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Reactive Energy Compensation with Capacitors

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Contents

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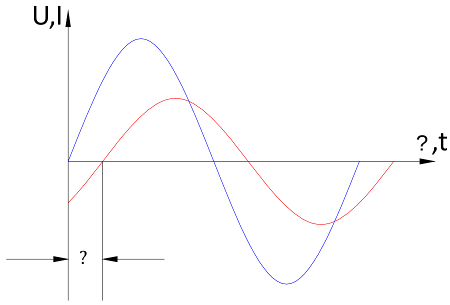
Definitions

1-PHASE SHIFT-ENERGIES-POWER

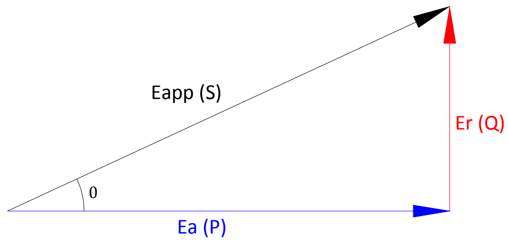
An alternating current electrical installation, including receivers such as transformers, motors, welding machines, power electronics, etc., and in particular any receiver for which the current is out-of-phase in relation to the voltage, absorbs a total energy called the apparent energy (E app).
This energy, which is generally expressed in kilovolt-ampere-hour (kVAh), corresponds to the apparent power S (kVA) and can be broken down as follows

Active energy (Ea): expressed in kilowatt hours (kwh). It can be used, after being transformed by the receiver, in the form of work or heat. This energy corresponds to the active power P (kW).

Reactive energy (Er) : expressed in kilovar hours (kvarh).It is particularly used in motor and transformer windings to create the magnetic field which is essential for operation. This energy corresponds to the Reactive power Q (kvar).Unlike the previous energy, this energy is said to be "unproductive” for the user.



Phase shift between current and voltage (angle ϕ)



Phase shift between current and voltage (angle ϕ)

- *Energies*

$$\overrightarrow{Eapp} = \overrightarrow{Ea} + \overrightarrow{Er} = \sqrt{(Ea)^2 + (Ea)^2}$$

- *Power*

$$\vec{S} = \vec{P} + \vec{Q} = \sqrt{(P)^2 + (Q)^2}$$

-For three-phase supply

$S = \sqrt{3}.U.I$

$P = \sqrt{3}.U.I.\cos\varphi$

$P = \sqrt{3}.U.I.\sin\varphi$

♦ *For a single-phase supply, the* $\sqrt{3}$ *term disappears.*

2-POWER FACTOR

By definition, the power factor, or the $\cos\varphi$, of an electrical device is equal to the ratio of the act over the apparent power S (kVA) and can vary from 0 to 1.

It can thus be used to identify the level of reactive energy
Consumption of devices easily.
A power factor equal to 1 will result in a zero reactive
energy consumption (pure resistance).

$$\boldsymbol{\cos\varphi = \frac{P(kW)}{S(kVA)}}$$

$$\boldsymbol{\tan\varphi = \frac{Q(kVAR)}{P(kW)}}$$

a power factor less than 1 will result in reactive energy
Consumption which increases as it approaches 0 (pure inductance)

In an electrical installation, the power factor may be Different from one workshop to another depending on the Devices installed and the way in which they are used (Off-Load, full-load operation, etc.).

$\tan\varphi$ is the quotient between the reactive power Q (kVAR) and the active power P (kW) used during the same period. Unlike $\cos\varphi$, it is easy to see that the value of $\tan\varphi$ must be as low as possible in order to have the minimum reactive energy consumption.
The relationship between $\cos\varphi$ and $\tan\varphi$ is given by the following equation:

$$\boldsymbol{\cos\varphi = \frac{1}{\sqrt{(1+(\tan\varphi)^2)}}}$$

But a simpler method consists of referring to a conversion table see section 6

Power factor of main receivers

The receivers which consume the most reactive energy are:

- Low-load motors
- Wilding machines
- Arc and indication furnaces -
- Power rectifiers

Equipment and appliances			$\cos\varphi$	$\tan\varphi$
Common induction motor	loaded at	0%	0.17	5.80
		25%	0.55	1.52
		50%	0.73	0.94
		75%	0.80	0.75
		100%	0.85	0.62
Incandescent lamps			1.0	0
Fluorescent lamps (uncompensated)			0.5	1.73
Fluorescent lamps (compensated)			0.93	0.39
Discharge lamps			0.4 to 0.6	2.29 to 1.33
Ovens using resistance elements			1.0	0
Induction heating ovens (compensated)			0.85	0.62
Dielectric type heating ovens			0.85	0.62
Resistance-type soldering machines			0.8 to 0.9	0.75 to 0.48
Fixed 1-phase arc-welding set			0.5	1.73
Arc-welding motor-generating set			0.7 to 0.9	1.02 to 0.48
Arc-welding transformer-rectifier set			0.7 to 0.8	1.02 to 0.75
Arc furnace			0.8	0.75
Thyristor power rectifiers			0.4 to 0.8	2.25 to 0.75

Why to improve the power Factor?

