



SELECTION AND PROTECTION OF CURRENT TRANSFORMERS FOR USE IN SHUNT CAPACITOR BANKS

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The factors considered in selecting the voltage and current ratings of current transformers used in shunt capacitor installations are discussed and application guidelines are suggested. The protection of the primary and secondary are considered and protection recommendations are outlined.

Background

A number of failures of current transformers in shunt capacitor banks have occurred due to misapplication. Some of the factors involved in the application of CT's on shunt capacitor banks may not be readily apparent. The purpose of this paper is to outline some of the principal factors involved and suggest application guidelines.

Selection of Voltage and Current Rating

Both normal line to ground voltage and BIL are considered in selecting the voltage rating. The CT thermal rating should be equal to or greater than the actual current, including harmonics, expected in the CT. A suggested normal application guideline is given in Figure 1.

The voltage rating for CT's at the line end of a grounded wye bank and all CT's on ungrounded banks is based on the same factors as CT's used elsewhere on the system, i.e., system operating voltage and BIL.

The voltage rating for CT's used at the neutral end of grounded wye capacitor banks is based on impulse considerations. It is suggested that the CT rating should be greater than or equal to about .2 times the system line to line voltage. This is not a precise value based on highly predictable voltages and established margins. It is, rather, a hopefully conservative application factor based on a number of considerations.

The voltage difference between the primary and secondary of the current transformer is not easy to predict for transient conditions. The secondary may be grounded at a point remote from the CT; the CT is usually mounted some distance above the ground mat, and even the ground mat will not have uniform potential under transient conditions. Perhaps the iron in the elevating structure will have an effect on the voltage drop in the ground wire. Differences in substation construction would be expected to significantly affect the primary-secondary voltage.

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There are several factors which suggest using a large factor of safety in applying this current transformer:

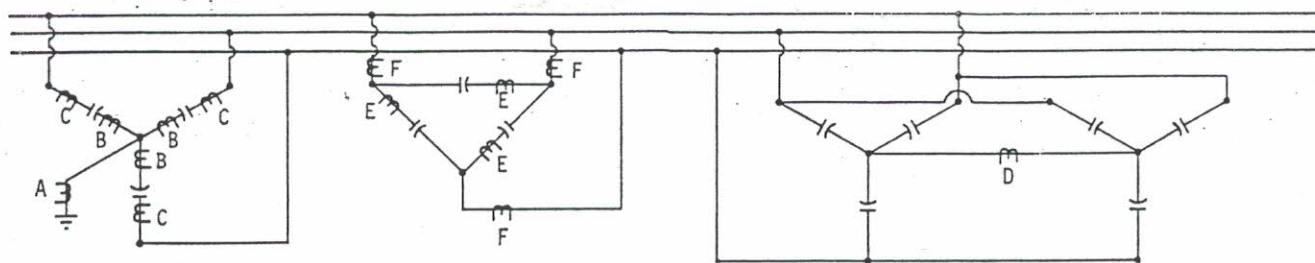
1. The uncertainty in predicting the primary-secondary voltage.
2. The frequency of switching, which may result in a large number of transients over the life of the installation.
3. The failures which have been experienced.
4. The undesirability of putting overvoltage protection across the line to ground insulation of the CT.

A simplified analysis would suggest that the maximum line to ground voltage to be experienced by the CT might be as much as one-half of the system crest line to ground voltage. This might occur for a bus to ground fault near the capacitor bank, where perhaps one-half of the applied voltage would appear between the CT and "ground". For a 138 kV system the crest line to ground voltage is 113 kV, one-half of this would be 57 kV. . . this would suggest that a 15 kV, 110 kV B.I.L. CT should operate satisfactorily. On the other hand, some users have experienced failures of 15 kV CT's in the neutral of 138 kV capacitor banks; perhaps there are sources of higher and lower voltages.

The use of a higher voltage CT would improve the factor of safety for induced voltage surges. Since the lowest voltage at which 15 kV CT's have apparently had problems is about 138 kV, this suggests that this is the first voltage at which a CT rating higher than 15 kV may be required. The next available rating is 25 kV, 25 kV divided by 138 kV suggests an application factor of .2; an application factor which can be used for extrapolating to higher and lower voltages.

There are some other factors which suggest that this application factor of .2 may not be excessively conservative:

1. A full system rated voltage CT would be required for a bus CT, in order to be able to withstand system transients. For very high frequency transients, the capacitor can be considered to be a short circuit; the percent of system transient voltage appearing on the neutral CT is determined by the length of conductor from the bus to ground. Approximately, this percent voltage would be the length of conductor from ground to the CT divided by the length of conductor from ground to the bus, and multiplied by 100. For many installations this would suggest an application factor of about .2 (or slightly higher).
2. What about an occasional switching accident on the capacitor bank? The voltage occurring at the CT for a restrike or closing on an already charged bank might damage a CT with too low a voltage rating.



