Application Note

Current Transformers for Protection of Electrical

Protective Current Transformers are designed to measure the actual currents in power systems and to produce proportional currents in their secondary windings which are isolated from the main power circuit . These replica currents are used as in-puts to protective relays which will automatically isolate part of a power circuit.

Satisfactory operation of protective relays can depend on accurate representation of currents ranging from small leakage currents to very high overcurrent's, requiring the protective current transformer to be linear, and therefore below magnetic saturation at values up to perhaps 30 times full load current .

This wide operating range means that protective current transformers require to be constructed with larger cross-sections resulting in heavier cores than equivalent current transformers used for measuring duties. For space and economy reasons, equipment designers should however avoid over-specifying protective current transformers ITL technical staff are always prepared to assist in specifying protective CT's but require some or all of the following information;

- Protected equipment and type of protection.
- Maximum fault level for stability.
- Sensitivity required.
- Type of relay and likely setting.
- Pilot wire resistance, or length of run and pilot wire used.
- Primary conductor diameter or busbar dimensions.
- System voltage level.

CAUTION: RELAY MANUFACTURER'S RECOMMENDATIONS SHOULD ALWAYS BE FOLLOWED

IEC Specification

According to IEC 60044-1 protective current transformers are specified as follows:

Rated Output:
The burden including relay and pilot wires (standard burdens are 2.5,5,75,10, 15 and 30VA)
Accuracy Class:

Accuracy Class	Current error @ rated primary current	Phase displacement @ rated primary current		Composite error @ rated accuracy limit primary current
	%	mins	Centiradians	%
5P	±1	±60	±1.8	**5**
10P	±3			**10**

Accuracy classes are defined as 5P or 10P (limits according to IEC 60044-1)

Accuracy Limit Factor

Accuracy limit Factor is defined as the multiple of rated primary current up to which the transformer will comply with the requirements of 'Composite Error' . Composite Error is the deviation from an ideal CT (as in Current Error), but takes account of harmonics in the secondary current caused by non-linear magnetic conditions through the cycle at higher flux densities.

Standard Accuracy Limit Factors are 5, 10, 15, 20 and 30. The electrical requirements of a protection current transformer can therefore be defined as :

RATIO / VA BURDEN / ACCURACY CLASS / ACCURACY LIMIT FACTOR.

For example: 1600/5, 15VA 5P10

Selection of Accuracy Class & Limit Factor.
Class 5P and 10P protective current transformers are generally used in overcurrent and unrestricted earth leakage protection. With the exception of simple trip relays, the protective device usually has an intentional time delay, thereby ensuring that the severe effect of transients has passed before the relay is called to operate. Protection Current Transformers used for such

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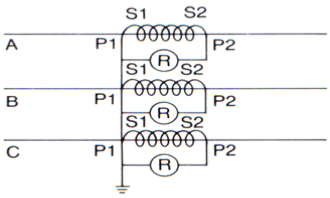
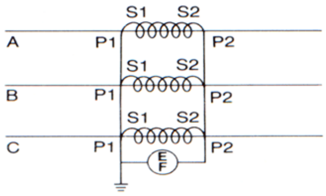
Current Transformers for Protection of Electrical Plant

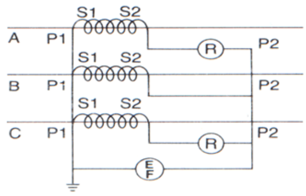
In some systems, it may be sufficient to simply detect a fault and isolate that circuit. However, in more discriminating schemes, it is necessary to ensure that a phase-to-phase fault does not operate the earth fault relay.



Three Phase
Overcurrent Protection



Unrestricted Earth fault Protection
(Detects earth faults on load side of
the CT's)



Combines 3 Phase & Unrestricted
Earth Fault Protection

Phase Fault Stability

Current transformers which are well matched and operating below saturation, will deliver no current to the earth fault relay, since 3-phase currents sum to zero.

If however, the transformers are badly matched, a spill current will arise which will trip the relay. Similarly, current transformers must operate below the saturation region, since, in a 3 phase system, third harmonics in the secondary are additive through the relay thereby creating instability and erroneously tripping the earth fault relay.

