Electrical energy supply
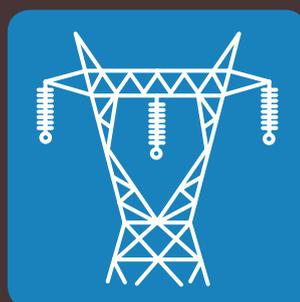
03

Llegrand®

INTRO

The convergence of physical means, established rules and shared procedures ensures the provision of safe, abundant and high quality electricity.
Everyone understands the need to improve this level of service, but its underlying complexity calls for serious consideration: distribution systems, equipment and infrastructures, neutral earthing systems, controlling disturbance, power factor compensation, etc. are just a few of the essential subjects.

The production, transmission, control and protection of electricity (from distribution systems through to the terminal connection of receivers, and including the transformation, metering and distribution stages) must be carried out in a totally safe way, taking care not to pollute it (which is a new aspect).

Electricity is a shared commodity that must be protected just like air or water. It is therefore important to avoid using it indiscriminately and discharging all types of disturbance onto the system. Deterioration of the power factor, harmonics, transients, etc. have a harmful effect on the signal and disadvantage all users. The quality of energy is now controlled by strict standards, but these will doubtless have to change further to control aspects of electromagnetic compatibility that are constantly changing with the introduction of new production technologies (wind-powered, solar, etc.) or operating technologies (power electronics, DC, etc.)

The solutions offered by Legrand contribute to more effective and more economical energy management.

A knowledge of the phenomena involved is also one of the key points that Book 3 sets out to explain using a totally qualitative approach that complements Book 2, which demonstrated this same need for energy efficiency by means of the power analysis operation.

Energy distribution conditions

Electricity is a flexible, adaptable form of energy, but it is difficult to store, and consumption by customers and coincidental demand are constantly varying. These requirements necessitate permanent transmission and provision of energy via a distribution system:
- High voltage for high powers and long distances
- Low voltage for medium and low powers and short distances

GENERAL STRUCTURE OF ELECTRICITY NETWORKS

Although the term "network" is often used in the singular to describe the whole infrastructure required to carry energy from the production centres to users, it would be more accurate to use the plural to cover all the different systems which make up each level of the overall system.

Electricity transport network

Distribution

Local distribution

400 kV

225 kV
90 kV
63 kV

20 kV
400/230V

Conurbations

Large centres of consumption

Railway network

Towns, businesses, superstores, housing

Transformer substations on the local distribution system

Rural housing, craft industry

Transformer substations on the distribution system

Industries

Production centres

Private production

Production centres

1 NATIONAL AND INTERNATIONAL ELECTRICITY TRANSPORT NETWORK

Voltages of 225 and 400 kV, in the VHV (Very High Voltage) range, have historically been used in France, but other voltages (see table 5 in standard IEC 60038) are used throughout the world. These very high voltages limit energy loss over long distances.
Production centres are connected to one another via interconnection stations which are used for distribution across the whole area and also, if required, for exchanging energy with bordering countries, as in Western Europe, by the use of a single voltage of 400 kV.

2 DISTRIBUTION NETWORK

This system carries the energy to regional or local distribution centres (conurbations) and to large consumers such as railway networks, chemical or iron and steel industries, etc. Switching stations incorporate transformers which reduce the voltage to various levels, according to requirements: 225 kV, 150 kV, 90 kV, 63 kV or even directly to 20 kV for short distance or limited power uses.

3 LOCAL DISTRIBUTION NETWORK

Using transformer substations (HV/HV), the high voltage (90 kV, 63 kV) is reduced to 20 kV or sometimes even 15 kV (historically medium voltage, MV) or directly to low voltage (230/400 V) which can be supplied to individual users (private houses, shops, tradesmen, small companies, farms, etc.). High voltage (generally between 3 and 35 kV) is supplied to small towns, districts of medium sized towns, villages, shopping centres, small and medium sized companies, etc. The same principles for providing and ensuring the safety of the high voltage supplies are used throughout the world. That is, the distribution part of the high voltage system consists of a transformer substation, known as the "Source substation". This substation comprises one or more transformers which supply a system that can take a number of forms, from the simplest (radial distribution) to the safest (double tap-off, looped). The principles of these systems are shown on p.08.
High voltage is generally distributed between three phases, usually without neutral. The HV neutral point is earthed by means of a neutral point resistor or coil which limits the current if there is a phase/earth fault. (see earthing diagrams on p.10).

Energy distribution conditions (continued)

The energy is delivered from the local distribution system via an HV/HV (bulk users) or more commonly an HV/LV "source substation". An HV/LV substation primarily consists of:
- One or more incoming cabinets, depending on the type of supply
- A protection and metering cabinet (with HV main circuit breaker)
- One or more transformer cabinets (one per transformer)
- The main LV distribution board based on standard IEC 60364, which can be located in the same place as the HV substation or in a different location.

Connecting wind-powered production sources

According to the EWEA (European Wind Energy Association) the wind-powered production base in Europe could reach an installed power of 180,000 MW in 2020, i.e. five the times the 2004 installed power, which was 34,000 MW. The procedures for connecting wind-powered installations to the electricity system are defined by decrees and orders. Installations with a maximum power of 12 MW are connected to the HV local distribution system. This system was originally set up to take consumers (see diagram on p.02). The gradual introduction of production into the system may lead to an inversion of the power flows at HV stations.
Installations with a power of more than 12 MW are usually connected to the distribution system (HV). The trend in the future will be the development of land-based or offshore wind farms, generating much higher powers (about one hundred MW) which could be connected directly into the transmission network.

From production to use

Scope of the standards

National standards [1]   **IEC 60364**
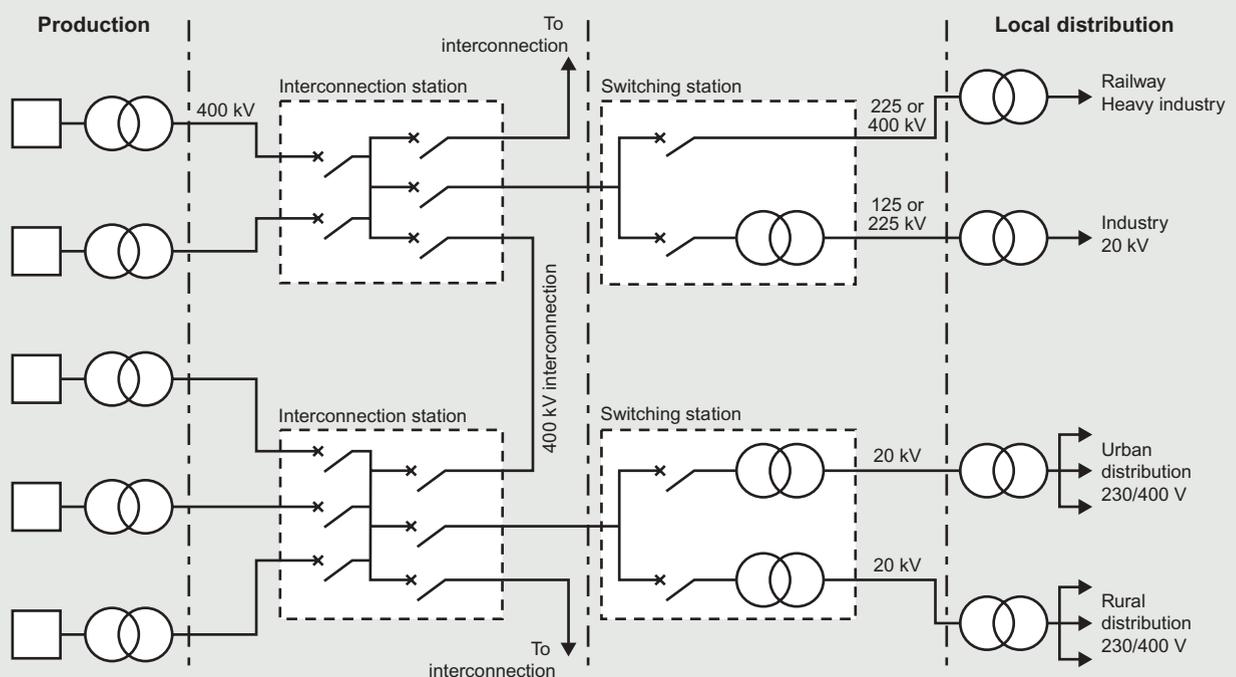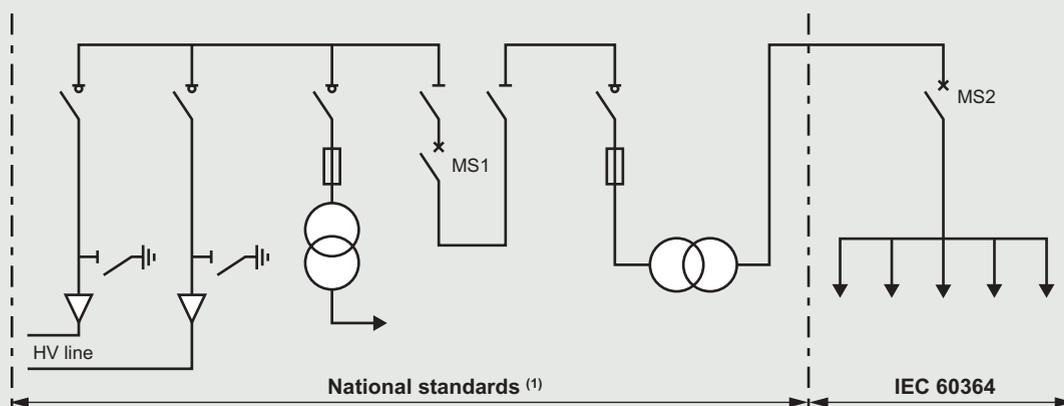
(1) In France, NF C 13100 (delivery substations) and NF C 13200 (high voltage installations)

**Standard IEC 60038 defines a set of "standard" voltages to be used for creating AC and DC power and traction systems. It refers to two voltage ranges, LV and HV, with segregation corresponding to the various voltages used throughout the world.
The various tables in this standard are given on the following pages.**

	Un (V) LV range	Un (V) HV range		
AC power systems	100 V to 1000 V[1]	1000 V to 35 kV[1]	35 kV to 230 kV[1]	>245 kV
DC traction systems	500 V to 900 V[1]	1000 V to 3600 V[1]	-	-
AC traction systems	-	12,000 V to 27,500 V[1]	-	-

(1) inclusive value

Classification of voltages

**French decree no. 88-1056 of 14 November 1988 divides voltages into five classes.
The feature that distinguishes it from the international approach is the division of LV and HV into four sub-classes LVA, LVB, HVA and HVB, which are used in many countries.**

		Nominal voltage Un (V)	
		AC	**DC**
Extra low voltage	**ELV**	Un ≤ 50	Un ≤ 120
Low voltage LV	**LVA**	50 < Un ≤ 500	120 < Un ≤ 750
	LVB	500 < Un ≤ 1000	750 < Un ≤ 1500
High voltage HV	**HVA**	1000 < Un ≤ 50,000	1500 < Un ≤ 75,000
	HVB	Un > 50,000	Un > 75,000

Energy distribution conditions (continued)

Changes in terms used

The term medium voltage, still in fairly common usage, referred in France more or less to the HVA range (MV/LV transformer) and applied to distribution or supply systems for industry. In other countries, the limit could be different. Standards ANSI/IEEE 1585 and IEEE Std 1623 therefore place it between 1 and 35 kV (range found in standard IEC 60038). For example, standard NEMA 600 refers to "medium voltage cables rated from 600 V to 69,000 VAC". Standard EN 50160 on the characteristics of distribution systems (see p.24) still defines medium voltage (MV) as the voltage range from 1 kV up to 35 kV.
It should also be noted that the terms "Very high voltage" (> 100 kV), "Extra High Voltage" (> 300 kV) and "Ultra High Voltage (> 800 kV) are not standardised either. We should therefore currently only refer to low voltage and high voltage.

AC systems whose nominal voltage is between 100 V and 1000 V inclusive and associated equipment

Values of the phase-neutral and phase-to-phase voltages of three phase four-wire systems to which single phase or three phase receivers can be connected.

Three-phase four-wire or three-wire systems		Single-phase three-wire systems
50 Hz	60 Hz	60 Hz
–	120/208	120/240
–	240[1]	–
230/400	277/480	–
400/690	480[1]	–
–	347/600	–
1000[1]	600[1]	–

(1) Three-wire systems without neutral

Three phase AC systems, with nominal voltage greater than 1 kV and not exceeding 35 kV and associated equipment

Two sets of highest voltages for equipment are given below: one for 50 Hz and 60 Hz systems (series I), the other for 60 Hz systems (series II – North American zone). It is recommended that only one of the two series is used in any one country. Series I systems are generally three-wire, while those in series II are four-wire.

Series I			Series II	
Highest voltage for equipment (kV)	Nominal system voltage (kV)		Highest voltage for equipment (kV)	Nominal system voltage (kV)
3.3	3.3	3	4.40	4.46
7.7	6.6	6	–	–
12	11	10	–	–
–	–	–	13.3	12.27
–	–	–	13.37	13.3
–	–	–	14.42	13.3
17.7[1]	–	15[1]	–	–
24	22	20	–	–
–	–	–	26.6	24.44
36	33	–	–	–
–	–	–	36.6	34.4
40.0	–	35	–	–

(1) Value not recommended for new systems

Three phase AC systems, with nominal voltage greater than 35 kV and not exceeding 230 kV and associated equipment

Highest voltage for equipment (kV)	Nominal system voltage[1] (kV)	
52[2]	45[2]	–
72.5	66	69
123	110	115
145	132	138
170[2]	150[2]	–
245	220	230

(1) Only use one of the recommended sets of values in any one country: 66/220 kV or 69/230 kV

(2) Values not recommended for new systems

Three phase AC systems for which the highest voltage for equipment is greater than 245 kV

Highest voltage for equipment (kV)
300[1]
362
420
550
800
1050
1200

(1) Values not recommended for new systems

Equipment with nominal voltage below 120 V AC or 750 V DC

DC		AC	
Nominal values		**Nominal values**	
Preferred (V)	Supplementary (V)	Preferred (V)	Supplementary (V)
-	2.2	-	-
-	3	-	-
-	4	-	-
-	4.4	-	-
-	5	-	5
6	-	6	-
-	7.7	-	-
-	9	-	-
12	-	12	-
-	15	-	15
24	-	24	-
-	30	-	-
36	-	-	36
-	40	-	-
48	-	48	-
60	-	-	60
72	-	-	-
-	80	-	-
96	-	-	-
-	-	-	100
110	-	110	-
-	125	-	-
220	-	-	-
-	250	-	-
440	-	-	-
-	600	-	-

DC and AC traction systems

	Voltage			Rated frequency of AC systems (Hz)
	Lowest (V)	Nominal (V)	Highest (V)	
DC systems	400[1]	600[1]	720[1]	-
	500	750	900	-
	1000	1500	1800	-
	2000	3000	3600	-
AC single-phase systems	4750[1]	6250[1]	6900[1]	50 or 60
	12,000	15,000	17,250	16 2/3
	19,000	25,000	27,500	50 or 60

(1) Values not recommended for new systems

Energy distribution conditions (continued)

HV DISTRIBUTION SCHEMATIC DIAGRAMS

Antenna (or single tap-off) distribution system

This is mainly used in rural areas, in overhead systems. If there is a fault on one section of cable or in one substation, the users have no supply while the repair is carried out.

D: Source substation outgoing line
A: Antenna incoming line
d: Outgoing line to HVA/LV transformer
F: Transformer upstream protection (HV fuse)
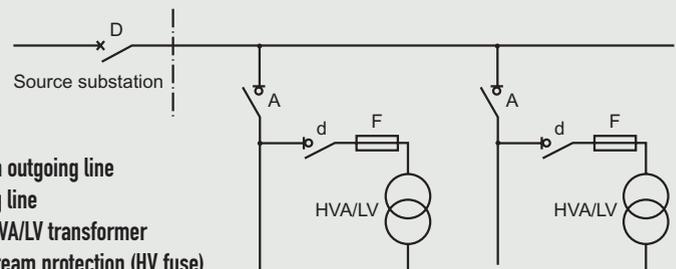
Ring (looped) distribution system

This is used in urban areas or large industrial sites and has the advantage of limiting the time during which users on the loop have no supply. If there is a fault on one section of cable or in one substation, the faulty section is isolated by opening the two devices on either side of that section, and the loop is re-supplied by closing the circuit breaker. The fault is located visually by an indicator light on the outside of the transformer substation.

D_1, D_2: Source substation outgoing lines
A_1, A_2: Loop incoming/outgoing lines
d: Outgoing line to HVA/LV transformer
F: Transformer upstream protection (HV fuse)
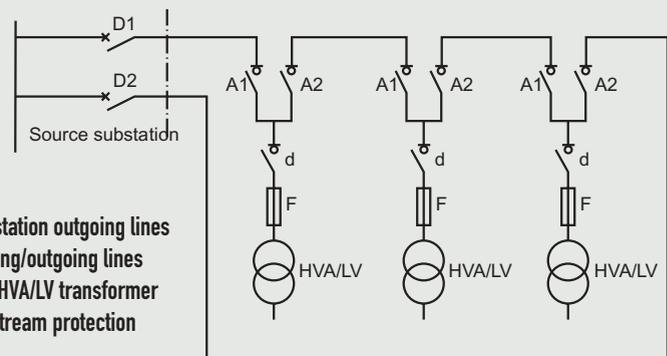
Double tap-off (or double antenna) distribution system

This is used to ensure optimum continuity of service.
If there is a fault on one of the lines, the subscriber's supply is switched over to the second line.

D_1, D_2: Source substation outgoing lines
A_1, A_2: Incoming lines (with mechanical locking)
d: Outgoing line to HVA/LV transformer
F: Transformer upstream protection (HV fuse)
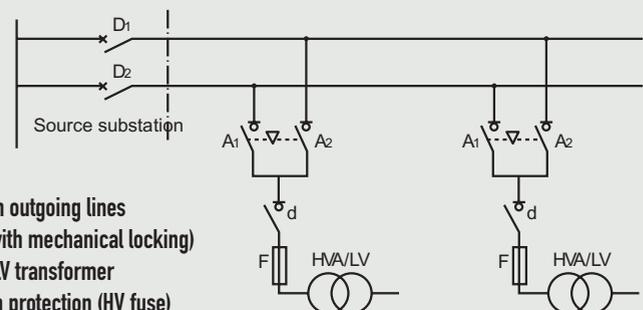
Organisation of the high voltage network

HV/HV transformers

Ring distribution

Radial distribution

Double tap-off distribution

HV/LV distribution substations

HV/LV distribution substations

Distribution substation (example HV/HV)
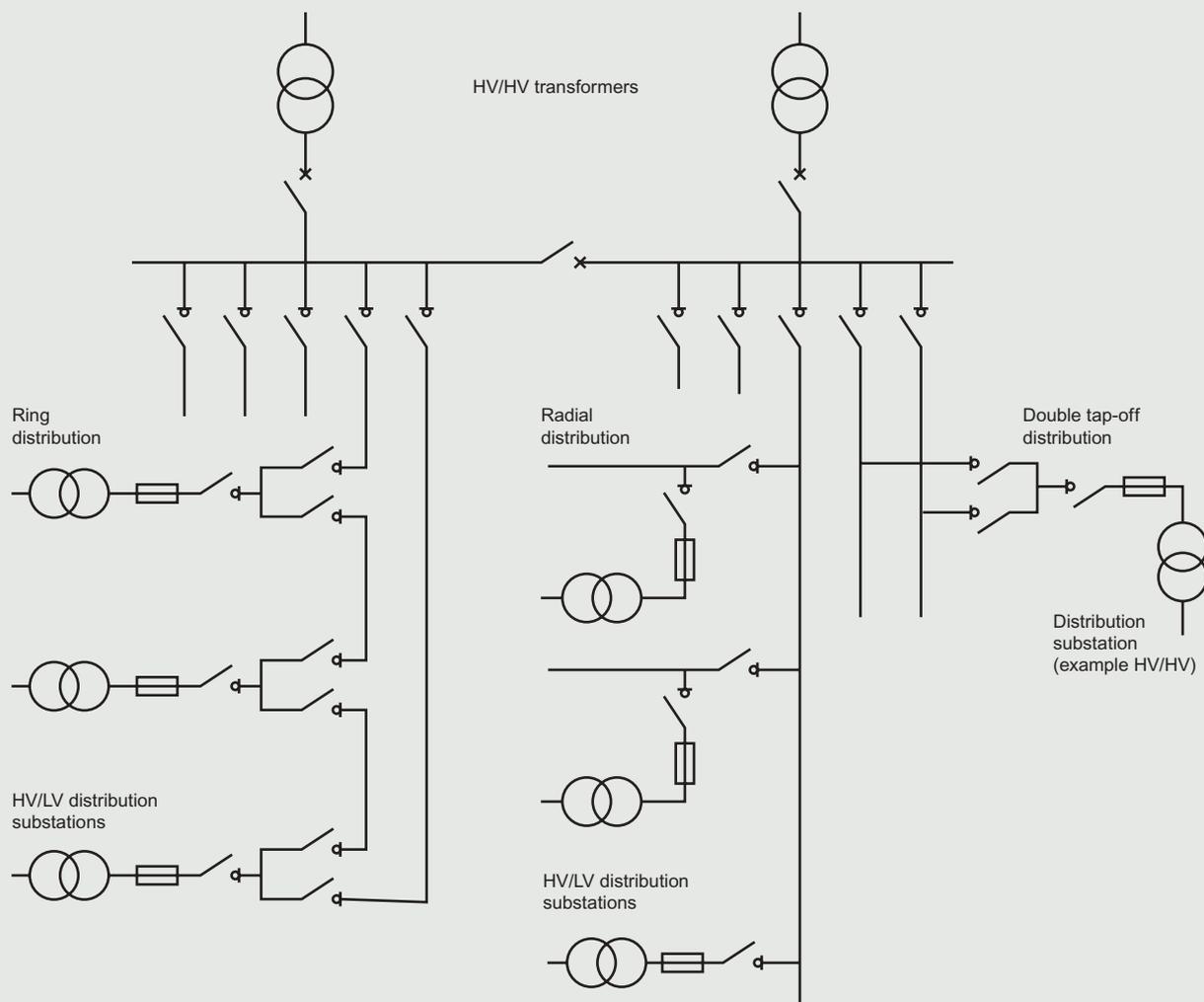
The distribution system transformers are coupled at the switching station (or source substation). The high voltage lines are distributed according to the various systems, depending on the users' requirements and service conditions and the geographical topology of the locations (distance to consumers). The distribution substation constitutes the boundary between high voltage and the low voltage used directly by consumers.

Energy distribution
conditions (continued)

SCHEMATIC DIAGRAMS OF HV NEUTRAL EARTHING SYSTEMS

As with LV installations, it is advisable to locate the high voltage system (neutral point) in relation to the earth potential. The default values (currents, over-voltages) will differ according to the characteristics of this link (direct, resistive, inductive) and the earth connection value.

Isolated neutral

Low fault current but overvoltages not discharged. Used in industry (< 15 kV).

Resistive neutral

**Limits fault currents and overvoltages, but requires the earth connection value to be controlled.
Used for overhead and underground HV systems.**

Impedance earthed neutral

**The compensation coil (also called arc suppression or Petersen coil) compensates for the capacitance of the system Cr by its inductance Ln: reduction of the fault currents if Ln and Cr matching, greater risk of overvoltage, possibility of permanent active compensation by computer.
Used in underground HV systems.**
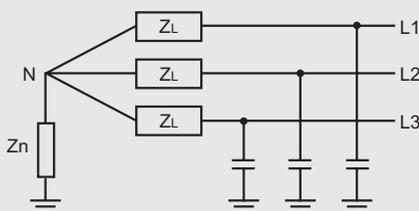
Earthed neutral

**Direct earthing eliminates overvoltages but the fault current is high.
Used on HV systems covering long or very long distances.**
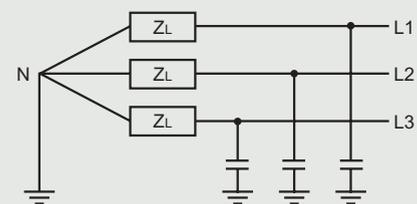
HIGH VOLTAGE CONDUCTIVE PARTS BONDING

Independently of the neutral earthing system specific to the high voltage network (which is the responsibility of the distributor), it is important to establish the procedures for earthing the high voltage conductive parts.

In practice, these are the exposed conductive parts of the HV delivery substation as against the earthing of the neutral and exposed conductive parts of the LV system.

The connection of these HV conductive parts is defined by an additional letter added to the usual designations TT, TN and IT (see p.48):

- R, the HV conductive parts are bonded to the earth of the neutral and the earth of the LV conductive parts
- N, the HV conductive parts are bonded to the earth of the neutral but not to the LV conductive parts
- S, the HV conductive parts are separated from the earths of the neutral and LV conductive parts.

This results in six possible combinations for the LV neutral earthing system and the situation of the HV conductive parts.

1 TNR AND ITR SYSTEMS

In these systems, the conductor of the HV conductive parts is electrically connected to the single main earth terminal that is common to the whole installation. The main earth terminal is connected to the general equipotential bonding. If other nearby buildings are being supplied, the main equipotential bonding of each building will be connected to the general equipotential bonding (see p.80).

> **!** **Any insulation fault in the TNR system results in a phase-neutral short circuit.**
> **The minimum current must be calculated to check that the overcurrent protection devices are suitable.**
> **The protective conductor must run close to the live conductors.**

TNR system
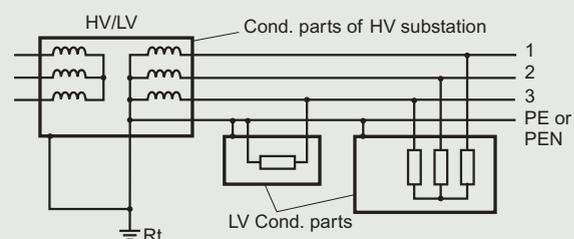
ITR system
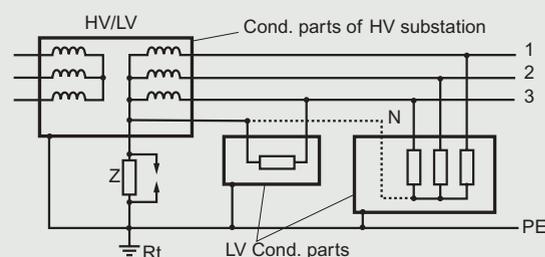
Energy distribution
conditions (continued)

2 TTN AND ITN SYSTEMS

In these systems, the HV conductive parts and the LV conductive parts are not electrically connected to the same earth connection. The TTN system is found in public LV distribution systems or installations covering large areas (buildings a long distance apart).
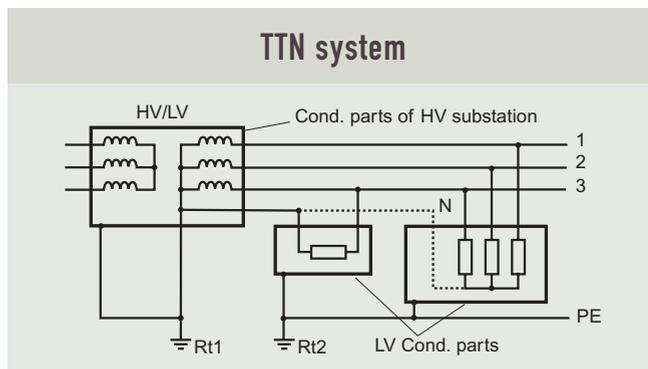
3 TTS AND ITS SYSTEMS

In these systems, the earth connections of the HV conductive parts, the neutral point of the LV supply and the LV conductive parts are all separate. This system is needed for long-distance supply requirements (mountain resorts or installations, etc.).

TTN system

TTS system

ITN system
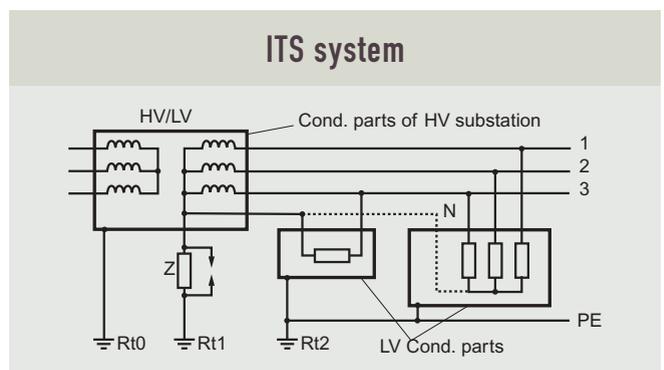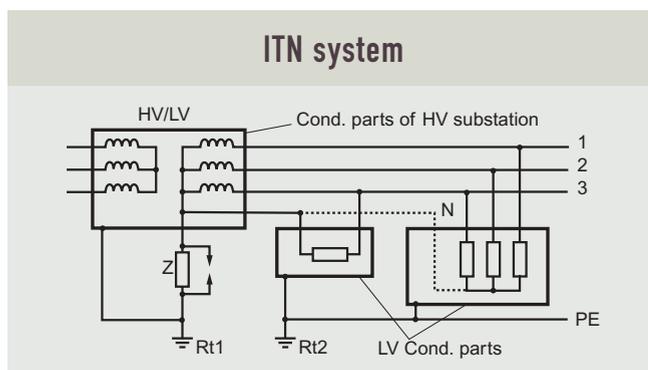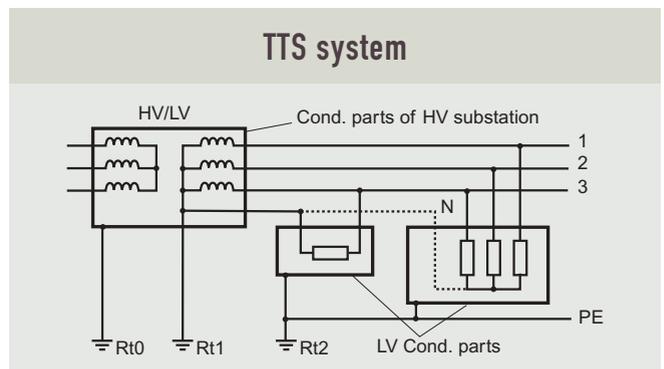
ITS system

In TTN and TTS systems, the fault currents are limited by a number of earthing resistors in series connected and by the interconnection of the conductive parts to these earths. The risk is that the fault current value could be insufficient to be detected. This must lead to the use of detectors (residual current coil sensitive to homopolar current) between the neutral point and earth leading to breaking on the 1st fault.

In ITN and ITS systems, not breaking on the 1st fault is permitted as long as the fault current is limited (resistance Z or capacitive coupling of the installation in relation to earth). Monitoring and indication by a permanent insulation monitor, and finding the fault quickly and eliminating it are mandatory and require an appropriate service on hand.

In ITN and ITS systems, the 1st fault current is only limited by the capacitive impedance to earth of the installation. The insertion of an impedance Z thus increases the value of the fault but limits transient overvoltages. In practice, the value of the impedance Z will be taken to be approximately half that of the capacitive impedance of the installation.

DELIVERY POINT AND CONNECTION TO HV NETWORK

The delivery point constitutes the boundary between the distribution structures and the customer's private installations. This is also referred to as the "concession boundary".

Pole-mounted substation

The distributor ensures that the structures for which it holds the concession operate in accordance with the specifications.
For operational reasons the distributor may need to carry out work in the customer's substation. The customer is responsible for the private installations that it uses.

^ HV delivery substation with isolation and protection

Example of design of a delivery substation

HV connection to transformer with or without transformer cabinet

LV connection

LV equipment

2 incoming cabinets
IM   IM

Protection cabinet
PM or QM

CT provided by the energy distributor

Connection to system with or without cable trough via single pole or three-pole cables

Cable trough for outgoing LV cables
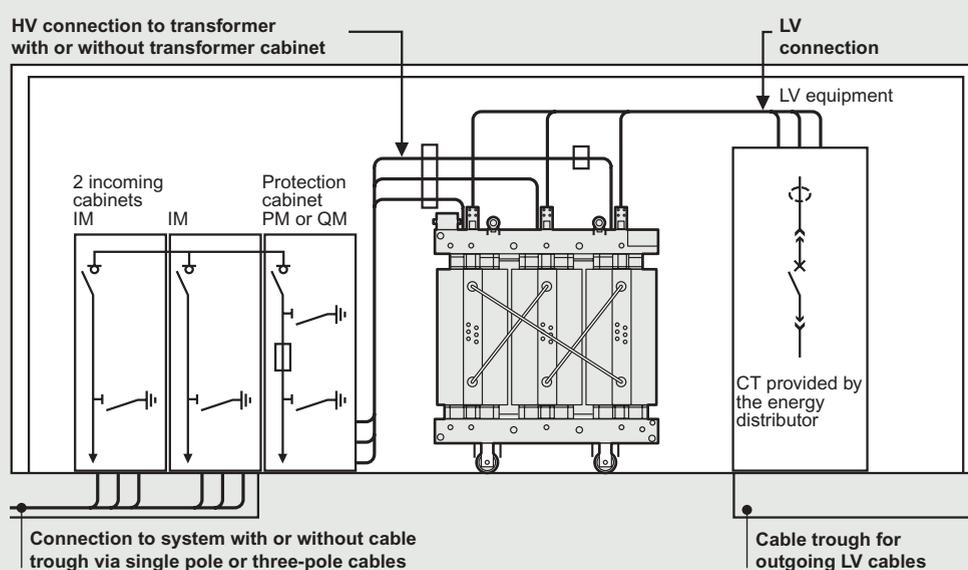
Energy distribution conditions (continued)

1 SELECTION OF HIGH VOLTAGE CABINETS

The cabinets must meet positive contact indication, locking and operation criteria and be suitable for the characteristics of the supply system:
operating voltage, line intensity, short-circuit power (or intensity).
A cabinet is characterised by:
- Its rated voltage (according to the system voltage)
- Its rated current (to be calculated according to the number of transformers to be supplied)
- Its short-circuit current withstand (according to the short-circuit power of the upstream system)
- Its function (switch, circuit breaker, etc.)
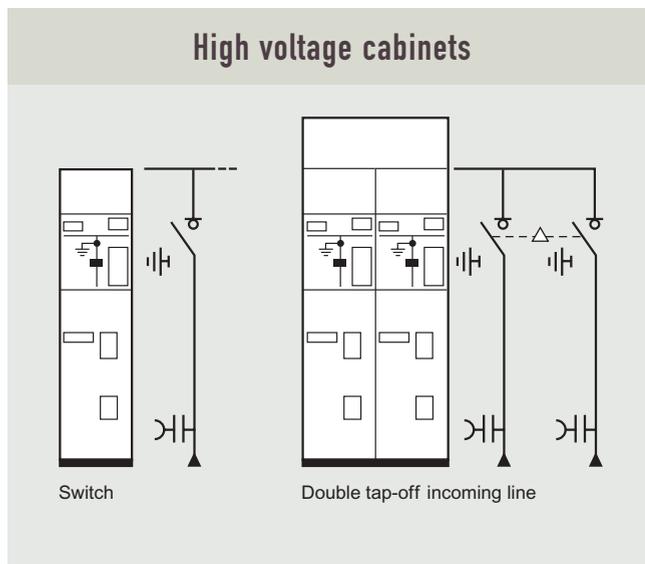
Standards and specifications applicable in France

Cabinets must comply with the following standards:

- EDF HN 64 S 41 (modular cabinets) or HN 64 S 42 (kiosk substation)

- NF C 13-100,13-200 and EN 62271-1 for cabinets, and other standards specific to each item of switchgear, in particular EN 62271-200 for positive contact indication

2 HV/LV TRANSFORMERS

Zucchini dry-type HV/LV transformers significantly reduce the installation stresses on delivery substations:
- No risk of leak
- Reduction of fire risks
- Reduction of electromagnetic radiation.
For selection and full characteristics please refer to Book 2: "Power balance and choice of power supply solutions"

High voltage cabinets

Switch   Double tap-off incoming line

Zucchini > transformer

Energy delivery substation

Legrand has a product offer for energy delivery substations for high and low voltage compensation, transformation, energy transmission, measurement and power analysis functions.

HIGH VOLTAGE

Zucchini Transformers
– From 100 to 20 000 kVA
– Cast resin transformers
– Certified Low Emission (CLE)

LOW VOLTAGE

Zucchini HR and SCP busbars
– For transport and distribution of high power
– Safe, flexible and fast installation system
– Designed for minimized electromagnetic emissions
– Reduced weight comparing to traditional installations
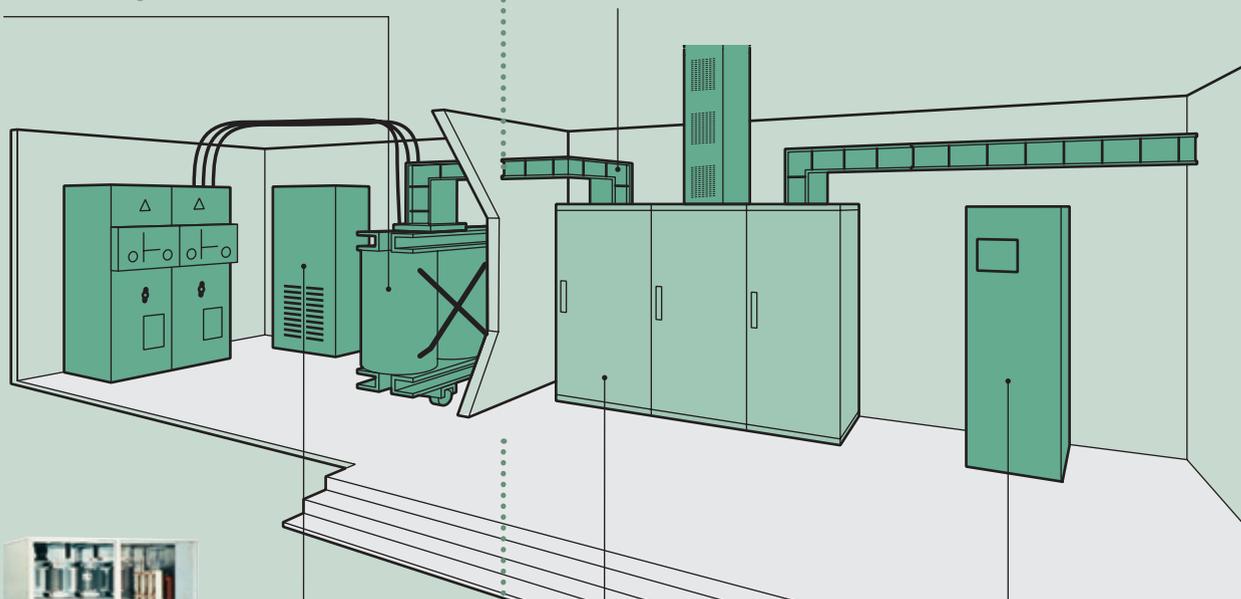
High voltage energy compensation and power quality monitoring
– Very high resistance to strong electrical fields
– Very low power losses, enabling considerable savings for highpower capacitor banks
– Real time power quality analysers : dips, swells, waveforms, power quality report, flicker, harmonics…
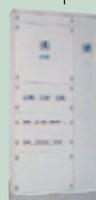
XL³ enclosures
– Modular system for safe and compliant installations up to 4000 A
– Form of separation, from 2a to 4b

Low voltage energy compensation Alpivar² and Alpimatic ranges
– Vacuum technology capacitors
– Automatic capacitor banks

Energy distribution conditions (continued)

3 POWER FACTOR COMPENSATION

Improving the power factor of an electrical installation consists 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 capacitor banks.

The capacitor is most frequently used thanks to:
- its non-consumption of active energy,
- its purchasing cost,
- its easy use,
- its service life,
- its very low maintenance (static device).

The capacitor is a receiver composed of two conducting parts (electrodes) separated by an insulator. When this receiver is subjected to a sinusoidal voltage, it shifts its current, and therefore its (capacitive reactive) power, by 90° in advance the voltage. Conversely, all other receivers (motors, transformers, etc.) shift their reactive component (inductive reactive power or current) by 90° delay the voltage. The vectorial composition of these (inductive or capacitive) reactive powers or currents gives a resulting reactive power or current below the existing value before the installation of capacitors. In other words, inductive receivers (motors, transformers, etc.) consume reactive energy, while capacitors (capacitive-receivers) produce reactive energy.

4 FILTERING HARMONICS

For installations with a high level of harmonic pollution, the user may be confronted with two requirements:
- compensating for reactive energy and protecting the capacitors
- reducing the voltage distortion rate to acceptable values compatible with the correct operation of most sensitive receivers (programmable logic controller, industrial computer hardware, capacitors, etc.). For this application, Legrand is able to offer passive type harmonic filters. A passive type harmonic filter is a serial combination of a capacitor and an inductive coil for which each combined frequency corresponds to the frequency of an interfering harmonic voltage to be eliminated.

For this type of installation, Legrand products offer services like:
- analysis of the supply on which the equipment is to be installed with measurements of harmonic currents and voltages
- computer simulation of the compatibility of the harmonic impedances of the supply and the different filters
- calculation and definition of the different components of the filter
- supply of capacitors, inductive coils, etc.
- measurement of system efficiency after installation on site.

5 METERING

Metering is an important element in an electrical distribution system. It provides information on the active power consumed on the installation as well as the reactive power, which is non-productive for the user, but necessary for creating the magnetic field in the windings of motors and transformers, without which they would not be able to operate.

In many countries the electrical energy distributors bill for this reactive energy, which can be eliminated by incorporating a capacitor bank in the customer's installation, hence the importance of metering, in order to determine whether this value needs to be improved. Metering is normally used, but there are still installations that do not have this function, leading to difficulty in optimising the energy consumption of these installations.

Intelligent metering

New sustainable development requirements will lead to a revision of metering principles in order to provide both compatibility with exchanges of energy flows and better realtime information for users and producers. The buildings of the future will be both producers and consumers and this balance will be, if possible, profitable (positive energy) as a result of integrated production installations (solar, wind-powered, etc.). The metering function will no longer be one-way but "intelligent" , incorporating real energy management.

The opening up of markets and the diversity of offers has led to there being a plethora of metering and billing arrangements today.

But as a general rule the metering principles are still linked to the terms of supply.

A distinction is therefore made between controlled power connections and monitored power connections. In the former, the limit of available energy is set by a detection device that trips if there is an overcurrent.

Different tariffs can be applied according to the time of day (peak times/off-peak times), the day (peak days) or other rules.

In the latter, protection is of course provided against overcurrents, but it does not have a limiting role in relation to a supply contract. The energy is billed according to more or less complex concepts: peak times, summer, winter, moving peak, adjustable peak, etc. and additional billing if the contractual values are exceeded.

Reactive energy measurement

The energy supplier measures and bills for the reactive power consumption according to the type of contract and the subscribed demand. In fact, even when it is not billed, it is always a good idea to evaluate the reactive power and compensate for it, if required, with capacitors (see p. 90). In this case, it is highly advisable to take measurements to ensure correct sizing, as inappropriate compensation can lead to malfunctions.

A better power factor makes it possible to limit or avoid the cost of reactive energy when it is billed. This monetary incentive is required for people to realise the obvious advantage of a good power factor, which is all too often downgraded these days by inductive loads and especially by distorting loads (harmonics). See Book 2.

< Flush-mounted central measure unit

Energy distribution conditions (continued)

LV RATIONALIZED VOLTAGES

Although a great deal of harmonisation work has been carried out internationally in order to adopt identical voltage values and electricity system characteristics, there are still a great many variants (see tables of countries' characteristics) which could hamper exchanges of products and above all risk creating dangerous situations.

To this end, standard IEC 60664-1 has established the concept of "rationalized voltage" which enables a number of nominal supply voltages to be linked to a reference value, referred to as "rationalized". This value can then be used for designing devices or in product standards. The insulation value of a device Ui should normally refer to a voltage of this type, which implies that the device can be used on all electrical supply systems that are included in that value.

Single-phase three or two-wire AC or DC systems		
Nominal voltage of the supply system (V)	Rationalized voltages	
	For insulation line-to-line	For insulation line-to-earth
	All systems (V)	3-wire systems with earthed mid-point (V)
12.5	12.5	-
24	25	-
25	25	-
30	32	-
42	50	-
48	50	-
50	50	-
60	63	-
30-60	63	32
100	100	-
110	125	-
120	125	-
150	160	-
200	200	-
100-200	200	100
220	250	-
110-220	250	125
120-240	250	125
300	320	-
220-440	500	250
600	630	-
480-960	1000	500
1000	1000	-

Three-phase four or three-wire AC systems			
	Rationalized voltages		
	For insulation line-to-line	**For insulation line-to-earth**	
Nominal voltage of the supply system (V)	**All systems (V)**	**Three-phase four-wire systems neutral-earthed**	**Three-phase three-wire systems unearthed or corner-earthed**
60	63	32	63
110	125	80	125
120	125	80	125
127	125	80	125
150	160	-	160
200	200	-	200
208	200	125	200
220	250	160	250
230	250	160	250
240	250	160	250
300	320	-	320
380	400	250	400
400	400	250	400
415	400	250	400
440	500	250	500
480	500	320	500
500	500	320	500
575	630	400	630
600	630	-	630
660	630	400	630
690	630	400	630
720	800	500	800
830	800	500	800
960	1000	630	1000
1000	1000	-	1000

The phase/earth insulation level for systems that are not earthed or are earthed via an impedance (IT neutral earthing system) must be considered as being the same level as that between phases. An insulation fault on one phase may result in a rise in earth voltage and increase the values of the other two phases in relation to the faulty phase to that of the phase-to-phase (or full) voltage.

For equipment designed to be used on either Three-phase four or three-wire systems, insulation should be considered necessary between phase and earth at the same level as between phases (read from the 3-wire three phase system column). The design of Legrand distribution blocks and busbars (see Book 12) incorporates this requirement by providing an identical insulation level for all phase and neutral poles.

Energy distribution conditions (continued)

Country	Frequency (Hz) and tolerance (%)	Household voltage (V)	Commercial voltage (V)	Industrial voltage (V)	Voltage tolerance (%)
Albania	50 + 0.5	220/380	220/380	220/380 • 6 kV - 10 kV	+5
Algeria	50 ±1	220	380/220	380/220 • 30 kV (rural) 10 kV (urban)	±10
Andorra	50 +1	230 400	230 400	230 • 400	+6/-10
Angola	50 ±5	380/220 • 220	380/220	400/231	±10
Antigua and Barbuda	60	400/230 • 120/208	400/230 • 120/208		
Argentina	50 ±2	220	380/220 220	380/220	±8
Armenia	50 ±0.4	380/220 • 220	380/220 • 220 • 110 kV 35 kV/6 kV •10 kV	380/220 • 220 • 110 kV 35 kV/6 kV • 10000 kV	±5
Australia	50 ±0.1	400/230	400/230	400/230	+10/-6
Austria	50 ±1	230	400/230	400/230	±10 (400/230)
Azerbaijan	50 ±0.4	380/220 • 220	380/220 220	380/220	±5
Barhain	50 ±2	415/240 • 240 400/230	415/240 • 240 400/230	11 kV • 415/240 240 • 400/230	±6
Bangladesh	50 ±2	400/230	400/230	11 kV • 400/230	±10
Belarus	50 ±0.8	380/220 • 220 220/127 • 127	380/220 • 220	380/220	Normally ±5 Maxi 10
Belgium	50 ±3	230 • 400/230	230 • 400/230	From 3 to 15.5 kV	+6/-10
Benin	50 ±5	220	220 to 380	15 kV/380V	±10
Bolivia	50 ±5	230	400/230 • 230	400/230	+5/-10
Bosnia Herzergovina	50±0.2	380/220 • 220	380/220 • 220	10 kV • 6.6 kV 380/220	±8 ±5
Brazil	60	220/127	380/220 • 220-127	380/220 • 440/254	+5/-7.5
Bulgaria	50 ±0.1	220/230	220/230	380	±10
Burkina faso	50 ±10	230	400	400	±10
Burundi	50 ±1	380/220	400/230	400/230 • 66 kV/400-230 10 kV/400-230 30 kV/400-230	±10
Cambodia	50 ±0.5	220	380/220	380/220	±5
Cameroun	50 ±1	220-260	260-220	380/220	+5/-10
Canada	60 ±2	240/120 240	347/600 • 416/240 208/120 • 600	46 kV • 34.5 kV/20 kV 24.94 kV/14.4 kV 13.8 kV/8 kV 12.47 kV/7.2 kV 4.16 kV/2.4 kV • 600/347	+4/-8.3
Canary island	50 ±5	220	220/380	380/220	±5
Cape Verde	50	220	220/380	380/400 • 20 kV • 6 kV 15 kV • 13 kV • 10 kV	±5
Central African Republic	50 ±4	220/380	15 kV • 220/380	15 kV • 220/380	±10
Chad	50 ±1	220	220	380/220	Not available
Chile	50 ±0.2	220	380	13.8 kV • 13.2 kV 12 kV • 440 • 380	±3.5
China	50 ±0.2	220	380 220	380 220	±7 +7/-10
Colombia	60 ±0.2	240/120 • 208/120	240/120 • 208/120	44 kV • 34.5 kV • 13.8 kV (11.4 kV Bogota only)	+5/-10
Congo (Democratic Republic)	50	220/240	380/220	380/220 • 6.6 kV 20 kV • 30 kV	±10
Costa Rica	60	240/120	240/120 • 208/120	240/120 • 208/120 400/277	±5
Cote d'Ivorie	50 ±2	230/400	15 kV • 19 kV • 43 kV	15 kV • 19 kV • 43 kV	+6/-10

Country	Frequency (Hz) and tolerance (%)	Household voltage (V)	Commercial voltage (V)	Industrial voltage (V)	Voltage tolerance (%)
Crotia	50	400/230 • 230	400/230 • 230	400/230	±10
Cuba	60 ±1	115/230	230/400	230/400	±10
Cyprus	50 ±2.5	230/400	230/400	22/11 kV • 230/440	±10
Czech republic	50 ±1	230/400	230/400 • 500 690	400 kV • 220 kV • 110 kV 35 kV • 22 kV • 10 kV 6 kV • 3 kV	+6/-10
Denmark	50 ±1	400/230	400/230	400/230	+6/-10
Djibouti	50	220	400/230	400/230 • 20 kV	±10
Dominican republic	60	240	240/120	7.2 kV • 480 • 220/110 208 • 115	±3
Ecuador	60 ±1	110	110	440/220	±5
Egypt	50 ±0.5	380/220 • 220	380/220 • 220	132 kV • 66 kV • 33 kV 20 kV • 22 kV • 11 kV 6.6 kV • 380/220	±10
Estonia	50 ±1	380/220 • 220	380/220 • 220	380/220	±10
Ethiopia	50 ±2.5	220	380/230	15 kV • 45 kV • 132 kV 230 kV • 380/230	±10
Fiji	50 ±2	415/240 • 240	415/240 • 240	11 kV • 415/240	±6
Finland	50 +/0.1	230 • 400	400/230	400/230 • 690/400 • 690/400 10 kV • 20 kV • 110 kV	+6/-10
France	50 ±1	400/230 • 230	400/230 • 690/400	20 kV • 10 kV • 400/230	+6/-10
French Guiana	50	220	230/ 400	15 kV • 20 kV • 30 kV • 400	Not available
Georgia	50 ±0.5	380/220	380/220	380 • 6 kV • 10 kV	±10
Germany	50 ±0.5	400/230 • 230	400/230 • 230	20 kV • 10 kV • 6 kV 690/400 • 400/230	+6/-10
Ghana	50 ±5	240-220	240-220	415-240	±10
Greece	50	230	230/400	400	+6/-10
Grenada	50	230	400/230	400/230	+4/-8
Guadeloupe	50 and 60	220	380/220	20 kV • 380/220	Not available
Honduras	60 ±3	220/110	480/277 • 240/120	69 kV • 34.5 kV • 13.8 kV 480/277 • 240/120	+ ou-5
Hong Kong	50 ±2	380/220	380/220	11 kV • 380/220	±6
Hungary	50 ±1	230/400	230/440	230/400	±10
Iceland	50 ±0.1	230	400/230	400/230	+6/-10
India	50 ±3	440 • 230	400 • 230	11 kV • 440/250	±10
Indonesia	50	220 • 220/380	220/380	150 kV • 70 kV • 20 kV	±5
Iran	50 ±5	220	380/220	20 kV • 400/230 • 380/220	±5
Iraq	50	220	380/220	11 kV • 6.6 kV 3 kV • 380/220	±5
Ireland	50 ±2	230	400/230	10 kV • 20 kV • 38 kV 110 kV • 400/230	+6/-10
Israel	50 +0.5/-0.6	400/230	400/230	For above 630 kVA: 12.6 kV/22 kV/33 kV /110 kV/161 kV	±10
Italy	50 ±2	400/230 • 230	400/230	20 kV • 15 kV 10 kV • 400/230	±10
Japan	50 (east) / 60 (west)	200/100	200/100 (up to 50 kW)	140 kV • 60 kV • 20 kV 6 kV • 200/100	±6V(101V) ±20V(202V) 6-140 kV
Jordan	50	230	400/230	415/240 • 3.3 • 6.6 • 11 kV	±7
Kenya	50 ±2.5	240	415/240	415/240	±6
Korea republic of south	60 ±0.2	220 ±13 • 110 ±10	380 ±38V • 220 ±13	20.8 kV • 23.8 kV 380 ±38V • 380/220	Not available
Kuwait	50 ±4	230	400/230	400/230	+10/-10
Latvia	50 ±0.4	380/220 • 220	380/220 • 220	380/220	+10/-15

Energy distribution conditions (continued)

Country	Frequency (Hz) and tolerance (%)	Household voltage (V)	Commercial voltage (V)	Industrial voltage (V)	Voltage tolerance (%)
Lebanon	50	220	380/220	380/220	±10
Lybian	50 ±1	220	220/380	380 11 kV	±10
Lithuania	50 ±1	400/230	400/230	400/230	±10
Luxembourg	50 ±0.0	400/230	400/230	65 kV • 20 kV	+6/-10
Macedonia	50	380/220 • 220	380/220 • 220	10 kV • 6.6 kV • 380/220	Not available
Madagascar	50 ±2	220/110 • 380/220	220/110 • 380/220	63 kV • 35 kV • 30 kV 20 kV • 15 kV 5.5 kV • 380/220	Low voltage: ±7 Hight voltage: ±5
Malaysia	50 ±1	240 415/240	415/240	415/240	+5/-10
Mali	50	220 380/220	220 • 380/220	Not available	Not available
Malta	50 ±2	230	400/230	11 kV • 400/230	+10/-6
Martinique	50	230	230/400V • 230	230/400 • 20 kV	-10/+6
Mauritania	50	380/220	380/220	15 kV • 380/220	±10
Mauritius	50 ±1	230	400/230	400/230	±6
Mexico	60 ±0.2	220/127 • 220 • 120	220/127 • 220 • 120	13.8 kV • 13.2 kV 480/277 • 220/127	±10
Morocco	50 ±5	380/220	380/220	225 kV • 150 kV 60 kV • 22 kV	±10
Netherlands	50 ±10	400/230 • 230	400/230	25 kV • 20 kV • 12 kV 10 kV • 230/400	±10
New Zealand	50 ±1.5	400/230 • 230	400/230 • 230	11 kV • 400/230	±6
Nigeria	50 ±1	230 • 220	400/230 • 380/220	15 kV • 11 kV 400/230 • 380/220	±5
Norway	50 ±1	400/230	400/230	400/230 • 690	±10
Pakistan	50	230	400/230 • 230	400/230	±5
Paraguay	50 ±5	220	380/220 • 220	22 kV • 380/220	±5
Peru	60 ±6	220	220	20 kV • 10 kV • 220	±5
Poland	50 +0.2/-0.5 50 +0.4/-1	230	400/230	1 kV • 690/400 400/230 • 6.3 kV	+6/-10
Portugal	50 ±1	400/230 • 230	60 kV • 30 kV • 15 kV 10 kV • 400/230 • 230	60 kV • 30 kV • 15 kV 10 kV • 400/230 • 230	60 ±10
Qatar	50 ±1	240	415/240	33 kV • 66 kV • 132 kV	±5
Romania	50 ±0.5	230	440/230	660/380 400/230	±10
Russia	50 ±0.2	380/220 • 220	660/380/220 380/220/127	660/380/220 380/220/127	+10/-20
Rwanda	50 ±1	220	380/220	15 kV • 6.6 kV • 380/220	±5
Saudi Arabia	60 ±0.3	220/127	220/127	13.8 kV • 380/220	±5
Senegal	50 ±5	220	380/220 • 220/127	90 kV • 30 kV • 6.6 kV	±10
Serbia	50	230/400 230	230/440 230	10 kV • 6.6 kV • 230/400	±10
Singapore	50 ±1	400/230 • 230	400/230	22 kV • 6.6 kV • 400/230	±6
Slovakia	50 ±0.5	230/030	230/400	230/400	±10
Slovenia	50 ±0.1	230/400	230/400	35 kV • 20 kV • 10 kV • 6 kV 3.3 kV • 1000V • 660V 500V • 400/230	+6/-10 for 400/230
Somalia	50	230 • 220 • 110	440/220 • 220/110 230	440/220 • 220/110	±10
South Africa	50 ±2.5	433/250 • 400/230 380/220 • 220	11 kV • 6.6 kV • 3.3 kV 433/250 • 400/230 380/220	11 kV • 6.6 kV • 3.3 kV 500 • 380/220	±10
Spain	50 ±0.5	380/220 • 220 220/127 • 127	380/220 • 220/127	25 kV • 20 kV • 15 kV 11 kV • 10 kV • 6 kV 3 kV • 380/220	±7

Country	Frequency (Hz) and tolerance (%)	Household voltage (V)	Commercial voltage (V)	Industrial voltage (V)	Voltage tolerance (%)
Sudan	50	240	415/240 • 240	415/240	Not available
Sweden	50 ±0.5	400/230 • 230	400/230 • 230	6 kV • 10 kV • 20 kV 400/230	+6/-10
Switzerland	50 ±2	400/230	400/230	20 kV • 16 kV • 10 kV • 3 kV 1 kV • 690/400 • 950/400	±10
Syrian Arab Republic	50	380/220 • 220	380/220 • 220 220/115	380/220	±5
Thailand	50 ±5	220	380/220 220	380/220	Not available
Tunisia	50 ±2	380/220 • 231/400 242/420	380/220 • 231/400 242/420	30 kV • 15 kV • 10 kV	±10
Turkey	50 ±1	380/220	380/220	36 kV • 15 kV 6.3 kV • 380/220	±10
Ukraine	50 +0.2/-0.4	380/220 • 220	380/220 • 220	380/220 220	+5/-10
United Arab Emirates (ADWEA)	50 ±0.5	415/240	415/240	11 kV • 415/240	±5
United Arab Emirates (DEWA)	50 ±1	380/220	380/220	11 kV • 6.6 kV • 380/220	±3
United Arab Emirates (SEWA)	50 ±1	415/240	415/240	11 kV • 6.6 kV • 415/240	±5
United Arab Emirates (FEWA)	50±1	415/240	415/240	11 kV • 415/240	±5
United Kingdom Excluding Northern Ireland	50±1	230	400/230	22 kV • 11 kV • 6.6 kV 3.3 kV • 400/230	+10/-6
UK Northern Ireland	50±0.4	230 • 220	400/230 • 380/220	400/230 • 380/220	±6
(USA) North Carolina	60 ±0.06	240/120 • 208/120	±10% 240 • 480/277 460/265 • 240/120 208/120	±10% 24 kV • 14.4 kV • 7.2 kV 2.4 kV • 575 • 460 • 240 460/265 • 240/120 • 208/120	+5/-2.5
(USA) Michigan	60 ±0.2	240/120 • 208/120	480 • 240/120 208/120	13.2 kV • 4.8 kV • 4.16 kV 480 • 240/120 • 208/120	+4/-6.6
(USA) California	60 ±0.2	240/120	4.8 kV • 240/120	4.8 kV • 240/120	±5
(USA) Miami	60 ±0.3	240/120 • 208/120	240/120 • 208/120	13.2 kV • 2.4 kV 480/277 • 240/120	±5
(USA) New York	60	240/120 • 208/120	240/120 • 208/120 240	27.6 kV • 13.8 kV • 12.47 kV 4.16 kV • 480/277 • 480	Not available
(USA) Pittsburgh	60 ±0.3	240/120	460/265 • 240/120 208/120 • 460 • 230	13.2 kV • 11.5 kV • 2.4 kV 460/265 • 208/120 460 • 230	±5 (ligthning) ±10 (power)
(USA) Portland	60	240/120	480/277 • 240/120 208/120 • 480 • 240	19.9 kV • 12 kV • 7.2 kV 2.4 kV • 480/277 208/120 • 480 • 240	Not available
(USA) San Francisco	60 ±0.08	240/120 • 208/120	480/277 • 240/120	20.8 kV • 12 kV • 4.16 kV 480 • 480/277 • 240/120	±5
(USA) Ohio	60 ±0.08	240/120 • 208/120	480/277 • 240/120 208/120	12.47 kV • 7.2 kV • 4.8 kV 4.16 kV • 480 480/277 • 208/120	±5
Uruguay	50 ±1	220	220 • 3x220/380	15 kV • 6 kV • 220 3x220/380	±6
Venezuela	60	120	480/277 • 208/120	13.8 kV • 12.47 kV 4.8 kV • 2.4 kV	Not available
Vietnam	50 ±0.1	220	380/220	500 kV • 220 kV • 110 kV 35 kV • 22 kV • 15 kV 10 kV • 6 kV • 3 kV	±5

Energy quality and disturbance of the power supply

The quality of the electrical energy may be affected either by events that occur on the distribution systems (switching, lightning, etc.) or by the use made of the electricity when for example certain receivers create significant variations in the current consumption (switching on) or alter the waveform (harmonics).
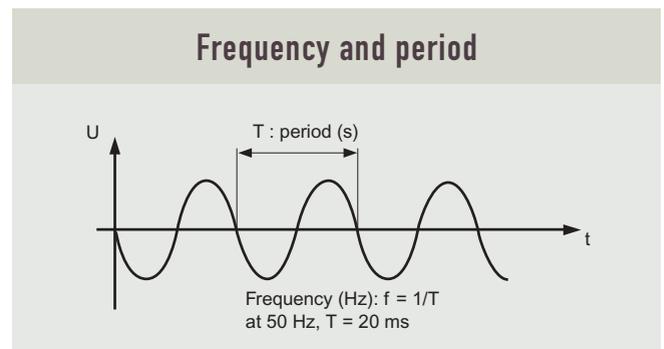
It is therefore important to set clear rules between the distributor and the consumer under a supply contract. This can specify stricter provisions than standard EN 50-160 (see below) but by default in Europe it constitutes the binding reference document in the absence of any specific regulations or other undertaking by the distributor.