A good power factor makes it possible to optimize on electrical installation and provide the following advantages

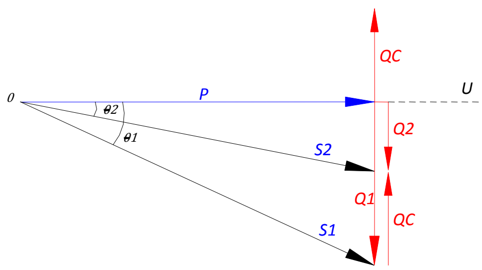
- No billing for reactive energy.
- Decrease in the subscribed power in kVA
- Limitation of active energy losses in cables given the decrease in the current conveyed in the installation
- Improvement in the voltage level at the end of the line
- Additional power available at the power transformers if the compensation is performed in the secondary winding

How to improve the power factor

Improving The power factor of an electrical installation consist of giving it the means to produce a varying proportion of the reactive energy that it consumes itself.
Different systems are available to produce reactive energy, particularly phase advancers and shunt capacitors (or serial capacitors for major transport networks).

The capacitor is most frequently used given:

- It's non-consumption of active energy,
- It's purchasing cost,
- It's easy use,
- It's service life (approximately 10 year),
- It's very low maintenance (static device)



POWER DIAGRAM

P: Active power
S1: Apparent power before compensation
S2: Apparent power after compensation
Q1: Reactive power before compensation
Q2: Reactive power after compensation
Qc: Reactive power of capacitor

Equation:
Q2=Q1-Qc
Qc=Q1-Q2
$Qc=P.\ tan\ \varphi 1 - P.\ tan\ \varphi 2$

$Qc=P.\ (tan\ \varphi 1 - tan\ \varphi 2)$

$\varphi 1$: Old phase shift (without compensation)
$\varphi 2$: Target phase

The capacitor is a receiver composed of two conducting part (electrodes) separated by an insulator. When this receiver is subjected to a sinusoidal voltage, it shifts its current, and therefore it's (capacitive reactive) power, by 90° forward the voltage.

Conversely, all other receivers (motor, transformer, etc.) shift heir reactive component (inductive reactive power or current) 90° backward the voltage.

The Victorial composition of these (inductive or capacitive) reactive powers or current gives a resulting reactive power or current below the existing value before the installation of Capacitors.
In simpler terms, it can be said that inductive receivers (motors, transformers, etc.) consu energy, while capacitors (capacitive receivers) produce reactive energy.

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How to calculate the power of capacitors

a- Calculation from electricity bills

For the calculation of the capacitor banks to be installed, proceed using the following method:

- analyses the 5 electricity bills from 5 months
- select the month for which the bill is the highest (kvarh to be billed),
- evaluate the number of hours of operation of the installation every month in day-tariff and peak hours (generally 6 am to 10 pm excluding holiday)
- calculate the capacitor power Qc to be installed

$$\boldsymbol{Qc}(Capictor\ bank\ to\ be\ installed) = \frac{\boldsymbol{KVARH\ to\ be\ billed\ (monthly)}}{\boldsymbol{No.\ of\ working\ hours\ (monthly)}}$$

Example:
Iron factory bills for 5 month are:

- January 60kVARH
- February 72KVARH
- Marsh 54kVARH
- April 66kVARH
- May 69KVARH

-Highest reactive energy bill is February
-Number of KVARH to be billed is 72,000
-Monthly number of hours of operation is 243hour (27day & 9 working hours)

$\boldsymbol{Qc}(Capictor\ bank\ to\ be\ installed) = \frac{\mathbf{72{,}000}}{\mathbf{243}}$**=296≈300Kvar**

b- Calculation from measuring elements read on the HV/LV transformer secondary winding/ PkW-$\boldsymbol{\cos\varphi}$

Example:
Take a plant powered From an 800 kVA HV/ LV subscriber station which would like to change the power factor of its Installation to:

- $\cos\varphi$ =0.928 ($\tan\varphi$=0.4) on the primary winding
- $or\ \ \cos\varphi$ =0.955 ($\tan\varphi$=0.31) on the secondary winding

With the following readings:

- Voltage: 400v three phase 50Hz
- P=475kW
- $\cos\varphi$ (secondary) =0.75($\tan\varphi$=0.88)

$\boldsymbol{Qc}(Capictor\ bank\ to\ be\ installed)$ =**PkW ($\boldsymbol{\tan\varphi}$Old- $\boldsymbol{\tan\varphi}$Targ**

Qc($Capictor\ bank\ to\ be\ installed$) =475(0.88-0.31)=270kVAR

Note the coefficient K= (tan φ1- tan φ2) is obtained easily from the cos φ values using the conversion table page 9

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c- Calculation for the future installations

For future installations, compensation is frequently requested from the commissioning stage. In this case, it is impossible to calculate the bank using conventional methods (electricity bill or measurements on site)
For his type of installation, it is recommended to install a capacitor bank equal to approximately 25% of the nominal power of the corresponding HV/LV transformer.

