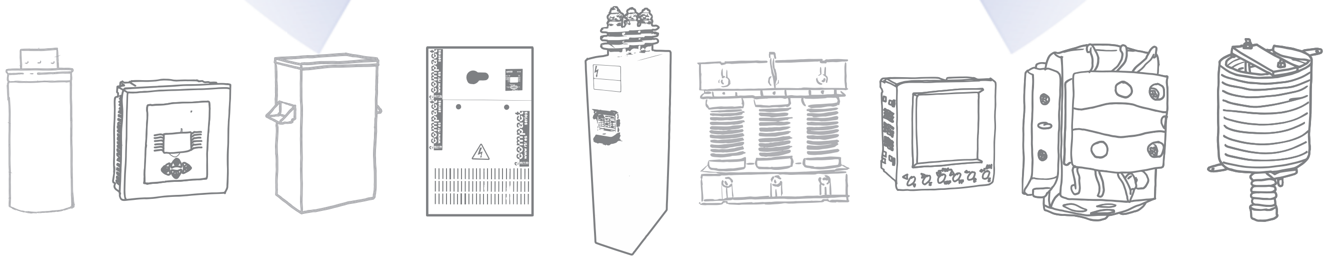
RTR



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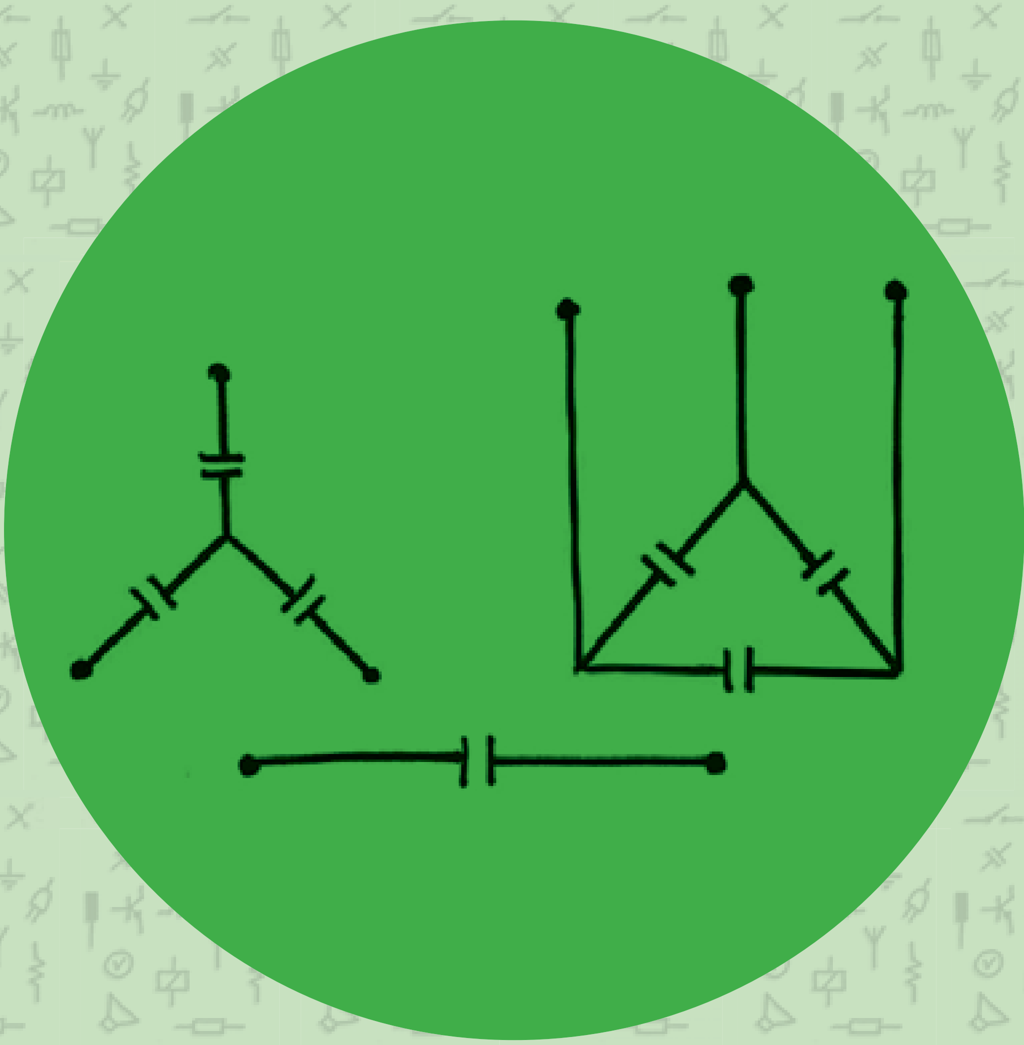
Electric



Capacitors

RTR energía

General Information

A capacitor is an electrical component, which stores electric charge. Its most important application is that of power factor correction (see Reactive compensation chapter).

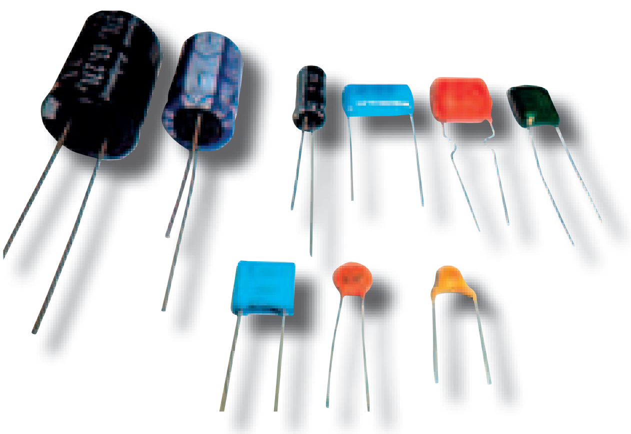
The capacitive element's constructive material depends on its application. RTR Energía S.L. manufactures cylindrical capacitors with propylene film, metallized with elements such as Al o Zn, which makes it self-healing and reduces the possible losses. This film will have different thicknesses depending on the working voltage. The elements used for metallizing act as current conductors, and the polypropylene as a dielectric.

After the manufacturing process and a quality control, the capacitive elements (coils) are introduced in aluminium or plastic cans, and then encapsulated with polyurethane resin, which is ecological and non-toxic. This resin is specially designed by the RTR Energía Chemistry Department and can be used with different capacitors and electric equipments which need encapsulation.

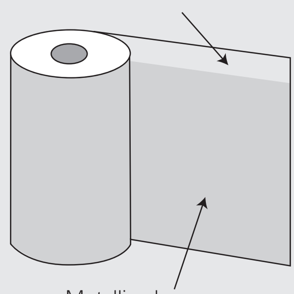
Another type of Capacitor

- MICA capacitors: used as high frequency and telecommunication capacitors.
- CERAMIC capacitors: used in telecommunication applications when there is not enough space.
- ELECTROLYTIC capacitors: used mainly for directcurrent rectifications.
- TRIM capacitors: their capacitance can be modified depending on the needs of the application.

Three-phase capacitor



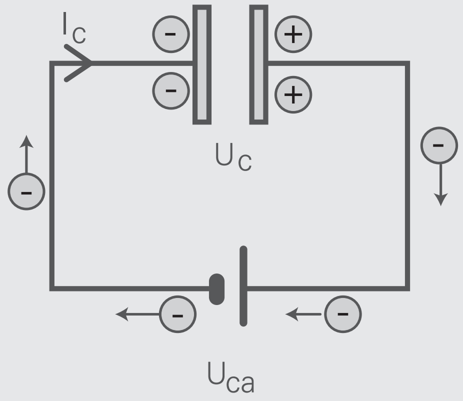
Capacitor's types



Capacitive element

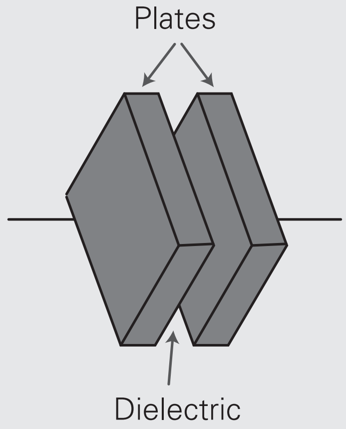
Electrical function of a capacitor

A capacitor is used for storing electrical energy. The capacitor is charged when the capacitor's plates voltage, Uc, levels up with the supply voltage, U_{ca}.
The movement of the electrons in between the plates of the capacitor constitutes the electrical capacitive current Ic, which flows through the line and provides electric energy to the capacitor, generating an electric field between the capacitor's plates.
If Ic is released, the electrical energy remains stored in the electric field, and so, in the capacitor.

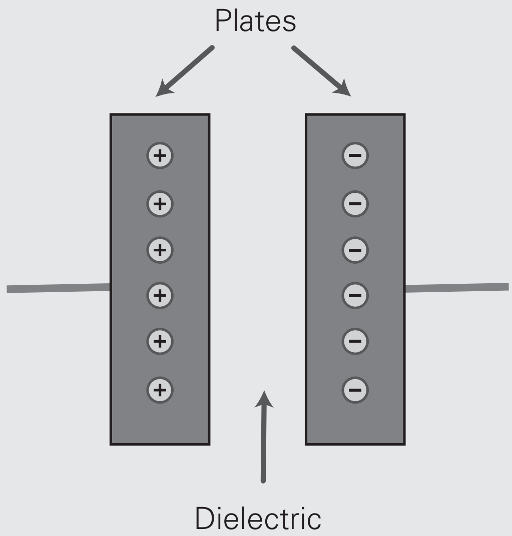


Capacitor´s Charge

$$Q = I \cdot t$$
$$I = \text{Amperes (A)}$$
$$t = \text{Seconds (s)}$$



The number of electrons which are moving during the charge of the capacitor (Q), measured in Coulombs (C) which are dimensionally equivalent to amperes times second (A·s). The charge is the amount of electricity stored in the capacitor.
Once the capacitor is charged, this charge is maintained even when the outer electrical energy is disconnected, as the attractive force between plates is also maintained, due to the polarity difference between them.
Because of this, the capacitors have a discharge resistor in their terminals so the discharge in the capacitor can be avoided when an operator is handling it.
This resistor must meet the standard UNE EN-60831-1-2 in its 22th chapter for three-phase power capacitors and the standard UNE-EN-61048-49 for lighting capacitors.



Capacitance and dielectric

Voltage is very influential in the behaviour of the capacitor, thus the charge fluctuates with it. Charge (Q) Supply voltage (U) ratio is a constant value, which depends on the capacitor's frame and is denoted as capacitance (C), measured in Farads (F).

$$C = \frac{Q}{U} \qquad Q = [\text{Coulombs}] \quad U = [\text{Volts}] \quad C = [\text{Farads}]$$

A capacitor has a 1 Farad capacitance when it stores a charge of 1 Coulomb if a 1 V voltage is applied between the plates.

Keeping the basic principle of capacitor's dependence, which states that the bigger it is the area of the plates, the bigger it is also the capacitance, and in the other way, the bigger it is the distance between these plates (dielectric's thickness) the lower it is the capacitance. Due to this principle, electric-field intensity (E) can be defined in a capacitor as:

$$E = \frac{U}{d} \left(\frac{V}{m}\right)$$

Dielectric and Regeneration

Electrical capacitors use nowadays dielectrics made of propylene film, metallized with elements such as Al or Zn, among others, with different thicknesses depending on the applied voltage between the plates.

As it was seen before with the basic principle of dependence, the lower it is the dielectric thickness, the bigger it is the electric-field intensity, which provokes that the size of the capacitors is gradually smaller, as they have for distances between the plates the thickness of the film, in micron.

Submutiples table		
10^{o}	Prefijo	Símbolo
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	mili	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p

Capacitor's design equation

$$C = \frac{\varepsilon}{4 \cdot \pi \cdot 9 \cdot 10^{9}} \cdot \frac{S}{d}$$

C: capacitance of a capacitor, in farads.
S: area of the plate, in m^2.
d: dielectric thickness, in m.
ε: dielectric constant.

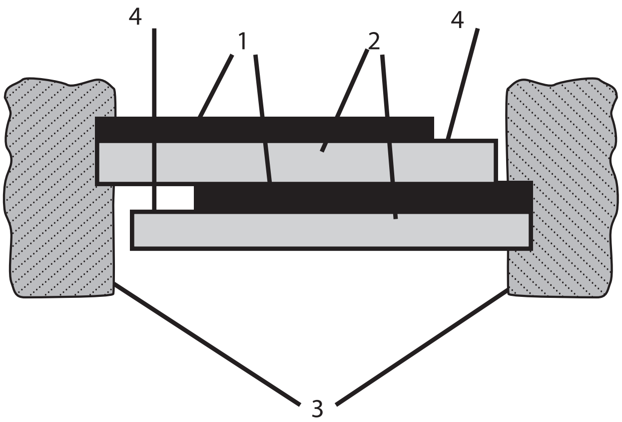
Different Isolators	
Sustance	ε
Air	1
Polypropylene	2,2
Mineral Oil	2,3
Polyester	3,3
Paper	3,5
Transformer oil	4,5
Pyrex glass	4,7
Mica	5,4
Porcelain	6,5
Silicon	12

Depending on the values of the constants of every dielectric, there is a limit potential difference, which all materials can manage throughout the thickness. this limit is defined as electrical stiffness.

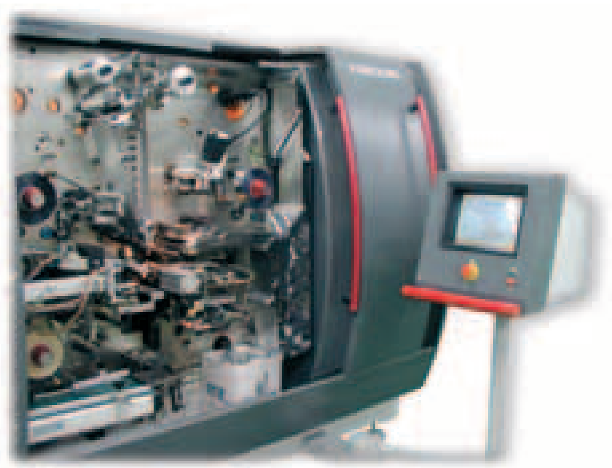
Because of determined electric-power system conditions or extrem temperatures, inadmissible for the correct working of the capacitor, this voltage limit can be overfilled. Thus, the dielectric can be bored and an electric arc will be formed between the plates.

The Polypropylene film self-healing means that the electric arc will not generate a short circuit, but will evaporate the metal which surrounds the breakthrough point. this way, the isolation between plates is repaired in the latter breakthrough point.

After this self-healing, the capacitor can work in normal conditions, with a capacitance leak inferior to 100 pF.



1 Electrodes (Metallized Film)
2 Polypropylene Film (Dielectric)
3 Electric connection
4 No metallized area



In **RTR Energía S.L.,** during the quality control of the metallized Polypropylene film, the breakdown of the dielectric (propylene) is forced and the self-healing of it can be observed. In this photograph the evaporated metal-coat and the still working capacitor can be seen.

Voltage influence in capacitors

Direct Voltage

When a capacitor is connected to a continuous voltage, Ucc, the current has a very high intensity and is limited by the ohmic resistance, which is tiny in the capacitor. When the voltage between the plates of the capacitor increases, the current gradually decreases.

When the charging process is finished, the current intensity becomes zero. In continuous rating and direct voltage, the capacitor behaves as an open circuit.

During the discharge process of the capacitor, the voltage and the current decrease with the same ratio, and so they become zero simultaneously.

