Prof. Ing. Dario Pozzetto

Department od Engineering and Architecture – University of Trieste

Via Valerio, 10 –34127 Trieste – Tel: 040.558.3805 / 7982 Fax: 040.558.3812

E-mail: pozzetto@units.it

INDUSTRIAL PLANTS II

Chapter six (part 3):
Electrical plants

DOUBLE DEGREE MASTER IN

“PRODUCTION ENGINEERING AND MANAGEMENT”

CAMPUS OF PORDENONE

UNIVERSITY OF TRIESTE

Classification of electrical systems

Electrical systems can be classified according to:

a) voltage

Low voltage systems (BT) are called electrical plants, whereas medium (MT) and high voltage (AT) plants are defined as electrical network or electrical systems due to the higher complexity in both the technological equipment, the analysis and the calculation needed.

Classification of electrical systems

Electrical systems can be classified according to:

b) grounding of neutral and ground

The classification of electrical systems according to the grounding is the following.

In BT referring to the Standard CEI 64-8/3, where according to the grounding, the electrical systems can be subdivided using an acronym composed by groups of letters with the following meaning.

The first letter specified the state of the distribution system in relation to the ground (condition of the power system):

T: directly grounding of a point belonging to the electrical system (usually the low voltage neutral center of the MT/BT transformer);

I: the system is isolated from the ground, or one point (usually the neutral) is grounded with a high impedance;

Classification of electrical systems

Electrical systems can be classified according to:

b) grounding of neutral and ground

The second letter specifies the status of users' ground (condition of ground) in relation to the ground.

T: the users' ground are directly connected to a ground plant which differs from the one of the electrical system (users' ground have their own grounding plant);

N: single grounding connection for both the ground and the neutral center of the MT/BT transformer (the users' ground are connected to the grounding point of the power system).

Other possible letters specify the condition of neutral and protection conductors:

S: neutral function (N) and protection one (PE) are done by different conductors;

C: neutral and protection function are done by a single common conductor (PEN).

Classification of electrical systems

Electrical systems can be classified according to:

b) grounding of neutral and ground

Due to the fact that the regulation oblige to ground, the following combinations of the first two letters are possible:

TT, TN and IT.

The TT system is always used to power low voltage and low and medium power users' plants without an owned transformation cabin, as could be a domestic users service industries, small and medium enterprise, artisan business, agricultural industries etc., with powers used until 200 kW.

In a TT system are present two independent grounding plants: the one in the public MT/BT cabin (supplier) and the one of the user's plant.

Classification of electrical systems

Electrical systems can be classified according to:

b) grounding of neutral and ground

In this system, the neutral conductor is connected to the ground plant of the electrical cabin (which is owned by the supplier).

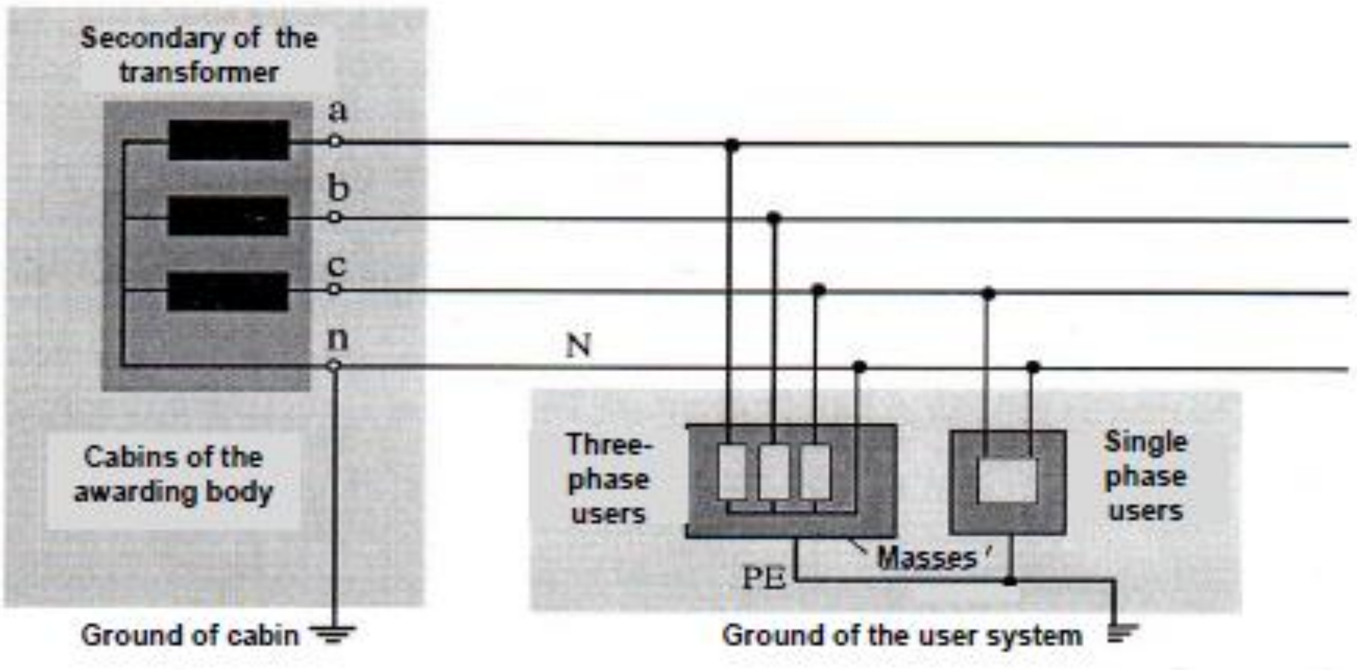
All the ground of the equipment are protected by the protection device against indirect contact and they must be connected to the ground plan (owned by the user) through the protection conductor (PE).

Classification of electrical systems

Electrical systems can be classified according to:

b) grounding of neutral and ground

The situation is illustrated in the figure, where as an example are presented two users, one three-phase and one single-phase.



Classification of electrical systems

Electrical systems can be classified according to:

b) grounding of neutral and ground

The TN system is always used to supply medium-high power users (usually higher than 200 kW), which powers users' plant is equipped with owned transformation cabin, as could be big users' plants (like industrial and civil one and common users of large condominiums).

In this system both the neutral and the ground protection conductor are connected to the ground plant of private electrical cabin's.

