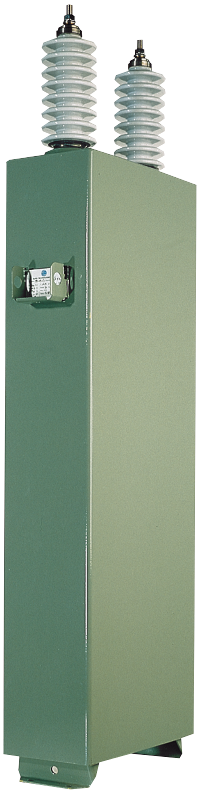
ALPES TECHNOLOGIES

Capacitor department

HIGH VOLTAGE CAPACITORS AND CAPACITOR BANKS

CONTENTS

GENERAL INFORMATION



High voltage capacitors are composed of elementary or partial capacitances generally connected in several serial-parallel groups used to obtain the required electrical characteristics for the unit.

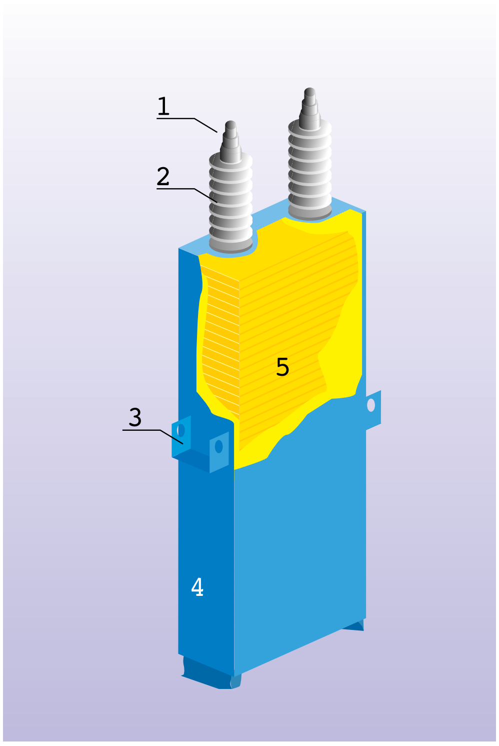
- the nominal voltage of a capacitor depends on the number of groups in series
- the nominal power of a capacitor depends on the number of partial capacitances in parallel per group

Each elementary capacitance is produced using two aluminium foils forming the armaments or the electrodes and high quality specific polypropylene films which are rough for easy impregnation, forming part of the insulating layer.
The wired capacitance assembly, called the "active section" is positioned in a stainless steel cell, equipped with insulated porcelain bushings or terminals used to connect the device.
After it has been dried and treated, the "active section" is impregnated under a vacuum with a liquid dielectric of the following type :

- non-chlorinated
- non-toxic
- biodegradable

With the polypropylene film, this liquid dielectric, which has a remarkably high chemical stability, a high gas absorption and partial discharge quenching capacity and a flash point of approximately 150°C, ensures total insulation between electrodes.
This "All-film" technology has the following main characteristics :

- very high resistance to strong electrical fields
- very low power losses, enabling considerable savings for high power capacitor banks.



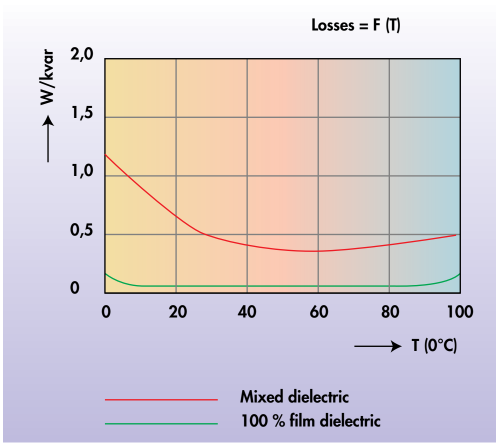
External view of a "All-film" H.V. capacitor
1. connection
2. porcelain terminal
3. fixing lug
4. stainless steel cell
5. active part

ELECTRICAL CHARACTERISTICS OF "ALL-FILM" H.V. CAPACITORS

In relation to the former generation of "mixed" type (paper + film) dielectric capacitors; synthetic "All-film" type dielectric capacitors have a much longer service life, due to :

- their very high thermal stability related to very low power losses due to the removal of the paper
- the remarkable chemical stability of the liquid dielectric enabling :
  - a high partial discharge absorption capacity
  - a high dielectric resistance to transient excess currents and excess voltages
  - very low variations of capacitance as a function of temperature

Curve 1 : variation of W/kvar losses as a function of temperature



Mean loss factor :

- 0.15 W/kvar at power-up
- 0.1 W/kvar after 500 hours of operation

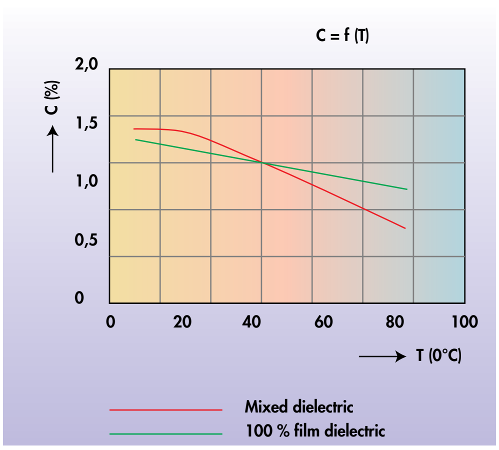
Variation of capacitance as a function of temperature :

- mean : 2 x 10^{-4}/°C

Internal discharge device :

- internal discharge resistors reducing the residual voltage to 75 V in 10 minutes after disconnection of the supply

Curve 2 : variation of capacitance C (µF) as a function of temperature



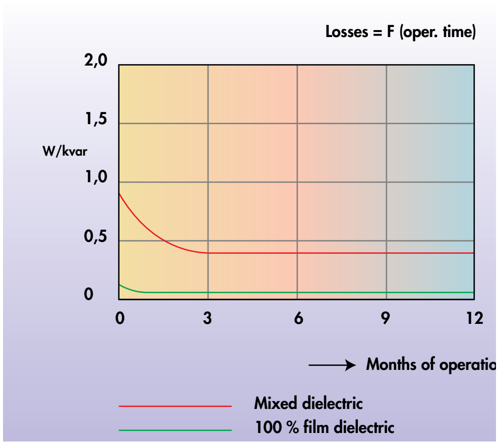
Frequency :