Time Grading

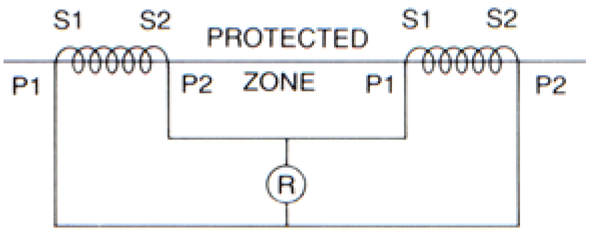
Time lags on relays are set in such a way that a fault in a sub-section will isolate that section of the distribution only. Accurate time grading can be adversely affected by inaccuracy or saturation in the associated current transformer. The following table is intended to show typical examples of CT applications However, in all cases manufacturers recommendations must be followed.

Protective System	CT Secondary	VA	Class
Overcurrent for phase & earth fault	1A 5A	2.5 7.5	10P20 or 5P20 10P20 or 5P20
Unrestricted earth fault	1A 5A	2.5 7.5	
Restricted earth fault	1A or 5A		Class PX, use relay manufacturers formulae
Sensitive earth fault	1A or 5A		Class PX, use relay manufacturers formulae
Distance protection	1A or 5A		Class PX, use relay manufacturers formulae
Differential protection	1A or 5A		Class PX, use relay manufacturers formulae
High impedance differential impedance	1A or 5A		Class PX, use relay manufacturers formulae
High speed feeder protection	1A or 5A		Class PX, use relay manufacturers formulae
Motor protection	1A or 5A		5P10

***Manufacturers recommendations must be followed. VA rating based on lead burdens <1.5VA**

Balanced Forms of Protection

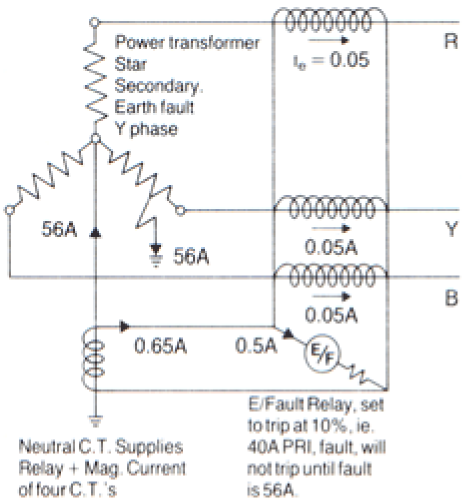
In balanced systems of protection, electrical power is monitored by the protective CTs at two points in the system as shown. The protected zone is between the two CTs If the power out differs from the power in, then a fault has developed within the protected zone and the protection relay will operate. A 'Through Fault' is one outside the protected zone Should such a fault occur, the relay protecting the protected zone will not trip, since the power out will still equal the power in. Numerous different types of balanced systems exist and advice may often have to be obtained from the relay manufacturer. However, in all cases Sensitivity and Stability must be considered.



Sensitivity

Sensitivity is defined as the lowest value of primary fault current, within the protected zone, which will cause the relay to operate. To provide fast operation on an in-zone fault, the current transformer should have a 'Knee-Point Voltage' at least twice the setting voltage of the relay.

The 'Knee Point Voltage' (Vkp) is defined as the secondary voltage at which an increase of 10% produces an increase in magnetising current of 50%. It is the secondary voltage above which the CT is near magnetic saturation.
Differential relays may be set to a required sensitivity but will operate at some higher value depending on the magnetising currents of the CTs, for example:



Primary Operating Current (P.O.C) = K (I_r + nI_e) where:
K = CT Ratio
I_r = Relay set current
I_e = CT magnetising current
n = Number of CTs in parallel

The diagram shows a restricted earth fault system with the relay fed from 400/5 CTs. The relay may be set at 10%, but it requires more than 40A to operate the relay since the CT in the faulty phase has to deliver its own magnetising current and that of the other CTs in addition to the relay operating current.

Stability

That quality whereby a protective system remains inoperative under all conditions other than those for which it is designed to operate, i.e. an in-zone fault Stability is defined as the ratio of the maximum through fault current at which the system is stable to nominal full load current. Good quality current transformers will produce linear output to the defined knee-point voltage (Vkp).

