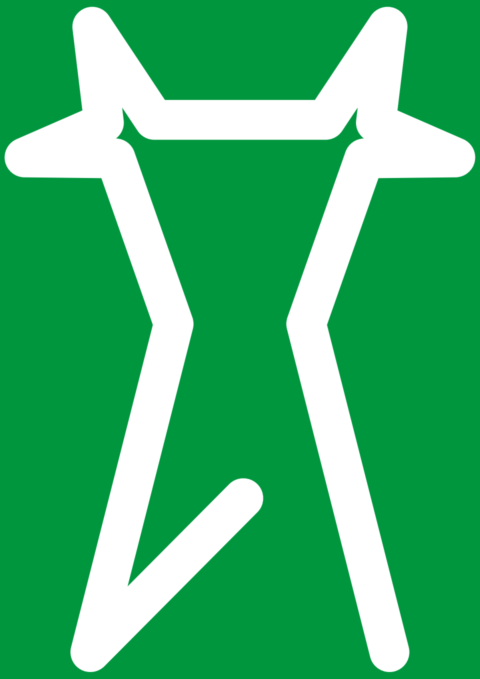
Energy Efficiency Technical Guide

How to select and maintain contactors for capacitor banks?

Energy Efficiency



A solution to improve power factor correction

Contents

Preamble

Definition of power factor

The active power P (kW) is the real power transmitted to loads such as motors, lamps, heaters, computers. The electrical active power is transformed into mechanical power, heat or light.

- In a circuit where the applied r.m.s. voltage is Vrms and the circulating r.m.s. current is Irms, **the apparent power S (kVA)** is:

$$S = V_{rms} \times I_{rms}$$

- The apparent power is **the basis for electrical rating. The power factor λ** is the ratio of the active power P (kW) to the apparent power S (kVA).

$$\lambda = \frac{P\,(kW)}{S\,(kVA)}$$

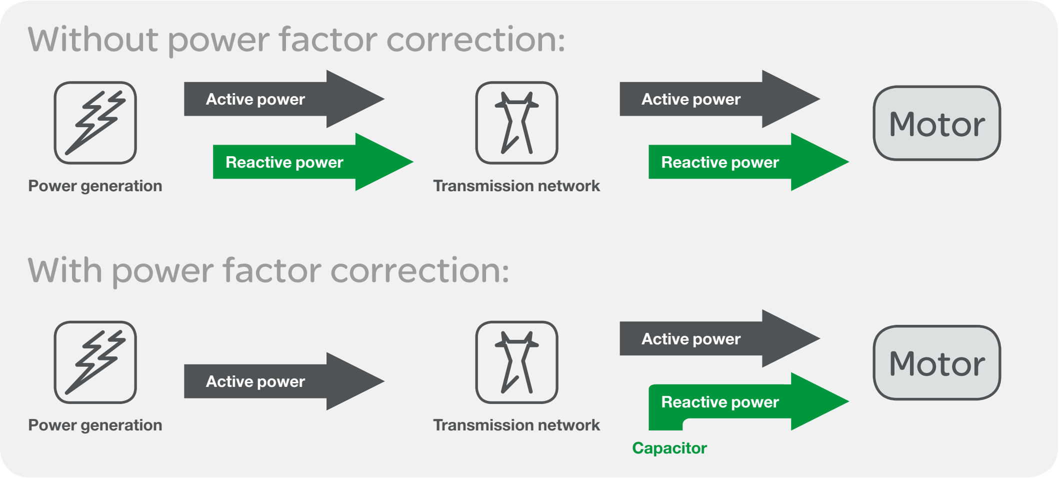
Power Factor

is deteriorated by:

- **Reactive power** (when voltage and current are phase-shifted)
- **Harmonics** (when voltage or current are distorted)