- standard : 50 Hz (60 Hz on request)

Reference standards :

- French : C 54 102
- International : IEC 871.1 and 2 (supply capacitors)
IEC 110 (air or water-cooled capacitors for induction furnaces)
- German : VDE 0560/4
VDE 0560/9
- British : BS 1650
- Other standards on request

Curve 3 : variation of W/kvar losses as a function of operating time
Losses = F (oper. time)



Admissible overloads

- current : 1.3 I nominal continuously
- voltage (between terminals) :
  1.1 U nominal 12 h/24 hours
  1.15 U nominal 30 minutes/24 hours
  1.2 U nominal 5 minutes/24 hours
  1.3 U nominal 1 minute/24 hours

Standard insulation levels (phases/ground) for unit capacitors

Highest voltage for equipment Um (RMS)	(kV)	2,4	3,6	7,2	12	17,5	24
Test voltage at industrial frequency (duration : 10 seconds)	(kV)	8	10	20	28	38	50
Lightning shock resistance voltage (peak value)	(kV)	35	40	60	75	95	125

Individual tests

- measurement of capacitance and losses
- voltage test between terminals, i.e. :
  - 2.15 U nominal 10 sec AC voltage
  - 4.3 U nominal 10 sec DC voltage
- voltage test between joined terminals and ground at industrial frequency
- discharge device and cell integrity check

"ALL-FILM" H.V. CAPACITOR PROTECTION DEVICES

There are four types of protection for "All-film" H.V. capacitors

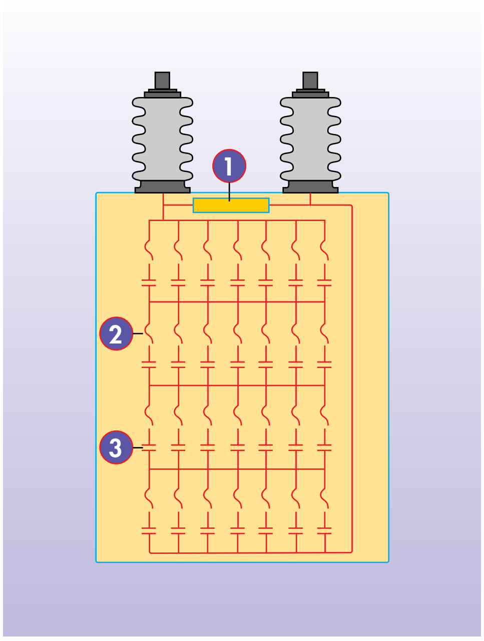
- **Without internal fuses** and external protection with unbalance monitoring
- **With internal fuses** and external protection with unbalance monitoring
- **Without pressure monitoring device** and external protection with HRC fuses
- **With pressure monitoring device** and external protection with HRC fuses

The choice between these four possibilities depends on the following criteria :

- electrical characteristics of capacitors (power, voltage, connection)
- customer's requirements concerning protection sensitivity

The following table gives, according to the above criteria, the possible type of protection for the capacitor and its advantages.

Capacitor power and voltage	Capacitor connection	Capacitor protection	Associated external protection	Advantages
all powers and all voltages	single-phase	without internal fuse	unbalance	
P ≥ 200 kvar and U ≤ 13 kV	single-phase	with internal fuses	unbalance	• No triggering at first fault. • Guarantees continuous operations
all powers and U ≤ 12 kV	three-phase	without pressure monitoring device	H.R.C. fuses	
all powers and U ≤ 12 kV	three-phase	with pressure monitoring device	H.R.C. fuses.	• No risk of case rupture



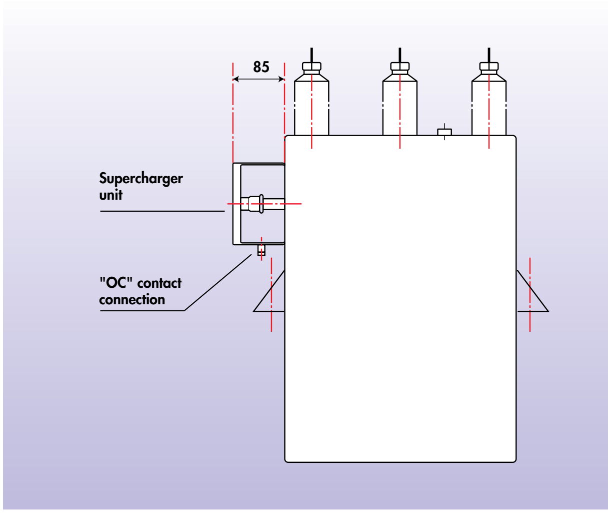
Internal view of a "All-film" H.V. capacitor with internal fuses

1. discharge resistor
2. internal fuse
3. elementary capacitance

Protection with internal fuses

Due to their advantages, whenever possible, internal fuses are mostly used to protect "All-film" H.V. capacitors.
In this technology, each elementary capacitance forming the capacitor is protected by its own internal fuse.
In the event of an elementary capacitance fault, the internal fuse eliminates the corresponding capacitance and guarantees continuous capacitor operation.
Given the high number of elementary capacitances forming the device, the power loss resulting from the first fault is negligible (less than 2 %).
The external unbalance protection is only activated when the number of "blown out" elementary capacitances in the same capacitor is significant and liable to cause an excessive balance.
An internal fuse is activated :

- When the capacitor voltage reaches its maximum value and, therefore, when the current reaches its minimum value. The potential difference at the terminals of the "faulty" elementary capacitance causes to the corresponding fuse to blow out.
- When the current reaches its maximum value and, therefore, when the voltage reaches its minimum value, the outflow in the "faulty" capacitance of the energy stored in the operational capacitances in parallel causes the corresponding fuse to blow.

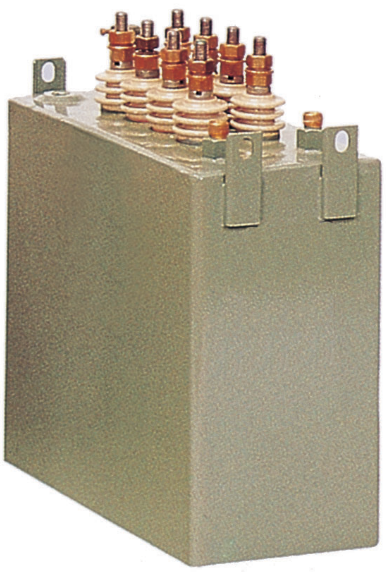


Protection with pressure monitoring device

Protection with a pressure monitoring device is of interest whenever the capacitor cannot be protected correctly (due to electrical characteristic or cost problems) with internal fuses or by unbalance monitoring.