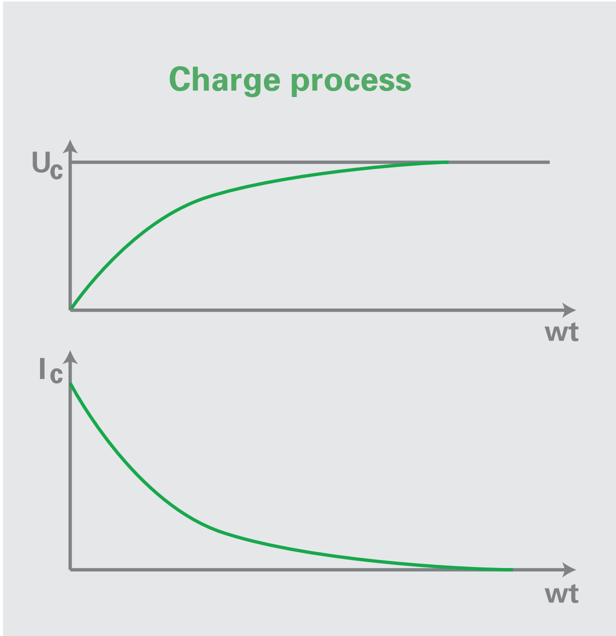
The charge and discharge time is directly proportional to capacitance and circuit resistance, and so, when the resistance fluctuates the charge and discharge process can be shortened or extended.

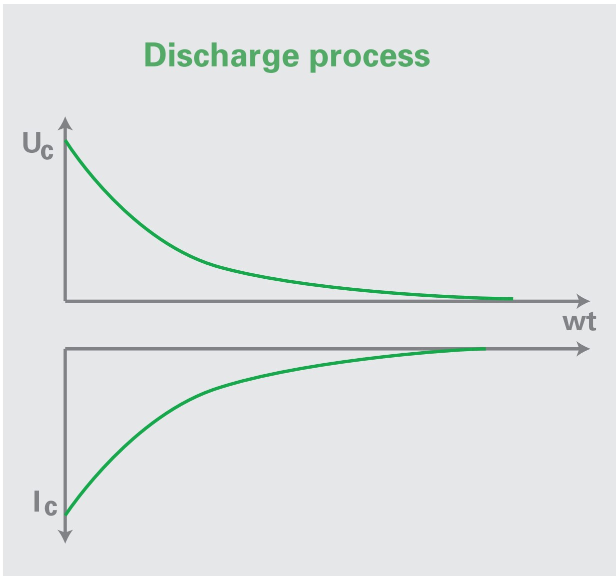
The time constant , is the time needed by a capacitor to gain a 63% of the charge of the impressed voltage, and is denoted as:

$$\tau = R \cdot C$$

R = Ohms (Ω)
C = Farads (F)

In theory, the total capacitor's charge or discharge is produced after an infinite interval of time, as the mathematical function which defines it attains the limit in an asymptotic way. But in practice, the capacitor is charged or discharged in a 5-times interval.





Alternating Voltage

When a capacitor is connected to an alternating voltage, the plates are positively and negatively charged, in an alternating and periodic way, with a flow of alternating current.

The capacitor is periodically charged and discharged, and so the two processes are simultaneous, because of the alternating current flowing through the network. This periodical process provokes an inversion in the direction of the current when this current's value is zero. In the same way as in direct current, the capacitor acts as a finite resistance, measured in ohms:

$$X_C = \frac{1}{2\pi \cdot f \cdot C} \ (\Omega)$$

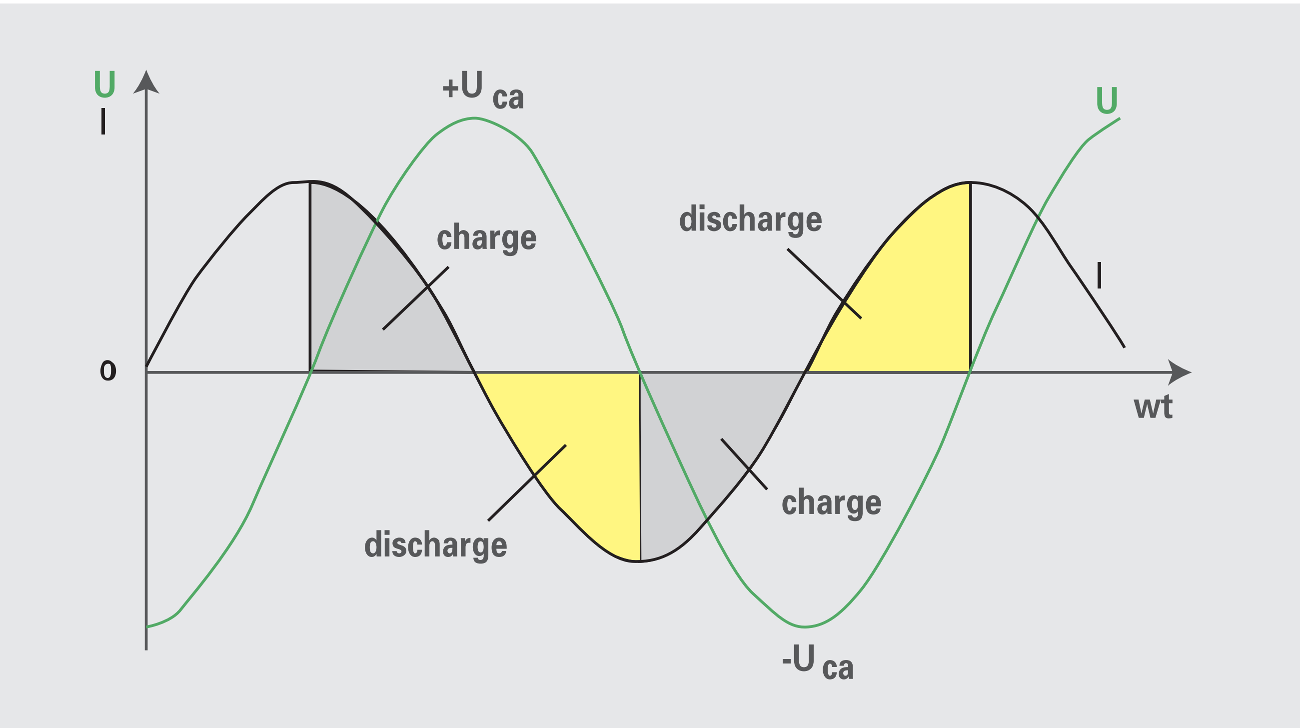
f = frequency (Hz)
C = Farads (F)

When the current's value is zero, the charge process in the capacitor is finished as it will be totally charged at the end of the positive half-wave of the current for a known value of voltage, $+U_{ca}$, and at the end of the negative half-wave with a voltage value of $-U_{ca}$.

The discharge process is produced when the current reaches its maximum value, therefore, the voltage value tends to be zero.

The complete charging and discharging process is done in an electrical voltage semi period. If the electrical voltage's period in Europe is 20 miliseconds, a capacitor will need half of this time for completing its charge or discharge.

$$T_{\text{charge and discharge}} = 10 \text{ ms}$$



Single-phase capacitors

A single-phase capacitor is that which can be implanted between two phases or between phase and neutral.

The reactive power of the capacitor (Q) is measured in VAr, and defined as:

$$I_c = \frac{U_{ca}}{X_c} = \frac{U_{ca}}{\frac{1}{\omega \cdot C}} = U \cdot \omega \cdot C = U_{ca} \cdot 2\pi \cdot f \cdot C$$

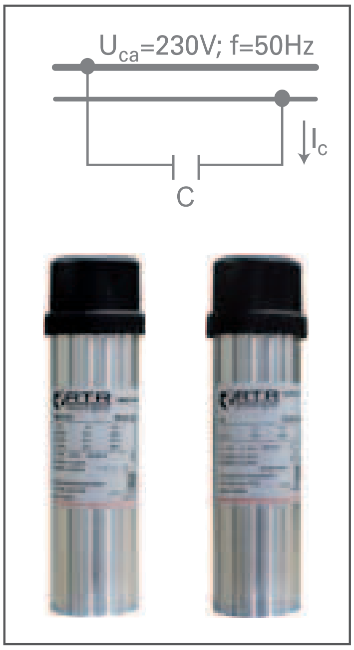
$$Q = U_{ca} \cdot I_c = U_{ca} \cdot (U_{ca} \cdot 2\varpi \cdot f \cdot C) = U^2_{ca} \cdot 2\varpi \cdot f \cdot C$$

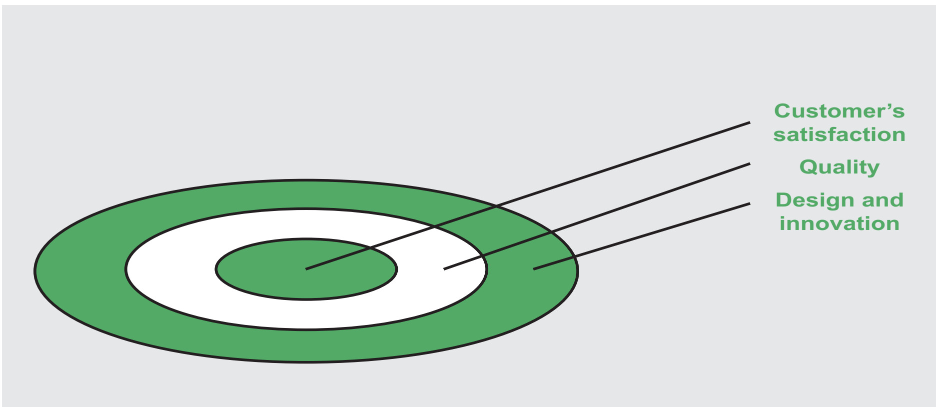
Q, power of the capacitor [VAr]
f, line frequency [Hz]
C, capacitance of the capacitor [F]
U_{ca}, supply voltage [V]
I_c, capacitive current [A]

440V Voltage
Due to the importance of the supply voltage on the reactive capacitor's power, there is a need of knowing why the nearly totality of capacitors **manufacturers**, included **RTR Energía S.L.,** design their capacitors for a 440 V voltage.

With this design, the capacitor's reliability and life increase because it warrants that it will resist an overvoltage that can be produced in the power lead, and that, as it is said in the standard **UNE-EN-50160**, it can be up to a 10%.

The content of the standard UNE-EN-60831-1/2 says that, for industrial frequencies, a capacitor must exist a voltage value of 1.10 x Un at least 8 hours a day.





Three-phase power capacitors

These capacitors are designed for being connected to a three-phase electric line, L1, L2 and L3, and the way of connecting the capacitive elements (coils) in its interior is with two possibilities.

Delta Connection

The total capacitance of the capacitor is divided in three partial capacitances C , as shown in the diagram.

If the capacitance between two phases is taped, for example R-S, the total capacitance will not be the C_Δ of the RS phases but the C_Δ(RS) in parallel with the series connection C_Δ(RT)-C_Δ(ST) (see section G), which means:

$$C_{RS} = C_\Delta + \frac{C_\Delta \cdot C_\Delta}{C_\Delta + C_\Delta} = 1,5 \cdot C_\Delta$$

Now, the reactive power in the capacitor (Q) can be defined, as well as its capacitive current (I_C).

$$Q = 3 \cdot U^2_{ca} \cdot 2\pi \cdot f \cdot C_\Delta$$

$$IC = \frac{Q}{\sqrt{3} \cdot U_{ca}}$$

$Q = [\ VAr\ ]$
$C_\Delta = [\ F\ ]$
$f = [\ Hz\ ]$

Star connection

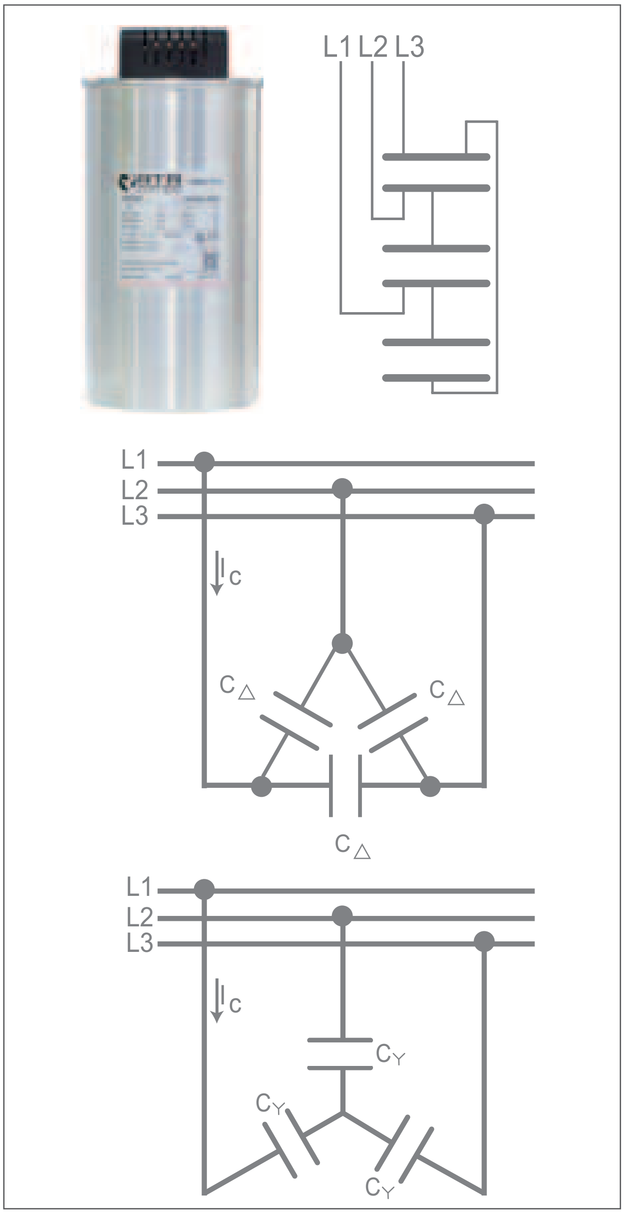
This connection scheme is not so usual, and is used when the line voltage is higher than the one that can be allowed by each of the wirings, as:

$$U_{coll} = \frac{U_{ca}}{\sqrt{3}}$$

The I_c is defined in the same way that it is done in the delta connection, while the reactive power is:

$$Q = U_{ca}^{\ 2} \cdot 2\pi \cdot f \cdot C\gamma$$

$Q = [\ VAr\ ]$ $C\gamma = [\ F\ ]$
$f = [\ Hz\ ]$



For the same 3 wirings:

$$Q_{delta} = 3 \cdot Q_{wye}$$

Combination of Capacitors

Parallel

In the parallel connection between capacitors, the global equivalent capacitance is the sum of the capacitances. The same occurs with the total reactive energy

$$C_T = C_1 + C_2 + C_3 + \ldots C_n$$
$$Q_T = Q_1 + Q_2 + Q_3 + \ldots Q_n$$

The impressed voltage between the capacitor's plates is the one that can be allowed depending on the capacitor's constructive characteristics. All the capacitors are affected by the same voltage.

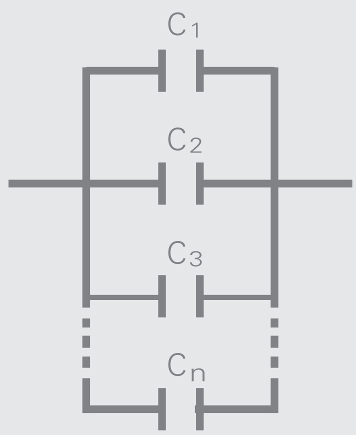
Series

When the working voltage, U_{ca} is higher than the rated voltage on the manufactured capacitor, a group of capacitors can be connected in series. In this case, every capacitor will have a different voltage between plates, depending on its capacitance and reactive power. As every series connection, the current flowing through them is the same for every capacitor. The inverse of the total capacitance (C_T) is the sum of the inverses of the different capacitances.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots + \frac{1}{C_n}$$

$$\frac{1}{Q_T} = \frac{1}{Q_1} + \frac{1}{Q_2} + \frac{1}{Q_3} + \ldots + \frac{1}{Q_n}$$

The reactive power (Q_T) has the same behaviour as the capacitance, thus the inverse of the total reactive is the sum of the inverses of the different reactives.