Compensation of reactive power / energy

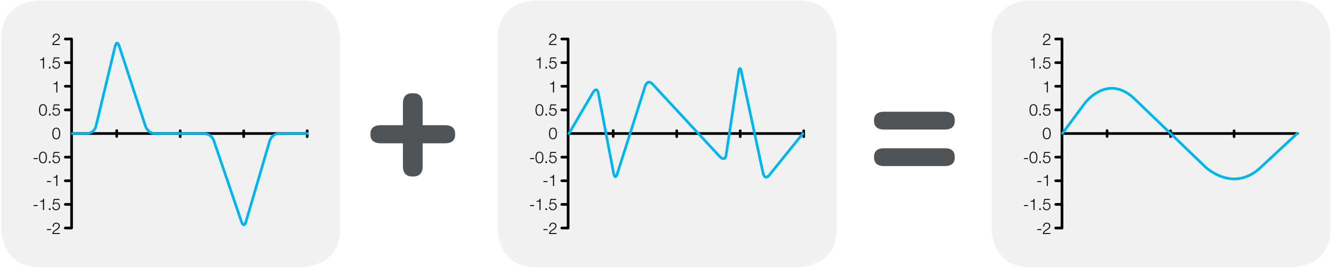
Generally, the electricity bill includes components related to active and reactive power absorbed over time (active and reactive energy). Compensation of reactive energy is typically achieved by producing reactive energy close to the consuming loads, through connection of capacitor banks to the network.
Then, only the active energy has to be supplied by the energy supplier.



Harmonic mitigation

Operation of active harmonic filter is identical to a noise-cancellation headset:

- The active filter injects currents on the network, eliminating the distortion
- Power losses and disturbances are reduced.



Harmonic generators

Active filter

Result

The advantages of reactive power factor correction

Do you need an easy solution to immediately boost your facility's energy efficiency and productivity?

Power factor correction helps lower operating and capital costs and can provide a very quick return on investments:

- **Reduce capital expense by up to 30%**

Optimise electrical system capacity, avoid oversizing and limit redundant capacity.

- **Reduce reactive energy billing penalties and lower operating expenses by up to 10%**

Boost the power factor to lower utility bills and reduce losses in transformers and conductors.

- **Reduce energy losses by up to 30%**

Optimise power consumption, reduce total process energy consumption and reduce CO_2 emissions.

- **Improve power system and equipment reliability by up to 18%**

Increase power quality to improve business performance and reduce unplanned outages, as well as enhance the reliability and service life of electrical devices, while reducing harmonic stress and potential damage to your electrical network.

Power factor	Cable cross section multiplying factor
1	1
0.95	1.05
0.9	1.1
0.85	1.17
0.8	1.25
0.7	1.43

Fixed capacitors

This arrangement employs one or more capacitor(s) to form a constant level of power factor correction. Control may be:

- Manual: by circuit-breaker or load-break switch
- Semi-automatic: by contactor
- Direct connection to an appliance and switched with it.

These capacitors are applied:

- At the terminals of inductive devices (motors and transformers)
- At busbars supplying numerous small motors and inductive appliance for which individual power factor correction would be too costly
- In cases where the load level is reasonably constant.

Automatic capacitor banks

This kind of equipment provides automatic control of power factor correction, maintaining the power factor within close limits around a selected level. Such equipment is applied at points in an installation where the active-power and/or reactive-power variations are relatively large, for example:

- At the busbars of a general power distribution board
- At the terminals of a heavily-loaded feeder cable.

The advantages of reactive power factor correction

The principles of, and reasons, for using automatic power factor correction

A capacitor bank is divided into a number of sections, each of which is controlled by a contactor. Closure of a contactor switches its section into parallel operation with other sections already in service.

The size of the bank can therefore be increased or decreased in steps, by the closure and opening of the controlling contactors.

A control relay monitors the power factor of the controlled circuit(s) and is arranged to close and open appropriate contactors to maintain a reasonably constant system power factor (within the tolerance imposed by the size of each capacitor bank step).

By closely matching power factor correction to that required by the load, the possibility of producing overvoltages at times of low load will be avoided, thereby preventing an overvoltage condition, and possible damage to appliances and equipment.

Overvoltages due to excessive reactive power factor correction depend partly on **the value of the source impedance.**

The choice between a fixed or automatically regulated bank of capacitors

Where the kvar rating of the capacitors is less than or equal to 15% of the supply transformer rating, a fixed value of power factor correction is appropriate. Above the 15% level, it is advisable to install an **automatically-controlled capacitor bank.**

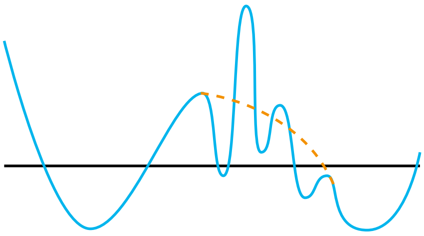
The location of low-voltage capacitors in an installation constitutes the mode of power factor correction, which may be global (one location for the entire installation), partial (section-by-section), local (at each individual device), or some combination of the two. In principle, the ideal power factor correction is applied at a point of consumption and at the level required at any particular time.