Example:
1000Kva transformer >>>> $Q_{capacitance}$ =250Kvar

Note: this type of ratio corresponds the following operation conditions

- 1000kVA transformer
- Real transformer load =75%
- $\cos\varphi$ of the load =0.80
- $\cos\varphi$ target =0.95

K=0.421 from table page 9
Qc=1000x75%x0.80x0.421=250kVAR

d- Calculation for independent producers (small power station)

For this type of installation, the independent producer must supply the electricity company with a quantity of & energy equal to at least 40% of its active energy production during winter day-tariff and peak hours. In this case, the calculation of the capacitor bank should account for:

- The on-load reactive consumption of the generator
- the on-load consumption of the LV / HV transformer (if applicable)
- the reactive energy to be supplied, or 40% of the active energy produced

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Capacitor power calculation table

- ***Conversion table***

Based on the power of a receiver in kW, this table can be used to calculate the power of the capacitors to change from an initial power factor to a required power factor. It also gives the equivalence between $cos\ \varphi$ & $tan\ \varphi$

Final power factor		Capacitor power in kVAr to be installed per kW of load to increase the power factor to:										
cosφ		**0.90**	**0.91**	**0.92**	**0.93**	**0.94**	**0.95**	**0.96**	**0.97**	**0.98**	**0.99**	**1**
	tg φ	0.48	0.46	0.43	0.40	0.36	0.33	0.29	0.25	0.20	0.14	0.0
0.40	2.29	1.805	1.832	1.861	1.895	1.924	1.959	1.998	2.037	2.085	2.146	2.288
0.41	2.22	1.742	1.769	1.798	1.831	1.840	1.896	1.935	1.973	2.021	2.082	2.225
0.42	2.16	1.681	1.709	1.738	1.771	1.800	1.836	1.874	1.913	1.961	2.002	2.164
0.43	2.10	1.624	1.651	1.680	1.713	1.742	1.778	1.816	1.855	1.903	1.964	2.107
0.44	2.04	1.558	1.585	1.614	1.647	1.677	1.712	1.751	1.790	1.837	1.899	2.041
0.45	1.98	1.501	1.532	1.561	1.592	1.626	1.659	1.695	1.737	1.784	1.846	1.988
0.46	1.93	1.446	1.473	1.502	1.533	1.567	1.600	1.636	1.677	1.725	1.786	1.929
0.47	1.88	1.397	1.425	1.454	1.485	1.519	1.532	1.588	1.629	1.677	1.758	1.881
0.48	1.83	1.343	1.730	1.400	1.430	1.464	1.467	1.534	1.575	1.623	1.684	1.826
0.49	1.78	1.297	1.326	1.355	1.386	1.420	1.453	1.489	1.530	1.578	1.639	1.782
0.50	1.73	1.248	1.276	1.303	1.337	1.369	1.403	1.441	1.481	1.529	1.590	1.732
0.51	1.69	1.202	1.230	1.257	1.291	1.323	1.357	1.395	1.435	1.483	1.544	1.686
0.52	1.64	1.160	1.188	1.215	1.249	1.281	1.315	1.353	1.393	1.441	1.502	1.644
0.53	1.60	1.116	1.144	1.171	1.205	1.237	1.271	1.309	1.349	1.397	1.458	1.600
0.54	1.56	1.075	1.103	1.130	1.164	1.196	1.230	1.268	1.308	1.356	1.417	1.559
0.55	1.52	1.035	1.063	1.090	1.124	1.156	1.190	1.228	1.268	1.316	1.377	1.519
0.56	1.48	0.996	1.024	1.051	1.085	1.117	1.151	1.189	1.229	1.277	1.338	1.480
0.57	1.44	0.958	0.986	1.013	1.047	1.079	1.113	1.151	1.191	1.239	1.300	1.442
0.58	1.40	0.921	0.949	0.976	1.010	1.042	1.073	1.114	1.154	1.202	1.263	1.405
0.59	1.37	0.884	0.912	0.939	0.973	1.005	1.039	1.077	1.117	1.165	1.226	1.368