DISTURBANCES DESCRIBED IN STANDARD EN 50160

The quality of the electricity supply is the subject of a European standard, EN 50160, which stipulates the permissible limits of 14 values or phenomena characterising or affecting the 50 Hz sinusoidal signal. Based on a statistical approach, it is designed to ensure a certain level of quality during normal operation.

1 SIGNAL FREQUENCY

The nominal voltage frequency is 50 Hz with a tolerance of +/-1% (i.e. 49.5 to 50.5 Hz) for 99.5% of each one-year period and +4 to -6% (i.e. 47 to 52 Hz) for the whole period.

Example of recording showing frequency drift and signal distortions

Model 7100 Waveshape Disturbance Three Phase Delta
350.0 V — 165.0 A
2
4
6
0.0 V — 0.0 A
-350.0 V — -165.0 A

Frequency and period

U

T : period (s)

t

Frequency (Hz): f = 1/T
at 50 Hz, T = 20 ms

This type of fluctuation is virtually nonexistent on public distribution systems in industrialised countries. In installations supplied by standalone sources (generator sets, inverters, etc.), different tolerance limits can be set, or regulation devices may even be necessary.
The same applies to systems that are not interconnected (for example, islands) where wider tolerances are permitted: +/- 2% for 99.5% of each week and +/-15% for 100% of the time.

2 AMPLITUDE OF THE SUPPLY VOLTAGE

The supply voltage represents the rms value measured at the delivery point. It is measured at a given moment and averaged over a time interval (typically 10 minutes).
The nominal voltage Un which characterises the system can be distinguished from the stated voltage Uc which would result from an agreement on values that are different from those in standard EN 50160.

The standard voltage for low voltage public systems in Europe is:
- 230 V between phases and neutral (400 V between phases) for three phase systems with neutral
- 230 V between phases for three phase systems without neutral

Example of recording showing amplitude variations of the supply voltage

Maxi
Medium
Mini

Example of recording showing slow voltage variations

Line-to-line voltage: FACEL TR1
U12 Moy
U23 Moy
U31 Moy
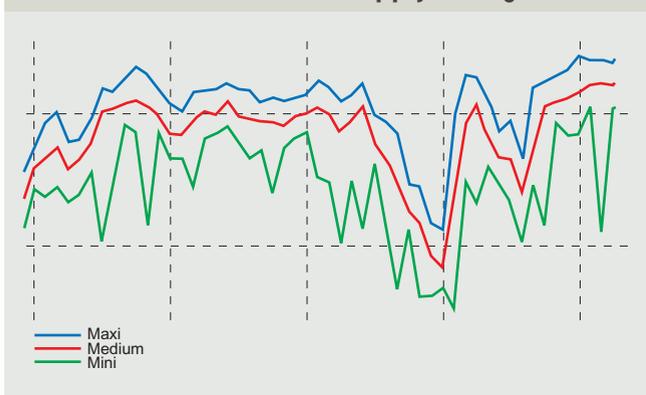
3 SLOW VOLTAGE VARIATIONS

Under normal operating conditions, the following slow voltage fluctuations are permitted over a period of one week: +/- 10% of the reference value (230 or 400 V), i.e. 207 to 253 V or 360 to 440 V for 95% of measurements, and - 15% to +10% for 100% of measurements, i.e. 195 to 253 V and 340 to 440 V.

The supply voltage of the system can fluctuate daily, weekly or seasonally as a result of significant variations in load on the system. Voltage regulation devices installed in transformer substations can limit these variations. In addition, high power receivers such as welding stations, large motors, furnaces and other energy-intensive installations may cause local voltage drops while they are in operation.

Power limits are generally set for motors supplied by a public distribution system.

The solution may therefore be to increase the power of the source (reduction of its impedance and increase in its short-circuit power) or compensate for the reactive energy connected with one device in particular that is causing disturbance (see page 99).

4 FAST SUPPLY VOLTAGE VARIATIONS

These variations, which come mainly from currents drawn by high loads, should not exceed 5 to 10% of the nominal voltage. Recordings show that momentary reductions of 30% are totally possible when receivers such as motors or transformers are switched on. These variations are non-periodic and occur at random moments.

When fast voltage variations become cyclical, this is referred to as flicker, with reference to light variations which can be annoying above a certain level.

Energy distribution conditions (continued)

5 FLICKER SEVERITY

The intensity of the annoyance caused by flicker is defined by a UIE-CIE (International Union for Electricity Applications - International Commission on Illumination) measurement method.
It is evaluated as follows:
– Short term severity (Pst) measured over a period of ten minutes
– Long term severity (Plt) calculated based on a sequence of 12 Pst values over a two-hour period, according to the following formula:

$$P_{lt} = \sqrt[3]{\sum_{i=1}^{12} \frac{P_{st}^3}{12}}$$

Under normal operating conditions, for each one-week period, it is recommended that the long term flicker severity level Plt associated with voltage fluctuations is less than or equal to 1 for 95% of the time.

6 VOLTAGE DIPS

These can be due to faults occurring at users' installations, but they often result from troubles on the public distribution system. The numbers of these vary considerably according to local conditions, and they generally only last up to one second.

Most voltage dips last less than 1 second with a depth of less then 60%. In other words, the residual voltage remains greater than 40%.
There is a voltage dip as soon as the rms value of one of the voltages, measured separately on each phase, falls below a set threshold.
Standard EN 50160 does not specify the number, duration or depth of voltage dips. This characteristic could form the subject of a contractual agreement.

Example of recording showing ficker severity variations

Example of recording of a voltage dip
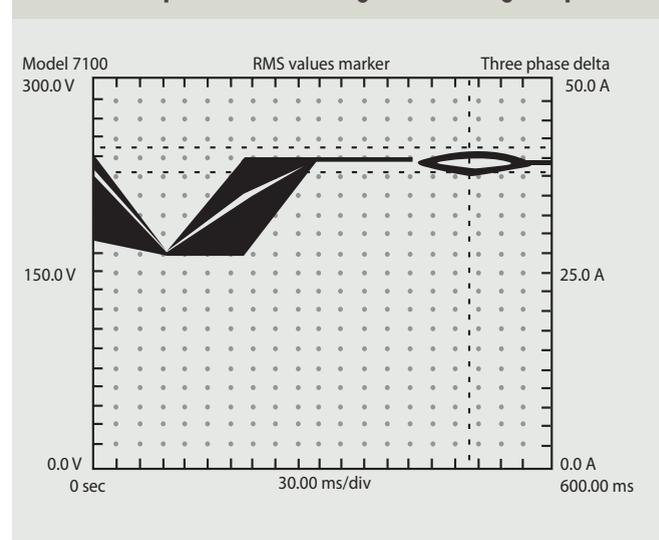
7 SHORT VOLTAGE INTERRUPTIONS

Short interruptions or microbreaks refer to when the value of the signal drops to 0 V or less than 1% of the nominal voltage. These generally last less than a second, although a break of 1 minute may still be considered as being short. Microbreaks and voltage dips are phenomena that are often random and unpredictable, and they may occur irregularly over time. It may be important to define contractually the maximum duration and threshold for a voltage dip to be considered as being a microbreak (for example a voltage < 40% of Un for less than 600 ms). In most cases, only recordings can enable a decision on the accuracy of the phenomena to be made with certainty.

Example of recording of a short voltage interruption

Model 7100	RMS Sag Disturbance	Three Phase Wye
300.0 V		50.0 A
		1V
150.0 V		25.0 A
0.0 V		0.0 A
0 sec	30.00 ms / div	600.00ms
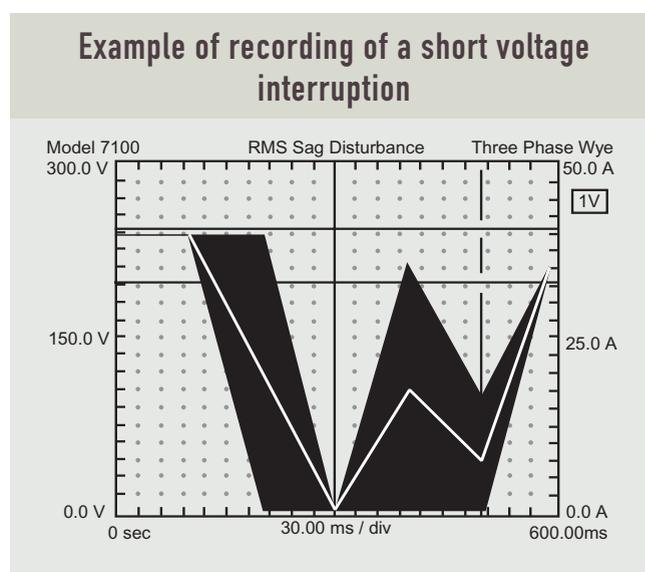
ITIC curves

Electronic and computing equipment is sensitive to voltage variations. The first installations, affected by apparently random faults, were historically the source of most Power Quality problems.
The creation of the Information Technology Industry Council curve (ITIC curve), has enabled a template to be defined, within which a voltage fault (dip or overvoltage) can be acceptable or unacceptable. Plotting the duration of an event as a function of the voltage in relation to the nominal supply voltage, these curves define the limits within which the device should continue to operate with no interruption or loss of data.

Percent of nominal value

Prohibited region: 0

No damage region: 0

Duration

10µs 100µs 1ms 10ms 100s 1s 10s 100s
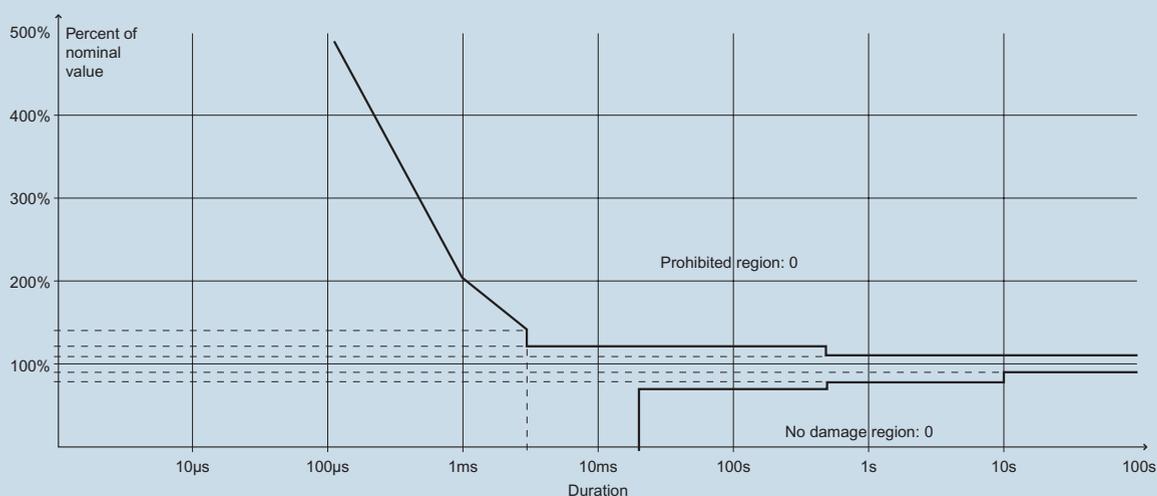
Energy quality and disturbance of the power supply (continued)

8 LONG VOLTAGE BREAKS

These values are not quantified as they depend on totally chance elements.

The frequency with which they occur is very variable and is dependent on the architecture of the distribution system or the exposure to climatic hazards.

Under normal operating conditions, the annual frequency of voltage interruptions of more than three minutes may be less than 10 or can reach as many as 50, depending on the region.

Example of recording of a long voltage break
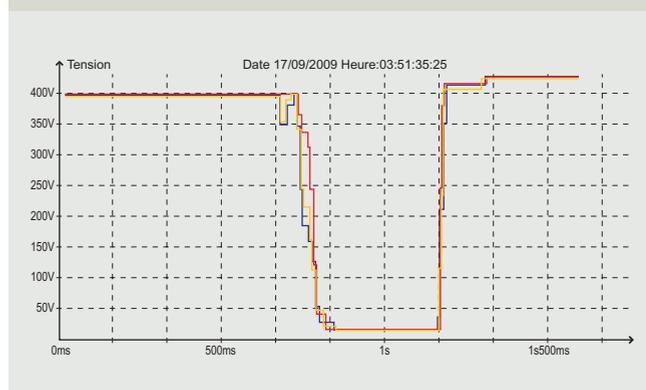
9 TEMPORARY OVERVOLTAGES

This type of fault can occur both on the distribution system and on the user's installation. It can be devastating as the voltage supplied may reach a level that is dangerous for equipment.

The main risk is there being a phase-to-phase instead of a phase-neutral voltage if, for example, the neutral fails. Faults on the high voltage system (fallen line) can also generate overvoltages at the low voltage end. Standard EN 50-160 does not set limits for these overvoltages. But on this point, it is essential, for the safety of people and installations, to choose equipment sized according to the standards (harmonised with IEC 60064-1) and tested for withstand to lightning impulses (see next section).

Insulation coordination in low voltage systems with regard to temporary overvoltages

Requirements of standard IEC 60064-1:

• Sturdy basic insulation and supplementary insulation must withstand the following temporary overvoltages:
- Short duration temporary overvoltages, amplitude Un + 1200 V for t ⩽ 5 s
- Long duration temporary overvoltages, amplitude Un + 250 V for t > 5s
(Un is the supply system nominal phase-neutral voltage to earth)

• Reinforced insulation must withstand values equal to double the overvoltage values

10 TRANSIENT (OR PULSE) OVERVOLTAGES

These phenomena are very variable. They are mainly due to lighting and switching on the system. Their rise time ranges from a few microseconds to a few milliseconds, so their frequency range is very wide, from a few kHz to several hundred kHz. Protection against overvoltages requires the use of protection devices such as voltage surge protectors (see Book 7) and the installation of equipment that is appropriate for its location in the installation.

Typical switching overvoltage wave
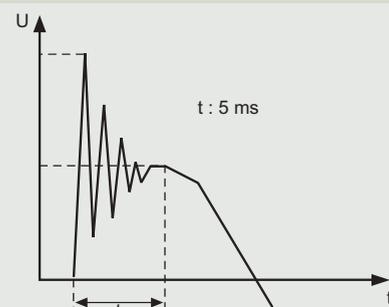
Recording of overvoltage due to lightning strike

Model 7100   Pulse   Single phase
600.0 V   50.0 A
261.6+   1V
225.7-
0.0 V   0.0 A
-600.0 V   -50.0 A
0 sec   1000.00 us/div   20.00 ms
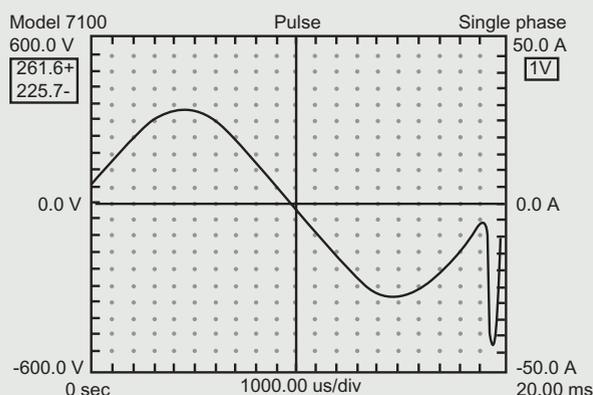
Lightning striking the system triggers overvoltages which are carried right to the users despite protection devices installed by the distributor. Unlike overhead systems, underground systems largely attenuate the shock wave.

Insulation coordination IEC 60664–1

The rated impulse voltage value (U_{imp}) that the equipment withstands must be the same as or greater than the test value corresponding to the overvoltage category (I to IV), which is chosen according to the location in the installation (see Book 7 p.15).

Phase-neutral voltage deduced from the AC or DC nominal voltages up to and including	Nominal voltages currently used in the world in volts (V)				Rated impulse voltage for equipment (V) Overvoltage category			
	4-wire three phase systems with earthed neutral	3-wire three phase systems, not earthed	Single phase systems 2-wire AC or DC	Single phase systems 3-wire AC or DC	I	II	III	IV
150	220/208	115, 120	100	100-200	800	1500	2500	4000
	127/220	127	-	-	-	-	-	-
	-	-	110, 120	110-220	-	-	-	-
	-	-	-	120-240	-	-	-	-
300	-	200, 220,	220	220-440	-	-	-	-
	220/380, 230/400	230, 240, 260,	-	-	1500	2500	4000	6000
	240/415, 260/440	277, 347	-	-	-	-	-	-
	277/480	380, 400, 415	-	-	-	-	-	-
	-	440, 480	-	-	-	-	-	-
600	347/600, 380/660	-	-	-	-	-	-	-
	400/690, 417/720	500, 577, 600	480	480-960	2500	4000	6000	8000
	480/830	-	-	-	-	-	-	-

For 230/400V systems the transient overvoltages at the point of supply are not generally considered to exceed 6 kV peak (EN 50-160)

Energy quality and disturbance of the power supply (continued)

11 VOLTAGE UNBALANCE

Voltage unbalance is caused by high power single phase loads.

It causes negative current components which can trigger braking torques and temperature rises in rotating machines.

It is advisable to divide the loads over the three phases as much as possible and to protect installations using appropriate detectors.

Under normal operating conditions, for each one-week period, 95% of the rms values of the negative sequence component of the supply voltage, averaged over ten minutes, must be between 0% and 2% of the positive sequence component.

Example of recording of voltage unbalance
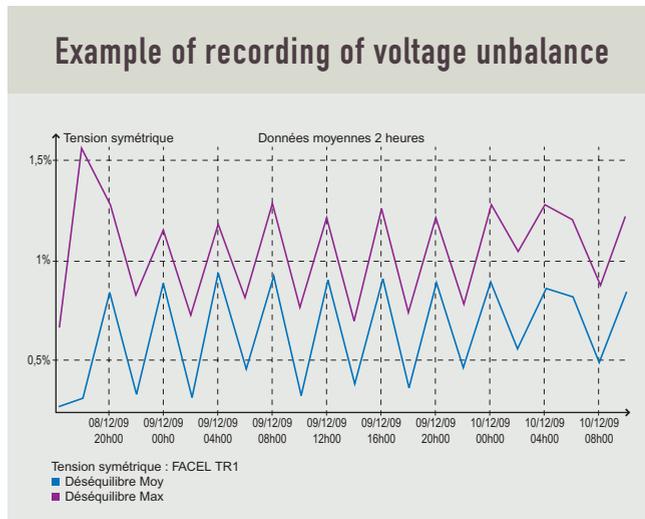
In some regions where parts of system users' installations have single phase connections or are connected between two phases, the unbalance can reach 3% at the three phase point of supply.

If τ_i is the instantaneous unbalance value, the average rate τ_{vm} is defined by the equation

$$\tau_{vm} = \sqrt{\frac{1}{T} \int_0^T \tau_i^2(t)\,dt}$$

where T = 10 minutes

Standard EN 50-160 only stipulates limits based on the negative sequence components of the voltage.

Satisfactory approximations can be made using conventional measurements enabling the unbalance ratio between negative and positive components to be ascertained.

voltage unbalance $= \sqrt{\dfrac{6 \times (U_{12}^2 + U_{23}^2 + U_{31}^2)}{(U_{12} + U_{23} + U_{31})} - 2}$

where $U_{12} + U_{23} + U_{31}$ are the three phase-phase voltages

Using symmetrical components

• **The symmetrical system corresponds to all the components (impedances, emf, back emf and loads) assumed to be symmetrical, i.e. identical on each phase. This must not be confused with balancing, which concerns the equality of the currents and voltages.**

• **An unbalanced symmetrical three phase system can be expressed as three balanced three phase systems (Fortescue method). This division can be carried out using three methods: positive, negative, zero sequence (homopolar).**
If there is a fault, overvoltage or short circuit affecting only one of the phases (which is the most common situation), the system becomes non-symmetrical and can then only be described by a real system, with separate V and I for each phase, representing the part concerned.
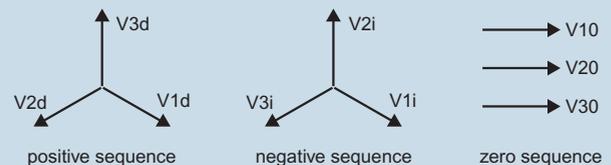
12 HARMONIC VOLTAGES

When the characteristics of a distribution system are described, the harmonic distortion of the distributed voltage(s) is an important factor with regard to opera-

ting problems (sensitivity of electronic equipment) and reliability problems (ageing by heating of windings and conductors, breakdown of insulation of capacitors) that this type of disturbance can cause.

But it is important to know that the source of harmonic voltages is in the first place harmonic currents. These currents can disturb equipment locally but above all they perniciously increase the level of distortion of the distributed voltage across the whole installation and for other users via the public distribution system.

Harmonic currents are generated by devices whose supply consumes non-sinusoidal currents. Electronic, computer and office equipment, some lighting fittings, industrial welding equipment, inverters, power converters and numerous machines are the main causes (see Book 2).

Like harmonic currents, harmonic voltages can be broken down into sinusoidal voltages than can be described:

– Individually, according to their relative amplitude (U_h) in relation to the fundamental voltage Un, where h represents the harmonic order

– As a whole, i.e. according to the value of the total harmonic distortion THD, calculated using the following formula:

$$THD = \sqrt{\sum_{h=2}^{40}(U_h)^2}$$

Example of recording of harmonic voltages

THD tension : FACEL TR1
V1 Moy | V2 Moy | V3 Moy
V1 Max | V2 Max | V3 Max

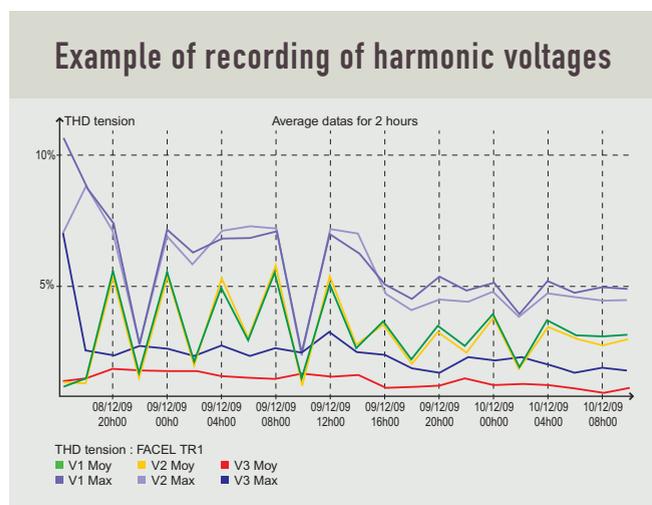Under normal operating conditions 95% of the rms values of each harmonic voltage averaged over ten minutes and measured over a week must not exceed the values given in the table below.

Maximum harmonic distortion at the point of supply, expressed as a percentage of the fundamental voltage U_1 According to IEC 61000-2-2					
Odd-order harmonics				**Even-order harmonics**	
Not multiples of 3		**Multiples of 3**			
Order h	Relative voltage (U_n)	Order h	Relative voltage (U_n)	Order h	Relative voltage (U_n)
5	6%	3	5%	2	2%
7	5%	9	1.5%	4	1%
11	3.5%	15	0.5%	6...24	0.5%
13	3%	21	0.5%	-	-
17	2%	-	-	-	-
19	1.5%	-	-	-	-
23	1.5%	-	-	-	-
25	1.5%	-	-	-	-

In addition, total harmonic distortion of the voltage supplied (including all harmonics up to order 40) must not exceed 8% of the fundamental voltage (order 1).

To limit the harmonics, it may initially be necessary to revise the structure of the installation:
- Increase the cross-section of the neutral conductor
- Regroup the polluting loads (if necessary with source separation)
- Use of transformers with special windings (coupling of the 3rd order harmonic and its multiples on the neutral)
- Connection of sensitive equipment away from the polluting loads
- Connection of polluting loads to the source with the lowest impedance and as far upstream as possible
It is also necessary to check that the capacitor banks for compensating the power factor cannot start resonating (possible use of anti-harmonic inductances connected in series). See p.114.
- The TN-C neutral earthing system must be avoided.

Energy quality and disturbance of the power supply (continued)

13 INTERHARMONIC VOLTAGES

This phenomenon refers to the frequencies located between the harmonics. These are caused by frequency inverters, uninterruptible power supplies, controlled rotating machines or arc devices.
Their interaction can cause flicker phenomena, but it is above all with regard to information signals transmitted on the system that they must be identified and controlled.

14 INFORMATION SIGNALS TRANSMITTED ON THE SYSTEM

In some countries, the public distribution system may be used by the distributor to transmit signals. The voltage value of the signals transmitted on the HV distribution system (1 to 35 kV), averaged over 3 s, must not exceed the values shown by the curve below over a period equal to 99% of one day.
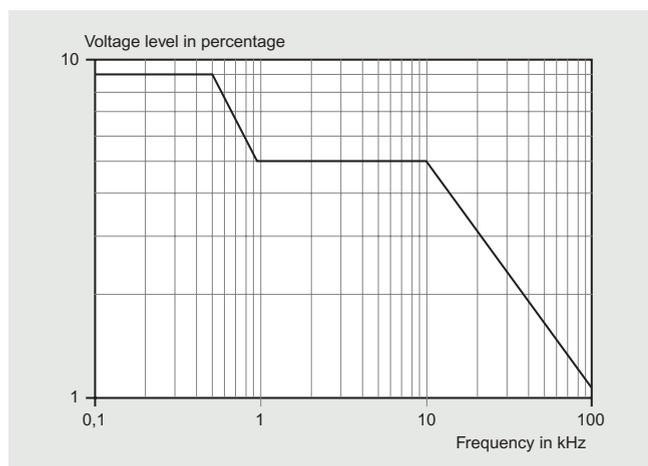
The system is used by the distributor to transmit information signals which are superimposed over the voltage supplied in order to transmit information to users' installations. However, the system must not be used to transmit information signals from private installations.
The frequencies of these signals vary from tens of hertz to several kilohertz, according to their function:
– **Centralised remote control signals**: superimposed sinusoidal voltage in the 110 Hz to 3000 Hz range
– **Power Line Carrier signals:** superimposed sinusoidal voltage in the 3 kHz to 148.5 kHz range
– **Wave marking signals:** short-time pulses (transients) superimposed at selected moments in the voltage wave.

> **+** All aspects of electromagnetic compatibility (EMC) are covered in this guide, including protection against lightning phenomena (see Book 7), the principles of building installations from the point of view of equipotentiality, shielding and coupling between conductors (see Book 8), taking harmonics into account (see Book 2) and the effect of the choice of the neutral earthing system vis-a-vis EMC (see p. 73).

15 NETWORK ANALYSIS

The devices in the Alptec ranges can be used to obtain full readings for the electrical characteristics of networks, store them and transmit them remotely for use. The choice of reactive power compensation or conditioning solutions will then be totally appropriate.

> **+** The entire range of Legrand analysers and associated services meets the requirements of institutional or private producers and distributors.
> The analysis of consumer sites (large-scale industrial or commercial sites) is also a major source of knowledge in energy management, with obvious potential savings as a consequence.
> This type of service can be designed on request, for conventional or renewable energy, for any local application, with the accompanying specific requirements.
> For reference, in a number of countries, including France with EDF, partnerships of several thousand measuring stations are currently working on all the distribution systems equipment using Alptec analysers.

Alptec network quality analysers

Example of a network of analysers installed as well in the electrical substations as in the consumer locations

Modem or Ethernet connection for remote statical analysis of the power quality

ALPTEC duo:
analysis of the power quality of the electricity provided by the production plant

ALPTEC 2444d

ALPTEC 2444i

USB connection for spot analysis

Local bus synchro.

GPS synchro.

Connection

Analysis of the power quality of the electricity provided by the transportation network

ALPTEC 2400R

GSM connection for remote analysis of the power quality and power supply failures

Several networks can be supervised by only one Server PC

Energy quality and disturbance of the power supply (continued)

Example of implementation for the analysis of a local and public energy distribution system

＊ Points of measurement and control
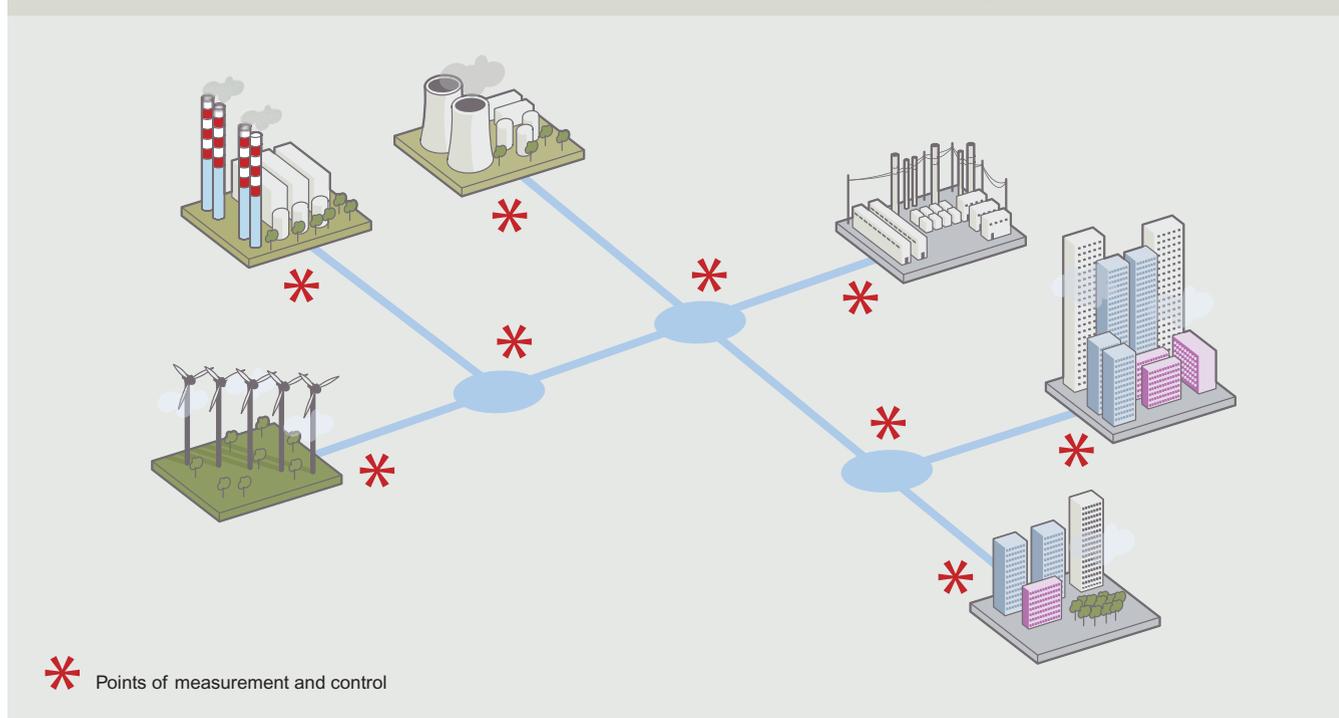
The new **Alptec 2333b portable compact analyser in a small, robust case can collect and store all the energy quality data for a given location. It is supplied with measuring probes and flexible current transformers that can be easily adapted to all conductors up to 3000 A. It can be powered by the circuit being measured or via a 2P+E mains cable.**
Its memory capacity is up to four months' recordings. The integrated GSM modem enables it to be interrogated remotely and the data to be processed using the Winalp software.
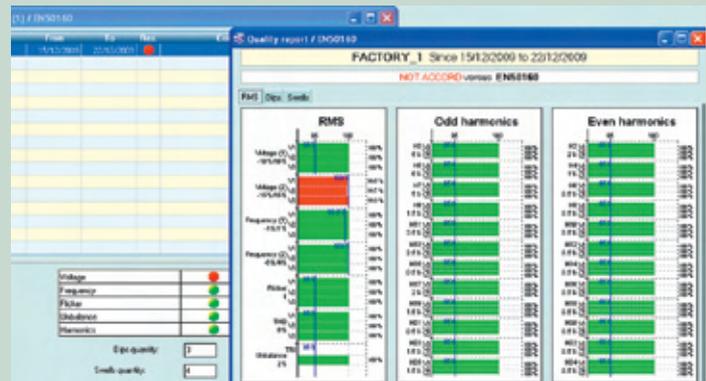
OTHER DISTURBANCES

Although standard EN 50-160 constitutes a contractual basis for establishing the minimum features of the energy distributed, the fact remains that numerous other disturbance phenomena circulate on the systems and that depending on the uses, it may be necessary to characterise them so that they can be minimised or protection provided against them.
It is sometimes difficult to deal with disturbance in that its origin and the routes it takes are complex.
In addition to the known phenomena of lightning and switching, numerous new sources, in particular power converters, can cause disturbance in installations. This disturbance, which is generated by the installation itself or carried by the system from external sources or by the conductive parts, earthing circuits and shared elements, depends on the characteristics of the installation (impedances, short-circuit power, resonance, etc.). The complexity of all these EMC phenomena makes them difficult to predict and even more difficult to simulate.

The various aspects of electromagnetic compatibility (EMC) are covered in this guide, including protection against lightning phenomena (see Book 7), the principles of building installations for aspects of equipotentiality, shielding and coupling between conductors (see Book 8), taking harmonics into account (see Book 2) and the effect of the choice of the neutral earthing system on EMC (see p. 71).
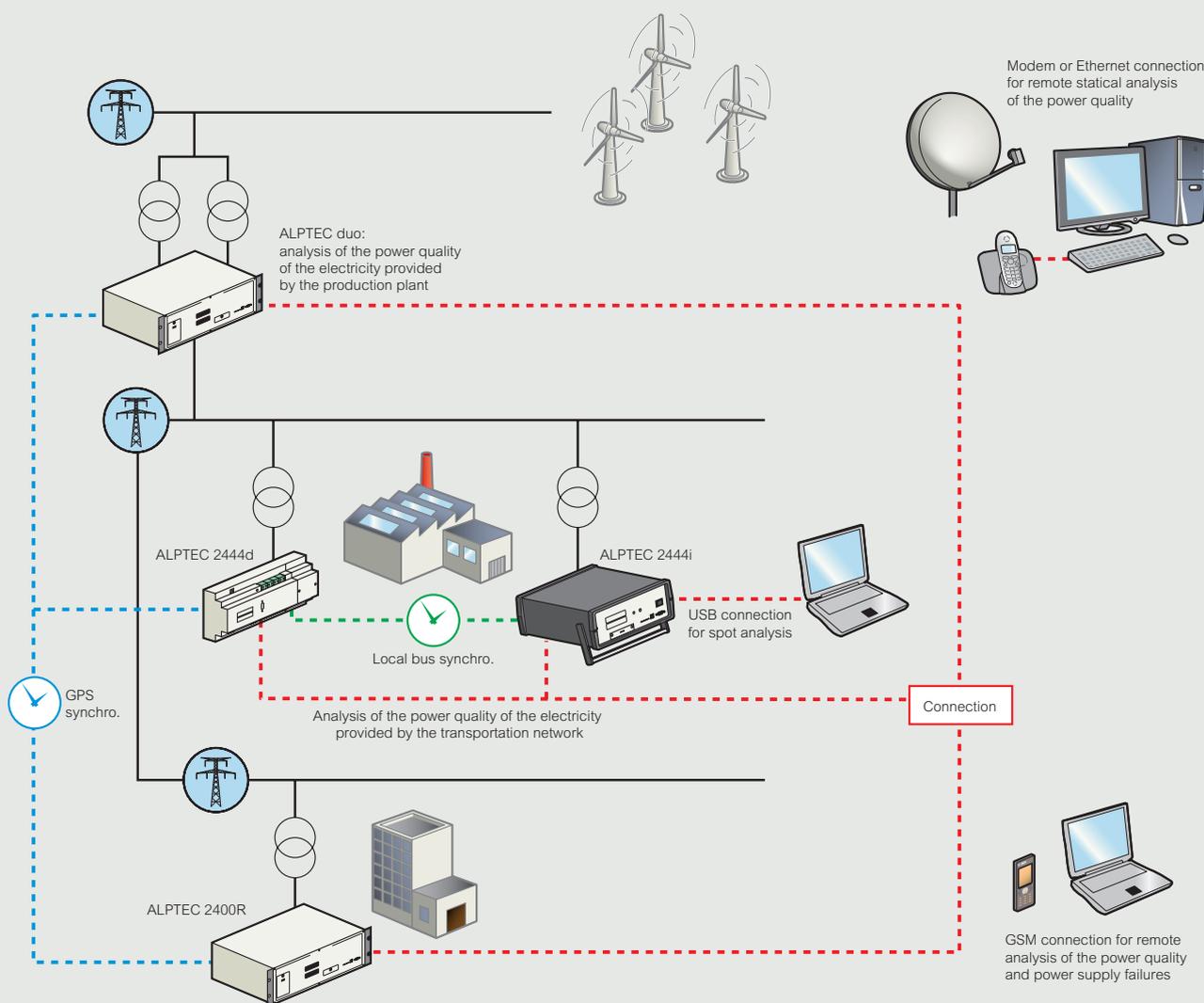Only the main phenomena conducted via the supply systems will be covered here, whether they are the

source of the phenomena or are affected by them: the effects of overvoltage and rapid voltage transients (capacitor switching, overvoltages caused by converters, restrikes, failure of fuses, etc.) that are mainly encountered in industrial or comme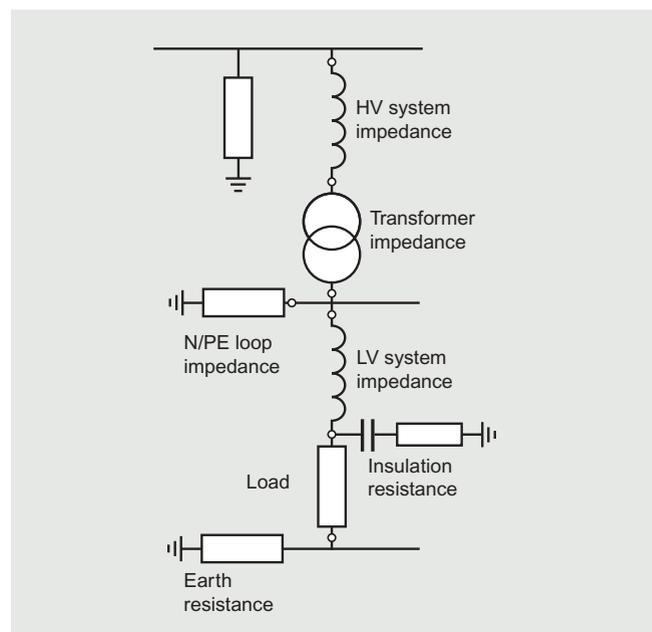rcial environments, as well as phenomena generated by receivers (DC components, leakage currents, discharge on the system, etc.), which can all affect the quality of the energy used, whether it comes from a public distribution system or any other origin.

The available values generally characterise balanced three phase systems (R, X, Ik3).
The faults therefore often affect single phase branches. The faults themselves are residual current or "bipolar" faults (phase/earth insulation fault, breaking overvoltage, short-circuit, etc.) and occur according to load (damping) conditions that are very different (no-load, capacitive effects, very high short-circuit current, inductive effects) and unbalanced. It is therefore very difficult to predict these random situations or to simulate them in terms of EMC.
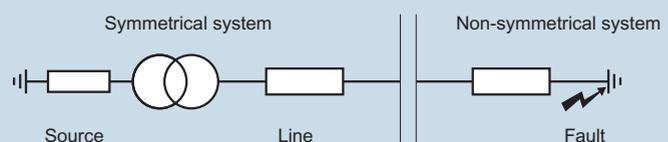
Energy quality and disturbance of the power supply (continued)

1 OPERATIONAL SWITCHING: OVERVOLTAGES AND OVERCURRENTS

Although these types of disturbance are mentioned in standard EN 50160, in which overvoltages are treated in terms of impulse withstand voltage (Uimp) to be applied when designing switchgear in order to protect against their possible destructive effects, they are also sources of potential malfunctions. Their very broad frequency spectrum, their random occurrence and their many forms make them difficult to eliminate. In fact, practically all operations on industrial systems, in particular high power operations, produce overvoltages. They arise from the sudden making or breaking of the current. Lines and transformers then behave like self-induction devices. The energy produced in the form of transients depends on the characteristics of the circuit being switched. The rise time is in the region of a few microseconds and its value can reach several kV.

The above oscillogram shows the voltage bounces and peak voltages that may occur for example when a fluorescent lighting circuit is energised.
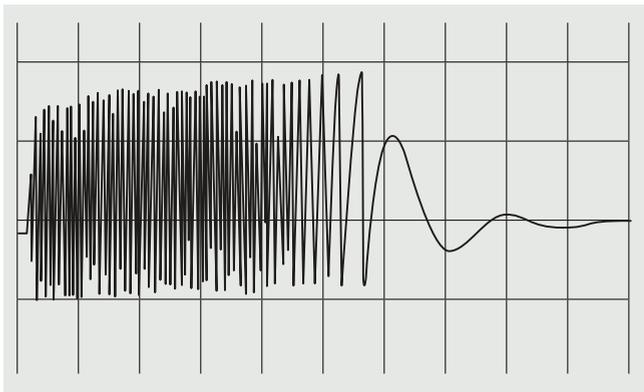
This type of disturbance is often accompanied by an overcurrent on the line concerned and emission of magnetic and electric fields.

Waveform

Main voltage

160 A current peak for 6 x 58 W tubes
frequency of the damped sine wave: 3 kHz

60 mA/m

100μs

A magnetic field is generated when the current is established.
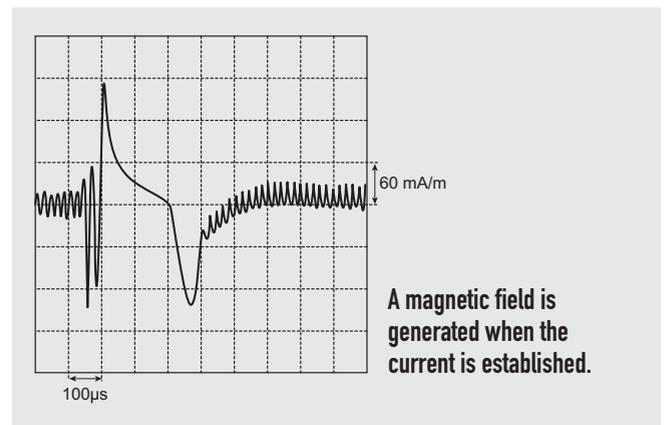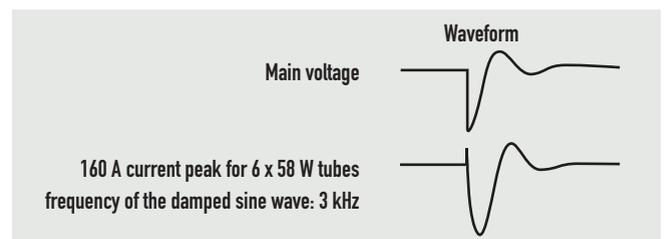
Due to the size of the LF transient current (10 kHz < f < 1 MHz) on closing, the radiated impulsive magnetic field can reach high values that may disturb sensitive products. If the overcurrent involved is high (several kA), the damped oscillatory magnetic field caused by the disturbance can be simulated in order to check the immunity of sensitive products.

Standard IEC 61000-4-10 (damped oscillatory magnetic field immunity test) describes a simulation test (100 A/m at a distance of 60 cm from the source causing the disturbance) for 1 MHz to 100 kHz damping. Knowledge of actual phenomena has led Legrand to develop tests at much higher field values over much wider frequency spectra.

Although closing operations are accompanied by high overcurrents and generally limited overvoltages, opening operations trigger overvoltages than can be very high. They can be accompanied by high frequency electric fields that could cause disturbances. The phenomenon of resonance plays a major role here (see p.40). Breaking the current in an electric contact generates damped oscillations at the resonance frequencies of the source and the load. The resonance frequency of the source is very often higher than that of the load. Transients caused by the load and the source are superimposed, leading to high voltage levels at the terminals of the electric contact. If they exceed the voltage withstand of the contact, an electric arc is created. A voltage collapse is then observed at the terminals, while the current continues to circulate (this is referred to as non-limiting self-extinguishing current). The arc ends when the electrical and thermal stresses on the contact are not sufficient to maintain it. The voltage transients during the switching phase oscillate at frequencies between 10 kHz and 10 MHz. The peak voltages of these transients range from a few hundred volts to several kilovolts.

The voltage/frequency parameters change inversely during the switching phase on opening: at the start the peak voltages are of small amplitude but have a high frequency, while at the end the amplitude is large but the frequency is lower. The duration of these burst voltage transients ranges from 20 µs to ten or so milliseconds. It depends on the load, the mechanical behaviour of the contact (switching speed) and the environment (temperature and pollution).

> **Standard IEC 61000-4-4 (electrical fast transient/burst immunity test) can be used to test equipment and appliances when coupled to their power supply access.**

To limit overvoltages and overcurrents during operations, it is essential to choose breaking devices that act very quickly and independently of the manipulation speed. They must be suitable for the loads. Standard IEC 60947-3 (switches, disconnectors, switch-disconnectors and fuse-combination units) specifies the various utilisation categories for typical applications.

Utilisation categories for switches, disconnectors and fuse-combination units according to IEC 60947-3			
Type of current	**Utilisation category**		**Typical applications**
	Category A	**Category B**	
AC	AC-20Aa	AC-20Ba	Connecting and disconnecting under no-load conditions
	AC-21A	AC-21B	Resistive loads, including moderate overloads
	AC-22A	AC-22B	Mixed resistive and inductive loads, including moderate overloads
	AC-23A	AC-23B	Motor loads or other highly inductive loads
DC	DC-20Aa	DC-20Ba	Connecting and disconnecting under no-load conditions
	DC-21A	DC-21B	Resistive loads, including moderate overloads
	DC-22A	DC-22B	Mixed resistive and inductive loads, including moderate overloads (for example: shunt motors)
	DC-23A	DC-23B	Highly inductive loads (for example: series motors)
Category A applies to equipment for frequent use, while category B applies to equipment for occasional use			

Energy quality and disturbance of the power supply (continued)

Isolating switches in the Vistop range (up to 160 A) and the DPX-I range (up to 1600 A) are particularly suitable for switching circuits that have a high inductive component. They are categories AC22A, AC23A and DC22A, DC23A (for the exact currents and voltages for each device, see the technical data).
Their energy accumulation system enables sharp making and breaking that prevents the establishment of an arc and limits "non-limiting self-extinguishing current".

Installing voltage surge protectors

Installing voltage surge protectors, designed to provide protection against overvoltages from the lightning effects, makes it possible to protect against the destructive effects of switching overvoltages which are more frequent but generally at a lower level than those due to lightning.
However the sparkover operating principle of these devices creates impulse currents in the bonding and earthing systems which are references for sensitive systems. Their installation is therefore recommended for optimum protection, but it does not in any way dispense with the need for all the other measures designed to minimise these overvoltages.

