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DOES YOUR CT MEASURE UP

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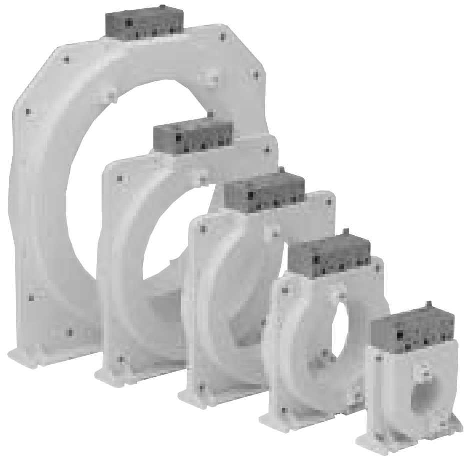
The humble current transformer (CT) is a simple device but not only can it be disappointing in its performance if not selected correctly, it can also shock you. Understand it and treat it with respect and all will be well. While a CT is essentially the same as a voltage transformer (VT) it is the mode of operation that sets it apart.

What's the difference

Let's compare a 100 A to 5 A CT with a 12 V to 240 V VT. Both have a 20:1 ratio so the number of turns on the secondary winding will be 20 times (ignoring errors) that of the primary. If there is a current of 100 A flowing in the primary of each transformer then in the secondary windings there will be 5 A. So what is the difference between the two. In the case of the VT we have just defined both the voltage and current in each winding while for the CT we have only defined the current. The voltage across the windings (again ignoring errors) will depend on the load or burden applied to the secondary. If the burden has a resistance of say 1 ohm then the voltage appearing at the secondary will be V = I x R = 5 x 1= 5 V. So looking at the secondary voltages we have 5 compared to 240. For the design of the transformer this means the number of turns on the VT secondary has to be 240/5 times that of the CT secondary, or the core size needs to be increased by the same ratio, or some combination of both. This is because the required cross section of the transformer core is proportional to the volts per turn.

Current and voltage transformers are therefore much the same. The core cross section and number of turns are proportioned to suit the different operation. In the case of the voltage



transformer the core cross section and number of turns must suit the input voltage while for a current transformer the core must be in proportion to suit the rated output voltage and number of secondary turns.

Selecting a CT for measurement

(a) Accuracy

The accuracy of a CT is influenced by many factors and as with most things the better the performance the higher the price. It is important therefore to match the CT to the application. If the application is to drive a panel meter of 3 % accuracy it is useless to select a CT of 0.1 % accuracy. The other thing to remember is that the burden influences the accuracy. The lower the burden the better the transformation accuracy so it is important to determine the burden.

Australian Standard AS 1675 specifies the maximum permissible errors for different accuracy classes. These are listed below together with the type of applications for which they would be used.

(b) Burden

The load of a current transformer is called the burden and can be

Class <0.1 As a standard for testing other current transformers

Class 0.1 Precision testing

Class 0.2 Precision measurement

Class 0.5 Tariff metering

Class 1 Non-revenue measurement including power and energy

Class 2 General measurements

Class 5 Approximate measurements for indication purposes only

expressed either as a VA load or as an impedance. In the former case the VA is taken to be at the CT nominal secondary current.

For example, a 5 VA burden on a 1 A transformer would have an impedance of 5 ohms:

$$\text{Impedance} = \frac{5}{5^2} = \quad = 5 \text{ ohms}$$

and with a 5 A current transformer:

$$\text{Impedance} = \frac{VA}{I^2} = \frac{5}{1^2}\, 0.2 \text{ ohms}$$

The burden on a CT includes the connected devices, the connecting cables and the impedance of the secondary winding itself. For measurement CTs the winding burden can usually be ignored.

A common problem experienced by CT users is that of the long cable run, ie. extended distance from CT to meter, results in inaccurate current indications of the meter.

Simply the VA rating of the CT must overcome the VA burden of the circuit (including the meter). The following tables will help in determining typical circuit burdens.

Consider a typical circuit run in 2.5 sq mm cable. At 5 amps it only takes 13 metres of wiring to give a burden of 5 VA.

(c) Typical cable burden

Cable diam. [mm]	VA/metre 1A CT	VA/metre 5 A CT
1	0.039	0.970
1.5	0.026	0.654
2.5	0.016	0.392
4	0.010	0.248
6	0.007	0.166

(d) Typical instrument burdens

(e) Methods of overcoming burden

1. Increasing cable size.

2. Generally higher ratio CTs have

Short scales moving iron ammeters 1.1-1.7 VA
240° scale moving iron meters 0.7 VA
Rectified moving coil ammeter 0.2-1.0 VA
Watt/var/phase angle meters 1.0 VA
Maximum demand indicators 2.8 VA
Combined MDI 3.8 VA
Transducers 0.5-5 VA
Electronic systems (with aux. supply) < 0.5 VA

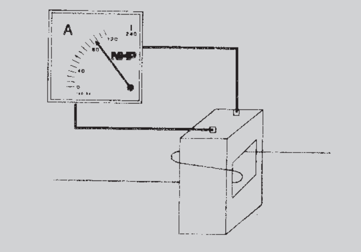
higher burden ratings. If a CT with twice the required ratio is used the primary turns can be doubled to bring the ratio back to what is required.

3. The use of 1 amp secondary CTs increases the VA rating (if the core size is not changed) and greatly reduces the wiring burden.

