Shunt Capacitor Bank Design and Protection Basics

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Shunt Capacitor Bank Design and Protection Basics

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Introduction

Shunt capacitor units are typically used to deliver capacitive reactive compensation or power factor correction. The use of shunt capacitor units has gained popularity because they are quite affordable, simple to install and commission and can be placed anywhere in the electrical distribution system. Their usage has additional advantages on the electrical distribution system such as enhancement of the voltage at the load side, increased voltage regulation, decrease of power losses and decrease or postponement of investments in electrical transmission network. The primary weakness of the shunt capacitor units is that their reactive power generation is relative to the square of the voltage and accordingly when the voltage is low, and the electrical system needs them most, they are delivering the least amount of the reactive power.

The Capacitor Unit and Bank Arrangements

The capacitor unit

The capacitor unit is the essential element of a shunt capacitor bank. The capacitor unit consists of individual capacitor segments, connected in parallel/series arrangements, within a steel case. The internal discharge element is a resistor that decreases the unit residual voltage to 50V or less in 5 min. Capacitor units come in a range of voltage ratings (240 V to 24940V) and ratings (2.5 KVAR to about 1000 KVAR).

Figure 1. Typical capacitor bank arrangement

Shunt capacitor unit features

Protection of shunt capacitor units calls for knowledge of the advantages and restrictions of the capacitor unit and related electrical devices that include: individual capacitor elements, bank switching equipment, fuses, voltage, and current sensing elements. Capacitors are meant to be run at or below their rated voltage and frequency since they are highly sensitive to these parameters; the reactive power produced by a capacitor element is relative to both (KVAR $\approx 2\pi f V^2$). Standard sizes of the capacitors elements made for shunt interconnection to AC electrical systems are given in IEEE Std 18-1992 and Std 1036-1992. These standards also give application guidelines. These standards specify that:

- Shunt capacitor units need to be designed for continuous service up to 110% of rated terminal RMS voltage and a crest voltage that does not exceed $1.2 \times \sqrt{2}$ of rated RMS voltage, considering harmonics but omitting transients. The shunt capacitor units should also be able to withstand 135% of nominal current.
- Shunt capacitors units should not provide less than 100% or more than 115% of rated reactive power at rated sinusoidal voltage and frequency.
- Shunt capacitor units are not supposed to be suited for continuous service at up to 135 % of rated reactive power made by the mixed impacts of:

- Voltage in extra of the nameplate rating at fundamental frequency, but not over 110% of rated RMS voltage.
- Harmonic voltages laid over on the fundamental frequency.
- Reactive power fabrication margin of up to 115% of rated reactive power.

Shunt capacitor bank arrangements

The function of fuses for protection of the shunt capacitor elements and its location (inside the capacitor unit on each element or outside the unit) is a significant topic in the design of shunt capacitor banks. They also impact the failure modality of the capacitor element and impact the setting of the capacitor bank protection. Depending on the usage any of the described arrangements are appropriate for shunt capacitor elements:

- External fuse - A separate fuse, externally installed between the capacitor element and the capacitor bank fuse bus bar, generally protects each shunt capacitor element. The shunt capacitor element can be made for a comparatively high voltage since the external fuse can clear a high-voltage fault. Application of capacitor elements with the greatest possible voltage rating will lead to shunt capacitive unit with the lowest number of series groups.

A fault of a capacitor element welds the foils together and causes short circuit currents to flow between capacitor elements arranged in parallel in the same group. The remaining capacitor elements in the bank stay in operation with an increased voltage across them than before the fault and an increment in capacitor element current. If a second element breaks down the procedure duplicates itself causing an even greater voltage for the remaining elements. Sequential faults within the same bank will make the fuse to trip, unplugging the capacitor element and suggesting the failed one.

Externally fused shunt capacitor units assembled using one or more series groups of parallel-connected capacitor elements per phase as shown in Figure 2. The unbalance signaling level reduces as the number of series groups of capacitors is raised or as the number of capacitor elements in parallel per series group is grown. Nevertheless, the reactive power rating of the separate capacitor element may require being littler since a minimum number of parallel elements are needed to allow the shunt capacitor bank to stay in operation with one fuse or unit out.

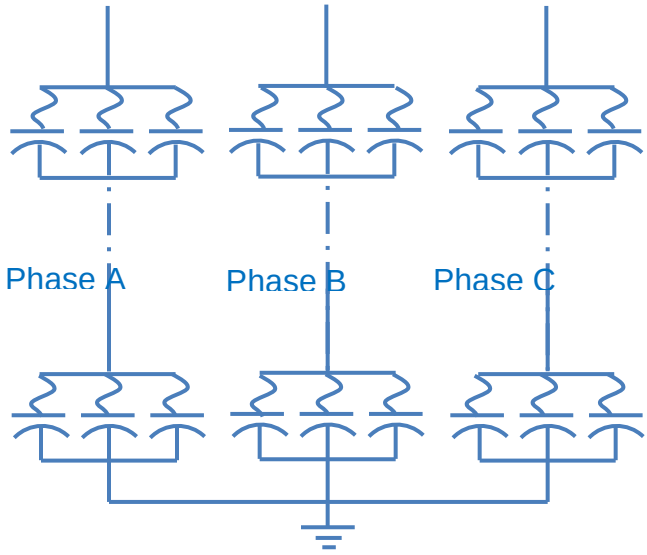

Figure 2. Shunt capacitor bank with external fuses

Shunt capacitor bank with internal fuses

Each capacitor element has fuse inside the capacitor element. The fuse is a basic part of wire enough to limit the current and capsulized in a wrapper that can resist the heat generated by the arc. Upon a capacitor element fault, the fuse takes out the struck element only. The remaining elements, linked in parallel in the same arrangement, stay in operation but with a somewhat increased voltage across them.

