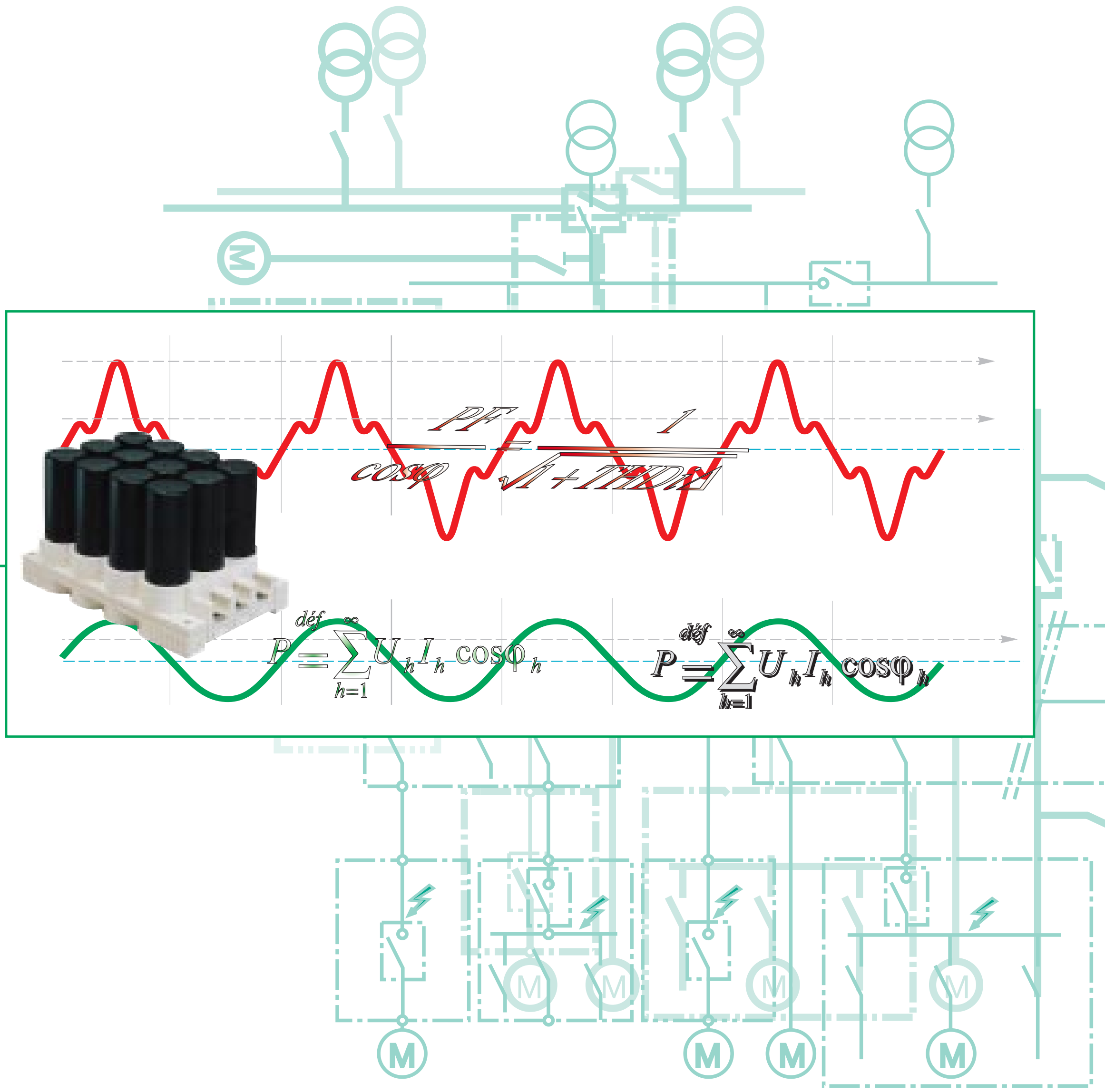
N° 6

Low voltage expert guides

Power factor *correction* and har*monic* filtering *guide*



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Contents

General information on Power Factor correction

In short

Energy, current and power consist of:
- active,
- reactive,
- apparent.

Only the active component creates work or heat.

1.1. Definitions

1.1.1. Active, reactive, apparent energies

All electrical machines using AC current (motor, transformer) involve two forms of energy: active energy and reactive energy.
Active energy consumption (kWh) results from **active power P (kW)** of loads. It is completely converted into mechanical power (work) and into heat (losses).
Reactive energy consumption (kvarh) is used to supply the magnetic circuits of electrical machines. It corresponds to **reactive power Q (kvar)** of loads.
Apparent energy (kVAh) is the vector sum of the two previous energies. It corresponds to the **apparent power S (kVA)** of loads, the vector sum of P (kW) and Q (kvar).

1.1.2. Active and reactive current components

Each active and reactive energy has a current.
Active current (Ia) is in phase with network voltage.
Reactive current (Ir) is phase-shifted by 90° with respect to active current, either lagging (inductive load) or leading (capacitive load).
Apparent current (It) is the resulting current that flows through the line from the source to the load.

If currents are perfectly sinusoidal, Fresnel's representation can be used. These currents are then composed as vectors as shown below:

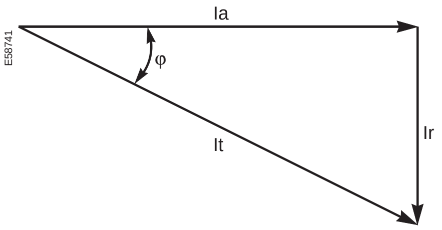

Figure 1: *Vector composition of currents*

$$It = \sqrt{Ia^2 + Ir^2}$$

$$Ia = I.\cos\varphi$$

$$Ir = I.\sin\varphi$$

1.1.3. Active and reactive power components

The above diagram drawn up for currents also applies to powers, by multiplying each current by the common voltage U.
We thus define:
- Apparent power: S = UI (KVA),
- Active power: P = UI.cosφ (kW)
- Reactive power: Q = UI.sinφ (kvar).

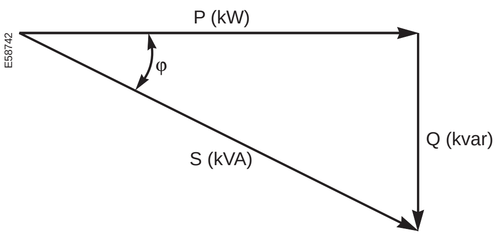

Figure 2 - *Vector composition of powers*

In short

The aim of power factor correction is to reduce the current drawn from the network.

Reactive energy is supplied by capacitors, as close as possible to the inductive loads.