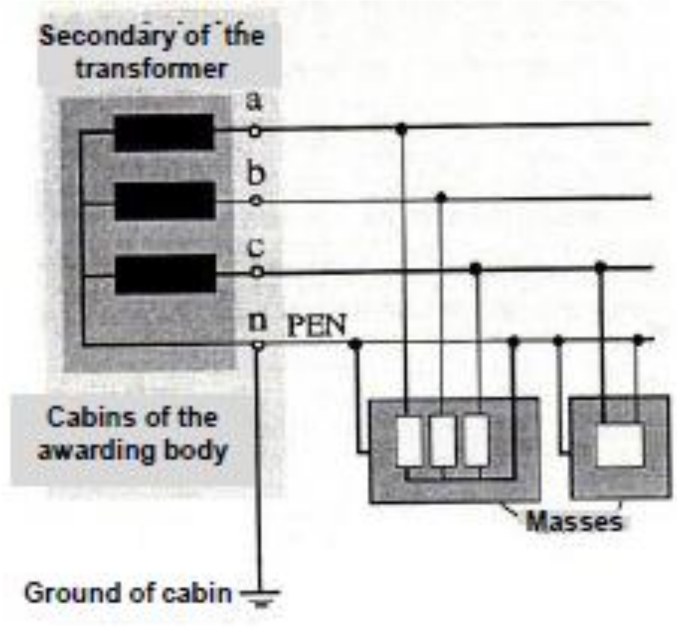
Classification of electrical systems

Electrical systems can be classified according to:

b) grounding of neutral and ground

TN systems can be subdivided into three types:

- TN-C where the neutral and protection functions are combined in only one conductor conventionally denoted as PE or PEN



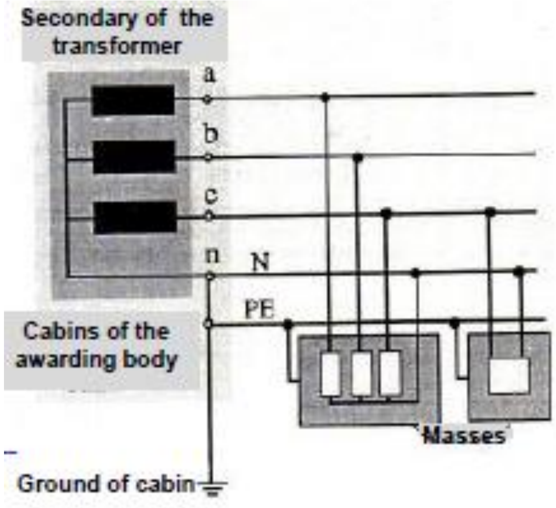
Classification of electrical systems

Electrical systems can be classified according to:

b) grounding of neutral and ground

TN systems can be subdivided into three types:

- TN-S where the neutral conductor and the protection, i.e. a system in which the neutral conductor and the protection one are split and the ground are connected to the cabin ground or to the neutral one through the protection conductor PE



Classification of electrical systems

Electrical systems can be classified according to:

b) grounding of neutral and ground

TN systems can be subdivided into three types:

- TN-C-S which result from the combination of the two precedent types (TN-C and TN-S) where the neutral and protection functions are, for part of the plant combined in only one conductor (TN-C) and for the other part are separated.

Classification of electrical systems

Electrical systems can be classified according to:

b) grounding of neutral and ground

The IT system is used (in case of supply with cabin owned by the client) only where there are particular requirements as the service continuity like in operating theatre, airports, continuous cycle plants, on-board equipment etc.

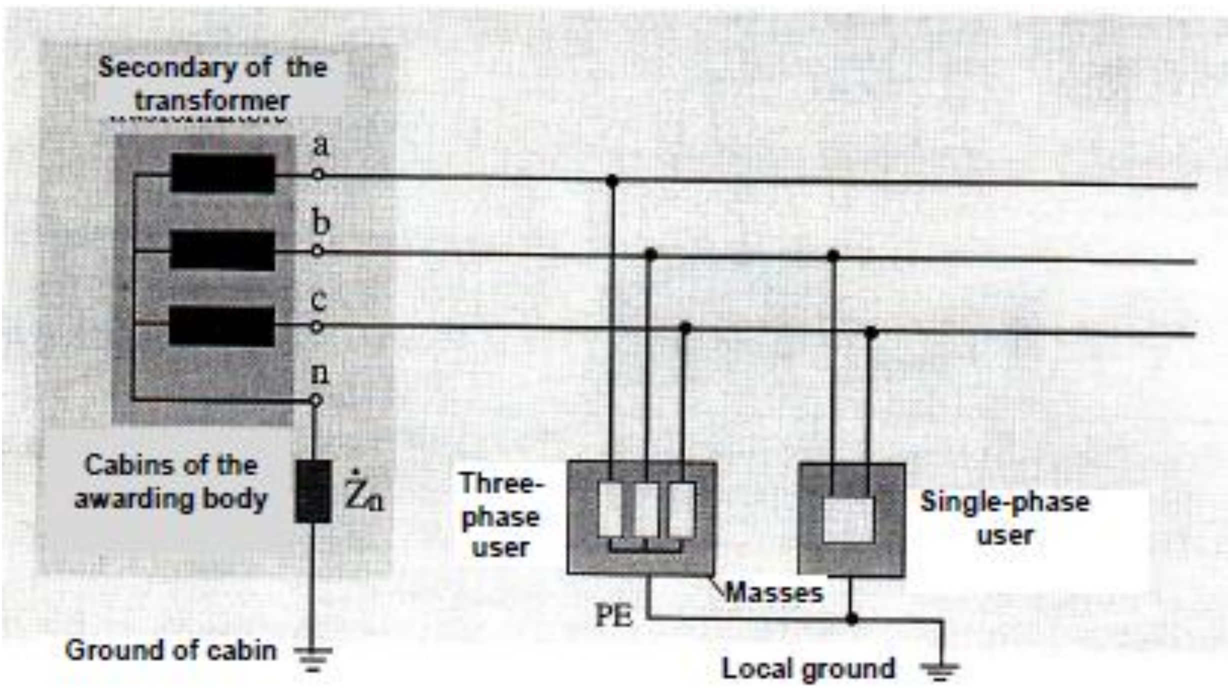
The neutral is usually not distributed. The secondary of the transformer have the neutral center connected to the cabin's grounding plant through an impedance with an elevated Zn modulus (the resistance could be of hundred of ohm).