In practice, technical and economic factors govern the choice.

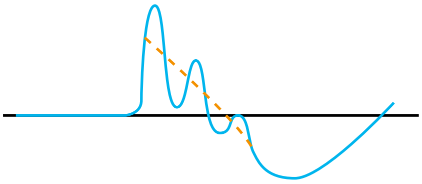
Selection guide to contactors and protection for stepped capacitor bank (without a choke)

Capacitor step control, a specific application

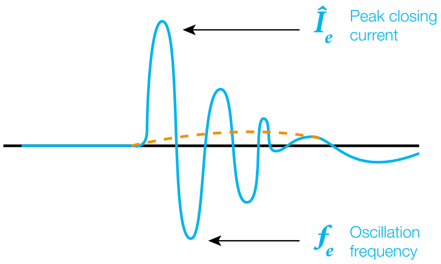
Capacitor control is accompanied by a transient state, resulting from the capacitor load. This can result in a massive overcurrent, equivalent to a short-lasting short-circuit. (See detail page 9)



Line supply voltage



Capacitor voltage



Capacitor current

Such repetitive high-frequency transient overvoltages can damage the reactive power factor correction capacitor insulation and other devices such as transformers.

LC1D•K contactors for capacitors

LC1-D•K contactors are specifically designed to control capacitors. They have a normally open switchover contact block and damping resistors limiting the current at switch-on. This technology is unique and is the subject of a patent.

Reference	LC1DFK	LC1DGK	LC1DLK	LC1DMK	LC1DPK	LC1DTK	LC1DWK12
Pmax @400 V θ ≤ 60°C	13 kVAR	16 kVAR	20 kVAR	25 kVAR	30 kVAR	40 kVAR	63 kVAR
Auxiliary contacts	1NO + 2NC	1NO + 2NC	1NO + 2NC	1NO + 2NC	1NO + 2NC	1NO + 2NC	1NO + 2NC
Width	45 mm	45 mm	45 mm	45 mm	55 mm	55 mm	85 mm
Size	**1**	**1**	**2**	**2**	**3**	**3**	**4**

See page 8 for the selection guide to contactors and associated fuse protection according to the step power rating.

Maintenance

Capacitor maintenance program

To ensure that the financial advantages of reduced billing are achieved it's necessary to perform periodic maintenance of the power factor correction capacitors and controlling switchgear. **Automatic capacitor bank** operating conditions involve various types of environmental stress: temperature variations, electrical stress (harmonics, transient inrush current).

In order to maintain the equipment performance during the whole installation life cycle, the maintenance program must be carried out systematically in order to ensure the equipment works properly, preserve its operating life and avoid serious operating faults, explosion and fire.

Please check the following points annually:

Maintenance program		When	
Type of checking	**Capacitor bank part**	**1 month after energization**	**Once a year**
Visual inspection	Enclosure		●
	Capacitors		●
	Controller		●
	Chokes if any		●
	Contactors and damping resistors	●	●
	Cables and connections		●
Checking switch-on	Controller settings/alarms		●
	Protection settings		●
	Capacitor status		●
Checking switch-off	Tightness	●	●

Note: With an automatic battery, one step may have failed and power factor correction is performed by some other steps, so the overall solution is satisfactory, but each time the faulty step is switched on, transient disturbance may occur. Regular inspection is therefore the only way to detect failure.

Visual inspection for contactors

The contactors are fitted with a block of early-make poles and damping resistors (external resistive wires), limiting the value of the current on closing to 60 In max. This current limiting increases the life of all the installation components, especially that of the fuses and capacitors.