This protection is individual for each capacitor. It is formed of a pressure switch sealed on the capacitor case. This pressure switch is composed of a "membrane" sensitive to pressure rises generated in the case due to a elementary capacitance blow-outs and an "O.C." contact used to trigger the bank control device (contactor - switch, etc.).

"ALL-FILM" HV CAPACITOR INSTALLATION CONDITIONS



Water-cooled capacitor
for medium frequency induction furnace.

Temperature class

- standard : - 25/ + 45 ° C
  (other temperature classes on request)
  or : 45°C average for 1 hours
  40°C average for 24 hours
  30°C average for 1 year

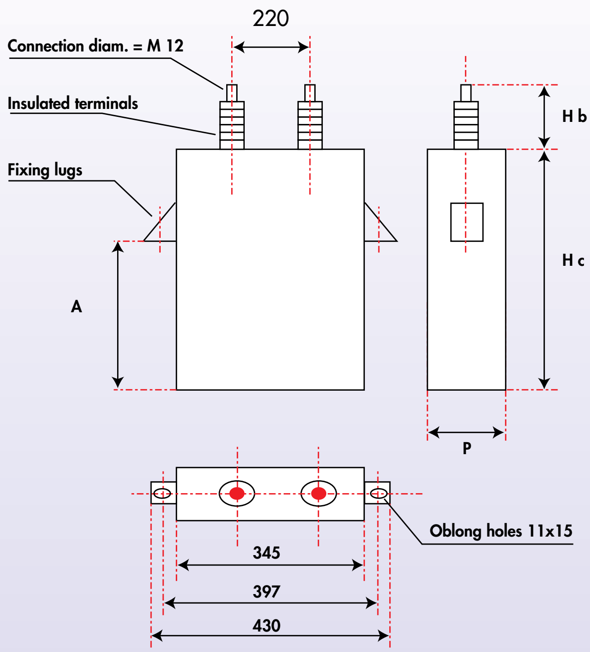
Protection against corrosion

- possible installation : internal or external
- stainless steel case, coated with one coat of primer and several finishing coats (RAL 7033)

Compatibility with environment

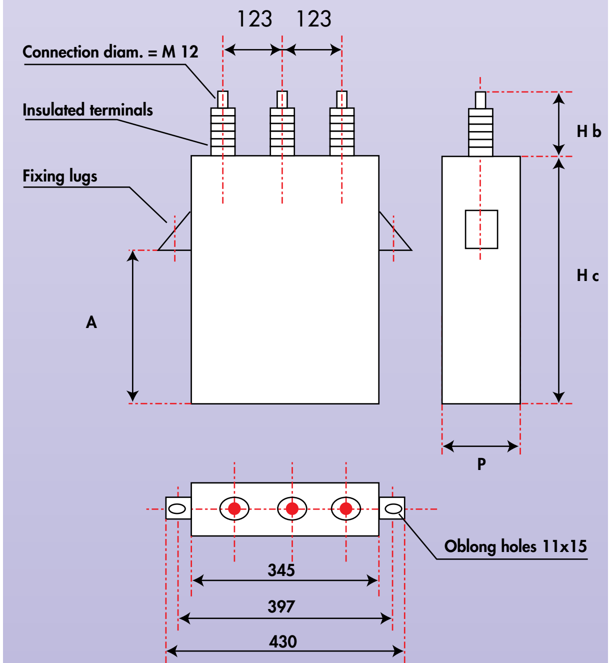
- "All-film" capacitors are impregnated with a (non P.C.B.) biodegradable liquid dielectric. No particular measures concerning the environment are required for their installation.

"ALL-FILM" H.V. CAPACITORS DIMENSIONS AND WEIGHT



Power (standard) kvar	Dimensions mm Hc	A	P	Weight kg	Capacitor connection
50	190	40	135	17	Three-phase or single-phase
75	250	100	135	21	
100	280	130	135	23	
125	350	200	135	27	
150	370	220	135	30	
175	450	300	135	33	
200	460	310	135	35	
250	460	310	135	42	
300	510	360	175	46	
350	590	440	175	53	
400	650	400	175	60	
450	730	480	175	65	
500	790	540	175	70	
550	880	630	175	76	
600	950	700	175	82	

Note : For specific applications (replacements, etc.), the value A can be adapted to customer requirements.



Hb Indoor type mm	Hb outdoor type mm	Um R.M.S. kV	Capacitor connection	
46	225	2.4	Three-phase	Single-phase
46	225	3.6		
172	225	7.2		
172	225	12		
225	225	17.5		
257	227	24		

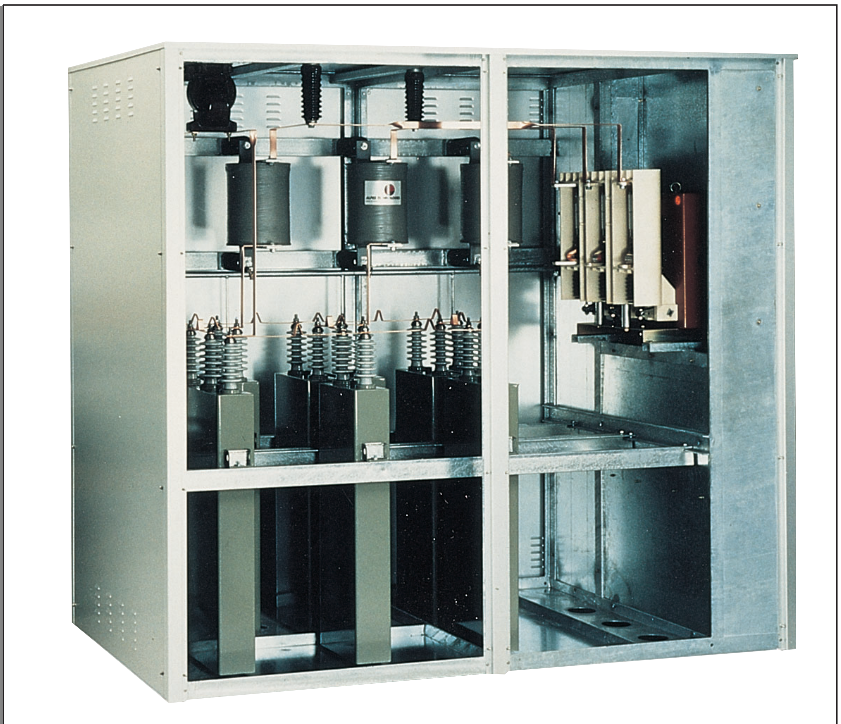
Note : The Um R.M.S. voltage to be taken into account is the supply voltage at which the capacitor is connected and not the nominal unit voltage (particularly applies to single-phase capacitors in star or double star connections).