1.1.1. Power factor

Power factor is equal by definition to:

$$FP = \frac{P}{S} = \frac{active\_power\_(kW)}{apparent\_power\_(kVA)}$$

If currents and voltages are perfectly sinusoidal signals, power factor equals cosφ.

The variable tgφ is also used. In the same conditions, we obtain the following equation:

$$tg\varphi = \frac{Q}{P} = \frac{reactive\_power\_(k\,\mathrm{var})}{active\_power\_(kW)}$$

For a given period of time, we also obtain:

$$tg\varphi = \frac{Wr}{Wa} = \frac{reactive\_energy\_consumption\_(k\,\mathrm{var}\,h)}{active\_energy\_consumption\_(kWh)}$$

1.2 Aims

Circulation of reactive energy has major technical and economic consequences. This is because, for the same active power P, the following figure shows that for a higher reactive power, a higher apparent power and thus a higher current must be supplied.

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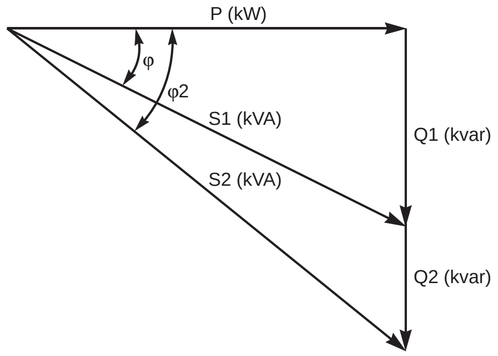

***Figure 3 -** Influence of reactive power*

Thus, due to a higher supplied current, circulation of reactive energy on distribution networks results in:
- Overloads of transformers,
- Temperature rise of the supply cables,
- Additional losses,
- Large voltage drops.

For these reasons, reactive energy must be produced as close as possible to the loads, to prevent the unnecessary circulation of current in the network. This is what is known as **“power factor correction”.**

To encourage this and avoid overcalibrating the network, the electrical utility financially sanctions reactive energy consumers beyond a certain threshold.

Capacitors are used to supply reactive energy to inductive loads.

To reduce the apparent power drawn up in the network from S2 to S1, a capacitor bank supplying reactive energy Qc must be connected, such that:
Qc = P.(tgφ2 - tgφ1).

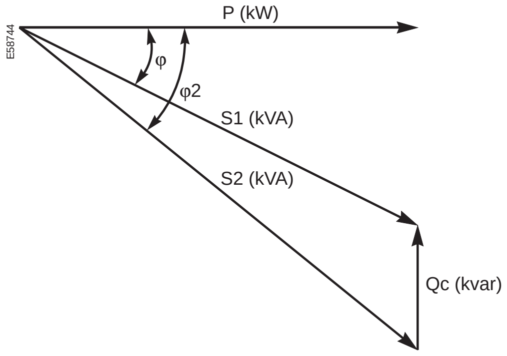

Figure 4 - *Principle of power factor correction*

1.3 Choice of correction type

The economic value of correction is measured by comparing the installation cost of capacitor banks with the savings it provides.

Capacitor bank cost depends on a number of parameters including:
- Installed power,
- Voltage level,
- Splitting into steps,
- Control mode,
- Protection quality level.

1.3.1. Choice of location

- Global correction

The capacitor bank is connected at the supply end of the installation and provides correction for all loads. This is suitable when the main aim is to eliminate sanctions and relieve the transformer substation.

- Local or sector correction

The capacitor bank is installed at the supply end of the installation sector to be corrected. This is suitable when the installation is extensive and contains workshops with different load conditions.

- Individual correction

The capacitor bank is directly connected to the terminals of each inductive load (in particular motor). This can be considered when motor power is high compared with subscribed demand. This correction is technically ideal as it produces reactive energy at the very point where it is consumed and in a quantity adjusted to demand.

1.3.2. Choice of correction type

- Fixed correction

The entire capacitor bank is put into operation, in an “ON/OFF” operating mode. Putting into operation can be manual (by circuit-breaker or switch), semi-automatic (by contactor), or dependent on motor terminals. This correction type is used when reactive power is low (<15% of transformer power) and the load relatively stable.

- Automatic or “step” correction

The capacitor bank is split into steps, with the possibility of putting a varying number of steps into operation, normally automatically. This capacitor bank type is installed at the supply end of the LV distribution or an important sector. It allows step-by-step regulation of reactive energy. Step switching and tripping is controlled by a varmetric relay.

In short

The harmonic currents generated by electronic devices may be responsible for an overload of the correction capacitors.

Various types of suitable capacitors are proposed..

1.4 Power Factor correction in presence of harmonics

Equipment using power electronics (variable speed drives, rectifiers, UPS, etc.), increasingly used, are responsible for the circulation of harmonic currents in networks. These harmonics disturb the operation of many devices. Capacitors are particularly sensitive to them since their impedance decreases proportionally to the order of the harmonics present.

In certain circumstances, resonance phenomena may occur, resulting in a high voltage distortion and in capacitor overload. These phenomena are described in 2.2.

According to the power of the harmonic generators present, various types of capacitors must be chosen, associated if necessary with reactors. The following table summarises the possible choices:

Power transformer Sn < 2 MVA			
Gh<0,15.Sn	0,15.Sn<Gh<0,25.Sn	0,25.Sn<Gh<0,6.Sn	Gh>0,6.Sn
standard correction equipment	H type correction equipment	detuned bank	harmonics filter

- *Gh: harmonic generator power*
- *Sn: Transformer Power*
- *H type: oversized capacitors*
- *detuned bank: oversized capacitors, associated with protection reactors*

For high power values of harmonic generators, harmonics normally need to be treated. The appropriate device (harmonics filter) performs both reactive energy correction and harmonic filtering functions.

1.5 Terms used for the Rectiphase correction devices

- Capacitor element or “pot”

Device made up of two electrodes separated by a dielectric, housed in a plastic enclosure. The enclosure also contains an end of life fault protection device, including an overpressure device and a HBC fuse that insulates the element should a fault occur.

- **Varplus M** capacitor block

Assembly of 3 or 12 capacitor elements configured in three-phase blocks.
Available in standard or H type versions, used according to the level of harmonic pollution.

- **Varplus high power** fixed capacitor bank

Assembly of Varplus M capacitor blocks, without protection device.
Available in standard, H type or detuned bank versions, used according to the level of harmonic pollution.

- **Rectibloc** fixed capacitor bank

Assembly of Varplus M capacitor blocks, protected by circuit-breaker.
Available in standard, H type or detuned bank versions, used according to the level of harmonic pollution.

- **Turbovar** automatic capacitor bank

Assembly of Varplus M capacitor blocks, controlled by a current relay.