Class II voltage surge protector

L1
L2
L3
N

Main protection

Circuit protection

Proximity protection
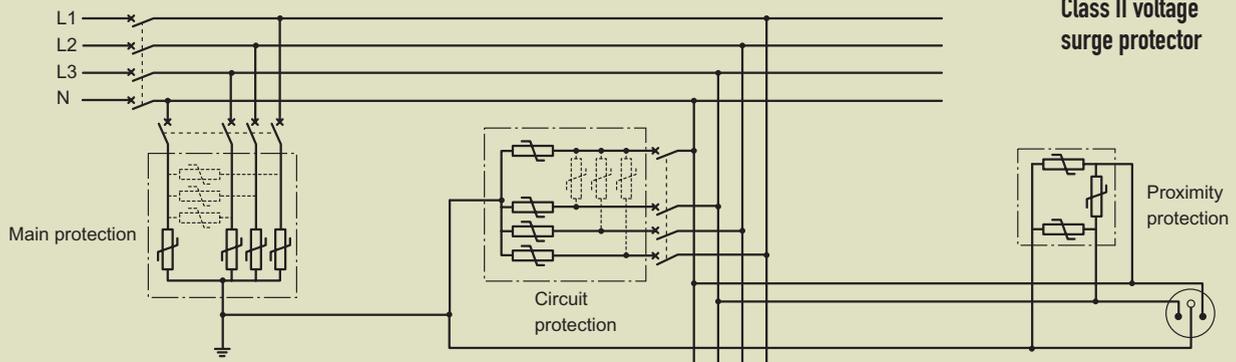
Typical switching overvoltage curves

Transient states, which may be the source of overvoltages and overcurrents, can occur when loads are switched on or off. The most common transients concern transformers, motors, capacitors and batteries.
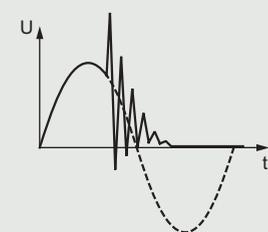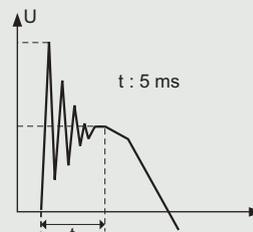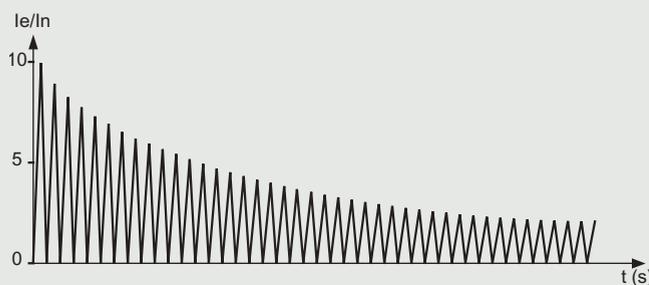
Overvoltage when breaking a transformer

Activating a transformer causes an inrush current of 10 to 20 In with a damped aperiodic component. This triggers an overvoltage in the secondary by capacitive coupling, and oscillatory effects due to the capacitances and inductances between the turns.
The breaking (or opening) of a transformer creates a transient overvoltage due to the breaking of the current in an inductive circuit. This overvoltage can create arc restrikes in the breaking devices, which must be chosen accordingly.

< Inrush current limiter

The inrush current limiter Cat. No. 442 96 reduces the current peak on activation of transformers and power supplies to a value of less than 5 In. This peak may be due to the aperiodic component (see box above) or to the load of a filter capacitor at the power supply. Used with an auxiliary relay Cat. No. 040 68, it can be used for limitation up to a power of 9000 VA (40 A).

Numerous products are likely to be disturbed by conducted overvoltage and overcurrent phenomena, and all the more so if they are associated with radiated magnetic field and electric field phenomena: products that incorporate analogue or digital electronics, radio controls, Power Line Carrier controls or even safety functions such as residual current devices. Although all these products are intrinsically designed and tested to operate and withstand numerous types of disturbance, they are not invulnerable.
How the installation is created is an essential element in combating these phenomena and limiting their destructive effects: equipotentiality, earthing, neutral earthing system, decoupling of circuits, voltage surge protectors, filtering, shielding, etc., are just some methods which must be considered and implemented at the design stage of installations. Book 8 explains the main guidelines for this.

Energy quality and disturbance
of the power supply (continued)

Electrical resonance

The phenomenon of electrical resonance is frequently found in installations. It can lead to destructive overvoltages and overcurrents.
Three types of receivers make up AC electrical circuits : resistors (in ohms), capacitors (in farads) and inductors (in henrys). The impedance Z of these receivers (which is also expressed in ohms) is a function of the frequency f (Hz), of the power supply signal and more precisely of its angular frequency $\omega = 2\pi \cdot f$ (expressed in radians per second) and is expressed respectively in the forms $Z_R = R$, $Z_C = 1/C\omega$ and $Z_L = L\omega$.
It is important to distinguish series resonance phenomena from parallel resonance phenomena.

• Resonance of a series RLC circuit
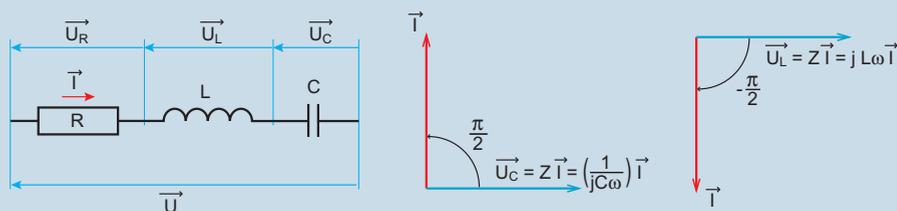
In a capacitance C, the current is in $\pi/2$ phase lead in relation to the voltage (lead quadrature)
In an inductance L, the current is in $\pi/2$ phase lag in relation to the voltage (lag quadrature).

The circuit is capacitive or inductive, depending on the respective values of C and L.
The electrical resonance phenomenon (also called anti-resonance in that the voltages are in anti-phase) occurs if the voltage at the terminals of the capacitance and those at the terminals of the inductance compensate one another exactly.
$L\omega = 1/C\omega$ which can also be written $LC\omega^2 = 1$.
ω is the resonance angular frequency, which is generally written ω_0 and the resonance frequency f_0 is equal to $\omega_0/2\pi$.

When there is resonance, the impedance of the circuit is practically the same as its resistance R. If the resistance is low (low resistance circuits such as distribution lines), the situation becomes critical. The voltage applied at the terminals of the circuit then creates a very high current. This current then imposes voltages U_C and U_L at the C and L terminals, which may exceed their withstand and cause dielectric breakdown. The properties of series RLC circuits are used to create filters.

• Resonance of a parallel RLC circuit

The same phenomena occur on parallel RLC circuits. But in this case it is not the current which is common to all three elements but the voltage $\vec{U}$.

The effects of the resonance differ according to whether it is series or parallel, and depending on whether the source behaves like a voltage source or a current source. An ideal voltage source maintains a constant voltage at its terminals irrespective of the current drawn. For small or medium sized consumers, the distribution supply network behaves like a voltage source. A high capacitance behaves like a voltage source for a reduced load (high resistance). On the other hand, a current source draws a constant current irrespective of the voltage at its terminals. For example, an inductance (known as a smoothing inductor) behaves like a current source.

In practice, industrial systems are complex and comprise both parallel and series elements (these are the receivers and also the conductors, the transformer windings, the stray capacitances, the leakage resistances, etc.) which represent both inductances and capacitances. It is thus always possible that resonance may occur, and adding compensation capacitors may modify or trigger the conditions for their occurrence (see p. 114).
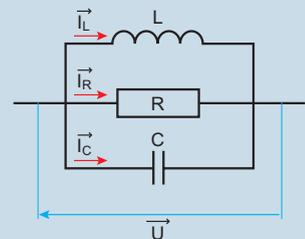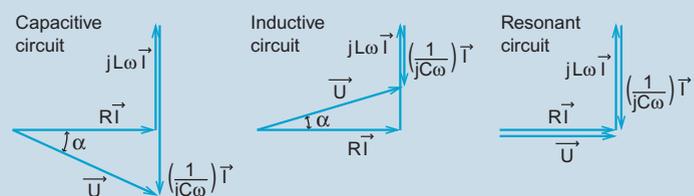
2 DISTURBANCES CAUSED BY STATIC CONVERTERS

Power electronics has gradually become established as the preferred method of controlling electrical energy. Originally used almost exclusively for varying speed or torque control applications, it has now spread to the field of the low power switching mode power supplies that are found everywhere, and in the future it will play a decisive role in the control and stability of smart electrical systems whose energy production with be both mixed and decentralised. (Smart grid).

Static converters

Static conversion consists of adapting an energy exchange process from a generator to a receiver (optionally reversible) by controlling solid state switches: MOSFET transistor (field-effect transistor), GTO thyristor (gate turn-off thyristor), IGBT (Insulated Gate Bipolar Transistor), etc., according to a defined sequence.

Various ways of carrying out conversion

DC source (=)	PULSE CONTROL (adjustable voltage)	DC receiver (=)

INVERTER   RECTIFIER

AC POWER CONTROLLER (rms voltage adjustable without changing frequency)

AC source (∿)	CYCLOCONVERTER (adjustable rms voltage and frequency)	AC receiver (∿)
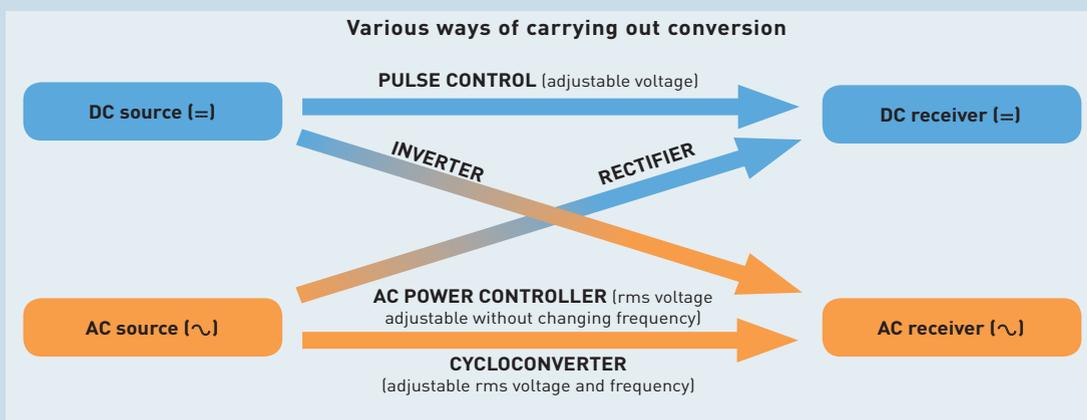
Converters are referred to as "direct" when they have only one conversion stage. But they are generally combined to create indirect converters. An AC/AC converter for variable control of an asynchronous motor is in fact made up of an initial AC/DC rectifier stage and a second DC/AC inverter stage. Likewise an AC/DC electronic power supply forming a battery charger is for example made up of an AC/DC rectifier stage, then a high frequency AC/AC pulse control stage, which changes the voltage at minimum cost and in minimum space, and then a final AC/DC rectifier stage that provides DC current (or similar). Other converters, such as dimmers or heating regulators controlled by varying the conduction angle, are reduced to a single AC/AC stage.

Inverters or static uninterruptible power supplies (UPS) consist of at least two AC/DC and DC/AC stages for the charging and output of a backup battery.

Converters are being used in an increasingly wide range of applications, and now cover all power ranges. New methods and equipment for measuring power must be used, and the increase in their use is accompanied by new mains supply disturbance (harmonics, overvoltages) that must be controlled.

Single phase or three phase system

Fixed DC voltage

Calibrated and filtered AC voltage

Rectification + battery charging device

Battery

Inverter + filter
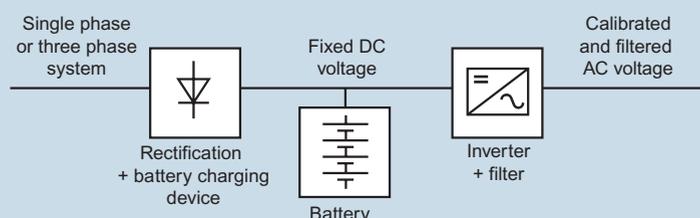
Energy quality and disturbance of the power supply (continued)

Unlike operational switching, described in the previous section, which is characterised by its more or less random and non-repetitive occurrence and by characteristics mainly due to loads and installations, that caused by static converters is recurrent. The operation of a static converter is intrinsically polluting, as the electrical values are extremely variable, over very short periods (10 ns to 1 µs), with high amplitudes (about one kilovolt and one kiloampere) and over a very wide frequency range (100 Hz to 1 MHz). In fact, each conversion stage contributes to disturbance over a frequency range that is dependent on its switching frequency: input rectifier up to a few dozen kHz, HF switching stage up to a few megahertz and phenomena associated with the switching transitions (resonance, normal mode excitation) up to several dozen megahertz. EMC treatment of converters will consist of limiting their spectral range or trying to confine all the undesirable parasitic effects in the converter.

A three-phase sinusoidal voltage is generally rectified using a thyristor bridge. The load current is drawn at the three phases by alternate operation of the thyristors. These are "trigged" in succession by the thyristor that was in control in the preceding time phase sending a pulse to their gate. The result is periods, which are of course very short (a few hundred µs), in which short-circuits occur between phases. The value of these short-circuits is only limited by the impedance of the upstream system. The effect of the inrush current is voltage drops and voltage increases that are referred to as "commutation notches". Rather than their amplitude, it is above all the differentials of these values (dV/dt), which may reach several hundred V/s, that cause electromagnetic disturbances. The resulting high frequencies may encounter resonance in the system, in particular in the presence of capacitances (cables, capacitors), and result in this case in real overvoltages on the system.

Thyristor bridge rectifier at the input of a conventional AC/DC converter
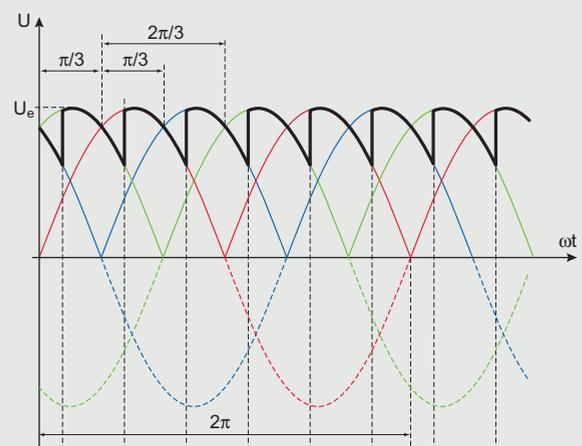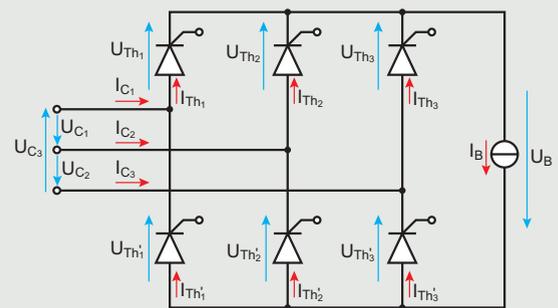
The shape of the current with a great deal of harmonics (signals with steep wavefronts) entering the pulse control stage of the converter can be seen
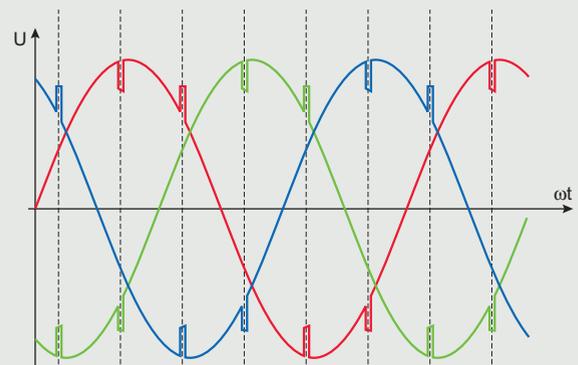
Illustration of undervoltages and overvoltages or "commutation notches"

3 SWITCHING OVERVOLTAGES OF CAPACITORS

The activation of capacitors placed on the HVA system may cause transient overvoltages (several times the value of Un) with sufficient energy to destroy the voltage surge protectors at the supply end of the low voltage installation or even the components of the static converters or reactive energy compensation capacitors.

This phenomenon may be particularly dangerous if, when the HVA capacitors are activated, the resonance frequency of the upstream circuit corresponds to the resonance frequency of the LV circuit. The characteristics of this phenomenon are essentially linked to the inductance L of the HVA/LV transformer, the capacitance C of the capacitors and the resistance R of the low voltage network. If the resistance is low

(not many resistive receivers), the damping of the transient overvoltages will be reduced, increasing the risk of resonance on the HVA and LV circuits at the same frequency ($f_{0H} = f_{0B}$).

Amplification of the disturbance associated with HVA capacitor switching is particularly sensitive if the reactive power used in HVA is much higher than that used in low voltage. This risk can be limited by using capacitor banks that are activated gradually (steps) or by activation at zero voltage.

High energy absorption (at least 1 kilojoule) voltage surge protectors can be used to limit transient overvoltages from the HVA system, in the same way as tuned filters with low voltage capacitor banks can shift the resonance frequency of the installation. Overvoltages from the HVA system will not be eliminated, but at least they will not be amplified.

Resonance frequencies of the circuits:
- HVB: $f_{0H} = 1/2\pi\sqrt{L_H\,C_H}$
- LV: $f_{0B} = 1/2\pi\sqrt{L_H\,C_H}$
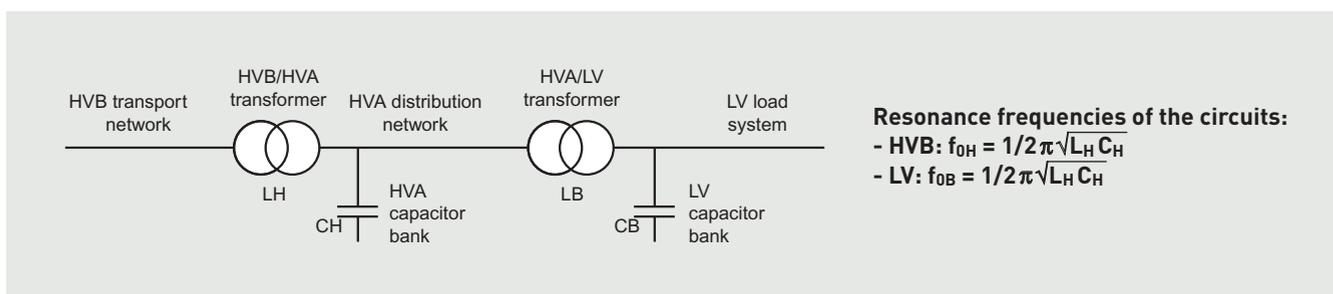
Legrand voltage surge protectors Cat. Nos 030 00 and 030 20/22/23, which are type 1 high capacity (H) and increased capacity (E), are suitable for protecting the supply end of power installations.
If switching overvoltages are found to occur frequently, it is important to count them and use the remote voltage surge protector status indication contact.

< Class I voltage surge protectors specifically for protection at the origin of installations requiring a high service level

Energy quality and disturbance of the power supply (continued)

Legrand can provide a solution that is a useful addition to voltage surge protectors: passive filters used with capacitor banks. Their tuning frequency is calculated to eliminate the suspect resonance frequency and thus limit its effects. The filter is calculated and defined after diagnosis and measurement on site using a network analyser.

The fact that Legrand is able to supply capacitor banks for both HVA supplies and LV supplies makes their mutual adaptation much easier, and having one manufacturer dealing with both levels of compensation is a guarantee of safety.

Breaking devices using technologies suitable for capacitive currents (vacuum or SF6 filled chambers) can also be provided with the capacitor banks.
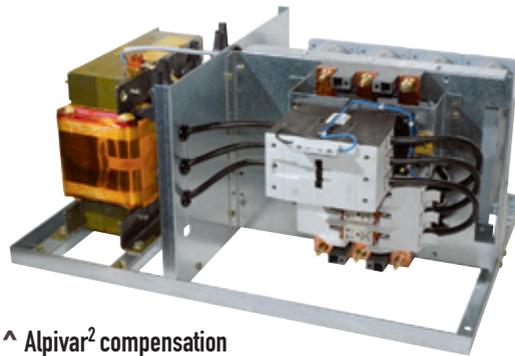
^ Alpivar[2] compensation
racks with detuned reactor

^ Alpivar[2] vacuum
technology capacitor

^ HV capacitor bank

4 DC COMPONENTS

The electronic supply stage of numerous machines and also many high consumption domestic appliances (washing machines, hobs, etc.) has a rectifying device. If there is an insulation fault downstream of this device, the earth leakage current may contain a DC component (more precisely a unidirectional pulsed component) which modifies the shape of the AC current consumed. This shape is thus asymmetrical, which may result in the residual current devices (RCD) failing to operate due to modification of the magnetic flux in the core. The two current half-waves are not identical, as the opposing field (coercive) no longer cancels the previous flux with the opposite sign every half cycle. The toroidal core may then remain magnetised (hysteresis phenomenon) and the residual current device is rendered inoperative.
AC type RCDs, used for the majority of circuits, cannot detect this type of fault. They should only be used for heating or lighting circuits that do not have an electronic power supply.
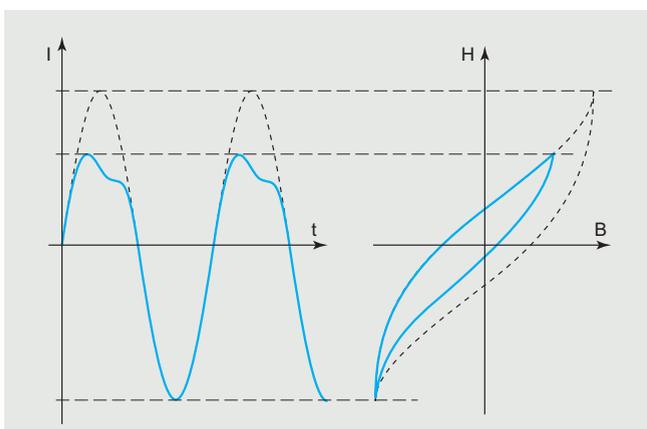
A type Legrand RCD >

New residual current devices have been developed to operate with electronically controlled loads.
Type "A" RCDs protect against sinusoidal AC fault currents and fault currents with a pulsed DC component. Type B RCDs also provide protection against smooth DC fault currents. These are mainly used in industry, on three-phase installations containing for example variable speed drives or an uninterruptible power supply (UPS).

5 PERMANENT LEAKAGE CURRENTS

Unlike fault currents, which flow accidentally between the live poles and the protection circuit or earthing, leakage currents exist while the installation is operating normally.

There are three different types of leakage current:
• Currents caused by receivers whose power supply is earthed (via bonding parts and the protection circuits) by means of capacitive electronic components (PCs, variable speed drives, etc.). On energisation, these currents are increased by an inrush current phenomenon associated with the load of the capacitors. Some typical potential leakage current values are given the the table below.

• Currents that are associated with stray capacitances from the installation's conductors which are proportional to the scale of the installation and the number of receivers supplied. There are no exact rules for calculating these currents other than that they can trip a 30mA residual current device when the installation reaches several hundred metres in length. It should also be noted that these currents may increase over time, depending on the ageing of the insulation. Monitoring the installation's insulation by means of continuous measurement (Permanent Insulation Monitor – PIM) or regular measurement (see Book 10: Measuring the insulation resistance) enables any changes to be anticipated.

• Leakage currents that frequently develop on certain types of installations due to their nature, without however reaching a dangerous level comparable to a fault current (resistance furnaces, cooking or steam installations, equipment with numerous auxiliaries or sensors, etc.). Using the TN-S neutral earthing system

Energy quality and disturbance of the power supply (continued)

limits the contact voltage to a value which is not dangerous, while permitting significant leakage currents to exist.(see p. 61). It should however be noted that although this situation provides better continuity of operation, it must be limited to the time spent finding and dealing with the leak, in order to avoid creating fire risks and to avoid increasing the EMC disturbance by the circulation of permanent currents in the protection circuits.

The design of an electrical installation must provide for the installation of protection devices for the safety of people and property which take account of these leakage currents. When these currents are added together in the protection circuits they can reach the trip threshold value of the residual current protection at the supply end of the group of circuits concerned, remembering that this value is generally much lower than the theoretical threshold: for example 15 to 20 mA actual for 30 mA nominal.

Typical leakage current values	
Electrical appliance	**Typical potential leakage current**
Computer workstation	1 to 3 mA
Underfloor heating	1 mA/kW
Fax machine/printer	< 1mA
Cooking appliances	1.5 mA/kW

Legrand Hpi RCD

A standard AC type RCD is considered to be capable of protecting 3 to 5 PCs, and more than this may cause unexpected tripping on energisation.
Using an HPI model enables current transients due to capacitive effects to be absorbed, while greatly limiting this risk of tripping and enabling a larger number of machines to be supplied[1].
In addition to their immunity to inrush current transients, HPI RCDs also have increased immunity to high frequency disturbance (lighting currents, switching overvoltages, disturbance on electronic power supplies). This characteristic is associated with the technology of the device itself and the use of a detector coil for which the saturation limits of the material are high.

(1) It is not possible to give precise details of the exact number of devices as the currents consumed are dependent on many factors (type of device, lengths and cross-sections of circuits, etc.).
It is advisable to check that the RCD does not trip when the installation is started up.

Circuit separation transformers

When the sum of the leakage currents of the devices supplied via the part of an installation protected by an RCD is likely to be greater than half the rated residual current (I△n) for this RCD, there is a high risk of tripping. This problem can be avoided by using a circuit separation transformer, under TN-S neutral earthing system conditions.

The conductive parts of the appliances are then connected to the neutral or middle point of the transformer secondary and this link is connected to an earth connection. Protection is provided by the overcurrent protection devices of the live conductors of the secondary circuit. (See "Supply via a specific transformer" p. 61)

6 CURRENT INVERSION

Any installation connected directly to a public energy distribution system and that may also be supplied via another source should normally incorporate a device to prevent backfeed of the distribution system (see Supply Inversion, Book 2)

Increasing numbers of installations are carrying out self-generation based on renewable energies (solar or wind-powered production, small power plants or other sources) and are connected to the supply network to feed energy back into it. This arrangement must of course form the subject of an agreement, as well as a number of precautions.
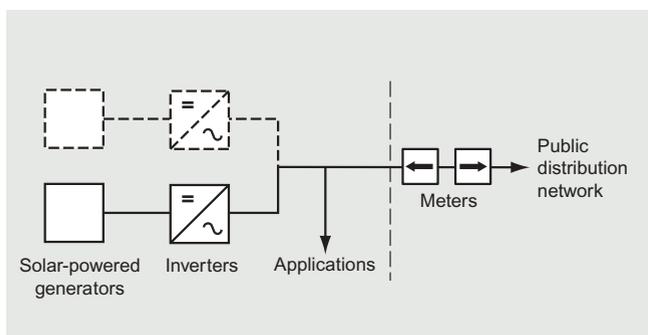
Decoupling protection must disconnect generators if the following occurs:
- Fault on the supply network

- Disappearance of the power supply via the supply network
- Voltage or frequency variations greater than those specified by the distribution company

This decoupling protection must be incorporated in an automatic breaking device that complies with a recognised European standard.

Danger associated with the presence of two energy sources

For safety reasons, it is essential to indicate to all those involved the specific danger associated with the presence of two energy sources. Warning signs must be placed close to protection and operating devices and inverters.

Caution: two power sources present:
- Distribution system
- Solar panels

Isolate both sources before carrying out any work

Neutral earthing systems

The earthing conditions of installations have been defined in regulations by means of neutral earthing systems, with the aim of protecting people against the consequences of insulation faults. Although all these systems provide a theoretical equivalent level of protection against electric shocks, they have different characteristics in terms of use, electromagnetic compatibility, adaptability, maintenance or cost, which it is important to know.

Standard IEC 60364 defines three neutral earthing systems, called TT, IT and TN. The 1st letter refers to the situation of the power supply (generally, the neutral of the transformer secondary) in relation to earth. The 2nd letter refers to the situation of the exposed metal conductive parts of the devices in the installation.

! **Several types of neutral earthing system can coexist in the same installation (islanding). The rules for the use of islanding are given on page 58.**

"Neutral earthing systems" represent the various possible organisations of the low voltage electrical installation in relation to the earth voltage.
Standard IEC 60364 uses the term "earthing arrangements" to define these systems.
In practice, even though it is not totally correct, the term "neutral earthing system" is more commonly used.

NEUTRAL EARTHING SYSTEMS
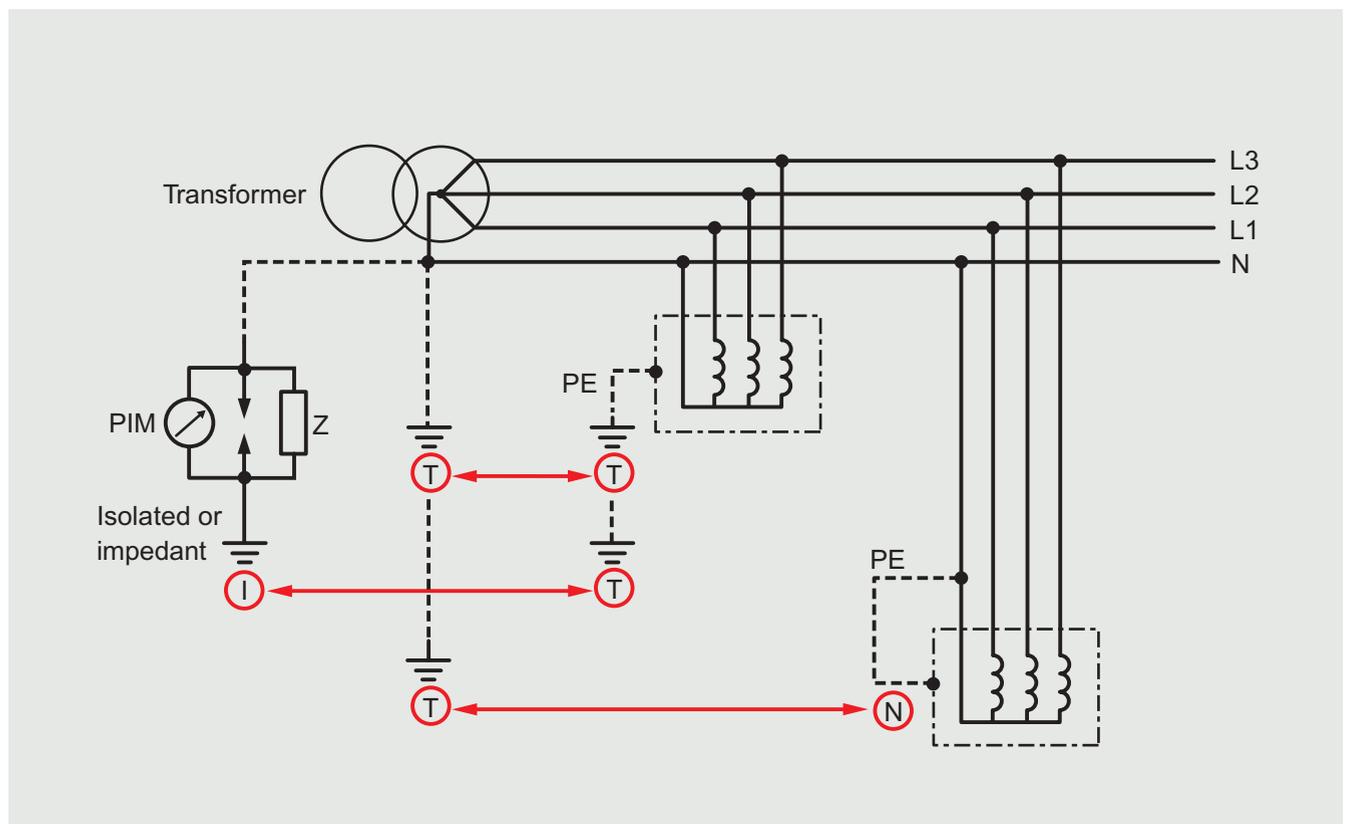
1 TT SYSTEM (NEUTRAL EARTHED)

T: neutral point earthed
T: exposed conductive parts earthed

In TT systems, the neutral point on the secondary of the installation's power supply transformer is connected directly to earth. The exposed conductive parts of this installation are connected to an electrically separate earth connection (in public distribution systems). The fault current is limited to a considerable extent by the impedance of the earth connections but may generate a dangerous contact voltage. This current is generally too low to activate the overcurrent protection devices, and should therefore preferably be eliminated by a residual current device.

The neutral conductor must never be connected to earth downstream of the residual current device. The exposed conductive parts must be connected to a single earth connection, and a single residual current device placed upstream is adequate. If the circuits are connected to different earth connections, each set of circuits must be protected by its own residual current device.
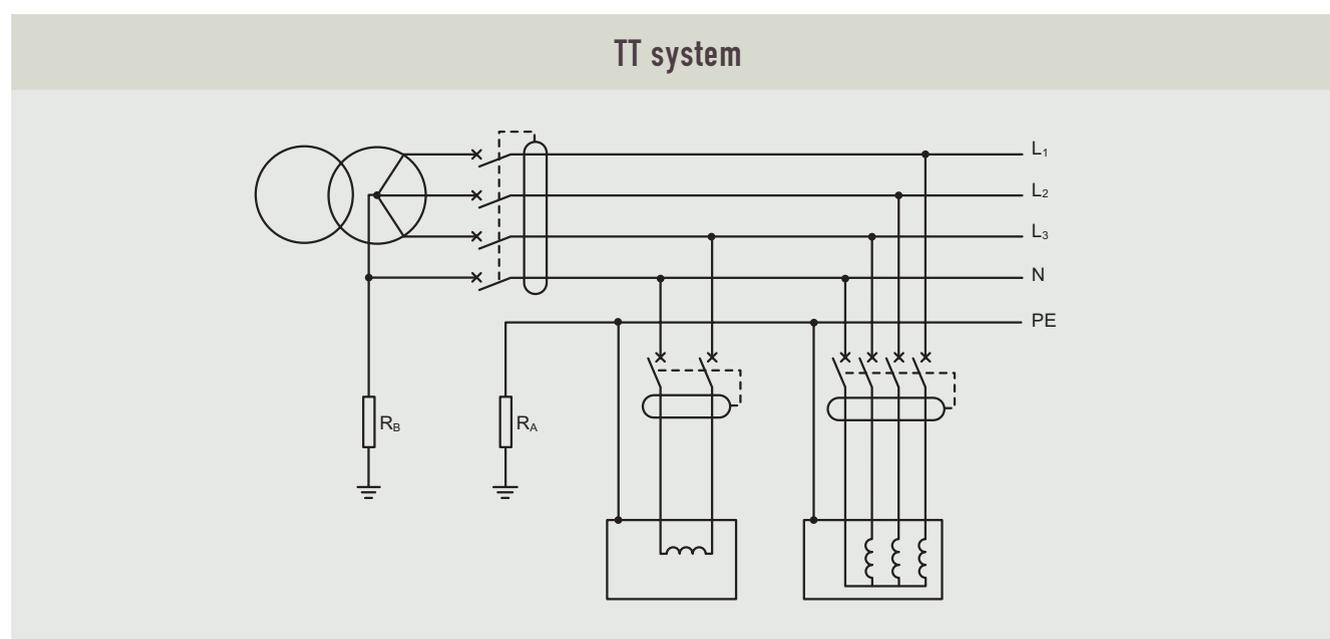
TT system

Neutral earthing systems
(continued)
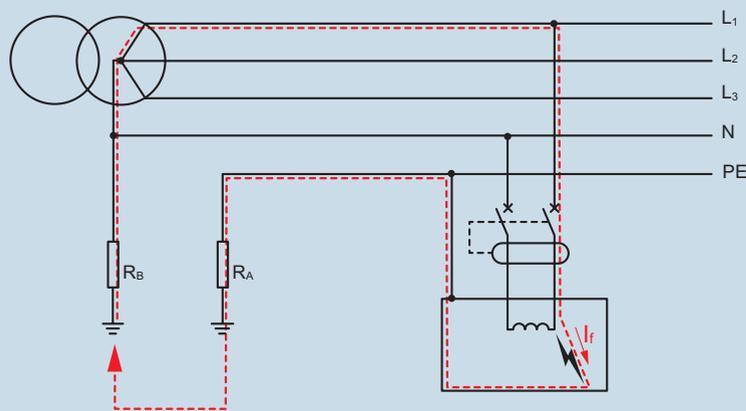
If there is an insulation fault on a receiver, the fault current I_f (I fault) circulates in the circuit referred to as the fault loop. This circuit comprises the fault impedance on the exposed conductive part of the receiver, the connection of this exposed conductive part to the protective conductor, the protective conductor itself and its earth connection (R_A).

The loop is closed by the transformer windings and the power supply circuit. Logically, the impedance of the loop should therefore be calculated based on all the elements in series that make up this loop.

In practice, and this is permitted in the standards, only the resistance of the earth connection of the exposed conductive parts R_A is taken into consideration. The fault current is overestimated a little, but the safety margin is increased.

The condition $R_A \times I_f \leqslant 50$ V must be met for AC installations.

The sensitivity threshold $I\triangle n$ of the residual current protection device is chosen so that $I\triangle n < \dfrac{50}{R_A}$

Sensitivity of the residual current device I△n according to the earth resistance

RCD I△n	R_A (Ω) U_L: 50 V
⩽ 30 mA	< 500
100 mA	500
300 mA	167
1 A	50
3 A	17

In practice, 100, 300, or even 500 mA residual current devices are used associated with earths of less than 100 Ω in dry areas. When the earth is poor, a sensitivity of 30 mA is necessary.

Standard IEC 60364 no longer uses the voltage limit U_L: 25 V. This value was applied for damp areas in which the insulation conditions are reduced.
The result was requirements for lower earth connection values.
Medical studies have shown that this value of 25 V is not justified.
The U_L value: 50 V must therefore be considered in all cases.
Instead, special additional provisions (additional equipotential links, circuits protected by high sensitivity RCDs) are specified for areas where there are increased risks.

The TT system with protection by a residual current device is simple to implement, naturally safe and does not require any calculations.

For these reasons, it is mandatory for connections to the public system.

Nevertheless, it can pose problems of vertical discrimination or sensitivity to leakage currents, but there are appropriate solutions:

- Several levels of residual current devices (with offset on the sensitivity and the breaking time) make it possible to maintain good discrimination (see Book 6)
- Use of Hpi residual current devices that have a good level of immunity to high leakage currents (computing)
- Use of a circuit separation transformer (see Book 6).

> ## Establishing the earth connection

The resistance of the earth connection depends on the nature of the ground. Average resistivity values ρ:
- Rich arable land, fill, compacted damp soil : 50 Ωm
- Poor arable land, gravel, coarse fill : 500 Ωm
- Stony soils, dry sand, impermeable rock : 3000 Ωm.

It generally depends on the geometry and dimensions of the earth electrode (rod, plate, conductor in foundations).

Details and corrosion-resistance precautions for establishing earth connections are given in Book 8.

! In some countries convention permits the protection to be provided by overcurrent devices. This results in requirements for earth connection values that are very difficult to achieve (< 0.5 Ω for a 32 A rating, for example) which leads to high fault currents.
This practice is prohibited by french standard NF C 15-100 (art. 531.1.2).

Practical formulae for calculating an earth connection R (in Ω)	
Vertical rod	$R = \rho/L$ (L: length of the rod in m)
Plate	$R = 0.8 \, \rho/L$ (L: perimeter of the plate in m)
Horizontal conductor	$R = 2 \, \rho/L$ (L: length of the conductor in m)

+ **High sensitivity residual current devices ($I\Delta n$: 30 mA) are used to provide protection against indirect contact when the conditions for establishing the earth connection are unfavourable (> 500 Ω) or even impossible. These devices, which are mandatory in many countries for the supply of power sockets up to 32 A and for increased risk operating conditions (portable devices, site installations, presence of moisture, etc.), provide additional protection against direct and indirect contact.**

Neutral earthing systems
(continued)

2 TN SYSTEM (NEUTRAL CONNECTED)
T: neutral point earthed
N: exposed conductive parts connected to neutral

In TN systems, a point on the power supply, generally the transformer neutral, is earthed. The exposed conductive parts of the installation are connected to the same point by a protective conductor. The system is called TN-C when the neutral function is combined with that of the protective conductor, which is then called PEN. If these conductors are separated, the system is named TN-S.
When both variants cohabit in the same installation, the term TN-C-S can be used, remembering that the TN-C system must always be upstream of the TN-S system.
The impedance of the fault loop is low (it does not flow through the earth).

If there is an insulation fault, it changes to a short circuit which must be eliminated by the overcurrent protection devices.
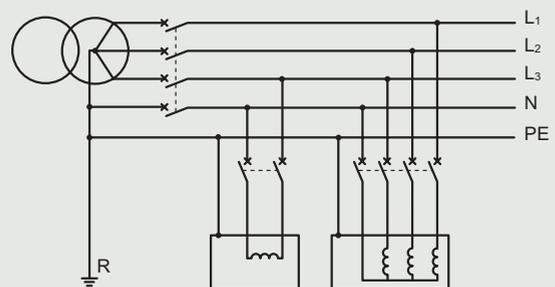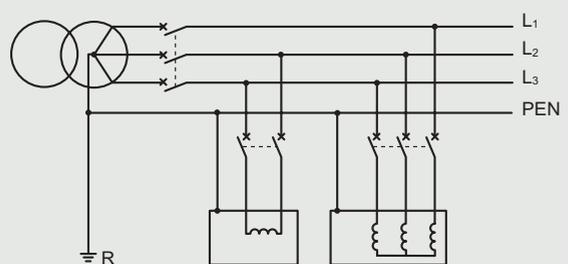
> **!** **If the loads are three phase only, the TN-S system can have a non-distributed neutral. The devices therefore have three poles, and the residual current toroid detection sensors must exclude the PE conductor. In principle, a TN system in which the neutral is not distributed is considered to be a TN-S system. A permanent warning sign is advisable in order to avoid confusion with a TN-C system.**

TN-S system

TN-C system

TN-C-S system
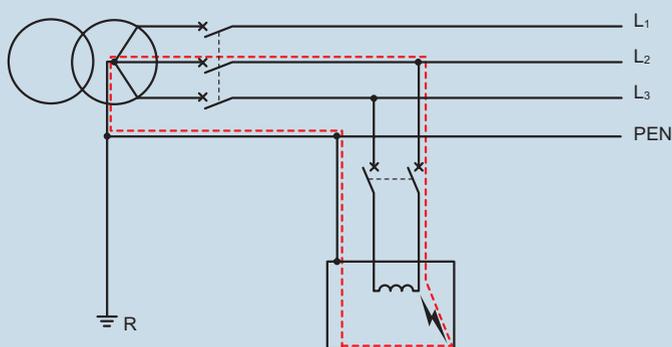
Max. breaking time t for terminal circuits	
Nominal voltage U_0 (V)	t (s)
$50 < U_0 \leqslant 120$	0.8
$120 < U_0 \leqslant 230$	0.4
$230 < U_0 \leqslant 400$	0.2
> 400	0.1

If there is a fault at any point in the installation affecting a phase conductor and the protective conductor or an exposed conductive part, the power supply must be cut off automatically within the specified breaking time t while complying with the condition $Z_S \times I_a \leqslant U_0$.

Z_S: impedance of the fault loop comprising the power supply line, the protective conductor and the source (transformer windings).

I_a: operating current of the protection device within the specified time

U_0: nominal phase/earth voltage

The maximum times must be applied to circuits that could supply class 1 mobile devices (in general all power sockets). In practice these times are complied with by the use of circuit breakers without time delays.

For the fixed parts of the distribution installation, longer times, but less than 5 s, are permitted as long as $R_{PE} \leqslant \dfrac{500}{U_0 Z_S}$, R_{PE} being the resistance of the protective conductor (highest value between a point on this conductor and the equipotential link).

This formula is used to check that the ratio of the impedance of the protective conductor to the total impedance of the fault loop is such that the voltage of the faulty exposed conductive part will not exceed 50 V, but it does not check that the break takes place within the required time.

In TN-C systems, the "protective conductor" function takes precedence over the "neutral" function. A PEN conductor must always be connected to the earth terminal of a receiver. If there is a neutral terminal, a "bridge" is created between it and the earth terminal.
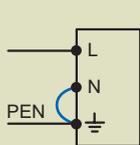
Single phase receiver
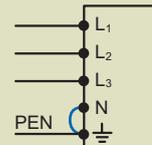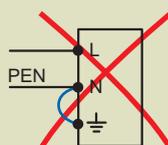
Three phase receiver
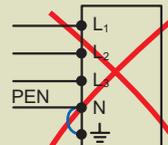
Neutral earthing systems
(continued)

Validation of the protection against indirect contact in TN systems is based on checking the operating conditions of the protective devices (see Book 6).
The higher the fault value, the easier it is to obtain the tripping conditions.
The value of the fault current decreases as the length of the busbars increases ... at the risk of no longer meeting the protection condition.
The following is then possible:
- Increase the cross-section of the conductors (reduction of the impedance of the fault loop)
- Create a local equipotential link (reducing the prospective touch voltage value)

- Use additional residual current protection devices
This last solution makes it possible to do away with checking. It protects terminal power socket circuits on which the receivers and cable lengths are often not known.

> **!** **Determination of the maximum line lengths protected against indirect contact and the minimum short-circuit currents is an essential condition for using the TN neutral earthing system (see Book 6).**

> **!** **In order to avoid differences in voltage between neutral and earth (in particular in widespread installations or in the event of lightning overvoltages), it is possible to use regular interconnections (removable for measurements) between the PE conductor and the N conductor: at the source (neutral point of the transformer), upstream of the main protection device (in the main LV distribution board), upstream of the protection devices on the load circuits (secondary distribution boards), at the point of use (power socket outlet).**
>
> L_1
> L_2
> L_3
> N
> PE
>
> **Caution: This arrangement is only applicable in countries in which breaking of the neutral is not mandatory. It is not possible in France for example.**
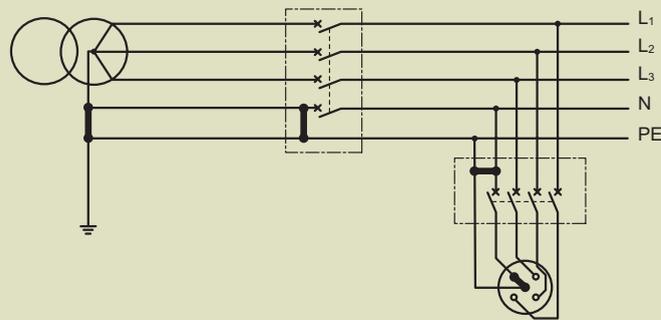
![legrand]

The detection of earth fault currents by residual current toroid sensors is prohibited in TN-C systems.
However it is possible to detect overcurrents in the PEN conductor that lead to breaking of the phase conductors (but not the PEN) by placing a toroid sensor on the neutral/PEN connection in the transformer. The smaller the cross-section of the PEN in relation to the phase conductors the more necessary this detection.

L_1
L_2
L_3

PEN

R
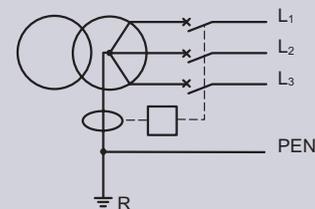
Using the PEN conductor

If there is a rupture or break in the PEN conductor, the exposed conductive parts of the installation may be increased to the voltage potential U_0. For this reason it must not be possible for the PEN conductor to be broken by any device (isolation, protection, emergency stop). For the same reasons of continuity, its minimum cross-section must be no smaller than 10 mm^2 if it is copper and 16 mm^2 if it is aluminium, to ensure adequate mechanical strength.
In TN systems, the safety connected with limiting the increase in the voltage of the exposed conductive parts is based on connection to the protective conductor, for which it is important to check that the voltage remains as close as possible to the earth. For this reason, it is recommended that the PE or PEN conductor is connected to earth at as many points as possible, and at least at the transformers supplying the main distribution board (main equipotential link), in each building, or even in each group of load circuits.

L1
L2
L3
PEN

Break

Increase in voltage

R
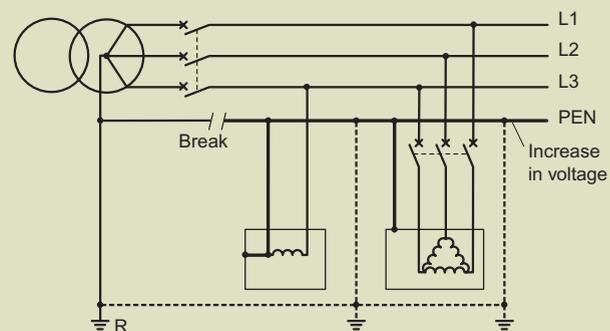
The rule concerning the non-breaking of the PEN conductor can be inconvenient when measuring the insulation, in particular that of the HVA/LV transformer. In fact breaking the earth conductor does not totally isolate the windings, which are still connected to the PEN conductor, which is itself earthed via the protective conductors or the equipotential links of the installation. To enable momentary isolation of the PEN conductor, a 4-pole isolating device should be installed (or better still, 3P + offset N). The pole of the PEN conductor will be short-circuited by a green/yellow conductor with the same cross-section. This conductor is disconnected to carry out measurements after isolation. The advantage of this solution is that the continuity of the PEN is physically linked to the re-energisation.

PEN   L1   L2   L3
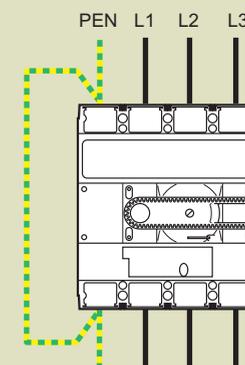
Neutral earthing systems
(continued)

3 IT SYSTEM (INSULATED OR IMPEDANCE EARTHED NEUTRAL)

I: "insulated" or "impedance earthed" neutral
T: exposed conductive parts earthed

In IT systems, the power supply of the installation is isolated from the earth or connected to it via a high impedance Z. This link is generally established at the neutral point or at an artificial neutral point.
The exposed conductive parts of the installation are interconnected and earthed. If there is an insulation fault, the impedance of the fault loop is high (set by the capacity of the installation in relation to earth or by the impedance Z).
At the 1st fault, the rise in the voltage of the exposed conductive parts remains limited and there is no danger. Breaking is not necessary and continuity is ensured, but the fault must be located and eliminated by an appropriate service.
A permanent insulation monitor (PIM) must be installed to monitor the insulation condition of the installation.
If a second fault is added to the 1st fault that has not been eliminated, the fault changes to a short circuit, which must always be eliminated by the overcurrent protection devices.

In IT systems, the exposed conductive parts can be earthed individually, in groups, or all interconnected together.
In all cases, it is necessary to check that the condition $R_A \times I_a \leqslant 50$ V is met for the earth resistance R_A of the exposed conductive parts in question (I_a being the tripping current of the protection device). Interconnection and linking to a single earth connection are preferable.
If a double fault occurs, the protection conditions to be implemented and checked for each group will be those of the TT system if the exposed conductive parts are separate, and those of the TN system if they are all interconnected.
(See determination of the protection conditions in Book 6).
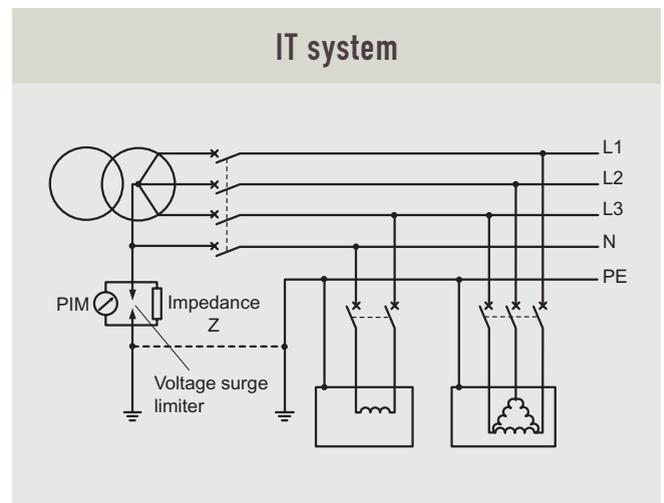
IT system

Permanent insulation monitor (PIM)

The PIM continuously injects a direct current (a few volts) between a point on the system and the earth. The capacitive part of the impedance is not therefore measured. The current drawn corresponds to the sum of the leakage currents of the three phases and characterises the insulation of the installation. An indication threshold (set to half the normal value) or a permanent display of the insulation value enables the installation to be monitored and maintained. An installation must only have one PIM. Its operating voltage must take account of whether or not there is a neutral (for example 250 V with neutral, 400 V without neutral).

Operating principle of the IT system

■ 1st fault: no danger for people

The current of the 1st fault (If) is limited by the sum of the resistances of the earth connections of the power supply (R_B), the exposed conductive parts (R_A) and the impedance (Z). Thus in the example above:

$$I_f = \frac{U_0}{R_A + R_B + Z} = \frac{230}{30 + 10 + 2000} = 0{,}112 \text{ A}$$

The non-breaking condition must be checked, ensuring that the current will not increase the exposed conductive parts to a voltage higher than the voltage limit UL. The following is therefore required:
$R_A \times$ If < 50 V, i.e. in the example: 30 × 0.112 = 3.36 V. The exposed conductive parts will not reach a dangerous voltage and non-breaking is permitted.
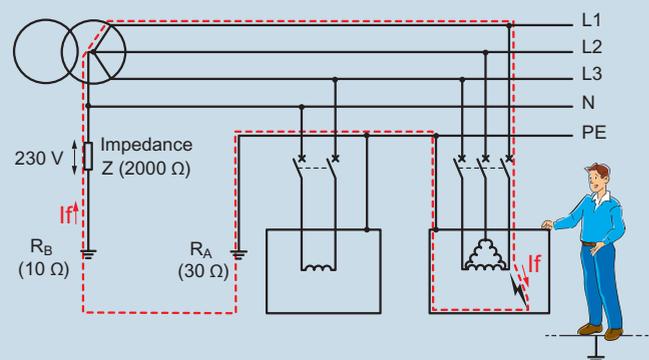
■ 2nd fault: short circuit

In the event of a 2nd fault affecting another phase, on the same or another exposed conductive part, a loop is created by the exposed conductive parts of the faulty receivers, the protective conductors and the power supply conductors. This will cause a high short-circuit current to circulate for which the elimination conditions are those of the TN or TT system. It should be noted that this double fault situation is totally independent of the situation of the neutral in relation to earth, which may be isolated or impedance earthed. The IT double fault current is often lower that it would be with a TN system. The protected line lengths will be reduced accordingly.
If there is a fault, the voltage of the neutral may increase to that of the faulty phase (phase-to-neutral voltage). The voltage of the other phases will tend to increase towards the value of the phase-to-phase voltage. It is therefore advisable not to supply devices between phase and neutral in IT systems and thus not to distribute the neutral.
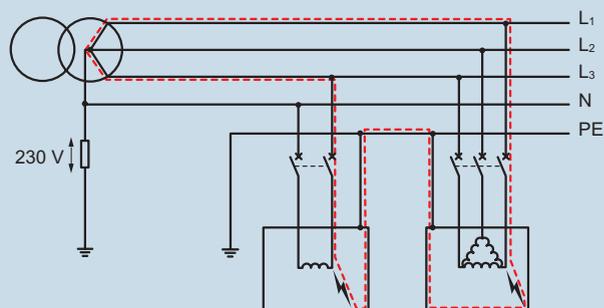
Neutral earthing systems
(continued)

ISLANDING

Each neutral earthing system has advantages and disadvantages for the safety of property, electromagnetic compatibility or continuity of service.
The main system must therefore be chosen according to these criteria, but the characteristics of the system, the receivers, and the requirements for their operation may not be compatible with this system alone within the same installation. Creating a specific system in part of the installation, or islanding, may be an appropriate solution.