HIGH VOLTAGE CAPACITOR BANKS

A capacitor bank is generally composed of several single-phase or three-phase unit capacitors assembled and interconnected to produce high power assemblies called "capacitor banks".

ALPES TECHNOLOGIES designs and manufactures different types of capacitor bank defined by :

- the total reactive power to be installed.
- the nominal network voltage
- electrical constraints :
  presence of harmonics, bank divided into sections or steps, etc.
- the installation
  - indoor
  - outdoor
- operator safety
  - IP 00 open rack
  - IP 315 cubicle



The different possible H.V. capacitor bank wiring modes

The "All-film" H.V. capacitor generally comes in the form of a single-phase unit (sometimes three-phase, but for max. voltages of 12 kV).

To form high power banks, there are three possible wiring or connection modes for combinations of unit capacitors, i.e. :

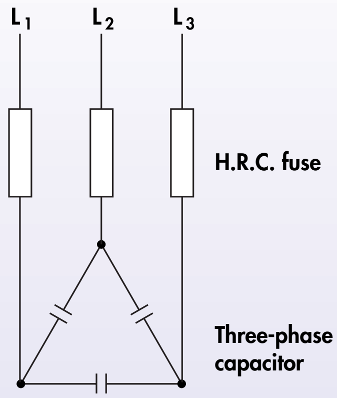


Fig. 1

- Delta wiring (fig. 1)
  This type of wiring is used for low power banks and of nominal voltages less than 12 kV.
  These banks are generally designed for direct compensation on HV motor terminals. The capacitor(s) is/are generally three-phase.

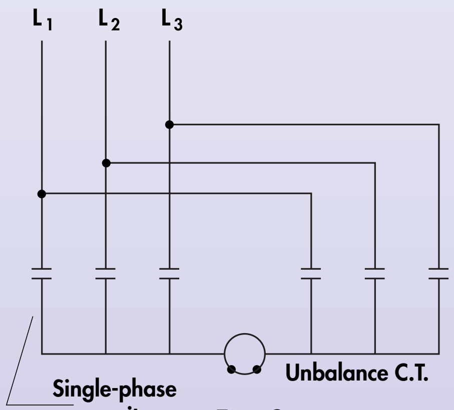


Fig. 2

- Double star wiring (fig. 2)
  This type of wiring is suitable for banks of all powers and voltages (in this case, single-phase capacitors are subjected to a single voltage).
  An unbalance protection device (current relay and transformer) continuously monitors the unbalance current between two neutral points and, in the event of faults in a capacitor, opens the bank control device.

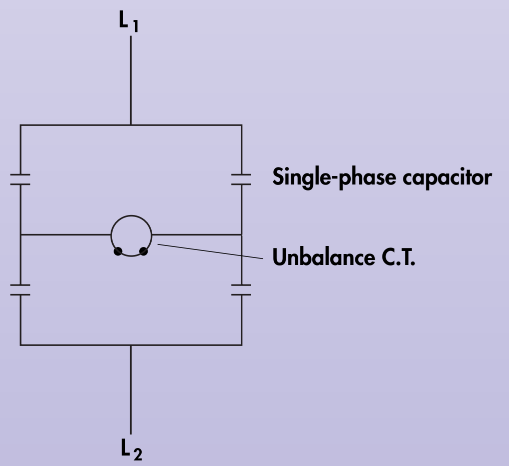


Fig. 3

- H wiring (fig. 3)
  This type of wiring is designed for high power single-phase H.V. banks and V.H.V. three-phase banks. For three-phase banks, the unbalance is monitored on each phase.
  This unbalance monitoring system applies to both star and delta banks.

Built-in electrical protection devices

In addition to the protection devices specific to each capacitor (internal fuses or superchargers), an additional external protection device must be incorporated in the bank.

The most commonly used external protection devices are :

- **H.R.C. fuses**
- **unbalance or differential protection**

H.R.C. fuses

protection with H.R.C fuses incorporated in the bank is suitable (for technical and economic reasons) for capacitor banks with the following characteristics :

- low power (< 1000 kvar)
- equipped with **three-phase connection** capacitors (fig. 1)
- network voltage less than 12 kV

The H.R.C. fuse rating will be selected at a value between 1.7 and 2.2 times the nominal bank current.
H.R.C. fuse blow-outs are generally caused by a direct short-circuit inside the capacitor.

unbalance or differential protection :

This protection generally applies for banks with the following characteristics :

- medium or high power (> 1000 kvar)
- equipped with **single-phase connection** capacitors (fig. 2 or 3)
- network voltage greater than 12 kV

Unbalance or differential protection is sensitive, capable of detecting and reacting to a partial fault in a capacitor.
It is composed of a current transformer connected between electrically balanced points linked to a current relay. A fault in a capacitor produces an unbalance and, therefore, flow of current in the current transformer which, by means of the relay, opens the bank control device (circuit breaker, switch, contactor, etc.).

Additional accessories

quick discharge reactors

Installing two quick discharge reactors or potential transformers between the phases of the bank makes it possible to reduce the capacitor discharge time from 10 minutes to approximately 10 seconds.
This reduction in the discharge time :

. provides safety for personnel during any interventions
. reduces the waiting period before ground (closing of MALT isolating switch)
. makes it possible to reactivate the banks in steps more quickly after a power cut, although a min. time of 5 minutes is essential between two discharges, in order to ensure correct cooling of the discharge reactors.

damping reactors

Installing damping reactors in series on each phase of the bank makes it possible to reduce surge currents to acceptable values for the corresponding control device.
These are necessary in the following cases :

. step banks
. very high network short-circuit power in relation to the power of the bank to be connected
. frequent capacitor bank control operations

PROTECTION AND OPERATING DEVICES

The protection and operating devices (circuit breaker, fuse, switch, contactor) of a high voltage capacitor bank must take the following constraints into account :

. capacity to withstand high transient currents when activated
. capacity to guarantee a disconnection without reconnection when opened (at disconnection, the bank may loaded at full voltage)
. capacity to withstand a continuous RMS current equivalent to at least 1.43 times the nominal 50Hz current of the bank in a steady state

The vacuum disconnection control devices or the operating devices in the SF6 are perfectly suitable for capacitor bank control and protection.

