ONE OPTIMISED NETWORK EQUIPMENT

CT selection for capacitor protection

Introduction

Medium and high voltage capacitor banks require protection against faults in the capacitor units and in the associated equipment such as feeder cables, overhead structures and conductors connecting the various parts of the capacitor bank.

Faults inside capacitor units are generally cleared by internal fuses. The operation of these fuses must be monitored to allow for appropriate alarm and trip instructions to be issued based on voltage stress levels in the capacitor units. The same applies for unfused units with unbalance current providing an indication of the number of shorted elements. Such protection depends on very sensitive detection of relatively small currents in the star points of capacitor banks.

External faults are either phase to ground or phase to phase and require more conventional over current and earth fault detection.

Both of these types of protection require current transformers to provide the necessary detection of current in the primary circuit. Appropriate selection of protection current transformers is therefore essential for safe operation of capacitor banks. This selection must be done to assure correct operation of protection while minimising cost and avoiding any false operation of protection, i.e. ensuring continuity of operation wherever possible.

Note that this article discusses only over current protection (of which unbalance and earth fault are subcategories). Other protection functions that may be applied to capacitor banks such as over- and under voltage, or specific protection against harmonic overloading are not dealt with here.

1 Current transformer ratings

Current transformers are specified in terms of AS 60044.1–2007, a close variation of IEC 61869-1(2007). Due consideration should be given to all the necessary aspects of the standard, including those of insulation coordination and testing. The key features to be specified from a functional perspective are:

1. Primary current, I_P in amperes
2. Short time thermal current, I_{th} in amperes or kilo amperes and duration t in seconds
3. For each secondary winding:
   a) Secondary current, I_S in amperes
   b) Accuracy limit factor, ALF
   c) Accuracy class
   d) Secondary burden, P_S in volt-amperes
4. Voltage withstand level: maximum continuous, short time and impulse withstand level. This aspect of the device rating is determined as part of a substation voltage coordination study and is not discussed further here.

These parameters are normally combined in a compact form of specification, for example a current transformer is described as a 100:5 A, 30 VA 5P10, 25 kA/1s device when it is to be used in an application where the highest thermal current rating is 25 kA for 1 second, the primary current is 100 A, the secondary current is 5 A (the current transformer ratio therefore is 20), the accuracy class is 5P, the accuracy limit factor is 10 and the burden of the secondary circuit is 30 VA.

There is strong interaction between the various ratings that needs to be considered when selecting the current transformer rating, as demonstrated in the following examples:

The current transformer is required to remain within the accuracy class up to the accuracy limit factor, so for example a 100:5 ratio current transformer with ALF of 20, burden of 15 VA and accuracy class 10P can produce at most a voltage at the secondary terminals of:

$$V_{S,Design} \approx \frac{\text{ALF} \times P_S}{I_S} = \frac{20 \times 15}{5} = 60\text{ V}$$

The relationship is approximate as the internal resistance of the CT secondary winding may need to be considered. As another example, a 1 A secondary current transformer with burden 5 VA and ALF of 20 can produce a maximum voltage of

$$V_{S,Design} \approx \frac{\text{ALF} \times P_S}{I_S} = \frac{20 \times 5}{1} = 100\text{ V}$$

across the secondary terminals of the current transformer. If the primary current rating was $I_P = 500$ A, then the ratio error would be less than 10% at $500 \times 20 = 10$ kA.

It is important to remember, especially for unbalance protection, that protection class specifications do not make any statements regarding ratio accuracy at currents lower than nominal current. Ratio errors can be quite large at low current due to the relatively large contribution of excitation current.

2 Selecting primary current

The nominal primary current I_P is selected based on the expected maximum current that can reasonably be expected to flow through the primary terminals, given changing network conditions and making provision for short periods of overload.

For example, if a capacitor bank of 15 Mvar is connected to a 33 kV busbar, and no future upgrades are foreseen for the capacitor bank, the primary current rating is determined from

$$\begin{aligned} I_P &= \frac{\text{Maximum power rating}}{\text{Phase voltage}} \times \text{Safety factor} \\ &= \frac{15 \times 1000}{33\sqrt{3}} \times 1.5 = 393.4\text{ A} \end{aligned}$$

The use of a safety factor is common in all component selection, and in this case is deemed necessary to make provision for short term overloads that are allowed according to capacitor standards, and additional provision for harmonic distortion that can appear continuously in the capacitor bank.

