MORRISON HERSHFIELD

Current Transformers for Protection Relays

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This **White Paper** describes the technical characteristics of Class C current transformers when used in protection relay applications.

Authored by:
Michael Mosman
Principal
Vice President and Senior Electrical Engineer

For more information contact:

Morrison Hershfield
1500 S Edgewood Street | Baltimore, MD 21227
Phone: 410-525-0010

www.morrisonhershfield.com

Current Transformers for Protection Relays

Current transformers for protection relays, as opposed to those use strictly for metering purposes, have an IEEE standard classification. There are two classifications, Class T CTs and Class C CTs. The ‘T’ stands for “tested” and the ‘C’ stands for “computed”.

Class T CTs generally have a high level of flux leakage (due to the way the primary is configured as multiple windings around the core) which requires the performance of the CT to be tested. Class T CTs are rarely used for commercial power system protection relays, and they will not be discussed further here.

Class C CTs have negligible flux leakage because the primary passes only once through the core “window” and the secondary is wound around the entire length of the core. The performance of Class C CTs can be derived (computed) from the manufacturer’s published data for the CT. Nearly all CTs used for power protection are Class C.

A CT is merely a transformer that is current excited instead of voltage excited. Figure 1 shows an equivalent circuit for a current transformer. It includes an ideal transformer in which the primary is a single-turn winding connected to a current source.

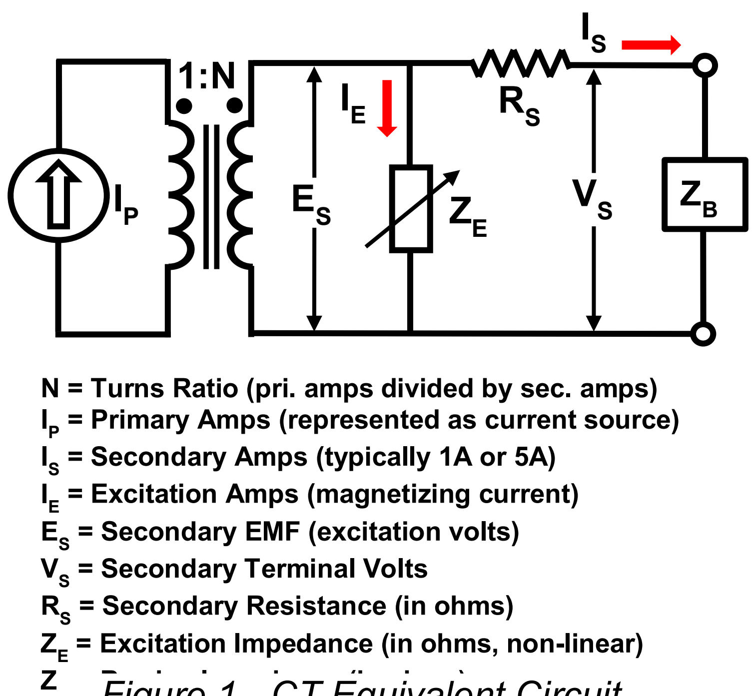
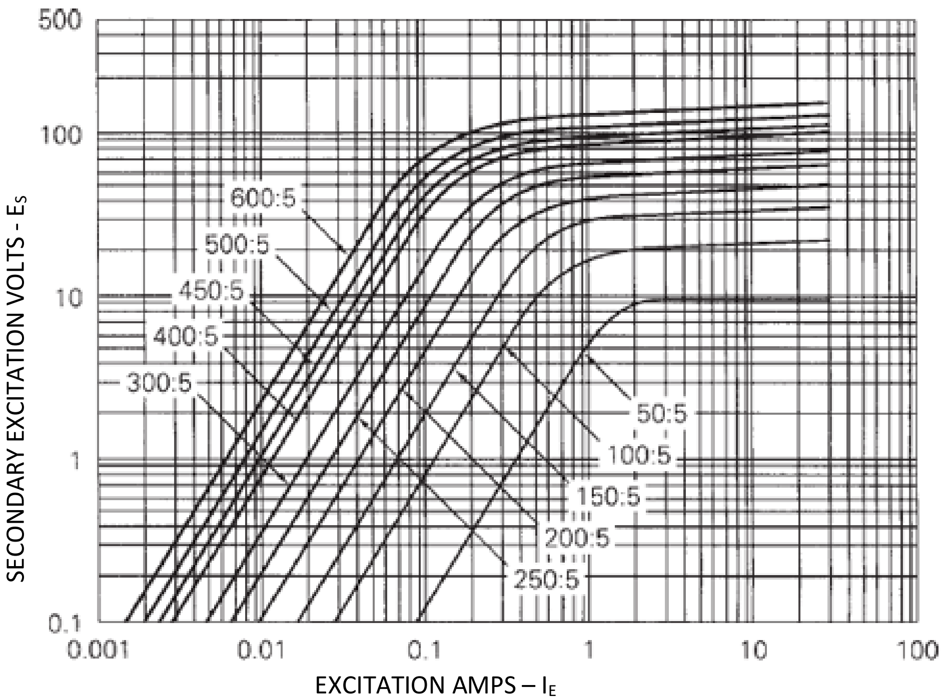


Figure 1 - CT Equivalent Circuit

The primary current I_P induces flux in the core of the CT which produces an electromotive force (EMF), or voltage E_S, in the secondary. The excitation impedance Z_E represents an amalgamation of leakage reactance, eddy current resistance and flux hysteresis losses that acts as a shunt impedance, diverting some current across the ideal transformer secondary. This current (I_E) is called the excitation current, or magnetizing current, and is non-linear. Because Z_E has resistive and reactive components, so does I_E. However, for simplicity I_E is usually considered as an absolute value in ohms, and assumed to be in phase with the secondary terminal current I_S.