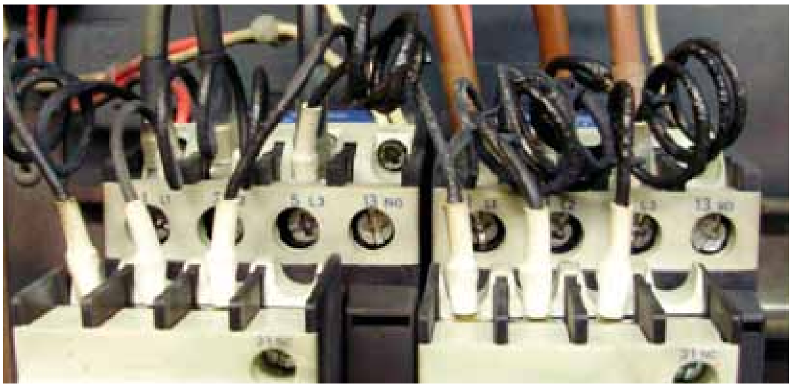
Visual inspection consists in:

- Checking presence of damping resistors
- Evaluating whether any overheating has occurred
- Examining for the presence of dust, moisture, etc.
- Visual checking of electrical connections

If the damping resistors are damaged or missing:

- the contactor shall be replaced immediately.
- the capacitors operated by the corresponding contactor shall be checked.

If a capacitor is damaged and replaced, the corresponding contactor shall also be replaced.



Example of damaged damping resistors

When replacing contactors, it is essential to observe the following rules:

- Use suitable connectors
- The tightening torque must conform to that specified by Schneider Electric
- Handle the resistor wires carefully to avoid creating a fracture starting point on the crimped tags
- Retighten the connectors 1 month after commissioning, then once a year.

Specific information about capacitor operation

Capacitor control is accompanied by a transient state, resulting from the capacitor load. This can result in a massive overcurrent, equivalent to a short-lasting short-circuit

Example of a **single fixed capacitor** bank *

* *Single fixed capacitor: No big disturbance, no special care*

The upstream line supply is deemed to be a pure inductance L_a such as:

$$L_a \omega = \frac{U_n^2}{S_{sc}} = \frac{U_n}{\sqrt{3}\, I_{sc}}$$

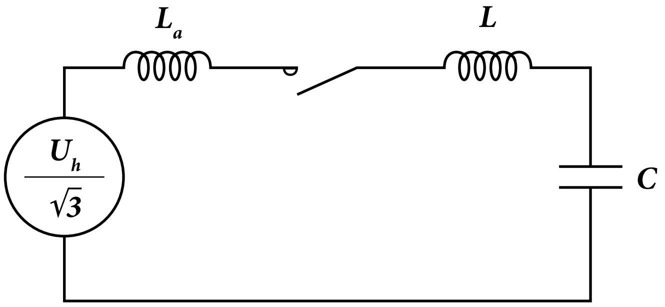
U_n : rated phase-to-phase voltage
I_{sc} : symmetrical three-phase short circuit current at the capacitor connection point
S_{sc} : short-circuit power at the capacitor connection point

By definition:

$$S_{sc} = \sqrt{3} \times U_n \times I_{sc}$$

The link between the breaking device (contactor, circuit-breaker or switch) and the capacitor bank is also deemed to be a pure inductance.

The equivalent single phase diagram is as shown in the figure below:



Simplified diagram of a fixed capacitor bank

L_a : upstream line supply inductance
L : inductance of the link between the breaking device and the capacitor bank

We can see that the peak switching current is:

$$\hat{I}_e = \sqrt{\frac{2}{3}}\, U_n \sqrt{\frac{C}{L_a + L}}$$

L is negligible in the presence of L_a hence:

$$\hat{I}_e = \sqrt{\frac{2}{3}}\, U_n \sqrt{\frac{C}{L_a}}$$

Specific information about capacitor operation

The natural frequency of this current is:

$$f_0 = \frac{1}{2\pi \sqrt{L_a C}}$$

Its duration is equivalent to the duration of a short circuit transient cycle, or several dozen ms.

We can compare this current to the capacitor bank rated current:

$$I_{ncapa} = C\omega \frac{U_n}{\sqrt{3}}$$

Hence:

$$\frac{\hat{I}_e}{I_{ncapa}} = \sqrt{2} \times \frac{1}{\omega \sqrt{L_a C}}$$

By using:

$$L_a \omega = \frac{U_n^2}{S_{sc}} \quad \text{and} \quad Q = C\omega U_n^2$$

This gives us:

$$\frac{\hat{I}_e}{I_{ncapa}} = \sqrt{2} \sqrt{\frac{S_{sc}}{Q}}$$

The overcurrent is accompanied by an overvoltage whose maximum value can be almost twice the peak line supply voltage.