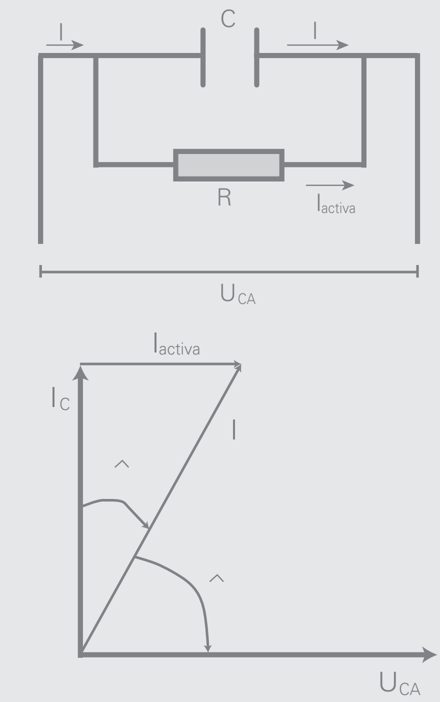


Leakage Capacitor's Tangent

The leakage tangent of a capacitor (tan δ) is the value that can define the quality and behaviour of an electrical capacitor. The leakages in a capacitor can be related and represented throughout the losses of an ohmic resistance (R).

Considering an ideal capacitor, without losses, the angle of phase difference $\hat{\phi}$ between the current I_C and the voltage U_{CA} is 90º.

Due to these losses, the angle of phase difference $\hat{\phi}$, is not of 90º, and the voltage, U_{CA} is lagging with respect to the active current I_{active} and the new angle formed is the loss angle, defined as $\phi = 90º - \hat{\phi}$, . Its tangent is the leakage tangent of the capacitor.



$$\tan\delta = \frac{I_{activa}}{I_C} = \frac{\frac{U_{CA}}{R}}{\frac{U_{CA}}{X_C}} = \frac{X_C}{R} = \frac{\frac{1}{2\pi \cdot f \cdot C}}{R} = \frac{1}{2\pi \cdot f \cdot C \cdot R}$$

The loss power (P_P) of a capacitor, measured in watts (*W*) is:

$$P_P = U_{CA} \cdot I \cdot \cos\hat{\varphi} = U_{CA} \cdot I \cdot \text{sen}\hat{\delta} = Q \cdot \text{tg}\hat{\delta}$$

$$P_P = Q \cdot \text{tg}\hat{\delta}$$

$$P_P = [\,W\,] \qquad Q = [\,VAr\,]$$

The capacitance of a capacitor is reduced with its lifetime, which increases gradually the capacitor's losses, due to the inverse ratio of the leakage tangent and the capacitance.

RTR Energía S.L. prioritizes its product's quality by using the best metallized film, manufactured in European Union.

The quality process guarantees that the losses power of the capacitors is inferior to 0.45 W/kVAr,

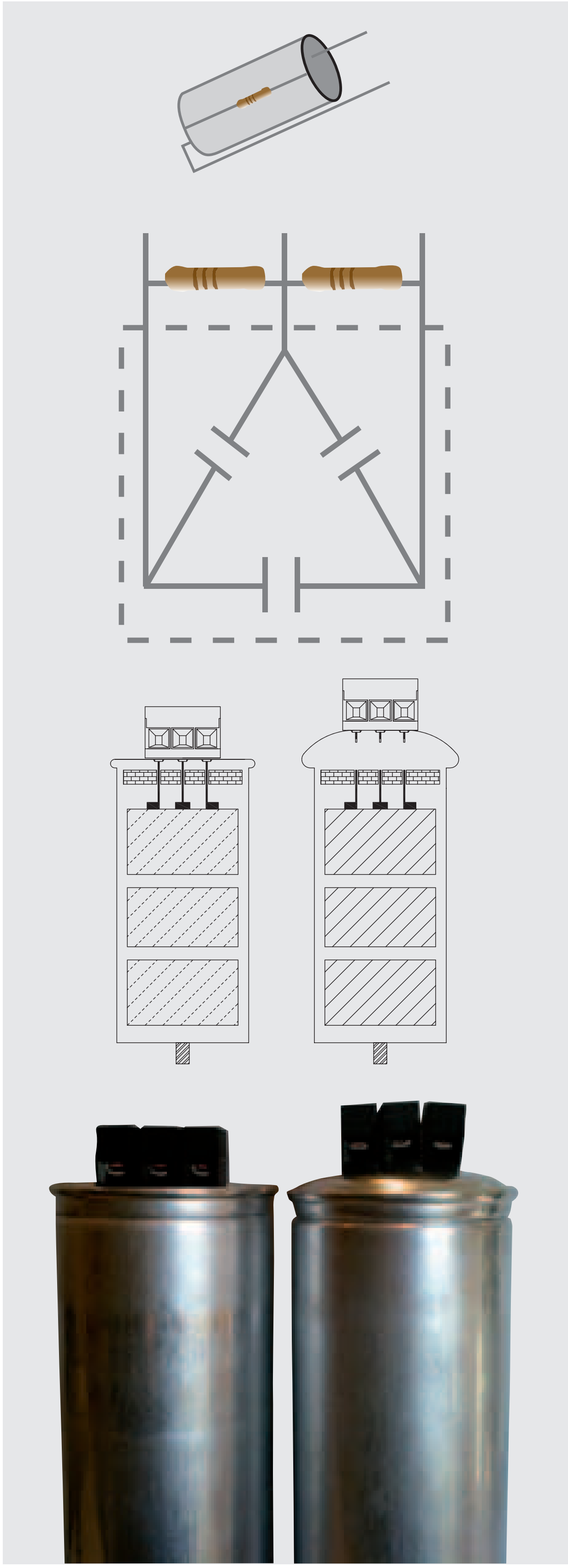
$$0.45 \leq \frac{P_P\,(W)}{Q\,(kVAr)} \rightarrow \text{tg}\hat{\delta} \leq 4.5 \cdot 10^{-4}$$

Handling Precautions and Security

When handling a capacitor, there is a need of taking into account a series of security precautions. When a capacitor is disconnected off the voltage, it remains charged with the supply voltage. If the plates are shorten and touched, they can cause a dangerous accident due to the violent discharge of the capacitor.

The standards **EN-61048** and **EN-60252** establish the need of the lighting and motor run capacitors of having a discharge resistors, so that when the supply voltage is switched off, it must store a maximum voltage of 50V in an interval of 60 seconds.

In the same way, the three-phase capacitors must be equipped with a snubber resistor, which can discharge voltage until its maximum value is 75V in an interval of 3 minutes, as it is stablished in the annexe B of the standard EN-60831-1/2.



Disconnection System

Due to extreme and inadmissible operating conditions of overvoltage, overcurrent or high temperature, RTR Energía S.L. has designed an overpressure release system, which works by unpacking the terminal covers, thus the terminal connection with the capacitive element is interrupted.

RTR Energía, patented design DWCAP capacitor have aditional safety feature which formed by two aligned elements with overpressure disconnection system in abnormal condition inner part of elements displace and interrupted.

Under this conditions and seeking a right performance of the release system, it is very important that the resin of the enclosure is designed to avoid that the metal fusion's gases are entrapped. It must allow these gases to rise, and so the system will work accurately. Because of this, RTR Energía S.L. has a Chemical division which develops and manufactures the electrical resins, depending on each of the applications.

Now, we use V0 self-extinguishing polyurethane resin, developed under standard UL94 and certification number 20141031-E470994.

Operating Conditions

TEMPERATURE
The capacitors must operate under the following limits:

Maximum 55ºC
Daily average 45ºC
Annual average 35ºC

This means that a capacitor must never reach a value beyond 55 ºC, or remain more than 24 hours beyond 45 ºC or more than a year beyond 35 ºC of temperature.

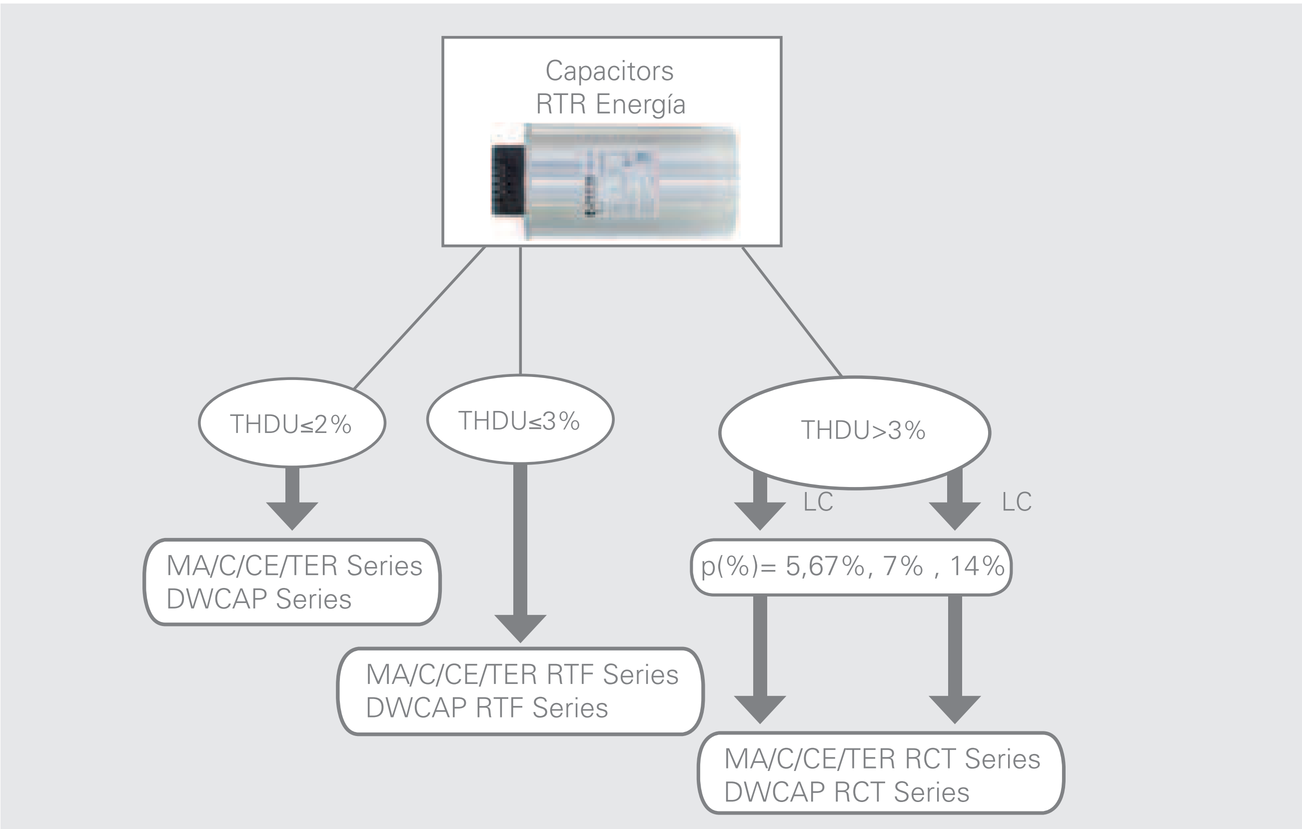
VOLTAGE
The maximum overvoltage that a capacitor can bear is of 1,10 times the rated voltage, as it has been explained in the Scheme E.

CURRENT
The maximum current that a capacitor can reach is 1,5 the rated current ($1{,}5 \cdot I_n$).

ALTITUDE
The capacitor's installation altitude must not exceed 2000 m over the sea level. In higher altitudes, the heat dissipation is reduced, and this must be considered when dimensioning the capacitor.

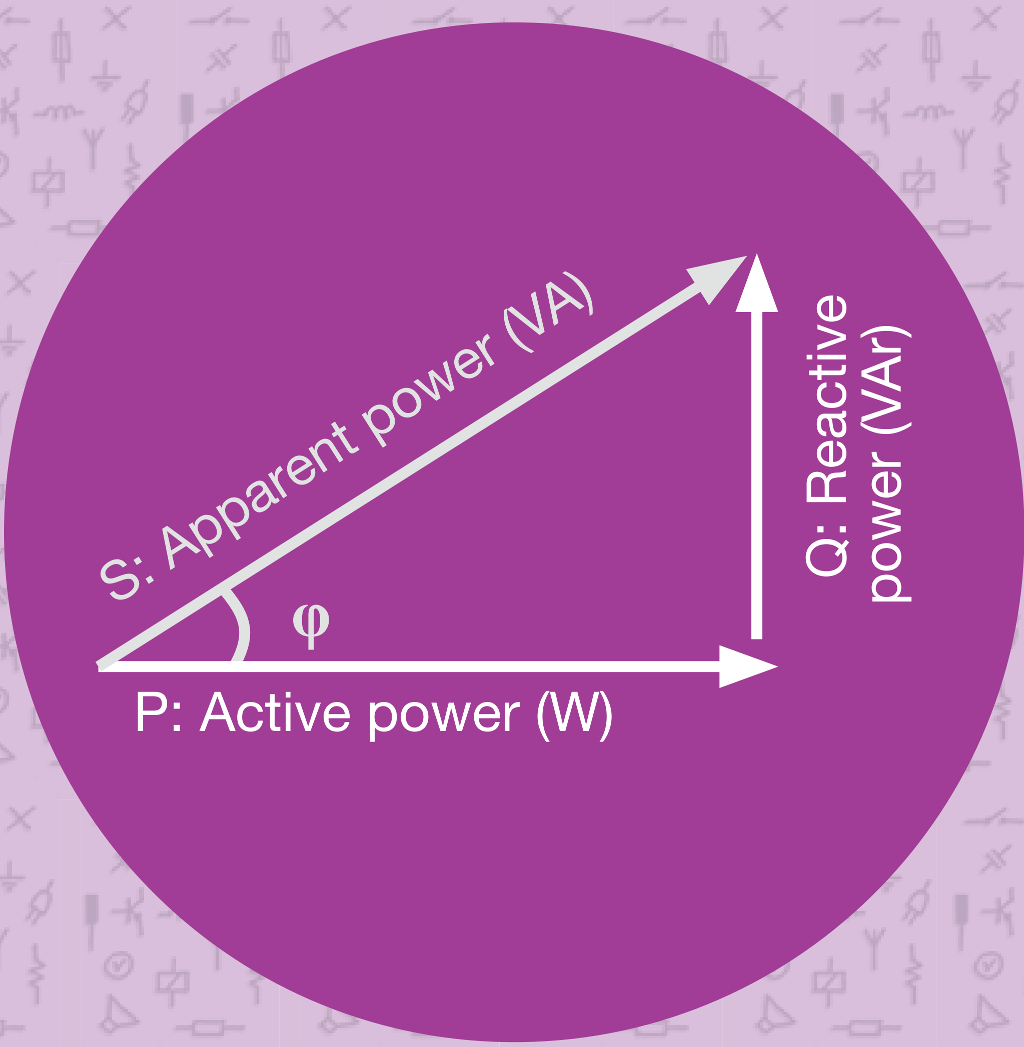
HARMONICS
The harmonics presence which a capacitor can bear is determined taking on account that the voltage and current maximum limits must not be surmounted. These limits are shown below:

$THDU_{max}$ 2%
$THDI_{max}$ 25%



NOTES

Reactive Energy



Compensation

Electric power

Electric power can be defined as "the capability of an electric equipment of doing a mechanical work, or the work quantity that can be obtained in a determined amount of time"

It is measured in watts (W), and its most frequent multiples are the kilowatt (kW) and the megawatt (MW), while the most used submultiple is the miliwatt (mW).

However, in AC power supply equipments which running is based in electromagnetism, such as transformers, motors, etc, by generating their own magnetic field, there are three different types of power coexisting:

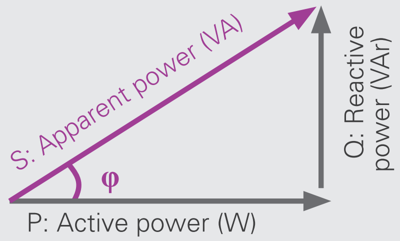
- Active power (P)
- Reactive power (Q)
- Apparent power (S)

These three different types of power can be related by a power-triangle. There is an angle "ϕ" formed by the apparent and the active powers, which defines the out-of-phase between the voltage (U) and the current (I), and its cosine of this phase angle is equivalent to the line power factor (PF) when there is no harmonic distortion.

POWER FACTOR (PF)

The power factor (PF) is the ratio of active power (P) to the apparent power (S) and is determined by the kind of loads connected to the installation, where the resistive loads have a power factor close to unity.

When inductive and reactive loads are introduced, power factor can vary by leading and lagging the current with respect to the voltage.



$P = S \cdot \cos(\varphi)$ $\qquad$ $Q = S \cdot \text{sen}(\varphi)$

Where S is:

$S = \sqrt{3} \cdot U \cdot I$ in three-phase lines

$S = U \cdot I$ in single-phase lines

This out-of-phase can measure the power factor.

