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CT Selection for the Medium Voltage Switchgears in Nuclear Power Plants

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1. Introduction

The selection of current transformers must be carried out with care if the protection, instrumentation and measuring systems are to function correctly. Current transformers (CT) for relaying should not saturate at maximum fault currents. Most modern digital relays have been made more able to function correctly in the presence of CT saturation by using adaptive filtering to circumvent CT saturation. The compact design of modern metal-clad switchgear has limited space for the number and size of current transformers that are required to perform satisfactorily in a high-fault-current environment. High rating CTs are physically large and, hence, optimizing CT design to meet the technical performance required while keeping the costs and size within limits needs a fine engineering balance.

This paper elaborates the selection methods of CT for medium voltage switchgears in nuclear power plants; while the main objective is to prevent CT saturation for relaying and reducing CT error for metering.

2. General Criteria for CT Selection

2.1 Current Rating

The rated primary current (I_{pn}) of CT will always be greater than or equal to the service current. The rated thermal short-circuit current (I_{th}) is usually the short-circuit current of the installation and its duration is usually assumed to be 1 sec. All CTs must be able to resist the rated short-circuit current in the primary winding both thermally and dynamically until the malfunction induces shutdown. The secondary circuits of a CT must be suitable for the constraints related to its application for metering or protection purposes [1]. In general, secondary current rating (I_{sn}) of the CT for use in a local situation is 5 A and for use in a remote situation is 1 A.

2.2 Accuracy class (CI)

The accuracy class of a North American CT is given by a letter and secondary voltage rating. The letter designation for the class such as:

Class C: Whereby the ratio error can be calculated, the secondary winding is distributed uniformly, and the leakage flux is negligible. The calculations assume that the exciting current and the burden are in phase. The knee-point voltage is 50- 75% of the accuracy of the terminal voltage.

Class K: This class of CT is the same as class C, but the knee-point voltage must be at least 70% of the secondary terminal voltage rating.

Class T: Ratio error of T-class CT is determined by tests. A T-class CT has an appreciable core flux leakage that contributes to a high ratio error.

The secondary terminal voltage or accuracy voltage rating is the CT secondary voltage that the CT will deliver at 20 times the rated secondary current when connected to a standard burden without exceeding a 10% error. The secondary voltage of a C100 CT is 20 * 5 A * 1.0 ohm (= 100 V). The standard burden of C100 CT is One ohm (Table 2).

3. CT Selection for Phase Connected Equipment

3.1 CT Ratio and Accuracy

The conventional practice, over many years, has been to set the secondary current just under 5 A for the maximum load. This was because instruments were often on the same circuit and had 5 A movements. Following this practice, select the CT ratio of 100:5 (CT ratio=20). This gives a maximum continuous secondary current when the load is 90 A, of I_S = 90/20 = 4.5 A.

Table 1. CT Accuracy Voltage Available in Medium-Voltage Switchgear [2]

CT Ratio	Min. Accuracy Class	Normal Accuracy Class	Accuracy Can be Provided
50:5	C10	C10	C20
75:5	C10	C10	C20
100:5	C10	C10	C20
150:5	C20	C20	C50
200:5	C20	C20	C50
300:5	C20	C50	C100
400:5	C50	C50	C100
600:5	C50	C100	C200
800:5	C50	C100	C200

The rated primary current (I_{pn}) of a 13.8kV MV switchgear feeders in APR 1400 is ranged from 50A to 450A. That means the accuracy class can be C20 to C200 according to Table1 If a motor load of 13.8kV switchgear is 1500 hp and rated current is 49A, a 50:5 CT or 75:5 CT is applicable in terms of CT ratio. And, the CT rated thermal short-circuit current (I_{th}) shall be no less than the rated short-circuit current in the primary winding.

