High Voltage AC Power Capacitors Metal-Enclosed Capacitor Banks (MECB)

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1. REACTIVE POWER COMPENSATION AND HARMONIC FILTERING

The reactive power required for the creation of the magnetic field in motors, transformers, and conductor lines oscillates continuously between the current generators and the consumers. However, the reactive power has a negative effect on generators, transformers, and conductor lines, causing voltage drops and financial losses due to additional electric heating. A more cost-effective way to provide this reactive power is to produce it by placing capacitors close to its consumers, thus relieving the line between generator and consumer of the transport of the reactive current portion and increasing the network capacity by reducing energy losses, voltage drops, and electricity charges. Capacitors can be connected at different points in the network to improve the power factor of one or more loads, by which we differentiate three types of reactive power compensation: central, group, and individual.

In addition to the above, the presence of non-linear loads such as drives / converters, welding machines, and arc furnaces may lead to the generation of current harmonics, which are injected into the network with the subsequent pollution and distortion of the waveforms on other connected loads. Harmonics are not only present in industrial networks but also in distribution networks, and can easily create many problems for the consumers.

Therefore, the use of harmonic filters containing capacitors in combination with reactors and / or resistances, depending on system requirements, contributes to the improvement of the network's overall power quality, also carrying out power factor correction at the network frequency when such filters are properly sized.

2. METAL-ENCLOSED CAPACITOR BANK (MECB)

Each MV capacitor bank project starts with basic information collection with respect to facility and immediate utility network characteristics. Network rated voltage, operating voltage, frequency, and short circuit availability are necessary for proper capacitor bank design. Information on power delivery transformer ratings (nominal kVA, impedance), the presence of any existing capacitor banks (type and ratings) in the facility or at the utility feeder, and general network topology and operation are necessary as well.

The required reactive power calculations greatly depend on the purpose (objective) of the compensation system. Special applications (i.e. motor starting compensation, highly fluctuating cyclical load compensation) may require special data collection, which is not typically available from general power metering devices. Load harmonic content, together with load variations, is important to set the required capacitor bank type and define its operation parameters.

Vishay metal-enclosed capacitor banks (MECB) combine primary components, secondary control, and protection devices within a compact modular enclosure. The system can be designed as a fixed or switched capacitor bank in several steps. Capacitor banks consist of either single-phase or three-phase capacitor units suitably designed and connected in order to meet the total amount of reactive power required for the specified frequency and voltage. Circuit breakers are also used, depending on customer application and requirements, in conjunction with other equipment and are designed as either SF_6 or vacuum-isolated devices, with the main purpose of capacitor protection.

Capacitor units are impregnated with a biodegradable, non-PCB fluid with high insulation strength to ensure excellent electrical performance. They are equipped with the discharge resistors, suitable to discharge the capacitors from peak rated voltage to less than 75 V within 10 minutes in accordance with the IEC standard, or to less than 50 V within 5 minutes according to IEEE / ANSI standard requirements. The metallic enclosure consists of all necessary internal connections and busbars, insulators, and other fittings, and is made from aluminum or stainless steel with protection up to IP55.

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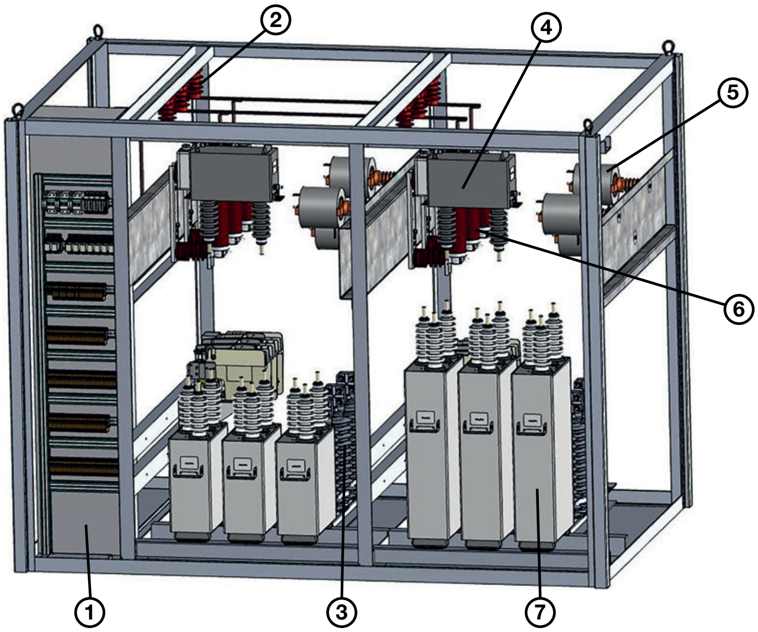

List of equipment:
1. Auxiliary compartment
2. Support insulator
3. Surge arrester
4. Unbalance current transformer
5. Inrush current reactor
6. Protection fuse
7. Capacitor unit

Form of construction with 1-phase capacitor units

3. ADDITIONAL EQUIPMENT FOR PROTECTION

(1) HIGH RUPTURING FUSES (HRC)

HRCs are used to protect capacitor banks and other equipment against short-circuits. Their great advantage is the very fast current limiting operation of just several milliseconds in the event of short-circuit failures. Additionally, they protect capacitors and other components against dynamic thermal effects of such short-circuits in a very effective way. Once the user has selected the general application needed, and knows the size of the bank, the concern is now the proper selection of individual capacitor and fuse sizes.

