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MV CAPACITOR BANKS

(with HARMONIC FILTERS)

Metal-Enclosed or ISO Container-Enclosed

Standards: IEEE Std. 1036, IEC 60871-1

- Stand-alone complete system with ease of installation
- Includes earthing switch to disconnect feeder & earth capacitors
- Includes three phase iron-core/air-core harmonic filter reactors or air-core inrush current limiting reactors
- Optional high pass low inductance resistors
- Vacuum contactors to switch capacitors
- Capacitor fuses included
- Automatic power factor correction controller included
- Over-voltage relay, over-current relay, CTs and VTs included
- Robust structure against corrosion, direct sunlight, rain and harsh environmental conditions
- Touch protections included for safety
- 2,4 kV - 36 kV 50-60 Hz BIL 200 kV
- Double star connection for unbalanced loading
- Optional smoke detector
- Indoor/outdoor modular structure
- Flexible and expendable structure

Areas of Use

- Power factor correction
- Harmonic Filtering
- Over-voltage protection
- Loss mitigation

Capacitor Battery Tests:

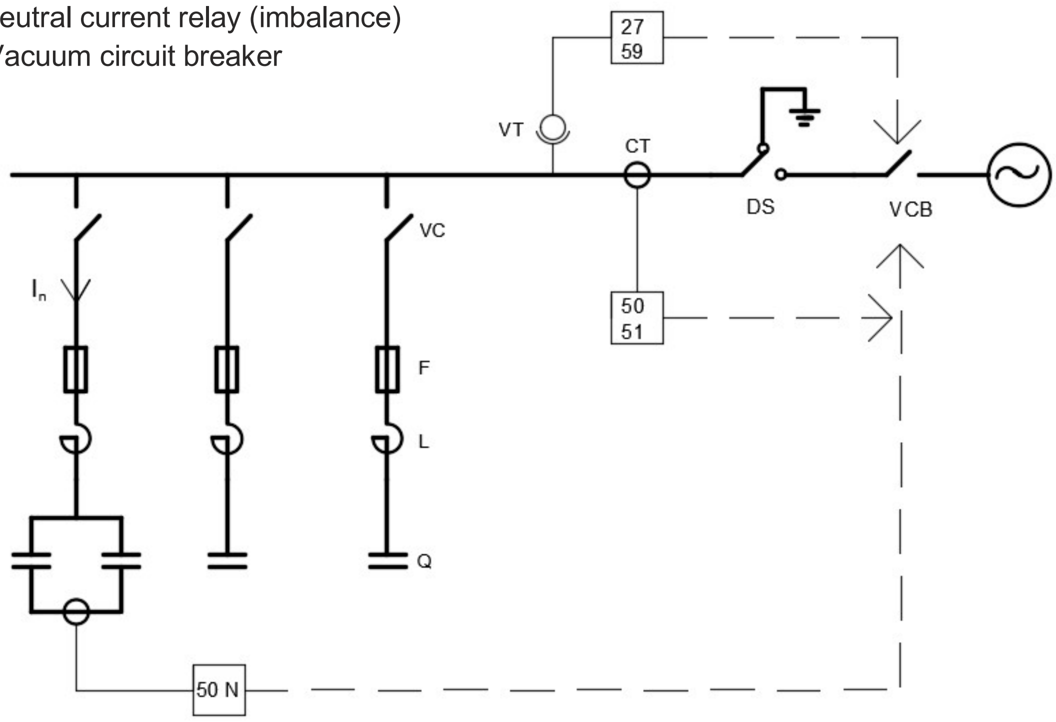
- $4V_n$ (DC) 10 sec. or $2V_n$ (AC) 10 sec. between terminals,
- $\tan(\delta)$ (loss angle) measurement
- Capacitance measurement
- Leakage test

Capacitor Bank Tests:

- Coating thickness measurement
- Capacitance measurement
- Power frequency withstand test
- Insulation resistance measurement
- Full capacity loading test
- Lightning impulse test
- Consult factory for other tests

DS: Earthed disconnector switch
27: Under-voltage relay
59: Over-voltage relay
50/51: Over-current relay
50N: Neutral current relay (imbalance)
VCB: Vacuum circuit breaker

F: Fuse
L: Current limiting (or harmonic filter) reactor
Q: Capacitor bank



Capacitor Bank Protections:

The current of the protection fuses should be selected as $I_f \cong 2I_n$.