The impedance of the wires and relays that are connected to the CT is call the "burden," and is represented in the equivalent circuit as Z_B. This impedance is mostly resistive, so the small reactive component in Z_B is usually ignored.

The relationship between E_S and I_E is found in Excitation Curves provided by the manufacturer of the CT. The manufacturer also provides the secondary resistance R_S for the CT. These data usually appear as a chart showing excitation curves for a family of CTs with different ratios but all with the same C rating. A typical chart of excitation curves is shown in Figure 2.



CT ratio	Secondary resistance Ω
50:5	0.061
100:5	0.082
150:5	0.104
200:5	0.125
250:5	0.146
300:5	0.168
400:5	0.211
450:5	0.230
500:5	0.242
600:5	0.296

Figure 1 – Typical Excitation Curve Chart

The Engineer must make an assessment of the burden resistance in the protection design and choose a CT with performance ratings suitable to support the burden under normal and fault conditions. In general, this amounts to selecting the proper "C" rating.

The "C" Class rating of a protection CT is usually shown next to the CT ratio on drawings and performance charts, and is a value in volts. For example, a CT labeled "600:5 C100" has a ratio N = 30 (600/5) and a "C" rating of 100 volts. This voltage is a measure of the CT's performance under a fault condition. It represents the secondary voltage V_S that the CT is capable of producing while the primary circuit I_P is under fault and the secondary current I_S is 20 times the CT's secondary amps rating. Furthermore, while in this fault condition the "ratio error" of the CT will not exceed 10%. IEEE Standard 37.110 defines the ratio error of a Class C current transformer as I_E/I_S. That means for a CT having a 5A rated secondary, with I_S at 20 x 5A = 100A, I_E will not exceed 100A x 0.1 = 10A.

The ratio error of a CT is basically a measure of the accuracy of the CT. I_E in a CT is current generated within the CT by the primary current that is "lost" and does not produce secondary terminal output current. This manifests itself as a slight difference between the CT's labeled ratio

N and the actual ratio I_P:I_S. The result is that I_P will always be higher than N x I_S by the percentage of ratio error.

The accuracy (ratio error) of a Class C CT can be calculated using the information in the manufacturer's Excitation Curve Chart. For any value of I_S the excitation voltage E_S can be found if the burden Z_B is known:

$E_S = I_S \times (R_S + Z_B)$

From the chart the value of IE can be derived, and from that the error ratio can be calculated. Notice that when Z_B becomes large, so does E_S and, consequently, so does I_E and the ratio error. The minimum "C" rating for a specific protection system CT must be able to support is dependent on the burden Z_B. By definition, the CT under fault must be able to sustain the "C" voltage rating with 100 amps flowing in the secondary terminals. Therefore, the voltage V_S = 100A x $Z_B\Omega$. In the example above, the 600:5 C100 CT would be appropriate for any burden up to 1 ohm (100A x 1Ω = 100V).

It is advisable to check the ratio error with the excitation chart for the CT. The value of ES can be found by adding the voltage drop across the secondary resistance R_S to the secondary voltage V_S. In the example, the 600:5 CT has a stated R_S = 0.296Ω. At 100A the voltage drop is 29.6V and E_S is 100 + 29.6 = 229.6V. On the excitation curve for the 600:5 CT, this value of E_S produces an excitation current I_E is approximately 5 amps. This CT exhibits a ratio error of 5A / 100A + 5%. A ratio error of only 5% indicates this CT is conservatively rated, and a good choice for a relay and leads with 1 ohm burden.

Suppose it was given that a 600:5 C100 CT was already in place, and the maximum burden needed to be determined. The maximum ratio error of 10% prescribes an I_E of 10 amps which corresponds to an E_S of approximately 150 volts. Reducing that by the voltage drop through the 0.296Ω R_S experiencing 100A of I_S indicates that a V_S of approximately 120 volts may still be with ratio accuracy limits. The CT has an effective "C" rating of 120, and would actually work acceptably with a burden up to 1.2 ohms. However, since "C" classifications come in standard voltages (20, 50, 100, 200, 400, 800) they can only be labeled with the highest standard "C" rating that falls below the actual CT capabilities.

Notice that this example has the maximum fault condition occurring above the knee of the excitation curve. This is typical. In fact, high-impedance differential relays (those with internal resistors that purposely raise the burden) are design to trip only when CTs operate in the saturated state, which is why those CTs usually have higher "C" ratings.
One final note: Current transformers with 1A secondary windings have only a 20 x 1A = 20A fault I_S and, therefore, require "C" ratings far below those for 5A CTs. For that reason alone 1A CTs should be seriously considered for complex protection systems.