3.2 CT Saturation Problems

The burden of C20 CT is 0.2 Ω and accuracy voltage is 20V (Table 2). If the short circuit current of the bus is 40kA then the voltage developed on the 50:5 CT secondary terminal is;

I_s = 40 kA / 10 = 4,000 A
V_{ef} = 4,000 A x 0.2 Ω = 800 V

Where I_s is the secondary current of current transformer and V_{ef} is the voltage developed on the secondary of the current transformer.

As a result, it will make CT saturation and errors. Instead, select 300:5 CT of which accuracy voltage is 100V then developed voltage is;

I_s = 40 kA / 60 = 666.7 A
V_{ef} = 666.7 A x 0.2 Ω = 133.3V

I_s is close to accuracy voltage 100V. Therefore, no lower than C100 accuracy class CT should be used in the 13.8kV switchgear circuits. Accordingly, CT ratio shall be 300:5 or higher for relaying CT.

Table 2. Standard CT Burden [3, ANSI C57.13, Table 9]

Secondary Voltage	Standard Burden	Imped. (Ω)	Power Factor
10	B-0.1	0.1	0.9
20	B-0.2	0.2	0.9
50	B-0.5	0.5	0.9
100	B-1	1.0	0.5
200	B-2	2.0	0.5
400	B-4	4.0	0.5
800	B-8	8.0	0.5

On the other hand, for metering the rated primary current should not exceed the service current by a factor greater than 1.5 so that the operator read the analog meter accurately. But in the above case the primary current rating (I_{pn}) of the 300:5 CT is more than 6 times of 49A rated current (I_n). At full load, the analog ampere meter will indicate only 16.3 % of full scale.

In addition, the relaying CT must perform with acceptable accuracy at (high) fault values of current, whereas a metering CT must perform well in the lower current range. Thus, a relaying CT must be capable of substantial voltage output at high current, which can stress the meters connected to a protection CT.

4. Coping CT Saturation and Surge Voltage

To resolve the problems brought up in the above section, the following methods are proposed

4.1 Parallel CTs for Small Loads

In figure 1, the load current is 83.7A and 150/5 CT is appropriate in terms of CT ratio. But 150/5 C50 CT will develop the secondary voltage at maximum fault current 40kA;

I_s = 40 kA / 30 = 1,333 A
V_{ef} = 1,333 A x 0.5 Ω = 666.7 V

However, If apply parallel CT as shown in Figure 1, the secondary voltage of 300/5 C100 CT at maximum fault current 40kA;

I_s = 40 kA / 60 = 666.7 A
V_{ef} = 666.7 A x 1 Ω = 666.7 V

By applying parallel CT, it is possible to increase CT accuracy voltage from 50V to 100V without reducing relay input current.

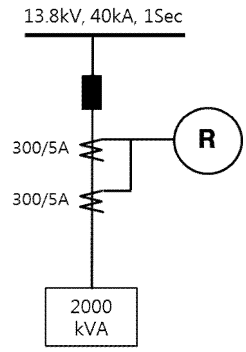


Fig. 1. Parallel CT connection for small size load feeder

4.2 High Ratio Standard CT for Digital Relays

The higher CT ratio the higher saturation voltage as it is shown in Figure 2. Since high CT ratio CTs are recommended for high fault current circuit.

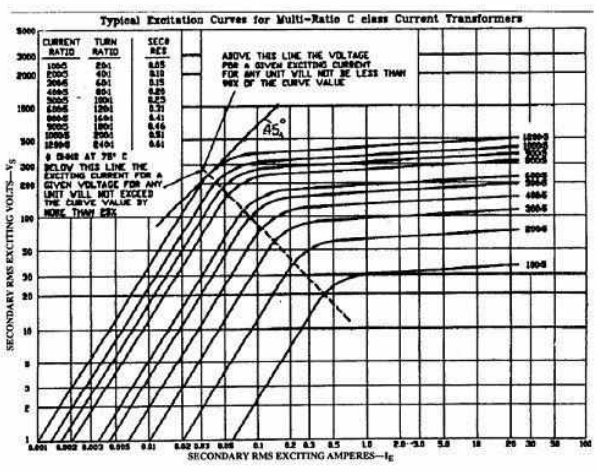


Fig. 2. Typical excitation curves for multi-ratio C or K class current transformers with nongapped cores [4]