The technical departments at ALPES TECHNOLOGIES can advise you on the choice of a suitable protection and operating device for your capacitor bank.

RACKS AND CUBICLES FOR CAPACITOR BANKS

Depending on the user's requirements, the various components of the high voltage capacitor banks :

. capacitors
. additional accessories (discharge reactors, damping reactors)
. built-in electrical protection devices (H.R.C. fuses, unbalance protection devices, etc.)
. any operating devices (circuit breakers, switches, contactors, etc.)

can be fitted and wired either :

- on open racks (IP 00)
- or in cubicles (IP 315)

These assemblies are suitable for either :

- **indoor type** installation
- or **outdoor type** installation

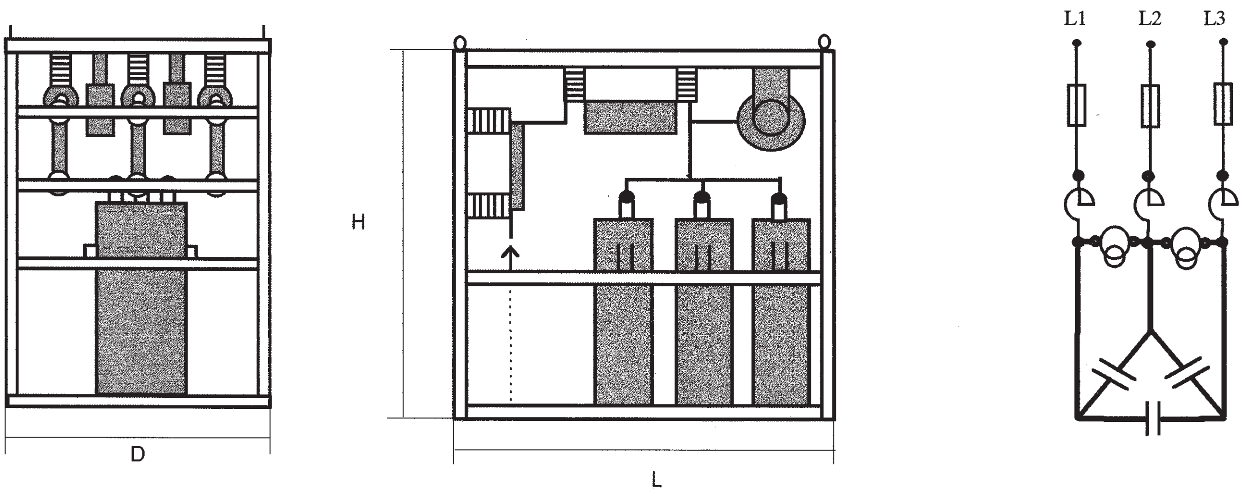
ALPES TECHNOLOGIES is in a position to offer standard equipment or specific equipment adapted to user requirements.

Standard H.V. capacitor banks on open racks (IP00)

H.T. 00-02

. max. voltage : 12 kV
. max. power : 1000 kvar
. installation : indoor
. delta wiring

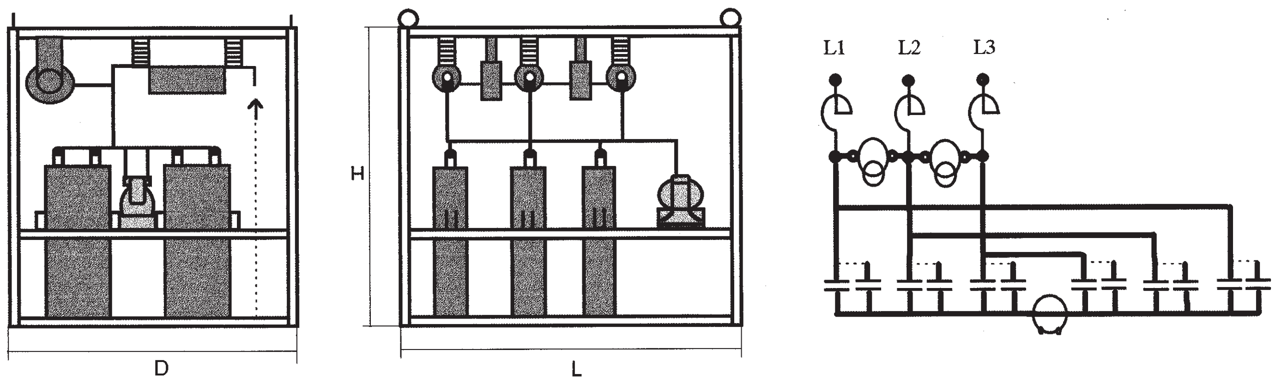
. accessories : discharge reactors - damping reactors - H.R.C. fuses
. dimensions (max.) mm : L = 1500 D = 900 H = 2000
. weight (kg) : 600



H.T. 00-03

. max. voltage : 24 kV
. max. power : 5000 kvar
. installation : indoor or outdoor
. double star wiring

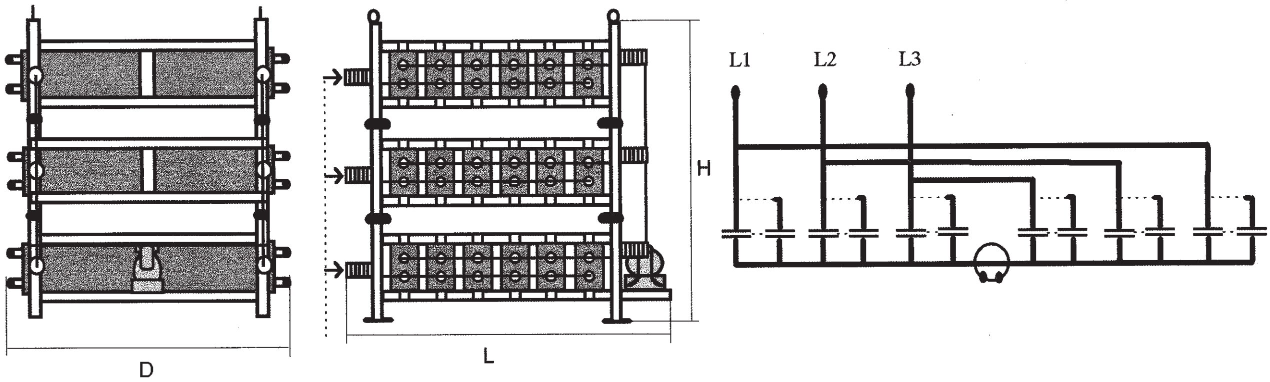
. accessories : discharge reactors - damping reactors - unbalance current transformer
. dimensions (maxi) mm : L = 2400   P = 1200 H = 2000
. weight (kg) : 1500