Fig.1

(f) Selection

If the CT is to drive a simple meter



LOOPED PRIMARY TO MODIFY RATIO

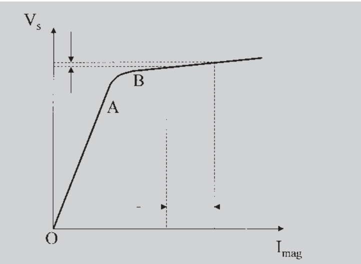
and they are mounted close together then no special selection is required. If the CT ratio is low (less than 200/5) and/or the cable run is long then the cable burden should be calculated and added to the burden of the connected device. The total burden should then be compared to the CT performance. It is common to quote the accuracy at different burdens and at low burdens it can be found that quite an inexpensive CT can have excellent accuracy.

Errors

By far the greatest error is caused by the magnetisation current necessary to produce the magnetic field which in turn produces the secondary voltage which drives the secondary current through the cable and instruments connected in the secondary.

The relationship between the magnetisation current necessary to produce the magnetic field which in turn produces in the secondary (Vs) is not linear but as shown below. Fig.2

The part of the curve from O to A is almost linear but then the curve bends noticeably between A and B. This is known as the KNEE of the curve. Beyond B the curve is almost horizontal and means that



there has to be a very considerable increase in magnetisation current for only a small increase in secondary voltage.

What this means in practical terms is that in the range of A to B the core of the CT is almost fully magnetised and it is extremely difficult to magnetise it further. This phenomenon is known as SATURATION and the magnetisation curve is sometimes also referred to as the SATURATION CURVE. This saturation affects the accuracy of the CT – but it also has an advantage as we shall see later in protecting the secondary circuit.

Taking a closer look, refer fig. 3 we see how some of the errors come about:

1. A portion of the primary current (Ip) is used as magnetisation current (Imag) to provide the magnetic field (ø) in the core to produce secondary voltage (Vs).

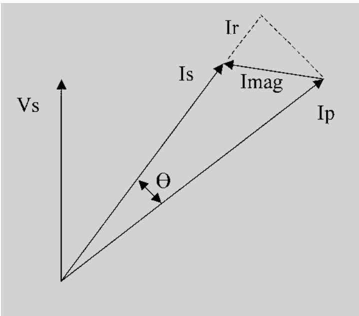
2. The current available to produce primary ampere-turns is therefore reduced by an amount seen in the vector diagram as (Ir) leaving a smaller secondary current (Is)

flowing in the secondary. This reduction is known as CURRENT ERROR and is expressed as a percentage of the theoretical current (measured in rms terms).

3. Because the magnetic circuit is inductive there is a slight phase shift in the secondary current by comparison with the primary current. This is known as PHASE ERROR and seen in the vector diagram as (Ο).

4. Averaging out over a complete cycle the instantaneous differences between the theoretical and the actual values we calculate the COMPOSITE ERROR because it takes into effect both current and phase errors.

Fig. 3 (2)

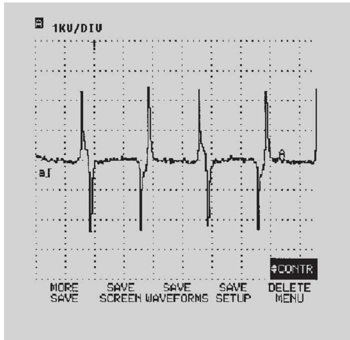


Open-circuited Current Transformer

If the burden is very high then the voltage calculated from I_S x burden will be very large, well above knee-point value and the magnetising current would become significantly large and I_S would be reduced. If the secondary was to become open-circuited, $I_S = 0$, the magnetising current will be such that it will drive the core into saturation. In effect the CT tries to act like a voltage transformer but the core size is inadequate for the applied voltage. The current that flows is determined by the load in the primary circuit. The greatly increased magnetising current will not cause much increase to the average voltage however, the change in flux from zero to the knee-point is not accomplished in 1/4 cycle but in perhaps 1/100 of this time. Thus the rate of change of flux and, therefore, the induced voltage during this period would be about 100 times the knee-point voltage and in some transformers this can translate to thousands of volts. Insulation can be damaged by this high short-duration voltage and overheating caused by the great increase of iron losses.

Fig. 4

CTs are normally tested to



withstand a voltage of 10 times the knee point voltage. The ability to produce high voltages makes CTs very dangerous and there have been fatalities associated with CT circuits. If work is required on the secondary circuit of a CT while primary current is present then the CT secondary terminal should be shorted together.

System Short Circuits

While saturation of the CT core causes accuracy problems, it is desirable in the case of short circuits on the primary side. Say a 200/5 CT is connected in a system with a prospective fault level of 30 kA, without saturation the secondary circuit would deliver 30,000 x 5/200 = 750 A. A 2.5 sq mm cable can only withstand this for about 0.14 seconds. The meter is likely to be damaged in an even shorter time.

CTs are required to be designed to withstand short circuit current levels and most measurement systems rely on the core saturation to restrict the current levels in the secondary circuit.

Protection CTs

CTs designed to operate with over current protection systems are required to operate at current levels up to typically 15 times the normal rated current. Their design requires much larger core sections and/or turns to raise the core saturation level. This in turn increases the cost and the potential to produce high voltage if open circuited. The connected burden is even more critical in selecting a protection CT. With some electronic protection relays with very low burdens it is possible to use a CT designed just for measurement purposes while the older electromechanical style relays require substantial core sections.

Footnote ([2]): Figure 3. based on Fig. JI Appendix J AS1675-1986

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