Selection of HRC Fuse

In order to withstand the higher harmonics and to reduce temperature rise, the rated current of the HRC fuses should be at least two times the capacitor bank rated current.

$I_f = I_c \times 2, A_{mps}$

where,

I_f : rated current of the HRC fuse
I_c : rated current of the capacitor bank

(2) REACTORS

Inrush Current Limiting Reactor

Inrush current reactors reduce the current surge to an acceptable value when switching capacitor stages, helping to reduce overheating of the equipment. They are connected in series with each capacitor stage and enable efficient protection of the capacitor units. In accordance with IEC 60871-1, the inrush current should be limited to 100 times the rated current of the capacitor bank.

When a capacitor bank is initially connected to a voltage source, the transient charging current will flow, attempting to equalize the system voltage and the capacitor voltage. If the two voltages are equal at the time of switching, no inrush current flows. If there is a voltage difference across the switch, the magnitude and frequency of this inrush current can be calculated. The magnitude and frequency of this charging current depends upon the total capacitance and inductance of the circuit as well as magnitude of the applied voltage.

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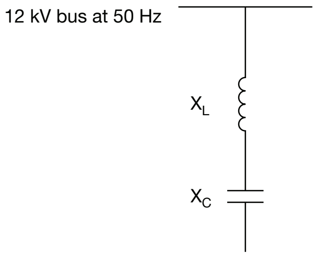
Selection of Inrush Current Reactor

The series reactors in the example below are designed to protect the capacitor banks against inrush currents and have to be selected based on the system requirements with regard to the induced inrush current.



It is then necessary to verify that the selected capacitors and reactors are suitably sized to limit inrush currents to less than a predefined maximum magnitude, which, for example, is 100 times the rated current, according to IEC 60871-1.

The selection of the series reactors is in due consideration of the inrush current requirements of the single-stage capacitor bank switching and also with the worst-case scenario of back to back switching in case of multiple steps.

Condition 1: Single Bank Switching

$$I(\text{inrush}) = U_r \times \sqrt{\left\{\frac{2}{3} \times \frac{C}{L_{sys} + L}\right\}}, A_{peak}$$

The frequency of inrush current is given by the formula:

$$f_i = \frac{1}{2\pi \times \sqrt{[C(L_{sys} + L)]}}, \text{Hz}$$

where,

U_r : rated system voltage
C : capacitance (Farad) of the equivalent stage
L : inductance in series with the switched stage
L_{sys}: source inductance

Condition 2: Back to Back Switching

The formula below applies to cases where n-banks are already connected in the system and then a stage is switched on.

$$I_{ib} = U_r \times \frac{n}{(n+1)} \times \sqrt{\frac{2C}{3L}}, A_{peak}$$

The frequency of inrush current is given by the formula:

$$f_{ib} = \frac{1}{2\pi \times \sqrt{[C(L)]}}, \text{Hz}$$

where,

n: number of banks already connected (ON)

Detuned Reactors

An effective protection against the high level of harmonics that can be present in the network is usually by installing detuned reactors in series with the capacitor units. A detuned reactor will increase the impedance of the capacitor units to the harmonic currents and will also perform the function of a damping reactor.

In practice, filter circuits will be tuned to about 95 % of the frequency of the harmonic current to be absorbed, balancing out network frequency variations and capacitance changes caused by temperature variations. The most cost-effective application of the detuned reactors would be in cases where moderately high and high levels of harmonic currents are present in the network.

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(3) SURGE ARRESTERS

Surge arresters are used to protect the capacitors from overvoltages caused by lightning or switching events and should have low impulse ratios so that a surge incident is bypassed to the ground instead of passing through the capacitors.

The discharged energy absorbed by the arrester is calculated in Joules as shown below:

$$W_C = \frac{Sk}{\omega} \times \left(3 - \frac{U_C^2}{U_S}\right)$$

where,

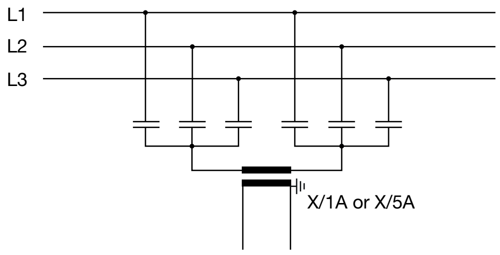
Sk: 3-phase reactive power of the capacitors
U_C: maximum continuous operating voltage
U_S: maximum system voltage phase to phase

(4) CAPACITOR MONITORING

When a short circuit occurs in the winding element of a capacitor unit, gas can form, causing the capacitor case to swell and eventually burst if left uncontrolled. Therefore, the operation of medium and high voltage capacitors shall be constantly monitored and hence ensure safety for people and equipment.

Unbalance or Differential Protection

A protection relay in combination with a current transformer connected between two electrically balanced points can be used to detect failures, such as element breakdowns or group short-circuits, which will cause a current flow through the current transformer, activating the protection relay by triggering an alarm or disconnecting the capacitors if the magnitude of the fault current is higher than a predetermined value.



(5) SAFETY INTERLOCKING SYSTEM

One of the important safety features of the MECBs is the safety interlocking system. The system ensures that access to the capacitor bank's live equipment is prevented until the associated main incoming circuit breaker is open and bank earthing is applied.