■ Automatic capacitor bank: **Rectimat, Secomat, Prisma**
Equipment produced by association of various correction assemblies, forming "steps". The various terms relate to different enclosure types.
A **Varlogic** varmetric controller, built into the equipment, controls each step separately. According to the global reactive energy needs, the controller controls switching on of a certain number of steps, by means of contactors.
The equipment can be optionally equipped with a circuit-breaker.
Available in standard, H type or detuned bank versions, used according to the level of harmonic pollution.

■ Equipped mounting plate or correction module
Correction subassembly forming a step and designed to be mounted in an automatic correction bank.
This subassembly mainly contains a Varplus M correction block, a switching on contactor and protection fuses.
Available in standard, H type or detuned bank versions, used according to the level of harmonic pollution.

Transient phenomena and disturbances

In short

Capacitors are the origin of various transient conditions and disturbances:
- High inrush current and high overvoltage on switching of capacitors,
- Resonance and harmonic overload.

2.1 Transient switching conditions

Switching of a capacitor bank is accompanied by transient current and voltage conditions. An overcurrent and an overvoltage appear, whose amplitude and frequency depend on the characteristics of the upstream network and the number of capacitor banks.

The upstream network is considered as a pure inductance L_a such that:

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

Where:
- Un: nominal phase-to-phase voltage,
- Isc: symmetrical three-phase short-circuit current at the capacitor connection point,
- Ssc: short-circuit power at the capacitor connection point.

(by definition, $S_{sc} = \sqrt{3}U_n.I_{sc}$).

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

2.1.1. Case of a fixed bank

Corresponding models in the Rectiphase range: **high power Varplus, Rectibloc**

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

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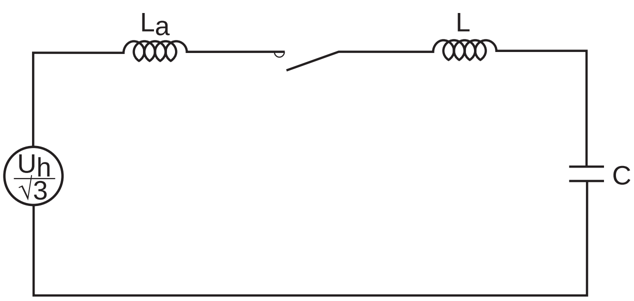

Figure 5 *- Simplified diagram of a fixed capacitor bank*

- L_a : upstream network inductance,
- L : inductance of the connection between the breaking device and the capacitor bank.

We prove that the expression of the peak switching current is:

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

L is negligible compared with L_a, hence :

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

The natural frequency of this current is:

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

Its duration is equivalent to the duration of the transient period of a short-circuit, i.e. a few dozen ms.

This current can be compared with the nominal current of the bank:

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

Hence:

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

Using:

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

We obtain:

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

The overcurrent is accompanied by an overvoltage whose maximum value can be nearly twice the network peak voltage.

■ **Example**
Let us take a fixed capacitor bank of 250 kvar with a phase-to-phase voltage Un = 400 V supplied by a network with a maximum short-circuit power Ssc = 20 MVA.
We obtain:

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

$$\frac{\hat{I}_e}{I_{ncapa}} = \sqrt{2}.\sqrt{\frac{20.10^6}{250.10^3}} = 12{,}6$$

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

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

The maximum peak switching current equals in this example 12.6 times the nominal current of the bank. Its natural frequency is 447 Hz.

The following figures represent the switching current and network voltage, when switching takes place at maximum voltage.

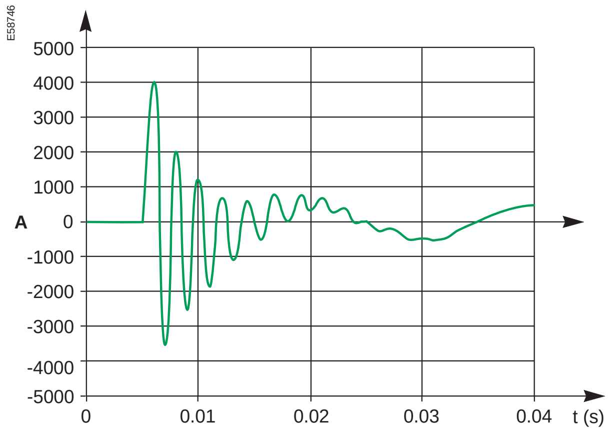

Figure 6 *- Switching current*

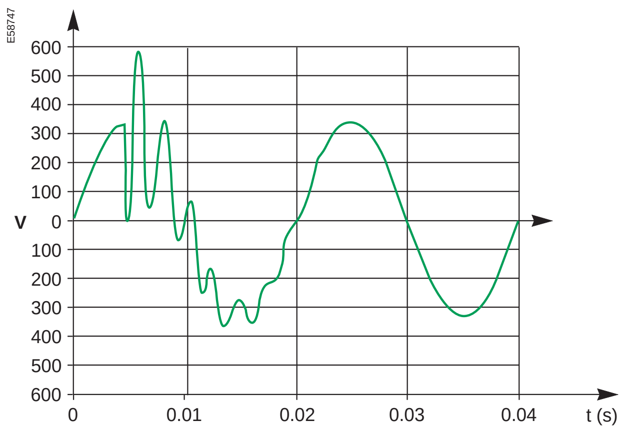

Figure 7 *- Network voltage on switching*

2.1.2. Case of an automatic capacitor bank

Corresponding models in the Rectiphase range: **Rectimat, Secomat, Prisma**.

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

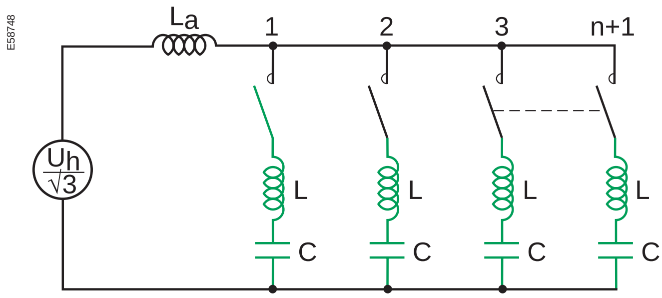

Figure 8 *- Simplified diagram of a step capacitor bank*

- L_a : upstream network inductance
- L :inductance of the connection between the breaking device and the capacitor bank (0.5 µH/m).

The peak switching current Ie is greatest when n steps are in operation and when the n + 1th step is energised. The steps in operation are discharged in the energised step. Since the inductances L are very small, this switching current is very high (it is independent from the network inductance L_a).