Example:

Assuming a 250 kvar fixed capacitor bank with phase-to-phase voltage U_n **= 400 V** powered by a maximum short circuit power supply network S_{sc} **= 20 MVA,** we get:

$$\frac{\hat{I}_e}{I_{ncapa}} = \sqrt{2} \times \sqrt{\frac{S_{sc}}{Q}}$$

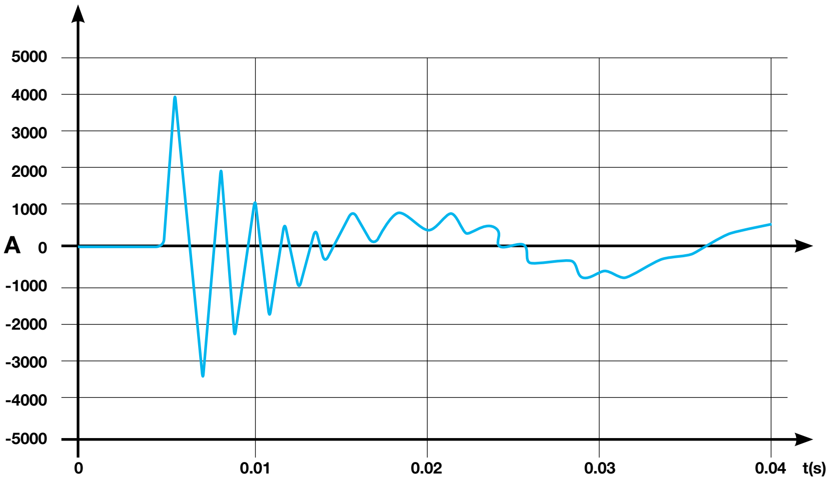
$$\frac{\hat{I}_e}{I_{ncapa}} = \sqrt{2} \times \sqrt{\frac{20.10^6}{250.10^3}} = 12.6$$

$$f_0 = \frac{1}{2\pi \sqrt{L_a C}}$$

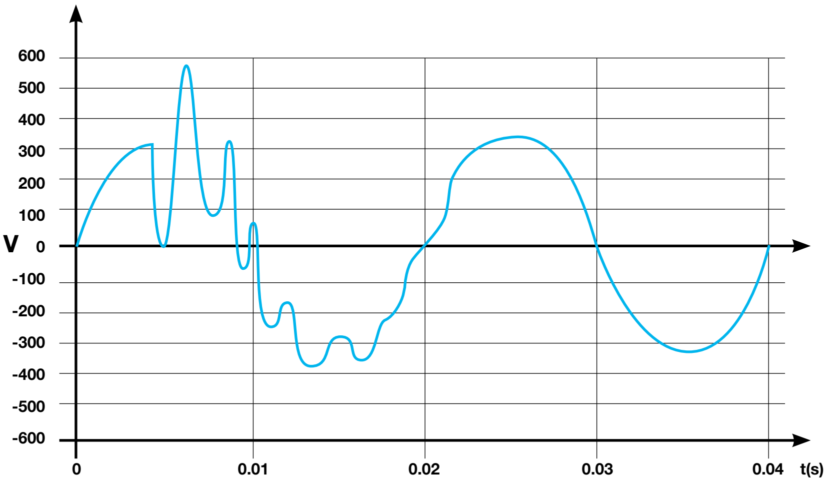
$$f_0 = \frac{\omega}{2\pi} \sqrt{\frac{S_{sc}}{Q}} = 50 \times \sqrt{\frac{20.10^6}{250.10^3}} = 447\ Hz$$

The maximum peak switching current in this example is 12.6 times the capacitor bank rated current, its natural frequency is 447 Hz.

The figures on the next page represent the switching current and the line supply voltage, when switching occurs at the voltage maximum.



Switching current



Line supply voltage on switching

Equipment selection for fixed capacitor bank

These transient states do not cause excessive stress to the protection and/or control device.

Specific information about capacitor operation

Example of a **stepped capacitor** bank *
(or several fixed capacitor banks connected to the same busbar).