<u>Classification of electrical systems</u>

Electrical systems can be classified according to:

b) grounding of neutral and ground

The ground are connected to the local grounding plant individually, in groups or together (it is recommend to ground them together),

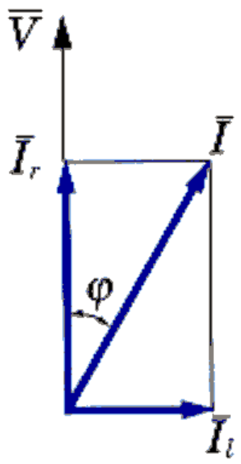


Power factor correction of electrical plants

Speaking of users' plants it is important to consider the problem of power factor correction loads. In this paragraph are going to be analyzed the plants for low voltage (BT) power factor correction, usually installed at users' place and realized with static capacitors, for which will be shown also the design process.

Power factor correction of electrical plants

Regarding the theoretical aspects, taking into consideration an electrical circuit, single-phase or three-phase, which operates in alternating sinusoidal regime, there is usually a phase-shift angle φ between voltage and current. In the majority of practical cases, having R-L users, the current is out-of-phase in delay compared to voltage.



Power factor correction of electrical plants

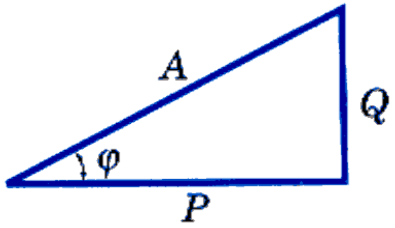
Decomposing current I into its components I_r and I_l, respectively in phase and in quadrature with the voltage, the following formulas are obtained:

$$I_r = I \cdot \cos\varphi \qquad I_l = I \cdot sen\varphi$$

The active P, reactive Q and apparent A powers, in the case of single-phase loads, are calculated from:

$$P = V \cdot I_r = V \cdot I \cdot \cos\varphi \qquad Q = V \cdot I_l = V \cdot I \cdot sen\varphi \qquad A = V \cdot I$$

and they are represented by the sides of a right triangle



Power factor correction of electrical plants

It is obvious in order to provide certain power P with a given voltage V, is needed a current equal to:

- if single-phase

$$I = \frac{P}{V \cdot \cos\varphi}$$

- if three-phase

$$I = \frac{P}{\sqrt{3} \cdot V \cdot \cos\varphi}$$

Power factor correction of electrical plants

In both cases, the current is inversely proportional to the power factor cos φ; in order to reduce as much as possible the current value, the cosφ should be equal to one and in the case the formulas become:

- if single-phase

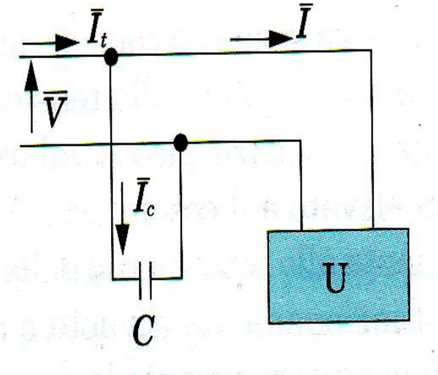
$$I = I_r = \frac{P}{V}$$

- if three-phase

$$I = I_r = \frac{P}{\sqrt{3} \cdot V}$$

Power factor correction of electrical plants

Considering a single-phase R-L load with a power factor cosφ (figure - power factor correction of a single-phase load).

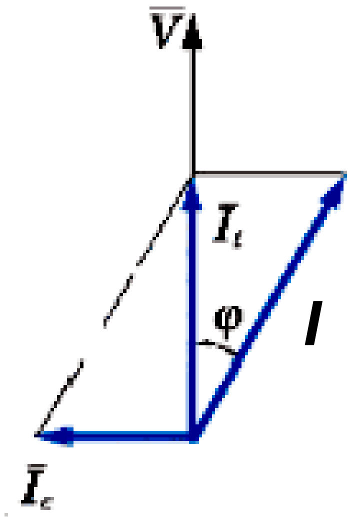


Putting in parallel a capacitor which absorbs a current I_c anticipated of 90° in comparison to the voltage, it is possible to obtain the total current given by the vector sum:

$$I_t = I_c + I$$

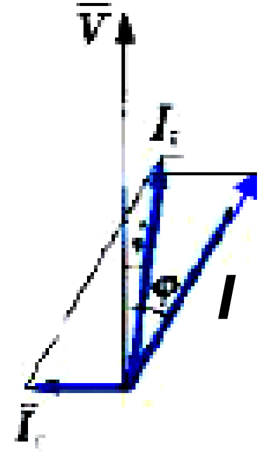
Power factor correction of electrical plants

Having a current I_c equal and opposite to the component of the current I, is obtain a total current which is in phase with the voltage and the total power factor (user + capacitor) (figure - vector diagram of total power factor correction $I_c = I \cdot sen\varphi$).



Power factor correction of electrical plants

This situation is called total power factor correction, while if I < I senφ the current It is still-out-of-phase of an angle φ‘ in comparison to the voltage, obtaining a partial power factor correction (figure - vector diagram of partial power factor correction $I_c < I \cdot sen\varphi$).



Power factor correction of electrical plants

It defined "**power factor correction"** every measure taken to increase or, as usually said, improve the power factor of a specific electrical load in a part of an electrical plant aiming to reduce, considering the same active power carried, the current value that flows ahead of the plant.
The power factor correction aims to decrease the transmission energy loss ahead the power factor correction position and to reduce the apparent powers to prorate both the machines and the lines.

Power factor correction of electrical plants

The power factor correction is a technique to rationally use energy: improving machine and equipment’s power factor, allow to obtain high economic savings, with benefits from both the side of the customer and the energy supplier.

The higher is the power requirement the higher are the saving.

Furthermore, it is important to consider the ***reasons of a low power factor***.

Power factor correction of electrical plants

The loads absorbing active power with a low power factor and representing the reason why there is a low power factor are usually the following:

- asynchronous engines (induction motors)
  cosφ without load= 0,1 – 0,2, with full load = 0,6 – 0,9 (it depends from the nominal power and from the number of poles)
- industrial transformers
  Usually cosφ without load = 0,1 – 0,2
- transformer welding apparatus (static welding apparatus with resistance arc with high frequency dielectric losses)
  Variable cosφ according to different uses, from 0.3 to 0,9
- Induction ovens
  cosφ, for low frequencies (50 Hz), 0,7 – 0,75, for high frequencies (1 – 20 kHz) $\leq$ 0,1

Power factor correction of electrical plants

The loads absorbing active power with a low power factor and representing the reason why there is a low power factor are usually the following:

- lamps with gas discharge (neon, sodium, mercury)
  Discharge lamp with stabilization reactors (today nearly all of them have power factor correction). If they have no power factor correction $\cos\varphi = 0,3 - 0,45$
- a.c. – d.c. conversion plants (more rare in comparison with precedent reasons) They input deformed power in the network, helping in decreasing the $\cos\varphi$

Power factor correction of electrical plants

A low power factor causes more than one problem in the plant, which are reflected upon both the efficiency and running costs.