We show that the expression of the peak switching current is:

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

This current can be compared with the nominal current of a step I_{ncapa} :

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

We obtain:

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

Where: Q = reactive power of a step

■ **Example**
Let us take a capacitor bank of 6 steps each 50 kvar, with a phase-to-phase voltage of 400 V, 1 metre away from their associated breaking device. We have:

$$\frac{\hat{I}_e}{I_{ncapa}} = \sqrt{\frac{2}{3}}.\frac{n}{n+1}.U_n.\frac{1}{\sqrt{Q.\omega.L}} = \sqrt{\frac{2}{3}}.\frac{5}{6}.400.\frac{1}{\sqrt{50.10^3.314.0,5.10^6}} = 168$$

The maximum peak switching current equals in this example 168 times the nominal current of a capacitor bank step.

This very high current cannot be supported by the capacitors and breaking devices. A device limiting switching current must thus be used.

With respect to Rectiphase capacitor banks, switching currents are limited by pre-insertion resistors whose principle is illustrated in the figure below:

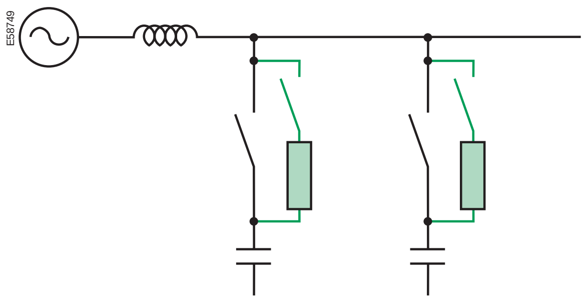

Figure 9 *- Schematic diagram showing the pre-insertion resistors*

Each capacitor bank step is controlled by a contactor equipped with auxiliary contacts. Resistors are serial-connected with these contacts.

When the contactor closes, the auxiliary contacts are immediately closed, thus allowing pre-loading through the resistors. After roughly 3 ms, the main contacts close, thus short-circuiting the resistors.

Illustration: on the data of the above example, with a pre-insertion resistor equal to 3.2 Ω :
❑ Current in the energised capacitor,
❑ Voltage at the terminals of the energised capacitor and network voltage.

Current peak on switching of the 6th step: $\hat{I}_{capa} \approx 700$ A, i.e. approximately 10 times the nominal current of a step.

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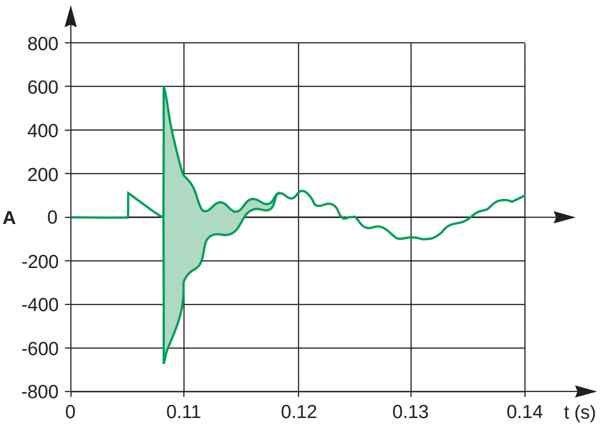

Figure 10 *- Current in the energised capacitor*

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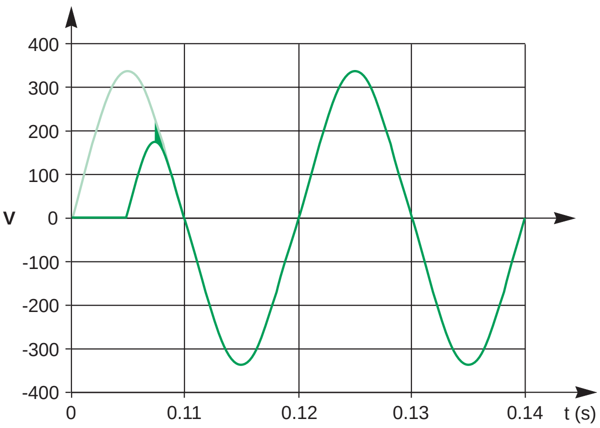

Figure 11 *- Voltage at the terminals of the energised capacitor and network voltage.*

2.2 Resonance

The resonance phenomenon is responsible for the greatest harmonic distortions in distribution networks and the major cause of correction capacitor overloads.

The phenomena described below are of the “parallel resonance” type.

Let us consider the following simplified diagram, representing an illustration containing:

- A supply transformer,
- Linear loads,
- Non-linear loads generating harmonic currents,
- Correction capacitors.

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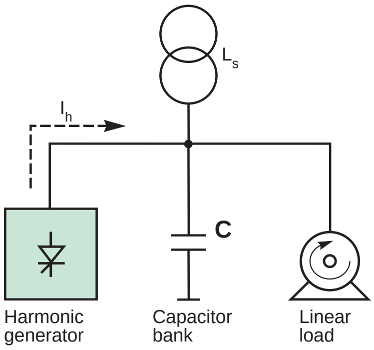

Figure 12 *- Simplified diagram of an installation*

For harmonic analysis, the equivalent diagram is as follows:

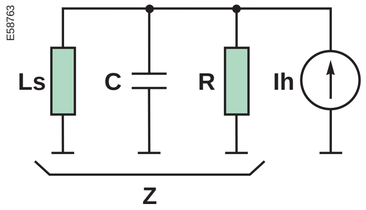

Figure 13 *- Equivalent diagram for harmonic analysis*

- Ls: supply inductance (network + transfo + line),
- C: correction capacitance,
- R: linear load resistance,
- Ih: harmonic generator

The impedance module seen by the harmonic currents is shown in the figure below:

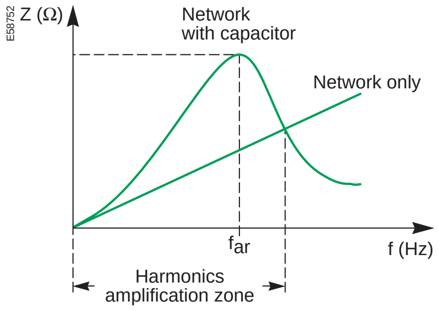

Figure 14 *- Impedance Z module as a function of frequency*

Physical interpretation:
- frequency f_{ar} is the tuning frequency of the circuit (ls + c),
- at frequency f_{ar}, the impedance module of the network seen by the harmonics is maximum. High harmonic voltages thus appear, and thus a high voltage distortion.
- in the harmonics amplification zone, harmonic currents higher than the injected harmonic currents flow in the circuit (ls + C).

