformers.

The C designator applies to a current transformer which has fully distributed secondary windings, and in which the leakage reactance (or, leakage flux in the core) is very low. In turn, this means that the relaying accuracy can be calculated (hence, "C"). Essentially, C relaying accuracy class applies to a current transformer of the toroidal, bushing or window type, commonly called donut-type transformers. Another type of current transformer which falls into the C class is a bar-type current transformer, where the primary conductor passes through the current transformer window but there is only one primary turn in the transformer.

The T designator applies to a current transformer in which there is a high leakage reactance that impacts the relaying accuracy, so that the accuracy must be determined by test (hence, "T"). These types of transformers are commonly called wound-type CTs, and have multiple primary turns. Wound-type CTs are typically applicable only for very low ratios, and these current transformers have very limited short-circuit strength. As a result, they are rarely used in modern metal-clad switchgear.

Answers for infrastructure and cities.

Since T class accuracy CTs are seldom used today, these will not be discussed further, except to say that the fundamental meaning of the accuracy class is similar to that of a C class CT.

IEEE C57.13 C-class relaying accuracy calculation

The most common relaying accuracy class for current transformers is the C designation, which requires a maximum limit of ratio error at 20 times rated primary current of 10 percent. The C designation is followed by a number, which is a secondary terminal voltage that the CT will support while meeting the error limit (≤ 10 percent) at 20 times rated primary current. In turn, the common secondary terminal voltage classes have a direct link to the allowable secondary circuit burden on the CT. The common generic accuracy classes in the standard, with the associated secondary burdens, are as shown in Table 1.

Table 1: IEEE C57.13 relaying accuracy classes and burden data

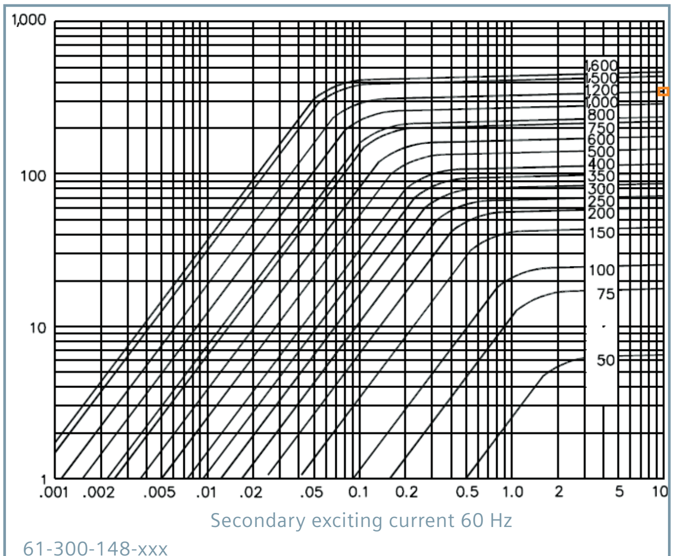
Secondary terminal voltage (V)	Secondary burden designation	Resistance (Ω)	Inductance (mH)	Impedance (Ω)	Total power (VA at 5 A)
10	B-0.1	0.09	0.116	0.1	2.5
20	B-0.2	0.18	0.232	0.2	5.0
50	B-0.5	0.45	0.580	0.5	12.5
100	B-1.0	0.50	2.30	1.0	25.0
200	B-2.0	1.00	4.60	2.0	50.0
400	B-4.0	2.00	9.20	4.0	100.0
800	B-8.0	4.00	18.40	8.0	200.0

It will be seen that, with the standard rated secondary current of 5 A, the short-circuit current of 20 times current would be 100 A, which when multiplied by the burden impedance in the table, results in the secondary terminal voltage shown. For example, with 20 times rated current flowing in a B-4.0 burden, if the accuracy limit is met, the secondary terminal voltage would be 400 V and the CT accuracy class is C400.

In the case of multi-ratio current transformers, the accuracy limits are always based on the full winding of the current transformer, i.e., the highest available tap. For a lower tap ratio, the accuracy is determined from the full winding-accuracy rating, multiplied by the ratio of the selected tap to the full winding ratio. Hence, for a C400 current transformer with 1200:5 full winding ratio, the accuracy at the 50 percent tap ratio (600:5 for this example) would be C400 times 0.50 = C200.

The relaying accuracy class of a donut-type current transformer can be determined from the secondary excitation curve for the current transformer, available from the manufacturer. An example of a secondary excitation curve for one of our current transformer families is shown in Figure 1. This curve will be used in the example calculation of the CT relaying accuracy.

Figure 1: Secondary excitation curve example



As an example, consider a 1,200:5 ratio current transformer, as shown in the curve. For a limit of error current of 10 percent with 20 times rated current flowing, the error current upper limit would be 10% x 5 A x 20 = 10 A. At 10 A secondary excitation current, the voltage from the curve would be about 340 V. For the 1,200:5 ratio, the secondary winding resistance is 0.418 Ω, so the voltage "lost" in the CT itself due to a secondary current of 100 A would be 0.418 x 100 = 41.8 V. So, the relaying accuracy class of this CT would be 340 – 41.8 ~ 298 V. For conservatism, this unit would be rated at 280 V, or C280. With the discrete classes in the standard, this would be a C200 current transformer.