A low $\cos\varphi$ produces:

- bad plants usage, i.e. a reduction of the supply plants available power or an oversizing of the plants having the same active power;
- more frequent voltage drops, with negative influences in users' equipment functioning;
- an increase in conductors' energy loss, caused by the higher intensity of circulating current with the same power;
- higher energy costs due to tariff related to the supplied reactive energy.

Power factor correction of electrical plants

Contractual situation - low power factor tariff

Among electric supplier - ENEL or other societies - and the customer who want to connect his own user intended for “other uses" and with an available active power higher than 15 kW with 230/400 V voltage, sign a "contract for electric energy supply".

Between the various contract paragraphs, present under “particular conditions“, there is a clause called "power factor and reactive energy"; in this part are described the technical and economic conditions that must be respected by the client in order to receive the supply of electric energy.

Being a very important clause, it is integrally reported below.

Power factor correction of electrical plants

Contractual situation - low power factor tariff

"Power factor and reactive energy"

The value of the instantaneous power factor at the maximum load should not be less than 0.90 and its average in a month must not be less than 0.70. If the average in month is less than 0.70, the customer must change his plants in order to bring it back at least to this value.

Power factor correction of electrical plants

Contractual situation - low power factor tariff

For users with available power higher than 6 kW and for inductive reactive energy consumption (expressed in kVArh) higher than half the value of active energy consumption (expressed in kWh), are applied the prices stated in the by the decisions of authorities in charge pro-tempore (see table attached to article 15, “prices for reactive energy consumption", of the 348/07 A.E:E:G. resolution attachment reported below).

The Authority for Electricity and Gas (A.E.E.G.) is an independent body set up by the 14th November 1995 by the law n. 481 with the aim of protecting the interests of consumers and to promote competition, efficiency and deployment of services with adequate levels of quality, through the activity of regulation and control under the areas of competence. In particular, the A.E.E.G. must "ensure the promotion of competition and efficiency" in the f electricity and gas sector, as well as to ensure "the availability and distribution of services evenly throughout the country, establishing a reliable and transparent tariff system based on predefined criteria, promoting the protection of users and consumers interests ...... “
The tariff system is required "to reconcile the economic and financial objectives of the parties operating the service with the general goals of a social character, environmental protection and efficient use of resources".

Power factor correction of electrical plants

Contractual situation - low power factor tariff

Prices for reactive energy consumption

Type of contract referred to in paragraph 2.2	Reactive energy between 50 and 75% of the active energy (euro cents / kVArh)	Reactive energy exceeding 75% of the active energy (euro cents / kVArh)
Letter a) Domestic uses at low-voltage	3,23	4.21
Letter b) Users in low-voltage of public ligHVing	3,23	4,21
Letter c) Other users in low-voltage	3,23	4,21
Letter d) Users in medium-voltage of public lighting	1,51	1,89
Letter e) Other users in medium-voltage	1,51	1,89
Letter f) Users in high and very high voltage different from those of the letter g)	0,86	1,10
Letter g) Uses in extra high voltage, greater than 220 kV	0,86	1,10

For the share of consumption of reactive energy between 50% (corresponding to cos φ = 0,8944) and 75% (corresponding to cos φ = 0,8) the active energy is charged a cost per kWh. For the share of consumption of reactive energy exceeds 75% of the active energy (less than 0.8), is charged a cost per kWh higher than the previous

Power factor correction of electrical plants

Contractual situation - low power factor tariff

For supplies with available power higher than 30 kW is in the supplier discretion to ask the client to modify his plant in order to bring the monthly average value of the power factor below 0.90.

Under no circumstances the client's plant should supply inductive reactive energy to the supplier network.

It is supplier's discretion to apply the tariff decided by authorities in change pro-tempore for the inductive reactive energy supplied by the client's plant.

Power factor correction of electrical plants

A plant's power factor correction regards the insertion of a certain number of capacitors in order to bring the power factor from a value $\cos\varphi_0$ to the wanted value of $\cos\varphi_1$.

The determination of the capacity or the reactive power of the capacitor bank to be installed in order to obtain the power factor correction is explained below.

Being P the absorbed active power of user's equipment with a power factor of $\cos\varphi_o$ which has to reach the value $\cos\varphi_1$, the formulas are the following:

$$P = V \cdot I \cdot \cos\varphi_o \qquad Q = V \cdot I \cdot sen\varphi_o$$

from which:

$$\frac{Q}{P} = tg\varphi_o$$

Power factor correction of electrical plants

The capacitors' reactive power Q_c has to be:

$$\frac{(Q - Q_c)}{P} = tg\varphi_1$$

then:

$$\frac{Q}{P} - \frac{Q_c}{P} = tg\varphi_1$$

and finally:

$$\frac{Q_c}{P} = \frac{Q}{P} - tg\varphi_1$$

but:

$$\frac{Q}{P} = tg\varphi_o$$

and then:

$$\frac{Q_c}{P} = tg\varphi_o - tg\varphi_1$$

Concluding, Q_c be expressed by:

$$Q_c = P \cdot (tg\varphi_o - tg\varphi_1)$$

Power factor correction of electrical plants

The reactive power of the capacitor bank, needed to bring the power factor from the value $\cos\varphi_o$ to $\cos\varphi_1$, is obtained by multiplying the active power P with the subtraction of the tangents related to $\cos\varphi_o$ and $\cos\varphi_1$.

Below is presented an example to illustrate the calculation of reactive power.

Having P = 20 kW and $\cos\varphi_o = 0,6$ ($tg\varphi_o = 1,333$) and wanting to correct the power factor in order to have $\cos\varphi_1 = 0,9$ ($tg\varphi_1 = 0,484$), the capacitor power obtained is:

$$Q_c = P \cdot (tg\varphi_o - tg\varphi_1)$$

$$Q_c = 20 \cdot (1,333 - 0,484) = 17 \;\; kVAr$$

The relation:

$$Q_c = P \cdot (tg\varphi_o - tg\varphi_1)$$

Is valid also to correct the power factor for a plant with more than one user.