The following diagram shows the circuit components affected by the harmonic currents:

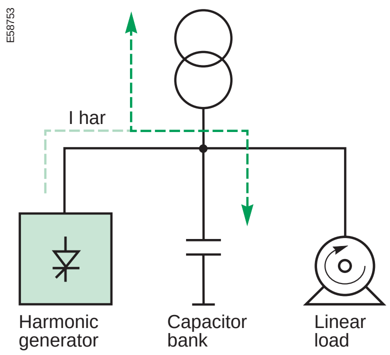

Figure 15 *- Circulation of harmonic currents*

The supply network and the correction capacitors are subjected to high harmonic currents and thus to the risk of overload.

■ **Example**
We shall first consider a network containing a transformer, a set of linear loads and a power factor correction bank.

The parameters are as follows:
■ Nominal power of transfo: Sn = 1000 kVA,
■ Short-circuit voltage of transfo: 5%,
■ Linear loads:
❑ power: P = 500 kW,
❑ cosφ : 0,75
■ capacitor bank: Q = 250 kvar.

We then assume that half the linear loads are replaced with non-linear loads.

We now observe a high current distortion in the correction capacitors.

Resonance frequency is 447 Hz, which results in marked amplification of 11^{th} order harmonics

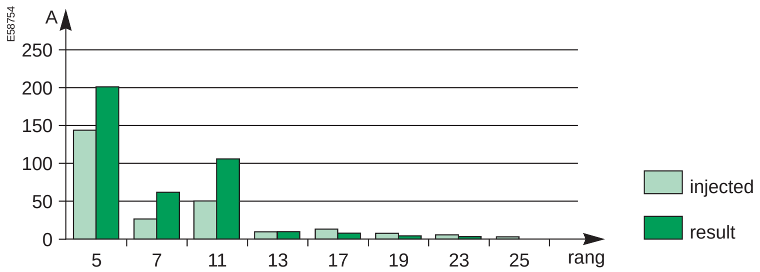

Figure 16 *- Harmonic current spectrum*

■ Capacitor current, without harmonic injection

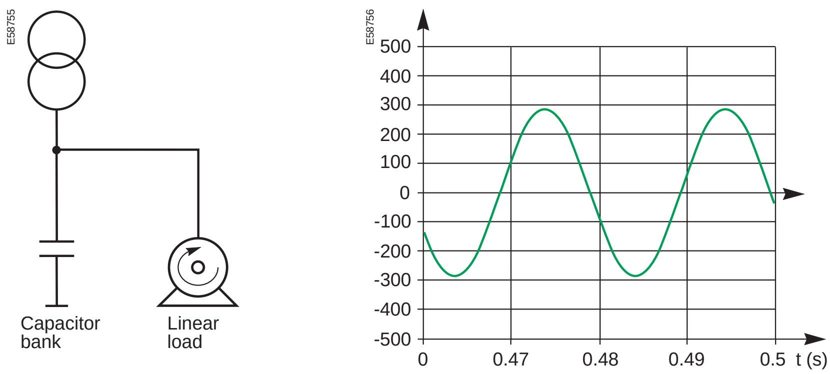

Figure 17 *- Correction without harmonic injection*

■ Capacitor current, with harmonic injection

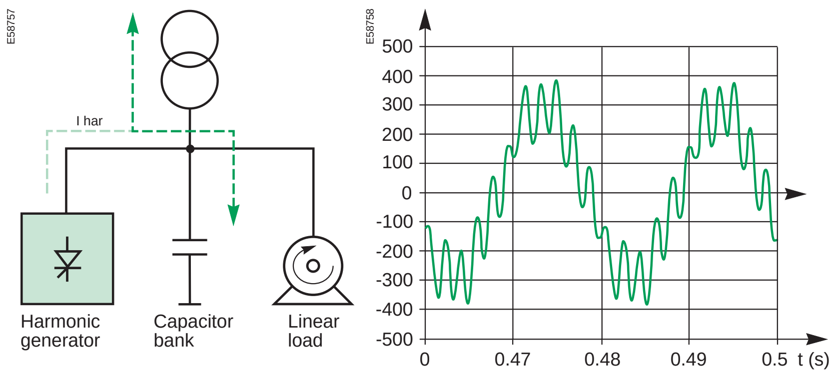

Figure 18 *- Correction with harmonic injection*

2.3 Harmonic overload

2.3.1. General case

The harmonic voltages applied to capacitors result in circulation of currents proportional to harmonic frequency. These currents are responsible for additional losses. The harmonic voltages also cause an increase in peak voltage value, thus accelerating the capacitor ageing process.

■ **Example**

❑ Fundamental voltage: U1

❑ Harmonic voltages:

- u5 = 8 %,
- u7 = 5 %,
- u11 = 3 %,
- u13 = 1 %,

(THDu = 10 %).

$$I_1 = U_1.C.\omega$$
$$I_5 = U_5.C.5.\omega = u_5.5.I_1$$
$$I_7 = U_7.C.7.\omega = u_7.7.I_1$$
$$I_{11} = U_{11}.C.11.\omega = u_{11}.11.I_1$$
$$I_{13} = U_{13}.C.13.\omega = u_{13}.13.I_1$$
$$I_{rms} = \sqrt{\sum I_h^2}$$
$$\frac{I_{rms}}{I_1} = \sqrt{1 + (u_5.5)^2 + (u_7.7)^2 + (u_{11}.11)^2 + (u_{13}.13)^2} = 1{,}19$$

The result is thus an overload of nearly 20% compared with operation at perfectly sinusoidal voltage.

Standard type capacitors can support a current overload of 30% (to support the cumulated effect of harmonics and voltage fluctuations).

In the event of high harmonic distortion, H type capacitors must be used, able to support 1.43 In.

2.3.2. Overload of harmonic filters

The aim of a harmonic filter is to shunt harmonic currents in a low impedance circuit, to prevent them from flowing in the supply network. This principle is illustrated in the figure below:

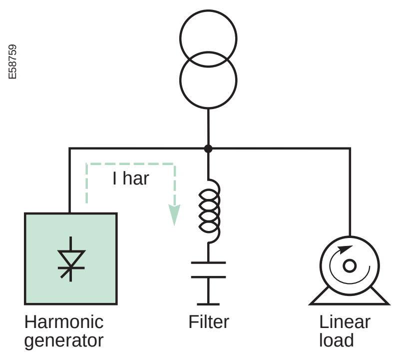

Figure 19 *- Simplified diagram of an installation with harmonic filter*

If the supply network has a pre-existing distortion (due to harmonic generating loads connected upstream of the installation), there is a risk of filter overload, as illustrated in the figure below:

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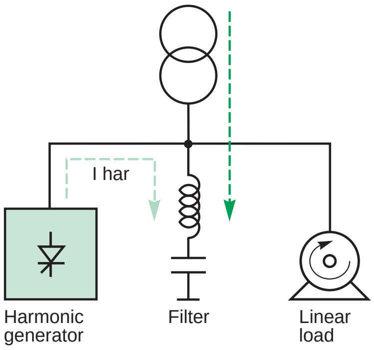


Figure 20 *- Risk of harmonic filter overload*

This pre-existing voltage distortion must be taken into account when sizing the harmonic filters.