** Stepped capacitor: Big disturbance = Special contactor and special care*

The equivalent single-phase diagram for $(n+1)$ capacitor bank steps is as shown in the figure below:

We can see that the peak switching current is expressed as:

$$\hat{I}_e = \sqrt{\frac{2}{3}} \times \frac{n}{n+1} \times U_n \times \sqrt{\frac{C}{L}}$$

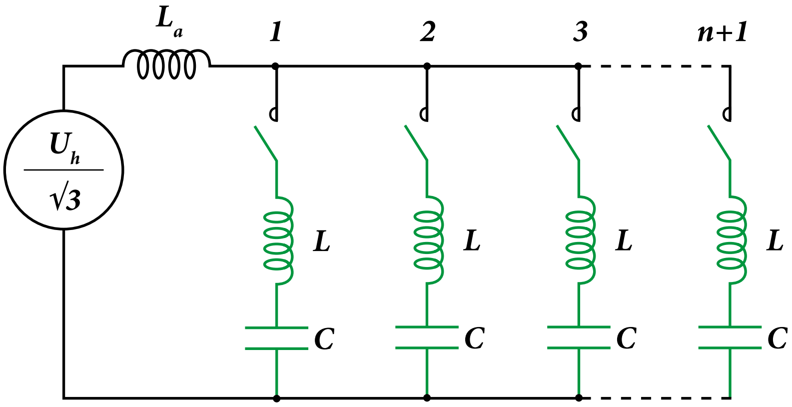
We can compare this current to the nominal current of a step I_{ncapa}

$$I_{ncapa} = C\omega \frac{U_n}{\sqrt{3}}$$

This gives us:

$$\frac{\hat{I}_e}{I_{ncapa}} = \sqrt{\frac{2}{3}} \times \frac{n}{n+1} \times U_n \times \frac{1}{\sqrt{Q\omega L}}$$

Where: Q = step reactive power



Simplified diagram of a stepped capacitor bank

L_a : upstream line supply inductance
L : inductance of the link between the breaking device and the capacitor bank (0.5 µH/m)

The peak switching current $\hat{I}_e$ is at its maximum when n steps are being used and the $n+1^{th}$ step is switched on.

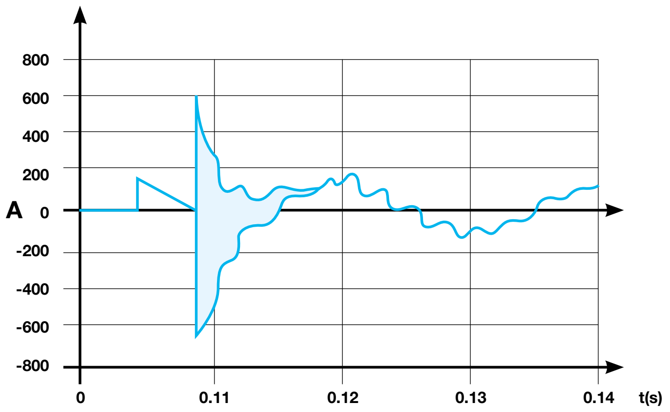
All steps in service discharge into this step. As the inductances (L) are very low, this switching current is very high (it depends on the line supply inductance L_a).

Example:

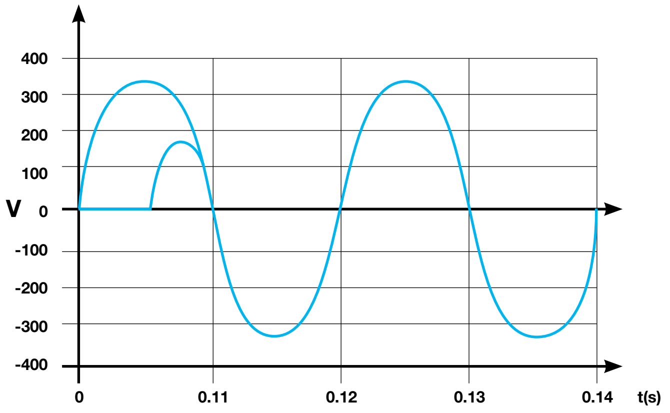
Assuming a bank with 6 steps, each of which is 50 kvar, with phase-to-phase voltage of **400 V**, 1 meter away from their associated breaking device. This gives us:

$$\frac{\hat{I}_e}{I_{ncapa}} = \sqrt{\frac{2}{3}} \times \frac{n}{n+1} \times U_n \times \frac{1}{\sqrt{Q\omega L}} = \sqrt{\frac{2}{3}} \times \frac{5}{6} \times 400 \times \frac{1}{\sqrt{50 \times 10^3 \times 314 \times 0.5 \times 10^6}} = 168$$

The maximum peak switching current in this example equals 168 times the capacitor bank step nominal current. The capacitors and breaking devices cannot withstand this very high current, therefore a device must be used to limit the switching current.