Most common industry power factors:	
Asynchronous motor 50% of load	0,73
Asynchronous motor 100% of load	0,85
Arc welding static equipments	0,5
Rotational welding groups	0,7-0,9
Arc welding recitfiers	0,7-0,9

Power factors in small electric installations:	
Fluorescent lamp	0,5
Discharge lamp	0,4-0,6
Dielectric heating furnaces	0,85
Arc furnaces	0,8
Induction furnaces	0,85

ACTIVE POWER (P)

Active power represents the real power, measured in watts (W). Thus, the amount of energy used when an electric equipment is functioning and working, i.e. the energy given by a motor shaft when moving a device, the energy given, in terms of heat, by an electric heater resistance, or the light given by a lamp, etc.

Active power is also the hired power to the electric company, and can reach households, industries, offices or any other facility when it is needed, along the supply network. The global amount of power, used by the totality of electric appliances is normally registered by counters or other electrical meters, which are installed by the deliverer companies in order to measure the totality of electric energy consumed in a particular period of time, specified in contracts.

REACTIVE POWER (Q)

Reactive power is the power consumed by motors, transformers or any other electric device including any kind of coil, so that it creates an electromagnetic field. These coils are part of an electric circuit, and in electric systems they constitute loads, consuming both active and reactive power. Their work efficiency depends on their power factor; the lower it is (far-off unitiy) the bigger is the amount of reactive power consumed. Besides, reactive power does not produce any effective power and produces a negative impact on the energy transmission through the distributing electric lines, thus its consumption is penalized throughout the tariff by the mains supply company. Reactive power is measured by volt-ampere reactive (VAr), and its most frequent multiple is the kilovoltampere (kVAr).

APPARENT POWER (S)

Apparent power or gross power is, according to the Pythagoras theorem, is the active and reactive power sum. These two components represent the total line input power, also the totality of the power given by the electric generators in the set. This power is imparted along distribution cables, also lines, reaching consumers in households, factories, industrial plants, etc. Apparent power is measured in volt-ampere (VA).

Reactive Energy Associated Troubles

Losses Increment in Conductors

- Conductor heating accelerates the isolation damage, reducing its lifetime and producing possible shortcircuits.
- Capacity droop on the National Electrical Network, when generating an extra amount of energy, due to loss compensation.
- Winding heating in transformers. -Resist drop-outs without an apparent cause.

Joule effect losses
$P_{losses} = I^2 \cdot R$

I: current flowing through the conductor, in ampere (A)
R: conductor's resistance, in ohm (Ω)

Generators and Transformers Overload

A current excess because of a low power factor can induce generators and transformers become overloaded, reducing therefore their useful lives when overrunning their design ratings.

Potential Drop Growth

Current flowing through an electric conductor produces a potential drop, which is defined by Ohm's Law.

The current growth because of a low power factor will produce a bigger potential drop, causing an insufficient power supply in loads requirement, reducing, thus reducing in them the output power.

Reactive Energy Compensation's Benefits

JOULE EFFECT LOSSES DROOP

If the current is substituted by the active power expression in the Joule's effect losses formula, the following relation is obtained:

$$\frac{Losses_f}{Losses_i} = \left(\frac{\cos\phi_i}{\cos\phi_f}\right)^2$$

Losses: initial losses
Losses: final losses
$\cos\phi_i$: initial power factor
$\cos\phi_f$: final power factor

Joule effect losses decrement:				
$\cos\phi_{inicial}$	$\cos\phi_{final}$			
	0,85	0,90	0,95	1,00
0,50	65,40%	69,14%	72,30%	75,00%
0,55	58,13%	62,65%	66,48%	69,75%
0,60	50,17%	55,56%	60,11%	64,00%
0,65	41,52%	47,84%	53,19%	57,75%
0,70	32,18%	39,51%	45,71%	51,00%
0,75	22,15%	30,56%	37,67%	43,75%
0,80	11,42%	20,99%	29,09%	36,00%
0,85	-	10,80%	19,94%	27,75%
0,90	-	-	10,25%	19,00%
0,95	-	-	-	9,75%

Reactive Energy Compensation's Benefits

POTENTIAL DROP DECREMENT ON DISTRIBUTION LINES

The current must overcome the conductor's electric impedance (Z) while the electric energy is being transported, therefore a potential drop is produced.

Potential drop can be determined by Ohm's law, and is the product of current and resistance. If the value of the demanded current is substituted by its equivalent in terms of line power, the following expression is obtained:

$$\Delta U = \frac{P_{active} \cdot Z}{\sqrt{3} \cdot U \cdot \cos\phi} = \frac{cte}{\cos\phi} \rightarrow \frac{\Delta U_f}{\Delta U_i} = \frac{\cos\phi i}{\cos\phi f}$$

ΔU Potential drop in the line
U, Distribution voltage
Z, Conductor's impedance

Powerl drop decrement on distribution lines:				
$\cos\phi_{inicial}$	$\cos\phi_{final}$			
	0,85	0,90	0,95	1,00
0,50	41,18%	44,44%	47,37%	50,00%
0,55	35,29%	38,89%	42,11%	45,00%
0,60	29,41%	33,33%	36,84%	40,00%
0,65	23,53%	27,78%	31,58%	35,00%
0,70	17,65%	22,22%	26,32%	30,00%
0,75	11,76%	16,67%	21,05%	25,00%
0,80	5,88%	11,11%	15,79%	20,00%
0,85	-	5,56%	10,53%	15,00%
0,90	-	-	5,26%	10,00%
0,95	-	-	-	5,00%

CAPACITY GAIN ON THE ELECTRIC LINE

If the power factor were compensated, part of the extra power, produced in order to reduce losses, could be used in the electrical provided consumption. Checking out the consumption and losses profiles, the Spanish National Electrical Distributor could gain a 0,5% in capacity, enough energy for more than a twoyear Ceuta and Melilla supply.

Reactive Energy Compensation´s Economic Saving

Reactive power compensation is good not only as a technical advantage but also as an economical one.

Since January 2012, companies in Spain with an electrical contract of 15kW or more (basically, every commercial enterprise from a small store up to a big industry) can be suffering bursts in their billing, because of a legal change published in BOE, on December 31, 2009, which tries to actuate on energetic efficiency throughout a more responsible use of energy in companies.

Obviously, this new legislation is specially affecting industrial plants which use transformers, motors and any other industrial receptor that needs magnetic fields for running.

Reactive energy compensation is achieved by the installation, in electric lines, of capacitor banks, which can generate capacitive loads, so that reactive losses in the wiring are reduced.

With these new rates, any industrial plant which has basic equipment, such as furnaces or fluorescent lamps (see charts in section A), can suffer charge build-ups due to reactive energy.

This amendment means to users which, until now did not pay any reactive energy consumption, are suffering, since January 2010, a burst on their electrical billing.

Reactive power prices in Spain			
cosϕ	/kVArh 2009	€/kVArh 2010	%increase 2009-2010
cosϕ ≥ 0,95	0	0	-
0,9 ≤ cosϕ < 0,95	0,000013	0,041554	319,546%
0,85 ≤ cosϕ < 0,9	0,017018	0,041554	144,18 %
0,8 ≤ cosϕ < 0,85	0,034037	0,041554	22,08 %
cosϕ < 0,8	0,051056	0,062332	22,08 %

Capacitive Energy Calculation Needed for Compensation

In order to determine the power factor for its correction, a three-step method is used, which can be followed in the attached block diagram:

1. Installation's reactive power computation
2. Capacitive power, needed to compensate, computation
3. Installation's power factor (*PF*) variability computation

REACTIVE ENERGY COMPUTATION

The installation's reactive power calculation implies determining its power factor (*PF*). Therefore, the facility needs to be studied with, among other equipment:

- An electric line analyser
- An energy consumption bills analysis, as shown in the block diagram.

CAPACITIVE POWER COMPUTATION

Once the installation's *PF* is determined, the value of the desired power factor (which will totally remove reactive energy), ($PF_{desired}$) must be selected. This value is going as close to unity as possible.
There is a value, named ***"k factor"***, which is defined by the tangent's difference, and its most frequent values are listed in the table below.

Once the *F* and *k* values have both been defined and calculated, the capacitive power (P_{kVAr}) in kVAr, needed for the FP compensation, can be calculated too ***RTR Energía S.L.*** suggests an increase of 15-20% of the (P_{kVAr}) value, in order to forecast any other capacity increments.

P = Σ Active powers (kWh)
Q = Σ Reactive powers (kVArh)

$$PF = \cos(\varphi) = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2}}$$

$$PF_{desired} = \cos(\varphi_{desired})$$

$$k = \tan(\varphi_{initial}) - \tan(\varphi_{desired})$$

F Value determination (kW):

- Power (kW) measured with a peak demand meter.
- Consumption of power (kW) by the plant.
- The product of the power value (kWh) and the operating number of hour.

$$P_{kVAr} = k \cdot F$$

Example

F = 85kW maximum demand
$\cos(\varphi_{initial})$ = 0,73
$\cos(\varphi_{desired})$ = 1

k = 0,936 table values

P_{kVAr} = 85 · 0,936 = 79,56 *kVAr*
$P_{kVAr\ recommended}$ = 95 *kVAr*

POWER FACTOR'S VARIABILITY COMPUTATION

If a central compensation scheme is chosen (see section F), the fluctuation pattern of the PF with time must be known, in order to decide the number of steps needed by the bank for achieving the calculated capacitive power throughout time.

For example, assuming an 80 kVAr battery is needed, and knowing that 60 kVAr are produced by a fixed motor, the remaining 20 kVAr can appear and disappear intermittently during the day.

- 1:1:1:1...all the steps' capacitive power is the same.
- 1:2:2:2...the capacitive power of the first step is half that of the other steps.
- 1:2:4:4...the capacitive power of the first step is half that of second step, and the latter is in turn half that of the rest of the step.

2 steps of 40 kVAr
Step Sequence: 1:1:

The second 40kVAr step is switched on and off permanently **NO**

4 steps of 20 kVAr
Step Sequence: 1:1:1:1

The fourth 20kVAr step is switched on and off permanently **NO**

2 steps of 5 kVAr
1 steps of 10 kVAr
3 steps of 20 kVAr
Step Sequence: 1:1:2:4:4:4

Optimum solution **OK**

Usual *k* factor vualues

FP before compensation		PF AFTER COMPENSATION											
		cosφ	**0,80**	**0,84**	**0,88**	**0,90**	**0,90**	**0,95**	**0,96**	**0,97**	**0,98**	**0,99**	**1,00**
		tgφ	0,750	0,646	0,540	0,484	0,484	0,329	0,292	0,251	0,203	0,142	0,000
cosφ	tgφ												
0,400	2,291		1,541	1,645	1,752	1,807	1,865	1,963	2,000	2,041	2,088	2,149	2,291
0,430	2,100		1,350	1,454	1,560	1,615	1,674	1,771	1,808	1,849	1,897	1,957	2,100
0,460	1,930		1,180	1,284	1,391	1,446	1,504	1,602	1,639	1,680	1,727	1,788	1,930
0,490	1,779		1,029	1,133	1,239	1,295	1,353	1,450	1,487	1,528	1,576	1,637	1,779
0,520	1,643		0,893	0,997	1,103	1,158	1,217	1,314	1,351	1,392	1,440	1,500	1,643
0,550	1,518		0,768	0,873	0,979	1,034	1,092	1,190	1,227	1,268	1,315	1,376	1,518
0,580	1,405		0,655	0,759	0,865	0,920	0,979	1,076	1,113	1,154	1,201	1,262	1,405
0,610	1,299		0,549	0,653	0,759	0,815	0,873	0,970	1,007	1,048	1,096	1,157	1,299
0,640	1,201		0,451	0,555	0,661	0,716	0,775	0,872	0,909	0,950	0,998	1,058	1,201
0,670	1,108		0,358	0,462	0,568	0,624	0,682	0,779	0,816	0,857	0,905	0,966	1,108
0,700	1,020		0,270	0,374	0,480	0,536	0,594	0,692	0,729	0,770	0,817	0,878	1,020
0,730	0,936		0,186	0,290	0,396	0,452	0,510	0,608	0,645	0,686	0,733	0,794	0,936
0,760	0,855		0,105	0,209	0,315	0,371	0,429	0,526	0,563	0,605	0,652	0,713	0,855
0,790	0,776		0,026	0,130	0,236	0,292	0,350	0,447	0,484	0,525	0,573	0,634	0,776
0,800	0,750		-	0,104	0,210	0,266	0,324	0,421	0,458	0,499	0,547	0,608	0,750
0,810	0,724		-	0,078	0,184	0,240	0,298	0,395	0,432	0,473	0,521	0,581	0,724
0,820	0,698		-	0,052	0,158	0,214	0,272	0,369	0,406	0,447	0,495	0,556	0,698
0,830	0,672		-	0,026	0,132	0,188	0,246	0,343	0,380	0,421	0,469	0,530	0,672
0,840	0,646		-	-	0,106	0,162	0,220	0,317	0,354	0,395	0,443	0,503	0,646
0,850	0,620		-	-	0,080	0,135	0,194	0,291	0,328	0,369	0,417	0,477	0,620
0,860	0,593		-	-	0,054	0,109	0,167	0,265	0,302	0,343	0,390	0,451	0,593
0,870	0,567		-	-	0,027	0,082	0,141	0,238	0,275	0,316	0,364	0,424	0,567
0,880	0,540		-	-	-	0,055	0,114	0,211	0,248	0,289	0,337	0,397	0,540
0,890	0,512		-	-	-	0,028	0,086	0,184	0,221	0,262	0,309	0,370	0,512
0,900	0,484		-	-	-	-	0,058	0,156	0,193	0,234	0,281	0,342	0,484
0,910	0,456		-	-	-	-	0,030	0,127	0,164	0,205	0,253	0,313	0,456
0,920	0,426		-	-	-	-	-	0,097	0,134	0,175	0,223	0,284	0,426
0,930	0,395		-	-	-	-	-	0,067	0,104	0,145	0,192	0,253	0,395
0,940	0,363		-	-	-	-	-	0,034	0,071	0,112	0,160	0,220	0,363
0,950	0,329		-	-	-	-	-	-	0,037	0,078	0,126	0,186	0,329
0,960	0,292		-	-	-	-	-	-	-	0,041	0,089	0,149	0,292
0,970	0,251		-	-	-	-	-	-	-	-	0,048	0,108	0,251
0,980	0,203		-	-	-	-	-	-	-	-	-	0,061	0,203
0,990	0,142		-	-	-	-	-	-	-	-	-	-	0,142

Configurations for Reactive Energy Compensation

INDIVIDUAL COMPENSATION

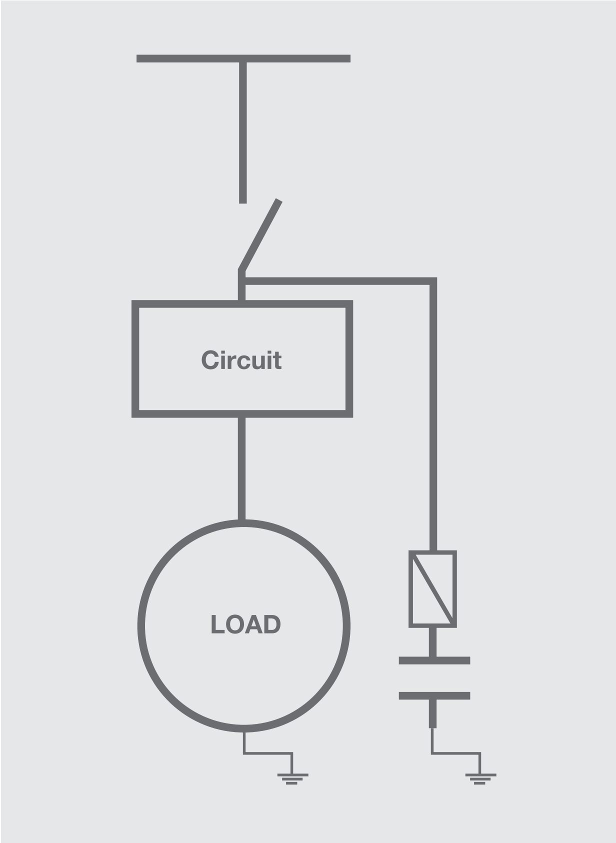
Individual compensation is used in continuous working cycle equipments, where reactive consumption is significant, mainly in electric motors and transformers. The capacitor is installed in every single load, so the only conductors affected by the reactive energy are those who are uniting load and capacitor. This configuration has, on the one hand, the following advantages:

- Reactive energy is confined between load and capacitor. Therefore, the remaining lines are free from this reactive energy.
- The capacitor is switched on only when there is a connected load, as the starter functions as the capacitor's switch so no other control system is needed.