1 SUPPLY VIA THE SAME TRANSFORMER

Whether it is possible to create different neutral earthing systems in one installation (islanding) is initially dependent on whether or not the island can be supplied via a separation transformer.
In practice, only TN and TT systems can cohabit,

subject to compliance with the following conditions:
- The neutral is earthed directly
- Each part of the installation is calculated and protected according to the specific rules of each system
- A main equipotential link is established in each building, and the protective conductors connected to it
- Each part of the installation (island) has its own protective conductor to which the exposed conductive parts are connected
- If there are exposed conductive parts of different installations in the same building, they must be linked by means of an additional equipotential link
- The rules specific to the use of the PEN conductor (TN-C system) must be complied with, in particular the non-breaking of the PEN or its connection to the general equipotential link downstream of the breaking device.

Schematic diagram of the power supply in the same building or in two buildings close to one another
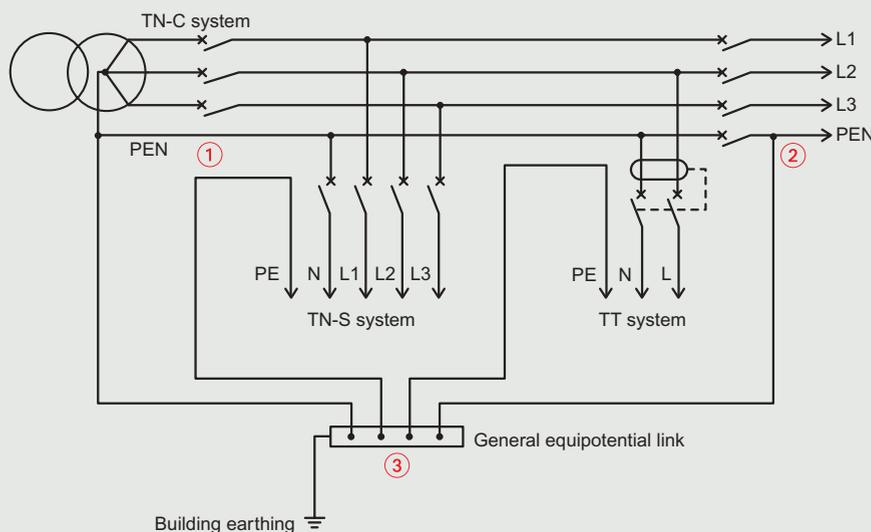
Non-breaking of the PEN ① or connection to the general equipotential link downstream of the breaking device ②.

All the protective conductors are connected to the same equipotential link ③.

Schematic diagram of the power supply of several buildings

Cable

L1
L2
L3
N
PE

PE

PE N L1 L2 L3
TT system

PE N L1 L2 L3
TN-S system

PE N L
TT system

Building 1
equipotential link

Building 1 earthing

Building 2
equipotential link

Building 2 earthing
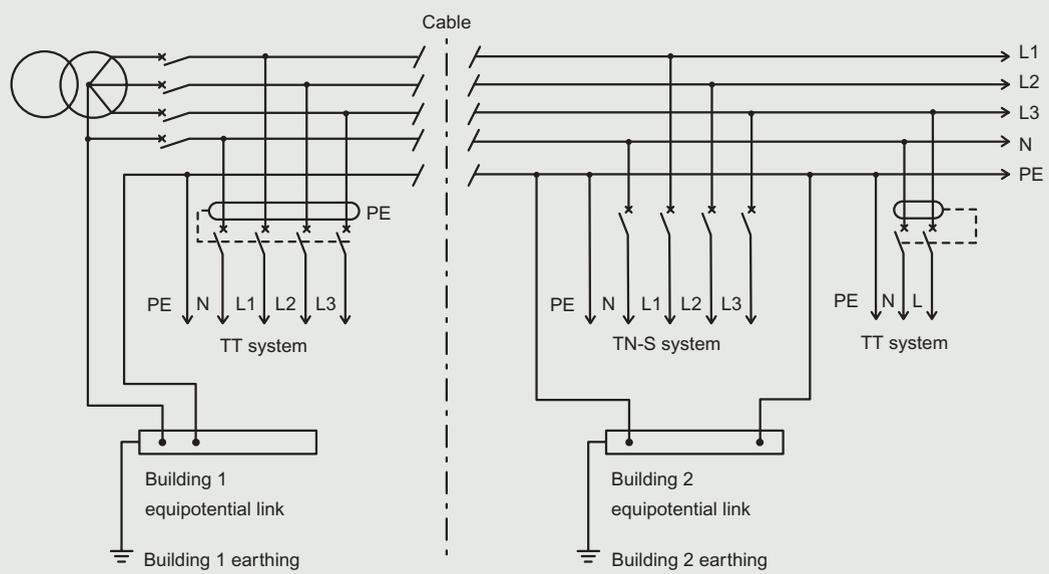
If only the TN-C system is used in the 1st building, the power supply cable of the second building can use the neutral conductor as the protective conductor (PEN) (cables with 4 conductors).
Otherwise (example in the diagram), the power supply cable must have five conductors (separate PE and N), or four conductors with a PE conductor placed in contact with the cable, to provide the link between the protective circuits of the two buildings.
If several earthing systems (identical or different) are used in the same building, the protective circuits (PE conductors) must be linked together and interconnected to the same equipotential link of the building concerned.

Changing from the TN-C system to the TN-S system is not considered to be a change of neutral earthing system, but in all cases, the TN-S system must be downstream of the TN-C system.

Neutral earthing systems
(continued)

! Connecting an installation to the public distribution system using a TN-C or TN-S system

Public distribution often uses the TT system. The use of a TN system link requires the agreement of the local distribution service:
- It is generally connected on underground systems
- The low voltage neutral is connected to the earth of the HVA exposed conductive parts of the substation (TNR system, see p.11)
- The PEN conductor is not broken, right up to the delivery point
- The characteristics of the system (distances, powers, changes) are required in order to calculate the possible fault loop.
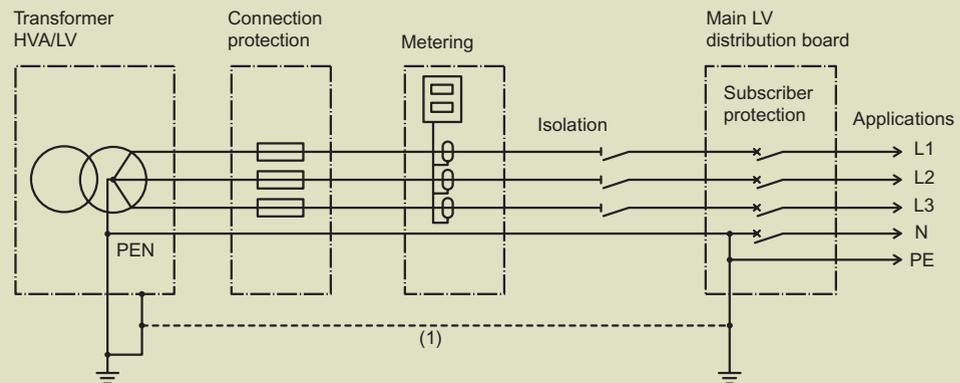
(1) If the delivery substation and the main LV distribution board are located in the same building, the exposed conductive parts of the substation must be linked to the same earth connection as the LV installations.

Example of cohabitation of systems: individual installation: TT system (subscribers), collective installation: TN (for example, heating)
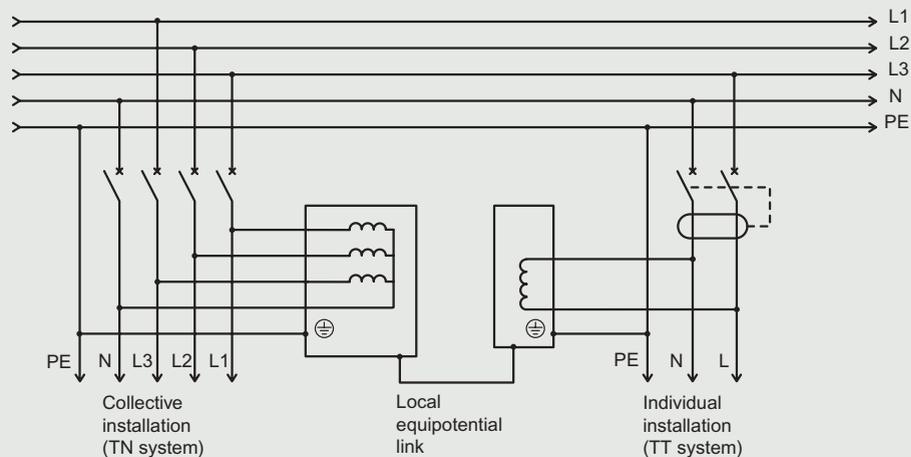
2 SUPPLY VIA A SPECIFIC TRANSFORMER

In this application, there are three situations.

• The use of a "circuit separation transformer", to separate the load circuit locally from the supply circuit in order to avoid the risk of indirect contact on the separate circuit. This precaution is applicable for the supply of a device or a set of devices grouped together (see Book 6).

• The use of an isolating transformer with separate windings to supply a specific device that is sensitive to electromagnetic disturbance. The transformer is thus used for its filtering properties (see Book 8).

• The use of an isolating transformer with separate windings intended to re-create a supply source at the start of which the neutral earthing system appropriate to the specific requirement of the island can be set up, generally TN-S or IT.

^ **Isolating transformer**

2.1. Supply via TN-S system (local neutral connected)

This system is used for installations with high leakage currents (data processing), low insulation (furnaces, welding machines) or those that are subject to a great deal of disturbance (microwave transmitters).
Applications where interference suppression is important (capacitors) may also need this type of system (industrial control or telecommunications equipment).
Protection against insulation faults (indirect contact) is provided by overcurrent protection devices, checking that the fault current is greater than the tripping current (+ 20%).
If the short-circuit power of the transformer is inadequate, a low sensitivity (for example 1 A) residual current device must be used.
Particular attention must be paid to the equipotentiality of the receivers. Additional links will have to be set up for this.
Neutral/protective conductor interconnections must be established as well as additional referencing to earth, if necessary.

Standard system diagram of an island with three phase TN-S system (can be applied to a single phase system)

Connection of
⊕ protective conductors
Equipotential link between
⇓ exposed conductive parts
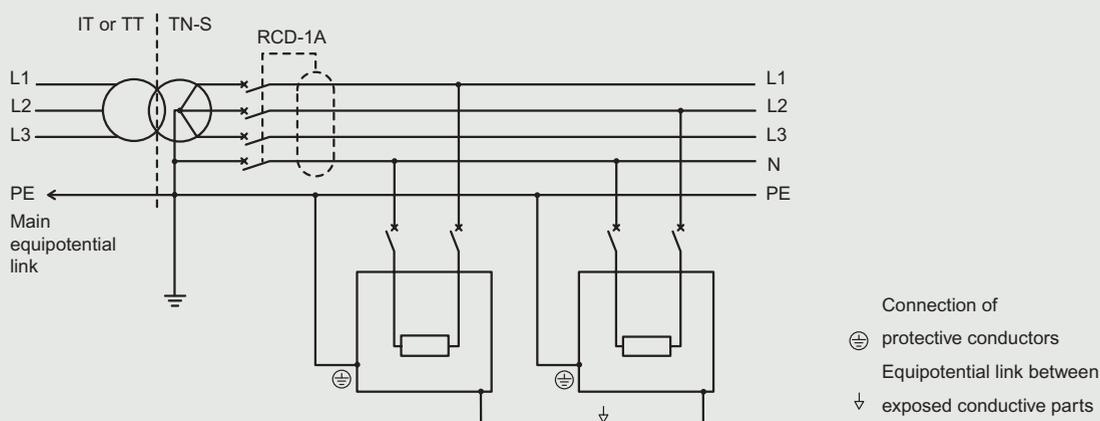
Neutral earthing systems
(continued)

🔍 Practical rule for determining the rating of the protection on the secondary

To check that the chosen device is suitable, an approximate value of the minimum short circuit at the furthest point of the installation can be obtained, using the following formula :

$$Ik\ min = \frac{U_S}{\left(\frac{U_S^2}{P} \times \frac{Ucc\%}{100}\right) + \frac{2\rho l}{S}}$$

U_S: transformer secondary voltage in V
P: transformer power in VA
Ucc %: transformer short-circuit voltage
l : length of the line in m
S: cross-section of the line in mm^2
ρ copper: 0.023 Ω mm^2/m

The rating of the protective device must be chosen to provide a breaking time of 5 s maximum for the Ik current previously defined.

gG fuse: In ≤ $\dfrac{Ik\ min}{4}$

Type C circuit breaker: In ≤ $\dfrac{Ik\ min}{8}$

2.2. Power supply in IT system

This arrangement is used for installations where there is:
- A need for continuity of service for safety (medical, food processing)
- A need for continuity of operation (ventilation, pumps, markers)
- A risk of fire (silos, hydrocarbons)
- A low short-circuit power (standalone generators)
Although the primary property of the IT system is to limit the 1st fault current and not "break", the fact remains that this choice may be made to the detriment of other requirements that must be given due consideration:
- The non-distribution of the neutral conductor, which is still recommended due to the risk of rise in voltage or breaking in the event of a double fault, is not very compatible with the use of single phase receivers
- The risk of rise in the voltage of the earth to which the exposed conductive parts of the electronic devices are connected by their protective conductors
- The difficulty of using high sensitivity residual current devices (30 mA) for power sockets that would break at the 1st fault.

> **!**
> It is recommended that the IT island is only created over a small area.
> If the neutral conductor is necessary, it must be systematically protected (and not just broken) and it must not have a small cross-section (it could melt if there were a double fault).
> The presence of harmonics connected with devices used in medical applications must also be taken into account when sizing this neutral conductor.
> To limit the risk of a rise in the voltage of the exposed conductive parts they must be interconnected and linked to the local earth connection, which must itself be connected to all the earth connections of the building via the main equipotential link.

Standard layout of an IT system island for continuity of operation, with distributed neutral conductor

TN or TT | IT

L1
L2
L3
N

PIM   Z

PE

Main equipotential link

PE
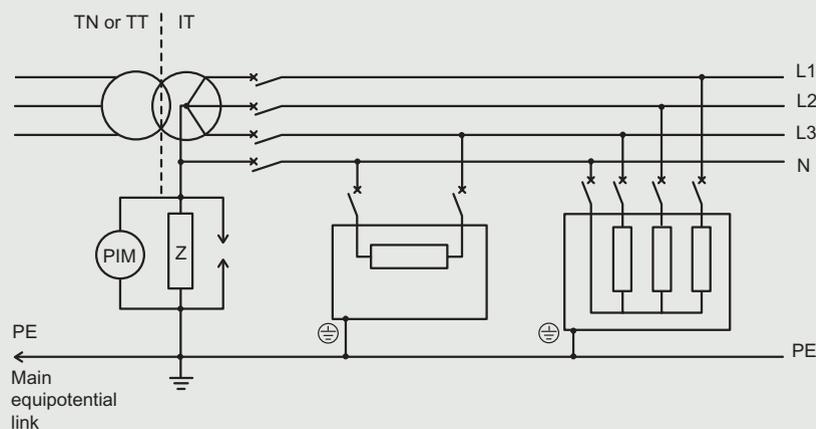
Medical IT system

The application of the medical IT system is defined in France by standard NF C 15-211 (measure P5). It is mandatory in anaesthetics rooms, operating theatres and cardiac catheterisation rooms. It is recommended in several other areas: hydrotherapy, recovery rooms, intensive care or haemodialysis units, etc.

The transformer and switchgear must be in an area separate from the room or unit, but an illuminated indication of the insulation monitoring device must be visible in the room or unit.

The impedance Z of the PIM must be at least 100 kΩ with an alarm threshold set at 50 kΩ corresponding to a fault

current of approximately 5 mA ($I_f = \dfrac{U_0}{Z} = \dfrac{230}{50000} = 4,6$ mA)
enabling any fault to be detected before the high sensitivity residual current devices break.

All circuits must be protected by type A high sensitivity residual current devices.

Devices with power > 5 kVA must be supplied directly with no socket.

Devices and sockets whose power is < 5 kVA must be supplied via a separation transformer for the three types of room or area for which a medical IT system is mandatory.

Compatibility between high sensitivity residual current devices and non-tripping at the 1st fault in IT islands

Protection of power sockets by high sensitivity residual current devices is mandatory, but unexpected breaking due to tripping can be anticipated by setting the detection current of the PIM to a value lower than that of the residual current device (see medical IT system). If continuity of operation is vital, high sensitivity residual current devices are not necessary if the devices are connected directly to the installation (with no power socket). The special use exemption measure can be applied to supply power sockets that are not protected if no device other than those intended are likely to be connected.

Neutral earthing systems
(continued)

NEUTRAL EARTHING SYSTEMS OF GENERATOR SETS

Generator sets have specific features that must be taken into account for protection against electric shocks. Mobile sets cannot be connected to earth and their connection by means of a flexible cable can be easily damaged. In general, generator sets have much lower short-circuit levels than transformers (around 3 In instead of 20 In). As a result, the tripping conditions required for protection against indirect contact cannot be provided by devices sized for operation on the normal supply.

1 PORTABLE GENERATOR SETS FOR TEMPORARY INSTALLATIONS

Limited to a few kVA, these supply directly a small number of receivers (market stall, kiosk, power supply for portable tools, etc.).
The exposed conductive parts of the set and those of the installation must be linked together by means of a protective conductor.
Each outgoing circuit must be protected by a residual current device IΔn ≤ 30 mA.
If the set has one or more power sockets without a protective RCD, there should be one RCD per circuit at a distance of less than 1 m. As earthing is not possible and the neutral pole is not accessible, the installation will operate as an IT system.
If the generator set supplies class II devices, the exposed conductive parts are not linked but the provision of one or more RCDs remains mandatory for supplementary protection against direct contact, in particular on the flexible connecting cable.
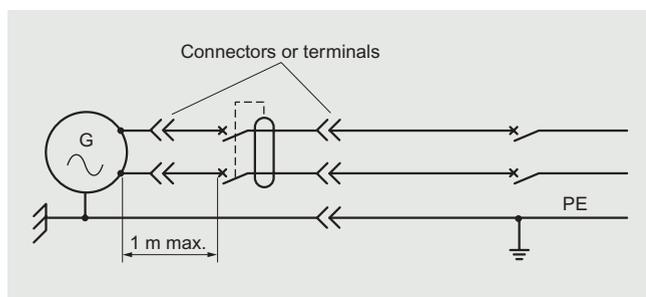
2 MOBILE GENERATOR SETS FOR TEMPORARY INSTALLATIONS

With powers greater than 10 kVA, these supply larger installations (building sites, carousels, circuses, etc.).
The exposed conductive parts of the set must be linked to the exposed conductive parts of the devices being used by means of a protective conductor. Protection against electric shocks is provided by a residual current device IΔn ≤ 30 mA protecting all the outgoing lines, usually incorporated in the set by construction.
If there are requirements for differential discrimination between the circuits supplied, secondary residual current devices IΔn ≤ 30 mA can be installed on each outgoing line, as long as they are at a distance of less than 1 m. The rules for selecting the devices described in Book 6 can be applied.
If there is a possibility of establishing a reliable earth connection, the installation can operate in TN-S system mode. The fault current is closed by the neutral or by linking the exposed conductive parts if the neutral is not distributed. This is possible for three-phase loads only, and enables three-pole devices to be used. In this case this is a TN-S system with non-distributed neutral, which should not be confused with a TN-C system.
If there is no earth connection established on the set, the installation will operate as an IT system. The breaking and protection devices must have staggered opening of the neutral with protection of all the poles. In addition, the cross-section of the neutral must not be reduced.

Connectors or terminals

G

PE

1 m max.

> **!** The installation and setup of generator sets are subject to specific regulations on the characteristics of the areas, the discharge and pollutant levels of the exhaust gases, and the permissible noise. It is advisable to refer to these regulations with the assistance of the manufacturers and competent bodies.

3 MOBILE GENERATOR SET FOR FIXED INSTALLATION FOR ONE-OFF RE-SUPPLY

Temporary one-off re-supply of a fixed installation instead of the mains supply or the usual power supply should only be carried out after isolation.
Manual opening of the main circuit-breaker generally provides this separation, as long as it is held in position (locking, padlocking) or indicated by a warning sign.
In all systems (TT, IT, TN) the exposed conductive parts of the generator set must be interconnected with the earth network of the existing installation.
If a local earth connection can be established for the set's neutral, the earth must be interconnected with the equipotential link of the installation.
If, as is often the case, this operation is not possible or not carried out, the installation will operate as an IT system if the generator's neutral is not accessible.
If the generator's neutral is accessible, it must be linked to the protection circuit of the fixed installation

via a protective conductor (with an identical cross-section) incorporated in the cable or via a separate cable sized for the fault conditions, with a minimum copper cross-section of 16 mm².
The installation will then operate as a TN-S or TT system.

> **!** In all systems (apart from TN-C), the provision of a residual current protection device is recommended. The residual current toroid sensor must be placed downstream of the earthing of the neutral point (see diagram opposite) or on the generator's neutral point earth conductor.

> **⚖** If the generator is a power supply for safety services, the earthing system used will be the IT system.

Connectors or terminals — L₁, L₂, L₃, N, PE
Mobile installation | Fixed installation

> **!** Caution, in TN or IT systems, protection against indirect contact may not be provided (Ik value too low).
> In installations that are to be re-supplied by a mobile generator set, a sign must be placed close to the connection point, with the wording:
>
> **Minimum power of the set to be installed: x kVA**

Neutral earthing systems
(continued)

4 MOBILE GENERATOR SET FOR FIXED INSTALLATION FOR RE-SUPPLY PLANNED AT THE DESIGN STAGE

When the re-supply of a fixed installation in place of the mains supply or the usual power supply is planned at the design stage, an all-pole supply inverter must be installed. Irrespective of the neutral earthing system of the fixed installation, it is necessary to interconnect the exposed conductive parts (TT, IT), the neutral point of the set and the exposed conductive parts of the set (TN) to the exposed conductive parts of the existing installation.

If the protection conditions (Ik min.) are not met by the overcurrent protection devices (IT and TN systems) or cannot be determined (see box), a high sensitivity residual current device (30 mA) must be used and the neutral earthed upstream of the RCD (see diagrams below).

In TT systems, an RCD must be used in all cases. The part upstream of the residual current device must have double or reinforced insulation (see Book 6). The toroid sensor must be placed on all the live conductors (phase + neutral) or on the conductor linking the neutral point on the alternator to the earth of the installation (TT or TN-S). This solution is not applicable in TN-C systems.

When a generator set supplies a standalone installation with no power sockets or whose continuity of service is paramount (machine, crane, carousel), it is permissible not to install a residual current device as long as the conditions for protection against indirect contact are met in line with the chosen neutral earthing system.

Rules for installing a mobile generator set for fixed installations

Re-supply — Fixed installation — Mains supply

G N

Part with double or reinforced insulation

general equipotential link

Application

Re-supply — Fixed installation — Mains supply

G N

Part with double or reinforced insulation

general equipotential link

Application
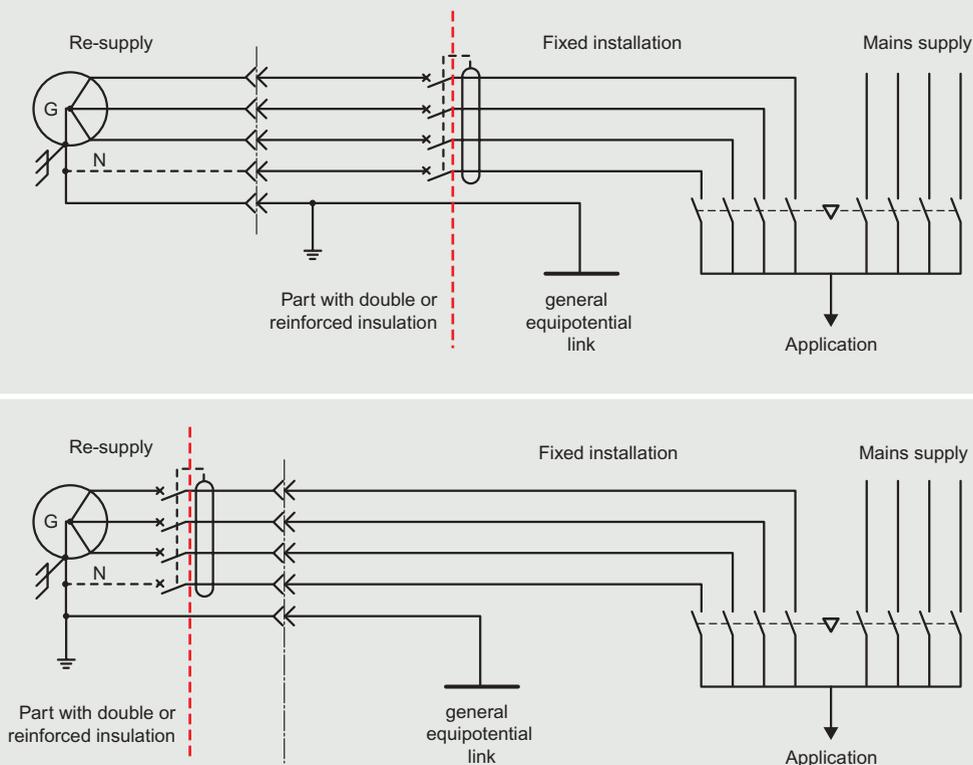
5 FIXED SETS FOR FIXED INSTALLATIONS

If the set is a replacement supply,
it must use the same neutral earthing system as the normal supply.
The conditions for protection against indirect contact and tripping for minimum short circuits must be checked (see Book 4), and must be met each time the installation is supplied by the normal supply and by the generator set.
Safety installations should preferably be created with IT systems or under TN system conditions.

+ **P17 portable combined units can be mounted on chassis and are particularly suitable for creating distribution panels for generator sets. The feedthrough ground terminal and the free terminal for connecting a protective conductor are suitable for the connection conditions of neutral earthing systems.**

Conditions for protection against short circuits and indirect contact

The setting or rating of the overcurrent protection devices that provide protection against indirect contact when using a neutral earthing system for a generator set must be chosen with care (see Book 4). The low value of the fault current (I_{kmin}) is not always compatible with the fuse breaking time. The rated current I_n of these fuses and that of the generator I_G must be similar and it is essential that the tripping conditions are checked. Likewise, if circuit breakers are used, the magnetic operation adjustment (short delay) must be set to a low threshold.
The short-circuit current at the terminals of the generator is determined in a simplified way using the formula:

$I_k = \dfrac{In}{X'd}$ where X'd represents the direct transient reactance of the generator as a %.

Its value in ohms is $Xd = \dfrac{U^2}{P}$ X'd where U represents the rated phase to phase voltage of the alternator (in V)

and P its apparent power (in VA). In the absence of any information, X'd is taken as being less than or equal to 30%.

In practice, the short-circuit current I_K will not exceed $I_k = \dfrac{In}{30\%}$, i.e. 3.In, and this value could even decrease in stabilised alternator operation.
An Im setting, minimum (1.5 or 2) Ir, will be applied using devices with electronic releases (see Book 5).

Attention must be paid to the calculation rules used by software packages, which take into consideration a relationship between the line resistance R_L and the reactance of the supply X_d that may be incompatible for calculating the protection devices near the generator.

If $\dfrac{R_L}{X_d} \leqslant 0.8$, exact mathematical calculations (see Book 4) or the use of calculation charts may be more appropriate.

Neutral earthing systems
(continued)

SELECTING NEUTRAL EARTHING SYSTEMS

The choice of a neutral earthing system is dependent on requirements and objectives that are often contradictory, to such an extent that sometimes several systems have to be created within one installation (islanding) in order to meet safety, maintainability or operating requirements that are too dissimilar. The following table summarizes the advantages and the disadvantages of each system.

	TT system		
General principle	Detection of a fault current running through the earth and disconnection of the power supply by a residual current device		
Advantages	- Simplicity (very few calculations when installing) - Extension with no need to calculate the lengths - Low fault currents (fire safety) - Very little maintenance (apart from regular testing of the RCDs) - Safety of people when portable devices are supplied or if earthing is defective (with 30 mA RCDs) - Operation on a source at low prospective Ik (generator set)		
Disadvantages	- No differential discrimination if only one device at supply end of installation - Need for RCDs on each outgoing line to obtain horizontal discrimination (cost) - Risk of false tripping (overvoltages) - Interconnection of exposed conductive parts to a single earth connection (widespread installations) or RCD needed for each group of exposed conductive parts - Level of safety dependent on the value of the earth connections		
Notes	- Voltage surge protectors recommended for overhead distribution - Possibility of linking the power supply earth connection and that of the exposed conductive parts for private HVA/LV transformer (check breaking capacity of RCDs) - Need to control equipment with high leakage currents (separation, islanding) - Importance of establishing and ensuring durability of earth connections (safety of people) - Ensure the earth values and tripping thresholds of the RCDs are checked periodically		

	TN system	IT system
	The fault current changes to a short-circuit current which is broken by the overcurrent protection devices, and the exposed conductive parts are kept below a safe voltage threshold	Keeping the 1st fault current at a very low value limits the voltage rise of the exposed conductive parts, and there is thus no need for disconnection
	- Low cost (protective devices are used for fault currents and overcurrents) - The earth connection has no effect on the safety of people - Low sensitivity to disturbance (good equipotentiality, neutral earthed) - Low sensitivity to high leakage currents (heating, steam, computing equipment)	- Continuity of service (no breaking on 1st fault) - 1st fault current very low (fire protection) - Fault current causes little disturbance - Operation on sources at low prospective Ik (generator set) - Supply of receivers sensitive to fault currents (motors)
	- High fault currents (generation of disturbance and risk of fire in particular with TN-C system) - Need for accurate calculation of lines - Risk in the event of refurbishment extensions or uncontrolled use (qualified staff)	- Installation cost (protected neutral, PIM, voltage surge protectors) - Operating cost (qualified staff, location of faults) - Sensitivity to disturbance (poor equipotentiality with earth) - Risks on 2nd fault: - Short-circuit overcurrents - Disturbance (rise in earth voltage) - Appearance of a phase-to-phase voltage (if neutral distributed)
	- The protection conditions must be checked: at the design stage (calculation), on commissioning, periodically and if the installation is modified - Practical checking requires special test equipment (measurement of the Ik at the end of the line) - The use of residual current devices enables the fault currents to be limited (check the breaking capacity) and risks not provided for by the calculations to be overcome (breaking of the protective conductors, line lengths of mobile loads, etc.)	- Indication of the 1st fault is mandatory and a search for the cause must be undertaken immediately - The situation of a 2nd fault must be avoided in view of the risks involved - Protection by voltage surge protectors is essential (risk of rise in earth voltage) - It is advisable to limit the scale of IT installations to what is strictly necessary (islanding)

SELECTING NEUTRAL EARTHING SYSTEMS

Neutral earthing systems
(continued)

The following tables give general rules for choosing the neutral earthing system according to the installation, the receivers and the operating conditions. However in some cases these rules may be inapplicable. The neutral earthing system must be chosen for the majority of the applications in the installation.

If one of them is not very compatible with this choice, it is preferable to isolate it and treat it separately (islanding, filtering, separation).
Choosing the overall system based on this single application would be to risk making the wrong choice for the rest of the installation.

Type and characteristics of the installation	Recommended system
- LV public distribution system	TT (TN on request)
- Widespread system with poor earth connections - Supply via transformer with low Ik - Generator set (temporary installation) - Overhead line system	TT
- System subject to disturbance (area subject to lightning) - System with high leakage currents	TN
- Generator set (temporary power supply)	TN-S
- Generator set (emergency power supply) - Emergency source for safety circuits in buildings open to the public	IT

Types of receiver and operating conditions	Recommended system
- Numerous mobile or portable devices - Installations with frequent modifications - Site installations - Old installations - Areas where there is a risk of fire	TT
- Electronic and computing equipment - Equipment with auxiliaries (machine tools) - Handling equipment (hoists, cranes, etc.) - Devices with low insulation (cooking, steam appliances, etc.) - Installations with high leakage currents (marinas, etc.)	TN-S
- Areas where there is a risk of fire - Control and monitoring installations with large numbers of sensors - Installations with requirement for continuity (medical, pumps, ventilation, etc.) - Devices that are sensitive to leakage currents (risk of damage to windings)	IT

NEUTRAL EARTHING SYSTEM AND EMC

The choice of the "neutral earthing system" has a direct effect on the "electromagnetic compatibility" of the installation:
- The consequences of a lighting strike are partly dependent on the situation of the power supply in relation to earth, defined by the first letter (I or T)
- The transmission of conducted or emitted high frequency disturbance depends on the connection of the exposed conductive parts of the installation and their equipotentiality, defined by the second letter (T or N)

Locally, the earth is not necessary for the equipotentiality of an installation. It is the equipotential bonding system which provides this equipotentiality. Thus when the energy source is nearby or standalone (batteries, solar panels, generator set, etc.) it is not necessary to earth the power supply and the installation. The protection can be provided simply by "local equipotential links" that are not earthed. If there is a lightning strike, which is the main risk, the voltage of the whole installation rises equally, and thus there is no damage. High altitude weather stations and isolated transmitters use this principle.

The energy transmission distances require a common voltage reference that can be accessible from the source to the load and can discharge disturbance such as lightning. Only the earth meets these conditions!

Standalone installation
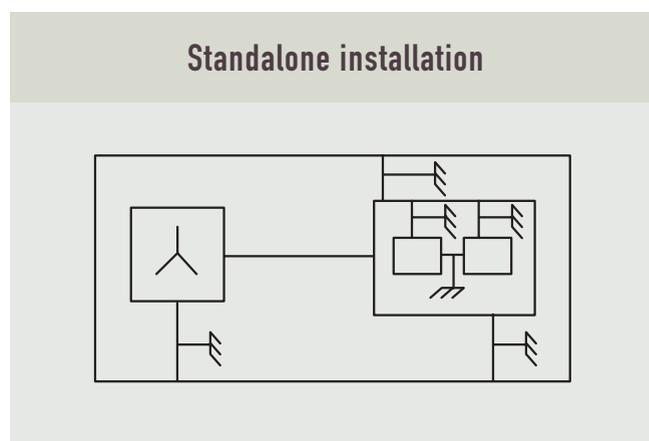
Separate installation and power supply (public distribution system)

The earth is used as equipotentiality reference between the source and the installation

The earth is not necessary to ensure equipotentiality in the installation
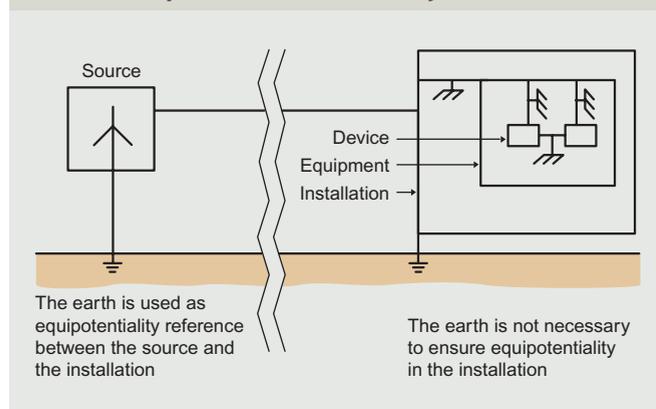
Neutral earthing systems
(continued)

Differential mode, common mode

In differential mode, the disturbance that will be linked to the line will give rise to a current I_{md}, and thus to a voltage U_{md} between the two outgoing and return conductors of the line. This voltage may be high enough to change the level of the signal that is normally transmitted and lead to a control error (transmission line) or equipment damage in the event of high-energy disturbance such as lightning (power line).
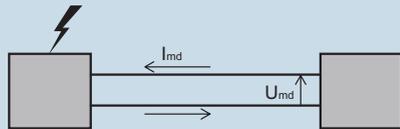
In common mode, the rise in the voltage U_{mc} is identical on both line conductors and occurs in relation to an external reference, generally the earth. The common mode current I_{mc} flows in the same direction on both conductors.
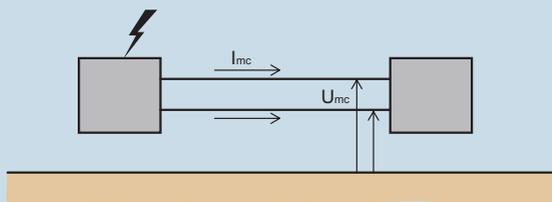
As a general rule, differential mode disturbance is more contraigant as it affects the products' own functional characteristics (measurement levels, trip thresholds, energy supply, etc.).
Common mode disturbance, even though it may be at a higher level, mainly affects the insulation of products, which for safety reasons, is generously sized.

It is always advisable to convert differential mode disturbance to common mode to limit its effects and for ease of filtering. Twisting is for example a very simple method that is used universally for data cables.
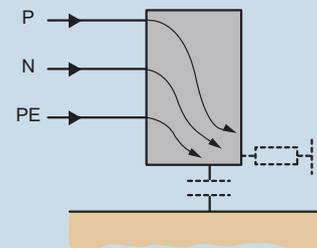
"True common mode" is characterised by the circulation of the disturbance in all conductors. Its return is ingoing via different capacitive or galavanic coupling with others devices. For example, a lightning overvoltage in top of installation is "true common mode". It is not stopped by a transformer.
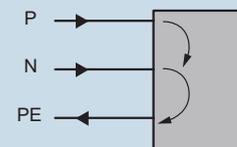
"False common mode" is characterised by the return of disturbance in the earthing sytem and bonding network. This is generally the case of components or devices under metal conductive parts (classe I) connected on terminal circuits.
The "false common mode" is stopped by a transformer, in particular transformer with screen.

Advantages and disadvantages of the neutral earthing systems in relation to EMC

Neutral earthing system	Advantages	Disadvantages
TT	- The neutral voltage is fixed. - The fault currents are low	- Source earth connection and load earth connection are separated and less equipotential. Impedance of the load earth connection can be high - PE conductor does not constitute a reliable voltage reference, resulting in the need for additional equipotential links - Lightning strike giving differentiel mode overvoltage (dissymetry of the system)
IT	- The fault currents are low - Good protection against conducted lightning (common mode overvoltages) but risk of sparkover on the neutral impedance, resulting in the need for a surge voltage protector	- "Load" earth voltage not fixed in relation to the source and consequently not fixed in relation to that of the exposed conductive parts - Increase in earth voltage (direct lightning strike) or after the 1st fault: loss of reference for electronic devices - Circulation of permanent currents by capacitive coupling between live and earth conductors
TN-S	- A single "source" and "load" voltage reference, the earth is not used as a conductor, and good equipotentiality of the exposed conductive parts - Low impedance of the protection circuit due to the need to carry high fault currents	- Specific installation rules and equipment (5 wires) - Possible rejection of disturbance on the neutral if the equipotentiality is uncertain between the neutral and the PE conductor or if their paths are different - High fault currents - Lightning strike giving differentiel mode overvoltage (dissymetry of the system)

It is generally agreed that the TN-S system is the best compromise in terms of EMC. It is easy to the make up for limitations of this system by the additional use of voltage surge protectors that combine common and differential modes.
Use, on each outgoing circuit, of RCBOs compatible with the leakage currents will limit the currents in the event of a fault.

> **!** **The TN-C system is not recommended due to the circulation of high fault currents in the PEN conductor.**

DC installation rules

DC has once again come to the fore. We can see history and Edison's theories being repeated. The days of the conflict between DC and AC are well and truly in the past, and what is important now is to make use of the complementary nature of these two forms of electrical energy.

As well as on-board installations (vehicles, ships, etc.) and telecommunications installations, DC is already used for numerous applications in static converters to supply machines or for installations supplied by means of batteries (backups, emergency lighting, etc.).
One of the main advantages of DC sources is their easy reversibility: generators discharging and receivers charging for batteries, receivers operating normally and as generators in braking mode for rotating machines which are also easy to control (varying speed or torque) using power electronics components (thyristor, IGBT, MOS transistor) up to several dozen kVA.
Recent developments in lighting (LEDs), direct electro-nic power supplies (computing) and in particular the expansion of solar-powered energy have extended the use of DC.
New rules are now needed (some are still being developed) and the choice of products must take into consideration very specific requirements which, if unknowned, will lead to major disappointment. It should also be remembered that, contrary to popular belief, DC can be very dangerous, with heart block mechanisms that are different from AC (see Book 6). Under these conditions, the imperative safety requirement necessitates the rigorous use of appropriate neutral earthing systems.

! Earthing

When the diagrams (on the following pages) indicate earthing of a specific polarity in a two-wire DC system, the decision to earth this positive or negative polarity must be based on the operating and protection conditions, and must in particular take account of electrochemical corrosion.
In solar-powered installations, no polarity on the DC installation side should normally be earthed and all the components must be class II or installed with additional insulation.
If there is an inverter present, with no separation transformer, the neutral earthing system of the DC part must be identical to that of the AC part.
According to the recommendations of solar panel manufacturers, a polarity can be earthed as long as measures are taken to ensure the safety of people (for example, permanent insulation monitor (PIM)).

NEUTRAL EARTHING SYSTEMS IN DC INSTALLATIONS

1 TN SYSTEMS IN DC INSTALLATIONS

The point directly connected to earth is generally the negative pole or the middle pole (diagrams below). As the fault loop is made up exclusively of galvanic elements (live conductors and protective conductors), any dead fault current between phase and the exposed conductive part becomes a short-circuit current that should be eliminated by appropriate overcurrent protection devices.
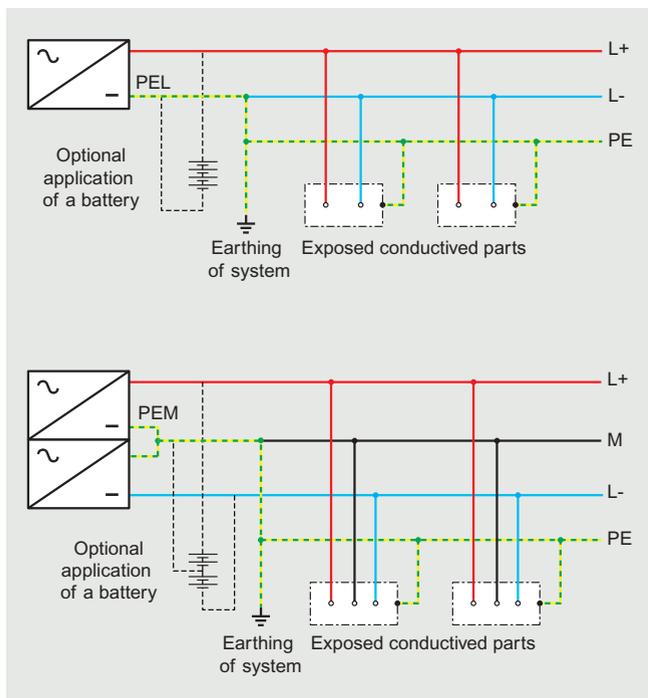
2 TN-C SYSTEMS IN DC INSTALLATIONS

The functions of the earthed live conductor (generally L-), or the earthed middle conductor (M) are combined in a single PEN conductor for the whole system.
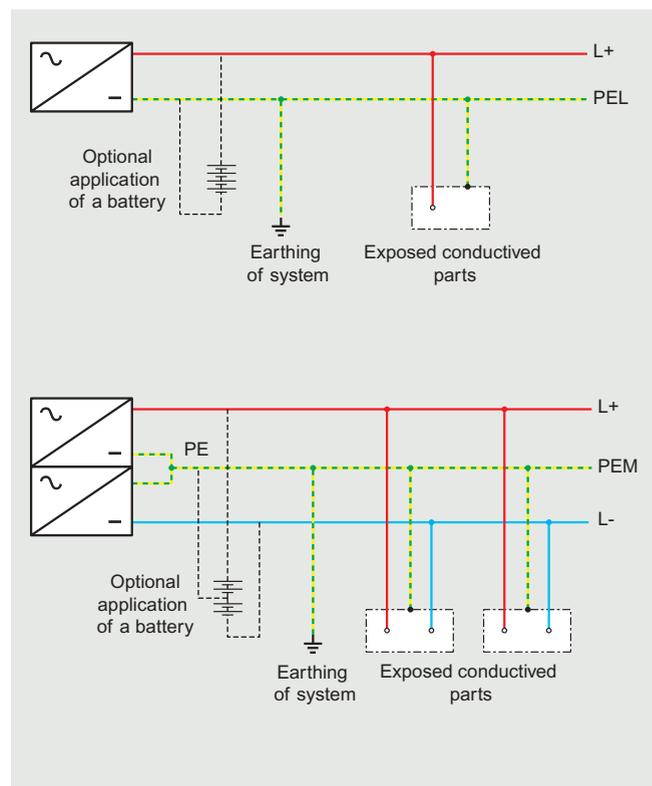
DC installation rules (continued)

3 TN-C-S SYSTEMS IN DC INSTALLATIONS

The diagrams below show the possibilities of parts of systems (on the left) in which the protective conductor and one of the polarities are combined (exposed conductive parts used as return) and parts of systems in which these conductors are separate (on the right) coexisting in the same installation, creating a TN-S neutral earthing system.
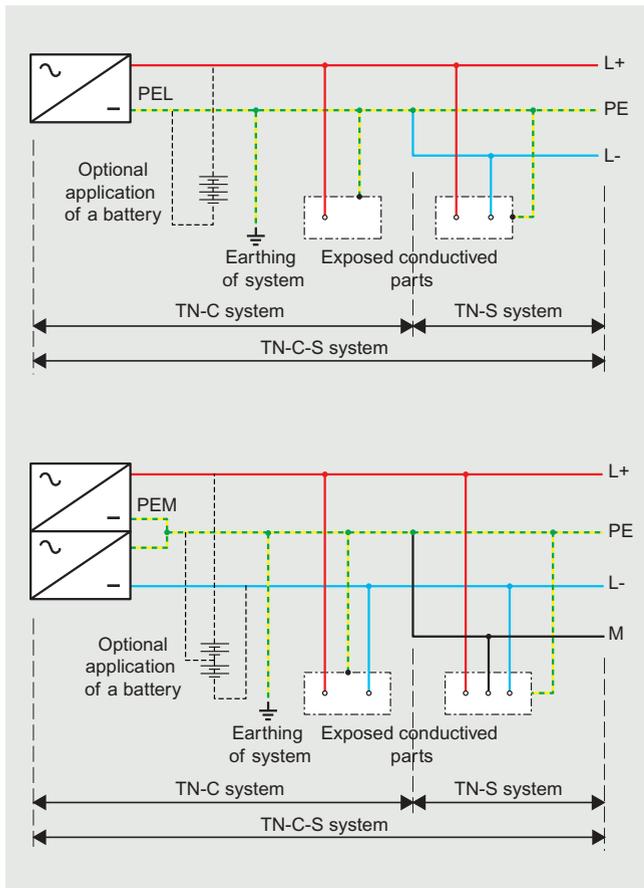
4 TT SYSTEMS IN DC INSTALLATIONS

The point on the power supply that is directly connected to earth is generally the negative pole or the middle pole.

The fault loop may include the earth over part of its path, which does not rule out the possibility of electrical connections, either intentional or de facto, between the earth connections of the installation's exposed conductive parts and that of the power supply.

Apart from in the latter hypothesis, the intensity of the fault current between phase and the exposed conductive part is lower than that of a short-circuit current, but it can nevertheless be sufficient to induce dangerous voltages. In practice, this system is not used, as the earth connections are not generally separate.
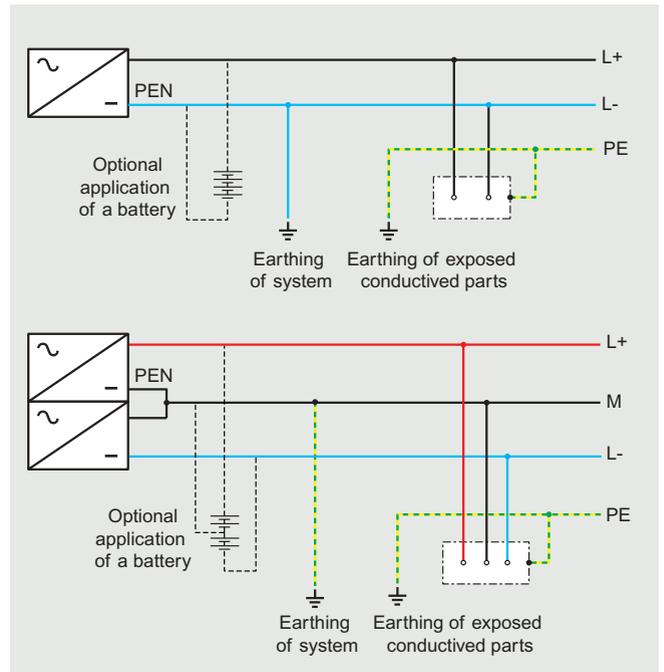
5 IT SYSTEMS IN DC INSTALLATIONS

In this system, the current resulting from a single fault between a live conductor and the exposed conductive part is sufficiently low not to induce a dangerous contact voltage.

The first fault current is closed by the leakage capacitance of the installation (on energisation) and optionally by the resistance R inserted between a point on the power supply (generally L-) or the middle conductor (M) and earth. The intensity of the current resulting from the first fault is limited either by the fact that the power supply has no earth connection or by the value of the resistance R.

Optional application of a battery — R

Earthing of system — Earthing of exposed conductive parts

L+ / M / L- / PE

Optional application of a battery — R

Earthing of system — Earthing of exposed conductive parts

L+ / L- / PE
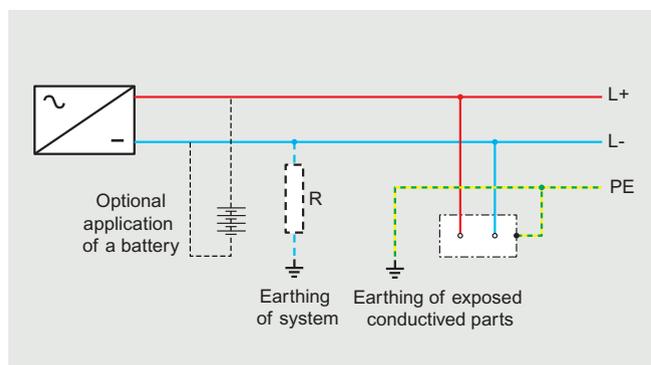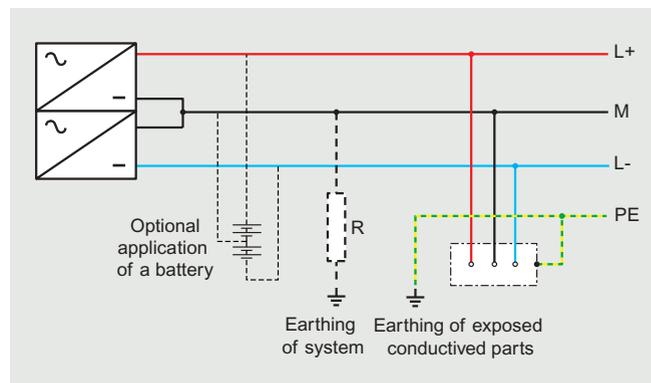
DC voltage ranges

Range	Directly earthed systems		Systems that are not directly earthed[1]
	Between pole and earth	Between poles	Between poles
I	U ≤ 120	U ≤ 120	U ≤ 120
II	120 < U ≤ 900	120 < U ≤ 1500	120 < U ≤ 1500

U is the nominal voltage of the installation (volts)

(1) If the compensator is distributed, the equipment supplied between pole and compensator is chosen so that its insulation corresponds to the voltage between poles

Example of a solar-powered installation

It is essential to coordinate the protective measures in the DC and AC parts of the installation with one another. The TN system should preferably be used.

Solar-powered modules

Voltage surge protector enclosure

Protection enclosure

DC/AC

Distribution enclosure

Meters

Earthing rod
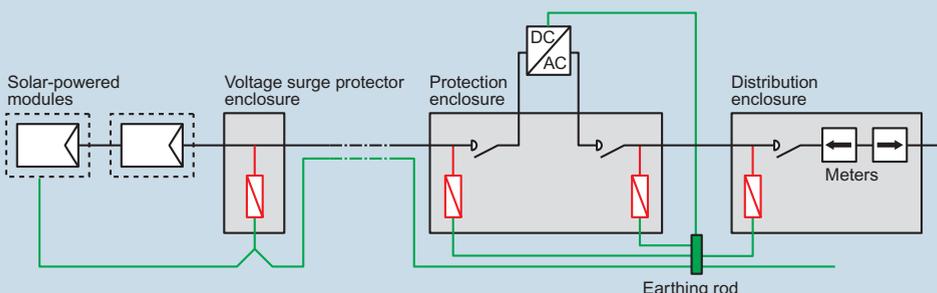
If the solar modules are not connected to a protection circuit, they must be installed in accordance with class II rules, or monitored by a permanent insulation monitoring device.

DC installation rules (continued)

DESIGNING DC INSTALLATIONS

The design and installation principles for a DC circuit are the same as those for an AC circuit.

The main differences concern the calculation of the short-circuit currents and the choice of protection devices.

1 INSULATION VOLTAGE

Standard IEC 60664-1, which is the reference standard for insulation, stipulates identical insulation values for AC and DC voltages. It is however important to specify and check the voltage to which reference is being made. For example, many products have an insulation voltage of 690 V between phases and implicitly 400 V between phases and earth. For DC they can only be used at 400 V.

Legrand distribution blocks, terminal blocks and busbars are designed with an identical level of insulation between phases and between phases and neutral. For these products, the DC insulation value corresponds to the given AC value.

2 RATED CURRENT OF BARS AND BUSBARS

The values given for AC bars can be directly used for DC bars (See Book 12 "Busbars and distribution"). For one bar, the values are totally transposable.

When busbars are concerned, the values given for AC can also be used; they are better and lead to a lower temperature rise, as there is no mutual inductance effect in DC circuits that would increase the impedance of the bars.

3 RESISTANCE TO SHORT-CIRCUIT CURRENTS

With regard to thermal stress I²t, the AC rms values can be directly transposed to DC for the rated currents. With regard to dynamic stress, a DC short circuit causes a higher degree of mechanical stress than a 3-phase short circuit (Ik3) and is more like a double phase short circuit (Ik2).

But there is no asymmetry factor leading to a one-off,

alternating force. The force is maintained and unidirectional.

The DC withstand value can be determined from the dynamic withstand value Ipk given for AC, reverting to the value corresponding to a symmetrical rms current and assigning it the corresponding ratio $\sqrt{2}$.