NORMAL CT APPLICATION

	<u>Ungrounded</u>			<u>Grounded</u>			<u>Delta</u>	
	<u>B</u>	<u>C</u>	<u>D</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>E</u>	<u>F</u>
Voltage Rating	V	V	V	.2V	.2V	V	V	V
Current (Thermal) Rating	1.25I	1.25I	(2)	.5I	1.35I	1.35I	.72I ⁽¹⁾	1.25I

V = system voltage

I = nominal capacitor (phase) current

(1) $.72 \sim 1.25/\sqrt{3}$

(2) Refer to Figure 2

Figure 1. Current Transformer Application Guide

- Perhaps during closing, the second and third phase might close at the most inopportune moment following closing of the first phase. This superposition of transients may cause a large voltage in the ground.

The application factor of .2 seems to be a reasonably conservative value. CT failures would not be expected with CT's applied on this basis. On the other hand, the overall costs for this increase in voltage rating is small, and certainly will be justified by any reduction in failures.

The selection of the thermal (current) rating of the CT is based on the current expected including the effects of overvoltage, overcurrent, and harmonics. The application guidelines in Figure 1 for CT's in the phase of wye connected banks and the phases and legs of delta connected banks are based on the same factors used for normal circuit breaker application.

Harmonic currents and unbalance currents need to be considered in the choice of ratings for CT's applied in the neutral of grounded wye shunt banks.

It is suggested that this CT be rated at least .5 times the nominal phase current. Three percent harmonic voltage on the system will result in 9% harmonic current in each phase and 27% harmonic current in the neutral. In addition to other harmonics, overcapacitance and overvoltage will increase this number. Possible increased heating of the CT due to the higher harmonics suggests a conservative application. The choice of rating also needs to consider the unbalance current which can exist for long periods of time. CT's capable of a thermal duty associated with 50% of the nominal phase capacitor current will normally be adequate.

The current rating of a CT applied in the neutral of an ungrounded wye-wye capacitor bank is determined primarily by the long term unbalance current which can flow between halves of the bank. Figure 2 can be used to estimate this current as a function of series groups. Current transformers chosen on this basis will normally have adequate thermal capability for brief periods of somewhat higher current during individual unit fuse operation.

Primary Protection

Transients associated with switching may cause high voltage to build up across the primary of wound type CT's. Overvoltage protection of the primary is suggested, particularly for CT's rated less than system voltage.

A gap for the protection of the primary of CT's used in shunt capacitor applications is illustrated in Figure 3. Its protective characteristic is shown in Figure 4.

Some surge arresters normally used for CT primary protection will be damaged by the high energy associated with the shunt capacitor. The gap illustrated will provide protection for many CT's. The normal low voltage across the CT will allow the gap to clear without the need for valve elements.

The approximate sparkover characteristics illustrated in Figure 4 are for near sea level conditions. At higher altitudes sparkover will be lower. It is not necessary to use a larger spacing at higher altitudes. 3/64" is suggested as a minimum reliable gap regardless of altitude.