H.T. 00-06

. max. voltage : 24 kV
. max. power : 20000 kvar
. installation : indoor or outdoor
. double star wiring

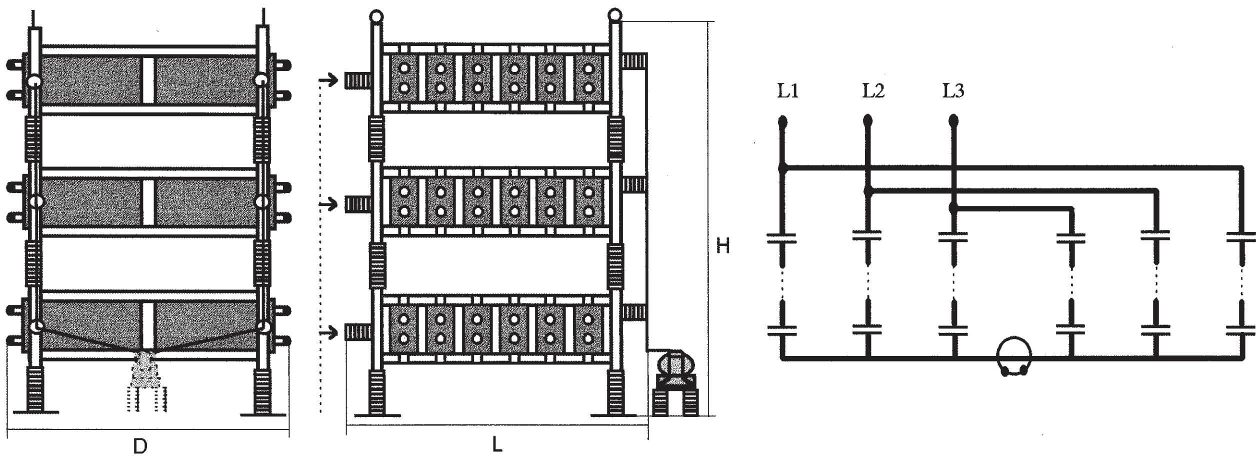
. accessories : unbalance current transformer
. dimensions (max.) mm : L = 3000 D = 2000 H = 2400
. weight (kg) : 3500



T.H.T. 00-01

. voltage > 24 kV
. max. power : 20000 kvar
. installation : indoor or outdoor
. double star wiring with serial groups for each branch

. accessories : unbalance current transformer
. dimensions (max.) mm : L = 3500 D = 2000 H = 3600
. weight (kg) : 4000

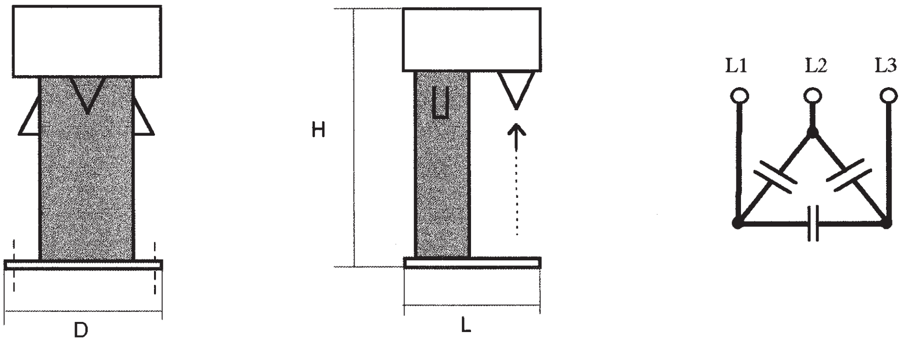


Standard H.V. capacitor banks in cells (IP315)

H.T. 315-01

. max. voltage : 12 kV
. max. power : 600 kvar
. installation : indoor
. delta wiring

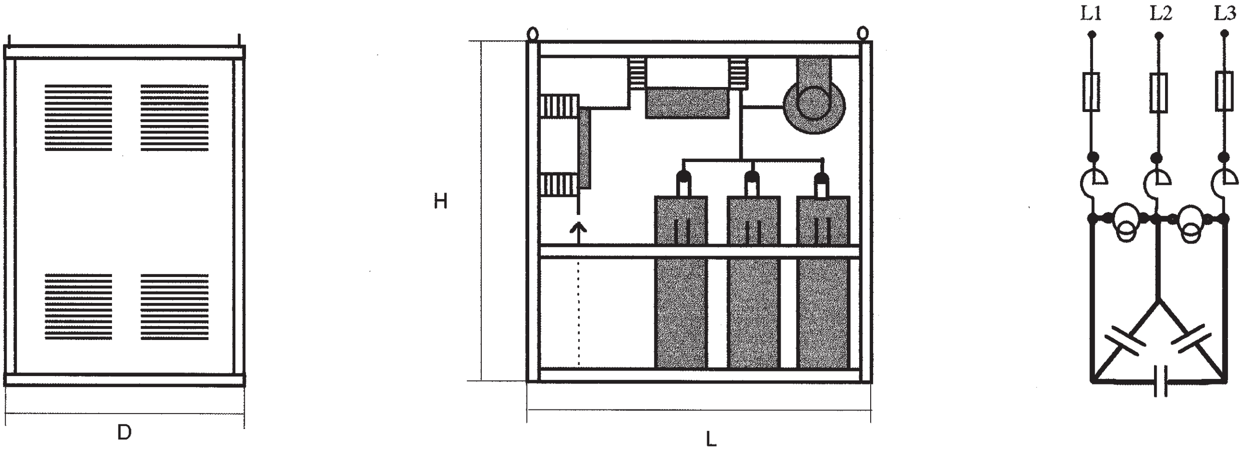
. dimensions (max.) mm : L = 600 D = 500 H = 1500
. weight (kg) : 150