Current in the switched-on capacitor



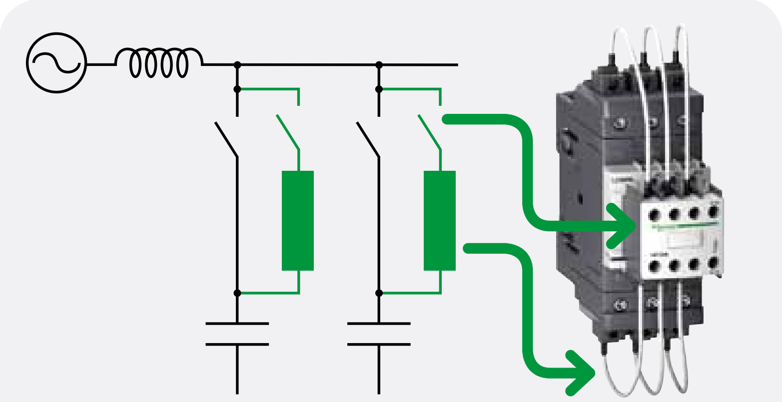
Voltage at the switched-on capacitor terminals and line supply voltage

Note: If it is not possible to use contactors specifically designed to control capacitors, chokes which limit the current at switch-on must be used.

Specific information about capacitor operation

Equipment selection for a stepped capacitor bank

The switching currents are limited by pre-insertion resistors; how these work is illustrated in the figure below:



Schematic diagram of pre-insertion resistors

LC1 DPK•

Each capacitor bank step must be controlled by a contactor equipped with auxiliary contacts. Resistors are connected in series with the auxiliary contacts.

On contactor closing, the auxiliary contacts are closed instantaneously, allowing precharging by means of the resistors.
After approximately 3 ms, the main contacts close, short-circuiting the resistors, then the auxiliary contacts open.

With such contactors there is no need to use choke inductors for either single or multiple-step capacitor banks.

Step power at 400 V kVAR	400 V step current Amps	Fuse protection rating (curve gG)	Contactor for capacitor application	Qmax 400 V ⊖ ≤ 60°C
2.5	3.6	6.3 A	LC1 DFK••	-
5	7.2	16 A	LC1 DFK••	-
6.25	9.0	16 A	LC1 DFK••	-
7.5	10.8	20 A	LC1 DFK••	-
10	14.4	25 A	LC1 DFK••	-
12.5	18.0	32 A	LC1 DFK••	13 kVAR
15	21.7	40 A	LC1 DGK••	16 kVAR
20	28.9	50 A	LC1 DLK••	20 kVAR
25	36.1	63 A	LC1 DMK••	25 kVAR
30	43.3	80 A	LC1 DPK••	30 kVAR
40	57.7	100 A	LC1 DTK••	40 kVAR
45	65.0	125 A	LC1 DWK12••	-
50	72.2	125 A	LC1 DWK12••	-
60	86.6	160 A	LC1 DWK12••	63 kVAR

The power values given in the selection table above are for the following operating conditions:

Prospective peak current at switch-on

- LC1 D•K .... 200 In

Maximum operating rate

- LC1 DFK, DGK, DLK, DMK .... 240 operating cycles/hour
- LC1 DPK, DTK, DWK .... 100 operating cycles/hour

Electrical durability at nominal load 400 V

- All contactor ratings .... 300,000 operating cycles

What's in the standard?

International standard IEC 60831-1 "Shunt power capacitors of the self-healing type for a.c. systems with a rated voltage up to and including 1000 V" recommend the use of such contactor.

Conclusion

The installation's global energy performance depends on the performance of the reactive power capacitor banks.

Failures in this type of equipment are difficult to detect as they do not have a direct effect on the electrical distribution network. Often customers only realise that reactive power correction is not working when they see their electrical bills from the energy company increasing. However any malfunctions can cause problems in the installation, and regular inspection of this equipment is therefore vital.

Make the most of your energy™

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