The preferred range of standard primary currents defined in the standard is 10,15, 20, 30, 50 and 75 and their decimal multiples, and one should pick a standard value as close as possible to these. In this case, neither 500 A nor 300 A would be deemed close to the calculated primary current, and the standard primary current of 400 A should be selected.

3 Selection of rated burden

The output rating in VA of the current transformer must be selected so that it exceeds the product of rated secondary current I_S (either 1 A or 5 A) and the impedance of the current circuit, including the current transformer, cabling and protective device.

Modern protection relays have very low internal impedance and hence the burden is determined largely by the cable between the current transformer and the protection relay. The resistance of this conductor is

$$R_S = \frac{\rho l}{A}$$

where ρ is the resistivity of the conductor (17.1 $\mathrm{n}\Omega\cdot\mathrm{m}$ for copper), l is the circuit length in meters, and A is the area of the conductor in square meters.

Since the burden of the cable is determined by I^2R the same cable will have 25 times the burden if used with a 5 A secondary current rating compared to a 1 A rating. Therefore 1 A secondary ratings are normally used when the current transformer is located in a switchyard.

The actual circuit resistance is often not known at the time of selecting current transformers. Assuming that the CT will not be over-burdened (i.e. the rated burden will exceed the actual circuit and internal burden) the total circuit resistance can be inferred from $R_S = P_S/I_S$, for example a CT with burden 5 VA and secondary current rating 5 A has total circuit resistance of 1 Ω.

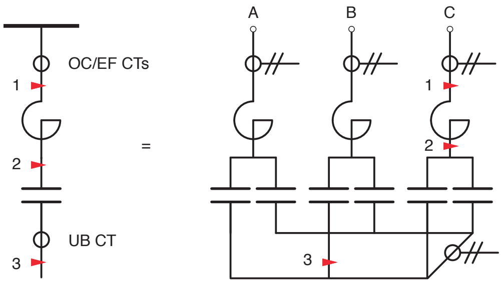
Standard current transformer burdens are 2.5, 5, 10, 15 and 30 VA. Current transformer costs generally increase with increasing burden.

4 Complete example

A 66 kV, 15 Mvar capacitor bank connected as an ungrounded double star requires line side and sensitive unbalance protection. Calculation has shown that the bank should trip before the unbalance current reaches 0.8 A. The fault level at the busbar is 31.5 kA.

The bank is located in an air-insulated switchyard some 80 m away from the control room. Calculations based on the assumption that the conductor will be 4 mm^2, and some allowance for deviations in the cable route results in secondary circuit resistance of R_S = 0.9 Ω.

Two sets of current transformers are required: three identical single phase devices for each phase, on the line side of the capacitor bank, and a single device located in the star point of the capacitor bank. The single line and three phase schematic indicate the locations of the current transformers.



4.1 Line side CTs

The purpose of the line side CTs is to detect over current and earth faults in the feeder between the location of the CT and the capacitor bank, including the capacitor bank, i.e. at any of the fault locations (1, 2 and 3) indicated in the schematic, including line-line faults.

For a secondary current rating of 1 A, the burden is therefore $P_S = I_S^2 \times R_S$ = 0.9 VA, and for a 5 A secondary the burden is 22.5 VA.

The nominal current of the bank is 131 A, and using a safety factor of 1.5 this implies a primary nominal current I_P = 200 A. Given the secondary burden based on conductor resistance only, it appears that a CT with rated burden of 2.5 VA would be more than sufficient. Note that secondary current of 5 A would require a rated burden of 30 VA.

Consider a typical CT described as 200:1, 2.5 VA, 10P10. Such a CT can produce a maximum voltage of

$$V_{S,Design} \approx \frac{\mathrm{ALF} \times P_S}{I_S} = \frac{10 \times 2.5}{1} = 25 \text{ V}$$

across the CT secondary terminals.

A fault current of 31.5 kA implies that the CT will attempt to produce 157.5 A through the CT secondary circuit, and given the burden of 0.9 Ω, a voltage of $157.5 \times 0.9 = 141.75$ V across the terminals. This clearly exceeds the capability of the current transformer and hence any protection relay connected to the CT will not correctly detect a fault.

There are two rating decisions available to correct the situation: the rated burden and the accuracy limit factor. A conversation with CT suppliers will assist in selecting the optimum solution from a cost perspective: in this case it is possible to maintain the ALF of 10 and increase the burden to 15 VA. Then $V_{S,Design}$ becomes 150 V and the CT will allow correct detection of the fault. Alternatively, the ALF can be increased to 30 and the burden increased to 5 VA for the same outcome.