0.60	1.33	0.849	0.878	0.905	0.939	0.971	1.005	1.043	1.083	1.131	1.192	1.334
0.61	1.30	0.815	0.843	0.870	0.904	0.936	0.970	1.008	1.048	1.096	1.157	1.299
0.62	1.27	0.781	0.809	0.836	0.870	0.902	0.936	0.974	1.014	1.062	1.123	1.265
0.63	1.23	0.749	0.777	0.804	0.838	0.870	0.904	0.942	0.982	1.030	1.091	1.233
0.64	1.20	0.716	0.744	0.771	0.805	0.837	0.871	0.909	0.949	0.997	1.058	1.200
0.65	1.17	0.685	0.713	0.740	0.774	0.806	0.840	0.878	0.918	0.966	1.007	1.169
0.66	1.14	0.654	0.682	0.709	0.743	0.775	0.809	0.847	0.887	0.935	0.996	1.138
0.67	1.11	0.624	0.652	0.679	0.713	0.745	0.779	0.817	0.857	0.905	0.966	1.108
0.68	1.08	0.595	0.623	0.650	0.684	0.716	0.750	0.788	0.828	0.876	0.937	1.079
0.69	1.05	0.565	0.593	0.620	0.654	0.686	0.720	0.758	0.798	0.840	0.907	1.049
0.70	1.02	0.536	0.564	0.591	0.625	0.657	0.691	0.729	0.796	0.811	0.878	1.020
0.71	0.99	0.508	0.536	0.563	0.597	0.629	0.663	0.701	0.741	0.783	0.850	0.992
0.72	0.96	0.479	0.507	0.534	0.568	0.600	0.634	0.672	0.721	0.754	0.821	0.963
0.73	0.94	0.452	0.480	0.507	0.541	0.573	0.607	0.645	0.685	0.727	0.794	0.936
0.74	0.91	0.425	0.453	0.480	0.514	0.546	0.580	0.618	0.658	0.700	0.767	0.909
0.75	0.88	0.398	0.426	0.453	0.487	0.519	0.553	0.591	0.631	0.673	0.740	0.882
0.76	0.86	0.371	0.399	0.426	0.460	0.492	0.526	0.564	0.604	0.652	0.713	0.855
0.77	0.83	0.345	0.373	0.400	0.434	0.466	0.500	0.538	0.578	0.620	0.687	0.829
0.78	0.80	0.319	0.347	0.374	0.408	0.440	0.474	0.512	0.552	0.594	0.661	0.803
0.79	0.78	0.292	0.320	0.347	0.381	0.413	0.447	0.485	0.525	0.567	0.634	0.776
0.80	0.75	0.266	0.294	0.321	0.355	0.387	0.421	0.459	0.499	0.541	0.608	0.750
0.81	0.72	0.240	0.268	0.295	0.329	0.361	0.395	0.433	0.473	0.515	0.582	0.724
0.82	0.70	0.214	0.242	0.269	0.303	0.335	0.369	0.407	0.447	0.489	0.556	0.698
0.83	0.67	0.188	0.216	0.243	0.277	0.309	0.343	0.381	0.421	0.463	0.530	0.672
0.84	0.65	0.162	0.190	0.217	0.251	0.283	0.317	0.355	0.395	0.437	0.504	0.645
0.85	0.62	0.136	0.164	0.191	0.225	0.257	0.291	0.329	0.369	0.417	0.478	0.602
0.86	0.59	0.109	0.140	0.167	0.198	0.230	0.264	0.301	0.343	0.390	0.450	0.593
0.87	0.57	0.083	0.114	0.141	0.172	0.204	0.238	0.275	0.317	0.364	0.424	0.567
0.88	0.54	0.054	0.085	0.112	0.143	0.175	0.209	0.246	0.288	0.335	0.395	0.538
0.89	0.51	0.028	0.059	0.086	0.117	0.149	0.183	0.230	0.262	0.309	0.369	0.512
0.90	0.48		0.031	0.058	0.089	0.121	0.155	0.192	0.234	0.281	0.341	0.484

Example: 200 kW motor - cos φ = 0.75 - required cos φ = 0.93 - Qc = 200 x 0.487 = 98 kVAr

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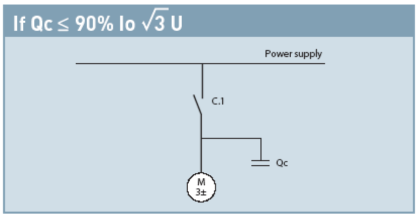
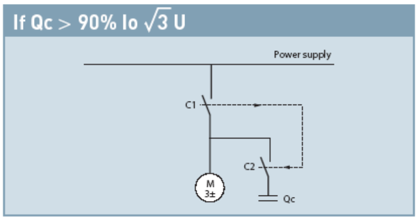
- ***Reactive Compensation of asynchronous motors (Compensation at motor Terminals)***

The table below gives, for information purposes only, the maximum power of the capacitor that can be connected **directly to the terminals of an asynchronous motor with no risk of self-excitation.** It will be necessary to check in all cases that the maximum current of the capacitor does not exceed 90% of the magnetising current (off-load) of the motor.