H.T. 315-02

. max. voltage : 12 kV
. max. power : 1000 kvar
. installation : indoor
. delta wiring

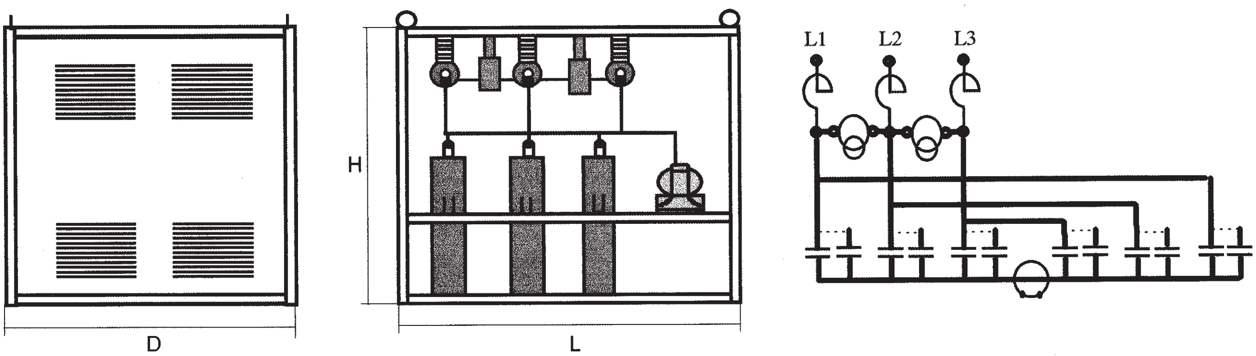
. accessories : discharge reactors - damping reactors - H.R.C. fuses
. dimensions (max.) mm : L = 1500 D = 900 H = 2000
. weight (kg) : 750



H.T. 315-03

. max. voltage : 24 kV
. max. power: : 5000 kvar
. installation : indoor or outdoor
. double star wiring

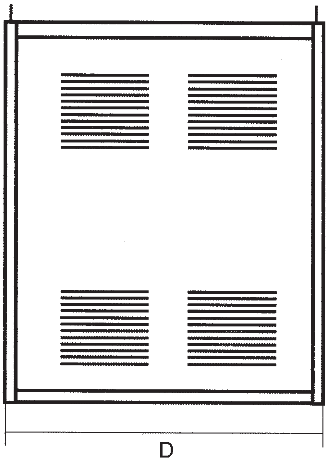
. accessories : discharge reactors - damping reactors - unbalance current transformer
. dimensions (max.) mm : L = 2400 D = 1200 H = 2000
. weight (kg) : 1800

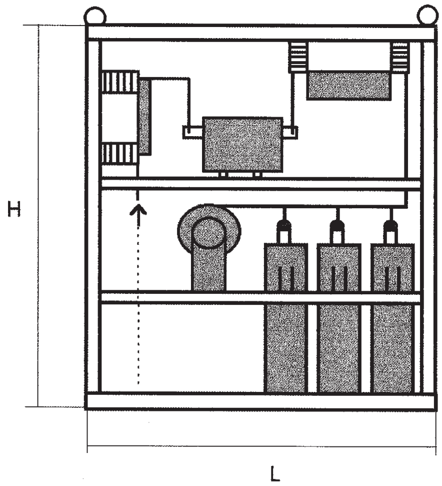


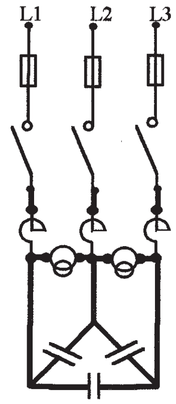
H.T. 315-04

. max. voltage : 12 kV
. max. power : 2000 kvar
. installation : indoor
. delta wiring

. accessories : discharge reactors - damping reactors - step contactor - H.R.C. fuses
. dimensions (max.) mm : L = 2000 D = 1000 H = 2000
. weight (kg) : 1000



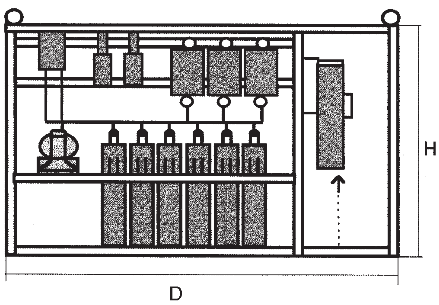


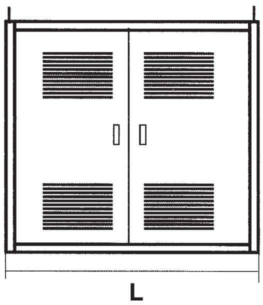


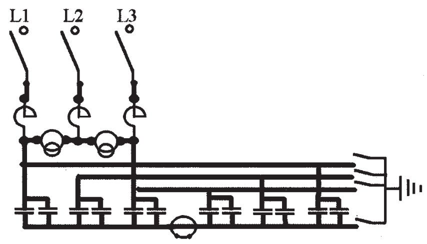
H.T. 315-05

. max. voltage : 24 kV
. max. power : 5000 kvar
. installation : indoor or outdor
. double star wiring

. accessories : discharge reactors - damping reactors - unbalance current transformer - step switch - ground switch
. dimensions (max.) mm : L = 2500 D = 1500 H = 2200
. weight (kg) : 2000







* other cubicle protection degrees avalaible on request.

HARMONICS

Introduction

In recent years, the modernisation of industrial processes and the sophistication of electrical equipment and machines has led to considerable development in power electronics :

These semi-conductor based systems (transistors, thyristors, etc.) designed for :
- static power converters : AC/DC
- rectifiers
- inverters
- frequency converters
- and many other wave train or phase setting control systems. For electrical supplies, these systems represent "non-linear" loads. A "non-linear" load is a load for which the current consumption does not reflect the supply voltage (although the load source voltage is sinusoidal, the current consumption is not sinusoidal).

Other, "non-linear" loads are also present in electrical installations, in particular :
- variable impedance loads, using electric arcs: arc furnaces, welding units, fluorescent tubes, discharge lamps, etc.
- loads using strong magnetising currents : saturated transformers, inducers, etc.