Power factor correction of electrical plants

However, if the users have different power factors and they do not operate simultaneously, as could be case of user plant, it is necessary to pay attention when determining the value of P and cosφ, which value would necessary be on average ones.

Willing to calculate the reactive power needed to correct the total power factor of the plant, it is required to obtain the values of P and tgφ based both on appropriate information (maybe also estimated by the user from his experience) over the operating hours and on the way the plant is used by the users, this is done in order to introduce these values into the formula presented before.

Power factor correction of electrical plants

P is the power that is used on average by the plant and tgφ_0 is the tangent related the average power factor caused by energy consumption.

The *technique to improve the power factor of an electrical network* have always the same aim: reduce the reactive (inductive) energy required by the network.

Power factor correction of electrical plants

This can be realized with two different type of actions::

1) direct methods and 2) indirect methods

1) direct methods

These methods are aimed to reduce the requirements of reactive energy by the users.

They consists into minimizing the causes of low power factor, which were examined before, by using the machines more rationally. In particular it is necessary to:

- use engines and transforms correctly sized (that is to say sized with a power proportional to the load), in this way they do not operate a long time with a reduce load;
- do not use engines and transformers operating with a low or without load, because in these operating conditions the cosφ has extremely low values;
- do not use faulty engines;

Power factor correction of electrical plants

This can be realized with two different types of actions.

2) indirect methods

With these methods the reactive energy is produced as near as possible to the point where is needed.

Since it is not possible, nor economically convenient, to reduce under a certain limit the use of reactive energy by the users, usually the same result is obtained by producing the magnetizing current needed by each equipment by using static capacitors installed on site.

Simply, when the actions described in the direct methods are not sufficient to reduce the cosφ as required, it is necessary to do a power factor correction. In order to do so are used static capacitors.

Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

Whereas machines and equipment with coils absorb reactive power to operate, a capacitor put into an electric circuit can produce this type of power.

In this way can be obtained a sort of balance and the cosφ of the system is improved. Simply, the situation is described by saying that the reactive capacitors power produced by the capacitors balances the inductive reactive power produced by the inductive circuits.

The contribution of reactive power given by the capacitors allow to reduce the total reactive power required by the network.

The power factor correction of the plant can be done in different ways, i.e. each of the possible positions could be the most advantageous from a technical and economic point a view and according to the circumstances.

Power factor correction of electrical plants

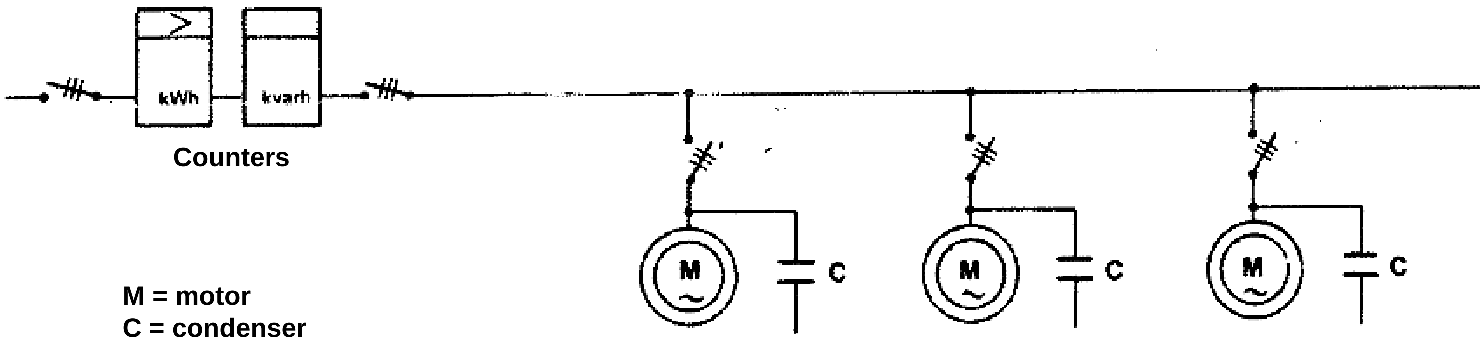
This can be realized with two different type of actions::

2) indirect methods

The types of power factor correction method are:

a) for plants powered by BT:

1) distributed or single power factor correction, i.e. power factor correction user to user



Power factor correction of electrical plants

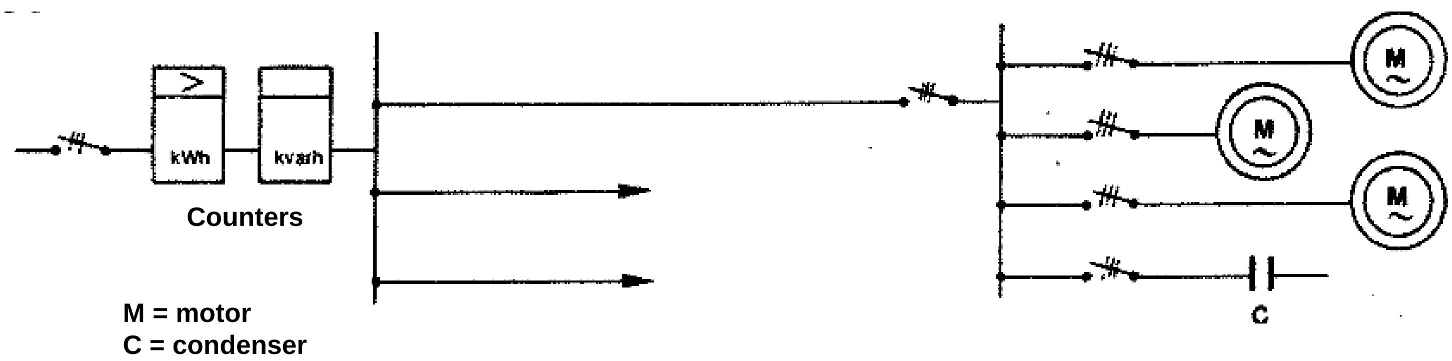
This can be realized with two different type of actions::

2) indirect methods

The types of power factor correction method are:

a) for plants powered by BT:

2) power factor correction for groups of user



Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

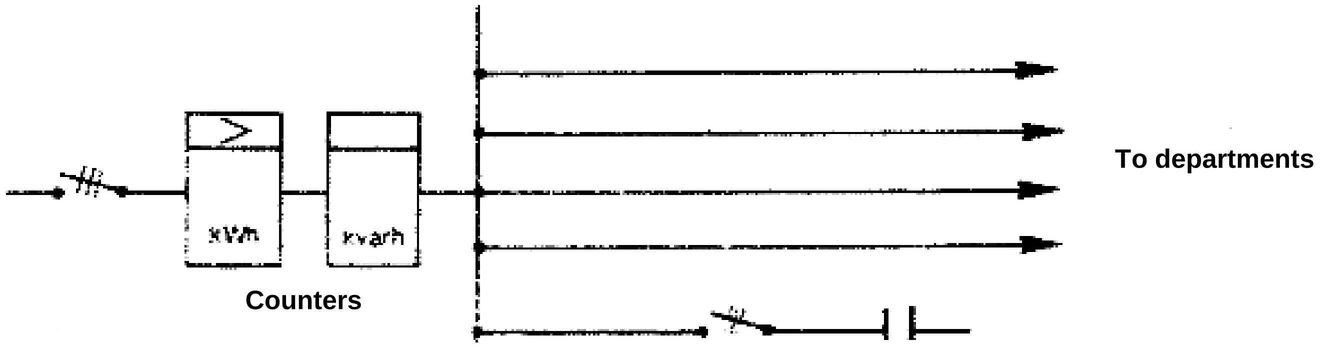
The types of power factor correction method are:

a) for plants powered by BT:

3) centralized power factor correction with batteries inserted:

- manually

- automatically



Power factor correction of electrical plants

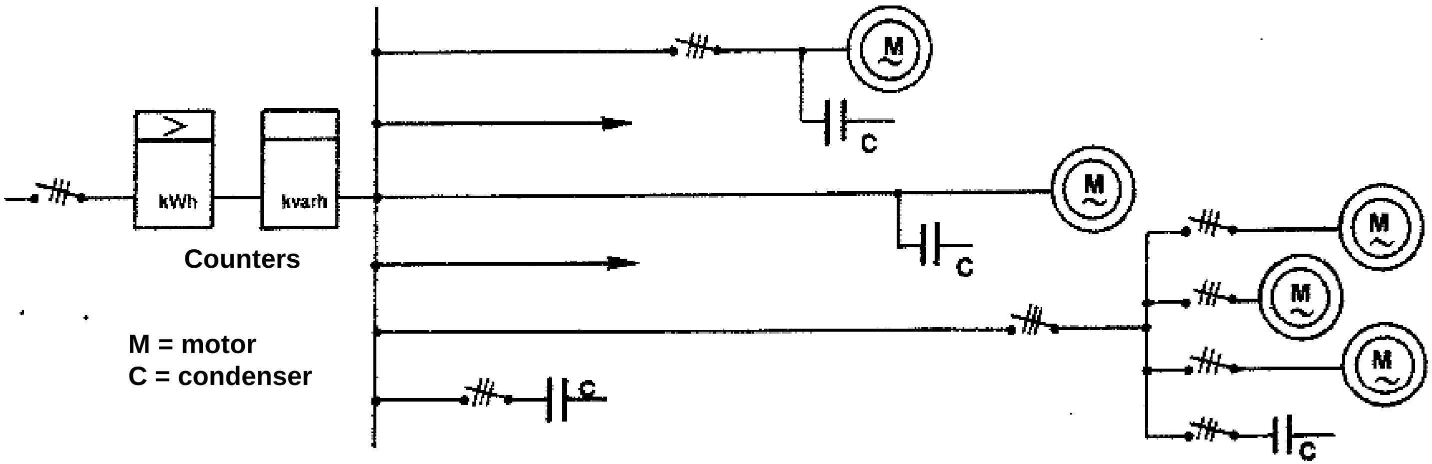
This can be realized with two different type of actions::

2) indirect methods

The types of power factor correction method are:

a) for plants powered by BT:

4) mixed power factor correction



Power factor correction of electrical plants

This can be realized with two different type of actions::

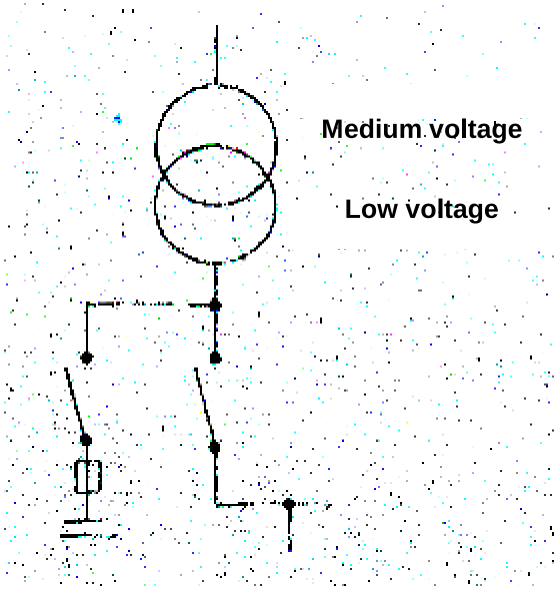
2) indirect methods

The types of power factor correction method are:

b) for plants powered by MT:

1) *centralized power factor correction*

The diagram of the way the capacitor is insered is showed in the figure



Power factor correction of electrical plants

This can be realized with two different type of actions:

2) indirect methods

The method to correct the power factor in plants powered by BT:

1) *distributed or single power factor correction*

It consist in installing a capacitor with appropriate power in parallel with each user which operates with a low power factor.

The distributed power factor correction is advantageous when coefficient near 1 or machines placed far from the energy delivery point (generating set). An example of this method is given by power factor correction done by fluorescent lamps producers.

Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

The method to correct the power factor in plants powered by BT:

1) *distributed or single power factor correction*

From a technical point of view this is the best solution because it allows saving when realizing the client’s plant, as:

- it allows to reduce losses and voltage drops in all the conductors till the user’s equipment terminals;
- except for particular situations, it does not require a protection an operation unit specific for the capacitor because it is possible to use the same parts of the equipment that need the power factor correction.

Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

The method to correct the power factor in plants powered by BT:

1) *distributed or single power factor correction*

From the economic point of view, the only disadvantage is the high cost that is not balanced when user equipment that need the power factor correction operate for few hours a day or if they are many and they are not used contemporaneously.

This solution could then turn out to be not so economic in comparision to the others;

Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

The method to correct the power factor in plants powered by BT:

2) *groups power factor correction*

It consist in installing one or more capacitors with an appropriate total power to every group of user equipment belonging to the same cable or placed in the same department.

The capacitors can be inserted or disconnected according to need from an amperometric relay or by an automatic regulator of the cosφ.

This kind of power factor correction is advantageous when the plants have more branches which power groups of users with operating machines with an homogeneous working cycle.

Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

The method to correct the power factor in plants powered by BT:

2) *groups power factor correction*

From a technical point of view and as opposed to the previous scheme, this power factor correction method do not reduce voltage drops and the losses in the downstream plant inside the factory.

From the economic point of view it is clear that it is difficult to establish the benefit of this solution;

Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

The method to correct the power factor in plants powered by BT:

3a) *centralized power factor correction with capacitors bank inserted manually*

It consists in installing a single capacitors bank for the whole plant, with a capacitive reactive power evaluated on the worst conditions; it is placed upstream the user equipment in the distribution center.

The bank has to be inserted at the beginning of the work shift and disconnected at the end in order to avoid the supply of reactive power during not working time of the factory.

Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

The method to correct the power factor in plants powered by BT:

3a) *centralized power factor correction with capacitors bank inserted manually*

This type of power factor correction is appropriate for small plants, which are formed by small and medium power machines, operating with a contemporaneity coefficient lower than 1.

It is possible to use this method only when the plant operates with constant power and cosφ, otherwise it is difficult to calculate a value of reactive power Q_c suitable for the different operating modes.

Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

The method to correct the power factor in plants powered by BT:

3a) *centralized power factor correction with capacitors bank inserted manually*

This solution is simple and cheap, but it has no advantage in the sizing of the plant situated downstream the point where the power factor correction is accomplished because it does not reduce voltage drop and losses;

Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

The method to correct the power factor in plants powered by BT:

3b) *centralized power factor correction with batteries inserted automaticaly*

This solution consists in subdividing the capacitive reactive power, calculated in the worst conditions, into a certain number of capacitors bank for the whole department, in order to able to vary the production of reactive power according to the load requirement (modulated reactive power); this is done automatically and every moment, in this way the obtained cosφ is almost constant in each situations.

The power factor correction regulator, by measuring the plant cosφ in every moment, controls the insertion or the disconnection of the capacitors bank obtaining always a cosφ of nearly 0.9.

Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

The method to correct the power factor in plants powered by BT:

3b) *centralized power factor correction with batteries inserted automaticaly*

The centralized power factor correction is used with variable loads, i.e. when the reactive power requirements have a high variability.

From the technical point of view, even this power factor correction method do not reduce the voltage drops and losses in the downstream plant (inside the factory).

From the economic point of view, the automatic centralized power factor correction, method should be used only when strictly required because it is very expensive necessary;

Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

The method to correct the power factor in plants powered by BT:

3b) *centralized power factor correction with batteries inserted automaticaly*

Power factor correction of electrical plants

This can be realized with two different type of actions::

2) indirect methods

The method to correct the power factor in plants powered by BT:

4) *mixed power factor correction*

In practice it is usually advantageous to use mixed solution, that is.:

- in part distributed for the higher power machines;
- partly using group power factor correction, especially at the beginning of the lines (cables), which power the equipment groups;
- for the other part, centralized downstream this energy delivery point (generating set).

Power factor correction of electrical plants

To correct the power factor in plants powered by MT it is used the centralized method. For MT supply (clients with owned MT/BT transformer cabin) it is appropriate to consider the compensation of transformer/s current/s without load with a specific power factor correction array inserted in the BT side.

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

a) *generality*

In the industrial systems in MT or BT, the rate of reactive power that has be in loco is usually produced using static capacitors and rarely using other means.

Usually the used capacitors have dielectric formed by a metalized polypropylene film with self-generating properties and with an aluminum armour.

In these capacitors, the dielectric is formed by a single polypropylene film upon which it is laid down by evaporation, a thin layer of aluminum, which forms the armour.

The essential property of these capacitors is the self-regeneration one, which consists in the reinstatement of the insulation in those points punctured by a stock.

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

a) generality

Static capacitors offer various advantages like:

- the possibility to fractionate the installed power by distributing the capacitors array where they can be used more efficiently;
- the opportunity of easily change the sizing when this is required;
- good performance and investment per installer kVAr which are constant ever if the power vary.

For the realization of the desired power, the elements are connected in parallel (forming the capacitors array).

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

a) generality

The capacitors array connected in parallel are used when an high capacity is needed. Rather than building one capacitor with extended armours, it is preferable to use more capacitors and to connect their armours as showed in the figure

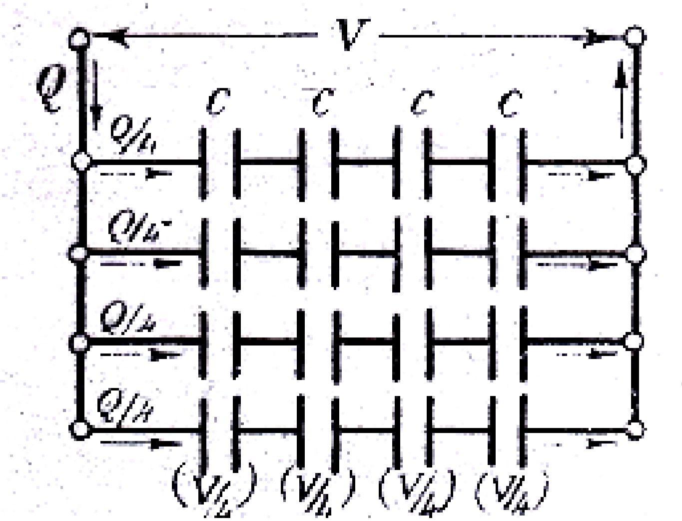
Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

a) generality

The capacitors bank connected in series are used when the voltage need to be subdivided between more capacitors and at the same time have a high capacity.

It is possible to form more identical series and the connect these series in parallel as showed in figure below.



Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

a) *generality*

The capacitors array produce a power that can be adjusted only in steps because it is not possible to continually control their capacity.

Copacitors are equipment:

- static;
- have a life of 25 or more years (obviously if there are no breakdowns);
- have reduced losses;
- they do not need maintenance.

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

b) commercial sizes and connection diagrams

The BT capacitors (220 ÷ 500 V) starts from 1 kVAr to 50 kVAr of power. They can be used as single-phase capacitors or as three-phase capacitors using appropriate connectors, usually triangle ones.

Generallyteh solutions used are modulate one, with modules of 2.5-10 kVAr, which allow a better operating flexibllity.

Single-phase MT capacitors (10.20 kV) are supplied in units and they are used with a power between 50 and 150 kVAr installed in array connected in triangle;

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) *reference data for power factor correction capacitors*

The general characteristics of static power factor correction capacitors with nominal voltage not higher than 1000 V are determined by CEI standards EN 60931-1 (CEI 33-8) and CEI EN 60831-1 (CEI 33-9).