Io: motor off-load current
U: supply voltage

Maximum power of the motor		Maximum speed rpm		
		3000	1500	1000
HP	kW	Max. power in kVAr		
11	8	2	2	3
15	11	3	4	5
20	15	4	5	6
25	18	5	7	7.5
30	22	6	8	9
40	30	7.5	10	11
50	37	9	11	12.5
60	45	11	13	14
100	75	17	22	25
150	110	24	29	33
180	132	31	36	38
218	160	35	41	44
274	200	43	47	53
340	250	52	57	63
380	280	57	63	70
482	355	67	76	86

If the capacitor power required to compensate the motor is greater than the values given in the above table or if, more generally: Qc > 90% Io 3 U, compensation at the motor terminals will however remain possible by inserting a contactor (C.2), controlled by an auxiliary contact of the motor contactor (C.1), in series with the capacitor.

- ***Reactive Compensation of the transformer***

In order to operate correctly, a transformer requires internal reactive energy to magnetisation its windings. The table opposite gives, for information purposes only, the value of the fixed capacitor bank to be installed according to the powers and loads of the transformer. These values may change, depending on the technology of the device. Each manufacturer can provide their own precise values.

Nominal power of the transformer kVA	KVAr power to be provided for the internal consumption of the transformer		
	Operation		
	off-load	75% load	100% load
100	3	**5**	6
160	4	**7.5**	10
200	4	**9**	12
250	5	**11**	15
315	6	**15**	20
400	8	**20**	25
500	10	**25**	30
630	12	**30**	40
800	20	**40**	55
1000	25	**50**	70
1250	30	**70**	90
2000	50	**100**	150
2500	60	**150**	200
3150	90	**200**	250
4000	160	**250**	320
5000	200	**300**	425

When defining a reactive energy compensation installation, it is advisable to provide a fixed capacitor corresponding to the internal reactive consumption of the transformer at 75% load.

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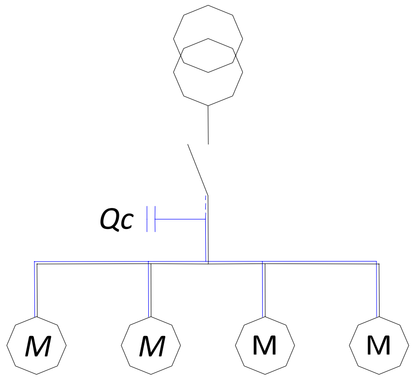
Different possible capacitor bank installations

In an L.V electrical installation, capacitor banks can be installed at 3 different levels:

- ***Global installation***

Advantages:
- No reactive energy bill.
- Represents the most economical solution since all the power is concentrated at one point and the expansion coefficient makes it possible to optimize banks
- Relieves the transformer.

Remark:
- The losses in the cables (RI^2) are not reduced.

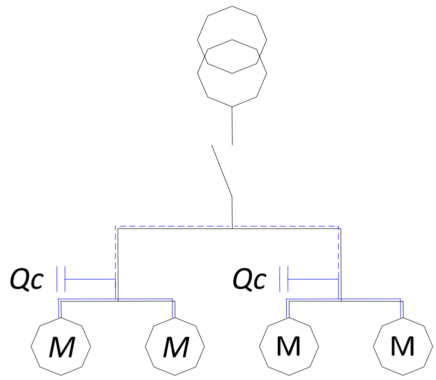


Global installation

- ***Sector installation***

Advantages:
- No reactive energy bill.
- Relieves most of the line feeders and reduces Joule's heat losses (RI^2) in these feeders
- Incorporates t he expansion of each sector.
- Relieves he transformer.
- Remains economical.

Remark:
- Solution generally used for a very large plan network.



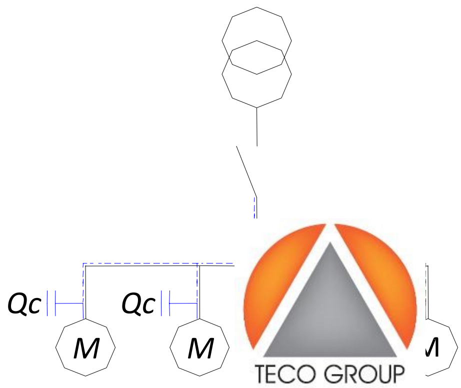
Sector installation

- ***Individual installation***

Advantages:

- No reactive energy bill.
- From a technical point of view, the ideal solution since the reactive energy is produced in the same place as where it is consumed; therefore, the Joule's heat losses (RI^2) are reduced in all the lines
- Relieves the transformer.

Remark:
- Most costly solution given:
  - The high number of installations
  - The non-incorporation of the expansion coefficient



Individual installation

Different compensation systems or types

To select a capacitor bank, there are two major compensation systems or types.