Typically,
Vkp = $2I_f (R_s + R_p)$ for stability, where
I_f = max through fault secondary current at stability limit
R_s = CT secondary winding resistance
R_p = loop lead resistance from CT to relay

Transient Effects

Balanced protective systems may use time lag or high speed armature relays. Where high speed relays are used, operation of the relay occurs in the transient region of fault current, which includes the d.c. asymmetrical component. The build up of magnetic flux may therefore be high enough to preclude the possibility of avoiding the saturation region.

The resulting transient instability can fortunately be overcome using some of the following techniques:

a) Relays incorporating capacitors to block the dc asymmetrical component.

b) Biased relays, where dc asymmetrical currents are compensated by anti-phase coils.

c) Stabilising resistors in series with current operated relays, or in parallel with voltage operated relays.
These limit the spill current (or voltage) to a maximum value below the setting value. For series resistors in current operated armature relays.

$$Rs = \frac{\frac{Vkp}{2I_r} - \frac{VA}{I_r}}{I_r}$$

Where:
Rs = value of stabilising resistor in ohms
Vkp = CT knee-point voltage
VA = relay burden (typically 3VA)
I_r = relay setting current

Special Note:
The value of R_s varies with each fault setting. An adjustable resistor is therefore required for optimum results. Often a fixed resistor suitable for mid-setting will suffice.

'Class PX' Protection CT's

Class 5P protection current transformers may be adequate for some balanced systems, however more commonly, the designer will specify a special 'Class PX' Current Transformer (CT) giving the following information.
(a) Turns ratio.
(b) Knee-point voltage Vkp.
(c) Maximum exciting current al Vkp.
(d) CT secondary resistance.

Apparatus	Protective System	Min. Stability Limit (x Rated Current)
Generators & Synchronous Motors	Differential Earth Fault	12.5
	Longitudinal Differential	12.5
Transformers	Differential Earth Fault	16
	Longitudinal Differential	16
Induction Motors	Differential Earth Fault	1.25 x Starting Current
	Differential Earth Fault	1 x Switchgear short-circuit rating

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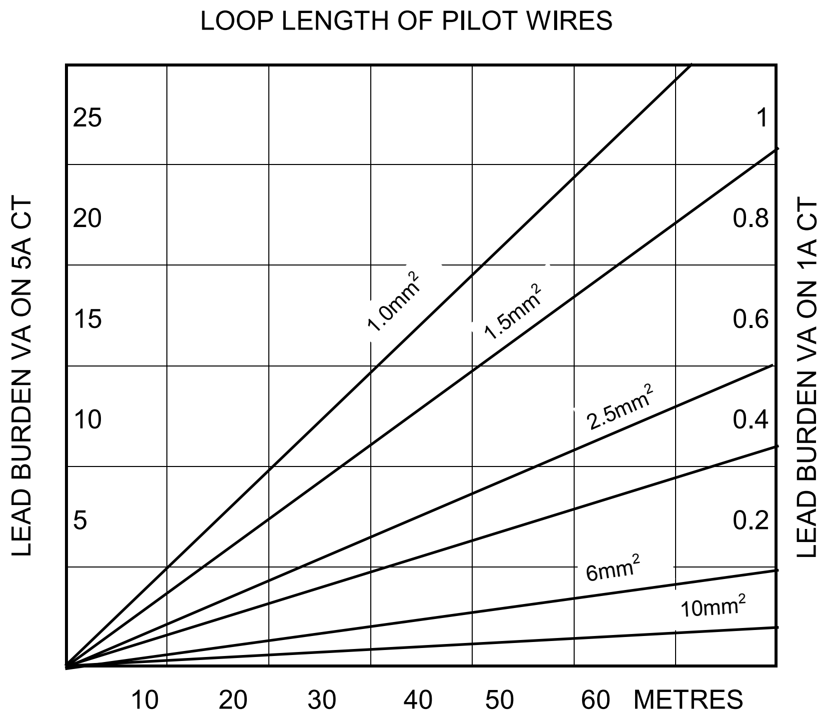
Pilot Wire Burden for 'Class PX' CT's

For 'Class PX' current transformers, the cross section and length of pilot wires can have a significant effect on the required Vkp and therefore the size and cost of the CT. When the relay is located some distance from the CT, the burden is increased by the resistance of the pilot wires. The graph shows the additional burden of pilot leads of various diameters. It should be noted that, by using a 1 amp instrument and CT, the VA burden imposed by the pilot wires is reduced by a factor of 25.



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