Below are explained the characteristics of power factor correction capacitors necessary to order them.

- single-phase or three-phase

  In the market are available both single-phase and three-phase units for low or medium voltage, until 200 kVAr.

  When are needed higher power it is recommended to use single-phase unit connected in three-phase groups;

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- nominal power or capacity

  The choice is between the started values;

- nominal frequency

  In Italy and in Europe the frequency is usually of 50 Hz. The capacitor power, if built for the American frequency of 60 Hz, should be reduced by 50/60 rate when used in the Italian network;

$\frac{1}{\sqrt{3}}$

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- nominal voltage

When are used three-phase units or single-phase units connected in triangle (usually in BT), the normal voltage should coincide the one used in the power network; instead when are used single-phase units connected with a wye connection (usually in MT),, their nominal voltage should be of $\frac{1}{\sqrt{3}}$ of the network voltage.

For higher voltages, the units should be connected in series. In this case it is better to order the whole bank pf capacitors which is provided on a metal structure and equipped with all the insulators and the connections;

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- reference voltage for isolation

  The reference voltage is the highest one the capacitor could continually work with. It states the test conditions of the insulation against the container, which are prescribed by the standards of insulation coordination.

  When in a capacitors array there are more units in series, the reference voltage chosen for each unit should guarantee the respect of the insulation level of the system to the branch in series;

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- type “I“ or type “E“

  Units of type “I” have all the terminals insulated from the container.

  Units of type “E” are single-phase units with an insulated terminal and one metallically connected to the container.

  The units of type “E” are more appropriate when the units are connected in series;

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- installation place and temperature class

  It is to specify if the capacitors are installed inside or outside. The capacitors are built taking into consideration two classes related to the maximum temperature:

  - class A: 40°C as the average of the hottest hour of the day; 30°C as average of the hottest day;
  - class B: 45°C as the average of the hottest hour of the day; 35°C as the average of the hottest day. Moreover it should be stated also the minimum environment temperature in which the capacitors should operate, the temperature considered are usually -25°C and -5°C (the latter as the reference temperature for in-house installation);

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- inner connection (for three-phase units)

  It is stated on the plate with the symbols Y (wye or star) or Δ (triangle);

- discharge device

  When the capacitor is disconnected from the network it should be able to discharge itself. The safety standards (CEI Standard Committee 33) order that, after disconnection, the voltage between the terminals should be reduced to less than 50 V in no more than a minute for BT capacitors (until 1000 V) and in no more than 5 minutes for the MT capacitors.

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- discharge device

  A lot capacitors are built with an inner resistor which has the function to discharge the appliance as prescribed by standard; the plate states if this device is provided.

  When the inner resistor is absent, if the capacitor is connected in parallel with an engine or a transformer, the discharge can happen through the coils of the machine; otherwise it is necessary to insertion of discharge resistors in the circuit;

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- discharge resistors

  As is common knowledge, a capacitor can remain charged namely maintaining a certain charge, this causes a potential difference between its terminals even when it has been disconnected from the power network.

  This can represent a danger due to possible accidental contacts.

  In order to limit this risk, the standards order that the capacitors should be provided of discharge devices.

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- discharge resistors

Generally the resistors used (called discharge resistors) can be connected in parallel with the capacitor and they have a value determined according to the CEI standard. Obviously these resistors cause an energy loss which can be estimated to be a low percentage of the apparent power of the capacitor.

Therefore, it is possible to decide to connect the resistors only to discharge the capacitor;

<u>Power factor correction of electrical plants</u>

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- <u>process to connect the resistors</u>

  The insertion and the disconnection of the capacitors array (or of the single capacitor) could be done by using switches, operating switches, contactors, appropriate switch disconnectors.

  he choice of using the discharge resistors all the time or only when needed depends on the operating parts used to insert the resistors.

  When switches are used, the discharge resistors should be permanently connected to the capacitor terminals.

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- process to connect the resistors

The implementation of switches or appropriate contactors allow to connect the resistors to the capacitor terminals only when the discharge has to start.

Obviously these resistors cause an energy loss which can be estimated to be a low percentage of the apparent power of the capacitor.

Some producers insert also some fuses inside the capacitor container in order to disconnect immediately faulty parts; in this way the service continuity is preserved.

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- process to connect the resistors

The figure below shows capacitors for electric engines where the required performance are high

Power factor correction of electrical plants

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- process to connect the resistors

The figures below show respectively a BT single-phase capacitor and a BT three-phase capacitors.

Power factor correction of electrical plants

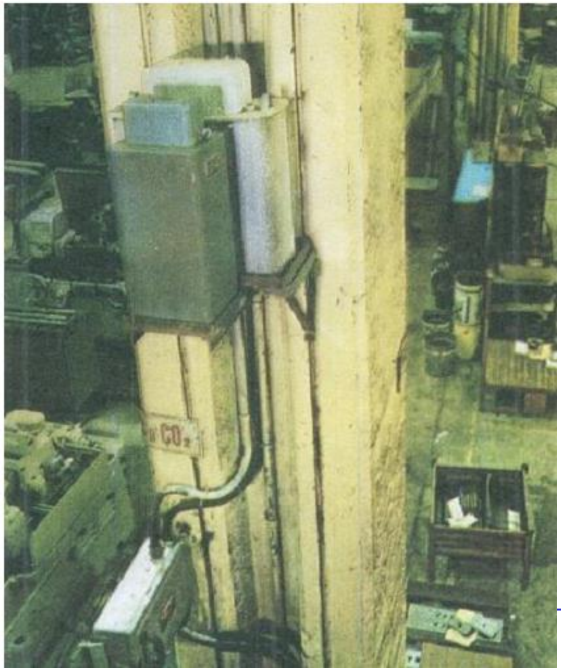
Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- process to connect the resistors

In the figures below are shown low voltage capacitors.



<u>Power factor correction of electrical plants</u>

Below we will analyze the static capacitors, identifying:

c) *reference data for power factor correction capacitors*

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- <u>process to connect the resistors</u>

In the figure is shown a medium voltage electrical capacitor with power factor correction..

<u>Power factor correction of electrical plants</u>

Below we will analyze the static capacitors, identifying:

c) reference data for power factor correction capacitors

Below are explained the characteristics of power factor correction capacitors necessary to order them:

- <u>process to connect the resistors</u>

The figure shows a set of automatic power factor correction equipment..