51 relay should be set with a delay for 0.1 seconds between $4 - 6I_n$ (short circuit protection)

50 relay should be set with a delay for 4 seconds for $1.3I_n$ (overload protection)

50N relay is recommended to be set with a delay for 4 seconds at the setting of $0.05I_n$ (overload protection)

The value of resistor R $(k\Omega)$ required to be connected across the capacitor to drop the voltage of the capacitor battery with a capacitance of C (μF) to under 75 V after 10 minutes (600 seconds), can be calculated as below:

For Delta connection: $R \leq \dfrac{600\ s}{C\ x\ I_n\left(\frac{\sqrt{2}\ U}{75\ V}\right)}$ For star connection: $R \leq \dfrac{600\ s}{\frac{1}{3}C\ x\ I_n\left(\frac{\sqrt{2}\ U}{75\ V}\right)}$

U: System voltage (V)

I_n: Capacitor nominal current (A)

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Inrush Current (I_C) Calculation When a Single Battery is Connected to the Circuit

U: Phase-Neutral voltage (V)

X_c : Phase-Neutral capacitive reactance (Ω)

X_L : Total inductive reactance between batteries (Ω)

$Q;\ Q_1;\ Q_2$: Battery powers (kVAr)

S_{SC}: Nominal power of the transformer (kVA)

S_{SC}: Short circuit power (kVA) at the point where the capacitors are connected

I_N : Nominal current (A_{rms}) of the battery.

I_{SC} : Short circuit current (A_{rms}) at the point where the capacitor bank is connected.

Z_{SC} : Short circuit impedance of the transformer (%)

$$I_C \cong I_N\sqrt{2\frac{S_{SC}}{Q}} = 1.41\sqrt{I_{SC}\ x\ I_N}\ \ (A_{peak}) \qquad S_{SC} = \frac{S}{Z_{SC}}\ (kVA)$$

I_C **:** The peak value of the initial charging current (A_{peak})

The value of the inductor to be connected in series with the capacitor to limit the inrush current down to $I_C \le 100 I_N$:

$$L = \frac{U^2}{2\pi f}\left[\frac{200}{Q}.\frac{10^6}{S_{SC}}\right]\ (\mu H)$$

Example:

Given than:

$\boldsymbol{Q = 200\ kVAr}$ $\boldsymbol{U = 5000\ V\ \ ph - ph}$

$\boldsymbol{S = 1000\ kVA}$ $\boldsymbol{Z = 5\%}$

Inrush current $I_C \cong I_N\sqrt{2\frac{S_{SC}}{Q}}$

$$I_N = \frac{Q}{\sqrt{3}.U} = \frac{200}{\sqrt{3}x5} = 23\ A_{rms}$$

$$S_{SC} = \frac{S}{Z_{SC}} = \frac{1000}{5/100} = 20.000\ \ kVA$$

$$I_C = 23\sqrt{2\frac{20.000}{200}} = 325\ A < 100\ x\ 23\ A$$

Inrush current limiting is not required in this specific example.

Inrush Current (I_C) Calculation When (n+1) Number of Capacitor Batteries are Connected in Parallel:

When (n) number batteries are energized, (n+1)st step will be energized.

$Q\ (kVAr)$: Power of a single step battery
$U\ (kV)$: Grid voltage (phase to phase)
$\omega\ (rad/s)$: 2.π.f
$C\ (\mu F)$: Capacitance of the capacitor
$I\ (\mu H/m)$: Inductance of bars and/or cables between the capacitor batteries
$f_r\ (Hz)$: Resonance frequency
$L\ (\mu H)$: Inrush reactor connected in series to the battery
$I_C\ (A)$: The peak value of the initial charging current
$I_N\ (A_{rms})$: Nominal current of the battery

$$Q = U^2.C.\omega = \sqrt{3}.U.I_N$$

$$I_C = \sqrt{\frac{2}{3}}.U.\frac{n}{n+1}.\sqrt{\frac{C}{I}}$$

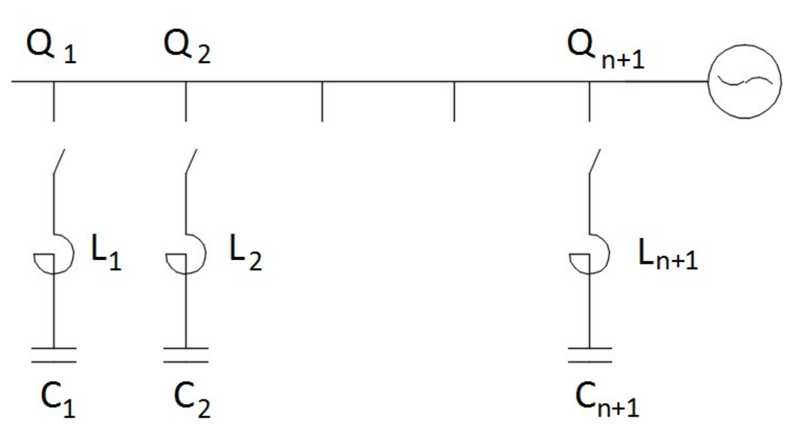
$$f_r = \frac{1}{2\pi.\sqrt{I.C}}$$

The required reactor to satisfy the expression $I_C \leq 100 I_N$:

$$L\ (\mu H) = \frac{2.10^6}{3}\ x\ \frac{Q}{2.\pi.f}\ x\ \left(\frac{n}{n+1}\right)^2 x\ \frac{1}{(I_C)^2}$$