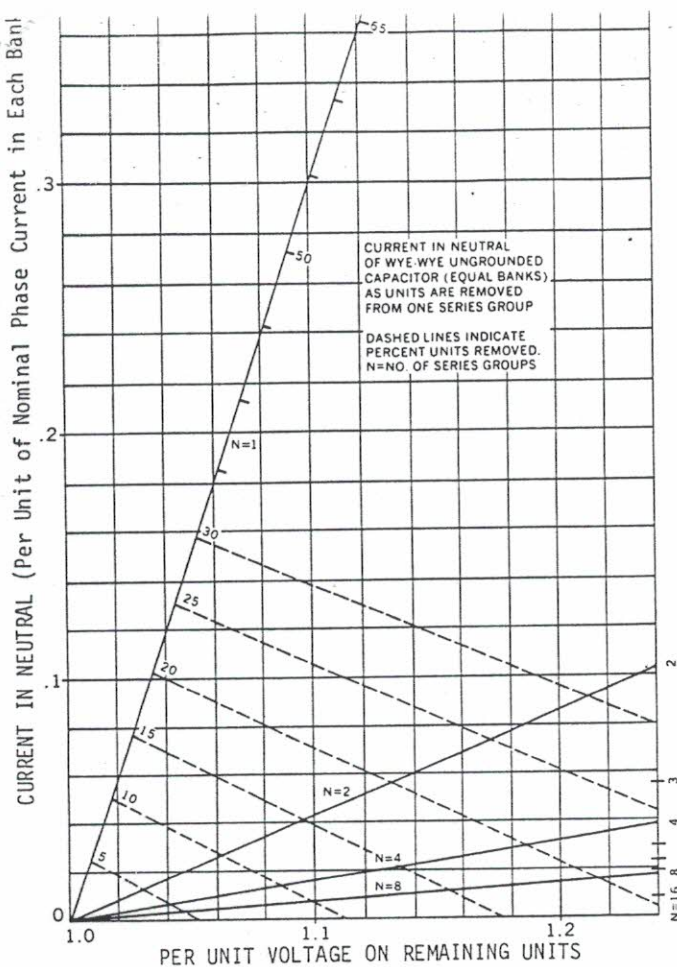


Figure 2 Application Guide for CT in Wye-Wye Bank Neutral

Secondary Protection

The high voltage generated on the secondary of a CT by the high frequency high current transients in the primary make secondary protection prudent. A low voltage gas-filled protector tube (300-500 V RMS breakdown, 50 amp 2 second discharge capability) will protect the CT, wiring and normal electromagnetic relays from damaging over-voltages. Sensitive electronic relays will normally have any additional limiting required at the input.

Conclusion

Recommendations are provided for CT applications in normal utility and industrial power factor correction capacitor installations. Specialized filter, energy storage, etc. installations deserve thorough consideration of the duty imposed on the current transformers.

Acknowledgements

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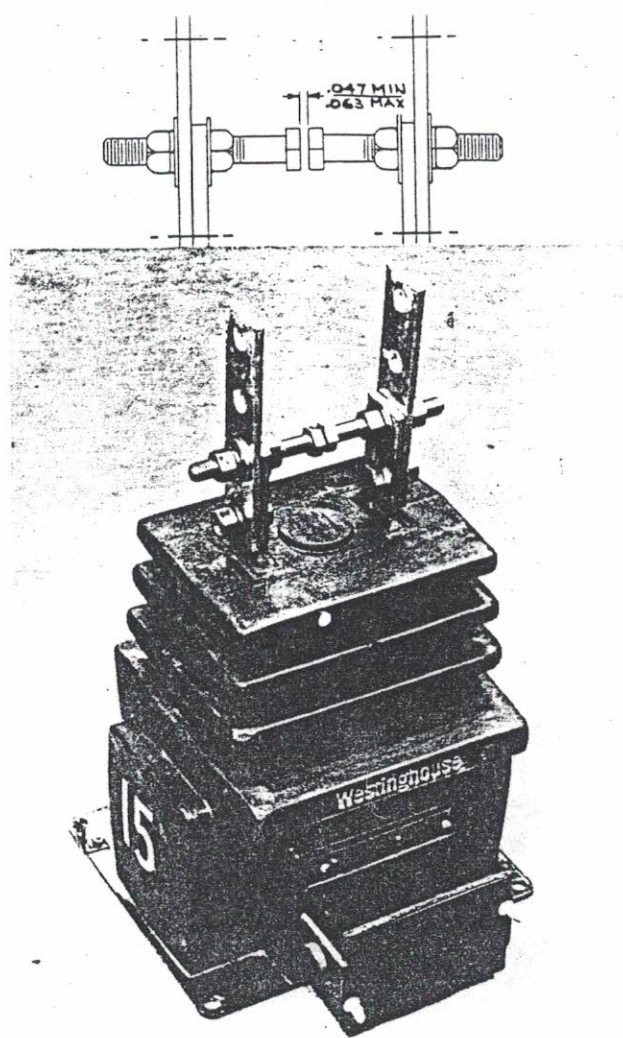


Figure 3 Gap for Protection of Current Transformer Primary

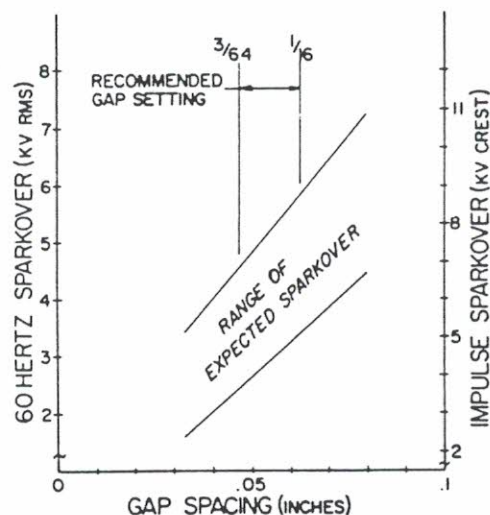


Figure 4 Protective Characteristics of Gap