- ***Fixed type capacitor banks:***

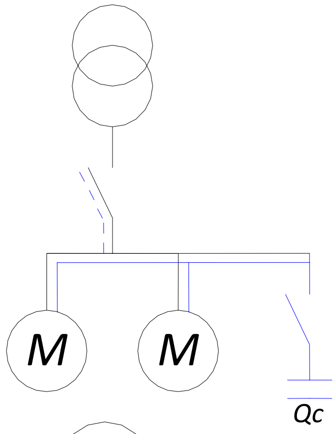
The reactive power supplied by the bank is constant irrespective of the variations of the power factor and load of the receivers and, therefore, of the reactive energy Consumption of the installation.

These banks are switched on:

- either manually by a circuit breaker or switch,
- or semi-automatically by a remote-controlled contactor

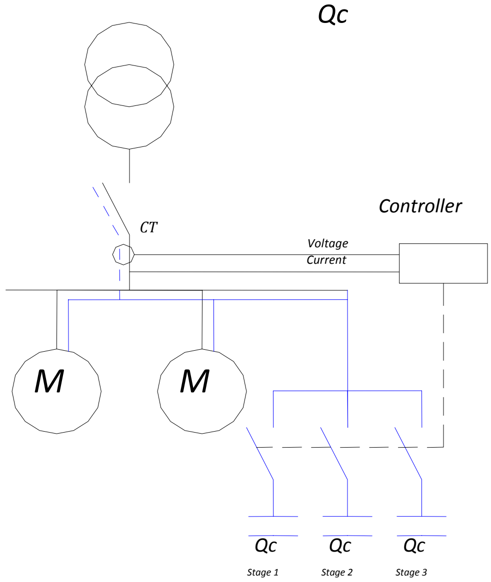
This type of bank is generally used in the following cases:

- Constant load electrical installations operating 24 hours a day,
- Internal reactive compensation of transformer,
- Individual compensation of motor.



- ***Automatic type capacitor banks:***

- The reactive power supplied by the bank can be modulated according to the variations of the power factor and the load of the receptors and, therefore, of the reactive energy consumption of the installation.
- This type of bank is composed of a parallel combination of capacitor steps (step= capacitor +contactor). Switching all or part of the bank on and off is controlled by a incorporated VAR meter regulator.
- h a banks are generally used in The following cases:
  1. variable load electrical installations,
  2. compensation of main switchboards (MDB) or major outlets,
  3. Installation of a bank with a power greater Than 15% of the Transformer power S(kVA).



$\boldsymbol{Qc}(Capictor\ bank\ to\ be\ installed) >$ **15% transformer S(kVA)**

Control, Protection, Connection of capacitors

- ***Control device***

The engagement current of a capacitor depends on:

- the power of the capacitor,
- the short-circuit power of the network to which it is connected,
- Whether capacitor banks already engaged ore present or not.

Given these parameters, it is essential to use quick opening and dosing control devices(switches, contactors, etc.).
When selecting the switch gear, the user must be made aware of the choice of equipment (capacitor control).
Contactors are specially designed by contactor manufacturers for capacitor control , particulary for automatically controlled banks.
These contactors are equipped with auxiliary contacts combined with preload resistors used to limit the current requirement during engagement.

In the case of high-speed cycle loads (welding machines, etc.), conventional systems (electromechanical contactors) are no longer suitable for controlling capacitors. High-speed switching compensation systems with solid state contactors are required.

- ***Protection***

In addition to the internal protective devices incorporated in the capacitor:

- Self-healing metalized polypropylene film
- Internal fuses
- Overpressure disconnecting fuse

it is essential to provide an external protective device on the capacitor.

This protection will be provided either:

- By a circuit breaker:
  - Thermal relay, sitting between 1.3 to 1.5 In
  - Magnetic relay, sitting between 5 to 10 In
- By HRC Fuses, rating 1.5 to 2 In

In=Nominal capacitor voltage,

$$In = \frac{Qc}{\sqrt{3}.U}$$

e.g.: Qc=50Kvar, U=400V three-phase

$In = \frac{50,000}{\sqrt{3}.400}$=72A

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➢ Connection (cable design)

Applicable capacitor standards are defined so that capacitors can withstand a permanent excess current of *30%*

These standards also authorize a maximum tolerance of +10% on the nominal capacitance.

Therefore, he cable should be designed at least for:
I cable = 1.3 x 1.1 x (I nominal capacitor)

I cable = 1.43 x (I nominal capacitor)

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Harmonics

- Introduction

The modernization of industrial processes, sophistication of electrical machines and equipment has, in recent years, led to significant development in power electronics:
These semi-conductor-based systems (transistors, thyristors, etc.) designed to produce:

- Solid state power converters : AC/DC
- rectifiers
- inverter
- frequency converters
- And many other wave train or phase setting control devices. For electrical supplies, these systems represent "non-linear" loads. A "nonlinear" load is o load for which he current consumption is not the reflection of the power supply voltage (even through the source voltage on the load is sinusoidal, the current consumption is non-sinusoidal).