If inrush reactor (L) is added,

$$I_C = \sqrt{\frac{2.10^6}{3}\ x\ \frac{Q}{2.\pi.f}\ x\ \left(\frac{n}{n+1}\right)^2 x\ \frac{1}{L}}$$



Example:

For a capacitor bank with 0,5 μH/m inductance with 5 meters long busbar and/or cable, U=5000 V (phase to phase) with (n+1) = 3 steps, each of which has Q = 200 kVAr power;

- $I_N = \frac{Q}{\sqrt{3}.U} = \frac{200}{1.73 \text{ x } 5} = 23\ A_{rms}$

  $C = \sqrt{3}.\frac{U.I_N}{U^2.2.\pi.f} = 1{,}73\ .\frac{23.5000}{5000^2.314} = 25{,}3x10^{-6}$

  $C = 25{,}3\ \mu F$

  Inrush current $I_C = \sqrt{\frac{2}{3}}.U.\frac{n}{n+1}.\sqrt{\frac{C}{I}}$

- $I_C = 0{,}81\ .5000.\frac{2}{3}\ .\sqrt{\frac{25{,}3}{0{,}5\ .5}}\quad =>$

  $I_C = 8589\ A_p = 8{,}59\ kA\ \geq 100\ x\ 23\ A$ Reactor required!

- Reactor inductance L(μH)

  $L\ \geq \frac{2.10^6}{3}\ x \frac{Q.10^{-3}}{\omega}\ x \left(\frac{n}{n+1}\right)^2 x \frac{1}{(I_C)^2}$

  $= 2.10^6\ .\frac{0{,}2}{2.\pi.50}\ .\left(\frac{2}{3}\right)^2.\frac{1}{(8590)^2} = 7{,}67\ \mu H$

If 50 μH reactor is connected instead of 7,67 μH, then the inrush current will be:

$$I_C = \sqrt{\frac{2}{3}}\ x5000\ x \frac{2}{3} x \sqrt{\frac{25{,}3}{50}} = 1935\ A_p$$

- Resonance frequency $f_r = \frac{1}{2\pi\sqrt{L.C}}$

  $= \frac{1}{2\pi\sqrt{50\ .10^{-6}\ .25{,}3\ .10^{-6}}}\ .= 4475\ Hz$

Calculations Related to Capacitor Banks:

In capacitors $I_{max} = 1.3\ I_n$

$V_{max} = 1.1\ V_n$ 12 hours / day

$V_{max} = 1.2\ V_n$ 5 min

$V_{max} = 1.3\ V_n$ 1 min

When a capacitor bank with a power of Q (kVAr) is connected to a system with a short circuit power of S_{sc} (kVA), the resonance frequency is:

$$f_r = f.\sqrt{\frac{X_C}{X_T}} = f.\sqrt{\frac{S_{sc}}{Q}} \qquad (Hz)$$

$$S_{SC} = \frac{S}{Z_{SC}} \text{(kVA)}$$

S: Power (kVA) of the transformer supplying the capacitor

S_{SC}: Short circuit power (kVA) of the transformer supplying the capacitor

Z_{SC}: Short circuit impedance of the transformer supplying the capacitor (%)

Determining the Q_N of the capacitor required in order to provide a capacitive power of Q_s to a system with a voltage of (U_s):

$$Q_N = Q_S\left(\frac{U_N}{U_S}\right)^2$$

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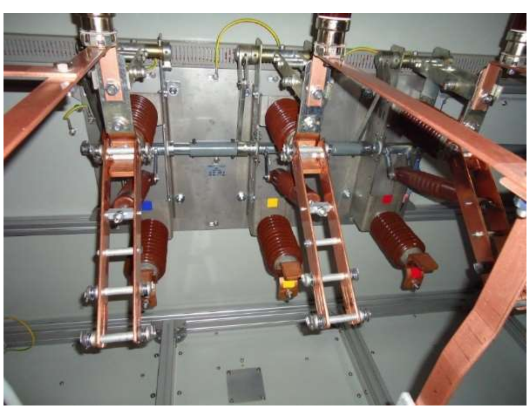
Vacuum circuit breaker at the entry

Equipped with inrush reactor

C.T. for unbalance protection



Disconnector switches for disconnecting and earthing the capacitors

Capacitor protection fuses