For example, an arrangement of bars with supports said to be 40 kÂ peak corresponds to an I rms of 40/2 = 20 kA (taking an asymmetry factor of 2 into account) The corresponding DC value would then be:

$20\sqrt{2}$ = 28 kA

4 CALCULATING SHORT-CIRCUIT CURRENTS

To calculate the short-circuit current Ik of a battery whose internal resistance is not known, the following formula can be used: C is the capacity of the battery in Ah.

$$I_K = 10\,C$$

To calculate the short-circuit current Ik at the terminals of a DC generator, the following formula is applicable: Ri is the internal resistance of the generator.

$$I_K = \frac{1.1\,U_n}{R_i}$$

To calculate the short-circuit current at any point in the installation, the following formula should be used: R_L is the resistance of the line.

$$I_K = \frac{1.1\,U_n}{R_i + 2\,R_L}$$

If there is a DC motor present, the above Ik value must be increased up to 6 times the In value of the motor.

5 SELECTING PROTECTION DEVICES

To select protection devices, it is advisable to check that the characteristics of the circuit (short-circuit current, rated current, time constant) are compatible with the choice of the appropriate protection device. Residual current devices for AC circuits are not suitable.

> **!** **gG and aM industrial fuse cartridges can be used in DC systems up to a voltage of 48 V**

5.1. DPX Moulded-case circuit beakers

Thermal-magnetic DPX can also be used up to an operating voltage of 250 V DC (two poles in series) or 500 V (three poles in series). Their magnetic thresholds are then increased by 50% (see table below).

Breaking capacities and protection thresholds of DPX with DC supply						
Devices		**2 poles in series**		**3 poles in series**	**Protection thresholds**	
		110-125 V	**250 V**	**500 V**	**thermal % Ir**	**magnetic % Im**
DPX 125	**16 kA**	20 kA	16 kA	16 kA	100 %	150 %
	25 kA	30 kA	25 kA	25 kA	100 %	150 %
	36 kA	36 kA	30 kA	30 kA	100 %	150 %
DPX 160	**25 kA**	30 kA	16 kA	16 kA	100 %	150 %
	50 kA	50 kA	25 kA	25 kA	100 %	150 %
DPX 250 ER	**25 kA**	30 kA	25 kA	25 kA	100 %	150 %
	50 kA	50 kA	36 kA	36 kA	100 %	150 %
DPX 250	**36 kA**	30 kA	25 kA	25 kA	100 %	150 %
DPX-H 250	**70 kA**	50 kA	36 kA	36 kA	100 %	150 %
DPX 630	**36 kA**	40 kA	36 kA	36 kA	100 %	150 %
DPX-H 630	**70 kA**	45 kA	40 kA	40 kA	100 %	150 %
DPX 1250	**50 kA**	50 kA	50 kA	36 kA	100 %	150 %
DPX-H 1250	**70 kA**	60 kA	60 kA	50 kA	100 %	150 %

5.2. DX circuit breakers

DX and DX-H circuit breakers (1P/2P/3P/4P - In ≤ 63 A) designed to be used with 230/400 V AC supplies, can also be used with DC supplies. In this case, the maximum value of the magnetic trip threshold must be multiplied by 1.4. For example: for a curve C circuit breaker whose trip threshold is between 5 and 10 In with an AC supply, the trip threshold will be between 7 and 14 In with a DC supply.
The thermal tripping curve is the same as with an AC supply.
The maximum operating voltage is 80 V per pole (60 V for single-pole + neutral). For voltages above this value, several poles must be wired in series.
The breaking capacity is 4000 A for a single-pole circuit breaker at maximum voltage (80 V DC per pole) At other voltages, the breaking capacities are given in the table below according to the number of poles in series.

Breaking capacity Icu according to EN 60947-2					
	Voltage	**Single pole**	**2-poles**	**3-poles**	**4-poles**
DX	≤ 48 V DC	6 kA	6 kA		
	110 V DC		6 kA	6 kA	
	230 V DC				10 kA
DX-H	≤ 48 V DC	10 kA	10 kA		
	110 V DC		10 kA	10 kA	
	230 V DC				15 kA

Structure of the protection system

The protective conductors always constitute the main part of this system, but the complexity of the system will increase with the requirements of information technology, voltage surge protection, local area networks, etc. with the risk of muddling the terminology somewhat. A quick reminder of the terminology may therefore be helpful...

Diagram of the protection system (see definitions on the following pages)

Local conductive structure connected to earth

Local equipotential link 12

Additional equipotential link 11a

Non-earthed equipotential link 17

Class II equipment 19

Circuit protective conductors 10

Main LV distribution board

Earthing conductor 18

Earthing of voltage surge protectors 15

Additional equipotential link 11b

Main equipotential link conductors 7

Earthed local conductive structure

Protective conductors main terminal or collector 9

Functional earth conductor 16

Main protective conductor 8

Lightning conductor

Metal busbar system

HV exposed conductive parts conductor 14

General main equipotential link conductors 6

HV/LV transformer protective conductor 13

Structure of the building

General equipotential link 5

Main earth terminal 4

Isolating device for measurement 3

Earthing conductor 2

Earth electrode 1

^ For a real "bonding" approach: earthing of shielding by clamps fixed on "Fixomega" claws clear identification of the circuits on Viking terminal blocks

Symbols

⏚ **Earth, general symbol**

⏚ **Green/yellow dual colour protective conductor Earth connection providing protection against electric shocks**

⏚ **Functional earth role, which does not necessarily include protection against electric shocks**

⊥ou⊥ **Exposed conductive part, electrical connection of chassis, voltage reference point**

↓ **Equipotential link**

⊗ **Exposed conductive part not linked to a protective conductor. If a functional link is necessary (for example linking exposed conductive parts), use the symbol ⊥.**

▣ **Device with double insulation achieved by construction, or assembly with double insulation (referred to as fully insulated), achieved by installation.**

DEFINITIONS

1 Earth electrode
Set of conductive elements in contact with the earth. The earth connection is established according to local conditions (type of ground) and the required resistance value.

2 Earthing conductor
Conductor providing the link with the earth electrode. It is generally not insulated, and has a minimum cross-section of 25 mm^2 (copper) or 50 mm^2 (galvanised steel).

3 Isolating device
This is inserted in the earthing conductor. The device is opened in order to measure the earth connection.

4 Main earth terminal
Electrical link between the earth circuit and the general equipotential link. Can be an integral part of the general equipotential link or the isolating device.

5 General equipotential link
Located at the origin of the installation and/or at the point of entry in each building. It links all the earthing conductors, the main equipotential link and the various protective conductors.

6 General main equipotential link conductor
Connects the metal parts of the structure, the busbars and frames to the general equipotential link. The cross-section must the same as that of the main protective conductor with a minimum of 6 mm^2 (10 mm^2 for aluminium) and a maximum of 25 mm^2 (35 mm^2 for aluminium).

7 Main equipotential link conductors
Connect the conductive parts near the main LV distribution board to the protective conductor terminals.
The cross-section must be the same as that of the protective conductor with a minimum of 6 mm^2 (10 mm^2 for aluminium) and a maximum of 25 mm^2 (35 mm^2 for aluminium).

8 Main protective conductor
Conductor linking the main earth terminal to the main protective conductor terminal. Its cross-section is determined according to the rules given in this section (choice or calculation).

Structure of the protection system (continued)

9 Protective conductors main terminal or collector
This is located in the main LV distribution board. It is chosen or determined according to the rules given in this section.

10 Circuit protective conductors
These are determined in accordance with the current of each load circuit, according to the rules given in this section (choice or calculation).

11 Additional equipotential links
These are used to ensure the continuity of the protective circuits.
a) Between exposed conductive parts, the cross-section is at least that of the smaller protective conductor of the two exposed conductive parts to be linked
b) Between exposed conductive parts and conductive parts, the cross-section must be at least half that of the protective conductor of the exposed conductive part to be linked.
NB: In both cases, a minimum of 2.5 mm^2 is necessary if the link is protected mechanically (in an enclosure, ducting, sleeve, etc.) and 4 mm^2 if it is not protected (flexible wire). These rules are applicable to the removable panels and doors of XL^3 and Altis enclosures when no equipment is fixed in them. When equipment is fixed in them or there are specific risks of indirect contact with these exposed conductive parts (feedthroughs for controls, no faceplate, etc.), the Legrand range of flexible braids provides an ideal solution for all installation requirements.

12 Local equipotential link: If in a TN or IT neutral earthing system, the lengths of the circuits upstream of the terminal circuits are not known or they are too long, a local equipotential link is created in each distribution board supplying the terminal circuits.
Its cross-section must be at least half that of the protective conductor supplying the board, with a minimum of 6 mm^2 (10 mm^2 for aluminium), and a maximum of 25 mm^2 (35 mm^2 for aluminium).

13 HV/LV transformer protective conductor
The cross-section is determined according to the type of conductor, the power of the transformer and the reaction time of the HV protection. In practice, its cross-section is identical to that of the main protective conductor.

< XL^3 enclosures:
the interconnection of the exposed conductive parts by design makes it a great deal easier to connect the protective conductors to the load circuits

< Equipotential link conductors connected to a collector bar or "main protective conductors terminal"

14 **HV exposed conductive parts conductor**
If the installation is supplied via a delivery substation, the cross-section used is 25 mm^2 (35 mm^2 for aluminium). For other types of supply, the cross-section must be calculated.

15 **Earthing of voltage surge protectors**
This is designed to discharge the fault currents resulting from the elimination of overvoltages. These conductors must be as short as possible and only used for this purpose. The minimum cross-section is chosen according the manufacturers' instructions: generally 4 to 16 mm^2

16 **Earthing conductor with no safety function**
This provides the earth connection, for functional reasons or due to the level of disturbance. Only use the green/yellow dual colour if the conductor also performs the protective function. The terms "noiseless earth" or "clean earth" must not be used

17 **Earthing conductor**
- Conductor for functional use only: voltage referencing (electronic exposed conductive parts), its cross-section is then chosen according to the actual current.
- Electromagnetic compatibility: the conductors must be chosen to be as short and wide as possible to reduce their impedance at high frequencies.

18 **Non-earthed equipotential link**
Link specific to certain restricted applications in non-conducting environments (test platform, etc.). All the exposed conductive parts and parts that are accessible simultaneously must therefore be linked.
The cross-sections are taken as being identical to those of the additional equipotential links.

19 **Class II equipment**
The exposed conductive parts of this equipment must not be connected to a protective conductor.

∧ **Connecting protective conductors by means of Viking green/yellow terminal blocks: the rail is used as collector**
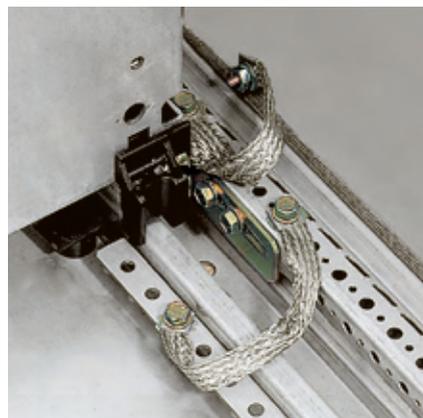
∧ **Earthing conductors consisting of braids (30 mm^2)**

Power factor compensation

Reactive energy compensation is an essential process in improving energy efficiency. It reduces the power consumption and thus its cost, enables optimum use of installations by preventing them being oversized, and more generally it improves the quality of energy systems.

Although it is currently only used in high power installations, there is no doubt that its application will become noticeable in the smallest installations where modern receivers with downgraded power factor (electronic devices, low consumption lighting, etc.) now play a major role.

Electrical installations are made up of three types of load: resistive loads, inductive loads and capacitive loads, which make up, in AC supplies, series and parallel arrangements of circuits known as RLC (see p. 86).

To this "historical" concept the following must now be added: the characteristic of signal distortion connected with the nature of the non-linear loads which absorb a non-sinusoidal current at the origin of an unnecessary additional power said to be distorting.

This distortion is quantified by the concepts of harmonics and total harmonic distortion THD (see Book 2).

It is essential to consider this new element as it has changed the treatment of power compensation by incorporating harmonic correction, thus leading to a change in what must be taken into consideration and in the products to be used, as "cleaning up" the system must now also be taken into account when choosing compensation solutions. This dual requirement is covered by the whole Legrand range.

From fixed capacitor banks to complete Alpimatic systems with protection against harmonics, high and low voltage, including Alptec measuring products and the various service and diagnostics offers, there is a comprehensive approach to compensation and improvement of energy quality.

^ **In industry, the presence of a large number of motors is the main cause of deterioration of the power factor**

Reactive power

Reactive power Q is an energy accumulated by the non-active or non-dissipative elements that make up capacitors (impedance $L\omega$) and inductances ($1/C\omega$). This energy is connected with the electric and magnetic fields that arise when they are supplied with power. In variable state, it passes alternately between capacitances and inductance and the voltages U_L at the terminals of the inductances and U_C at the terminals of the capacitances are always in anti-phase.

By sign convention to quantify these exchanges, it is said that inductances absorb reactive power and that capacitors create it.

The exchange can therefore be written:

If $L\omega = 1/C\omega$	The loads are equal at all times and Q = 0
If $L\omega > 1/C\omega$	The source must supply a power $Q = (L\omega - 1/C\omega) \cdot I^2$ (Q is positive)
If $L\omega < 1/C\omega$	The source receives reactive energy (Q is negative)

The reactive power supplied by the source is generally written Q, while that supplied by a compensation device is written Q' or Qc.

BALANCING SYSTEMS

In order to fully understand the effect of reactive power and the need to compensate for it, the equivalent diagrams applied to the systems (generators-lines-receivers) must be examined. It is first and foremost

on these and on upstream production centres that the reactive power called by users has harmful effects. The active power transferred between two voltage systems (generator E1 and receiver E2) with a transmission angle τ (phase shift between $\overrightarrow{V1}$ and $\overrightarrow{V2}$) due to impedance X of the transmission line is given by the equation:

$$P = \frac{V1 \cdot V2}{X} \cos \tau$$
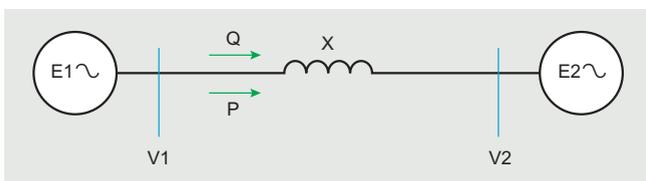
Applied voltage diagrams

• **Without compensation:**
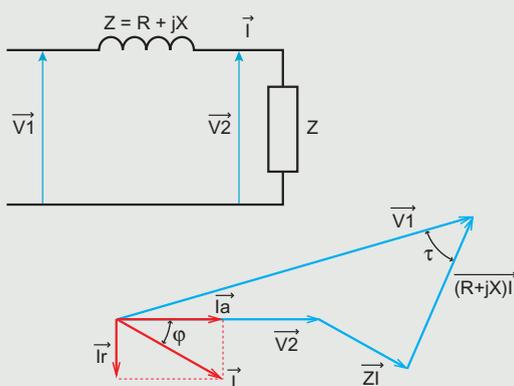
On this diagram, it can be seem that current I in load Z is shifted in relation to voltage V2 with a phase shift angle φ due to the reactance of this load (current Ir). The apparent current I is thus increased and the voltage drop (R + jX)·I in the line is also increased. In addition to the losses in the installation there are also further losses in the line, due to the reactive part of load Z.

• **With compensation:**
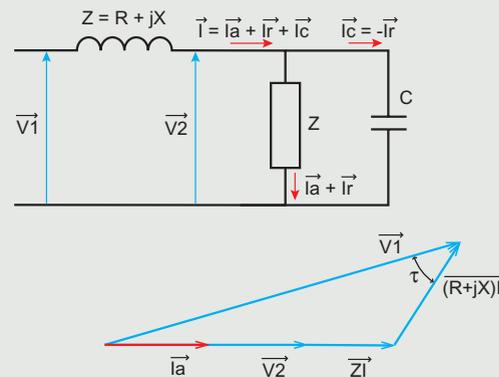
If this load is compensated in order to totally counteract the phase shift (φ = 0, cos φ =1), the current in load Z is reduced to its active part Ia.
The line voltage drop (R + jX)·I is also reduced, as is the line phase shift (transmission angle τ).

! Compensation of the load improves the energy supply conditions, beyond local treatment of an active/reactive imbalance, giving real coherence to the whole of the electrical system: generators-transmission lines-receivers. Legrand's compensation offer, which covers both high and low voltage, provides an ideal answer to all requirements. The financial and technical rules for distribution and location of capacitor banks are given on page 97.

Power factor compensation (continued)

THE NEED TO COMPENSATE FOR REACTIVE ENERGY

Inductive loads, typically motors and transformers, and also certain types of lighting with ballast, as well as welding equipment (see Book 2) or induction heating, have the particular feature of operating with the help of a magnetic field. Some of the power needed to generate this magnetic field is not converted into heat or work. Very long lines (by inductive storage) and also static converters (controlled rectifiers, AC power controllers, etc.) can also consume unnecessary energy by phase-shifting the current behind the fundamental voltage.

The energy that corresponds to this power is called reactive energy. It is expressed in "kilovolt-ampere-reactive hour" (kvarh).

Whatever the source and type of energy: public distribution system, standalone set, UPS or other, it is energy that is needlessly consumed.

> **!** Unlike the compensation of inductive circuits, compensation of predominantly capacitive circuits requires the use of inductances to absorb the reactive energy that is produced. This situation is found on distribution circuits (very long lines, cable networks), often when there is a low load on the circuits. New installations that use numerous electronic power supplies (data centres) may also have this particular feature. As well as avoiding feeding the energy back onto the system, compensation of an installation with too high a capacitance is necessary to limit the transient overcurrents and overvoltages that could occur when such loads are switched on, and to avoid self-excitation of synchronous motors.

The harmful consequences of reactive power on transmission lines described previously is also found in installations:
- It increases the necessary current at the risk of causing destructive overcurrents and problematic voltage drops leading to the need to oversize the conductors.
- It reduces the available active power, which limits the possibilities of using the source or

requires it to be oversized.
- It generates an additional operating cost connected with the pricing of the reactive energy consumed and measured by the distribution company.

Over-compensation
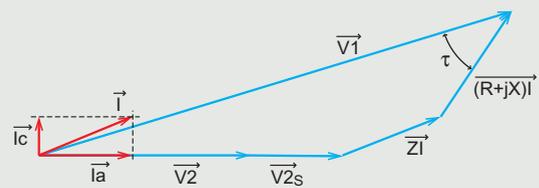
Over-compensation (Ic >Ir), increases the apparent current consumed (see p. 85) and also increases the voltage applied to the equipment. The illustration of vectors $\overrightarrow{V2_S}$ (with over-compensation) and $\overrightarrow{V2}$ (with appropriate compensation) shows this phenomenon, which must be avoided. Care must be taken when choosing energy compensation.

1 PARALLEL RLC CIRCUIT
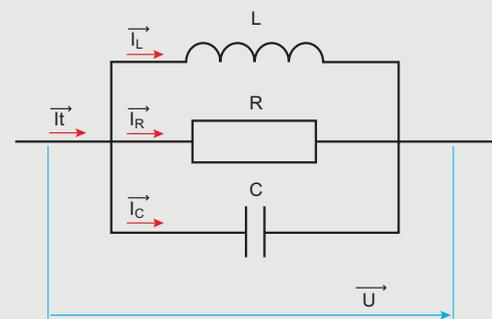
The impedances of the inductive, resistive and capacitive branches of the circuit are respectively:
$Z_L = L\omega$
$Z_R = R$
$Z_C = -1/C\omega$

Industrial systems are generally parallel RLC circuits. However each branch may itself make up other complex series or series/parallel systems. All three elements share the same supply voltage. The total current It is equal to the vectorial sum of the currents of all three elements: $\vec{It} = \vec{I_R} + \vec{I_L} + \vec{I_C}$
The impedance of this type of circuit is equal to the inverse of the sum of the inverses of each impedance, i.e. using complex numbers (see Book 2):

$$Z = \frac{1}{1/R + j(C\omega - 1/L\omega)} \text{ where } j = \sqrt{-1}$$

This equation shows that the impedance part due to the capacitance and the inductance may tend towards 0 if $L\omega = -1/C\omega$. This is the phenomenon of resonance (or more precisely, anti-resonance, as U_L and U_C are in anti-phase) which occurs at certain frequencies corresponding to an angular frequency:

$$\omega_o = \frac{1}{\sqrt{LC}}$$

Due to the equality $L\omega = -1/C\omega$, the impedance of the circuit is reduced at the resistive branch R. The current may then suddenly increase to dangerous or even destructive values. This phenomenon must in particular be controlled when installing compensation capacitors, especially if there are harmonics, as the frequency ω_0 can be reached more easily, and/or if there is a high impedance L (in particular in low power installations). See p. 115.
The power of each branch is written as follows:

$$P_R = I_R^2 \cdot R \qquad Q_L = I_L^2 \cdot L\omega \qquad Q_C = I_C^2 \cdot (1/C\omega)$$

2 CURRENT DIAGRAM

The phase shifts between currents in parallel RLC circuits and the powers associated with each of the impedances that make up these circuits can be represented by Fresnel current and power diagrams, which show the concepts of phase shift (φ) and power factor (PF or λ).
The power factor characterises the ratio of the active (useful power) power to the apparent power (sum of the active power and the reactive power).

When the currents and voltages are totally sinusoidal, the current diagrams and power diagrams are similar and the power factor (PF or λ) is identical to the cosine φ of the displacement angle between the U and I vectors.

2.1. Inductive circuit

I_R: current in the resistive branch
I_L: current in the inductive branch
I_C: current in the capacitive branch
It: total apparent current
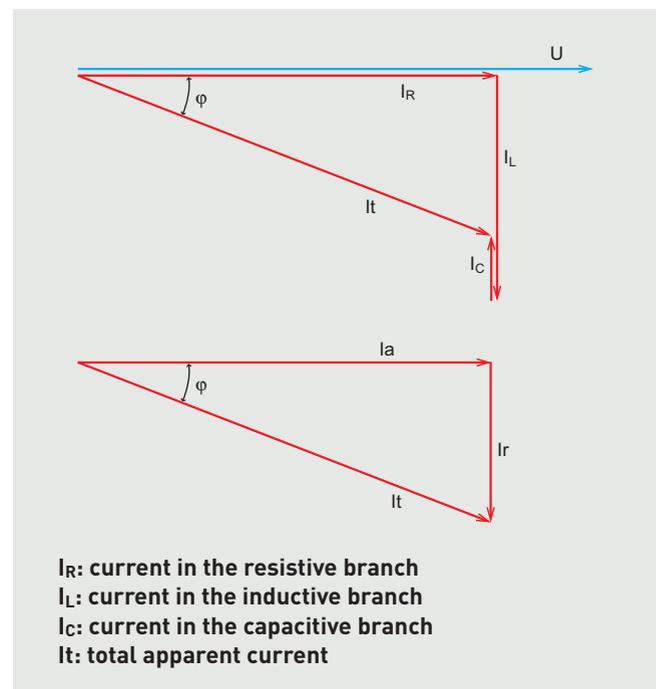
The above current diagram can be used to locate the vectors representing each of the three components of a parallel RLC circuit. The voltage U of the source is considered to be the reference. It should be noted that in this example, the value of I_L (reactive current in the inductance) is greater than that of I_C (reactive current in the capacitance). The φ angle is negative.
Adding capacitors will thus make it possible to supply the reactive current necessary for the compensation of I_L. The 2nd diagram is a simplified representation that is often used, in which the sum of I_L and I_C is written Ir (for reactive), which must not be confused with I_R (current of the resistive branch in the left-hand diagram).

Power factor compensation (continued)

The following relationships are established based on this diagram: Ia = It cos φ (active current), Ir = It . sin φ (reactive current), It² = Ia² + Ir² (apparent current).

2.2. Capacitive circuit

In the diagram below, the value of I_C (reactive current in the capacitance) is greater than that of I_L (reactive current in the inductance); the φ angle is positive.
To compensate for the reactive current I_C being too high, shunt reactors must be used. This must not be confused with the insertion of inductances in series with the capacitors, which is intended to limit the risk of resonance. See p. 114.
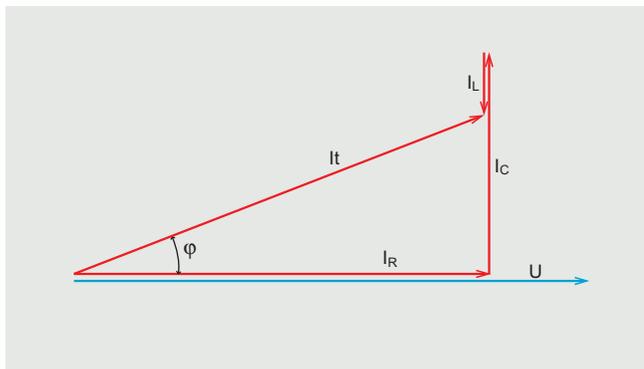
The 2nd diagram is a simplified representation that is often used, in which the sum of I_L and I_C is written Ir (for reactive)

If there are non-linear loads an additional power, referred to as distorting power, is introduced and the equality of the ratios between the power and the sinusoidal currents is no longer verified. Only measurement of the power rms values will give the power factor (see Book 2).

2.3. Groups of loads: additivity of reactive powers

Installations are made up of numerous groups of loads connected in parallel (A, B, C, etc. in the example below). The current/voltage phase shift and the total current It consumed by these groups of loads are the result of adding the current vectors. This is a somewhat complicated mathematical approach. However, the reactive power is easy to calculate from the arithmetical sum of the various powers of each load.
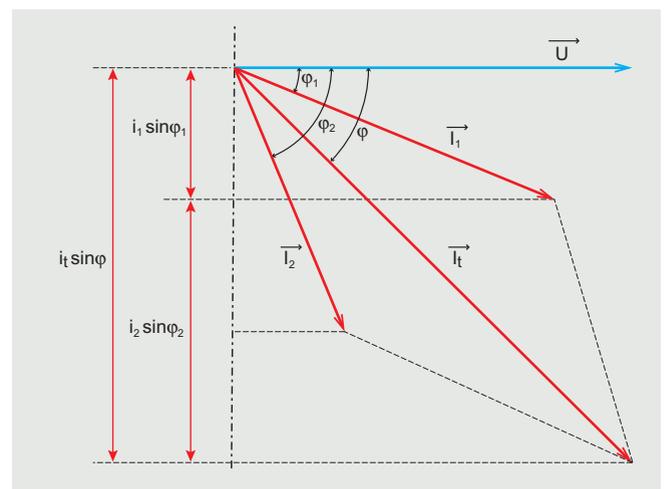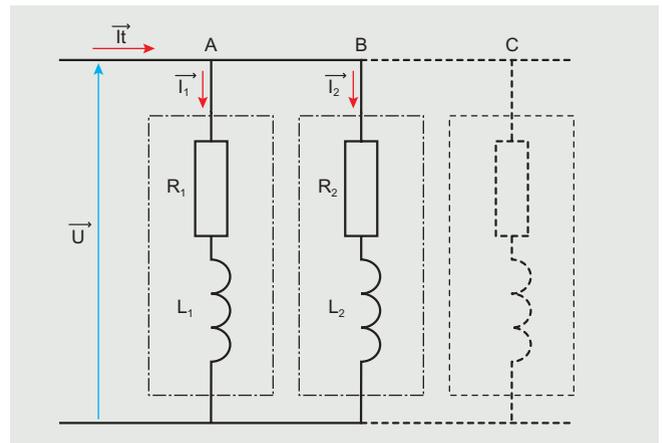
Receiver A is made up of inductance L_1 and resistor R_1, receiver B is made up of inductance L_2 and resistor R_2. The Fresnel diagram of the group of receivers A and B

demonstrates the relationship between vectors I_t, I_1 and I_2 associated with the sinusoidal values i_t, i_1 and i_2 respectively:

$I_t \sin \varphi = I_1 \sin \varphi_1 + I_2 \sin \varphi_2$

Multiplying the two members of the equation by U (common voltage in parallel group), gives:

$U.I_t \sin \varphi = U I_1 \sin \varphi_1 + U I_2 \sin \varphi_2$

The reactive power of the group of receivers is equal to the sum of the reactive powers of each receiver, i.e. $Q = Q1 + Q2$

This rule, which can be generalised to any group of receivers supplied with the same sinusoidal voltage is known as Boucherot's theorem. $Q = \Sigma Qn$

3 POWER DIAGRAM
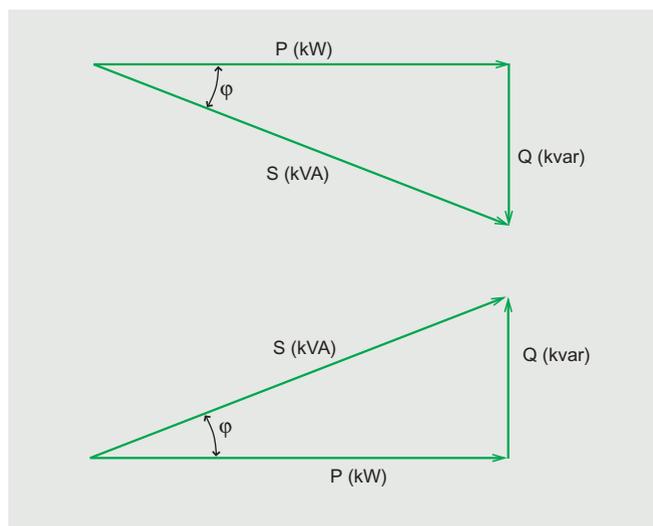
The two representations above are possible as the power has no sign. However, and by analogy with the current diagram, the first representation is preferable.

$P = U I \cos \varphi$ (active power in kW)
$Q = U I \sin \varphi$ (reactive power in kvar)
$S = U I$ (apparent power in VA)

For linear loads (see Book 2) :

$$\cos \varphi = \frac{\text{Active power P (kW)}}{\text{Apparent power S (kVA)}}$$

4 USE OF THE TANGENT φ

The tangent φ characteristic is widely used for its practicality. The closer it is to zero the less reactive energy is consumed. The advantage of this expression is that it characterises the balance of the exchange of reactive energy between the supply source and the consuming installation. Thus, if the power compensation is too high, the reactive power Q becomes positive again and the tangent φ once again moves away from zero.

$$\tan \varphi = \frac{\text{Reactive power Q (kvar)}}{\text{Apparent power S (kVA)}}$$

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

The permitted values for tan φ vary according to the country and the supply contract.
In France, the value above which billing is triggered (according to tarif period) is 0.4 (corresponding to a cos φ of 0.93) seen from the High Voltage metering side which also incorporates the reactive consumption of the connection transformer.
In Low Voltage metering, the reactive consumption of the HV/LV transformer is added on a fixed basis, reducing the permitted value of tan φ by 0.09. The tan φ value is then 0.31, corresponding to a cosine φ of 0.955.
The separation of electrical energy transmission and distribution companies leads to consideration of the possibility of lowering the tan φ value to 0.2.
The search for additional savings by penalising the reactive energy comes up against the technical requirement of reducing the resonance frequency of installations caused by too many capacitors (see p. 114). These are all contradictory elements that show that it is important to have a good knowledge of the characteristics of the installation and its receivers when implementing any compensation project.

Power factor compensation (continued)

INSTALLATION OF CAPACITORS

Adding capacitors gives the distribution system the necessary reactive power to return the power factor to the required level. Capacitors act like a source of reactive energy, which accordingly reduces the reactive power that the energy source must supply. The power factor of the system is therefore improved.
In an installation consuming reactive power Q1 (diagram 1), adding a capacitor bank generating a reactive compensation power Qc (diagram 2) improves the overall efficiency of the installation.
The reactive power Q1 initially supplied by the source is reduced to a new Q2 value (diagram 3), the φ angle is smaller and the cosine of this angle is improved (moves towards 1). The current consumption is also reduced.

P (kW)	P (kW) Qc (kvar)	P (kW)
φ1	φ1	φ2 Q2
Q (kvar)	Q1 (kvar)	Q1
S (kVA)	S1 (kVA)	S2 (kVA) Qc
Diagram 1	**Diagram 2**	**Diagram 3**
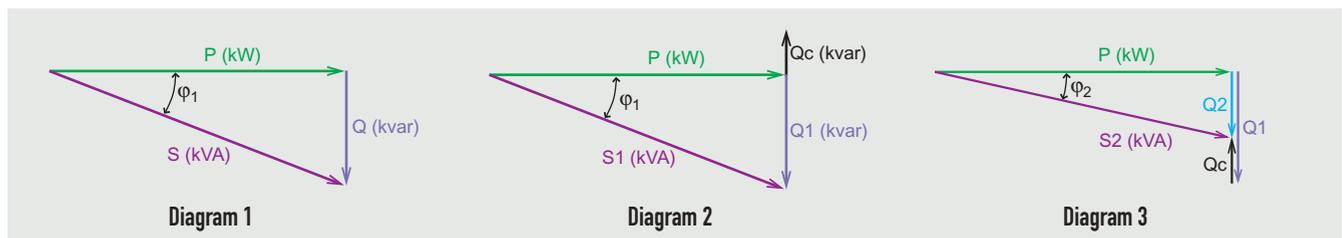
An energy efficiency tool

Power compensation enables the interests of the user and those of the energy distribution company to be combined, by improving the efficiency of installations through better use of the available power by limiting the consumption of reactive energy that is not only unnecessary and expensive but also a source of overcurrents in conductors. The example below shows how, by "increasing" the power factor from 0.7 to 0.95, for the same active power of 100 kW, the apparent power S (in VA), in comparison to that which actually has to be supplied, has been reduced by 35%.

Real power = 100 kW
After = 105 kVA
Reactive power after = 33 kvar
Apparent power
Before = 142 kVA
Reactive power before = 100 kvar
Capacitance added =67 kvar
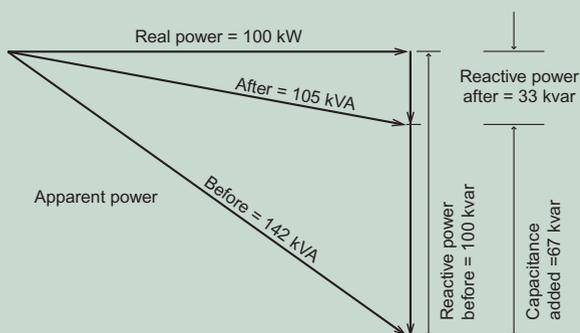
Power factor calculations:
Before PF = 100/142 = 0.70 or 70%
After PF = 100/105 = 0.95 or 95%

When the cos φ changes from an initial value cos φ1 to a final value cos φ2, as a general rule, the ohmic losses are reduced by: (1 − (cos φ1/cos φ2)²) × 100 as a %. Thus changing from a cos φ of 0.7 to 0.95 reduces the losses by 45%.
A poor cos φ therefore causes voltage drops in the conductors. The voltage drop in an electric line can be calculated using the formula: ∆U = I (R cos φ + L ω sin φ).

The maximum power that can be transmitted in an AC system is calculated using the following formulae:
P = UI cos φ for single phase and P = UI √3 cos φ for three-phase.

For the same current, the power transmitted is in direct proportion to the cos φ.
Thus changing from a cos φ of 0.7 to 0.95 enables the active power (in W) to be increased by 35% while reducing the associated line heat losses and voltage drops (see above). The power that a transformer can deliver is expressed in kVA. This is the available apparent power.
Even better use will be made of this transformer if the cos φ of the load is close to 1.
Improving the cos φ from an initial value cos φ1 to a final value cos φ2, for X (W) power used, releases an additional usable apparent power of: S (kVA) = P(kW) x [(1/cos φ1) − (1/cos φ2)]. Therefore a 1000 kVA transformer delivering a load of 700 kW with a cos φ of 0.7 is at its maximum load.
By improving the cos φ from 0.7 to 0.95, an additional available active power of 250 kW is released.

1 DETERMINING THE COMPENSATION BY THEORETICAL CALCULATION

1.1. Based on the cos φ and the currents
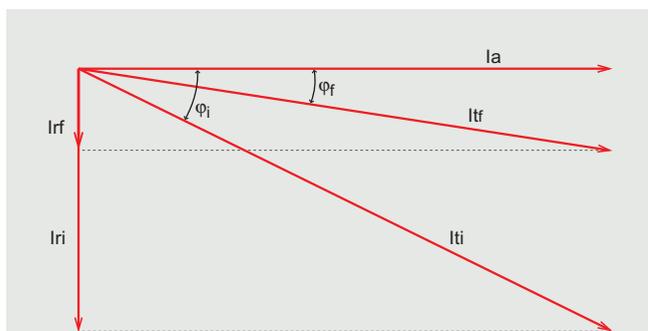
Ia: active current
Iti: initial apparent current (before correction)
Itf: final apparent current (after correction)
φ_i: phase shift before correction
φ_f: phase shift after correction
Iri: reactive current before correction
Irf: reactive current after correction
Ia = Iti.cos φ_i = Itf. cos φ_f

The final current is reduced so that:
Itf = Iti.cos φ_i/cos φ_f
The reduction of the apparent current is proportional to the improvement of the cos φ for the same active power P = UI cos φ.
Likewise, compensation of the cos φ, at constant apparent current, will enable an active power Pf increased in the same proportion as the ratio between the initial cos φ and the corrected cos φ to be carried.
Pf/Pi = cos φ_f/cos φ_i
The reactive power compensation Qc can be defined as being the difference between the initial power (Qi = U.Ir$_i$.sin φ_i) and the reactive power obtained after compensation (Qf = U·Ir$_f$·sin φ_f):
Q_C = U·(Ir$_i$ – Ir$_f$)·(sin φ_i – sin φ_f).

1.2. Based on tan φ and powers

Calculation based on the powers enables the required tan φ value to be used directly to determine the reactive power compensation to be installed.
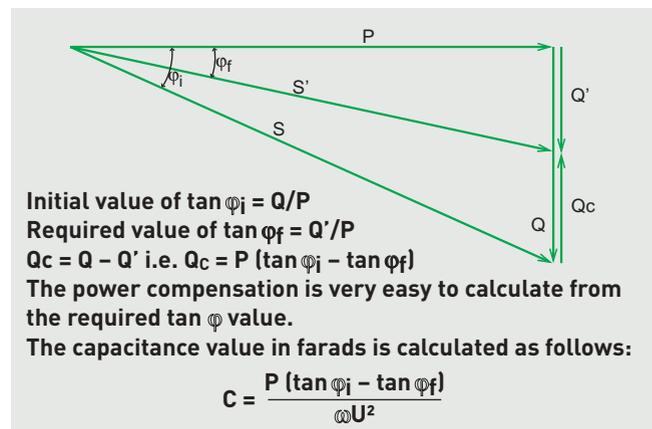
Initial value of tan φ_i = Q/P
Required value of tan φ_f = Q'/P
Qc = Q – Q' i.e. Q_C = P (tan φ_i – tan φ_f)
The power compensation is very easy to calculate from the required tan φ value.
The capacitance value in farads is calculated as follows:

$$C = \frac{P \left(\tan \varphi_i - \tan \varphi_f \right)}{\omega U^2}$$

🔍 Over-compensation

When the power compensation (Q_{C1}) is determined correctly, its value must be as close as possible to the reactive power Q to be compensated and the phase shift angle (φ') tends towards 0.
If the compensation (Q_{C2}) is greater than the reactive power, the phase shift angle (φ'') increases and the apparent power S'' increases.
The circuit becomes predominantly capacitive.
This leads to an increase in the current consumed which defeats the purpose.
Over-compensation also tends to increase the voltage applied to the installation (see p. 86). It must be avoided. It is generally considered that it should not exceed 1.15 times the power to be compensated.
The use of power factor controllers and step capacitor banks (see p. 105) avoids problems of over-compensation.

Power factor compensation (continued)

2 DETERMINING THE COMPENSATION BASED ON BILLING INFORMATION

As pricing and metering methods can vary from country to country, only a general process for assessing the need for reactive compensation, using the energy distribution company's readings or bills, will be described here.

Depending on the pricing method, access to the reactive energy consumption (kvarh) may be direct, together with the number of hours to which this value refers. It is then billed proportionately. This is generally the case for high power connections with one or more HV/LV transformers dedicated to the installation. For lower power connections, the reactive power consumption may be indirectly billed by the overconsumption of the apparent power (in VA) that is causes. For a "monitored power" connection, it is then billed according to the amounts by which the subscribed nominal apparent power is exceeded.

2.1. With reactive energy metering

In general, billing is applied when the $\tan\varphi$ exceeds a certain value (0.4 for example) and also according to time periods (peak times) or seasons (winter). The following calculation method, given for information purposes only, can be used to calculate the capacitor banks to be installed at the supply end of an installation with regular, repetitive operation. For random or sequenced operation, automatic banks, which switch on according to the load, are recommended so as not to "overcompensate" the installation.
- Analyse the bills for the period for which the reactive power is charged
- Select the month in which the bill is highest (kvarh to be billed)
- Evaluate the number of hours the installation operates per month (NBhm) (for example high-load times and peak times) during which the reactive energy is billed.

The amount of reactive energy billed Er fac will be:
$Er_{fac} = Er - Ea \cdot \tan\varphi = Er - (0.4 \cdot Ea)$
Power Qc of the capacitors to be installed:
$Qc = Er/NBhm$
- Er_{fac}: reactive energy billed each month (in kvarh)
- Ea (kWh) is the monthly active energy consumption for the period and the times defined above
- Er (kvarh) reactive energy consumption for the same period
- NBhm: number of hours operation per month for which Er is billed

Depending on the metering and billing methods, a certain amount of reactive energy may be permitted free or at a discounted rate by the distribution company.

In the same way, if metering is carried out at low voltage, the share of the reactive power consumed by the HV/LV transformer is added to the billed energy on a fixed basis. For example, if the permitted value of $\tan\varphi$ changes to 0.31 (see p. 89), the amount of reactive energy billed Er fac will become:
$Er_{fac} = Er - Ea \cdot \tan\varphi = Er - (0.31 \cdot Ea)$

< Multifunction digital measurement control unit with reactive energy metering

2.2. Without reactive energy metering

In this type of supply contract (for example, "yellow tariff" - low power supply - in France), the reactive energy consumption is not shown on the electricity bill. It is charged indirectly, based on the consumption of apparent power in kVA.

The distribution company charges a "fixed charge" that depends on the subscribed apparent power. Above this power, the consumer pays penalties. This is the principle of "monitored power".
Reactive energy compensation reduces the fixed charge by reducing the subscribed apparent power. It also enables the amounts over and above this subscribed demand to be limited (billing of the additional kVA over the limit).

To determine the reactive power value to be installed, the capital investment costs of the capacitors must be compared with the savings on the fixed charge paid to the distribution company.

> **!** In practice it is extremely inadvisable to install a capacitor bank without an accurate power analysis (calculated or simulated using software) or without preliminary measurements.
> Under-compensation will not provide the expected saving on the power consumption, while over-compensation will lead to probable overvoltages and resonance in relation to the supply (see p. 110).
> Remember that there is an increased risk of malfunctions in low power installations or those with distorting loads (harmonics).

> Nowadays reactive power is only billed for high power installations, using direct metering (of the reactive power in kvar) or indirect metering (of the apparent power in kVA). Low power installations (household subscribers or SOHO) are billed in kW and therefore their only disadvantage is the limitation of the available current. For responsible energy management with the aim of making better use of resources, and in view of the increasing numbers of receivers with a poor power factor (electronic power supplies, low consumption light bulbs), billing should logically move towards taking reactive power into account, which the next generation of "intelligent" meters will be capable of doing. Compensation of small installations will then come into its own.

Example of potential savings on an installation billed in kVA

An installation usually operates with a subscribed demand S of 160 kVA.
The average value of $\tan \varphi$ read is 0.75 (estimated $\cos \varphi$ 0.8).
At peak demand, the power reached is close to the subscribed demand.
At its peak, this installation therefore consumes an active power $P = UI\sqrt{3} \cos \varphi = 160 \times 0.8 = 128$ kW
and a reactive power $Q = P. \tan \varphi = 128 \times 0.75 = 96$ kvar.
Setting a target value of $\tan \varphi$ at 0.4, it will be possible to reduce the reactive power consumption
to $Q = P (\tan \varphi i - \tan \varphi f) = 128 \times (0.75 - 0.4) = 45$ kvar.
The saving in the reactive power consumption is G = 96 - 45 = 51 kvar.
The power compensation Qc could be 50 kvar by default.

The power S for the subscribed demand then becomes $S = \sqrt{(P)^2 + (Q)^2} = \sqrt{(128)^2 + (51)^2} = 138$ kVA.

All that remains is to compare the potential saving on the subscribed tariff with the necessary expenditure in terms of the installation of compensation capacitors. The payback time on such an investment is generally very fast and is justified as soon as $\tan \varphi$ exceeds 0.6.

This simplified approach may lead to a risk of overcompensation when the installation is not subject to high loads (for example, in the summer). This is why more or less detailed readings, depending on the complexity of the consumption cycles, are always recommended in practice.

Power factor compensation (continued)

3 CALCULATION BASED ON MEASURED ELEMENTS

Power measurements have changed a great deal due to the increasing complexity of the signals and current waveforms absorbed, and as a consequence metering equipment has also advanced (see Book 2), to such a degree that one no longer talks about power measurement but power analysis.

3.1. Power measurement

Power measurement is a one-off measurement that can provide useful information as to the operating conditions of an installation, but it remains more or less limited depending on the equipment used (direct access to $\cos\varphi$, $\tan\varphi$, and harmonic powers), may be marred by errors due to the waveforms and frequencies of the signals, and above all only provides an image at a given moment.

• In single phase systems the power can be measured (using a wattmeter), and also the voltage and the current. The P/UI ratio gives the $\cos\varphi$.

• In three-phase systems, power P1 and P2 can be measured, using the two wattmeters method.

$$\mathbf{P1 = U_{13}{\cdot}I_1{\cdot}cos\,(\widehat{U_{13}{\cdot}I_1}) = \overrightarrow{U_{13}}{\cdot}\overrightarrow{I_1}}$$
$$\Rightarrow \mathbf{P2 = U_{23}{\cdot}I_2{\cdot}cos\,(\widehat{U_{23}{\cdot}I_2}) = \overrightarrow{U_{23}}{\cdot}\overrightarrow{I_2}}$$
$$\mathbf{\overrightarrow{I_1} + \overrightarrow{I_2} + \overrightarrow{I_3} = 0 \;\;\Rightarrow\;\; \overrightarrow{I_3} = -\,\overrightarrow{I_1} - \overrightarrow{I_2}}$$
$$\Rightarrow \mathbf{P = \overrightarrow{V_1}{\cdot}\overrightarrow{I_1} + \overrightarrow{V_2}{\cdot}\overrightarrow{I_2} - \overrightarrow{V_3}{\cdot}\overrightarrow{I_1} - \overrightarrow{V_3}{\cdot}\overrightarrow{I_2}}$$
$$\mathbf{P = \overrightarrow{I_1}\,(\overrightarrow{V_1} - \overrightarrow{V_3}) + \overrightarrow{I_2}\,(\overrightarrow{V_2} - \overrightarrow{V_3}) = \overrightarrow{I_1}{\cdot}\overrightarrow{U_{13}} + \overrightarrow{I_2}{\cdot}\overrightarrow{U_{23}} = P1 + P2}$$
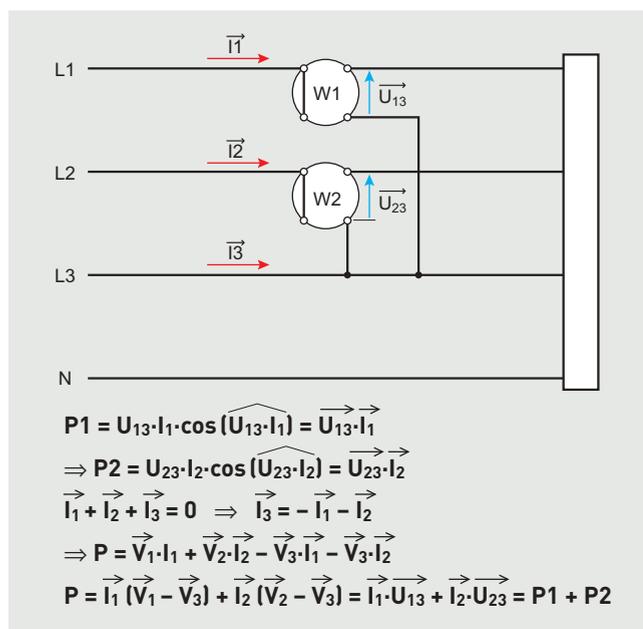
The total power in three-phase systems is obtained by adding together the readings from two wattmeters. The $\tan\varphi$ is calculated the same way:
$\tan\varphi = \sqrt{3}{\cdot}(P1 - P2) / (P1 + P2)$.

In balanced state, the reactive power Q can be measured using a single wattmeter.

It is demonstrated that $\cos\,(U_{13}{\cdot}I_1) = \cos\,(\pi/2 - \varphi)$
The reactive power in three-phase systems is written
$Q = \sqrt{3}{\cdot}P$.

$$\mathbf{P = U_{23}{\cdot}I_1{\cdot}cos\,(\widehat{U_{13}{\cdot}I_1}) = \overrightarrow{U_{23}}{\cdot}\overrightarrow{I_1}}$$
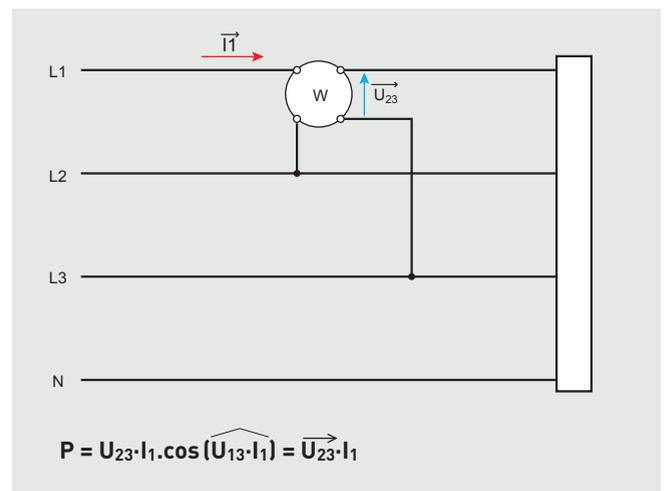
🔍 Calculation for energy suppliers (small power plants)

For this type of installation, the independent power producer must supply the distribution company with an amount of reactive energy equal to a contractual share of its production of active energy during high-load times and peak periods. In this case, the calculation of the capacitor bank must take the following into account:
• The on-load active consumption of the generator
• The on-load reactive consumption of the LV/HV transformer (if there is one)
• The reactive energy to be supplied (contractual share of the active energy produced)

4 CONVERSION TABLE

This table can be used to calculate (based on the power of a receiver in kW) the power of the capacitors to change from an initial power factor to a required power factor. It also gives the equivalence between cos φ and tan φ

Power of the capacitors to be installed (in kvar) per kW of load												
Current values		**Target values**										
cos φ →		**0.90**	**0.91**	**0.92**	**0.93**	**0.94**	**0.95**	**0.96**	**0.97**	**0.98**	**0.99**	**1**
↓		**0.48**	**0.46**	**0.43**	**0.40**	**0.36**	**0.33**	**0.29**	**0.25**	**0.20**	**0.14**	**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

Power factor compensation (continued)

Power of the capacitors to be installed (in kvar) per kW of load (continued)											
Current values		**Target values**										
cos φ →		**0.90**	**0.91**	**0.92**	**0.93**	**0.94**	**0.95**	**0.96**	**0.97**	**0.98**	**0.99**	**1**
↓		**0.48**	**0.46**	**0.43**	**0.40**	**0.36**	**0.33**	**0.29**	**0.25**	**0.20**	**0.14**	**0**
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
0.91	**0.46**			0.300	0.061	0.093	0.127	0.164	0.205	0.253	0.313	0.456
0.92	**0.43**			0.000	0.031	0.063	0.097	0.134	0.175	0.223	0.283	0.426
0.93	**0.40**				0.000	0.032	0.066	0.103	0.144	0.192	0.252	0.395
0.94	**0.36**					0.000	0.034	0.071	0.112	0.160	0.220	0.363
0.95	**0.33**						0.000	0.037	0.079	0.126	0.186	0.329
0.96	**0.29**							0.000	0.041	0.089	0.149	0.292
0.97	**0.25**								0.000	0.048	0.108	0.251
0.98	**0.20**									0.000	0.060	0.203
0.99	**0.14**										0.000	0.143
1	**0**											0.000

Example: 200 kW motor - cos φ = 0.75 - cos φ to be achieved: 0.93 - Qc = 200 × 0.487 = 98 kvar.

INSTALLING CAPACITORS AND SPECIFIC INSTALLATIONS

1 FINDING THE OPTIMUM LOCATION

Although in general, the calculation of the reactive power to be installed is initially carried out globally, it is advisable not to be swayed by the apparent simplicity of this process, and to look further for the optimum locations for more targeted compensation, referred to as "sector" or even "individual" compensation.
The choice of capacitors and the type of operation of the bank (fixed or automatic) can then be adapted to provide better efficiency and a quicker return on investment.
In all cases, the active and reactive powers must be determined first of all and as far as possible the profile of the consumptions at the various places in the installation where capacitors may be located.
The analysis of this data (see the Power Analysis process in Book 2) enables the values of the minimum, average and maximum reactive powers to be supplied at each point studied to be determined.

> **Installing compensation depends on the minimum reactive power to be supplied locally compared with the global power that would be necessary for the whole installation. In other words, there is no point in compensating an entire installation if only one receiver or one sector consumes reactive energy, especially if this demand is variable. A dedicated automatic capacitor bank would be much more effective in this case.**
> **A local or individual reactive energy demand that is greater than 50% of the global demand can be considered to justify specific compensation.**

1.1. Global compensation

When the load does not vary, global compensation is suitable and provides the best savings/performance compromise.

> High voltage global compensation

The capacitor bank is connected upstream of the HV/LV transformer.
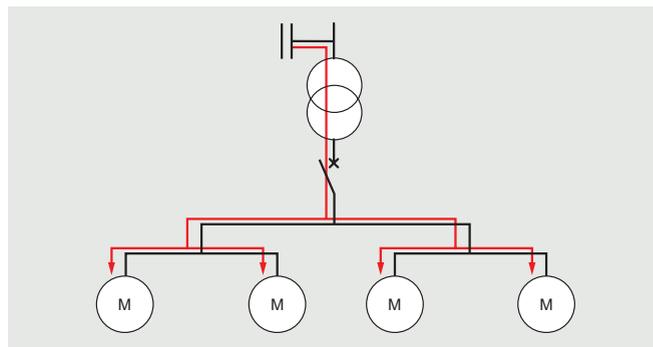
The additional cost connected with high voltage insulation rules out any benefit of using this for low power compensation (apart from in the case of individual requirements). The median value of 1000 kvar is the level above which the installation of an HV capacitor bank can be considered, as the supply currents and ratings of the associated protection devices can become prohibitive in low voltage at this level.

> Low global voltage compensation

Power factor compensation (continued)

The capacitor bank is connected to the main distribution board and provides compensation for the whole installation. It remains in operation permanently, at least during the reactive energy billing period for normal operation of the site.

> Mixed compensation
This can combine the advantages of high voltage global compensation with low voltage sector compensation. But it may also concern high voltage compensation (on a specific receiver) combined with global compensation that may be low voltage.