On the other hand, this configuration has the following disadvantages:

- Individual capacitor's price is higher than that of an equivalent capacitor on its own.
- Capacitor's are under-used when an individual load remains idle for a long period of time.

This fixed-compensation configuration has to be studied carefully when any of the following highlighted cases: in asynchronous motor's compensation and power transformers (see section G).

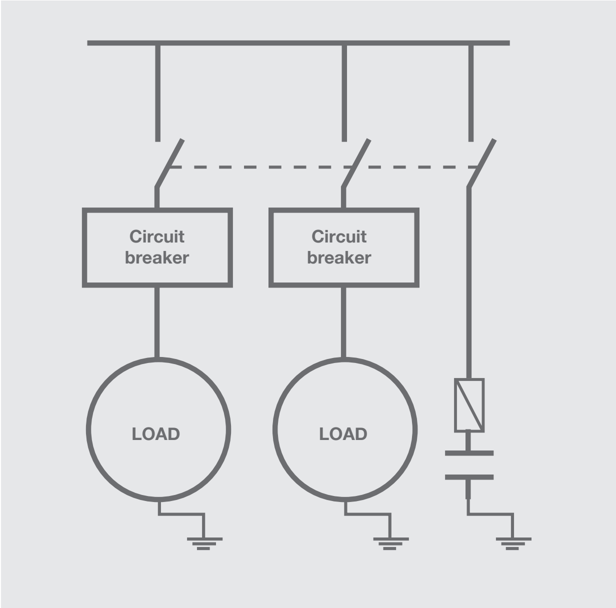


GROUP COMPENSATION

The group-compensation configuration is suggested when a group of loads (either different or not) are simultaneously connected, thus demanding a constant amount of reactive energy.
This configuration has, on the one hand, the following advantages:

- The capacitors bank can be put in where motors control centre.
- Capacitors are only used when the loads are working
- It has a lower set-up cost.
- Reactive power is totally removed from distribution lines.

There is, on the other hand, a disadvantage on the main power lead: there is still reactive power remaining between loads and the motors control centre.

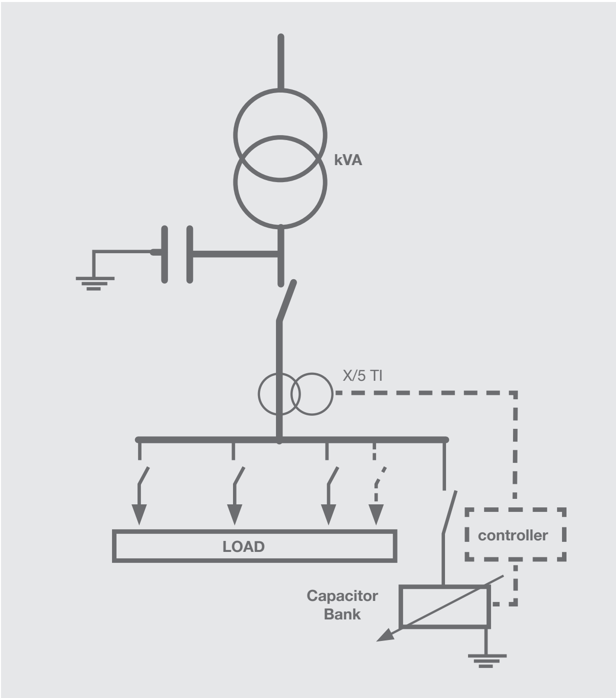


CENTRALIZED COMPENSATION

The total capacitor's bank power is installed (put in) on the tapping, next to the energy feedboards. The total bank power is divided between a number of packs or steps, put through with an automatic controller which can switch them on and off when wanted, depending on the instant reactive consumption. This configuration has, on the one hand, the following advantages:

- More efficient use of capacitor's capacity.
- Better voltage regulation in electric systems.
- Bank's power output adjusts according to any given instant requirement

On the other hand, the shortcoming of this configuration is that power distribution lines are not relieved from reactive power, and still an automatic controller is needed in the setup.



Motors and Transformers Compensation

ASYCHRONOUS THREE-PHASE MOTOR'S DIRECT STARTING

When compensating individual asynchronous motors, care must be taken in order to avoid self-excitation appearance. Self-excitation begins when the motor is turned off, as it remains spinning because of the inertia, until it finally stops. When the feed is cut out, if the compensation has been done on the motor's terminals then the capacitor's capacitive currents on the stator will generate a magnetic field on the rotor in the same direction as the decreasing magnetic field. Thus, the motor will work as a generator, and this will cause overvoltages in the motor terminals.

There are two possible solutions in order to avoid self-excitation appearance:

- Capacitor's capacitive currents can be limited through the capacitor bank power's limitation so that they are lower than the motor's void current (EN60831-1 standard advices that void current should never be higher than the 90% reactive void motor's power).
- Compensation can be done in terminals throughout a contactor. This way, when the motor is turned off from the feed, capacitors will remain insulated from the motor terminals.

In practice we can consider:

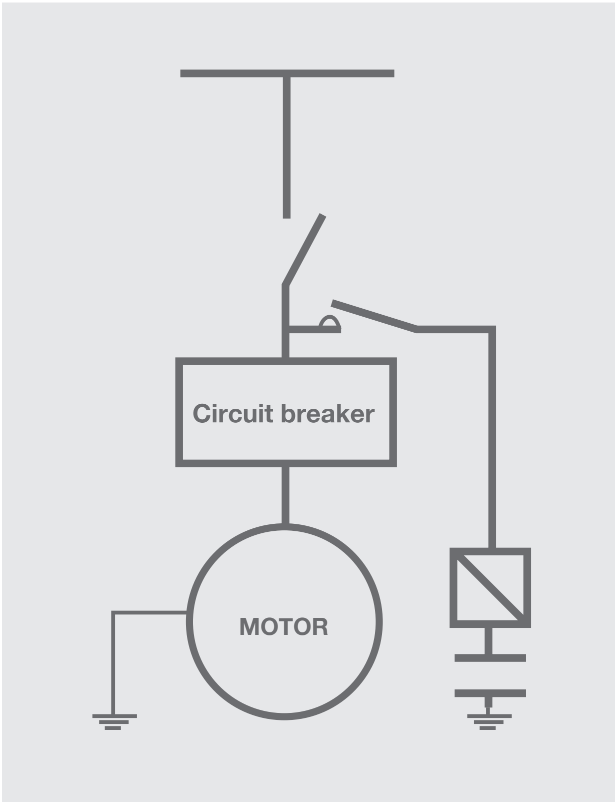
$Q_{compensation} = 0,3 \cdot P_{prated\ of\ motors}$

$$Q_{compensation} = P \cdot (\tan\phi_i - \tan\phi_f)$$

$$Q_{compensation} \leq Q_{limit}$$

$$Q_{limit} = 0.9\sqrt{3} \cdot U_n \cdot I_0 \quad ó$$

$$Q_{limit} = 2 \cdot P (1 - \cos\phi_{initial})$$

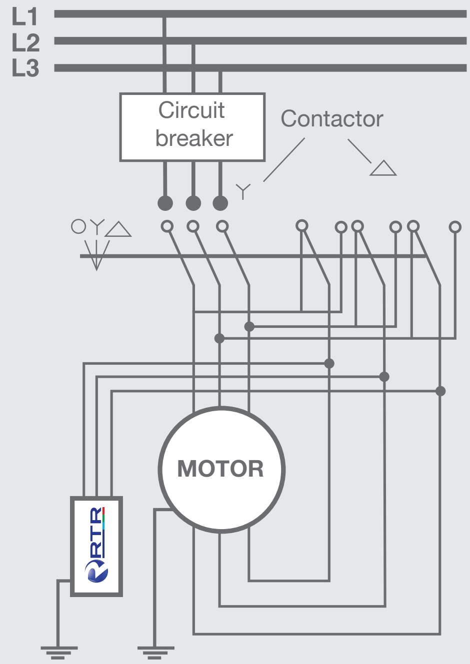


WYE-DELTA STARTER

Sometimes the direct asynchronous motor's connection is not possible, normally because of the current peaks that appear during the starting (start). When this occurs, wye-delta commutators are used.

If the motor is fitted with a wye-delta starter, the capacitor's connection will be done with connectors, so that the capacitor will be switched when the motor has finished its start (wye) and has achieved a continuous rating.

Using this starting method avoids overcurrents and overvoltages during motor starting.



Switching from Closed to Wye:
1. Open Delta connections.
2. Close connections to the grid.
3. Close connections to the neutral point.

Wye - Delta connections switching:
1. Open connections to the neutral point.
2. Close Delta connections.

ASYNCHRONOUS THREE PHASE MOTOR'S COMPENSATION TABLE:

Motor Output		Capacitor power kVAr			
kW	**CV**	**3000 rpm**	**1500 rpm**	**1000 rpm**	**750 rpm**
7,5	**10**	2,50	2,50	2,50	5,00
11	**15**	2,50	2,50	5,00	5,00
15	**20**	5,00	5,00	5,00	7,50
18	**25**	5,00	5,00	7,50	10,00
22	**30**	7,50	7,50	10,00	10,00
30	**40**	10,00	10,00	12,50	15,00
37	**50**	12,50	15,00	17,50	20,00
45	**60**	15,00	17,50	20,00	22,50
55	**75**	17,50	25,00	22,50	25,00
75	**100**	22,50	27,50	27,50	32,50
90	**125**	25,00	30,00	35,00	40,00
110	**150**	30,00	35,00	42,50	45,00
132	**180**	37,50	45,00	45,00	55,00
160	**220**	45,00	50,00	60,00	65,00
200	**270**	50,00	60,00	67,50	80,00
250	**340**	60,00	65,00	75,00	85,00
280	**380**	70,00	77,50	85,00	95,00
355	**485**	85,00	95,00	107,50	122,50
400	**544**	100,00	105,00	125,00	135,00

Note: The values in this table are for information only

REACTIVE ENERGY COMPENSATION

Motors and Transformers Compensation

POWER TRANSFORMERS

Transformers reactive energy compensation must be enough to rectify the reactive energy that can appear during its void working, as this is a constant value (Q_0) and also the absorbed reactive energy when charged.

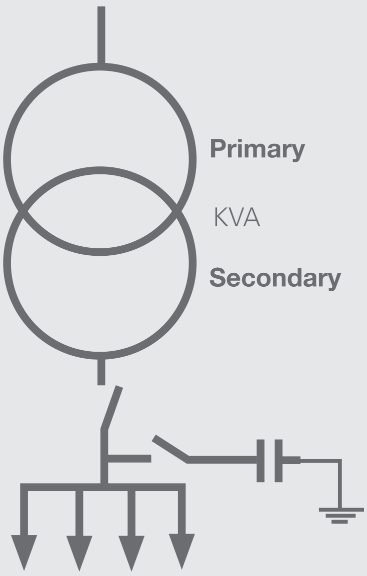
The following table includes some approximate reactive power values of the capacitors, depending on the transformer power.

$$Q_{compensation} = Q_0 + Q_{load}$$

$$Q_{compensation} = \sqrt{3} \cdot U \cdot \frac{I_0}{100} + \frac{U_{CC}}{100} \cdot \left(\frac{S}{S_n}\right)^2 \cdot S_n$$

Where:

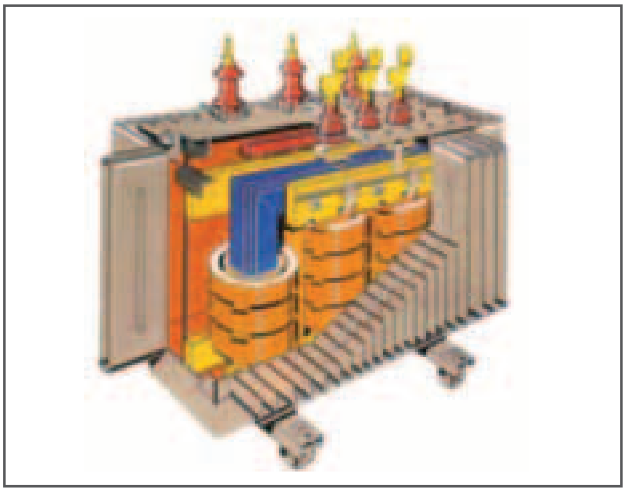
I_0 = Magnetizing current in %
U = Rated Primary Voltage
U_{CC} = Short Circuit Voltage %
S = Rated Apparent Power
S_n = Working Power



In practice we can consider:

$Q_{compensation} = 0{,}05 \cdot S_n$ si $S_n \leq 1000kVA$

$Q_{compensation} = 0{,}03 \cdot S_n$ si $S_n > 1000kVA$



POWER TRANSFORMERS COMPENSATION TABLE

Power kVA	Voltage < 24 kV	Voltage > 24 kV
25	2,50	2,50
50	5,00	5,00
100	7,50	10,00
160	10,00	12,50
250	15,00	20,00
400	20,00	25,00
500	25,00	30,00
630	30,00	40,00
800	45,00	50,00
1000	60,00	65,00
1250	70,00	80,00
1600	90,00	100,00
2000	112,50	120,00
2500	155,00	165,00

Note: The values in this table are for information only

Quality, Installation and Protection

RTR Energía S.L. power capacitors are manufactured under a strict Quality Control that verifies the capacitor's correct working in every production line. In order to obtain the best capacitor's performance it is very convenient to follow the installation suggestions, supplied with every capacitor.

SWITCHGEARS
They should be, preferably suitable for sudden breakdown, and dimensioned for a 1.6 to 2 times the rated capacitor's current.

FUSES
As switchgears, they should be suitable for sudden breakdown and able to manage the high charge and discharge current capacitor's values. So, their calibration must be done between 1.6 and 2 times the capacitor's rated one.

CONDUCTORS
For the same reasons explained before, the minimum wire section must be 1.8 times bigger than that used for rate current.

TEMPERATURE
Ambient temperature for a satisfactory capacitors working should be within -25° C and 55° C. Because of this, if there were reactances placed in the setup, capacitors should be located below them, in ventilated and air-conditioned areas if needed.

RTR Energía S.L. seeks to maintain continuous improvement, and has been awarded the certification of its Quality Assurance System under **ISO 9001**, as well as the enviromental management systems **ISO 14001** by **SGS** and products certified by **UL** and **AENOR**

Never manipulate charged capacitors. Before touching a capacitor, even when discharge resistors have been fitted, the capacitor terminals should be short-circuited and grounded.

Case Study: Commercial Establishment

An example of a real-life case of power factor compensation in a hostelry-place is presented here. The installation has a 40 kW demand and a monthly bill of 1468,66 of the consumed energy plus 420,42 of reactive energy. Therefore, if reactive energy is compensated, the billing will be reduced in a 28%.
The power consumption statistics shown below divides the customer's power bill in 6 day-intervals. For each period, the active and reactive powers and the peak demand (peak demand meter reading) are shown.

GLOBAL COMPENSATION COMPUTING

Following the calculation steps shown in schedule E, and considering the hired power as F's value, the installation's power factor can be determined, as well as the capacitive power needed for the reactive energy compensation.

STEPS CALCULATION

Always following the procedure shown in Schedule E for each of the time periods, and taking F as the corresponding peak demand meter reading, the power factor and needed capacitive power can be we can determined for each of the intervals.
Thus, the capacitors bank power should be of, at least, 37.5 kVAr.