The harmonic filtering equipment is systematically equipped with an overload protection device.

Choice of protection devices

In short

Choice and calibration of protection devices take a variety of restrictions into account:
- Switching current,
- Harmonic components,
- Network voltage fluctuations,
- Manufacturing dispersion.

3.1 Switching current

We saw earlier that the value of peak current on switching of a capacitor bank could be very high, particularly for an automatic step bank. In practice, the Rectiphase low voltage automatic capacitor banks are equipped with contactors with a resistor limiting switching current.

This resistor is used:
- to avoid reaching the maximum peak current acceptable to the capacitor banks,
- to avoid reaching the maximum switching current acceptable to the breaking devices (contactor, circuit-breaker or switch),
- to increase contactor lifetime.

3.2 Thermal sizing of the equipment (breaking devices and cables)

The permissible fluctuations in fundamental voltage and harmonic components may lead to a 30% to 45% current increase in capacitors.

Fluctuations due to tolerances on capacitor capacitance may result in an additional increase of 15% (according to standard IEC). With respect to Rectiphase capacitors, this additional increase is reduced to 5%.

The cumulated effect of the two phenomena means that equipment must be sized for the following currents:

- 1.3 x 1.15 = 1.5 times nominal current of capacitor banks in general,
- 1.3 x 1.05 = 1.36 times nominal current in the case of standart type or by coil protected Rectiphase capacitor banks (SAH type),
- 1.45 x 1.05 = 1.5 times nominal current in the case of reinforced Rectiphase capacitor banks (H type),

3.3 Choice and calibration of protection devices for Rectiphase capacitor banks

Low voltage capacitors can be protected by fuse or circuit-breaker.

- Protection by circuit-breaker:

As mentioned above, rating must be greater than 1.36xI_{ncapa}: the thermal threshold can be set at 1.36xI_{ncapa}.

The protection device must be sensitive to the rms value of the current (including the harmonics).

The instantaneous tripping threshold must be set at 10xI_{ncapa}.

■ Type of trip unit
Thermal magnetic type trip units are ideal for the application.

If electronic trip units are used, the “short time” tripping threshold must be fixed at 10 times setting current Ir in order to allow passage of the switching current peak.

■ Co-ordination of circuit-breakers with correction equipment.
For protection of a capacitor bank by a limiting circuit-breaker, the bank does not need to be sized for the same short-circuit current as the installation (refer to the limiting curves of Compact and Masterpact circuit-breakers).

■ Use of residual current devices (RCD)
On switching of a capacitor bank, the 3 phase currents are not balanced, even if the sum of these 3 currents is zero. These currents are high. Consequently, it is necessary to geometrically centre as accurately as possible the measurement toroid on the 3 cables, to prevent asymmetry from causing stray current detection and nuisance tripping.
The use of high immunity RCD is recommended. Example: Vigi C60 si.

■ Protection by fuse

❑ Case of a fixed bank:

To prevent risk of fuse blowing after a large number of switchings, rating must be greater than $1.6xI_{ncapa}$.

❑ Case of an automatic bank:

E58761

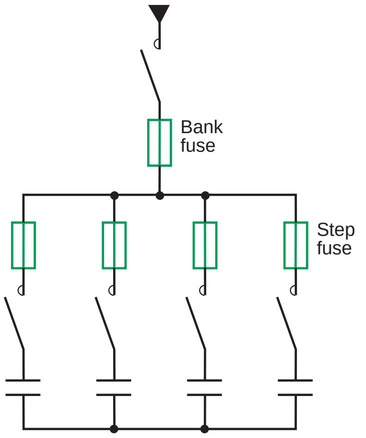


Figure 21 *- Protection by fuses of a step bank*

The fuse rating of each step must be greater than $1.6x_{ncapa}$
(I_{ncapa}: nominal current of a step).

The fuse rating of the bank must be greater than $1.4xI_{nbat}$
(I_{nbat}: nominal current of the bank).

Note that the increase coefficient of the fuse rating of the bank is 1.4 instead of 1.6 since steps are not energised at the same time.

Fuses must be of the gL type. In view of over-calibration, they cannot provide overload protection.

Although capacitor elements are equipped with protection devices against internal faults, the Rectiphase equipped mounting plates are, by precaution, normally equipped with fuses and occasionally with circuit-breakers.

The automatic correction capacitor banks can be optionally equipped with a master circuit-breaker.

❑ Case of capacitors with detuned reactors and filters

The rated voltage of the capacitors must be at least 10% higher than the rated voltage of the network to take into account the overvoltage due to the reactor.

Fuse rating is chosen according to nominal rms current (allowing for harmonics).

Reminder: rms current is $I_{rms} = \sqrt{I_1^2 + ... + I_1^2 + ...}$

Where:
- I_1 : value of current at 50 Hz (or 60 Hz),
- Ii : value of the i^{th} order harmonic current.

The fuse rating of each step must be greater than $1.4xI_{ecapa}$
(I_{ecapa}: nominal rms current of a step).

The fuse rating of the bank must be greater than $1.2xI_{ebat}$
(I_{ebat}: nominal rms current of the bank).

Note that the increase coefficients of the fuse ratings are lower if there are no detuned reactors or filters. This is because these reactors limit the switching current.

■ Cable protection
The supply cables must be sized in the same way as the control and protection devices, i.e. for a value 1.36 times the nominal current of the bank.

They must also be protected against short-circuits that can occur on the cables or in event of capacitor failure.

Notes

Additional technical information

E54600

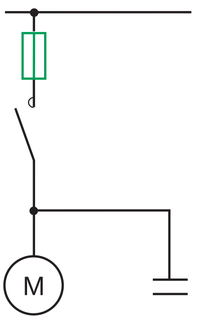
Correction of asynchronous motors

The cos φ of motors is normally very poor off-load and when slightly loaded, and poor in normal operating conditions. Installation of capacitors is therefore recommended for this type of load.