Recently in a nuclear power plant project, a standard ratio CT was used for small load feeders. All CTs of which ratio is equal or less than 400:5 in the conventional design were replaced by 400:5 CT with the integrated digital relays. By doing so saturation problem in low ratio CT was mitigated. In terms of metering, the accuracy of digital current meter is ±0.1% of rated current at 0.1 to 2.0 times of CT rating and, ±1.0% of reading at the current greater than 2 times of CT rating. If the rating of a load is smaller than 1,000kVA at 13.8kV, the full load current is lower than 10% of 400/5 CT. In that case, current meter error is not guaranteed by the manufacturer. To resolve this problem an interposing CT is proposed as described in Section 4.3.

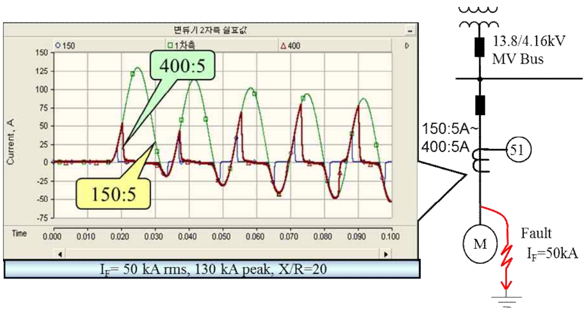
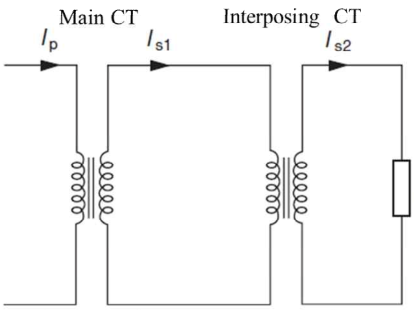


Fig. 3. CT secondary current when short circuit fault occurs in the primary circuit

4.3 Interposing CT for Isolation and Current Balancing

The method of avoiding surge voltage produced by high fault current, if a shared CT should be used, is to connect a metering-class interposing CT after the protection circuit and use that to feed the metering circuit [5].



Main CT ratio 400/5A
Required ratio 50/5A
Interposing CT ratio 0.625/5A
Final Ratio 50/5A

Fig. 4. Interposing CT for meter in a relay and meter shared CT

If the high ratio is selected for the main CT against a low load current, interposing CTs may be used across the main CT to reduce the ratio effectively and satisfactorily cater to the rated current requirement of the burden [6]. The CTs are interposed between the main CT and the burden (Load) so that the secondary current of the main CT is adjusted as required by the burden. Interposing CTs are equipped with a ratio that can be selected by the user to achieve the balance required.

5. Conclusion

As described in the introduction, the main objective of this paper is to explore the CT selection methods for the design of medium voltage switchgears in nuclear power plants. Basically accuracy class of relaying CT and metering CT are different that because relaying CT pickup a fault current and metering CT measure a normal current. It means that the dedicated CT is required for relays and meters. However, nowadays CT is shared by digital type relay and meters integrated.

In that point, a CT should be selected to do not make CT saturation in the expected fault current and also do not sacrifice accuracy of the meter. To satisfy such requirements three methods; parallel CTs, high ratio standard CT, and interposing CT were proposed. Former two methods are adopted in the field as required but the interposing CT method is scarcely used in the nuclear power plant. To improve relaying and metering performance and enhance the reliability of electric power distribution system the interposing CT for metering should be considered for small loads in medium voltage switchgears at the same time with a review of CT saturation problem.

ACKNOWLEDGMENTS

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