Common capacitor bank that uses capacitor elements with internal fuse is shown in Figure 3. Generally, shunt capacitor using capacitor elements with internal fuses are assembled with less capacitor elements in parallel and more series groups of elements than are utilized in banks employing elements with internal fuses. The capacitor elements are typically big because the whole unit is not anticipated to break down.

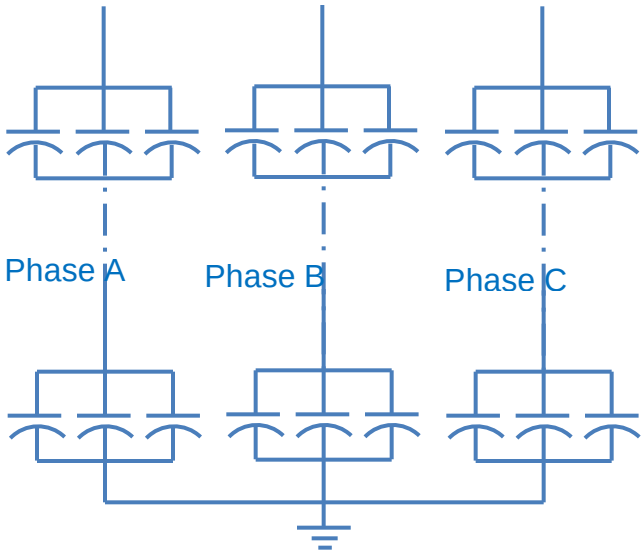

Figure 3. Shunt capacitor bank with internal fuses

Fuseless shunt capacitor units - The capacitor elements for capacitor banks without fuses are same to those with external fuses. To make a bank, capacitor elements are arranged in series chains between phase and neutral, as displayed in Figure 4.

The protection is founded on the capacitor elements (inside the unit) breaking down in a shorted mode, causing short circuit in the group. Once the capacitor element breaks down it welds, and the capacitor unit stays in operation. The voltage across the broken capacitor element is then split among left over capacitor element groups that are connected in the series. For instance, in the case, there are 6 capacitor units connected in series and each unit consists of 8 element groups in series there is a total of 48 element groups connected in series. If one capacitor element breaks down, the element is bridged and the voltage on the left-over elements is 48/47 or around a 2% increment in the voltage. The capacitor bank remains in service; nevertheless, consecutive breakdowns of elements will cause removal of the bank. The design without fuses is not typically used for system voltages lower than about 34.5 kV. The cause is that there shall be more than 10 elements connected in series so that the capacitor bank does not have to be taken away from operation for the breaking down of one element since the voltage across the left-over elements would grow by a factor of about E (E – 1), where E is the number of elements in the chain.

The discharge energy is insignificant since no capacitor units are linked directly in parallel. Additional benefit of units without fuses is that the unbalance protection does not have to be stayed to achieve coordination with the fuses.

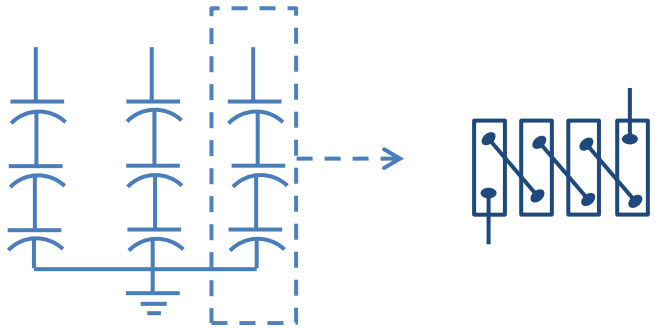

Figure 4. Shunt capacitor bank and series chain without fuses

Unfused Shunt Capacitor Units - Opposite to the fuseless arrangement, where the units are linked in series, the unfused shunt capacitor bank applies a series/parallel arrangement of the capacitor units. The unfused arrangement would typically be utilized on units below 34.5 kV, where series chain of capacitor units is not practical or on higher voltage units with small parallel energy. This arrangement does not need as many capacitor units connected in parallel as bank with external fuses.

Design of the

The protection als of capacitor bank construct systems of series/paralle roup and series linked groups fo

As a universal rul isolation of one capacitor unit in a e more than 110% of rated vol number of series linked groups is th ones staying in operation to a last

The maximum num uled by unlike conditions. When a same parallel group hold some an quency transient current th e fuse holder and the brok

The discharge transie eled capacitors can be serious enough to tear the broken-down unit or the expulsion fuse holder that may end in damage to