Power calculation	***FP= cosφ***	***k***	***F(kW)***	***P_{kVAr}***
	0,73	0,935	40	37,42

Power calculation	***FP= cosφ***	***k***	***F(kW)***	***P_{kVAr}***
P1	0,77	0,826	35	28,89
P2	0,77	0,841	40	33,65
P3	0,61	1,291	22	28,40
P4	0,78	0,807	32	25,82
P5	0,70	1,012	32	32,37
P6	0,68	1,085	21	22,79

Time Period	**Consumption**	
Active Power P1	1737	kWh
Active Power P2	4863	kWh
Active Power P3	1427	kWh
Active Power P4	683	kWh
Active Power P5	1820	kWh
Active Power P6	610	kWh
Reactive Power P1	1434	kVArh
Reactive Power P2	4091	kVArh
Reactive Power P3	1842	kVArh
Reactive Power P4	551	kVArh
Reactive Power P5	1841	kVArh
Reactive Power P6	662	kVArh
Peak demand meter reading P1	35	kW
Peak demand meter reading P2	40	kW
Peak demand meter reading P3	22	kW
Peak demand meter reading P4	32	kW
Peak demand meter reading P5	32	kW
Peak demand meter reading P6	21	kW

RTR Energía S.L. advices an increase of this value of 15-20%, in order to satisfy future power demand increments. So, the chosen capacitor bank in this case would be a mural-series one, precisely a 45kVAr one, with 5 steps (1x5+4x10).

The minimural-series would not be suitable in this case, as it only has three steps (3x15).

Conclusions

Reactive power compensation offers the following advantages:

INCREASE OF ENERGY USAGE EFFICIENCY by reducing transport losses. When losses are reduced, there is no need of producing an extra amount of energy, in order to compensate these losses. Thus, the greenhouse gasses emitted when electric energy is generated are also reduced.

INCREASE OF THE NATIONAL GRID'S CAPACITY, since the energy, generated as an extra due to compensate losses can be used as consumption energy. Based on power consumption and losses statistics, the Spanish National Grid's capacity would increase by 0.5%, energy enough to supply, for example, more than twice the yearly consumption of Ceuta and Melilla.

OPTIMIZATION OF THE INSTALLATION DESIGN as the increment of the conductor's size is prevented even though the current is increasing. Therefore, resources such as copper, which has an important influence in the installation's budgets, are used in a more efficient way.

INCREASE OF THE ELECTRICAL MACHINE'S DURABILITY. The reactive energy removal provokes a current's growth, which is responsible for a reduction of the power appliances useful lifes.

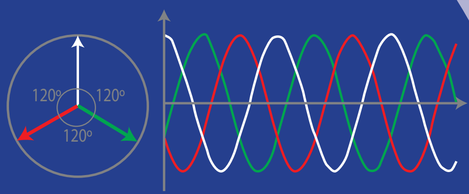
INCREASE OF THE ELECTRICITY SUPPLY QUALITY by reducing the increment in power drops during its transport. This voltage drop is responsible for the decreased output power in loads, such as motors, lamps, etc.

ECONOMICAL SAVING in electrical billing, obtained by removing the reactive energy consumption penalties. This penalties may nowadays mean a 30% of the total power bill.

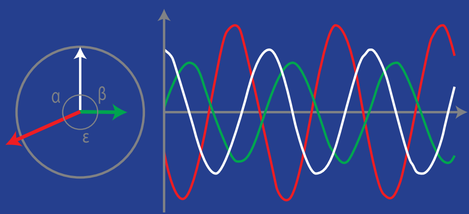
NOTES

Harmonics

Jean-Baptiste Joseph Fourier,
french mathematician (1768-1830)



Balanced three-phase system



Unbalanced three-phase system

RTR energía

Quality of Electric Energy

The basic fundamental parameters which define an electrical energy supply are: supply voltage (U) and current (I).

The right voltage supply (U) and the ability for giving users the amount of needed energy in a particular moment depends on the electricity supplier company, which distributes the energy.

In Spain, voltage is supplied at 400 volts (V) in a three-phase system, with a frequency value of 50Hz, considering this as low voltage up to 1000V. From 1000V up to 25 kilovolts (kV) it is considered as medium voltage, which depends on the areas and the supply companies.

Finally, values over 25 kV are considered high voltage, and it is used basically for transporting electrical energy in large distances.

Actually, **QUALITY (correct energy supply) and ELECTRIC ENERGY EFFICIENCY (obtaining the maximum yield out of it)** concepts must be unified. Because of this, the maximum consumption of energy must be optimized, as well as its transport and use. This will grant the correct running of the electrical equipment.

Negative **quality** aspects of the electrical supply, as established in the standard EN-UNE-60150:1996, are:

- Overvoltage
- Electric Power Interruptions
- Cutoffs
- Voltage fluctuations
- Flicker
- Voltage holes

The most important characteristic in quality and energetic efficiency is that of generating and transporting the maximum amount of active energy, which produces effective power. This compensates the oscillating energy loads, as well as the nonproductive ones, as reactive energy (see chapter of reactive energy compensation) or distortion energy, produced by some of the electrical appliances with nonlinear components, such as non-filtered reactances, speed shifters, rectifiers or electronic starters, among many other.

Electrical Network Disturbances

With the aforesaid standard, UNE-EN-60150, here are some of the most important electrical network disturbances.

FREQUENCY VARIATIONS

Frequency disturbances measured in 10 seconds average values. These variations produce an inaccurate running in electric motors, both synchronous and asynchronous, electrical household appliances, etc. .

UNBALANCED THREE-PHASE POWER SYSTEM

The voltage or current three-phase system is perfectly balanced when its three phases (R, S and T) have a 120° angular displacement between them, and when its vector modulus have the same value.

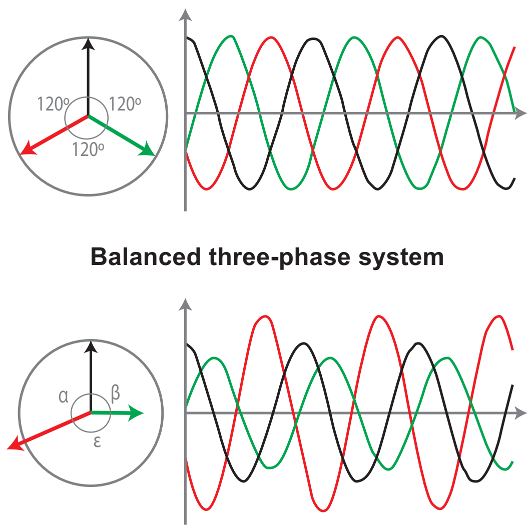
If the system is unbalanced, it can occur that the modulus of each of the different phases are different, or that the phase shift between two of the vectors is not the usual value of 120°. Furthermore, these two things can happen simultaneously.

Displaying a three-phase system this way, either balanced or unbalanced is valid if the system has three wires or four, including the neutral wire.

The unbalanced systems must not exceed the following values:

Current < 10%
Voltage < 3%

When the system is unbalanced, the current through the neutral wire increases.



Balanced three-phase system

Unbalanced three-phase system

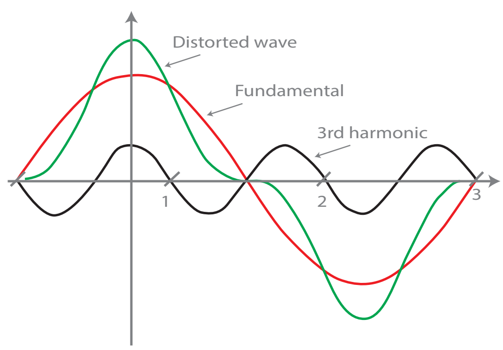
Harmonics

Harmonic voltage is defined by the standard UNEEN-60150:1996 as "a sinusoidal voltage, where the frequency is an integer multiple of the system's supply voltage fundamental frequency".

Fourier, a French mathematician, defined this phenomenon by the following assertion: "any periodic signal, no matter its complexity, can be split in a number of signals, and the sum of these signals will have a frequency which will be a multiple of the fundamental or reference frequency"

After analysing this phenomenon, the conclusion in RTR ENERGIA S.L. is that this is the most accurate definition for a harmonic, though the Fourier's mathematic series expansion is not going to be studied here, as it is not part of the purpose of this handbook.

Harmonics generate non-linear loads. These loads, when connected to a sinusoidal and alternating electrical network, absorb non-linear currents. Their amplitude and frequency depends on the current's wave distortion when a sine voltage is applied to them. These non-linear loads are generally periodic.



Jean-Baptiste Joseph Fourier, French mathematician (1768-1830)

HARMONICS ORIGIN

Among many others, the main causes of the harmonic distortion are the following.

- Electromagnetic and electronic lighting ballasts
- Electric welding equipment
- Single-phase network connected electronic equipment
- Electromagnetic reactance for discharge lamps
- Electronic starter
- Speed shifters

HARMONICS EFFECTS ON ELECTRICAL NETWORK

- Increase of transported power, worsening the network power factor
- Automatic switch untimely drop-out
- Conductors overloads
- Vibrations and overloads in machinery
- Establishment of instabilities in electrical systems
- Wrong operation of protective relays
- Capacitors' impedance fall-off (Xc) = 1/• · C. This may produce a failure in the automatic regulated battery, which is installed in order to rectify the power factor when the resonant phenomenon appears (XL=Xc). This situation is explained in detail in section D.
- Wrong measures in measurement apparatus
- Noises in control equipment

The electrical companies analyse the penalties to be applied to industrial installations which generate harmonics, as well as to the ones which generate reactive energy.

Harmonics Parameters

Harmonics can be classified by three different parameters: order, frequency and sequence, which can perfectly define each of the harmonic functions in the electrical network.

HARMONICS ORDER

The fundamental frequency value in Spain is 50 Hz, and the order number defines the number of times in which the harmonics' frequency is higher than the fundamental value: 1, 2, 3, 4, 5, 6, 7… the natural order of numbers.

It can also be defined as the ratio of the harmonic frequency (fn) and the fundamental frequency (f_{50})

$$n = \frac{f_n}{f_{50}}$$

FREQUENCY

The harmonics' frequency is defined as the result of multiplying the order number of the harmonic and the fundamental frequency (50 Hz), e.g:

3rd harmonic 3 x 50Hz = 150Hz
5th harmonic 5 x 50Hz = 250Hz
7th harmonic 7 x 50Hz = 350Hz

Odd-order harmonics can be found in the electrical network of all kind of industries, buildings, industrial runnings, airports, etc. Even-order harmonics can be found in unbalanced electric signals.

SEQUENCE

The positive or negative sequence of the harmonics does not establish a specific behaviour of the aforesaid harmonics in electric networks. They are both equally harmful.

In the particular case of the capacitors' banks for the correction of the power factor, the most harmful harmonic is that of negative sequence, specially the 5° one.

Instead, harmonics with null sequence have a frequency which is an electrical multiple of the fundamental frequency. These harmonics are displaced along the uncharged wire, so that the current flow is of the same value or even higher than the current flow through the phases. This produces the uncharged wire heating, so it makes it necessary to have the same section on both uncharged and phase wires.

The most usual harmonics parameters are the following:

Order	Frequency	Sequence
1	50	+
2	100	-
3	150	0
4	200	+
5	250	-
6	250	0
7	350	+
8	400	-
9	450	0
...	...	...
n	50·n	...

INDIVIDUAL RATE OF HARMONIC DISTORTION ON VOLTAGE (U) AND CURRENT (I)

The harmonic distortion rate can be defined as the voltage or current percentage rate (%), with the effective value of the corresponding harmonic frequency and the effective value of the voltage or current corresponding to the fundamental frequency.

$$HD\,U_n\,\% = \frac{U_{ca \quad f_n}}{U_{ca \quad f_{50}}} \cdot 100$$

$$HD\,I_n\,\% = \frac{I_{ca \quad f_n}}{I_{ca \quad f_{50}}} \cdot 100$$

TOTAL RATE OF HARMONIC DISTORTION: THD_U - THD_I

The total rate of harmonic distortion is the rate referenced to the fundamental frequency

$$THD_{f_{2-n}} = \frac{\sqrt{h_2^2 + h_3^2 + h_4^2 + \cdots + h_n^2}}{h_1} \cdot 100$$

For a better understanding of this parameter, the total rate of harmonic distortion (THD) is going to be referred to the two fundamental values: the effective voltage (U_{ca}) and the effective current (I_{ca}).

$$THD_{U_{2-n}} = \frac{\sqrt{U_{ca\,2}^2 + U_{ca\,3}^2 + U_{ca\,4}^2 + \cdots + U_{ca\,n}^2}}{U_{ca\,1}} \cdot 100$$

$$THD_{I\,2-n} = \frac{\sqrt{I_{ca\,2}^2 + I_{ca\,3}^2 + I_{ca\,4}^2 + \cdots + I_{ca\,n}^2}}{I_{ca\,1}} \cdot 100$$

The standard to be consulted is the IEC-555, where the "n" value is limited to the 40th harmonic.

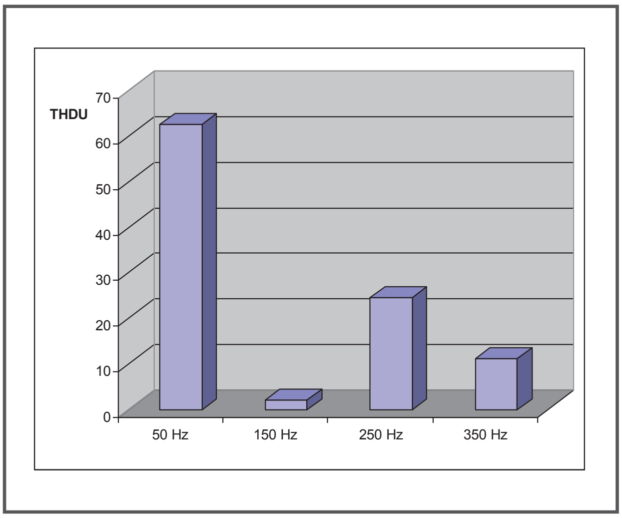
The total rate referred to the current, THD_I, is generated by the non-linear loads in the wiring circuit.

The total rate referred to the voltage, THD_U, is the result of a very distorted current in the circuit.

THE HARMONIC SPECTRUM

When decomposing a signal into its harmonics in the frequency domain, the harmonic spectrum is formed. This harmonic spectrum can be represented in a bar-graph, by including the percentage of each of the different harmonic signals. The sum of these percentages gives the total analysed signal.

In the attached figure a harmonic spectrum, where the 5th harmonic achieves approximatety a 25% of the voltage value, can be observed.



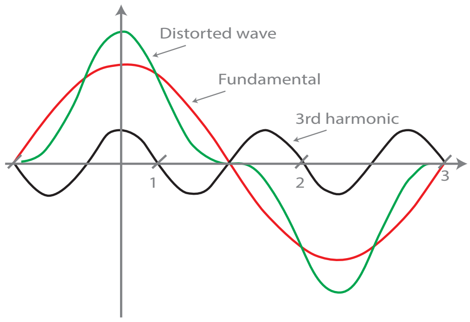
The 3rd and 5th harmonics

THE 3rd HARMONIC

In the figure attached, the distorted wave is represented and its peak value is the graphical addition of both of the sine waves.

The amplitude of the fundamental wave is three times the 3rd harmonic, and both of them have the peak value in the same instant of time.

The 3rd harmonic has a special feature: its frequency is an electrical multiple of the fundamental frequency, and has a null sequence, so that in a three-phase 4wire system (R, S, T and N) there is a mesh entering with the three phases (R, S and T) while there is a shift along the discharged wire (N). This occurs the same way with the harmonics 6, 9, etc.



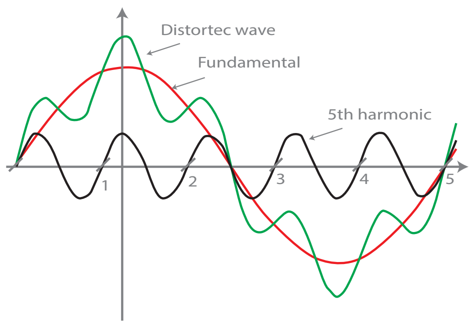
The third harmonic has a frequency three times higher (points 1, 2 and 3)

THE 5th HARMONIC

In the figure attached, the 5th harmonic is represented, as well as the distorted wave with its peak value. This peak value is the graphical addition of the fundamental and the harmonic waves.