1.2. Sector compensation
The capacitor bank is connected in the distribution board at the head of a circuit or a group of circuits, or better still in the distribution switchboard of the sector concerned, and supplies the reactive energy required by one sector of the installation.
A large part of the installation is thus freed from the consumption of reactive power.
As with any compensation, the important point is to eliminate the penalties for excessive consumption of reactive energy and increase the transformer's available active power. At the same time, the currents carried upstream of the compensated sector and the

associated ohmic losses are reduced. The active power availability (kW) is increased. But a risk of over-compensation if there are significant load variations must be taken into account. This risk can be eliminated by installing step capacitor banks.
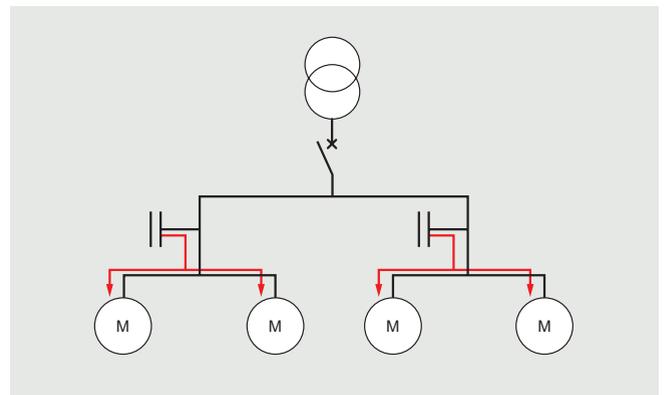
Sector compensation is recommended when the installation covers a large area and when it contains sectors with high or mixed reactive energy consumption.
High voltage compensation can also be used in sectors when it is applied to very high power motors for example, which are often supplied with high voltage.

Power factor controllers

Alptec power factor controllers continuously control the power factor of the installation. These devices control the connection and disconnection of the compensation capacitors according to the required power factor, the value of which can be programmed. Depending on the model, they can control 3, 5, 7 or 12 capacitor steps (see p. 105). They have advanced control functions (digital screen, internal temperature sensor) and communication functions (RS232 port for management via a PLC or PC, programmable relay for remote alarm).
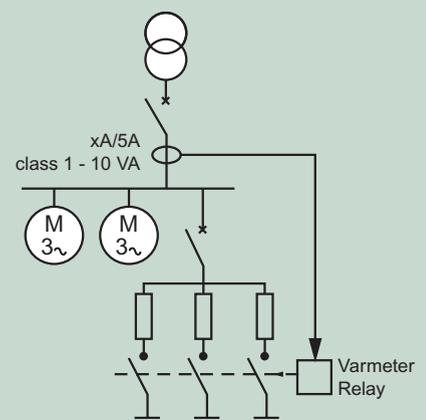
1.3. Individual compensation

In this configuration, the capacitor bank is connected directly to the terminals of the receiver (motor, variable control unit, furnace, etc.).
The compensation produces the right amount of reactive energy at the location where it is consumed.
This is the type of compensation that offers the most advantages but which is the most costly.
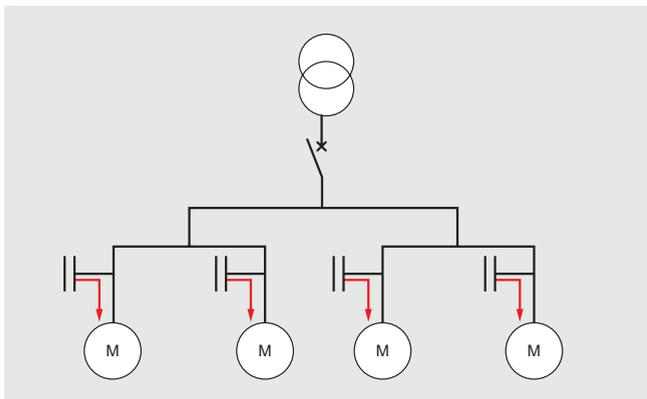
As well as eliminating the penalties for excessive consumption of reactive energy and increasing the transformer's available active power, the main advantage of this type of compensation is the limitation of the currents carried in the busbars located upstream of the receiver, thus reducing the heat losses (kWh) and voltage drops in the busbars. If capacitor banks with harmonic filters are used (see p.122), eliminating the harmonics as close as possible to their source will prevent them circulating in the whole installation, reducing the losses due to the distorting power as well as reducing the risk of possible resonance with another capacitor bank installed further upstream.

> **!** Consideration of the layout of the capacitor banks and their distribution is of primary importance. Legrand's services are available to provide help with these choices. The savings made and achieving the required flexibility of operation will depend on these choices.

2 REACTIVE COMPENSATION OF ASYNCHRONOUS MOTORS (compensation at the motor terminals)

• If $Qc \leqslant 90\%\ I_0 \sqrt{3}\,U$ • If $Qc > 90\%\ I_0 \sqrt{3}\,U$

I_0: Motor off-load current
U: Supply voltage
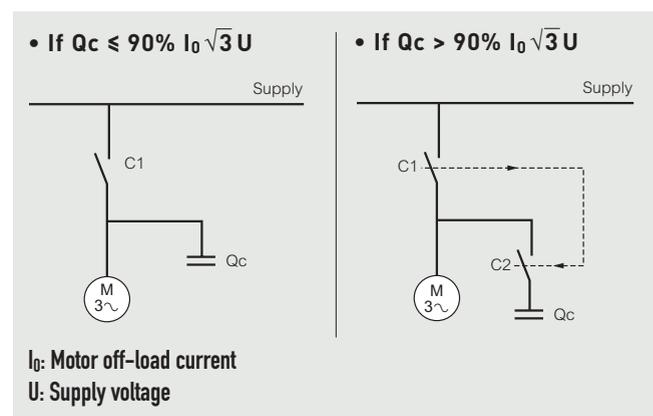
The table below gives, for information purposes only, the maximum capacitor power that can be connected directly to the terminals of an asynchronous motor without any risk of self-excitation. It will be necessary to check in all cases that the maximum current of the capacitor does not exceed 90% of the magnetising current (off-load) of the motor.

Maximum motor power		Maximum speed rpm		
		3,000	1,500	1,000
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

INSTALLING CAPACITORS AND SPECIFIC INSTALLATIONS

Power factor
compensation (continued)

If the capacitor power required to compensate the motor is greater than the values given in the previous table or if, more generally: $Q_c > 0.9 \cdot I_0 \cdot \sqrt{3}\, U$, compensation at the motor terminals will however remain possible by inserting a contactor (C2), controlled by an auxiliary contact of the motor contactor (C1), in series with the capacitor.

3 REACTIVE COMPENSATION OF TRANSFORMERS

In order to operate correctly, a transformer requires internal reactive energy to magnetise 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) | Power (kvar) 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.

Capacitors for induction furnaces

Legrand has a range of special "all film" technology capacitors (see p.104) for compensation and balancing of induction furnaces.
These products conform to standard IEC 60110 covering a voltage range from 50 V to 3000 V.
They are air or water-cooled depending on the frequency, which may cover a range from 50 Hz to 200 kHz.
These capacitors are custom designed according to the requirements and characteristics of the installation.
They can be supplied with or without discharge resistor, internal fuses, multiple outlets or pressure monitoring and thermostat protection devices.
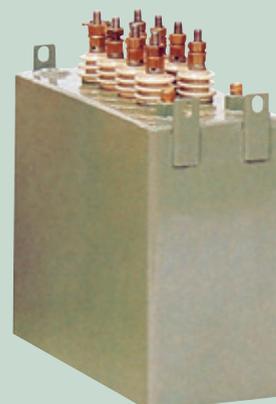
Water-cooled capacitor for medium frequency induction furnaces

STRUCTURE OF HV CAPACITORS

Compensation capacitors are installed in numerous locations in electrical installations. They are to be found in high voltage transmission and distribution systems, in transformer substations and also at various levels in low voltage installations. Capacitors therefore have to be made in accordance with very diverse technical specifications, for powers ranging from a few kvar to several Mvar. Installing capacitors in electrical systems fulfils several functions. Although the most well-known is power factor compensation, they also improve the voltage regulation of transmission lines by reducing the voltage drop (see p. 85) and increase the capacitive component of lines that are naturally inductive.

Capacitor banks are made up of capacitor units wired, protected and connected together according to different connection modes appropriate to each type of use. Each of these modes has advantages and disadvantages.

It should also be noted that numerous detection systems (current or voltage relays, controllers, etc.) are used with capacitor banks to detect (alarm threshold) and eliminate dangerous situations that could occur: unbalance, cascading damage, etc.

1 DELTA CONNECTION

This is the most commonly used connection mode for capacitor banks with voltages lower than 12 kV. This configuration, which is used in particular in distribution installations, provides maximum reactive power in minimum dimensions. The compensation balances itself "naturally" if there is current unbalance or phase shifting of one phase in relation to another (presence of powerful single-phase receivers).

However, this connection mode does not allow filtering of zero sequence components (3rd order harmonics and their multiples). The capacitors must be insulated for the full voltage (connection between phases), and if there is a breakdown the consequence is that the fault current is high as it is the result of a phase-to-phase short circuit.
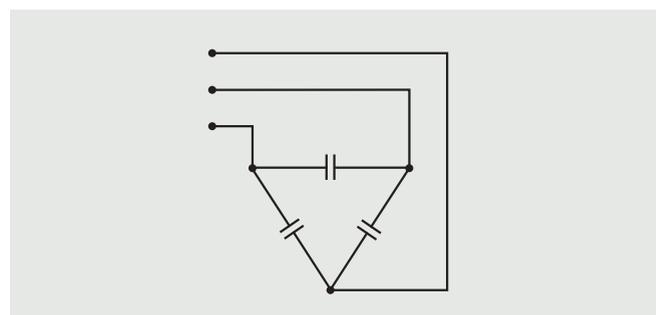
2 STAR CONNECTION, NEUTRAL NOT CONNECTED

Star connection has a number of technical advantages in relation to delta connection, but it is less favourable from an economical point of view. Amongst other things it can block zero sequence currents. As the capacitors are subject to phase-to-neutral voltage, their value must be multiplied by $\sqrt{3}$ to obtain the same reactive power as in delta connection. Their
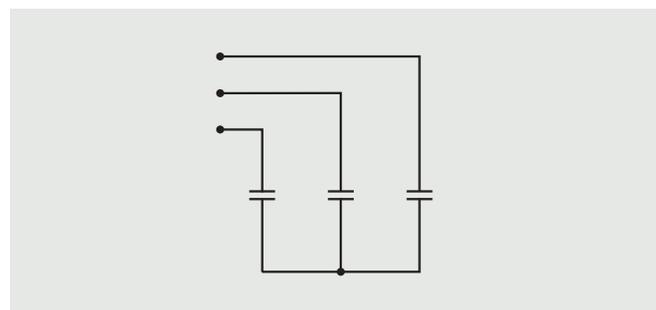
insulation voltage must nevertheless be provided for the phase-to-phase voltage to avoid the breakdown of one branch causing another branch to break down. This is the main drawback of this layout, where the loss of capacitor elements may not be detected, leading to load unbalance and no compensation. For this reason, double star connection is preferable.

Power factor compensation (continued)

3 DOUBLE STAR CONNECTION, NEUTRAL NOT CONNECTED

Current transformer and detection
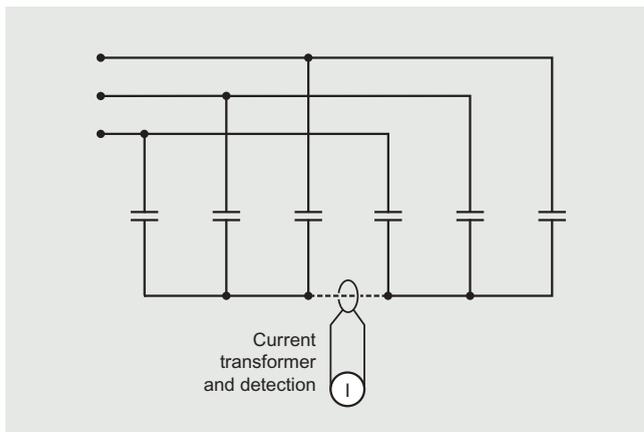
This type of wiring is suitable for all powers and all voltages of capacitors. It retains the advantages of star connection, and adds a protection mode enabling internal faults to be detected. As well as increasing the capacity of the bank, it also enables capacitors only insulated for phase-to-neutral voltage to be used. An unbalance protection device (transformer and current relay) continuously monitors the unbalance current between the two neutral points and if necessary triggers the disconnection of the bank.

High voltage capacitor banks are composed of elementary capacitors, generally connected in several serial-parallel groups, providing the required electrical characteristics for the device. The nominal insulation voltage of the bank depends on the number of groups in series, while the power depends on the number of elementary capacitors in parallel in each group.

4 STAR AND DOUBLE STAR CONNECTIONS, NEUTRAL EARTHED

Connections with earthed neutral provide better protection against transient overvoltages (lightning) and against electromagnetic disturbance in general.
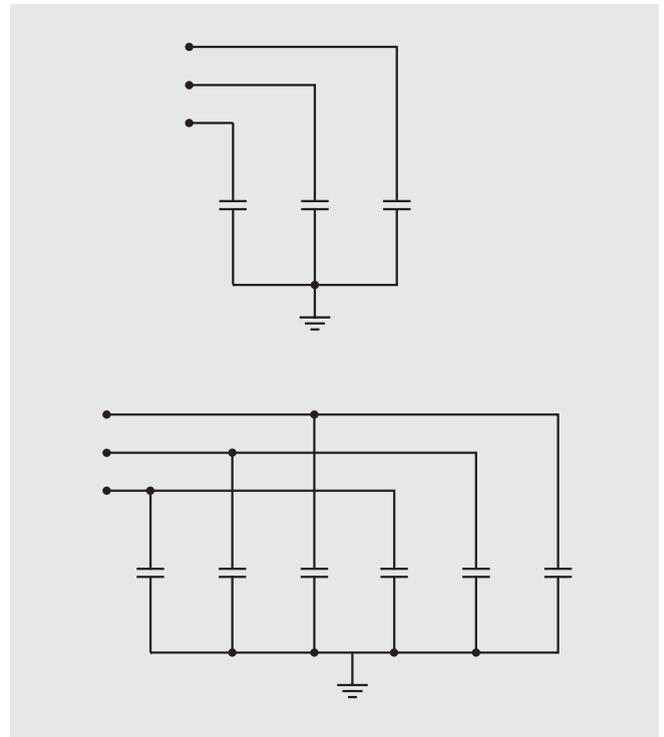
However, resonances and zero sequence currents can be produced if there is a fault either as a result of internal breakdown or loss of a supply phase. These configurations require protection against overvoltages and unbalance.

5 H CONNECTION

H connection can be used for delta or star single-phase or three-phase connections. The diagram opposite represents a branch (between two phases or between phase and neutral).
This type of wiring is intended for high power HV capacitor banks. For three-phase capacitor banks, the unbalance is monitored on each phase. It provides greater current unbalance measurement sensitivity.

Single-phase capacitor

Unbalance CT
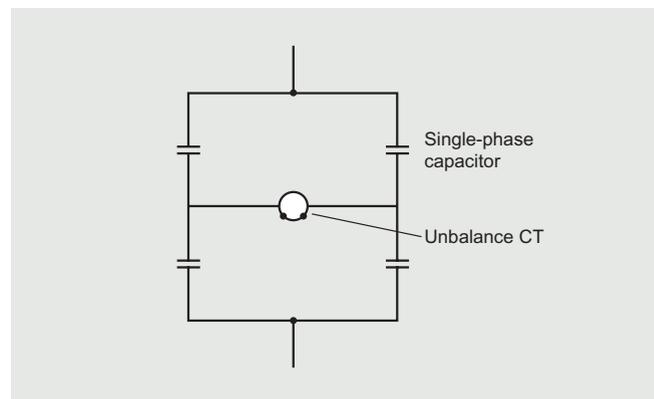
Internal faults in capacitor banks

■ **Protection by pressure monitoring device**

In addition to or instead of fuses, and depending on the required protection conditions, capacitors can also be protected using a pressure switch that detects increased pressure in the case, generated by the breakdown of the elementary capacitances. A contact feeds back the measured state to trigger the breaking of a protection device.

■ **Protection using internal fuses**

**When an internal fault affects one or more elementary capacitors, it is important to detect this fault and eliminate it as quickly as possible to avoid avalanche breakdown of the bank. If there is a fault in an elementary capacitor, the corresponding internal fuse eliminates the faulty element. Given the large number of elementary capacitors that make up the device, the resulting loss of power is negligible (less than 2%). The breaking of an internal fuse can be triggered by an overvoltage or overcurrent originating externally which exceeds the limits set for the product or if there is an internal insulation fault.
Used with fuses, protection based on maintaining the symmetry (see above diagram), enables detection of an unbalance that corresponds to a number of faulty capacitors. The adjustment threshold, precisely defined by the manufacturer, sets maximum operating conditions with a view to ensuring maximum reliability and continuity.**

Legrand offers four configuration possibilities for its "All Film" capacitors (see p. 139).
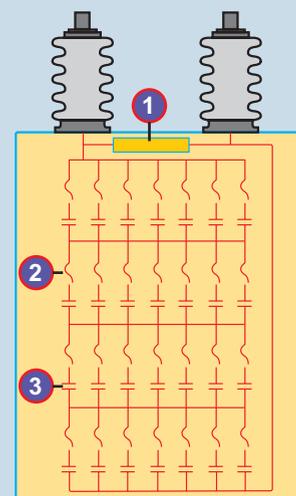
Internal view of an "all-film" HV capacitor with internal fuses
1. Discharge resistor
2. Internal fuse
3. Elementary capacitance

Power factor compensation (continued)

"All film" HV capacitors

Using the most modern insulating polymer film technologies, Legrand HV capacitors provide optimum reliability.
Each elementary capacitance is made using two aluminium foils forming the armatures insulated by a high dielectric quality polypropylene film. After being dried, treated and impregnated under vacuum with a non-chlorinated, non-toxic, biodegradable liquid dielectric, all the interconnected elements are placed in a stainless steel case, with porcelain terminals or insulated feedthroughs at the top, for connecting the device.
This "all film" capacitor technology has top quality characteristics: excellent resistance to electrical fields, very low ohmic losses limiting temperature rises, a much longer service life than with previous technologies using paper, and excellent resistance to transient overcurrents and overvoltages. With the polypropylene film, the liquid dielectric, which has a remarkably high chemical stability, a high gas absorption capacity and a high partial discharge extinction capacity (flash point approximately 150°C), ensures total insulation between electrodes.

Technical characteristics:

Average loss factor	on energisation	0.15 W/kvar
	after 500 hours' operation	0.10 W/kvar
Average variation of the capacitance as a function of the temperature		$2 \times 10^{-4}/°C$
Operating frequency	Standard	50 Hz
	On request	60 Hz
Permissible overloads	permanent	1.3 In
Permissible overvoltages	12 h/24 h	1.1 Un
	30 min/24 h	1.15 Un
	5 min/24 h	1.2 Un
	1 min/24 h	1.3 Un

Standard insulation levels (phases/earth) for individual capacitors						
Highest voltage for equipment Um (rms value in kV)	2.4	3.6	7.2	12	17.5	24
Test voltage (10 s) at industrial frequency (in kV)	8	10	20	28	38	50
Lightning impulse withstand voltage (peak value in kV)	35	40	60	75	95	125
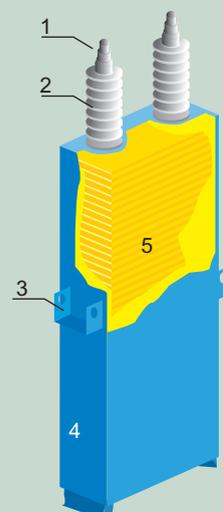
1. Connection
2. Porcelain terminal
3. Fixing lug
4. Stainless steel case
5. Active part

COMPOSITION OF LV CAPACITOR BANKS

A distinction is made between fixed value capacitor banks and "step" (or automatic) capacitor banks which have an adjustment system that adapts the compensation to the variations in consumption of the installation.

1 FIXED CAPACITOR BANKS
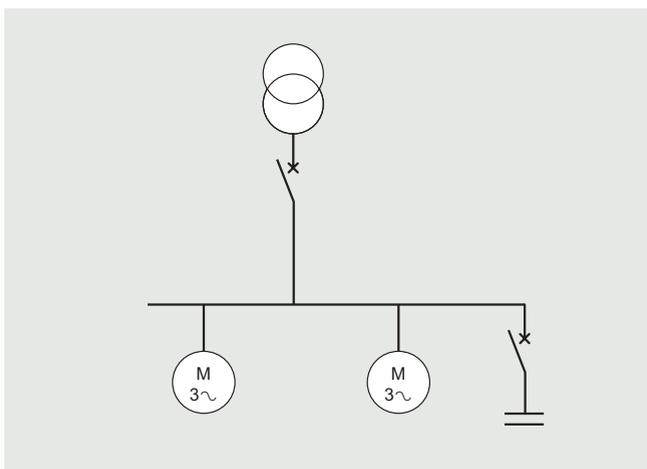
With constant power, these are suitable for individual compensation at the terminals of receivers (motors, transformers, etc.) or more generally for installations where the load is constant and fluctuates very little.

< Alpivar² fixed capacitor bank

2 STEP CAPACITOR BANKS WITH AUTOMATIC REGULATION

This type of device enables the reactive power supplied to be adapted to variations in consumption, thus keeping the compensation at its optimum value.
It is used in situations where the reactive power consumption varies considerably and is high in relation to the power of the transformer. Such situations are encountered at the terminals of main LV distribution boards or at the origin of high power outgoing lines. Step capacitor banks are made up of a combination of steps in parallel.
A step consists of a capacitor (or a combination of capacitors) and a contactor. Switching all or part of the capacitor bank on and off is controlled by an integrated power factor controller.
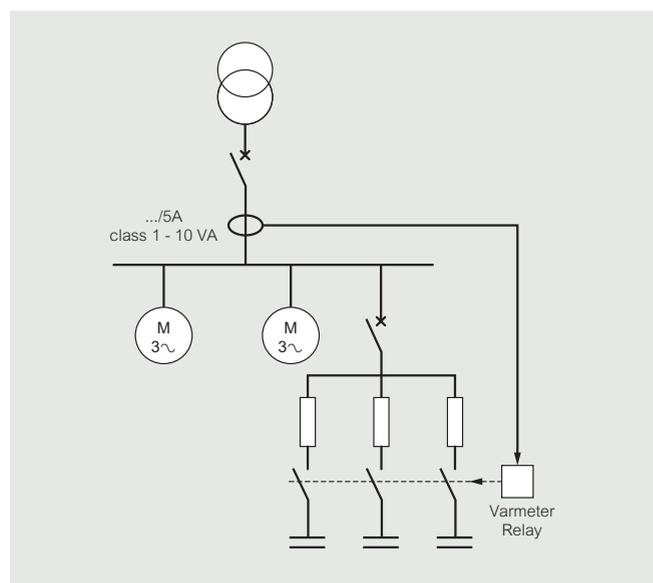
Power factor compensation (continued)

< Alpimatic step capacitor bank

The capacitors will therefore only be activated after the motor starts. Likewise, they may be disconnected before the motor is switched off.

The advantage of this system is the ability to totally compensate the reactive power of the motor at full load. An optional damping reactor should be provided if several capacitor banks of this type are installed on the same system.

< Alpibloc capacitor banks can be equipped on request with a contactor combined with HRC fuses

3 CAPACITOR BANKS WITH SEPARATE CONTROL

Optional damping reactor

M
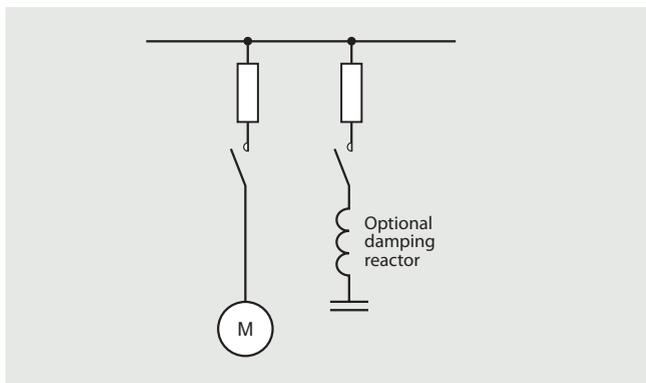
It may be necessary to have separate switching of a capacitor bank to avoid overvoltages, by self-excitation or when a motor starts, using a special device: rheostat, change of coupling, reactors, auto-transformer, etc.

> **! Conventional rule for selecting the capacitor bank technology**
>
> **Fixed compensation has the risk of over-compensation which increases the operating voltage abnormally. Automatic compensation avoids permanent overvoltages resulting from over-compensation when the system has a very low load**
> **A steady operating voltage is thus maintained, avoiding the additional cost of billed reactive energy.**
> **If the power of the capacitors (in kvar) is less than 15% of the power of the transformer (in kVA), choosing a fixed capacitor bank will definitely provide the best cost/savings compromise.**
> **If the power of the capacitors (in kvar) is more than 15% of the power of the transformer, a step capacitor bank with automatic regulation must be chosen.**

CHARACTERISTICS OF CAPACITORS

The technical performance of a capacitor depends on several parameters relating to both its design (type of insulation material, volume of dielectric, etc.) and use (frequency, voltage applied, etc.). Depending on their technology, capacitors have varying degrees of losses which can cause premature ageing and unnecessary energy consumption.

As well as providing an optimum performance/size/safety ratio, capacitors must operate with minimum losses. These losses are due to conduction but above all to dielectric hysteresis. The complete theoretical electrical model of a capacitor can be described by the diagram below.
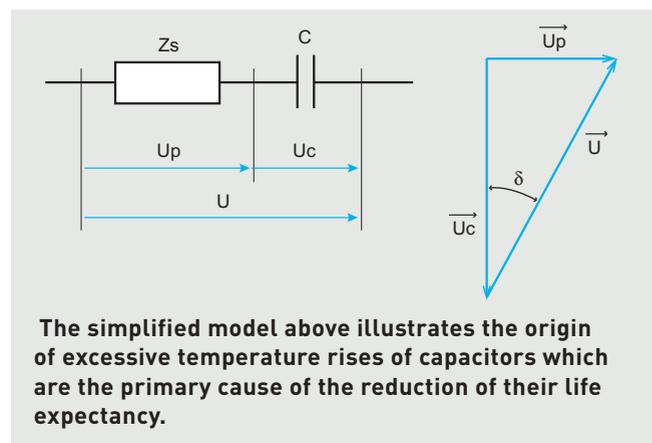
The simplified model above illustrates the origin of excessive temperature rises of capacitors which are the primary cause of the reduction of their life expectancy.
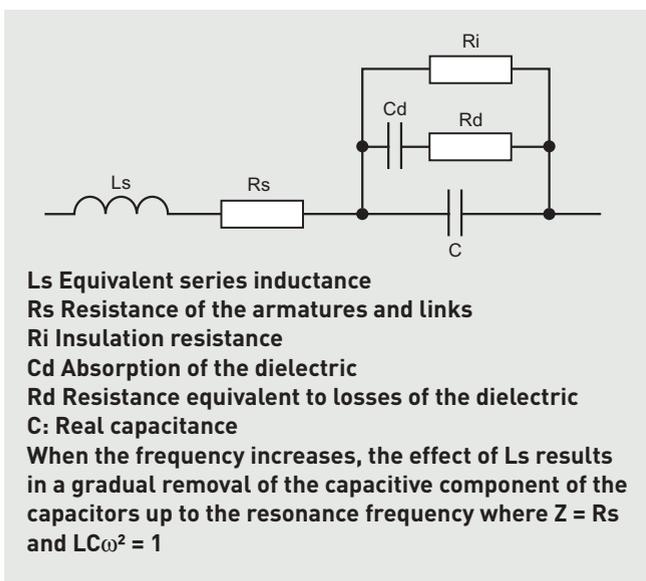
Ls Equivalent series inductance
Rs Resistance of the armatures and links
Ri Insulation resistance
Cd Absorption of the dielectric
Rd Resistance equivalent to losses of the dielectric
C: Real capacitance
When the frequency increases, the effect of Ls results in a gradual removal of the capacitive component of the capacitors up to the resonance frequency where Z = Rs and $LC\omega^2 = 1$

These characteristics vary according to the technologies used (films, metallised films, dielectric films, etc.), but it must be remembered that the value of the capacitance C tends to decrease with the temperature, as does the insulation resistance Ri, and that the dielectric characteristics of the insulating material Cd and Rd (see loss angle δ below) are dependent on keeping within the set temperature range and the frequency.

> Losses by conduction

These are due to the leakage current which crosses the dielectric. This is similar to a resistance Ri determined by the resistivity of the insulation material used and the dimensions of the capacitor. In capacitors other than electrolytic capacitors, these losses are very low. They depend on the characteristics of the insulation material. See table below for the characteristics of a few common insulation materials.

Characteristics of various dielectrics		
Insulation	tan δ at 50 Hz[1]	Volume resistivity at 20°C[2] ($\Omega \cdot$cm)
Paper (dry)	10^{-3} to $1.7 \cdot 10^{-3}$	$5 \cdot 10^{15}$
Cellulose acetate	$1.3 \cdot 10^{-2}$ to $6 \cdot 10^{-2}$	10^{10} to 10^{14}
Mica	$4 \cdot 10^{-4}$ to $2 \cdot 10^{-3}$	10^{14} to 10^{16}
Glass	$5 \cdot 10^{-4}$	$>10^{16}$
Polyvinyl chloride	$7 \cdot 10^{-3}$ to $4 \cdot 10^{-2}$	10^{15} to 10^{17}
Polystyrene	$5 \cdot 10^{-4}$	10^{16}
Polysulphone	$8 \cdot 10^{-4}$	$5 \cdot 10^{16}$
Polypropylene	$3 \cdot 10^{-4}$	$3 \cdot 10^{15}$ to $3 \cdot 10^{18}$
Polytetrafluoroethylene	$2 \cdot 10^{-4}$	10^{18}

(1) The loss angle is generally measured at low frequency (50 Hz to 1 kHz) and the insulation resistance at 20°C
(2) The volume resistivity can be measured at different temperatures

Power factor compensation (continued)

> Losses by dielectric hysteresis

In addition to losses by conduction associated with the leakage resistance Ri, the dielectric can be likened to an imaginary impedance Zs.

From the point of view of losses by hysteresis, the capacitor can be represented by an ideal capacitor C in series with a resistance Rs. Voltages Up and Uc are out of phase by 90°. Angle δ between vectors Up and Uc is called the loss angle. The tangent of this loss angle is used to express the quality of the dielectric.

Replacing Up and Uc by their values according to Rs and Xc (capacitance of C) gives the following formula: $\tan \delta = Rs \cdot C \cdot 2 \cdot \pi \cdot f$.

Losses by hysteresis are a problem as then can cause the temperature of the capacitor to rise and modification of its characteristics (permittivity of the dielectric, insulation resistance, increase of the loss angle, etc.).

✚ ALPIVAR² low voltage capacitors

The patented technology of ALPIVAR² capacitors combines several leading-edge techniques to provide better performance, greater safety and greater ease of use.

Better performance due to the use of coils, made of metallised polypropylene film, impregnated under vacuum with a self-extinguishing polyurethane resin. This provides both better heat dissipation and reinforced electrical insulation. Losses by partial discharges are limited and the risks

For a quick check, the activation status of the pressure monitoring devices is directly visible from the outside of the capacitor bank

of breakdown greatly reduced. Features that are not found at this level with conventional dielectrics like air or oil.

Greater safety due to the addition of three devices whose operating level adapts to the level of the fault.

The metallised film of which the electrodes are made is self-healing. If there is a local perforation, the zinc deposit vaporises around the fault and the insulation is automatically restored. If the short-circuit persists, an internal fuse will break the coil concerned.

Finally, if a more serious fault occurs, the gas overpressure, which can cause explosion of conventional capacitors (in aluminium tube), is avoided here by pressure monitoring devices consisting of a stepped membrane.

Greater ease of use due to incorporation in modular units which can be assembled to create capacitor banks with different powers. Installation is made easy with fixings incorporated in the unit, and connection on terminals makes for easy wiring of the cables and lug terminal. It will be noted that the polyamide 6 case has a high degree of mechanical strength (impact, vibration) and chemical resistance (solvents, alkalis, hydrocarbons), as well as climatic resistance (damp, sun, corrosion).

When the pressure monitoring devices are operating, the faulty coil is de-energised by blowing of the fuse.

TRANSIENT ACTIVATION STATES

The activation of capacitor banks is accompanied by transient voltage and current states. The energisation of discharged capacitors is in practice equivalent to a short circuit whose value depends on the short-circuit power Ssc of the source and is only limited by the impedance of the system. The currents can reach several dozen times the nominal current value. In capacitor banks that are split or in steps, the phenomenon is increased by the discharge of the steps already in operation.

It should also be noted that these currents can be increased to a dangerous level if there are resonance phenomena. This is in particular the case when HV capacitors are activated if the resonance frequency of the upstream HV circuit corresponds to the resonance frequency of the LV circuit.

The risks connected with the activation of capacitors placed on the HV system are described in § 3 of the section entitled "Other disturbance". They are even more dangerous if they are accompanied by transient overvoltages that have sufficient energy to destroy the voltage surge protectors at the supply end of the low voltage installation or even the components of the static converters or compensation capacitors themselves.

The implementation of a number of practical measures can provide protection against these phenomena: insertion resistors, damping inductances also known as "damping reactors" and solid state contactors controlled to activate and disconnect the capacitor bank or capacitor bank steps under optimum conditions.

The advanced technology of Legrand Alpistatic automatic capacitor banks limits switching transients and their consequences.

1 ACTIVATION OF A CAPACITOR BANK

The whole of the system upstream of the capacitor bank is modelled as a source of voltage Vs and impedance applied to an inductance L.
The symmetrical three-phase short-circuit current Ik_3

corresponds to a short-circuit power S_{sc} which is therefore: $S_{SC} = V_S \cdot \sqrt{3} \cdot Ik_3$.
V_C: voltage at the capacitor bank connection point.
The peak-switching current is equal to:

$$I_{pk} = \sqrt{2} \cdot \sqrt{Ik_3 I_n} = \sqrt{2} \cdot V_S \cdot \sqrt{\frac{C}{L}}$$
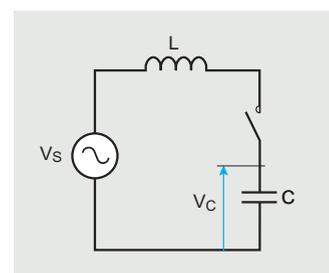
The nominal current of the capacitor bank is $I_n = C\omega \cdot V_C$

The natural frequency of this current is $f_o = \dfrac{1}{2\pi\sqrt{LC}}$

The relationship between the peak current and the nominal current of the capacitor bank can therefore be written as follows:

$$\frac{I_{pk}}{I_n} = \sqrt{2} \cdot \frac{1}{\omega\sqrt{LC}}$$

When there is a short-circuit or inrush current due to the capacitor bank, it is considered that the power S_{sc} is determined by the inductance L of the system, whereas in steady state the power consumption is linked to the impedance C of the capacitor bank.

$$S_{sc} = \frac{V_S{}^2}{L\omega} \quad \text{and} \quad Q = C\omega^2 \cdot V_C$$

To simplify, considering $V_S = V_C$, the relationship between the peak current and the nominal current of the capacitor bank can be calculated as the relationship of the apparent short-circuit power to the reactive power of the capacitor bank.

$$\frac{I_{pk}}{I_n} = \sqrt{2} \cdot \sqrt{\frac{S_{sc}}{Q}}$$

Likewise, the natural frequency can be calculated from this relationship

$$f_o = \frac{\omega}{2\pi} \cdot \sqrt{\frac{S_{sc}}{Q}}$$

Applying the above to an example gives a better understanding of the importance of this relationship, which clearly underlines the risk of overvoltage on activation and thus of associated overvoltage, and all the more so if the power of the source is high in relation to the power of the capacitors.

Power factor compensation (continued)

Taking the example of an installation whose power is 1000 kVA at 400 V with a prospective Isc of 25 kA, i.e. a short-circuit power S_{sc} of approximately 17 MVA, compensated by a 250 kvar capacitor bank, the relationship between the switching current and the nominal current could reach:

$$\frac{I_{pk}}{I_n} = \sqrt{2} \cdot \sqrt{\frac{17\,10^6}{250\,10^3}} = 11.6$$

The resonance frequency will be

$$f_o = \frac{\omega}{2\pi} \cdot \sqrt{\frac{17 \cdot 10^6}{250 \cdot 10^3}} = 412 \text{ Hz}$$

> **!**
>
> To limit the risk of dielectric breakdown of capacitors in transient activation states, irrespective of whether or not they are amplified by resonance phenomena, the current that is generated and passing through the capacitors must be limited.
> The use of a pre-insertion impedance, often called a damping reactor, on the capacitor bank switching device is therefore necessary. It will also protect the switching device.

2 ACTIVATION OF A STEP CAPACITOR BANK
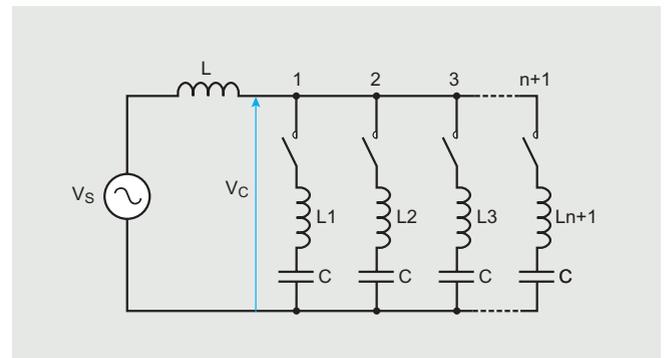
The whole of the system upstream of the capacitor bank is modelled as a source of voltage Vs and impe-

dance applied to a source inductance L comprising the upstream system, transformer and busbars.
The switching currents of a step capacitor bank increase as the capacitors are added. At the 1st step, the value of the switching current depends on the impedance L upstream of the system and the short-circuit power of the supply as in the case of a single capacitor bank. When the 2nd and subsequent steps are activated, the steps already in operation discharge into the last step activated.
There is no longer any limitation by the upstream impedance L.
Inductances L1, L2, L3, etc. representing the wiring between steps are too low to limit the current, which may then reach very high values (several hundred times the nominal current) and damage the capacitors or breaking devices.
On the other hand, the overvoltage associated with the activation of the steps that is spread to the system decreases with the number of steps already in operation.

🔍 Natural frequency and resonance frequency

When a stable system that has been moved from its position of equilibrium is left, it returns to that position, generally naturally by means of the natural oscillations that correspond to a preferred frequency Frp known as the natural frequency. Analogies can be drawn between mechanical systems and electrical circuits, so that natural frequency can be mentioned in connection with the characteristics of a circuit. It exists even when there are no stresses. If a sinusoidal excitation is applied in the region of this natural frequency and the system is not damped, the oscillation will then tend to be amplified by the phenomenon of resonance. It is this similarity of the resonance amplification factor to the natural frequency that has led to the use of the term resonance frequency, which combines both the causes and the consequences.
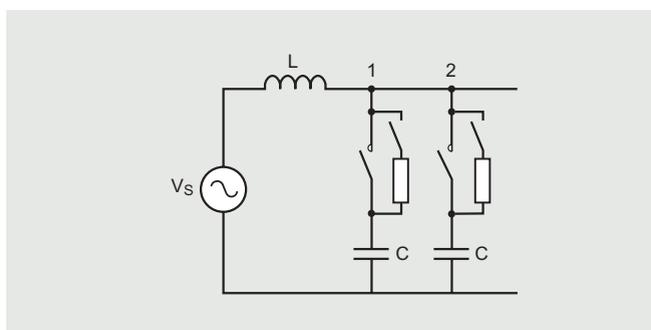
It is essential to limit the inrush currents in step capacitors. This can be done by inductances in series with the capacitors or pre-insertion resistors that are connected by auxiliary contacts during the activation phase of the capacitor.

The peak-switching current of a step increases with the number of steps already in operation. It is equal to

$$I_{pk} = \sqrt{2} \cdot V_S \cdot \sqrt{\frac{C}{L_n}} \cdot \frac{n}{n+1}$$

The nominal current of a step is $I_n = C\omega \cdot V_c$

The relationship between the switching current and the nominal current can be expressed as follows:

$$\frac{I_{pk}}{I_n} = \sqrt{2} \cdot \frac{1}{\omega \sqrt{LC}} \cdot \frac{n}{n+1}$$

or by the notation of the powers:

$$\frac{I_{pk}}{I_n} = V_c \cdot \sqrt{2} \cdot \frac{1}{\sqrt{Q\omega L_n}} \cdot \frac{n}{n+1} \text{ for one step}$$

A calculation example easily shows the order of magnitude of this relationship and the risks of damage to the associated devices.

With a capacitor bank with ten 5 kVA steps connected in a delta configuration at 400 V (V_c = 230 V) whose wiring is made up of loops of conductors between two steps corresponding to an inductance L_n of 1 mH/m, it can be calculated that on activation of the tenth and last step, the overcurrent will reach 233 times the nominal current of one step:

$$\frac{I_{pk}}{I_n} = 230\sqrt{2} \cdot \frac{1}{\sqrt{5 \cdot 10^3 \, 314 \, 1 \, 10^{-6}}} \cdot \frac{9}{10} = 233$$

Reminder: $Q = -C\omega U^2$ where $C = Q/\omega U^2$, i.e. in the example (where $V_c = U/\sqrt{3}$ and $\omega = 314$ at 50 Hz):

$$C = \frac{5 \cdot 10^3}{314 \cdot (230\sqrt{2})^2} = 100 \text{ µF}$$

The nominal current I is equal to $\sqrt{Q \cdot C \cdot \omega}$ = 12.5 A
The theoretical switching current I_{pk} may reach 12.5 x 233 = 2912 A.

3 RESONANCE BETWEEN UPSTREAM AND DOWNSTREAM IMPEDANCES ON ACTIVATION

L_H: inductance of the upstream HV system
C_H: capacitance of the upstream HV system (HV capacitor banks)
L_B: inductance of the downstream LV system
C_B: capacitance of the upstream LV system (LV capacitor banks)
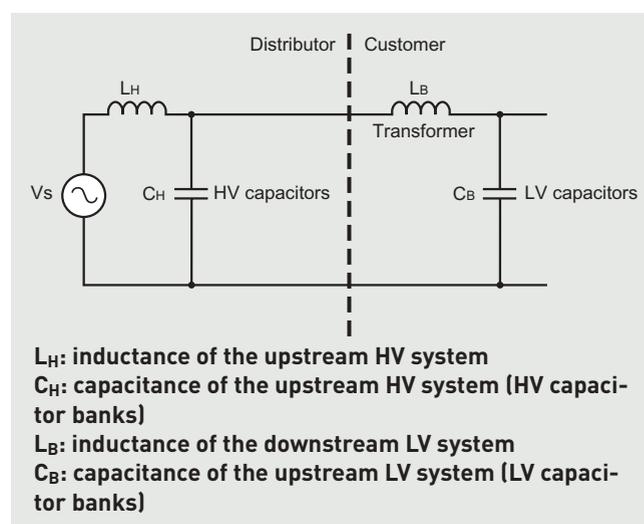
There is a risk of amplification when the series resonance frequency f_{oLV} of the downstream LV installation is in the region of the natural frequency f_{tHV} of the transient overvoltage due to the activation of the HV capacitor bank in the upstream installation.

At resonance $L_B C_B \omega_0^2 = 1$
i.e. a resonance frequency $f_{oLV} = \dfrac{1}{2\pi \sqrt{L_B C_B}}$

At resonance $L_H C_H \omega_0^2 = 1$
i.e. a resonance frequency $f_{tHV} = \dfrac{1}{2\pi \sqrt{L_H C_H}}$

When f_{oLV} and f_{tHV} are equal, the series resonances cause an impedance of all the L and C components, on both the HV and LV sides. The impedance of the circuit is then limited to its resistance R. If the upstream system behaves like a voltage source, that is, its voltage hardly decreases at all with the current drawn (as is the case with a distribution system that is powerful in terms of the power of the connection), the value of

Power factor compensation (continued)

the current I corresponding to f_0 will be very high because it is only limited by its resistance. As the current passing through the capacitors increases considerably, the capacitors will be subjected to voltages that may exceed their insulation level and result in their dielectric breakdown.

4 ELECTRICAL STRESSES CONNECTED WITH DEACTIVATION

During breaking of a capacitor bank or a capacitor bank step, the capacitor that has been separated remains charged with a certain level of voltage which depends on the angle at which the breaking was carried out.

For breaking at zero current, which is of interest from the point of view of arc suppression and wear of the contacts, the voltage is then at its full value due to the current/voltage phase shift $(\pi/2)$ at the capacitors.

But if a restrike phenomenon occurs at the contacts, it can lead to the voltage increasing again, resulting in a phenomenon similar to switching, with an associated overcurrent and overvoltage that are both even higher (see p. 36).

Devices that limit switching currents, resistors and, better still, damping reactors will also be useful in this case.

> **!** **Alpistatic automatic capacitor banks manage all these phenomena, controlling the switching phases by microprocessor.**
> **Ensuring the safety of people also requires that the capacitors are discharged after disconnection of the installation. Discharging is generally carried out by the resistors within 3 minutes. It is also possible to install high-speed discharge reactors which will reduce this time to around ten seconds. This is a useful option for the safety of people if they are to work on the equipment (reduction of waiting time before isolation and earthing), or in the case of resetting after breaking (taking the cooling periods of the components into consideration, if necessary).**

+ Alpistatic realtime automatic compensation to meet all the requirements inherent to the installation of capacitor banks

■ **Conventional switching using electromechanical contactors**
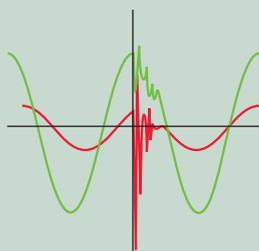
Coupling a step
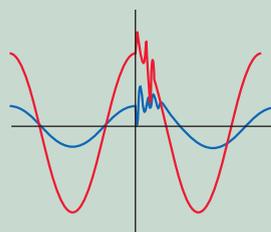
Uncoupling a step

■ **Soft switching using Alpistatic static contactors**
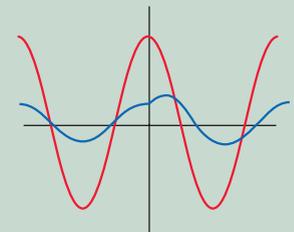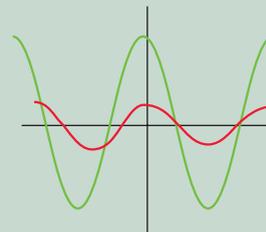
- Soft switching using Alpistatic static contactors does not cause disturbance on the system.
- Its reaction speed (40 milliseconds) provides instant control of the reactive power.

Comparison of the main characteristics

Sensitive data	Alpistatic	Conventional
Presence of electromechanical contactors	No	Yes
Wear of moving parts	No	Yes
Contact bounce phenomenon	No	Possible
Contact fatigue	None	Considerable
Transient overcurrents on activation and deactivation of steps	No	Yes (May exceed 200 ln)
Transient undervoltages	None	Yes (up to 100%)
Compatibility (PLCs, computer equipment, etc.)	Excellent	Average
Compatibility (welding machines, generator sets, etc.)	Excellent	Poor
Activation and deactivation response time	40 milliseconds	Approx. 30 seconds
Number of operations	Unlimited	Limited (electromechanical contactor)
Sound level during operation	Zero	Low (electromechanical contactor)
Reduction of flicker	Yes (for highly inductive loads)	No
Creation of harmonics	No	No

ALPISTATIC comprises:
• The capacitor part, subdivided into a number of steps depending on the power rating of the compensator
• One three-pole static contactor per step (breaking all three phases)
• Cooling of each static contactor by fan-cooled heat sink
• Standard and H type: 3 single phase damping reactors protecting the static contactor
• SAH type: 1 three-phase anti-harmonic reactor protecting the static contactor and providing protection against harmonics
• One set of 3 HRC fuses per step
• A system for controlling the static contactors, comprising:
- A reactive energy controller for automatic control
- A microprocessor instrumentation and control card for each static contactor, that activates and deactivates the static contactors within 40 ms max. and avoids any transient voltage and current phenomena when steps are activated or deactivated.

Power factor compensation (continued)

ELECTRICAL RESONANCE AND ENERGY COMPENSATION

Resonance phenomena in electrical installations is well known and is simply a high amplification of the magnitude of the current and of the tension at a given frequency. During an installation, to a large extent it therefore depends on the impedance of all constituent components: networks, sources, transformers, circuits and loads.

The electrical source and its mathematical explanation are given again on page 40.

1 PARALLEL RESONANCE OR ANTI-RESONANCE BETWEEN SOURCE AND CAPACITORS.

The impedance of the source of an installation (network and transformer) is inductive by nature and increases proportionally with the frequency whilst that of the capacitors decreases. The result is a potential resonance between these two elements, which can lead to significant amplification of the currents and voltages; a phenomenon that can be produced during the propagation of transitory signals (operations in the upstream system, switching on the HVA batteries, etc.) and particularly if there are harmonics due to the loads present in the installation.

The most critical resonance frequencies are the orders 3 (single-phase sources), 5 and even 7 in commercial installations whilst in the industrial installations, orders 5 and 7 are predominant, even though the speed control systems or the continuous power supplies can also generate higher orders: 11, 13.

Capacitor banks are one of the most sensitive components of harmonics, absorbing them easily by virtue of their higher frequencies (network multiples) and causing their amplification when they are tuned to the resonance's proper frequency.

There are Legrand solutions therefore for protecting capacitors (anti-harmonic reactors) or for limiting harmonics in highly polluted installations.

The modelling that follows can be used to understand resonance phenomenon between source and capacitor, its cause and consequences, from calculation methods based on the impedances.

In practice, the calculation does not need to go into this kind of detail and formulas (see page xx) are based on power values (Ssc, P and Q). The values are generally known or can be accessed and they can be used to assess, with a sufficient degree of accuracy, the proper resonance frequencies (Frp) of the installation and to check that these frequencies are far enough away from the harmonic frequencies (FA).

2 SIMPLIFIED MODELLING OF AN INSTALLATION

X_R: reactance of the upstream system

X_T: reactance of the user transformer

X_C: reactance of the capacitor bank when present

R: resistance corresponding to the active power absorbed
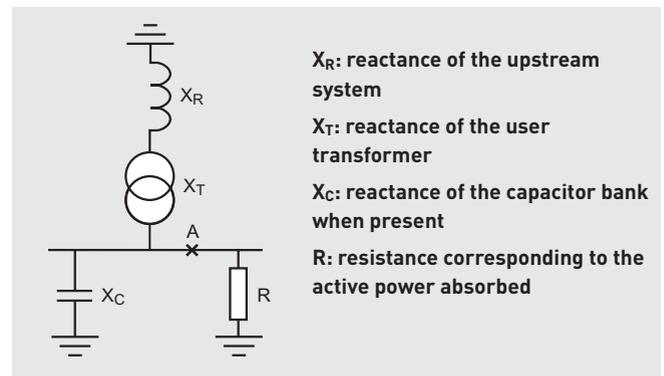
The source is simplified by ignoring its resistive part and only retaining its reactance (X_R and X_T). Likewise, the usage side of the installation is only considered for its corresponding active load. (the inductive part is ignored because it is normally compensated by the capacitors). It should also be noted that in the modelling with capacitors, the R part is not included in the impedance calculation as is not part of the resonance frequency calculation. On the other hand, R plays a significant role as a damping element of the resonance (see p.117).

2.1. Equivalent impedance without capacitors

Seen from point A, the system's overall impedance can be written as a combination of X_{RT} and R, with: $X_{RT} = X_R + X_T$

$$\frac{1}{Z_A} = \frac{1}{X_{RT}} + \frac{1}{R} \implies Z_A = \frac{X_{RT} \cdot R}{X_{RT} + R}$$

which can also be written as: $Z_A = \dfrac{R \cdot jL\omega}{R + jL\omega}$

by considering the reactance X_{RT} as purely inductive.

The greater ω is, the greater $jL\omega$ is and the more Z tends towards R.

The smaller ω is the more that Z tends towards $jL\omega$.
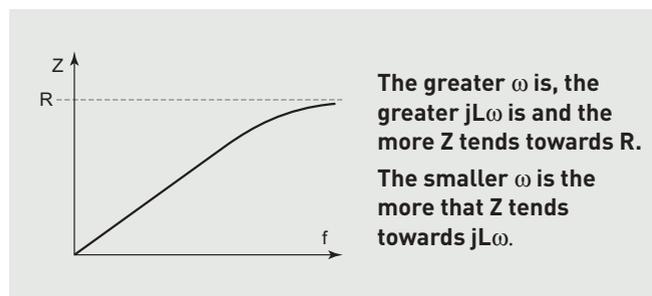
2.2. Equivalent impedance with capacitors

The system's overall impedance can be written as a combination of X_{RT}, R and C with the impedance seen from A written:

$$\frac{1}{Z_A} = \frac{1}{X_{RT}} + \frac{1}{R} + \frac{1}{X_C} \text{ , with } X_{RT} = X_R + X_T$$

$$Z_A = \frac{X_{RT} \cdot R \cdot X_C}{X_{RT} + R + X_C}$$

which can also be written as:

$$Z_A \approx \frac{1}{\sqrt{\frac{1}{R} + \frac{1}{jL\omega} + jC\omega}}$$

If the impedance part R associated with the resistance of the receivers absorbing active power is excluded, the LC branch of the diagram composed of the reactance (inductance) of the source and of the reactance (capacity) of the capacitors is simply expressed as:

$$\frac{1}{Z_A} \approx \sqrt{\left(C\omega - \frac{1}{L\omega}\right)^2} \implies Z_A \approx \frac{1}{C\omega - \frac{1}{L\omega}}$$

Typical impedance

The curves below show the occurrence of resonance phenomenon between source (inductance expressed in μH) and capacitors (expressed in kvar). The inductance of the source is calculated from its total reactance X_{RT} (sum of reactances X_R of the HVA network and X_T of the transformer; the reactance of the distribution elements such as the busbars is negligible). Typical values are given in the chapter "Short-circuit value at the origin of the installation" in book 4.
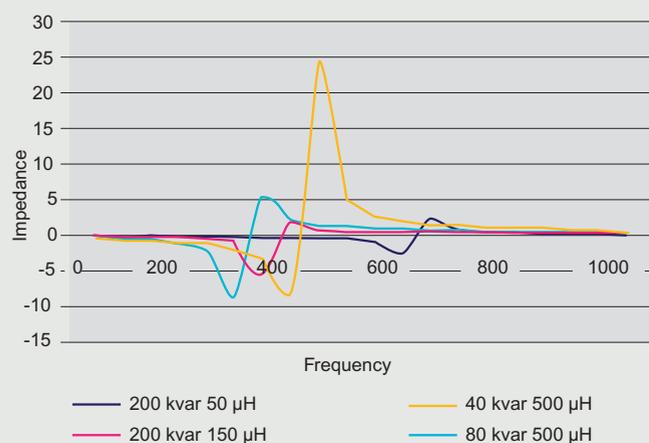
The more prospectively powerful the source (low characteristic inductance), the higher the proper resonance frequency (in Hz). Conversely, the weaker the source (high inductance 500 μH in the example), the more this frequency value decreases.