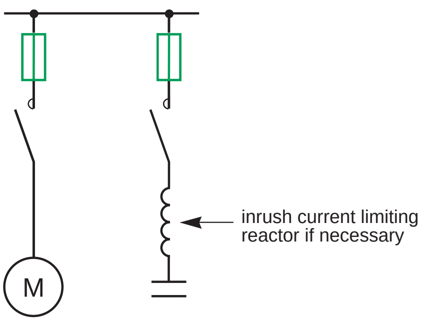
The table opposite gives, by way of an example, the values for capacitor bank power in kvar to be installed according to motor power.

motor nominal power		power (in kvar) to be installed number of pole pairs			
kW	**CV**	**1**	**2**	**3**	**4**
22	30	6	8	9	10
30	40	7,5	10	11	12,5
37	50	9	11	12,5	16
45	60	11	13	14	17
55	75	13	17	18	21
75	100	17	22	25	28
90	125	20	25	27	30
110	150	24	29	33	37
132	180	31	36	38	43
160	218	35	41	44	52
200	274	43	47	53	61
250	240	52	57	63	71
280	380	57	63	70	79
355	482	67	76	86	98
400	544	78	82	97	106
450	610	87	93	107	117

Correction requirements of asynchronous motors



Mounting capacitors at motor terminals



Parallel-mounting of capacitors with separate operating mechanism

When a motor drives a high inertia load, it may, after breaking of supply voltage, continue to rotate using its kinetic energy and be self-excited by a capacitor bank mounted at its terminals.
The capacitors supply the reactive energy required for it to operate in asynchronous generator mode. Such self-excitation results in voltage holding and sometimes in high overvoltages.

Case of mounting capacitors at the motor terminals
To avoid dangerous overvoltages caused by the self-excitation phenomenon, you must ensure that capacitor bank power verifies the following equation:
$Qc \leq 0{,}9 \sqrt{3}\ Un\ Io$
Io : motor off-load current
Io can be estimated by the following expression:
$Io = 2In\ (l - \cos \varphi_n)$

In: value of motor nominal current
Cos φn: cos j of the motor at nominal power
Un: nominal phase-to-phase voltage

Case of parallel-mounting of capacitors with separate operating mechanism
To avoid dangerous overvoltages due to self-excitation or in cases in which the motor starts by means of special switchgear (resistors, reactors, autotransformers), the capacitors will only be switched after starting.
Likewise, the capacitors must be disconnected before the motor is de-energised.
In this case, motor reactive power can be fully corrected on full load.
Caution: if several banks of this type are connected in the same network, inrush current limiting reactors should be fitted.

Correction of transformers

052304

A transformer consumes a reactive power that can be determined approximately by adding:

■ a fixed part that depends on the magnetising off-load current Io:

■ a part that is approximately proportional to the square of the apparent power that it conveys: Q = Usc

Usc: short-circuit voltage of the transformer in p.u.
S: apparent power conveyed by the transformer
Sn: apparent nominal power of the transformer
Un: nominal phase-to-phase voltage

The total reactive power consumed by the transformer is: Qt = Qo + Q.
If this correction is of the individual type, it can be performed at the actual terminals of the transformer.
If this correction is performed globally with load correction on the busbar of the main switchboard, it can be of the fixed type provided that total power does not exceed 15% of transformer nominal power (otherwise use banks with automatic regulation).
The individual correction values specific to the transformer, depending on transformer nominal power, are listed in the table below.

power in kVA (400 V)	**reactive power to be corrected in kvar**	
	off-load	**on-load**
100	2,5	6,1
160	3,7	9,6
250	5,3	14,7
315	6,3	18,4
400	7,6	22,9
500	9,5	28,7
630	11,3	35,7
800	20	54,5
1000	23,9	72,4
1250	27,4	94,5
1600	31,9	126,2
2000	37,8	176

Cable cross-section

Cable dimensioning must take into account:
- Harmonic currents + 30%,
- Capacitor tolerances + 15% reduced to 5% for Rectiphase capacitors i.e. in all 1.36 In for Rectiphase capacitors.

Acceptable variations in fundamental voltage and harmonic components may lead to a current increase of 30%.
Variations due to tolerances on capacitors may lead to a current increase of 15%: this tolerance is 5% for Rectiphase capacitors.
Consequently, the supply cables and the devices controlling and protecting these capacitor banks must also be oversized for a value of 1.3 x 1.15 = 1.5 In, but only for a value of 1.3 x 1.05 = 1.36 In in the case of Rectiphase capacitors.
The tables opposite list the following for a given capacitor bank power: the minimum cross-section of the supply cable.
If capacitors other than Rectiphase capacitors are used, select the rating immediately higher than the one listed in the table.

Cross-section of cables connecting medium and high power capacitor banks (1) (U 1000 RO2V cables)

bank power (kvar) 230 V	400 V	copper cross-section (mm²)	alu cross-section (mm²)
5	10	2,5	16
10	20	4	16
15	30	6	16
20	40	10	16
25	50	16	25
30	60	25	35
40	80	35	50
50	100	50	70
60	120	70	95
70	140	95	120
90-100	180	120	185
	200	150	240
120	240	185	2 x 95
150	250	240	2 x 120
	300	2 x 95	2 x 150
180-210	360	2 x 120	2 x 185
245	420	2 x 150	2 x 240
280	480	2 x 185	2 x 300
315	540	2 x 240	3 x 185
350	600	2 x 300	3 x 240
385	660	3 x 150	3 x 240
420	720	3 x 185	3 x 300

***(1)** Minimum cross-section not allowing for any correction factors (installation mode, temperature, etc.). The calculations were made for single-pole cables laid in open air at 30°C.*

Choice of protection devices

Fixed correction: Rectibloc

Set composed of Varplus M capacitors mounted either in a wall mounting cabinet or back to back in a painted metal structure, both incorporating a circuit-breaker

046214

Enclosure

052291

Structure

057489

Rectibloc detuned type

Network voltage 400/415 V

Standard type

no polluted network Gh/Sn ≤ 15%

power (kvar)	nominal current (A)	circuit-breaker	Ir (A)	type
10	15	NC100L	20	enclosure
15	22	NC100L	30	enclosure
20	29	NC100L	40	enclosure
25	36	NS100N/H/L	50	structure
30	43	NS100N/H/L	60	structure
40	58	NS100N/H/L	80	structure
50	72	NS100N/H/L	100	structure
60	87	NS160N/H/L	120	structure
70	101	NS160N/H/L	140	structure
80	115	NS160N/H/L	160	structure
100	144	NS250N/H/L	200	structure
120	173	NS250N/H/L	240	structure

Installation

■ wall mounting cabinet: wall mounted

■ structure: free standing with bottom entry cables.