As it was previously mentioned, the amplitude of the fundamental wave is five times the 5th harmonic, and both of them have the peak value in the same instant of time.

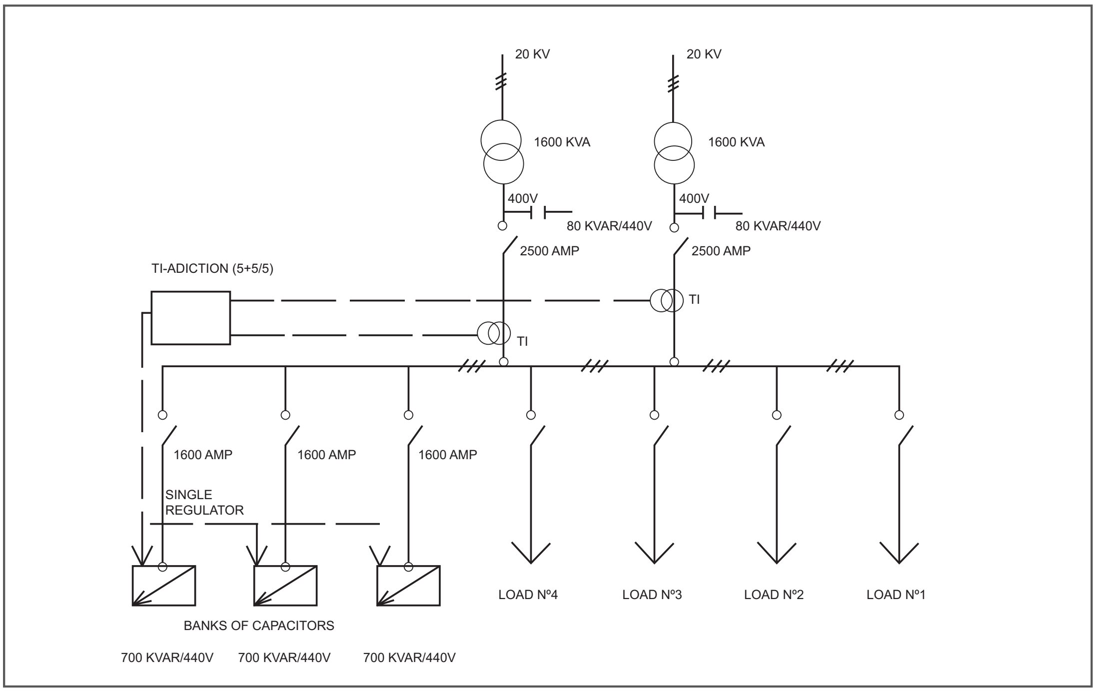
In contrast to the 3rd harmonic, the 5th harmonic is NOT an electrical multiple of the fundamental wave, so the frequency shift will be through the phases R, S, and T and it will be the 1st harmonic the one who affects the capacitors and the three-phase system, as well as the harmonics 7, 11, etc



The tifth harmonic has a frequency five times higher (points 1, 2, 3, 4 and 5)

In RTR ENERGIA S.L., these two harmonic distortions (3rd and 5th) are the most important ones when determining the power factor correction in industrial facilities, since the capacitors must be installed forming passive filters (L-C) as it is explained in section D.

Reactive Energy Compensation in Harmonic Distorted Networks



In a complex circuit, as the one shown in the image below and the usual ones in almost any industrial facilities, there are commonly different kinds of loads (as linear or non-linear) which can appear, as well as a capacitors' bank for compensating the power factor of the mounting.
If there is a possibility of harmonic distortion presence in the electrical network of the facility, an analysis of the electrical network must be made with a properly calibrated network analyser.

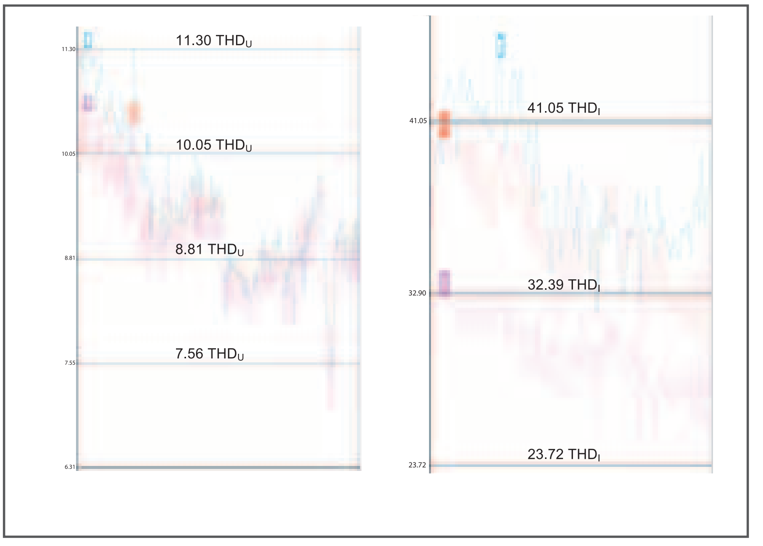
RTR Energía S.L. performs this sort of network analyses with properly calibrated equipment when their clients ask for it.

Once completed these network analyses, which must last for approximately 4 or 5 days including a weekend, the necessary data will be obtained in order to diagnose the electrical requirements of the mounting.

- Supply voltage "U_{ca}"
- Electric current "I_{ca}"
- Frequency
- Power in the installation
- Power factor
- Capacitive energy demanded by the installation
- Current in the discharged wire
- Unbalance in the mounting because of consumption
- THDU since the 3th, 5th, 7th… harmonic (total and for each of the harmonics)
- THDI since the 3th, 5th, 7th… harmonic (total and for each of the harmonics)
- The predominant harmonic in the network both in voltage and current.

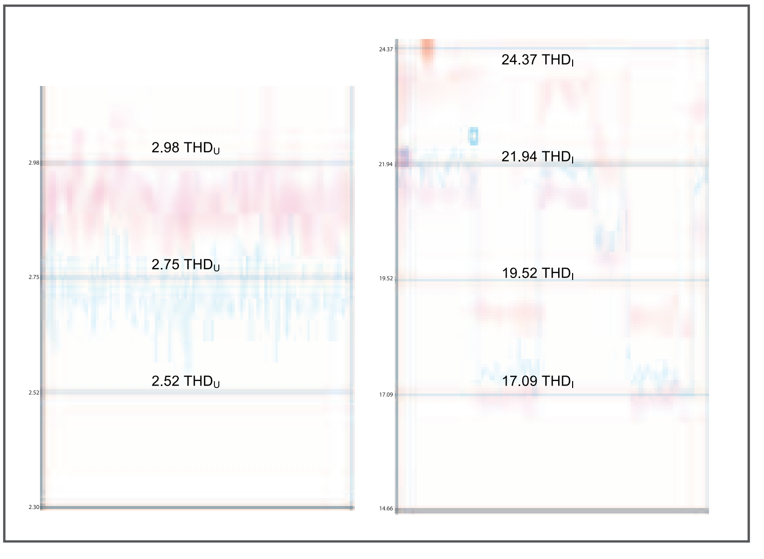
Sometimes, in order to check the harmonics presence in the mounting, performing an analysis for a brief period of time is enough to decide the best capacitors' bank for the installation.
Following there are some examples shown:

Harmonic distortions spectrum in voltage (THD_U) and current (THD_I) are obtained by a network analyser. It can be observed, as the distortions are very high, and as it will be seen afterwards, the chosen solution for the set up of the bank of capacitors due to compensate de reactive energy was the placing of passive filtering with an overvoltage of 14%.



In such case, it can be clearly noticed the presence of harmonic distortion, although the network analysis will be fulfilled in a brief period of time. It is not this way in the following example.

In this case, the harmonic distortion spectrum in voltage (THD_U) and current (THD_I) is plotted between the acceptable limits, so the capacitor bank installed can be an RTF with reinforced capacitors from the RTR Energía S.L. catalogue, or even for a passive filter set up with an overload factor of 7%. In order to make the correct decision, the network analyses must include a wide range of time so that the evolution of the harmonic content can be verified.



HARMONICS RESONANCE

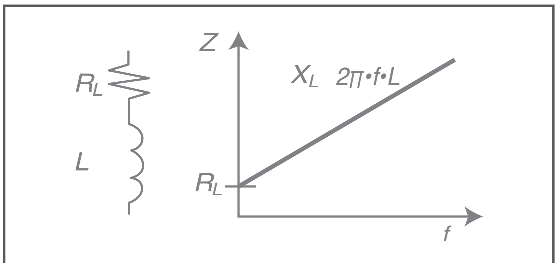
The resonance phenomenon is produced when $X_L=X_C$ in a parallel or series circuit with non-linear loads, capacitors or inductive loads.

$$\left.\begin{array}{l} X_L = \omega \cdot L \\ X_C = 1/\omega \cdot C \end{array}\right\} \Rightarrow \omega \cdot L = \frac{1}{\omega \cdot C}$$

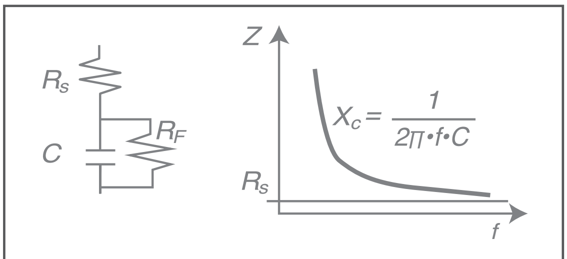
The frequency value in which this occurs, that is, in which $X_L=X_C$, is named resonance frequency, f_R.

$$\omega_R = \frac{1}{\sqrt{L \cdot C}} \Rightarrow 2\pi \cdot f_R = \frac{1}{\sqrt{L \cdot C}} \Rightarrow f_R = \frac{1}{2\pi\sqrt{L \cdot C}}$$

Both of the impedances depend on the frequency (f), but X_L has a direct proportionality with the frequency, while X_C is inversely proportional to the frequency. So, when there is a raise in the frequency, the value of the impedance X_C decreases while X_L increases.
Generally, capacitors in industrial facilities are set in parallel as it can be seen in the equivalent circuit attached.

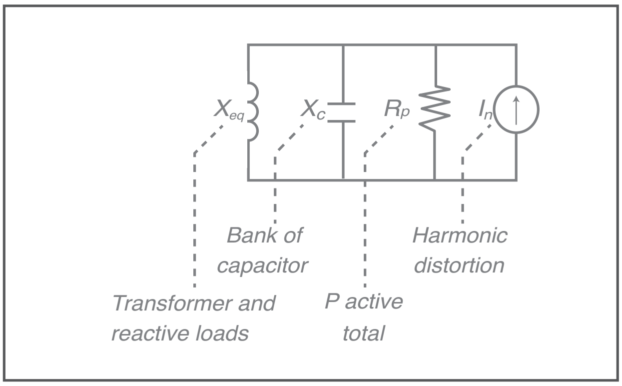


Impedance of a non-linear winding



Impedance of a non-linear capacitor

When this configuration acts as a current divider and the value of XC is the lowest one, the majority of the current will flow through the capacitors, **and this is why the capacitors may malfunction.**



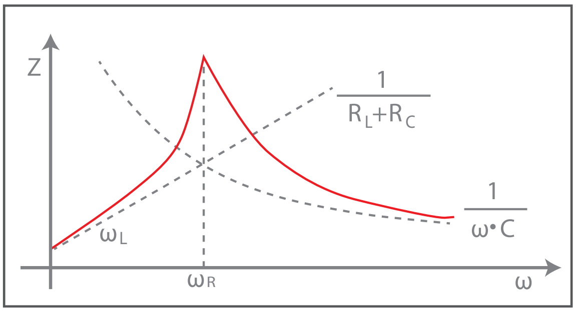
PARALLEL RESONANCE

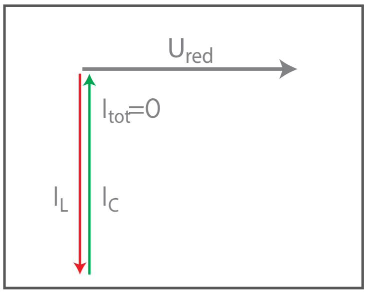
Resonance is produced in a parallel circuit when the resultant current and the line voltage are in-phase. When with a specific value of resonance frequency in the parallel L-C circuit, as ω_R = 150 Hz, (frequency on the 5th harmonic), this circuit is inductive ($\omega < \omega_R$) the current is delayed so voltage will lead current. If the circuit is capacitive ($\omega > \omega_R$) current will lead voltage.

In an L-C circuit, the resultant current of the windings (L, etc.) is the same value as the current of the capacitors (C, etc.) but with the opposite sign, so both the algebraic and vector addition have as a result the maximum value of the impedance and a null value of the resultant current (the opposite results of a series circuit).

In this situation, the current in both L-C branches is extremely high which is hazardous for the capacitor as the X_C value is the lowest of the whole circuit.

It can be clearly seen in the chart how the impedance (Z) raises until reaching the maximum value.





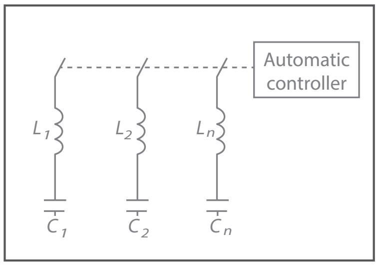
Because of this, it is necessary to protect the capacitors when they are parallel installed in a high harmonic content circuit.

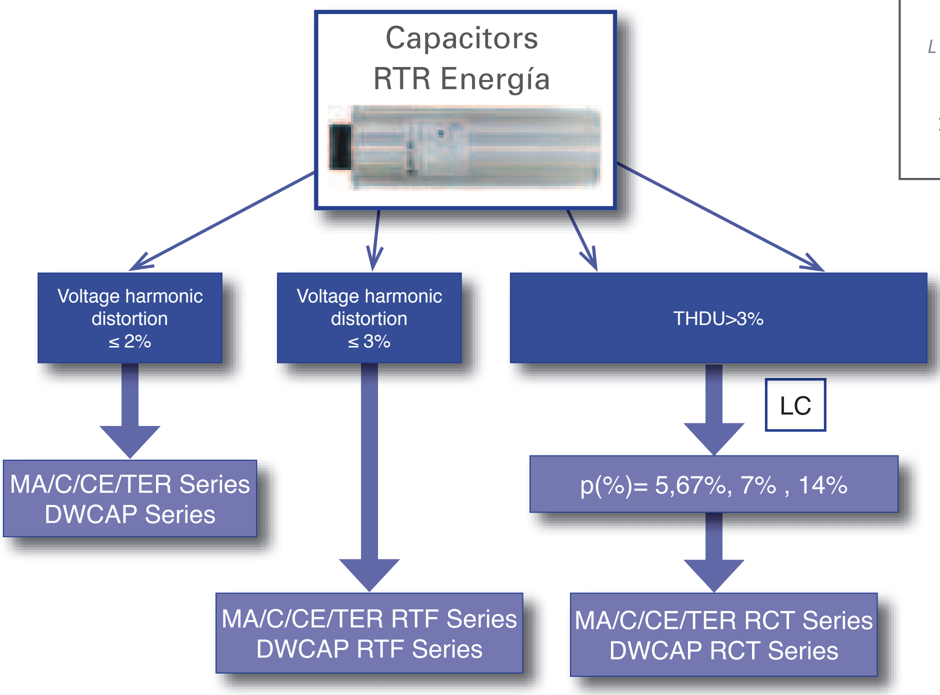
When an industrial facility, with a high harmonic content, is supplied by a power transformer (medium/ low) it is necessary to have the compensating capacitors installed on the base of the transformer so that they can be protected from the harmonics action (see section **G** on the **reactive energy compensation's chapter**).

CAPACITOR PROTECTION

In presence of harmonic distortions, a passive filter (LC) must be used, as their main function is to protect the capacitors. This filtering is recommended in the standard UNE EN-61642 and as a practical data **RTR Energía S.L.** establishes that in facilities with distortions on voltage on the 5th harmonic higher than 3%, the installation of L-C filters is required, as well as in 5th harmonic current distortions higher than 30%.

RTR Energía S.L. manufactures two classes of capacitors: **Standard** which can bear harmonic distortions on voltage lower than 2% and in current lower than 25% and **Reinforced** which can bear distortions on voltage lower than 3% and in current lower than 30%.