4.2 Unbalance CT

The purpose of the unbalance CTs is to detect very small changes in the capacitance of the bank. As it is connected in the star point of the bank, it only detects the current that will flow as a result of unequal capacitance in any of the six branches of the capacitor bank.

If the capacitor bank star point is not earthed, then no fault in the bank (three-phase, phase-phase, phase-phase-ground, or phase to ground) will cause current to flow in the unbalance CT. If the star point is earthed, then phase-ground or phase-phase-ground faults will cause fault current to flow in the unbalance CT. In the case of an ungrounded bank, if there is simultaneously a fault to ground in the star point and a phase to ground fault in the capacitor bank, then fault current will flow though the unbalance CT.

As this CT is not intended to provide detection of over current and earth faults, it is only necessary to ensure that the CT can withstand such fault currents, and not to be able to detect such currents accurately. The maximum fault current through the unbalance CT can be determined from the fault level at the busbar and taking into consideration the exact location and type of fault, and the effect of the capacitor and reactor impedance.

In this example, a phase-phase-ground fault in the connections between the damping reactors and capacitor bank (location 2 in the figure above) will result in a fault current of approximately 12 kA. Since the bank star point is not grounded, the unbalance current transformer will not detect any current.

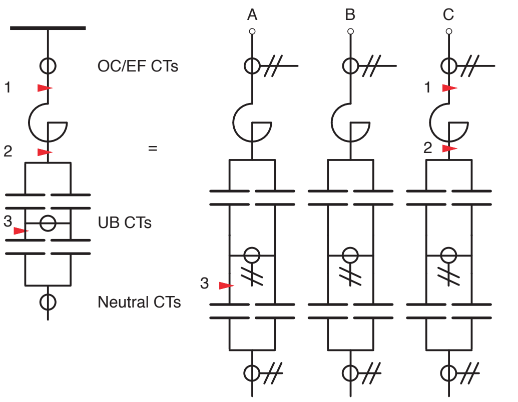
If the bank star point was grounded, the same fault between damping reactor and capacitor current will result in a current of less than 200 A in the unbalance protection CT. It is clear that this CT does not require the same fault rating as the line side devices.

The selection of the unbalance CT ratings is somewhat different from line side over current protection: fault rating is determined by the maximum fault current that the CT could in fact experience, and may be different from the line side ratings. The burden is selected to ensure that the the CT is capable of driving the relatively small unbalance current through the secondary circuit. To ensure reliable, accurate detection of relatively low current the use of measurement class 1 or better CTs is recommended.

The ratio selection is the most important aspect, and should be selected as low as possible to ensure optimum resolution at low current. For a trip current of 0.8 A in the primary circuit the primary current rating I_P should not exceed 5 A. Should a ratio of 5:5 be selected, then the maximum secondary current that should ever flow before a trip instruction is given is 0.8 A. To improve resolution the 1 A input of a protection relay is often selected despite being connected to a 5 A CT secondary, since no more than 1 A should ever occur in this circuit.

4.3 High voltage example

A typical EHV capacitor bank with a large number of units in series in each phase and the bank connected in a grounded H configuration is shown below. Line side and neutral side CTs may be used to provide over current and earth fault protection as well as some form of differential protection.



The unbalance CTs are generally required to register very low unbalance current, with trip levels in the range of 200 mA. CTs with good accuracy in the lower current ranges are therefore required. In the case of a typical 330 kV 160 Mvar capacitor bank with damping reactors of 11 mH and a network fault level of 50 kA, a typical line side CT specification will be 500:1 A, 10P20 5 VA, for the same physical layout as earlier.

It should be noted that fault rating and voltage withstand should be related to the actual fault currents and voltage stresses that may occur at different locations in the bank in order to obtain an optimised solution.

5 Concluding notes

The use of Intelligent Electronic Devices (IEDs) with integrated metering results in conflicting requirements of the current transformer. For the protection application, it should not saturate and be accurate for high current values. For the purpose of metering it should be accurate for currents less than the nominal current and saturate for high currents to protect metering devices. IED burden is now much lower than before and A/D converters saturate at a certain current value. The classical arguments for selecting current transformers have been modified and the use of dual rated metering and protection class current transformers is now common.