In the same way, the higher the installed reactive power (kvar) compared with the source power, the more the proper frequency value decreases.

Installing high compensation in a low-power installation must therefore be checked carefully as regards the resonance risk to frequencies that are low and close to harmonic frequencies of the network.

Frequency / Impedance

— 200 kvar 50 μH
— 200 kvar 150 μH
— 40 kvar 500 μH
— 80 kvar 500 μH

Power factor compensation (continued)

The capacitor bank reactance X_C (1/cω) is inversely proportional to the frequency whilst the reactance of the source X_{RT} (Lω) is proportional to the latter. Depending on the relative part of C and L, for a certain frequency known as "resonance", these two reactances become equal and cancel each other out as they are in anti-phase (this is why the term anti-resonance is also used between capacitors and source). The impedance Z_A is therefore reduced to resistance R.

In fact, the consequences of this phenomenon will differ depending on whether the upstream system is acting as a voltage source or as a current source (see below). A feature that depends on the network's capacity to supply energy which will result in short-circuit power S_{sc} compared with the active power absorbed by the installation and the reactive power of installed compensation.

Equivalent wiring diagram to the resonance between the upstream system (source) and the compensation capacitors

The R value (associated with the active power absorbed) has no direct effect on the resonance frequency value; on the other hand, it does play a role in damping this resonance by decreasing its intensity. It is the quality factor concept.

- If the source is acting as a voltage source (high S_{sc}), the voltage U can be considered to be constant. The currents I_L and I_C are equal to the resonance and reverse direction.
The current $I_L + I_C$ tends towards 0

$$I_L = I_C = \frac{U}{L\omega_0} = U\,C\omega_0$$

$\omega_0 = 2\pi f_0$, angular frequency to resonance frequency f_0
These currents are not necessarily very high and they only depend on U. However, if U is high and if L to f_0 is a low value, the damping will be reduced and an overcurrent in C cannot be excluded.
By integrating overload factors of 1.3In (standard) and 1.5In (reinforced version H), Legrand capacitors are designed to exclude this risk.

Upstream system

- If the source is acting as a current source (high upstream inductance and generally low associated Ssc power), the current $I_L + I_T$ will remain constant and the equivalent impedance ZA will become very high, close to the resonance (see illustration on the characteristic impedance curves).
The voltage U = ($I_L + I_T$) Z_A can increase significantly: there is a risk therefore of destruction by overvoltage, as well as from associated overcurrent.

$$I_L = I_C = \frac{U}{L\omega_0} = UC\omega_0 = I_{(L+C)}\,Z_A = \frac{I_{(L+C)}\,jL\omega_0}{(1-LC\omega_0^2)\,jL\omega_0} = \frac{1}{(1-LC\omega_0^2)}$$

If $1-LC\omega_0^2$ tends towards 0, then $I_L = I_C$ tends towards infinity
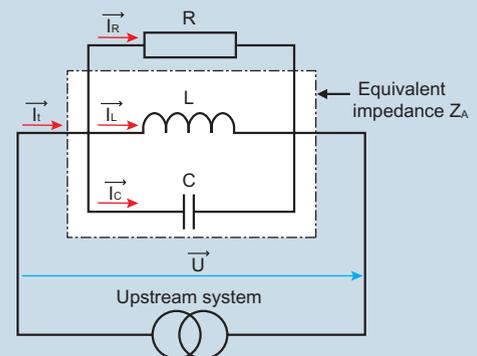
3 AMPLIFICATION FACTOR AND ACUTENESS OF THE RESONANCE

The amplification factor of an RLC circuit is used to take into account the damping supplied by the resistive branch of the system; it allows potential resonance overcurrents and overvoltages to be predicted. It is defined by the formula:

$$F_A = \frac{L\omega_0}{R} = \frac{1}{C\omega_0 R}$$

It is also called quality factor or overvoltage factor.

$$U_L = U_C = F_A \times U = \frac{L\omega_0 \times U}{R} = \frac{U}{C\omega_0 R}$$

For its part the resonance acuteness defines the ratio between the nominal current I and maximum current I_M circulating to the resonance of the circuit, i.e. when the impedance of the circuit is reduced to its resistance R.

$$\frac{I}{I_M} = \frac{1}{\sqrt{1 + F_A^2\left(\frac{f}{f_0} - \frac{f_0}{f}\right)^2}}$$

Example of type of response

- $F_A = 0.1$
- $F_A = 1$
- $F_A = 10$
- $F_A = 100$
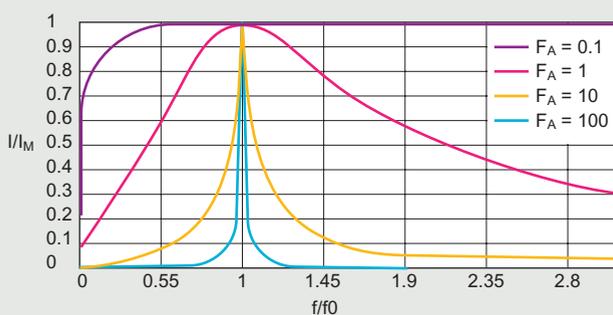
On this network of curves it can be seen that the lower the amplification factor F_A numerically, the more the overcurrent is limited (I/I_M tends towards 1).
A situation that corresponds with a significant part of the R resistance in proportion to the reactances $L\omega$ and $1/C\omega$.
The same curve type could be plotted for the voltage ratio U_L/U and U_C/U for different F_A values.

As such, a smaller or greater resonance acuteness can be observed depending on the frequency value compared with this resonance (f/f_0 ratio) and depending on amplification factor F_A.
The voltage values at the L and C terminals are expressed by the formulas:

$$\frac{U_L}{U} = \frac{U_C}{U} = \frac{\frac{f}{f_0}}{\sqrt{\frac{1}{F_A^2} + \left(\frac{f}{f_0} - \frac{f_0}{f}\right)^2}}$$

To the resonance, $f = f_0$ and the expression is simplified into:

$$\frac{U_L}{U} = \frac{U_C}{U} = \frac{1}{F_A}$$

For example, an overvoltage of 2 corresponds to an F_A factor of this same value 2.

4 EXPRESSION OF THE AMPLIFICATION FACTOR THROUGH THE POWERS

The formula used to obtain F_A from the power values allows the extent of each of the terms and the damping effect caused to be understood easily:
- by the ratio of the active power absorbed compared with the power of the source (P/S_{sc}); a loaded installation has better damping of resonance overvoltages and overcurrents.
- by the ratio of the compensation power to the active power (Q_C/P); the increase of Q_C increases Fq and also decreases damping.

$$F_A = \frac{\sqrt{Q_C \times S_{sc}}}{P}$$

Q_C: reactive power of all compensation capacitors (in kvar).

$Q_C = C \cdot \omega \cdot U^2 \Rightarrow C = Q_C/\omega \cdot U^2$ to determine the corresponding value in farads.

S_{SC}: short-circuit power at the calculation reference point (generally the short-circuit power of the transformer which has potentially decreased by losses through the length of the trunking between transformer and capacitor banks)

P: active power of all linear loads of the installation

Power factor compensation (continued)

Value of the amplification factor F_A

Power of capacitors as a % of the active load

— 50% of P   — 20% of P

$\dfrac{P}{S_{sc}} = \dfrac{\text{Active load of the system (P)}}{\text{Short-circuit power } (S_{sc})}$ as a %
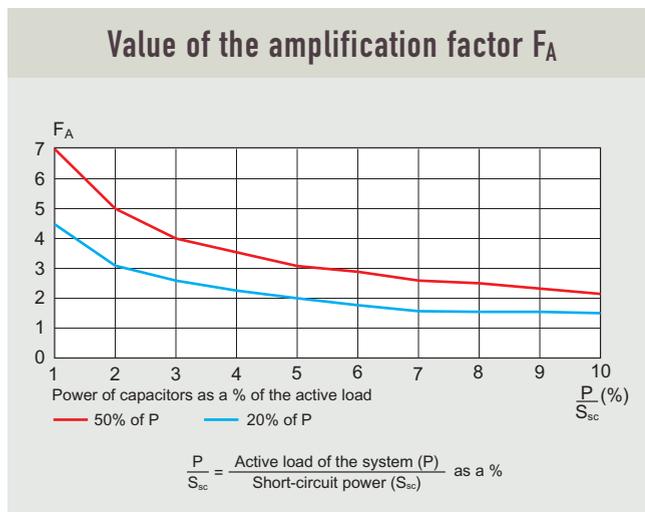
On the low-voltage distribution networks, the amplification factor F_A varies between 1.5 and 6.
In high-voltage networks, it is lower and is limited to between 1 and 3.
In industrial and commercial installations, on the other hand, a high number of compensation capacitors can increase its value up to 10 and above.
The expression of this factor shows that it is as favourable as the active power load is high.

> **!** Operation of an installation under damping conditions of the resonances and of the limitations in overvoltages and overcurrents will be all the more effective given that it will be close to the full load, the upstream power will be greater and the compensated reactive power part will be limited.

5 EXPRESSION OF THE PROPER FREQUENCY THROUGH THE POWERS

The proper frequency between source and capacitors can be calculated via a method using the impedances (see p.110). This allows accurate modelling of all the component parts: supply impedance, impedance of the transformer(s), impedance of the lines and of the capacitors, etc.
In practice the calculation can be simplified and reduced to determine the value of the natural frequency Frp between the source transformer and the capacitor bank

$$Frp = f\sqrt{\dfrac{S_{sc}}{Q_C}}$$ (f fundamental frequency of the network)

or in the form of its harmonic order Hr.

$$Hr = \sqrt{\dfrac{S_{sc}}{Q_C}}$$

S_{sc} : short-circuit power of the transformer (in kVA)
Q_C: reactive power of all compensation capacitors (in kvar).
A more simple calculation can potentially be done from the short-circuit voltage Uk expressed in % and the nominal power of the transformer S_T (in kVA).
The formula then becomes:

$$Hr = \sqrt{\dfrac{100 \times S_T}{U_k \times Q_C}}$$

Calculation example:
For a power transformer S_T of 1000 kVA with a short-circuit voltage Uk of 6% and installed reactive power of 300 kvar, the natural frequency order of the system will be:

$$Hr = \sqrt{\dfrac{100 \times 1000}{6 \times 250}} = 8.16 \text{ i.e. } Frp = 50 \times 8.16 = 408 \text{ Hz,}$$

a frequency which on the face of it is far away from the main harmonics.
If in the same example, the compensation power is increased to 500 kvar, the natural frequency order goes down to

$$Hr = \sqrt{\dfrac{100 \times 1000}{6 \times 500}} = 5.7 \text{ i.e. } Frp = 50 \times 5.7 = 288 \text{ Hz:}$$

a frequency close to order-5 harmonics capable of being present in the installation and therefore requiring special precautions.

HARMONICS AND ENERGY COMPENSATION

The harmonic currents are mainly down to the non-linear loads in the installations (see book 2). The most frequent harmonic sources are linked to the use of electric arcs (welding, arc furnaces, discharge lamps, etc.) and to magnetic machines. Power electronics (converters, variable control units, power supplies, ballasts, induction heating) is also a significant source of harmonics in the industrial field.

An additional source has recently appeared with the increased use of the following products amongst the general public and in the commercial area, which are all low-power devices but are in widespread use: computers, printers, televisions and small applicators that all have common electrical switching mode power supplies. The new forms of "low consumption" economic lighting are also new sources of harmonics.

One new feature: distorting power that is due to harmonics must be calculated in any electrical assessment going forward.

Harmonics can lead to numerous malfunctions: temperature rises in conductors, tripping of protective devices, EMC interference in control systems, vibration and noise in magnetic machines, etc., and even destructive effects: overloading, overheating and breakdown of transformers and more particularly of capacitors.

For these latter devices, apart from creating additional losses through hysteresis due to the increase in frequency (see p.108), the presence of harmonics with higher frequency than that of the network leads to a decrease in the impedance of the capacitors, which results in overload currents and even destruction in the event of resonance.

Depending on the "total harmonics" present, reinforced compensation solutions (type H) will have to be implemented, or solutions that include suitable protective devices from the risk of resonance with harmonics (types SAH and SAHR).

The design of the installation considered and calculation of the elements present which may be completed using on-site measurements will be essential in getting rid of resonance risk, the causes and consequences of which are described in the previous chapter.

1 THE CHARACTERISATION OF HARMONIC INTERFERENCE

This distortion corresponds to unnecessary power consumption at multiple frequencies of the fundamental frequency; the distorted current matches the superposition of the various harmonic orders.
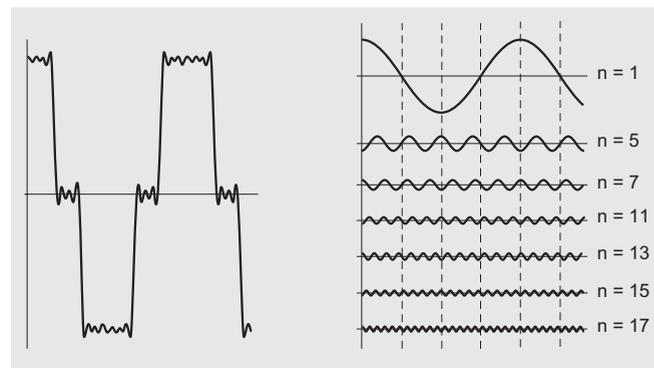
^ Signal distorted by the presence of high harmonics orders, particularly orders 5 and 7 (even 11 and 13), typical of industrial environments (frequency controls for example)
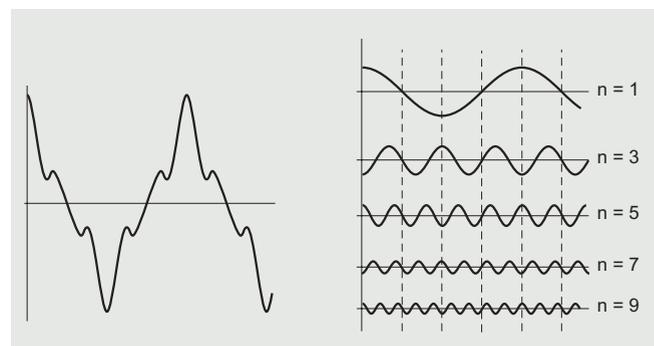
^ Signal distorted by the presence of harmonics, particularly order 3 and 5 which are typical in commercial environments (electrical power supplies, computers)

Power factor compensation (continued)

Harmonic interference can be characterised using several methods:
- by its value (in amps or volts) for each harmonic order (multiple of the fundamental frequency)
- by the total harmonic distortion (THD) in % which quantifies the harmonic signal part (defined in voltages or in currents) in relation to the sinusoidal fundamental wave (see book 2).
- by the corresponding harmonic power or distorting power D.

1.1. Calculation of the value of each harmonic order with reference to its frequency

$$Y(t) = Y_0 + \sum_{h=1}^{n=\infty} Y_h \sqrt{2} \sin(h\omega t - \varphi_h)$$

Y_0: value of the DC component generally nil
Y_h: effective value of the n-order harmonic,
ω: angular frequency of the fundamental frequency,
φ_h: phase shift of the harmonic component to t = 0.

1.2. Calculation of harmonic distortion (HD) and of total harmonic distortion (THD)

$$HD = \sqrt{\sum_{h=2}^{\infty} Y_h^2}$$

This magnitude is used to assess voltage or current distortion using a unique number. In practice, the total harmonic distortion is usually expressed as a percentage by limiting the range (most often order 25, or 40 or 50 in the event of high pollution).

$$THD\ (\%) = \frac{\sqrt{\sum_{h=2}^{25} Y_h^2}}{Y} \times 100$$

1.3. Calculation of harmonic pollution or distorting power

With harmonics present, the actual apparent power represents the geometric sum of the voltage/current products of each harmonic order.

• **The THD does not provide any information on the spectral contents of the signal, and therefore does not constitute adequate means for calculating filtering methods in relation to resonance risks. On the other hand, it does give an interesting indication of the installation's degree of pollution and of the risks incurred.**

• **The voltage THDu characterises the voltage wave distortion.**

A THDu value of less than 5% is considered normal: there is no fear of malfunction. A THDu value between 5% and 8% still complies with the standard EN 50160 (see p.31) but does reveal significant harmonic pollution and some malfunctions are possible.
A THDu value higher than 8% reveals high harmonic pollution: malfunctions are probable. An in-depth analysis and the implementation of filtering devices are required.
The presence of a high number of "polluting" consumers compared with too high a source impedance creates a voltage distortion, despite the presence of capacitors which may also be the amplification source of the resonance harmonics.

• **The voltage THDi characterises the current wave distortion.**

A THDi value lower than 10% or even 15% is considered normal: there is no fear of malfunction.
A THDi value of between 15% and 35% (standard value 33%) reveals significant harmonic pollution: there is a risk of overheating, which involves oversizing of the cables and the power supplies.
A THDi value higher than 35% reveals high harmonic pollution: malfunctions are probable. It is, therefore, important to know the exact nature (the order) of the harmonics and, in particular, the potential part of order 3 which is often predominant. Use of harmonics compensation devices is recommended. This becomes essential beyond 50% THDi.

$$S^2 = \left(\sum_{h=1}^{\infty} U^2h \right) \left(\sum_{h=1}^{\infty} I^2h \right) \text{ avec } I = \sqrt{I_{h1}^2 + I_{h2}^2 + I_{h3}^2 + ... + I_{hn}^2}_{\ n \to \infty}$$

The effective value l of the current is determined by the contribution of the currents of each harmonic order.

The apparent power due to orders higher than 1 (fundamental order) constitutes the harmonic power or distorting power D.

$$D = U \sqrt{\sum_{h=2}^{\infty} I_h^2} \text{ avec } I_h = \sqrt{I_{h2}^2 + I_{h3}^2 + ... + I_{hn}^2}_{\ n \to \infty}$$

The active power P and reactive power Q are linked to the current of the 1st fundamental order.

The distorting power is linked to the harmonic orders higher than 1.

The distorting power D increases the apparent power S and damages the power factor λ.

$$S = \sqrt{P^2 + Q^2 + D^2} \text{ and } \lambda = \frac{P}{\sqrt{P^2 + Q^2 + D^2}}$$

> **❗ The presence of harmonics is a source of deterioration of the power factor. It generates unnecessary power consumption not compensated by the capacitor banks. The harmonics generate capacitor overloads and the capacitors must therefore be reinforced or protected using special layouts.**
> **In the event of very high harmonic power, the critical frequencies must be eliminated or minimised using suitable filters. There are several technological possibilities: passive, active, hybrid**

2 THE BEHAVIOUR OF THE CAPACITORS WITH THE PRESENCE OF HARMONICS

The harmonics circulate preferentially in the capacitors at the risk or overloading and destroying them.

The impedance of a capacitor is inversely proportional to the frequency ($Z_C = 1/C\omega$); the more the frequency increases (the case with harmonics), the more the impedance decreases.

The total harmonics present in the installation is deci-sive therefore in the choice of capacitor type and its potential protection.

It can be difficult to calculate the actual harmonic power or the distorting power D. On the other hand, the active power S_H of the harmonic generator products compared with the power of the source S_T is easier to estimate.

A ratio S_H/S_T in % is thus determined.

Introducing capacitors, however, also has the effect of changing the impedance of the installation compared with that of the source, therefore risking resonance phenomenon occurring between the two, which is all the more easily attained given the fact of the frequency increase, i.e. the case where harmonic currents are present.

The amplification factor (see p.117) is used to calculate the resonance risk according to the power compensation Q_C compared with the source power S_T (or of its short-circuit power S_{SC}), with this factor also dependent on the active power load P.

As for the S_H/S_T ratio, a practical approach of the resonance risk between source and capacitors can be made by the Q_C/S_T ratio, which defines in % the proportion of the reactive power installed Q_C compared with the source power S_T.

These two factors are used to balance the choice in a practical way through assessing the risk of harmonic pollution of the installation S_H/S_T compared with the power compensation used Q_C/S_T (see next page).

> **❗ The installation's total harmonic distortion level and the compensation rate are two essential factors in choosing capacitor type. The more distorting loads incorporated in the installation and/or the more significant the compensation compared with the power supply, the higher the risk of harmonic overload of the capacitors. Reinforced solutions or solutions that incorporate protective devices are therefore required. Care should be taken when installing compensation capacitors in low-power installations with several distorting loads (shops, offices, etc.)**

Power factor compensation (continued)

Choice of capacitors

The two curves below show the usage limits advised for standard capacitors (red curve) and for type H capacitors (yellow curve)

Q_C/S_T (%)
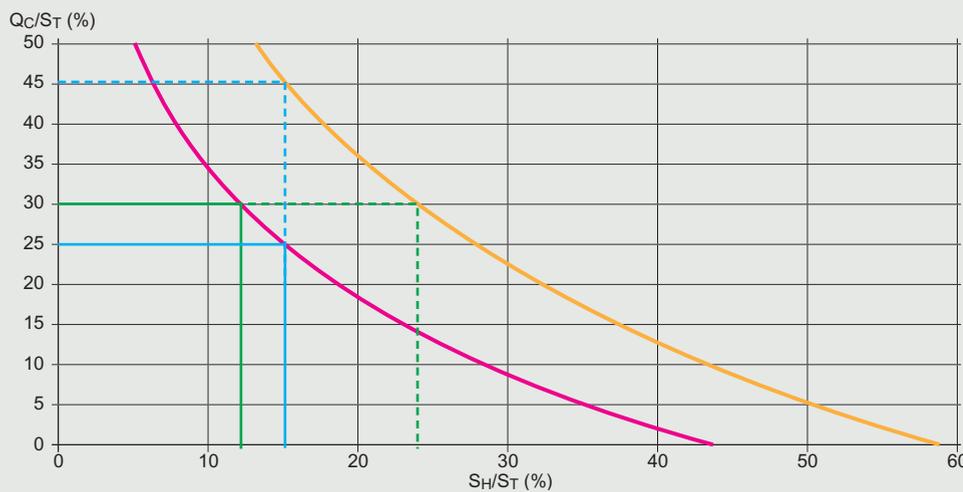
S_H: total power weighted in kVA of the harmonic generators present in the transformer secondary supply.
S_T: power in kVA of the HV/LV transformer

S_H/S_T (%)

Reading examples:
—— For a standard capacitor, the usage limit for the ratio $S_H/S_T \leq 15\%$ corresponds with a Q_C/S_T ratio of 25%.
- - - - For the same S_H/S_T ratio, the Q_C/S_T limit would be 45% with a type H reinforced capacitor.
—— For a regular power compensation $Q_C/S_T = 30\%$ (roughly corresponding with a power factor reading of 0.85 to 0.95), the S_H/S_T ratio must not exceed 12% with a standard capacitor whereas it can reach 25% with a reinforced type H one (- - - -).
Beyond a ratio of $S_H/S_T > 25\%$ or compensation of $Q_C/S_T > 30\%$, capacitor solutions with filtering inductance (SAH or SAHR) would have to be chosen in this example.

Degree of pollution

$$\frac{S_H}{S_T}$$

| ≤ 15% | 15% to 25% | 25% to 35% | 35% to 50% | > 50% |

Standard · H · SAH · SAHR · SAHXR
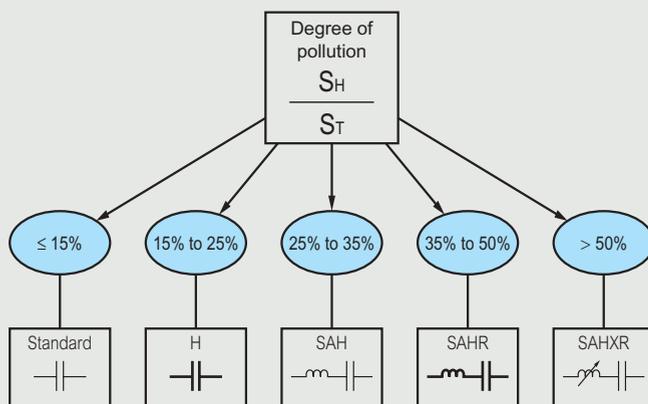
Type H corresponds with a type of capacitor that is reinforced against overcurrents caused by harmonics.

Type SAH has a tuned protective reactor in series that limits the resonance phenomena to harmonic frequencies.

Types SAHR (reinforced) and SAHXR (extra-reinforced) enable partial or total removal of harmonic pollution from the network using tuned inductances. These devices are proposed after studying the exact characteristics of the network and the requirements with regard to the equipment being supplied.

3 HARMONIC CURRENT CIRCULATION

3.1. Installation without capacitors

The harmonic currents circulate naturally or "go back up" from their source to the circuits which show the lowest impedance.

In theory, most of these (Ihs) are therefore sent back towards the source and the network by crossing the power supply transformer.
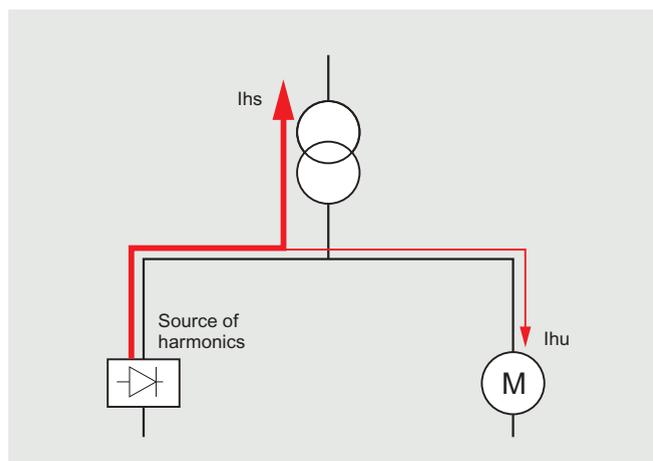
In practice, harmonic currents (Ihu) are also fed back into the other load circuits of the installation: mutual pollution between harmonic generators and sensitive reactors is therefore possible.

An installation's sensitivity to the harmonics that it generates is of course linked to the quantity of these harmonics, and especially to the impedance characteristics of the installation in relation to the source.

> **!** **In order to limit the propagation of the harmonic currents in the installation, the supply must be as powerful as possible when compared to the pollution receiver harmonic generators.**

Equivalent wiring diagram
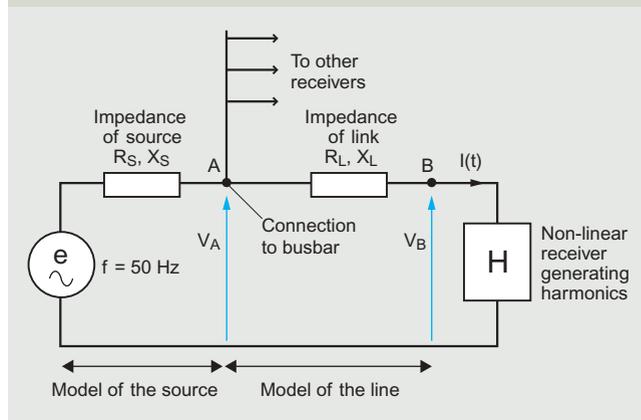
- Impedance of the source $Z_S = \sqrt{R^2_S + X^2_S}$
- Impedance of the harmonic generator receiver and of its power supply line $Zu = \sqrt{R^2_L + X^2_L}$

If $Z_S \ll Zu$, the voltage $V_A = e$, the source and the upstream system acts as one ideal voltage source. The network is "immensely powerful" compared with the installation to be supplied. Frequency behaviour is linear, i.e. the contribution of the different harmonic orders does not change the voltages V_A and V_B in the mathematical application of the superposition theorem known as "de Parseval":

$$V_A = \sqrt{\sum_{h=1}^{\infty} V_{A}^{2}{}_h} \text{ and } V_B = \sqrt{\sum_{h=1}^{\infty} V_{B}^{2}{}_h}$$

This same concept is used to link the harmonic pollution probability with the power of the source and the polluting element ratio.

The inequality is transposed to the power in the form $S_{SC} \gg S_U$

S_{SC}: short-circuit power of the impedance source Z_S
S_U: apparent power of the impedance pollution receiver Zu

The same approach has been shown to the resonance risk between source and installation (see p.111).

Power factor compensation (continued)

The special case of the order-3 harmonic and of its multiples (3, 9, 15, 21, etc.)
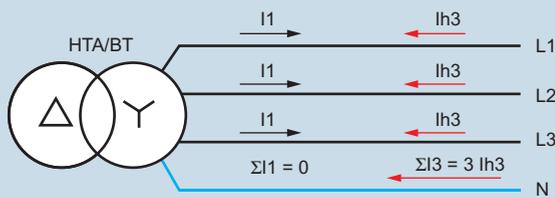
The order-3 harmonic does not "go back up" through the HVA/LV transformer. The harmonics of the three phases add up to neutral, which can lead to its overloading and require an oversizing of cross-section (see book 2).

The order-3 harmonics circulate in the installation and can interfere with other receivers, particularly single phase ones. They can have receivers as their source in addition to protected power supplies.

Special filters can be installed at the output of the pollution source (with uninterruptible power supplies) or before the pollution receivers (particularly single phase receivers). These filters can combine the absorption of the order-3 harmonic and the reactive power compensation.

Typical shape of the current distorted by the order-3 harmonic (single-phase load with rectifier bridge at the input for example)
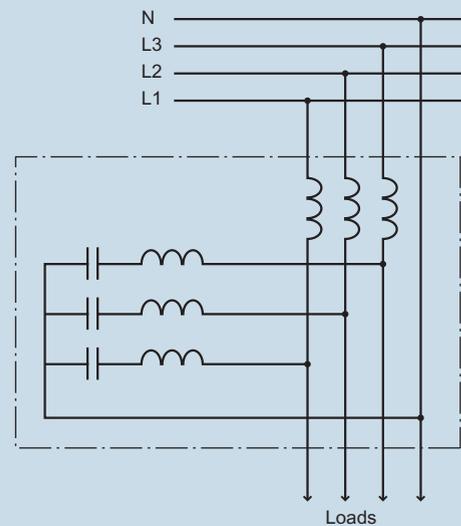
The primary/secondary Dy coupling of the tri-phase transformers is known for stopping the order-3 harmonics, which are closed again by the neutral. Other specific couplings can be used to stop certain harmonic orders however. As such the Dz coupling stops the order-5 harmonics whilst the Dyd coupling stops the order-5 and order-7 harmonics.
Whilst it may be useful to stop these harmonics from "reverting" to the network, they are still not eliminated and they continue to circulate around the installation, which risks polluting sensitive receivers and overloading the capacitors.

3.2. Installation with capacitors

The installation of capacitors changes the harmonics circulation.

The capacitors' impedance is lower than that of the source when the frequency increases. The harmonics circulate naturally, therefore, towards the capacitors and do not revert (or do so much less) towards the source. The behaviour of the entire source/installation is changed and varies according to the harmonics frequency.
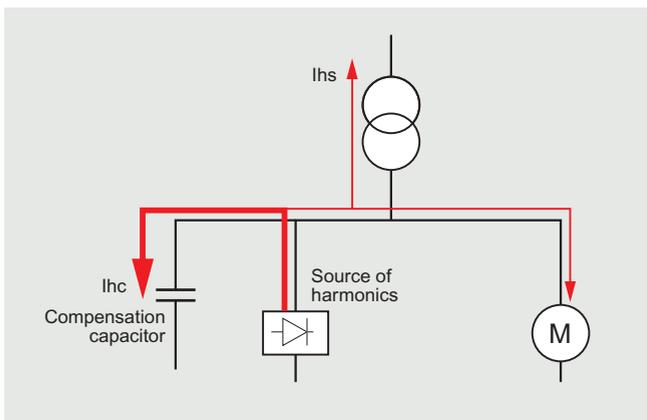
From a mathematical point of view, the superposition theorem no longer applies and calculation of the contribution of each harmonic order would show that impedance Z_U decreases with the frequency. On the equivalent wiring diagram (see p.123), the voltage V_A differs from e.

A significant Ihc part of the harmonic currents is diverted towards the capacitor.

There is a risk therefore of the latter being overloaded or destroyed.

> **!** **The curves (see p.122) can be used to position the capacitor usage limits in relation to the power supplies, the compensation bank (capacitors) and the harmonic pollution elements. Beyond these limits, the harmonics must be filtered or eliminated.**

4 FILTERING AND ELIMINATION OF HARMONICS

With significant harmonics present (S_H/S_T: 25 to 35%), installation of an inductance in series with the capacitor (type SAH with anti-resonance reactor) can be used to increase the impedance of the latter to harmonic frequencies and to move the resonance frequency of the LC filter thus created below the frequencies due to the main harmonic currents. This technique has its limits; it partially eliminates the harmonic currents, but a part continues to revert to the source.

Typical tuning frequency values:
- close to 200 Hz (networks up to 50 Hz) and to 240 Hz (networks up to 60 Hz): eliminates the possible resonance with the order-5 harmonic (for tri-phase systems where the order-3 harmonic is reduced or eliminated)
- close to 135 Hz (networks up to 50 Hz) and to 160 Hz (networks up to 60 Hz) for tri-phase systems where the order-3 harmonic is predominant.
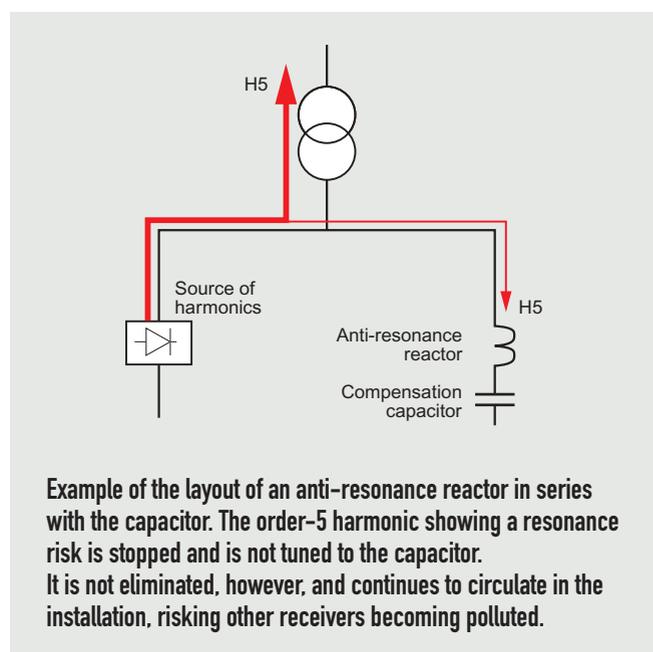
Example of the layout of an anti-resonance reactor in series with the capacitor. The order-5 harmonic showing a resonance risk is stopped and is not tuned to the capacitor.
It is not eliminated, however, and continues to circulate in the installation, risking other receivers becoming polluted.

Power factor compensation (continued)

If the harmonic currents are too large (S_H/S_T: 35 to 50%), they must be eliminated using special filters (SAHR). A passive harmonic filter is essentially made up of an inductance in series with a capacitor. The two components are sized in such a way that they resonate at the unwanted frequency, thus leading the current to run through the filter. As such different "tuned" filters can each be installed on the frequency to be eliminated (250 Hz for order 5, 350 Hz for order 7). The advantage of these solutions is the simplicity and the limited cost.
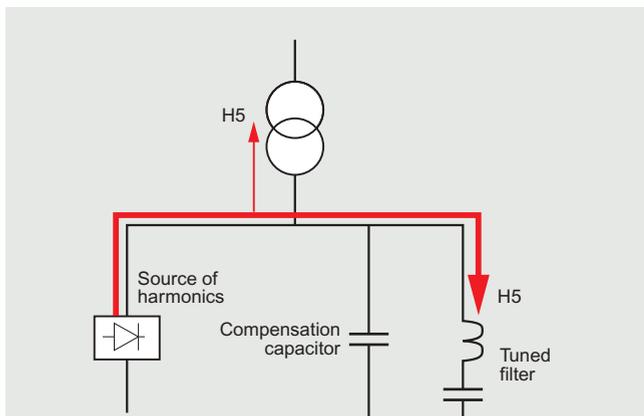
Example of the layout of a filter tuned to a harmonic frequency (order 5).
The filter absorbs the harmonic and prevents resonance starting with the compensation capacitor. Depending on the position of the filter in the installation it allows the circulation of the "captured" harmonic to be decreased. The filter must be sized so as to absorb currents that may be high where resonance occurs.

Types of filter

■ **Passive filter**
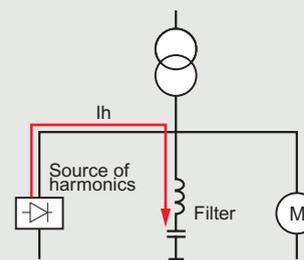
**The passive filter is made up of an inductance in series with a capacitor. The LC cell made up in this way is connected to a given (order) harmonic frequency.
It is an all-purpose solution that can be** adapted to numerous configurations. Its installation in parallel does not limit the power field.
It is a solution that is completely compatible with the power compensation from the moment that an analysis of the harmonic content of the installation has been carried out.

■ **The active filter**
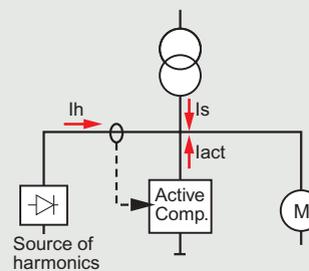
The active filter analyses the harmonics that circulate around the installation in real time (current harmonics) or that are present at the terminal of a sensitive receiver (voltage harmonics).
In anti-phase the filter feeds back a signal corresponding with the harmonics present in order to cancel them out. The active filter is used for harmonics compensation over a wide frequency band. It adapts according to the load but has a higher cost and its power remains limited.

■ **The hybrid filter**
This is an association of two systems, passive and active, which is used to extend the power area. Harmonics filtration is effective as long as a suitable system is chosen, which means that analysis and prior measurements are essential. If these are not completed then malfunctions are inevitable.

INSTALLATION DIAGNOSTICS

The electrical networks are subject to more and more interference and equipment operating anomalies are often ascertained without it being possible to identify the cause with certainty.
A series of measurements over a period representing at least 7 days will enable the compensation devices and their value to be chosen with the required reliability and security.

The Alptec 2333 network analyser is a device for characterising and recording all electrical magnitudes and phenomena that are causing interference (harmonics, voltage dips, overvoltages, etc.). These recordings comply with applicable standards (EN 50160, IEC 61000-4-30) and can be read remotely for analysis and for measurement reporting.

^Alptec 2333 network analyser

As in the case of the 2333 model, the quality Alptec 2444 analyser can measure and record all values inherent in the signal quality (voltage dips, overvoltages, flickers, harmonics and inter-harmonics, imbalances, etc.) in addition to the conventional values (inc. voltage, current, active power P, reactive power Q and apparent power S, power factor, total harmonic distortion in the voltage and the current). The 2444 model comes in a portable version or as a fixed installation version on DIN rail TH 35-15.

< Alptec 2444 quality analyser

Winalp 2400 software (Windows® environment) allows data from one or more analysers to be stored and compared.

• Active power

• Reactive power

• Power factor

— Average values
— Maximun values
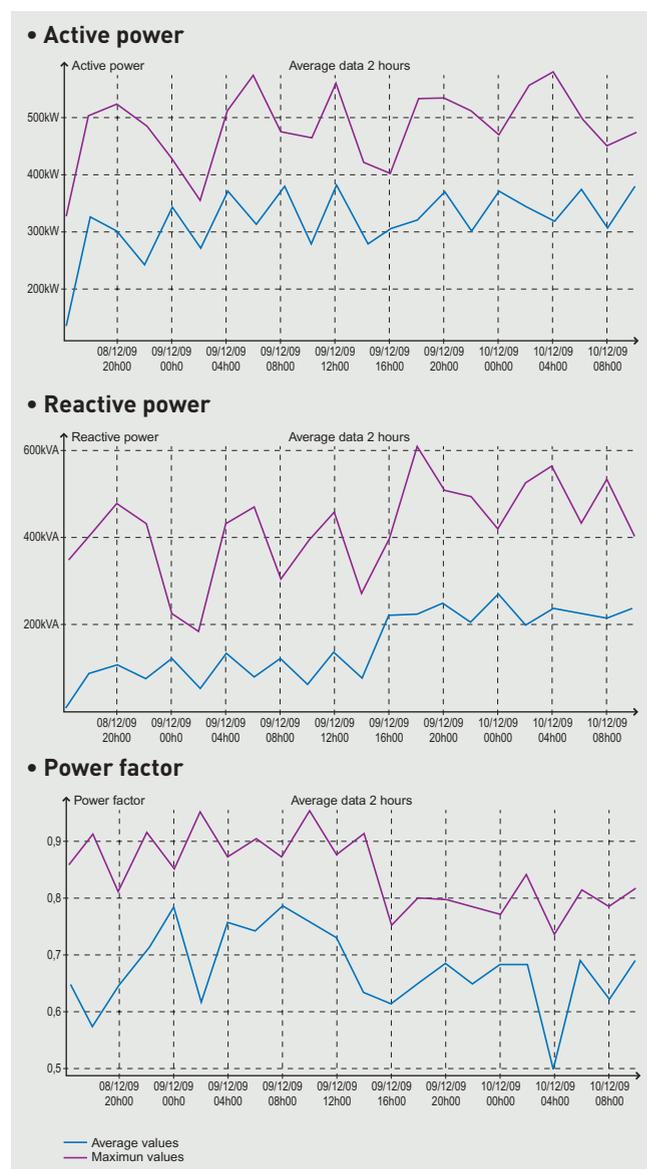
^ Examples of readings taken with Winalp 2400

Power factor compensation (continued)

CAPACITOR PROTECTION

By their nature, the capacitors show significant inrush currents when switched on.
In addition, harmonic currents often pass through them, increasing the actual current absorbed. Finally, standardisation requires a manufacturing tolerance of 15% to be taken into account.
The sum in the strict sense of all tolerances leads to the application of a significant derating coefficient of the protection devices (see framed text opposite).
The structural layouts of Legrand capacitors: reinforced insulation Type H, models with harmonics fibering type SAH, compact manufacturing tolerance allowing the increase in the actual current used to be limited between 1.3 and 1.5 times the theoretical current, and to make optimum economic use of all capacitors and protection devices.
The tables on the following pages specify the most appropriate choice of DX, DPX or DMX³ protection devices with Alpivar, Alpimatic and Alpistatic banks.
Attention: they must not be used for other products where performance and suitability cannot be guaranteed.
Although the majority of capacitor banks are fitted with internal protection devices
(e.g. self-healing metallised film, internal fuses, over-pressure disconnection devices), it is essential that the capacitor also has an external protection device. This protection may be provided by a circuit breaker or by a fuse, and its breaking capacity must be compatible with the prospective short-circuit value at the point of installation.

> Protection by HPc fuses type gL

A rating between 1.5 and 2 In is chosen. The fuses do not provide protection against overloads bearing in mind their over-calibration. Checks should therefore be made so that the capacitors are effectively self-protected.

> Protection using circuit breakers

The circuit breaker rating is selected according to the increased rated current. Depending on whether the device has a fixed or adjustable rating, the Ir thermal

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🔍 Practical determination of the rating or of the setting of the protection device

In the absence of precise manufacturer data, the rating of the protection device can be determined based on an actual rated current (I_B) increased by the factor K:

K = 2 for Q < 25 kvar
K = 1.8 for Q < 50 kvar
K = 1.7 for Q < 100 kvar
K = 1.5 for Q > 100 kvar

$$I_B = \frac{Q \times 1000}{U\sqrt{3}} K$$

Q: reactive power of the capacitor bank (in kvar)
U: nominal voltage of the 3-phase network (in volts)

The K value takes into account the permissible variation in the power supply voltage as well as the presence of harmonics that are proportionally higher in low-power installations corresponding with banks that are also low capacity.
It also takes into account the variation in capacity due to the manufacturing tolerances for the capacitors which can lead to a 15% increase.

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setting is adjusted to correspond to the exact value of the required protection device (see table on adjustment of DPX devices).
For type H standard and reinforced capacitors, the instant magnetic setting (Im) is placed over 10 In so as to absorb the overcurrents when switched on.
The use of curve C circuit breakers is recommended if modular circuit breakers are used.
Where capacitors equipped with damping reactors are used (type SAH), the inrush current is reduced and a magnetic setting between 5 and 7 In is generally possible.
Alpistatic type banks limit overcurrents considerably and a lower Im setting (3 In) is used for even more effective protection of the entire compensation installation.

> Choice of protection circuit breakers

Tables below give the circuit breakers to be intalled and their thermal adjustment according to the capacitor banks. The breaking capacity of the device must at least equal to the maximum prospective short-circuit current at its installation point.

The cross-section for cables in these tables is given for information purposes. It refers to a reference method E for cables or conductors of the U1000R2V type (PR3 column IEC 60364-5-52). See book 4 for an exact determination according to installation conditions.

Adjustment of DPX devices

The number of adjustment steps of the thermal threshold (Ir = x times In) and the corresponding value are given in the table below.

Devices	Adjustment steps											
	1	2	3	4	5	6	7	8	9	10	11	12
DPX 125	0.70	0.85	1.00									
DPX 160	0.64	0.67	0.71	0.74	0.77	0.80	0.84	0.87	0.90	0.93	0.97	1.00
DPX 250 ER	0.64	0.67	0.70	0.74	0.77	0.80	0.83	0.87	0.90	0.93	0.96	1.00
DPX 250 MT	0.64	0.68	0.72	0.76	0.80	0.84	0.88	0.92	0.96	1.00		
DPX 250 EL	0.40	0.50	0.60	0.70	0.80	0.90	0.95	1.00				
DPX 630 MT	0.80	0.83	0.86	0.90	0.93	0.96	1.00					
DPX 630 EL	0.40	0.50	0.60	0.70	0.80	0.90	0.95	1.00				
DPX 1250 MT	0.80	0.83	0.87	0.90	0.93	0.96	1.00					
DPX 1600	0.40	0.50	0.60	0.70	0.80	0.90	0.95	1.00				

Choice of protection for Alpivar² or Alpibloc fixed 3-phase capacitor banks standard type and H type

Capacitors 400 V		MCBs		MCCBs						Cross-section of the phase conductors (mm²)	
				Thermal-magnetic DPX			Electronic DPX				
Nominal power (kvar)	In (A)	DX-h In (A)	DX-L In (A)	Device	In (A)	Ir	Device	In (A)	Ir	Cu	Al
2.5	3.6	6		-	-	-	-	-	-	1.5	2.5
5	7.2	10	10	DPX 125	16	0.7 In	-	-	-	1.5	2.5
7.5	10.9	16	16	DPX 125	16	1 In	DPX 250	40	0.4 In	2.5	2.5
10	14.5	20	20	DPX 125	25	0.85 In	DPX 250	40	0.5 In	2.5	4
12.5	18.1	25	25	DPX 125	25	1 In	DPX 250	40	0.6 In	4	4
15	21.7	32	32	DPX 125	40	0.85 In	DPX 250	40	0.8 In	4	6
20	29.0	40	40	DPX 125	40	1 In	DPX 250	40	1 In	6	10
25	36.2	50	50	DPX 125	63	0.85 In	DPX 250	100	0.5 In	10	16
30	43.5	63	63	DPX 125	63	1 In	DPX 250	100	0.6 In	10	16
35	50.7	80	-	DPX 125	100	0.7 In	DPX 250	100	0.7 In	16	25
40	58.0	80	-	DPX 125	100	0.85 In	DPX 250	100	0.8 In	16	35
50	72.5	100	-	DPX 125	100	1 In	DPX 250	100	1 In	25	35
60	87.0	-	-	DPX 125	125	1 In	DPX 250	160	0.8 In	35	50
75	109	-	-	DPX 160	160	1 In	DPX 250	160	0.95 In	50	70
90	130	-	-	DPX 250	250	0.64 In	DPX 250	250	0.7 In	50	70
100	145	-	-	DPX 250	250	0.8 In	DPX 250	250	0.8 In	70	95
125	181	-	-	DPX 250	250	1 In	DPX 250	250	1 In	95	120
150	217	-	-	DPX 630	320	0.9 In	DPX 630	400	0.8 In	120	150
175	254	-	-	DPX 630	400	0.86 In	DPX 630	400	0.9 In	150	185

Power factor compensation (continued)

Choice of protection for Alpivar² or Alpibloc fixed 3-phase capacitor banks SAH type, standard, reinforced and extra-reinforced class

Capacitors 400 V		MCCBs						Cross-section of the phase conductors (mm²)	
Nominal power (kvar)	In (A)	Thermal-magnetic DPX			Electronic DPX				
		Device	In (A)	Ir	Device	In (A)	Ir	Cu	Al
40	58	DPX 125	100	0.85 In	DPX 250	100	0.9 In	16	35
50	72.5	DPX 125	100	1 In	DPX 250	100	1 In	25	35
72	104	DPX 160	160	0.9 In	DPX 250	160	0.95 In	50	70
75	109	DPX 160	160	1 In	DPX 250	160	1 In	50	70
80	116	DPX 160	160	1 In	DPX 250	160	1 In	70	95
100	145	DPX 250	250	0.8 In	DPX 250	250	0.8 In	70	95
120	174	DPX 250	250	0.92 In	DPX 250	250	0.95 In	95	120
144	209	DPX 630	320	0.9 In	DPX 630	320	0.9 In	95	150
150	217	DPX 630	320	0.9 In	DPX 630	320	0.95 In	120	150
160	232	DPX 630	320	1 In	DPX 630	320	1 In	120	150
200	290	DPX 630	400	0.9 In	DPX 630	400	0.95 In	150	185
216	313	DPX 630	500	0.8 In	DPX 630	630	0.6 In	150	240 (2 x 95)
240	348	DPX 630	500	0.9 In	DPX 630	630	0.7 In	185	240 (2 x 120)
250	362	DPX 630	500	0.9 In	DPX 630	630	0.8 In	185	240 (2 x 120)
280	406	DPX 630	630	0.8 In	DPX 630	630	0.8 In	240 (2 x 120)	2 x 150
288	417	DPX 630	630	0.9 In	DPX 630	630	0.9 In	240 (2 x 120)	2 x 185
300	435	DPX 630	630	0.9 In	DPX 630	630	0.95 In	2 x 150	2 x 185

Choice of protection for Alpimatic 3-phase capacitor racks

Capacitors 400 V		MCBs		MCCBs						Cross-section of the phase conductors (mm²)	
Nominal power (kvar)	In (A)	DX-h In (A)	DX-L In (A)	Thermal-magnetic DPX			Electronic DPX				
				Device	In (A)	Ir	Device	In (A)	Ir	Cu	Al
Standard and H type											
12.5	18	25	25	DPX 125	25	1 In	DPX 250	40	0.6 In	4	4
25 (12.5+12.5)	36	50	50	DPX 125	63	0.85 In	DPX 250	100	0.5 In	10	16
50 (25+25)	72.5	100	-	DPX 125	100	1 In	DPX 250	100	1 In	25	35
75 (25+50)	109	-	-	DPX 160	160	1 In	DPX 250	160	0.95 In	50	70
SAH type, classical, reinforced and extra-reinforced class											
12.5	18	25	25	DPX 125	25	1 In	DPX 250	40	0.6 In	4	4
25	36	50	50	DPX 125	63	0.85 In	DPX 250	100	0.5 In	10	16
40	58	80	-	DPX 125	100	0.85 In	DPX 250	100	0.8 In	16	35
50	72.5	100	-	DPX 125	100	1 In	DPX 250	100	1 In	25	35
72	104	-	-	DPX 160	160	0.9 In	DPX 250	160	0.9 In	50	70
75	109	-	-	DPX 160	160	0.96 In	DPX 250	160	0.95 In	50	70
80 (40+40)	116	-	-	DPX 160	160	1 In	DPX 250	160	1 In	70	95

Choice of protection for Alpimatic automatic 3-phase capacitor banks standard type and H type														
Capacitors 400 V		MCBs		MCCBs						ACBs			Cross-section of the phase conductors (mm²)	
Nominal power (kvar)	In (A)	DX-h In (A)	DX-L In (A)	Thermal-magnetic DPX			Electronic DPX			DMX³				
				Device	In (A)	Ir	Device	In (A)	Ir	Device	In (A)	Ir	Cu	Al
10	14.5	20	20	DPX 125	25	0.85 In	DPX 250	40	0.5 In	-	-	-	2.5	4
15	22	32	32	DPX 125	40	0.85 In	DPX 250	40	0.8 In	-	-	-	4	6
20	29	40	40	DPX 125	40	1 In	DPX 250	40	1 In	-	-	-	6	10
25	36	50	50	DPX 125	63	0.85 In	DPX 250	100	0.5 In	-	-	-	10	16
30	44	63	63	DPX 125	63	1 In	DPX 250	100	0.6 In	-	-	-	10	16
35	51	80	-	DPX 125	100	0.7 In	DPX 250	100	0.7 In	-	-	-	16	25
40	58	80	-	DPX 125	100	0.85 In	DPX 250	100	0.8 In	-	-	-	16	25
50	73	100	-	DPX 125	100	1 In	DPX 250	100	1 In	-	-	-	25	35
60	87	-	-	DPX 125	125	1 In	DPX 250	160	0.8 In	-	-	-	35	50
75	109	-	-	DPX 160	160	1 In	DPX 250	160	0.95 In	-	-	-	50	70
87.5	127	-	-	DPX 250	250	0.64 In	DPX 250	250	0.7 In	-	-	-	50	70
100	145	-	-	DPX 250	250	0.8 In	DPX 250	250	0.8 In	-	-	-	70	95
125	181	-	-	DPX 250	250	1 In	DPX 250	250	1 In	-	-	-	95	120
150	217	-	-	DPX 630	320	0.93 In	DPX 630	400	0.75 In	-	-	-	120	150
175	254	-	-	DPX 630	400	0.9 In	DPX 630	400	0.95 In	-	-	-	150	185
200	290	-	-	DPX 630	400	1 In	DPX 630	400	1 In	-	-	-	185	240
225	326	-	-	DPX 630	500	0.9 In	DPX 630	630	0.7 In	-	-	-	2 x 120	2 x 150
250	362	-	-	DPX 630	500	1 In	DPX 630	630	0.8 In	-	-	-	2 x 150	2 x 185
275	399	-	-	DPX 630	630	0.9 In	DPX 630	630	0.9 In	-	-	-	2 x 150	2 x 185
300	435	-	-	DPX 630	630	0.9 In	DPX 630	630	0.95 In	-	-	-	2 x 150	2 x 185
350	507	-	-	DPX 1250	800	0.83 In	DPX 1600	800	0.85 In	-	-	-	2 x 185	2 x 240
400	580	-	-	DPX 1250	800	0.96 In	DPX 1600	1250	0.6 In	DMX³ 2500	800	1 In	2 x 185	2 x 240
450	652	-	-	DPX 1250	1000	0.9 In	DPX 1600	1250	0.7 In	DMX³ 2500	1000	0.9 In	2 x 240	2 x 300
500	725	-	-	DPX 1250	1000	0.96 In	DPX 1600	1250	0.8 In	DMX³ 2500	1000	1 In	2 x 240	4 x 185
550	797	-	-	DPX 1250	1250	0.83 In	DPX 1600	1250	0.8 In	DMX³ 2500	1250	0.8 In	2 x 240	4 x 185
600	870	-	-	DPX 1250	1250	0.9 In	DPX 1600	1250	0.9 In	DMX³ 2500	1250	0.9 In	4 x 150	4 x 240
675	979	-	-	-	-	-	DPX 1600	1600	0.8 In	DMX³ 2500	1600	0.8 In	4 x 150	4 x 240
750	1087	-	-	-	-	-	DPX 1600	1600	0.9 In	DMX³ 2500	1600	0.9 In	4 x 185	4 x 240
825	1196	-	-	-	-	-	DPX 1600	1600	0.95 In	DMX³ 2500	1600	1 In	4 x 185	4 x 240
900	1304	-	-	-	-	-	-	-	-	DMX³ 2500	2000	0.8 In	4 x 240	4 x 300