The Fourier series transformation of the current consumption by a non-linear receiver shows :
- a sinusoidal term at a 50 Hz supply frequency, the fundamental.
- sinusoidal terms with frequencies which are multiples of the fundamental frequency, the harmonics.
  According to the equation :

$$I_{rms} = \sqrt{I_1^2 + \sum_{h=2}^{n} I_h^2}$$

$\sum$: Sum of all harmonic currents from rank 2 (50 Hz x 2) to last rank n (50 Hz x n)

These harmonic currents circulate in the source. The harmonic impedances induced give rise to harmonic voltages according to the equation $U_h = Z_h \, x \, I_h$.

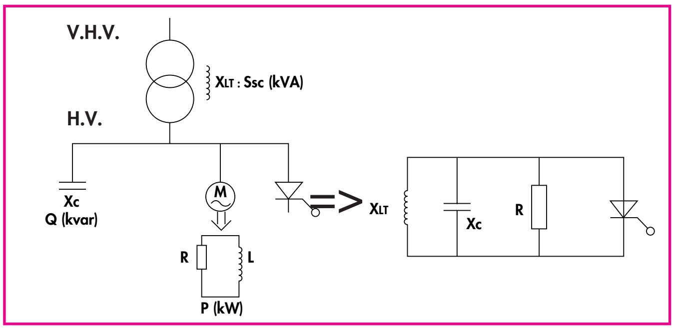
The harmonic currents induce most of the harmonic voltages causing the global harmonic distortion of the supply voltage.

$$U_{rms} = \sqrt{U_1^2 + \sum_{h=2}^{n} U_h^2}$$

Note : Harmonic distortion of the voltage generated by manufacturing defects of AC generator and transformer coils is generally negligible.

Effect of harmonics on capacitors

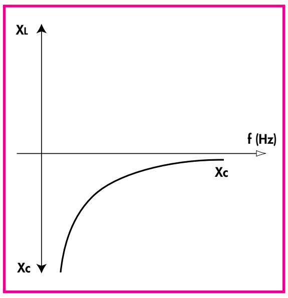
Principle diagram / Equivalent diagram



Note : since the inductance of the motor is must higher than that of the source, it becomes negligible, in parallel connection.

- Ssc (kVA) : Source short-circuit power
- Q (kvar) : Capacitor bank power
- P (kW) : Non-interfering load power

a) Decrease in capacitor reactance

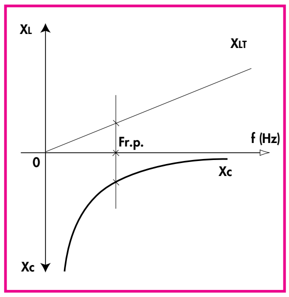


The capacitor reactance

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

is inversely proportional to the frequency, its curve is reciprocal and its capacity to cancel out harmonic currents decreases significantly when the frequency increases.

b) Parallel resonance or anti-resonance between capacitors and source



- the reactance of the source X_{LT} is proportional to the frequency.
- the reactance of the capacitors X_C is inversely proportional to the frequency.

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

$$Fr.p. = F\ supply. \sqrt{\frac{Ssc}{Q}} \qquad F.A. = \frac{\sqrt{Ssc \cdot Q}}{P}$$

It is important to note that :
- the higher the source short-circuit power (Scc), the further the resonance frequency is from dangerous harmonic frequencies.
- the higher the load power (P), the lower the harmonic current amplification factor is.

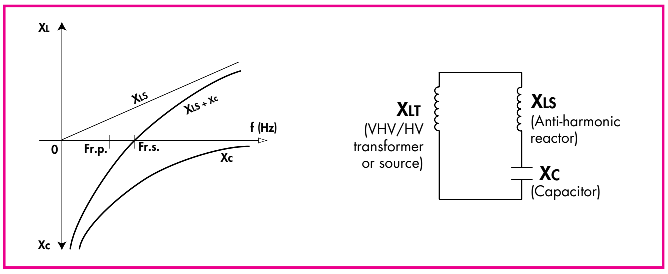
Main harmonic currents :
The main harmonic currents present in electrical installations are induced by semi-conductor based systems :

harmonic 5 (250 Hz) - $I5 = 20\ \%\ I1$
harmonic 7 (350 Hz) - $I7 = 14\ \%\ I1$
harmonic 11 (550 Hz) - $I11 = 9\ \%\ I1$
harmonic 13 (650 Hz) - $I13 = 8\ \%\ I1$

* $I1$ Semi-conductor system current at 50 Hz.

Capacitor protection with anti-harmonic reactors

For supplies with high interference by harmonics, connecting an anti-harmonic reactor in series with the capacitor is the only effective means of protection.
The anti-harmonic reactor has two functions :
* to increase the impedance of the capacitor against harmonic currents
* to move the parallel resonance frequency (Fr.p.) of the source and the capacitor below the main harmonic frequencies of the interference.



* Fr.p. : Anti-harmonic reactor/capacitor/VHV/HV transformer parallel resonance frequency
* Fr.s. : Anti-harmonic reactor/capacitor serial resonance frequency,
(Most frequently used values : 190 - 210 and 225 Hz. Other typical values : 205 Hz and 215 Hz).

* for frequencies less than Fr.s., the reactor/capacitor system behaves like a capacitance and compensates the reactive energy.
* for frequencies greater than Fr.s., the reactor/capacitor system behaves like an inductance which, in parallel with the XLT inductance, cancels any danger of any parallel resonance at the frequencies greater than Fr.s. and particularly at the main harmonic frequencies.

Harmonic filters

For installations subject to high harmonic interference, the user may be faced with two needs :
- compensating reactive energy and protecting the capacitors
- reducing the voltage distortion rate to acceptable values compatible with the correct operation of most sensitive receivers (PLCs, industrial systems, capacitors, etc.).

For this application, **ALPES TECHNOLOGIES** is in a position to offer "passive type" harmonic filters. A "passive type" harmonic filter is a serial combination of a capacitor and an inductance for which the tuning frequency corresponds to a harmonic voltage to be eliminated.

For this type of installation, ALPES TECHNOLOGIES offers the following services :
- analysis of network on which the equipment is to be installed with measurements of harmonic voltages and currents
- computer simulation of the compatibility of the harmonic impedances of the network and the various filters
- design and definition of the various filter components
- supply of capacitors, inductive resistors, etc.
- measurement of system efficiency after installation on site.

■ The characteristies of our units are given for information only, and are only binding after confirmation by our services.

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