Overrated type

polluted network 15% < Gh/Sn ≤ 25%

power (kvar) (*)	nominal current (A)	circuit-breaker	Ir (A)	type
7,5	11	NC100L	15	enclosure
10	15	NC100L	20	enclosure
15	22	NC100L	30	enclosure
20	29	NS100N/H/L	40	structure
22,5	32	NS100N/H/L	45	structure
30	43	NS100N/H/L	60	structure
35	51	NS100N/H/L	70	structure
40	58	NS100N/H/L	80	structure
45	65	NS100N/H/L	90	structure
52,5	76	NS160N/H/L	105	structure
60	87	NS160N/H/L	120	structure
70	101	NS160N/H/L	140	structure
80	115	NS250N/H/L	160	structure
90	130	NS250N/H/L	180	structure
105	152	NS250N/H/L	210	structure

(*) : usable power under 400 V.

Detuned type

polluted network 25% < Gh/Sn ≤ 60%

power (kvar)	nominal current (A)	circuit-breaker	Ir (A)	type
25	36	NS100N/H/L	50	cubicle
37,5	54	NS100N/H/L	75	cubicle
50	72	NS100N/H/L	100	cubicle
75	108	NS160N/H/L	150	cubicle
100	144	NS250N/H/L	200	cubicle
125	180	NS250N/H/L	250	cubicle
150	217	NS400N/H/L	300	cubicle

Choice of protection devices
(cont.)

Automatic correction
Rectimat 2

The Rectimat 2 capacitor banks are automatic compensation equipment in the form of an enclosure or a cubicle according to the power ratings

056637

Rectimat 2 enclosure 1

056639

Rectimat 2 cubicle 1

056643

Rectimat 2 cubicle 3

Network voltage 400 V
Rectimat 2

Standard type

no polluted network Gh/Sn ≤ 15%

power (kvar)	nominal current (A)	circuit-breaker	Ir (A)	type
30	43	NS100N/H/L	60	enclosure 1
45	65	NS100N/H/L	90	enclosure 1
60	87	NS160N/H/L	120	enclosure 2
75	108	NS160N/H/L	150	enclosure 2
90	130	NS250N/H/L	180	cubicle 1
105	152	NS250N/H/L	205	cubicle 1
120	173	NS250N/H/L	235	cubicle 2
150	217	NS400N/H/L	300	cubicle 1
180	260	NS400N/H/L	350	cubicle 1
210	303	NS630N/H/L	415	cubicle 2
240	346	NS630N/H/L	470	cubicle 3
270	390	NS630N/H/L	530	cubicle 3
315	455	NS630N/H/L	620	cubicle 3
360	520	C801N/H/L	710	cubicle 3
405	585	C801N/H/L	800	cubicle 3
450	650	C1001N/H/L	885	cubicle 3
495	714	C1001N/H/L	975	cubicle 4
540	779	C1251N/H	1060	cubicle 4
585	844	C1251N/H	1150	cubicle 4
630	909	C1251N/H	1240	cubicle 4
675	974	CM1600N/H	1325	cubicle 4
720	1039	CM1600N/H	1415	cubicle 4
765	1104	CM1600N/H	1500	cubicle 4
810	1169	CM1600N/H	1600	cubicle 4
855	1234	CM2000N/H	1680	cubicle 4
900	1299	CM2000N/H	1770	cubicle 4

Overrated type

polluted network 15% < Gh/Sn ≤ 25%

power (kvar)	nominal current (A)	circuit-breaker	Ir (A)	type
30	43	NS100N/H/L	65	enclosure 2
45	65	NS100N/H/L	100	enclosure 2
50	72	NS160N/H/L	110	enclosure 2
80	115	NS250N/H/L	175	cubicle 2
100	144	NS250N/H/L	220	cubicle 1
120	173	NS400N/H/L	260	cubicle 1
160	231	NS400N/H/L	345	cubicle 2
180	260	NS630N/H/L	390	cubicle 2
210	303	NS630N/H/L	455	cubicle 2
245	354	NS630N/H/L	530	cubicle 3
280	404	NS630N/H/L	610	cubicle 3
315	455	C801N/H/L	685	cubicle 3
350	505	C801N/H/L	760	cubicle 3
420	606	C1001N/H/L	910	cubicle 4
455	657	C1001N/H	985	cubicle 4
525	758	C1251N/H	1140	cubicle 4
560	808	C1251N/H	1215	cubicle 4
630	909	CM1600N/H	1370	cubicle 4
700	1010	CM1600N/H	1520	cubicle 4

Choice of protection devices
(cont.)

Rectimat 2 cubicle 2

Rectimat 2 cubicle 3

Detuned type

polluted network 25% < Gh/Sn ≤ 60%

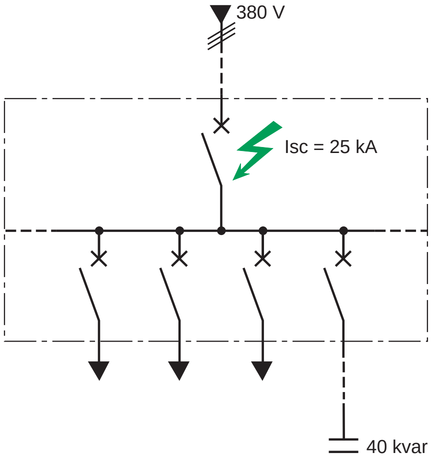
power (kvar)	nominal current (A)	circuit-breaker	Ir (A)	type
25	36	NS100N/H/L	50	cubicle 2
37,5	54	NS100N/H/L	75	cubicle 2
50	72	NS100N/H/L	100	cubicle 2
62,5	90	NS160N/H/L	125	cubicle 2
75	108	NS160N/H/L	150	cubicle 2
100	144	NS250N/H/L	200	cubicle 2
125	180	NS250N/H/L	250	cubicle 3
150	217	NS400N/H/L	300	cubicle 3
175	253	NS400N/H/L	350	cubicle 3
200	289	NS400N/H/L	400	cubicle 3
250	361	NS630N/H/L	490	cubicle 3
300	433	NS630N/H/L	590	cubicle 4
350	505	C801N/H/L	690	cubicle 4
400	577	C1801N/H/L	785	cubicle 4
450	650	C1001N/H/L	885	cubicle 4
500	722	C1001N/H/L	980	cubicle 4

Example

400 V 3-phaser LV Network
Isc = 25 kA at the busbar.
A 40 kvar H type Rectibloc condensator bank is to install in a cubicle supplying a workshop.
Determine the minimal supply cable size and the circuit-breaker rating:

■ page 24 table indicates a minimal cable size of 10 mm² for cupper or 16 mm² for alu
■ page 26 table indicates serval possibilities for protection circuit-breaker..

For a short-circuit current of 25 kA, the right choice is to install a NS100N (Breaking capacity: 25 kA) which magneto thermic TM80D or static STR22SE 100 A trip unit.



Notes

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