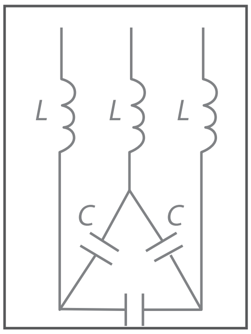


Repulsion Passive Filters

The aim of the repulsion filters is that of avoiding the gain of the facility preponderant harmonic, mainly the 5th harmonic either on voltage or on current and also impeding the parallel resonance between the inductive loads "*L*" (transformers, starter motors, etc.) and the capacitors "*C*", avoiding the overloads and possible damage or destruction of the automatic controlled battery of the bank of capacitors of reactive equalization.

The filter is a cascade arrangement, properly calculated and previously tuned,
and is made up of:

- A three phase / single phase reactance.
- A three phase / single phase capacitor, with the needed setup power (in kVAr).



This is known as **compensation branch**, and each of the branches must be designed with the required protection.
The various L-C branches form an automatic controlled bank of capacitors, which acts as a complete filter with the aim of compensating the power factor of the setup and its overall power is the sum of the power of all of the branches.

HOW TO SELECT A BANK OF CAPACITORS (L-C)

With the network analysis of the facilities' harmonics, the preponderant harmonic can be determined, usually being the 5th harmonic (with a frequency value of 250Hz).
Once known the frequency value of the harmonic, the resonance frequency of the filter (R) is established and it must never coincide with any integer multiple of the current frequency (50-60 Hz). Among this, the value of the resonance frequency (ω_R), must be a lower value than that of the preponderant harmonic one, so that the resonance with any other harmonic is impossible.
The resonance frequency (ω_R) is determined through the overvoltage factor (p%), which relates both the capacitor and reactance voltages.

$$p(\%) = 100 \cdot \frac{U_{C_C} - U_L}{U_L} = 100 \cdot \left(\frac{\omega_{current}}{\omega_{resonance}}\right)^2 = 100 \cdot \left(\frac{f_{current}}{f_{resonance}}\right)^2$$

RTR Energía S.L. designs its own capacitors, with the appropriate passive filters so that they are able to bear a 15% overvoltage, introduced by the filter. As an example, a 440V capacitor with an installed reactance of an overvoltage value of p(%)=7 can bear a voltage value of: 440·1.07·1.15 = 540 V.

THDU	p(%)	f current	f resonance
3-7%	7	50 Hz	189 Hz
		60 Hz	227 Hz
>7%	14	50 Hz	134 Hz
		60 Hz	160 Hz

Basic Formulas

BASIC FORMULAS

Magnitudes and Associated Units Table

Active Quantity	Simbol	S.I units	Other useful units
Active power	P	Watt (W)	1kW=1000W
Reactive power	Q	volt-ampere reactive (VAr)	1kVAr = 1000VAr
Apparent power	S	volt-ampere (VA)	1kVA = 1000VA
Power factor	PF o $\cos\varphi$	-	-
Capacitance	C	Farad (F)	1μF = 10^{-6}F
Inductance	L	Henry (H)	1mH = 10^{3}mH
Current	I	Ampere (A)	1kA= 1000A
Voltage (electric tension)	U	Volt (V)	1kA= 1000A
Electrical resistance	R	Ohm (Ω)	1kΩ = 1000Ω
Capacitive reactance	X_C	Ohm (Ω)	1kΩ = 1000Ω
Inductive reactance	X_L	Ohm (Ω)	1kΩ = 1000Ω

Most frequent multiples and submultiples table

10n	Prefix	Simbol	Equivalent decimal prefixes
10^{12}	Tera	T	1.000.000.000.000
10^{9}	Giga	G	1.000.000.000
10^{6}	Mega	M	1.000.000
10^{3}	Kilo	k	1.000
10^{2}	Hecto	h	100
10^{1}	Deca	da	10
10^{-1}	deci	d	0,1
10^{-2}	centi	c	0,01
10^{-3}	mili	m	0,001
10^{-6}	micro	μ	0,000001
10^{-9}	nano	n	0,000000001
10^{-12}	pico	p	0,000000000001

Electric Capacitors

CAPACITOR POWER (Q)

$$Q = U^2 \cdot 2 \cdot \pi \cdot f \cdot C$$

Where:
U = line voltage in volts (V_{ca})
f = line frequency, in hertz (Hz)
C = capacitance volt-ampere reactive in farads (F)
Q = capacitor power in volt-ampere reactive (VAr)

CAPACITOR REACTANCE (X_C)

$$X_c = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

Where:
X_c= capacitive reactance in ohms (Ω)
f = line frequency in hertz (Hz)
C = capacitor's capacitance, in farads (F)

CAPACITANCE OF CAPACITOR (C)

$$C = \frac{Q}{U^2 \cdot 2 \cdot \pi \cdot f}$$

Where:
U = line voltage, in volts (V_{ca})
f = line frequency in hertz (Hz)
C = capacitance, in farads (F)
Q = capacitor power in reactive volt ampere (VAr)

Capacitance, in microfarads

$$(\mu F) = \frac{\text{Capacitance in farads (F)}}{1000\,000}$$

Example: Three-phase capacitor 30kVAr – 440V – 50Hz

$$C = \frac{30000\text{VAr}}{(440\text{ V})^2 \cdot 2 \cdot \pi \cdot 50\text{Hz}} = 0.00049325\text{F} = 493{,}25\,\mu\text{F}$$

Electric capacitors

CURRENT THROUGH PHASES IN A THREE-PHASE CAPACITOR (I_C)

$$I_c = \frac{Q}{\sqrt{3} \cdot U}$$

Where:
U =Line voltage in volts (V_{ca})
Q = capacitor power in volt-ampere reactive (VAr)
I_C= current in amperes (A)

$$I_c = \frac{2 \cdot \pi \cdot f \cdot C \cdot U}{\sqrt{3}}$$

Where:
U = line voltage in volts (V_{ca})
f = line frequency in hertz (Hz)
C = capacitance in farads (F)
I_C = current in amperes (A)

In single-phase capacitors, √3 is substituted by 1.

√3 = 1,7321

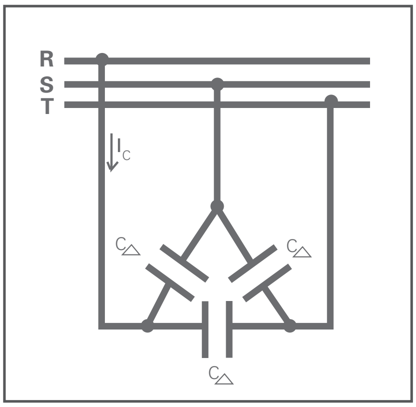
Example: Three-phase capacitor 30kVAr – 440V – 50Hz

$$Ic = \frac{30000VAr}{\sqrt{3} .440V} = 39{,}36A$$

INSIDE CONNECTION FOR A THREE-PHASE DELTA-CONNECTED (Δ)

$$C_\Delta = \frac{C}{3}$$

Where:
C = capacitance in farads (F)
C_Δ= capacitance of each of the windings, in farads (F)



How to calculate the capacitance when knowing the capacitance between 2 phases ($C_{R\text{-}S}$ o $C_{R\text{-}T}$ o $C_{S\text{-}S}$):

$$C_\Delta = \frac{2}{3} \cdot C_{R\text{-}s}$$

$$C = 2 \cdot C_{R\text{-}s}$$

Example: Winding capacitance in a three-phase capacitor of 30kVAr – 440V – 50Hz with delta connection.

$$C_{\Delta} = \frac{493{,}25\mu F}{3} = 164{,}42\mu F$$

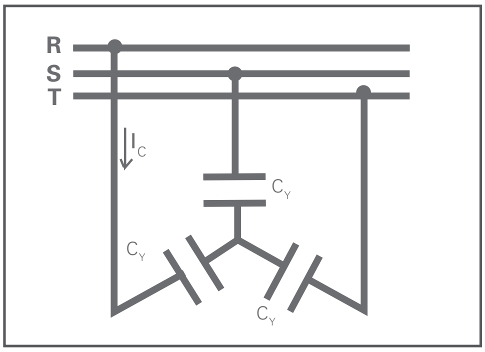
INSIDE CONNECTION FOR A THREE-PHASE Y-CONNECTED (Y)

$$\mathbf{C_Y = C}$$

Where:

C = capacitance in farads (F)

C_y= capacitance of each of the windings in farads (F)



How to calculate the capacitance when knowing the capacitance between 2 phases (C_{R-S} o C_{R-T} o C_{S-S}):

$$C_Y = 2 \cdot C_{R-S}$$

$$C = 2 \cdot C_{R-S}$$

SERIES CONNECTION OF CAPACITORS

The global capacitance (C_T) for a group of capacitors, where each of the individual capacities are (C_1, C_2, C_3,..., C_n) when united in series, is:

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots \frac{1}{C_n}$$

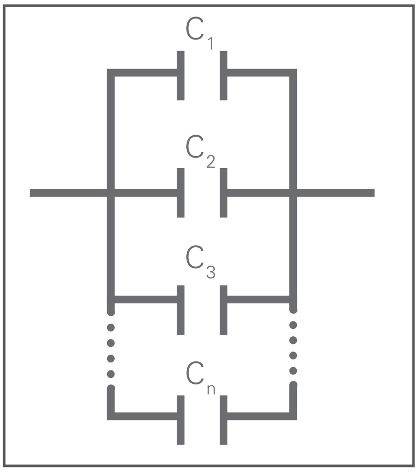
The global reactive power of the group (Q_T) depending on the individual reactive power of each of the united capacitors (Q_1, Q_2, Q_3,..., Q_n) is:

$$\frac{1}{Q_T} = \frac{1}{Q_1} + \frac{1}{Q_2} + \frac{1}{Q_3} + \dots \frac{1}{Q_n}$$

Electric capacitors

The current (I_C) flowing through each of the capacitors is going to be the same, and its value is that of a capacitor which has either C_T for capacitance or Q_T, for reactive power, depending on the used formula.

PARALLEL CONNECTION OF CAPACITORS



The global capacitance (C_T) for a group of capacitors, where each of the individual capacities are (C_1, C_2, C_3,..., C_n) when united in parallel, is:

$$C_T = C_1 + C_2 + C_3 + ... + C_n$$

The global reactive power of the group (Q_T) depending on the individual reactive power of each of the united capacitors (Q_1, Q_2, Q_3,..., Q_n) is:

$$Q_T = Q_1 + Q_2 + Q_3 + ... + Q_n$$

The current (I_{Cn}) flowing through each capacitor is the value corresponding to each of them depending on C_T or Q_T, and the formula that is used. The global current (I_T) flowing through the group is valued by the expression:

$$I_T = I_1 + I_2 + I_3 + ... + I_n$$

Example: Parallel connection between a capacitor of 15 kVAr, two of 30 kVAr and one of 60 kVAr to a 440V, 50H line

$$Q_T = 15kVAr + 30kVAr + 30kVAr + 60kVAr = 135kVAr$$

$$C_T = \frac{135000VAr}{(440V)^2 \cdot 2 \cdot \pi \cdot 50Hz} = 0.00221961F = 2219{,}61 \quad \mu F$$

$$I_T = \frac{135000VAr}{\sqrt{3} \cdot 440V} = 177{,}14A$$

Capacitors and Filter Reactances in Case of Harmonic Presence

OVERLOAD FACTOR IN A CAPACITOR (p%)

$$p(\%)=100 \cdot \left(\frac{f_{red}}{f_{resonance}}\right)^2$$

Where:

f_{red}= line frequency in hertz (Hz)
$f_{resonance}$= detuned frequency in hertz (Hz)
p(%)= overload factor

The most usual resonance frequencies in a passive filter (L-C) are (see UNE-EN-61642):

Line frequency	p=7% (3%<THD-U<7%)	p=14% (THD-U>7%)
50 Hz	189 Hz	134 Hz
60 Hz	227 Hz	160 Hz

VOLTAGE AT TERMINALS IN A CAPACITOR (U_C)

$$U_c = U \cdot \left(1+\frac{P}{100}\right)$$

Where:

U = line voltage, in volts (V_{ca})
p = overload factor, in percentage (%)
U = voltage at terminals in the capacitor, in volts (V)

CAPACITOR'S CAPACITANCE WHEN INSTALLING IT WITH REACTANCES (C_{RCT})

$$I_c = \frac{Q}{\sqrt{3} \cdot U}$$

Where:

Q = capacitor power in volt-ampere reactive (kVAr)
U = line voltage in volts (V_{ca})
I_c= current in ampere (A)

$$C_{RCT} = \frac{\sqrt{3} \cdot I_c}{2 \cdot \pi \cdot f \cdot U_c}$$

Where:

f = line frequency in hertz (Hz)
U_c= voltage at terminals in the capacitor in volts (V)

Capacitors and filter reactances in case of harmonic presence

INDUCTIVE REACTANCE IN A FILTER REACTANCE (X_L)

$$X_L = X_C \cdot \frac{p}{100}$$

Where:
X_L= inductive reactance, in ohms (Ω)
X_C= capacitive reactance, in ohms (Ω)
p= overload factor in percentage (%)

REACTOR´S INDUCTANCE (L)

$$L = \frac{X_L}{2 \cdot \pi \cdot f}$$

Where:
L= inductance, in Henry (H)
X_L= inductive reactance, in ohms (Ω)
f = line frequency, in hertz (Hz)

Example: Required reactance for a capacitor of 30kVAr – 440V – 50Hz detuned in 189Hz

$$p(\%) = 100 \cdot \left(\frac{50Hz}{189Hz}\right)^2 = 7\%$$

$$U_c = 440V \cdot \left(1 + \frac{7}{100}\right) = 470,8V$$

$$I_c = \frac{30000VAr}{\sqrt{3} \cdot 440V} = 39,36A$$

$$C_{RCT} = \frac{\sqrt{3} \cdot 39,36A}{2 \cdot \pi \cdot 50Hz \cdot 470,8V} = 458,72\mu F$$

$$X_C = \frac{1}{2 \cdot \pi \cdot 50Hz \cdot 458,72 \cdot 10^{-6}F} = 6,94\Omega$$

$$X_L = 6.94\Omega \cdot \left(\frac{7}{100}\right) = 0,49\Omega$$

$$L = \frac{0.49\Omega}{2 \cdot \pi \cdot 50Hz} = 0,00155H = 1,55mH$$

Reactive Power of a Capacitor Bank

POWER FACTOR IN AN INSTALLATION (PF) OR COS (φ_0)

$$PF = COS(\varphi_0) = \frac{P}{\sqrt{P^2 + Q^2}}$$

Where:
P = global active energy consumed by the electric installation, in kilowatts per hour (kWh)
Q = global reactive energy consumed by the electric installation, in kilovoltamperes per hour (kVArh)
PF o COS(j_0) = original installation's power factor

$\varphi 0$ = arc cos(PF)

CAPACITOR BANK'S POWER (Q_B)

$$Q_B = F \cdot (\tan(\varphi_0) - \tan(\varphi_f))$$

Where:
F = power consumption in the installation, in kilowatts (kW).
$\tan(\varphi_0)$ = φ_0 angle's tangent
$\tan(\varphi_f)$ = φ_f angle's tangent
Q_B= bank's reactive power in kilovolt-ampere reactive (kVAr)

VALUE SELECTION FOR tan(φ_f):

Example: Equipment with a load of 40 kW, consuming an amount of active energy of 10150 kWh and a reactive one of 10400 kVArh.
The final desired value of PF is .1

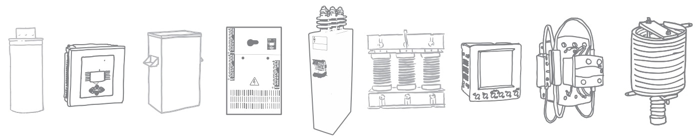
$$PF = COS(\varphi_0) = \frac{10150kWh}{\sqrt{(10150kWh)^2 + (10400\ kVArh)^2}} = 0{,}698$$

$\tan(\varphi_0) = 1{,}026$

$\tan(\varphi_f) = 0{,}000$

$$Q_B = 40kW \cdot (1{,}026 - 0.000) = 41{,}04kW$$

NOTES



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