Other "non-linear loads are also present in electrical installations, in particular:

- Variable impedance loads, using an electric arc: arc furnaces, welding stations, fluorescent tubes, discharge lamps, etc.
- Loads using strong magnetising currents saturated transformers, inductors, etc.

The Fourier series breakdown of the current consumption of a non-linear receiver reveals:

- a sinusoidal term at the supply 50 Hz frequency, the fundamental
- Sinusoidal terms for which the frequencies are multiples of the frequency of the fundamental, the harmonics.

According to the equation:

$$I_{rms} = \sqrt{I_1^2 + \sum_{i=2}^{n} . I_1^2}$$

∑=Sum of all the harmonic currents from rank 2(50Hz x 2) to the last rank n (50Hz x n)

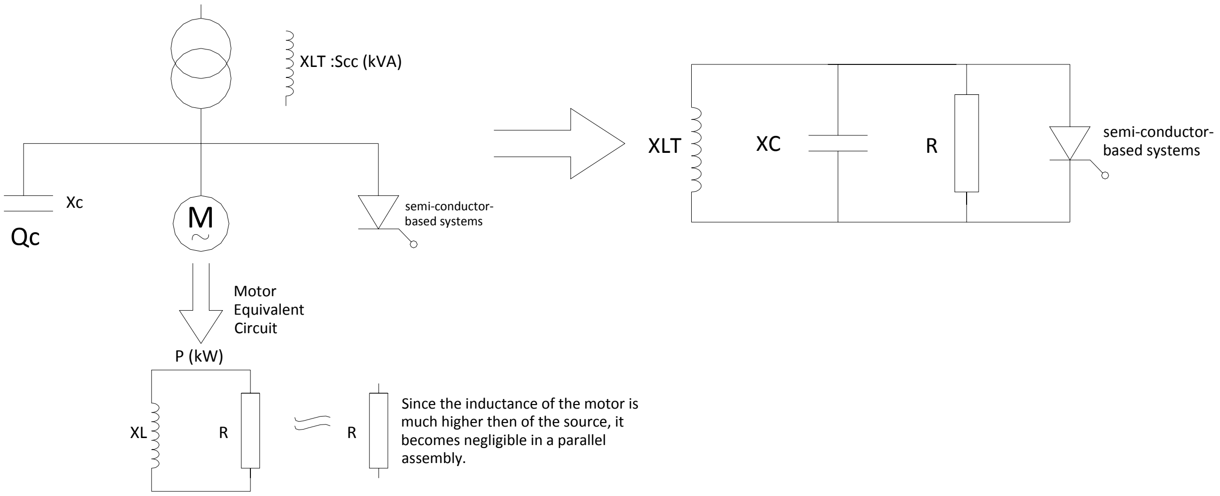
This harmonics current circulate in the source and the harmonic voltage according to the equation

$$I_{rms} = \sqrt{U_1^2 + \sum_{i=2}^{n} . U_1^2}$$

Note: the harmonic distortion of the voltage generated by manufacturing defects of the alternator and transformer windi negligible.

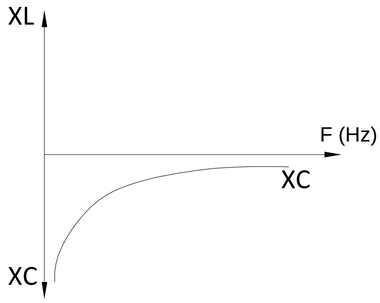
- Influence of harmonics on capacitors

Priniciple Diagram　　　　　　　　Equivalent Diagram



-Scc(Kva): Short-circuit power of source
-Q (kVAR): Capacitor bank power
-P (kW): Non-interfering load power

- **Decrease in capacitor reactance**



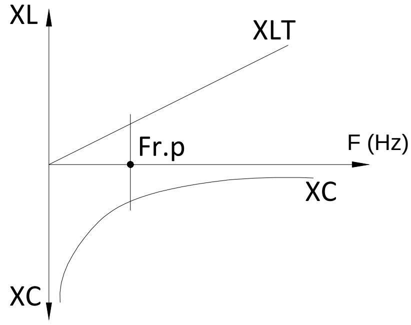
The reactance of the capacitor is inversely proportional to the frequency, its ability
To dlock harmonic currents decreases considerably when the frequency increases.

$$Xc = \frac{1}{C.2.\pi.f}$$

- **Parallel resonance or anti-resonance between the capacitors and the source**

-the reactance of the source XLT is proportional to the frequency
-the reactance of the capacitors XC is inversely proportional to the frequency

At the frequency Fr.p, there is parallel resonance or anti-resonance (since the two reactance are equal but opposite) and amplification (F.A) of the harmonic current in the capacitors and in the source (transformer) where:



$$\boldsymbol{Fr.p = Fsupply.}\sqrt{\frac{\boldsymbol{Scc}}{\boldsymbol{Q}}}$$

$$\boldsymbol{F.A =}\sqrt{\frac{\boldsymbol{Scc.Q}}{\boldsymbol{P}}}$$

It's important to know that:
-the higher short-circuit power of the source (Scc) is, the further the resonance frequency moves away from the dangerous harmonic.
-the higher power (P) of non-interfering load is, the more the amplification factor of the harmonics current is reduced.