One aspect that this illustrates is that practical units do not fall neatly into the accuracy classes in the standards (C100, C200, C400, and so on). In reality, the values seldom just barely fall into a class such as C100. The secondary terminal voltage usually falls above one class rating but not up to the next class rating. The user can benefit from having more information about the capabilities of the CT than is provided by the discrete classes in the standard. This is why Siemens publishes relaying accuracies for current transformers used in our metal-clad switchgear using the actual accuracy class voltage, in this case, C280 rather than merely C200.

IEC 61869-2 protection (relaying) accuracy classes

The classification scheme of IEC 61869-2 is substantially different from that of IEEE C57.13, but since the underlying physics are the same, the two systems are able to be correlated, at least in part.

In IEC, the current transformer class of interest to this discussion is the class P protective current transformer. The rated output classes in IEC are 5, 10, 15, 20, and 30, where the number represents the load output in VA at rated secondary current. The preferred accuracy classes are 5P (5 percent maximum error) and 10P (10 percent maximum error). Lastly, IEC has an accuracy limit factor (ALF), which indicates the multiples of rated secondary current at which the accuracy class applies. The typical value of the ALF is 10, with values of 20 and 30 also available. So, the complete accuracy specification for a particular current transformer might be 20 VA class 5P10, to signify a transformer with less than 5 percent error at 10 times rated current, with a load output of 20 VA.

IEC discusses the excitation characteristic and defines it as the

"…graphical or tabular presentation of the relationship between the rms value of the exciting current and a sinusoidal voltage applied to the secondary terminals of a current transformer, the primary and other windings being open-circuited, over a range of values sufficient to define the characteristics from low levels of excitation up to 1.1 times the knee point emf."

This is essentially the same manner as a secondary excitation curve is obtained for transformers to IEEE C57.13. In addition to defining the excitation characteristic in this manner, this is how current transformers with low-leakage reactance are tested for accuracy in IEC. The manner of testing to IEEE standards is essentially the same. So, the secondary terminal voltage is obtained in tests of both IEEE and IEC transformers in essentially the same manner.

But, how is some equivalence or correspondence between accuracy requirements to IEC and to IEEE determined?

First, the components of the IEC accuracy designations have to be understood.

- The first element of the IEC designation is the rated output.
- The second element of the IEC designation (the value in front of the P) is easy to understand. 5 designates 5 percent allowable error, whereas 10 designates 10 percent allowable error.
- The final element of the IEC designation is the ALF. A designation of 10 indicates that the accuracy limit applies at 10 times rated current.

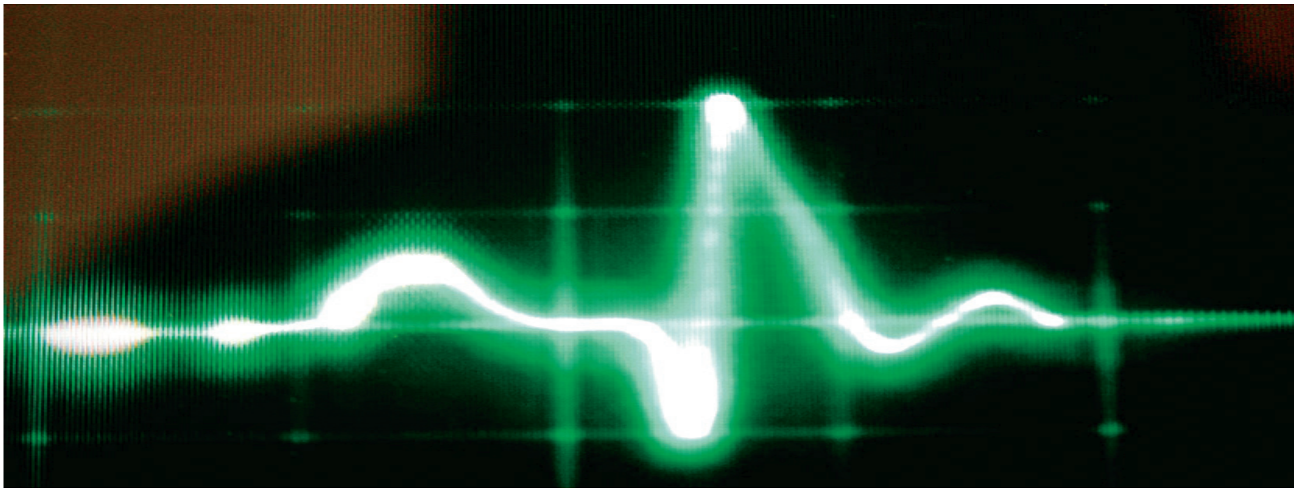
If these concepts are now converted to the terms used in IEEE, the following is seen:

- The rated output is equivalent to specifying the secondary burden. The output power is the square of the rated current times the burden in ohms (Ω), or for rated current of 5 A, 25 times the burden.
- For an IEEE C57.13 current transformer, the allowable error is always 10 percent. However, in IEEE, the secondary burden has a 60-degree impedance angle, whereas in IEC the secondary burden is purely resistive. As a consequence, an IEEE current transformer with a limiting error of 10 percent with the IEEE burden will have a limiting error of 5 percent with the IEC resistive burden. Therefore, in IEC terms, the accuracy is a 5P class rather than 10P.
- For an IEEE C57.13 current transformer, the ALF is always 20.

Now, the IEEE C57.13 relaying accuracy classes and burden data presented in Table 1 earlier in this issue is reviewed, and the secondary terminal voltage column along with the impedance column is extracted, the equivalent IEC accuracies corresponding to the IEEE accuracy classes can be constructed in Table 2.

Table 2: IEC protective accuracy vs. IEEE relay accuracy (for 5 A CTs)

Secondary terminal voltage (V)	Secondary burden designation	Impedance (Ω)	IEEE relay accuracy	Equivalent IEC protective accuracy
10	B-0.1	0.1	C10	2.5VA – 5P20
20	B-0.2	0.2	C20	5.0VA – 5P20
50	B-0.5	0.5	C50	12.5VA – 5P20
100	B-1.0	1.0	C100	25VA – 5P20
200	B-2.0	2.0	C200	50VA – 5P20
400	B-4.0	4.0	C400	100VA – 5P20
800	B-8.0	8.0	C800	200VA – 5P20



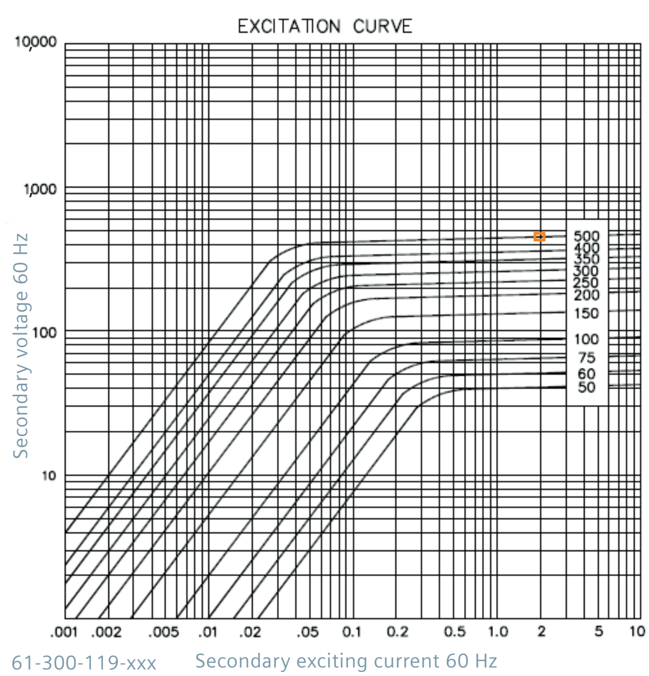
What we also see is that the rated output in IEC is equal to the VA calculated for IEEE C57.13 current transformers, as shown in the last column of the Table 1 in this issue of TechTopics.

1 A CTs as compared to 5 A CTs

How is this altered for a current transformer with 1 A rated secondary current instead of 5 A? In this case, the secondary burden is increased by a factor of $(I_5/I_1)^2 = (5/1)^2 = 25$ from those in the table earlier in this issue of TechTopics. So, for example, a C100 current transformer with 5 A secondary is rated on the basis of a 1 Ω secondary burden, whereas a C100 current transformer with 1 A secondary would be rated on the basis of a 25 Ω secondary burden. The VA output in either case is I^2 x burden, or 25 VA for this example.

The change of rated secondary current also changes the calculation of the C relay accuracy. Consider the 500:1 CT in the secondary excitation curve shown in Figure 2.

Figure 2: Secondary excitation curve example



The secondary terminal voltage is determined at 20 times rated secondary current, or 20 A for a CT with 1 A secondary. An error current of 10 percent would thus be 2 A. The voltage from the curve at 2 A excitation current is about 570 V. The secondary resistance of the CT is 3.92 Ω. The voltage "lost" in the CT itself is 20 A x 3.92 Ω ~ 79 V. Therefore, the accuracy class of this current transformer is 570 – 79 = 491; for conservatism, we rate this current transformer at C400 relay accuracy. The secondary burden for a 1 A current transformer with C400 relaying accuracy would be 4 Ω x $(5\text{ A}/1\text{ A})^2$ = 100 Ω.

This illustrates that the relay accuracy number for current transformers with 1 A secondary is rather significantly different from that of a similar current transformer with 5 A secondary.

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