Main harmonics currents:
The main harmonic currents present in electrical installations are produced by semi-conductor based systems, i.e.:
-Harmonic 5 (250Hz)-15-20% Iscs
-Harmonic 7 (350Hz)-17-14% Iscs
-Harmonic 11 (550Hz)-11-9% Iscs
-Harmonic 13 (650Hz)-13-8% Iscs

*Iscs Current of semi-conductor system at 50Hz

- Insensitivity of capacitors to harmonics

By design and in compliance with applicable standards, capacitors are capable of withstanding a continues rms current equal to 1.3 times the nominal current defined at nominal voltage and frequency values.

This excess current coefficient has been defined to account for the combined effects of the presence of harmonics and excess voltage (with the capacitance variation parameter being negligible).

It can be noted that according to the degree of harmonic interference SH (power of harmonic generators), this coefficient generally proves to be insufficient snd that the parameter Scc (short-circuit power) directly related to the power of the sours ST is preponderant in the value of the parallel resonance frequency (Fr.p)

By combining these two parameters SH and ST, three type of networks can be defned with a corresponding "type" of capacitor to be installed:

Type of supply	Pollution criterion	Type of capacitor to be used
Low level of interference	$If\,\frac{SH}{ST} \leq 15\%$	*Standard type*
Moderate level of interference	$If\,\frac{SH}{ST} \leq 25\%$	*H type*
High level of interference	$If\,\frac{SH}{ST} > 25\%$	*SAH type (Anti-harmonic reac* *FH type (Harmonic filter)*

SH: Expanded power in kVA of harmonic generators present in the secondary windeing of the MV/LV transformer(s) to be compensated.
ST: power in kVA of the MV/LV transformer(s)

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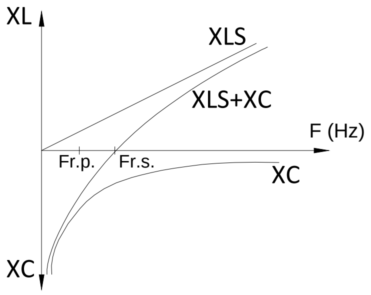
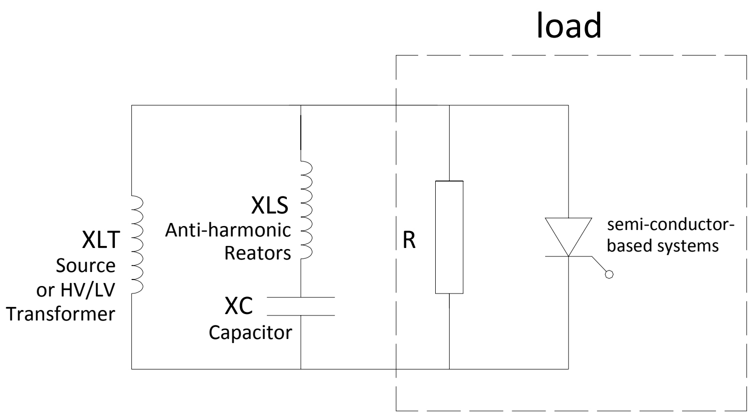
- **Protection of capacitors with anti-harmonic reactors**

For supplies with a high level of harmonics interference, installing an anti-harmonic reactors connected in series with the capacitor proves to be the only effective solution. The anti-harmonic reactors have two purposes:
-to increase the impedance of the capacitor against harmonics currents
-to shift the parallel resonance to below the main frequencies of the interfering harmonic currents.





Fr.p.: Anti-harmonic reactors/capacitor/MV/HV transformer parallel resonance frequency
Fr.s.: Anti-harmonic reactors/capacitor serial resonance frequency.(most common values used 190-210 and 225Hz and 215Hz)

-for frequencies below Fr.s, the reactors/capacitor system behaves like a capacitance and compensates for the reactive energy
-for frequencies above Fr.s., the reactors/capacitors system behaves like an inductance which , in parallel with the inductance XLT, cancel any risk of parallel resonance at frequencies above Fr.s., particularly at the main harmonic frequency.

- **Harmonic filter**

For installation with a high level of harmonic pollution, the user may be confronted with two requirement:
- ✓ Compensating for reactive energy and protection the capacitors
- ✓ Reducing the voltage distortion rate to acceptable value compatible with the correct operation of most sensitive receivers (automatic control systems, industrial computer hardware, capacitors, etc.)

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