Power factor compensation (continued)

Choice of protection for Alpimatic automatic 3-phase capacitor banks SAH type, standard, reinforced and extra-reinforced class											
Capacitors 400 V		MCCBs						ACBs			Cross-section of the phase conductors (mm²)	
Nominal power (kvar)	In (A)	Thermal-magnetic DPX			Electronic DPX			DMX³				
		Device	In (A)	Ir	Device	In (A)	Ir	Device	In (A)	Ir	Cu	Al
75	109	DPX 160	160	1 In	DPX 250	160	0.95 In	-	-	-	50	70
100	145	DPX 250	250	0.8 In	DPX 250	250	0.8 In	-	-	-	70	95
120	174	DPX 250	250	0.96 In	DPX 250	250	0.95 In	-	-	-	95	120
125	181	DPX 250	250	1 In	DPX 250	250	1 In	-	-	-	95	120
144	209	DPX 630	320	0.9 In	DPX 630	400	0.7 In	-	-	-	120	150
150	217	DPX 630	320	0.93 In	DPX 630	400	0.8 In	-	-	-	120	150
160	232	DPX 630	400	0.8 In	DPX 630	400	0.8 In	-	-	-	150	185
200	290	DPX 630	400	1 In	DPX 630	400	1 In	-	-	-	185	240
216	313	DPX 630	500	0.86 In	DPX 630	630	0.7 In	-	-	-	2 x 120	2 x 150
225	326	DPX 630	500	0.9 In	DPX 630	630	0.7 In	-	-	-	2 x 120	2 x 150
240	348	DPX 630	500	1 In	DPX 630	630	0.8 In	-	-	-	2 x 150	2 x 185
250	362	DPX 630	500	1 In	DPX 630	630	0.8 In	-	-	-	2 x 150	2 x 185
275	399	DPX 630	630	0.9 In	DPX 630	630	0.9 In	-	-	-	2 x 150	2 x 185
280	406	DPX 630	630	0.9 In	DPX 630	630	0.9 In	-	-	-	2 x 150	2 x 185
288	417	DPX 630	630	0.9 In	DPX 630	630	0.9 In	-	-	-	2 x 150	2 x 185
300	435	DPX 630	630	0.93 In	DPX 630	630	0.95 In	-	-	-	2 x 150	2 x 185
320	464	DPX 630	630	1 In	DPX 630	630	1 In	-	-	-	2 x 185	2 x 240
350	507	DPX 1250	800	0.83 In	DPX 1600	800	0.85 In	-	-	-	2 x 185	2 x 240
360	522	DPX 1250	800	0.86 In	DPX 1600	800	0.9 In	-	-	-	2 x 185	2 x 240
375	544	DPX 1250	800	0.9 In	DPX 1600	800	0.9 In	-	-	-	2 x 185	2 x 240
400	578	DPX 1250	800	0.96 In	DPX 1600	1250	0.6 In	DMX3 2500	800	1 In	2 x 185	2 x 240
432	626	DPX 1250	1000	0.83 In	DPX 1600	1250	0.7 In	DMX3 2500	1000	0.8 In	2 x 240	2 x 300
450	652	DPX 1250	1000	0.9 In	DPX 1600	1250	0.7 In	DMX3 2500	1000	0.9 In	2 x 240	2 x 300
504	730	DPX 1250	1000	0.96 In	DPX 1600	1250	0.8 In	DMX3 2500	1000	1 In	2 x 240	4 x 185
520	754	DPX 1250	1000	1 In	DPX 1600	1250	0.8 In	DMX3 2500	1000	1 In	2 x 240	4 x 185
525	761	DPX 1250	1000	1 In	DPX 1600	1250	0.8 In	DMX3 2500	1000	1 In	2 x 240	4 x 185
560	812	DPX 1250	1250	0.83 In	DPX 1600	1250	0.85 In	DMX3 2500	1250	0.8 In	2 x 240	4 x 185
600	870	DPX 1250	1250	0.9 In	DPX 1600	1250	0.9 In	DMX3 2500	1250	0.9 In	4 x 150	4 x 240
640	928	DPX 1250	1250	0.96 In	DPX 1600	1250	0.95 In	DMX3 2500	1250	0.96 In	4 x 150	4 x 240
648	939	DPX 1250	1250	1 In	DPX 1600	1250	1 In	DMX3 2500	1250	1 In	4 x 150	4 x 240
675	978	-	-	-	DPX 1600	1600	0.8 In	DMX3 2500	1600	0.8 In	4 x 150	4 x 240
720	1044	-	-	-	DPX 1600	1600	0.85 In	DMX3 2500	1600	0.84 In	4 x 185	4 x 240
750	1087	-	-	-	DPX 1600	1600	0.9 In	DMX3 2500	1600	0.9 In	4 x 185	4 x 240
792	1148	-	-	-	DPX 1600	1600	0.95 In	DMX3 2500	1600	0.96 In	4 x 185	4 x 240
800	1160	-	-	-	DPX 1600	1600	0.95 In	DMX3 2500	1600	0.96 In	4 x 185	4 x 240
864	1252	-	-	-	-	-	-	DMX3 2500	2000	0.8 In	4 x 240	4 x 300

Choice of protection for Alpistatic 3-phase capacitor racks

| Capacitors 400 V | | MCBs | | MCCBs | | | | | | Cross-section of the phase conductors (mm²) | |
| | | DX-h | DX-L | Thermal-magnetic DPX | | | Electronic DPX | | | | |
Nominal power (kvar)	In (A)	In (A)	In (A)	Device	In (A)	Ir	Device	In (A)	Ir	Cu	Al
Standard and H type											
25	36	50	50	DPX 125	63	0.85 In	DPX 250	100	0.5In	10	16
50	73	100	-	DPX 125	100	1 In	DPX 250	100	1In	25	35
75	109	-	-	DPX 160	160	1 In	DPX 250	160	0.95In	50	70
125	181	-	-	-	-	-	-	-	-	-	-
SAH type, classical, reinforced and extra-reinforced class											
25	36	50	50	DPX 125	63	0.85 In	DPX 250	100	0.5In	10	16
40	58	80	-	DPX 125	100	0.85 In	DPX 250	100	0.8In	16	35
50	73	100	-	DPX 125	100	1 In	DPX 250	100	1In	25	35
72	104	-	-	DPX 160	160	0.9 In	DPX 250	160	0.9In	50	70
75	109	-	-	DPX 160	160	0.93 In	DPX 250	160	0.95In	50	70
80	116	-	-	DPX 160	160	1 In	DPX 250	160	1In	70	95
100	145	-	-	DPX 250	250	0.8 In	DPX 250	250	0.8In	70	95
120	174	-	-	DPX 250	250	0.96 In	DPX 250	250	0.95In	95	120
125	181	-	-	DPX 250	250	1 In	DPX 250	250	1 In	95	120

Choice of protection for Alpistatic automatic 3-phase capacitor banks standard type and H type

| Capacitors 400 V | | MCCBs | | | | | | ACBs | | | Cross-section of the phase conductors (mm²) | |
| | | Thermal-magnetic DPX | | | Electronic DPX | | | DMX³ | | | | |
Nominal power (kvar)	In (A)	Device	In (A)	Ir	Device	In (A)	Ir	Device	In (A)	Ir	Cu	Al
100	145	DPX 250	250	0.8 In	DPX 250	250	0.8 In	-	-	-	70	95
125	181	DPX 250	250	1 In	DPX 250	250	1 In	-	-	-	95	120
150	217	DPX 630	320	0.93 In	DPX 630	400	0.75 In	-	-	-	120	150
175	254	DPX 630	400	0.9 In	DPX 630	400	0.95 In	-	-	-	150	185
200	290	DPX 630	400	1 In	DPX 630	400	1 In	-	-	-	185	240
225	326	DPX 630	500	0.9 In	DPX 630	630	0.7 In	-	-	-	2 x 120	2 x 150
250	362	DPX 630	500	1 In	DPX 630	630	0.8 In	-	-	-	2 x 150	2 x 185
275	399	DPX 630	630	0.9 In	DPX 630	630	0.9 In	-	-	-	2 x 150	2 x 185
300	435	DPX 630	630	0.9 In	DPX 630	630	0.95 In	-	-	-	2 x 150	2 x 185
350	507	DPX 1250	800	0.83 In	DPX 1600	800	0.9 In	-	-	-	2 x 185	2 x 240
400	578	DPX 1250	800	0.96 In	DPX 1600	1250	0.6 In	DMX3 2500	800	1 In	2 x 185	2 x 240
450	652	DPX 1250	1000	0.9 In	DPX 1600	1250	0.7 In	DMX3 2500	1000	0.9 In	2 x 240	2 x 300
500	725	DPX 1250	1000	0.96 In	DPX 1600	1250	0.8 In	DMX3 2500	1000	1 In	2 x 240	4 x 185
525	761	DPX 1250	1250	0.8 In	DPX 1600	1250	0.8 In	DMX3 2500	1250	0.8 In	2 x 240	4 x 185

CAPACITOR PROTECTION

Power factor compensation (continued)

Choice of protection for Alpistatic 3-phase capacitor banks standard type and H type (continued)											
Capacitors 400 V		**MCCBs**						**ACBs**			**Cross-section of the phase conductors (mm²)**	
Nominal power (kvar)	**In (A)**	**Thermal-magnetic DPX**			**Electronic DPX**			**DMX[3]**				
		Device	**In (A)**	**Ir**	**Device**	**In (A)**	**Ir**	**Device**	**In (A)**	**Ir**	**Cu**	**Al**
575	833	DPX 1250	1250	0.86 In	DPX 1600	1250	0.9 In	DMX3 2500	1250	0.9 In	4 x 150	4 x 185
600	870	DPX 1250	1250	0.9 In	DPX 1600	1250	0.9 In	DMX3 2500	1250	0.9 In	4 x 150	4 x 185
625	906	DPX 1250	1250	0.93 In	DPX 1600	1250	0.95 In	DMX3 2500	1250	0.95 In	4 x 150	4 x 185
700	1015	-	-	-	DPX 1600	1600	0.8 In	DMX3 2500	1600	0.85 In	4 x 185	4 x 240
750	1087	-	-	-	DPX 1600	1600	0.9 In	DMX3 2500	1600	0.9 In	4 x 185	4 x 240
825	1196	-	-	-	DPX 1600	1600	0.95 In	DMX3 2500	1600	1 In	4 x 185	4 x 240
875	1268	-	-	-	-	-	-	DMX3 2500	2000	0.85 In	4 x 240	4 x 300
950	1377	-	-	-	-	-	-	DMX3 2500	2000	0.9 In	4 x 300	-
1000	1449	-	-	-	-	-	-	DMX3 2500	2000	0.95 In	4 x 300	-
1125	1630	-	-	-	-	-	-	DMX3 2500	2500	0.85 In	4 x 300	-
1250	1812	-	-	-	-	-	-	DMX3 2500	2500	0.95 In	-	-
1375	1993	-	-	-	-	-	-	DMX3 4000	3200	0.8 In	-	-
1500	2174	-	-	-	-	-	-	DMX3 4000	3200	0.9 In	-	-

Choice of protection for Alpistatic automatic 3-phase capacitor banks SAH type, standard, reinforced and extra-reinforced class											
Capacitors 400 V		**MCCBs**						**ACBs**			**Cross-section of the phase conductors (mm²)**	
Nominal power (kvar)	**In (A)**	**Thermal-magnetic DPX**			**Electronic DPX**			**DMX[3]**				
		Device	**In (A)**	**Ir**	**Device**	**In (A)**	**Ir**	**Device**	**In (A)**	**Ir**	**Cu**	**Al**
100	145	DPX 250	250	0.8 In	DPX 250	250	0.8In	-	-	-	70	95
125	181	DPX 250	250	1 In	DPX 250	250	1In	-	-	-	95	120
144	209	DPX 630	320	0.9 In	DPX 630	400	0.7In	-	-	-	120	150
150	217	DPX 630	320	0.93 In	DPX 630	400	0.8In	-	-	-	120	150
160	232	DPX 630	400	0.86 In	DPX 630	400	0.8In	-	-	-	150	185
175	254	DPX 630	400	0.8 In	DPX 630	400	0.9In	-	-	-	150	185
200	290	DPX 630	400	1 In	DPX 630	400	1In	-	-	-	185	240
216	313	DPX 630	500	0.86 In	DPX 630	630	0.7In	-	-	-	2 x 120	2 x 150
225	326	DPX 630	500	0.9 In	DPX 630	630	0.7In	-	-	-	2 x 120	2 x 150
240	348	DPX 630	500	1 In	DPX 630	630	0.8In	-	-	-	2 x 150	2 x 185
250	362	DPX 630	500	1 In	DPX 630	630	0.8In	-	-	-	2 x 150	2 x 185
275	399	DPX 630	630	0.9 In	DPX 630	630	0.9In	-	-	-	2 x 150	2 x 185
280	406	DPX 630	630	0.9 In	DPX 630	630	0.9In	-	-	-	2 x 150	2 x 185
288	417	DPX 630	630	0.9 In	DPX 630	630	0.9In	-	-	-	2 x 150	2 x 185
300	435	DPX 630	630	0.93 In	DPX 630	630	0.95In	-	-	-	2 x 150	2 x 185
320	464	DPX 630	630	1 In	DPX 630	630	1In	-	-	-	2 x 185	2 x 240

Choice of protection for Alpistatic 3-phase capacitor banks
SAH type, standard, reinforced and extra-reinforced class (continued)

Capacitors 400 V		MCCBs						ACBs			Cross-section of the phase conductors (mm²)	
Nominal power (kvar)		Thermal-magnetic DPX			Electronic DPX			DMX³				
	In (A)	Device	In (A)	Ir	Device	In (A)	Ir	Device	In (A)	Ir	Cu	Al
350	507	DPX 1250	800	0.83 In	DPX 1600	800	0.85In	-	-	-	2 x 185	2 x 240
360	522	DPX 1250	800	0.86 In	DPX 1600	800	0.9In	-	-	-	2 x 185	2 x 240
375	544	DPX 1250	800	0.9 In	DPX 1600	800	0.9In	-	-	-	2 x 185	2 x 240
400	578	DPX 1250	800	0.96 In	DPX 1600	1250	0.6In	DMX3 2500	800	1 In	2 x 185	2 x 240
432	626	DPX 1250	1000	0.83 In	DPX 1600	1250	0.7In	DMX3 2500	1000	0.8 In	2 x 240	2 x 300
440	638	DPX 1250	1000	0.86 In	DPX 1600	1250	0.7In	DMX3 2500	1000	0.8 In	2 x 240	2 x 300
450	652	DPX 1250	1000	0.9 In	DPX 1600	1250	0.7In	DMX3 2500	1000	0.9 In	2 x 240	2 x 300
480	697	DPX 1250	1000	0.93 In	DPX 1600	1250	0.7In	DMX3 2500	1000	0.96 In	2 x 240	2 x 300
504	730	DPX 1250	1000	0.96 In	DPX 1600	1250	0.8In	DMX3 2500	1000	1 In	2 x 240	4 x 185
520	754	DPX 1250	1000	1 In	DPX 1600	1250	0.8In	DMX3 2500	1000	1 In	2 x 240	4 x 185
525	761	DPX 1250	1000	1 In	DPX 1600	1250	0.8In	DMX3 2500	1000	1 In	2 x 240	4 x 185
560	812	DPX 1250	1250	0.83 In	DPX 1600	1250	0.8In	DMX3 2500	1250	0.8 In	2 x 240	4 x 185
576	835	DPX 1250	1250	0.86 In	DPX 1600	1250	0.8In	DMX3 2500	1250	0.86 In	2 x 240	4 x 185
600	870	DPX 1250	1250	0.9 In	DPX 1600	1250	0.9In	DMX3 2500	1250	0.9 In	4 x 150	4 x 185
640	926	DPX 1250	1250	0.96 In	DPX 1600	1250	0.95In	DMX3 2500	1250	0.96 In	4 x 150	4 x 185
648	939	DPX 1250	1250	1 In	DPX 1600	1250	1In	DMX3 2500	1250	1 In	4 x 150	4 x 185
675	978	-	-	-	DPX 1600	1600	0.8In	DMX3 2500	1600	0.8 In	4 x 150	4 x 185
680	986	-	-	-	DPX 1600	1600	0.8In	DMX3 2500	1600	0.8 In	4 x 150	4 x 185
720	1044	-	-	-	DPX 1600	1600	0.8In	DMX3 2500	1600	0.86 In	4 x 185	4 x 240
750	1087	-	-	-	DPX 1600	1600	0.9In	DMX3 2500	1600	0.9 In	4 x 185	4 x 240
792	1148	-	-	-	DPX 1600	1600	0.95In	DMX3 2500	1600	0.96 In	4 x 185	4 x 240
800	1160	-	-	-	DPX 1600	1600	0.95In	DMX3 2500	1600	0.96 In	4 x 185	4 x 240
825	1196	-	-	-	DPX 1600	1600	0.95In	DMX3 2500	1600	1 In	4 x 185	4 x 240
840	1217	-	-	-	-	-	-	DMX3 2500	1600	1 In	4 x 185	4 x 240
864	1252	-	-	-	-	-	-	DMX3 2500	2000	0.86 In	4 x 240	4 x 300
875	1268	-	-	-	-	-	-	DMX3 2500	2000	0.86 In	4 x 240	4 x 300
920	1333	-	-	-	-	-	-	DMX3 2500	2000	0.9 In	4 x 240	4 x 300
950	1377	-	-	-	-	-	-	DMX3 2500	2000	0.9 In	4 x 240	4 x 300
960	1391	-	-	-	-	-	-	DMX3 2500	2000	0.9 In	4 x 240	4 x 300
1000	1449	-	-	-	-	-	-	DMX3 2500	2000	0.96 In	4 x 300	-
1080	1565	-	-	-	-	-	-	DMX3 2500	2500	0.8 In	-	-
1200	1739	-	-	-	-	-	-	DMX3 2500	2500	0.9 In	-	-
1250	1812	-	-	-	-	-	-	DMX3 2500	2500	0.96 In	-	-
1320	1913	-	-	-	-	-	-	DMX3 2500	2500	1 In	-	-
1375	1993	-	-	-	-	-	-	DMX3 4000	3200	0.8 In	-	-
1440	2087	-	-	-	-	-	-	DMX3 4000	3200	0.86 In	-	-
1500	2174	-	-	-	-	-	-	DMX3 4000	3200	0.9 In	-	-

Choice of products

V7540CB

ALPIVAR² CAPACITORS

Standard type and H type – three–phase – 400 V – 50 Hz						
Nominal power (kvar)	Cat.Nos		Dimensions (mm)			Weight (kg)
	Standard type 470 V max.	H type 520 V max.	W1	W2	H	
2,5	V2.540CB	VH2.540CB	90	70	275	3.5
5	V540CB	VH540CB	90	70	275	3.5
7,5	V7.540CB	VH7.540CB	90	70	275	3.5
10	V1040CB	VH1040CB	90	70	275	3.5
12,5	V12.540CB	VH12.540CB	90	70	275	3.5
15	V1540CB	VH1540CB	90	70	275	3.5
20	V2040CB	VH2040CB	90	70	275	3.5
25	V2540CB	VH2540CB	90	70	275	3.5
30	V3040CB	VH3040CB	180	156	275	7
35	V3540CB	VH3540CB	180	156	275	7
40	V4040CB	VH4040CB	180	156	275	7
50	V5040CB	VH5040CB	180	156	275	7
60	V6040CB	VH6040CB	270	244	275	10.5
75	V7540CB	VH7540CB	270	244	275	10.5
80	-	VH8040CB	360	332	275	14
90	V9040CB	VH9040CB	360	332	275	14
100	V10040CB	VH10040CB	360	332	275	14
125	V12540CB	VH12540CB	450	419	275	17.5
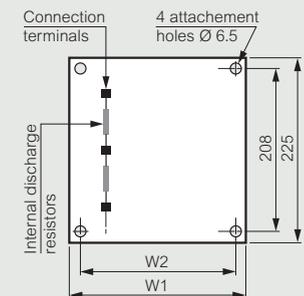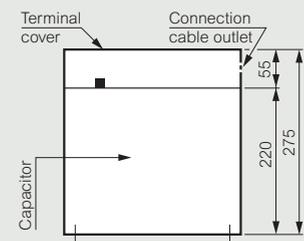
Terminal cover
Connection cable outlet
55
220
275
Capacitor

Connection terminals
4 attachement holes Ø 6.5
Internal discharge resistors
208
225
W2
W1

SAH type (with detuned reactor) – three-phase – 400 V – 50 Hz

Nominal power (kvar)	Cat.Nos			Dimensions (mm)			Weight (kg)
	Standard class 470 V max.	Reinforced class 520 V. max	Extra-reinforced class 620 V max.	Height	Width	Depth	
40		VS.R4040.189		1400	600	500	120
50	VS5040.189			1400	600	500	120
72			VS.RS7240.189	2100	1000	600	180
75	VS7540.189			1400	600	500	140
80		VS.R8040.189		1400	600	500	150
100	VS10040.189			1400	600	500	160
120		VS.R12040.189		1400	600	500	180
144			VS.RS14440.189	2100	1000	600	250
150	VS15040.189			1400	600	500	180
160		VS.R16040.189		1900	800	500	220
200	VS20040.189	VS.R20040.189		1900	800	500	250/260
216			VS.RS21640.189	2100	1000	600	320
240		VS.R24040.189		1900	800	500	280
250	VS25040.189			1900	800	500	275
280		VS.R28040.189		1900	800	500	300
288			VS.RS28840.189	2100	1000	600	380
300	VS30040.189			1900	800	500	300

Alpivar² and Alpimatic technical characteristics

technical characteristics		Vacuum technology capacitors		Compensation racks		Compensation racks with detuned reactor	
		Standard type	H type	Standard type	H type	Standard type	Reinforced type
Loss Factor		< 0.3 W/kvar		< 2 W/kvar		⩽ 6 W/kvar	
Tolerance on the capacitance		-5 to +10 %		-5 to +10 %		-5 to +10 %	
Max. permissible voltage		1.18 Un (24 h/24)		1.18 Un (24 h/24)		1.18 Un (24 h/24)	
Max. permissible current		1.3 In	1.5 In	1.3 In	1.5 In	1.3 In	1.5 In
Insulation class	withstand 1 minute at 50 Hz	6 kV		6 kV		6 kV	
	withstand 1.2/50 µs shock wave	25 kV		25 kV		25 kV	
Standards		IEC 60831-1 and 2 CSA 22-2 No 190		IEC 60439-1 EN 60439-2		IEC 60439-1 EN 60439-2	
Operating temperature		-25°C to +55°C		-10°C to +45°C		-10°C to +45°C	
	Average over 24h	45 °C		40 °C			
	Annual average	35 °C					
Storage temperature				-30°C to +60°C		-30°C to +60°C	

B6040

ALPIBLOC CAPACITORS WITH BUILT-IN CB

Standard type and H type – 400 V – 50 Hz

Nominal power (kvar)	Circuit breaker Isc (kA)	Cat.Nos		Dimensions (mm)			Weight (kg)
		Standard type 470 V max.	H type 520 V max.	Height	Width	Depth	
10	50	B1040	BH1040	380	190	230	5
15	50	B1540	BH1540	380	190	230	5
20	50	B2040	BH2040	380	190	230	5
25	50	B2540	BH2540	380	190	230	7.5
30	50	B3040	BH3040	380	365	230	10
40	25	B4040	BH4040	380	365	230	10
50	25	B5040	BH5040	380	365	230	12,5
60	25	B6040	BH6040	380	365	230	15
75	25	B7540	BH7540	380	365	230	15
90	36	B9040	BH9040	380/1000	550/350	230/500	20
100	36	B10040	BH10040	380/1000	550/350	230/500	20
125	36	B12540	BH12540	380/1000	550/350	230/500	25
150	36	B15040	BH15040	1000	350	500	75
175	36	B17540	BH17540	1000	350	500	100

SAH type (with detuned reactor) – 400 V – 50 Hz

Nominal power (kvar)	Circuit breaker Isc (kA)	Cat.Nos			Dimensions (mm)			Weight (kg)
		Standard class 470 V max.	Reinforced class 520 V max.	Extra-reinforced class 620 V max.	Height	Width	Depth	
40	16		BS.R4040.189		1400	600	500	125
50	25	BS5040.189			1400	600	500	125
72	36			BS.RS7240.189	2100	1000	600	185
75	25	BS7540.189			1400	600	500	145
80	25		BS.R8040.189		1400	600	500	155
100	36	BS10040.189			1400	600	500	165
120	36		BS.R12040.189		1900	600	500	200
144	36			BS.RS14440.189	2100	1000	600	255
150	36	BS15040.189			1900	600	500	190
160	36		BS.R16040.189		1900	800	500	230
200	36	BS20040.189	BS.R20040.189		1900	800	500	260/270
216	36			BS.RS21640.189	2100	1000	600	325
240	36		BS.R24040.189		1900	800	500	290
250	36	BS25040.189			1900	800	500	285
280	36		BS.R28040.189		2100	800	500	350
288	50			BS.RS28840.189	2100	1000	600	385
300	36	BS30040.189			1900	800	500	320

P7540
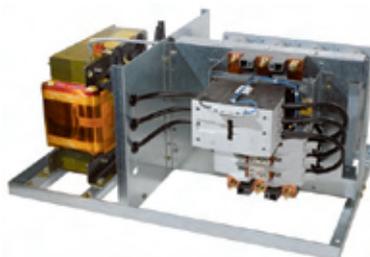
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ALPIMATIC RACKS

Standard type and H type – three–phase – 400 V – 50 Hz

Nominal power (kvar)	Cat.Nos		Weight (kg)	
	Standard type 470 V max.	H type 520 V max.	Standard type	H type
12.5	P12.540	PH12.540	6	7
12.5 + 12.5	P12.512.540	PH12.512.540	11	14
25	P2540	PH2540	9	10
25 + 25	P252540	PH252540	16	17
25 + 50	P255040	PH255040	22	23
50	P5040	PH5040	16	17
75	P7540	PH7540	22	23

Junction bars

Fixing holes Ø 7

248 160 240 400

225 565 580

SAH type (with detuned reactor) – three–phase – 400 V – 50 Hz

Nominal power (kvar)	Cat. Nos			Rack type	Weight (kg)	
	Standard class 470 V max.	Reinforced class 520 V max.	Extra-reinforced class 620 V max.		Standard class	Reinforced and extra-reinforced class
10	R5.1040.189	-		R5	30	
20	R5.2040.189	-		R5	35	
20 + 20	R5.202040.189	-		R5	45	
40	R5.4040.189	R5.R4040.189		R5	40	50
	R7.4040.189	R7.R4040.189		R7	42	52
40 + 40	R7.404040.189	R7.R404040.189		R7	70	85
72			R9.RS7240.189	R9		80
80	R7.8040.189	R7.R8040.189		R7	65	80

Junction bars

325

21x7 oblong fixing holes

458 425 R5 type Ø7 fixing holes

468 500

Junction bars

325

24x8.2 oblong fixing holes

458 425 R7 type Ø 8.2 fixing holes

665 700

Junction bars

400

24x8.2 oblong fixing holes

558 425 R9 type Ø 8.2 fixing holes

865 900
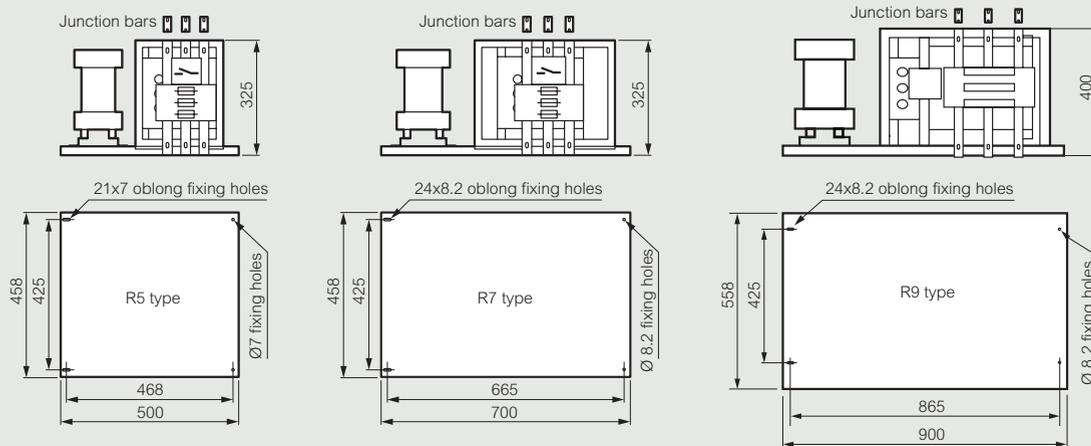
M20040

M20040

ALPIMATIC AUTOMATIC CAPACITOR BANKS

Standard type and H type – three-phase – 400 V – 50 Hz							
Nominal power (kvar)	Steps (kvar)	Cat.Nos		Dimensions (mm)			Weight (kg)
		Standard type 470 V max.	H type 520 V max.	Height	Width	Depth	
10	5 + 5	M1040	MH1040	650	260	320	40
15	5 + 10	M1540	MH1540	650	260	320	40
20	10 + 10	M2040	MH2040	650	260	320	40
25	10 + 15	M2540	MH2540	650	260	320	40
30	5 + 10 + 15	M3040	MH3040	650	260	320	45
35	5 + 10 + 20	M3540	MH3540	650	260	320	45
40	10 + 10 + 20	M4040	MH4040	650	260	320	45
50	10 + 15 + 25	M5040	MH5040	650	260	320	45
60	20 + 20 + 20	M6040	MH6040	770	260	320	50
75	25 + 25 + 25	M7540	MH7540	770	260	320	75
87,5	12.5 + 25 + 50	M87.540	MH87.540	1000	350	500	80
100	25 + 25 + 50	M10040	MH10040	1000	350	500	80
125	25 + 50 + 50	M12540	MH12540	1000	350	500	90
150	25 + 50 + 75	M15040	MH15040	1400	600	500	125
175	25 + 25 + 50 +75	M17540	MH17540	1400	600	500	140
200	50 + 75 + 75	M20040	MH20040	1400	600	500	150
225	25 + 50 + 75 + 75	M22540	MH22540	1400	600	500	160
250	50 + 50 + 75 + 75	M25040	MH25040	1400	600	500	170
275	25 + 50 + 50 + 75 + 75	M27540	MH27540	1400	600	500	190
300	25 + 50 + 3 x 75	M30040	MH30040	1400	600	500	200
350	50 + 4 x 75	M35040	MH35040	1900	600	500	260
400	2 x 50 + 4 x 75	M40040	MH40040	1900	600	500	290
450	6 x 75	M45040	MH45040	1900	600	500	300
500	50 + 6 x 75	M50040	MH50040	1400	1200	500	370
550	2 x 50 + 6 x 75	M55040	MH55040	1400	1200	500	400
600	8 x 75	M60040	MH60040	1400	1200	500	430
675	9 x 75	M67540	MH67540	1900	1200	500	490
750	10 x 75	M75040	MH75040	1900	1200	500	500
825	11 x 75	M82540	MH82540	1900	1200	500	540
900	12 x 75	M90040	MH90040	1900	1200	500	560

MS28040.189

SAH type (with detuned reactor) – three-phase – 400 V – 50 Hz							
Nominal power (kvar)	Steps (kvar)	Cat.Nos			Dimensions (mm)		Weight (kg)
		Standard class 470 V max.	Reinforced class 520 V max.	Extra-reinforced class 620 V max.	Height	Width	Depth	
75	25 + 50	MS7540.189			1400	600	500	180
100	2 x 25 + 50	MS10040.189			1400	600	500	230
120	3 x 40		MS.R12040.189		1400	600	500	250
125	25 + 2 x 50	MS12540.189			1400	600	500	250
144	2 x 72			MS.RS14440.189	2100	1000	600	300
150	3 x 50	MS15040.189			1400	600	500	300
160	2 x 40 + 80		MS.R16040.189		1900	800	500	300
200	50 + 2 x 75	MS20040.189			1900	800	500	340
200	40 + 2 x 80		MS.R20040.189		1900	800	500	340
216	3 x 72			MS.RS21640.189	2100	1000	600	380
225	3 x 75	MS22540.189			1900	800	500	360
240	2 x 40 + 2 x 80		MS.R24040.189		1900	800	500	370
250	2 x 50 + 2 x 75	MS25040.189			1900	800	500	380
275	50 + 3 x 75	MS27540.189			1900	800	500	400
280	40 + 3 x 80		MS.R28040.189		1900	800	500	400
288	4 x 72			MS.RS28840.189	2100	1000	600	460
300	4 x 75	MS30040.189			1900	800	500	420
320	4 x 80		MS.R32040.189		1900	800	500	430
350	50 + 4 x 75	MS35040.189			2100	800	500	460
360	40 + 4 x 80		MS.R36040.189		2100	800	500	470
360	5 x 72			MS.RS36040.189	2100	2000	600	600
375	5 x 75	MS37540.189			2100	800	500	470
400	5 x 80		MS.R40040.189		2100	800	500	520
432	6 x 72			MS.RS43240.189	2100	2000	600	680
440	40 + 5 x 80		MS.R44040.189		1900	1600	500	600
450	6 x 75	MS45040.189			1900	1600	500	600
480	6 x 80		MS.R48040.189		1900	1600	500	630
504	7 x 72			MS.RS50440.189	2100	2000	600	760
520	40 + 6 x 80		MS.R52040.189		1900	1600	500	670
525	7 x 75	MS52540.189			1900	1600	500	630
560	7 x 80		MS.R56040.189		1900	1600	500	700
576	8 x 72			MS.RS57640.189	2100	2000	600	820
600	8 x 75	MS60040.189			1900	1600	500	730
600	40 + 7 x 80		MS.R60040.189		1900	1600	500	750
640	8 x 80		MS.R64040.189		1900	1600	500	800
648	9 x 72			MS.RS64840.189	2100	3000	600	950
675	9 x 75	MS67540.189			2100	1600	500	800
720	9 x 80		MS.R72040.189		2100	1600	500	860
720	10 x 72			MS.RS72040.189	2100	3000	600	1130
750	10 x 75	MS75040.189			2100	1600	500	860
792	11 x 72			MS.RS79240.189	2100	3000	600	1200
800	10 x 80		MS.R80040.189		2100	1600	500	920
864	12 x 72			MS.RS86440.189	2100	3000	600	1260

ALPIMATIC AUTOMATIC CAPACITOR BANKS
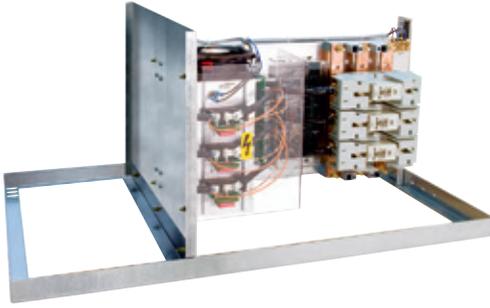
RST7.5040

ALPISTATIC RACKS

Standard type and H type – three-phase – 400 V – 50 Hz

Nominal power (kvar)	Cat.Nos		Rack type	Weight (kg)	
	Standard type 470 V max.	H type 520 V max.		Standard type	H type
25	RST7.2540	RST7.H2540	7	45	50
50	RST7.5040	RST7.H5040	7	50	55
75	RST7.7540	RST7.H7540	7	55	60
100	RST7.10040	RST7.H10040	7	60	65
125	RST9.12540	RST9.H12540	9	65	70

SAH type (with detuned reactor) – three-phase – 400 V – 50 Hz

Nominal power (kvar)	Cat. Nos			Rack type	Weight (kg)
	Standard class 470 V max.	Reinforced class 520 V max.	Extra-reinforced class 620 V max.		
25	RST7.2540.189			7	50
40		RST7.R4040.189		7	60
50	RST7.5040.189			7	60
72			RST9.RS7240.189	9	100
75	RST7.7540.189			7	70
80		RST7.R8040.189		7	80
100	RST7.10040.189			7	80
120		RST9.R12040.189		9	90
125	RST9.12540.189			9	90
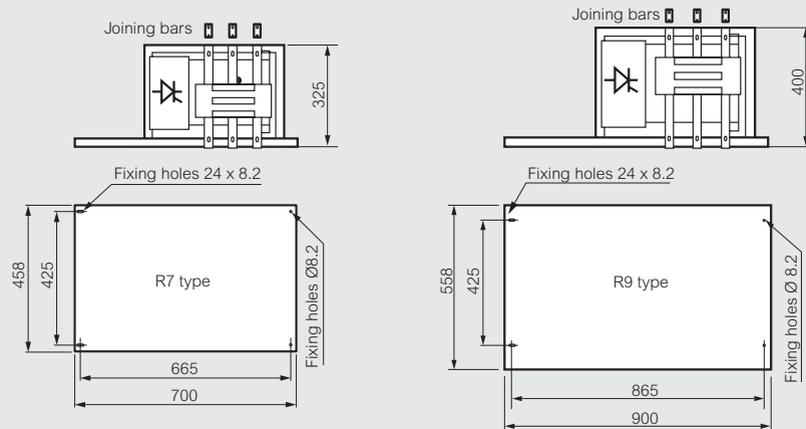
STS40040

ALPISTATIC AUTOMATIC CAPACITOR BANKS

Standard type and H type – three–phase – 400 V – 50 Hz							
Nominal power (kvar)	Steps (kvar)	Cat.Nos		Dimensions (mm)			Weight (kg)
		Standard type 470 V max.	H type 520 V max.	Height	Width	Depth	
100	2 x 25 + 50	ST10040	STH10040	1900	800	500	170
125	25 + 2 x 50	ST12540	STH12540	1900	800	500	200
150	50 +100	ST15040	STH15040	1900	800	500	210
175	2 x 50 + 75	ST17540	STH17540	1900	800	500	220
200	50 + 2 x 75	ST20040	STH20040	1900	800	500	250
225	25 + 50 + 2 x 75	ST22540	STH22540	1900	800	500	260
250	50 + 2 x 100	ST25040	STH25040	1900	800	500	280
275	50 + 3 x 75	ST27540	STH27540	1900	800	500	300
300	2 x 50 + 2 x 100	ST30040	STH30040	1900	800	500	320
350	50 + 3 x 100	ST35040	STH35040	1900	800	500	350
400	4 x 100	ST40040	STH40040	1900	800	500	375
450	75 + 3 x 125	ST45040	STH45040	2100	1000	600	400
500	4 x 125	ST50040	STH50040	2100	1000	600	425
525	2 x 75 + 3 x 125	ST52540	STH52540	2100	2000	600	475
575	75 + 4 x 125	ST57540	STH57540	2100	2000	600	525
625	5 x 125	ST62540	STH62540	2100	2000	600	550
700	75 + 5 x 125	ST70040	STH70040	2100	2000	600	575
750	6 x 125	ST75040	STH75040	2100	2000	600	600
825	75 + 6 x 125	ST82540	STH82540	2100	2000	600	625
875	7 x 125	ST87540	STH87540	2100	2000	600	650
950	75 + 7 x 125	ST95040	STH95040	2100	2000	600	700
1000	8 x 125	ST100040	STH100040	2100	2000	600	750
1125	9 x 125	ST112540	STH112540	2100	3000	600	800
1250	10 x 125	ST125040	STH125040	2100	3000	600	850
1375	11 x 125	ST137540	STH137540	2100	3000	600	1000
1500	12 x 125	ST150040	STH150040	2100	3000	600	1200

STS28040.189

ALPISTATIC AUTOMATIC CAPACITOR BANKS (CONTINUED)

Nominal power (kvar)	Steps (kvar)	Cat.Nos			Dimensions (mm)			Weight (kg)
		Standard class 470 V max.	Reinforced class 520 V max.	Extra-reinforced class 620 V max.	Height	Width	Depth	
100	2 x 25 + 50	STS10040.189			1900	800	500	210
120	40 + 80		STS.R12040.189		1900	800	500	250
125	25 + 2 X 50	STS12540.189			1900	800	500	240
144	2 x 72			STS.RS14440.189	2100	1000	600	350
150	50 + 100	STS15040.189			1900	800	500	280
160	2 x 40 + 80		STS.R16040.189		1900	800	500	280
175	2 x 50 + 75	STS17540.189			1900	800	500	300
200	40 + 2 x 80		STS.R20040.189		1900	800	500	320
200	50 + 2 x 75	STS20040.189			1900	800	500	320
216	3 x 72			STS.RS21640.189	2100	1000	600	430
225	25 + 50 + 2 x 75	STS22540.189			1900	800	500	360
240	2 x 40 + 2 x 80		STS.R24040.189		1900	800	500	360
250	50 + 2 x 100	STS25040.189			1900	800	500	380
275	50 + 3 x 75	STS27540.189			1900	800	500	400
280	40 + 3 x 80		STS.R28040.189		1900	800	500	400
288	4 x 72			STS.RS28840.189	2100	1000	600	510
300	2 x 50 + 2 x 100	STS30040.189			1900	800	500	430
320	4 x 80		STS.R32040.189		1900	800	500	430
350	50 + 3 x 100	STS35040.189			1900	800	500	460
360	40 + 4 x 80		STS.R36040.189		2100	800	500	460
360	5 x 72			STS.RS36040.189	2100	2000	600	650
400	4 x 100	STS40040.189			1900	800	500	500
400	5 x 80		STS.R40040.189		2100	800	500	500
432	6 x 72			STS.RS43240.189	2100	2000	600	730
440	80 + 3 x 120		STS.R44040.189		2100	1000	600	530
450	75 + 3 x 125	STS45040.189			2100	1000	600	530
480	4 x 120		STS.R48040.189		2100	1000	600	630
500	4 x 125	STS50040.189			2100	1000	600	630
504	7 x 72			STS.RS50440.189	2100	2000	600	810

Table title: SAH type (with detuned reactor) – three–phase – 400 V – 50 Hz

Nominal power (kvar)	Steps (kvar)	Cat.Nos			Dimensions (mm)			Weight (kg)
		Standard class 470 V max.	Reinforced class 520 V max.	Extra-reinforced class 620 V max.	Height	Width	Depth	
520	2 x 80 + 3 x 120		STS.R52040.189		2100	2000	600	660
525	2 x 75 + 3 x 125	STS52540.189			2100	2000	600	660
560	80 + 4 x 120		STS.R56040.189		2100	2000	600	690
575	75 + 4 x 125	STS57540.189			2100	2000	600	690
576	8 x 72			STS.RS57640.189	2100	2000	600	870
600	5 x 120		STS.R60040.189		2100	2000	600	720
625	5 x 125	STS62540.189			2100	2000	600	720
648	9 x 72			STS.RS64840.189	2100	3000	600	1000
680	80 + 5 x 120		STS.R68040.189		2100	2000	600	780
700	75 + 5 x 125	STS70040.189			2100	2000	600	780
720	6 x 120		STS.R72040.189		2100	2000	600	810
720	10 x 72			STS.RS72040.189	2100	3000	600	1180
750	6 x 125	STS75040.189			2100	2000	600	810
792	11 x 72			STS.RS79240.189	2100	3000	600	1250
800	80 + 6 x 120		STS.R80040.189		2100	2000	600	850
825	75 + 6 x 125	STS82540.189			2100	2000	600	840
840	7 x 120		STS.R84040.189		2100	2000	600	900
864	12 x 72			STS.RS86440.189	2100	3000	600	1310
875	7 x 125	STS87540.189			2100	2000	600	870
920	80 + 7 x 120		STS.R92040.189		2100	2000	600	930
950	75 + 7 x 125	STS95040.189			2100	2000	600	910
960	8 x 120		STS.R96040.189		2100	2000	600	950
1000	8 x 125	STS100040.189			2100	2000	600	930
1080	9 x 120		STS.R108040.189		2100	3000	600	1000
1125	9 x 125	STS112540.189			2100	3000	600	1000
1200	10 x 120		STS.R120040.189		2100	3000	600	1100
1250	10 x 125	STS125040.189			2100	3000	600	1100
1320	11 x 120		STS.R132040.189		2100	3000	600	1200
1375	11 x 125	STS137540.189			2100	3000	600	1200
1440	12 x 120		STS.R144040.189		2100	3000	600	1300
1500	12 x 125	STS150040.189			2100	3000	600	1300

Table title: **SAH type (with detuned reactor) – three-phase – 400 V – 50 Hz (continued)**

ALPISTATIC AUTOMATIC CAPACITOR BANKS (CONTINUED)

ALPTEC12.400

RBAA001.1

RDAB002

ALPTEC POWER FACTOR CONTROLLERS AND POWER QUALITY ANALYSER

Alptec power factor controllers		
Number of steps	**Power supply**	
	400 V - 50 Hz	**230 V - 50 Hz**
3	ALPTEC3.400	ALPTEC3.230
5	ALPTEC5.400	ALPTEC5.230
7	ALPTEC7.400	ALPTEC7.230
11		ALPTEC11ST
12	ALPTEC12.400	ALPTEC12.230 ALPTEC12H[1]

(1) with harmonic measurement

Alptec power quality analyser							
Device	**Cat.Nos**	**Mounting**	**Measurement**	**Power supply**	**Backup battery autonomy**	**Flash memory card**	**Communication mode**
Alptec R2444d	RBAA001.1	DIN rail	4 voltages and 4 currents	190-264 V AC 240-360 V DC	> 30 minutes	512 MB	USB Ethernet RTC modem
Alptec R2444i	RBAD001.1	portable device	4 voltages and 4 currents				
Alptec 2333	RBAB002	portable IP 54 device	3 voltages and 3 currents	3-Ph mode: 215-600 V AC 1-Ph mode: 125-325 V AC	> 45 minutes	1 GB	USB

Accessories and software for power quality anlyser	
10 A micro clamps (supplied with 2 m cable)	RBAE016
Switchable clamp: 10 A/100A/1000 A (supplied with 2 m cable)	RBAG007
Aptec switchable flexible coil (supplied with 3 m cable)	RBAE017
Novaflex 56000 modem (56 kb/s)	RBAE006
Winalp 2400 software	RBAT001
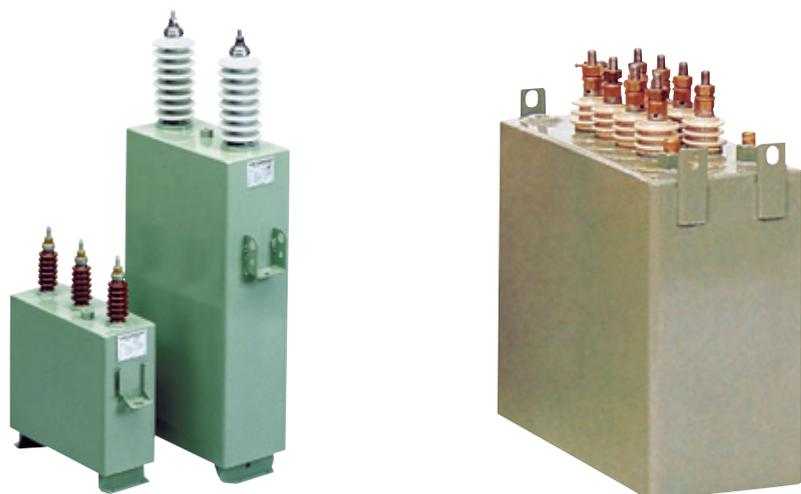
"ALL–FILM" HV CAPACITORS

<table>
<tr><th colspan="3">Technical characteristics</th></tr>
<tr><td rowspan="2">Average loss factor</td><td>at power-up</td><td>0.15 W/kvar</td></tr>
<tr><td>after 500 hours' operation</td><td>0.10 W/kvar</td></tr>
<tr><td colspan="2">Variation of the capacitance as a function of the temperature</td><td>$2 \times 10^{-4}/°C$</td></tr>
<tr><td colspan="2">Discharge time to reduce the residual voltage to 75 V after disconnection of the supply</td><td>10 minutes</td></tr>
<tr><td rowspan="2">Frequency</td><td>standard</td><td>50 Hz</td></tr>
<tr><td>on request</td><td>60 Hz</td></tr>
<tr><td colspan="2">Reference standards</td><td>NF C 54 102, IEC 60 871-1 et 2, IEC 60 110, VDE 0560/4, VDE 0560/9, BS 1650</td></tr>
<tr><td colspan="2">Permissible overloads · continuously</td><td>1.3 In</td></tr>
<tr><td rowspan="4">Permissible overvoltage</td><td>12 hours in every 24 hours</td><td>1.1 Un</td></tr>
<tr><td>30 minutes in every 24 hours</td><td>1.15 Un</td></tr>
<tr><td>5 minutes in every 24 hours</td><td>1.2 Un</td></tr>
<tr><td>1 minute in every 24 hours</td><td>1.3 Un</td></tr>
<tr><td rowspan="4">Temperature class</td><td>standard</td><td>-25°C to +40°C</td></tr>
<tr><td>max.</td><td>45°C</td></tr>
<tr><td>average over 24 hours</td><td>35°C</td></tr>
<tr><td>average over 1 year</td><td>25°C</td></tr>
</table>

Standard insulation levels (phases/earth) for individual 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 impulse withstand voltage (peak value) (kV)	35	40	60	75	95	125

Possible type of protection for capacitors

Capacitor power and voltage	Capacitor connection	Capacitor protection	Associated external protection	Advantages
All powers and all voltages	Single phase	without internal fuses	Unbalance	-
P ≥ 200 kVAr and U ≤ 13 kV	Single phase	with internal fuses	Unbalance	• Does not trip on 1st fault • Assured continuity of service
All powers and U ≤ 12 kV	Three-phase	without pressure monitoring device	HRC fuses	-
All powers and U ≤ 12 kV	Three-phase	with pressure monitoring device	HRC fuses	• No risk of rupture of case

Dimensions and weight
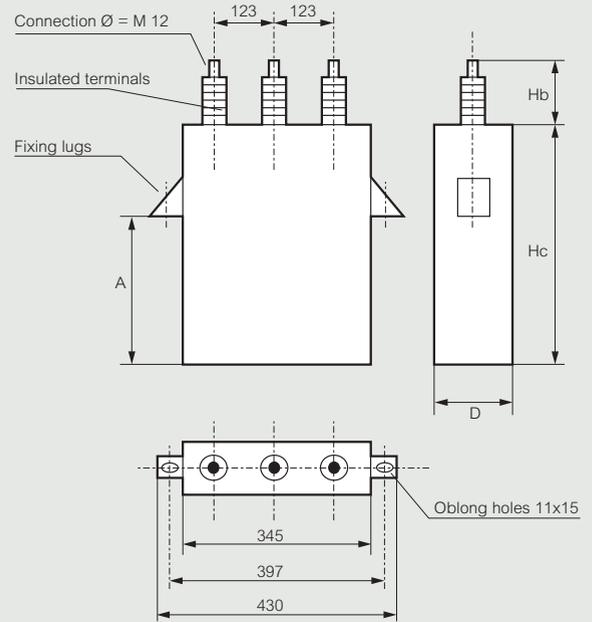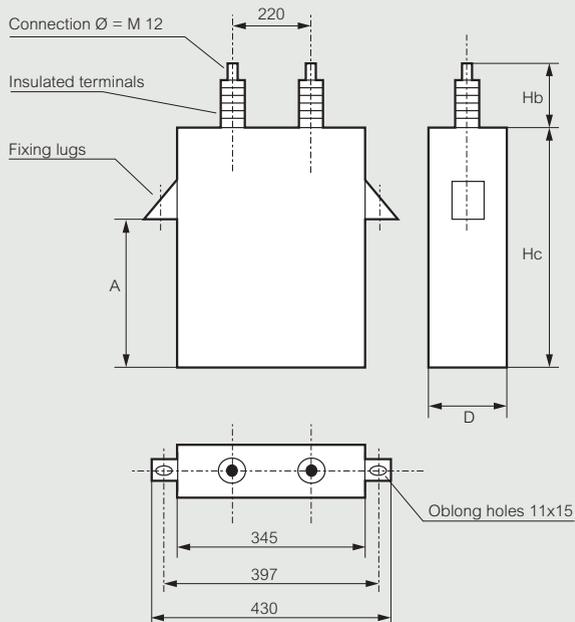
Power (standard) kvar	Dimensions[1] (mm)			Weight (kg)
	Hc	A	D	
50	190	40	135	17
75	250	100	135	21
100	280	130	135	23
125	350	200	135	27
150	370	220	135	30
175	450	300	135	33
200	460	310	135	35
250	460	310	135	42
300	510	360	175	46
350	590	440	175	53
400	650	400	175	60
450	730	480	175	65
500	790	540	175	70
550	880	630	175	76
600	950	700	175	82

(1) Given the multiplicity of MV capacitor voltages, these dimensions must be confirmed by our technical departments.

| Um rms[2] kV	Dimension Hb (mm)	
	Indoor type	Outdoor type
2,4	75	235
3,6	160	235
7,2	160	235
12	160	235
17,5	235	235
24	265	265

(2) The Um rms voltage to be taken into account is the voltage of the mains supply to which the capacitor is to be connected, and not the nominal voltage of the unit (applies in particular to single phase capacitors wired in star or double star configurations).
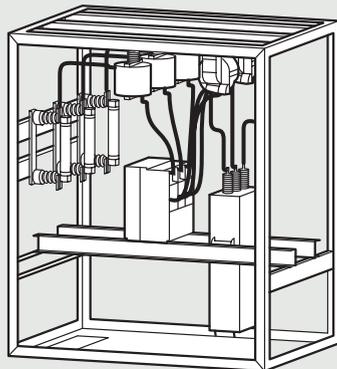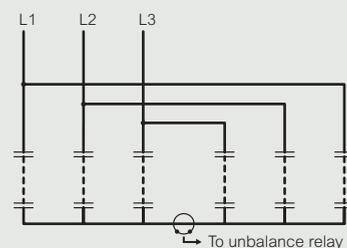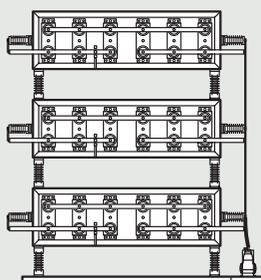
Installation examples
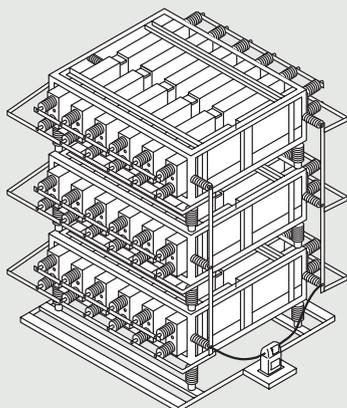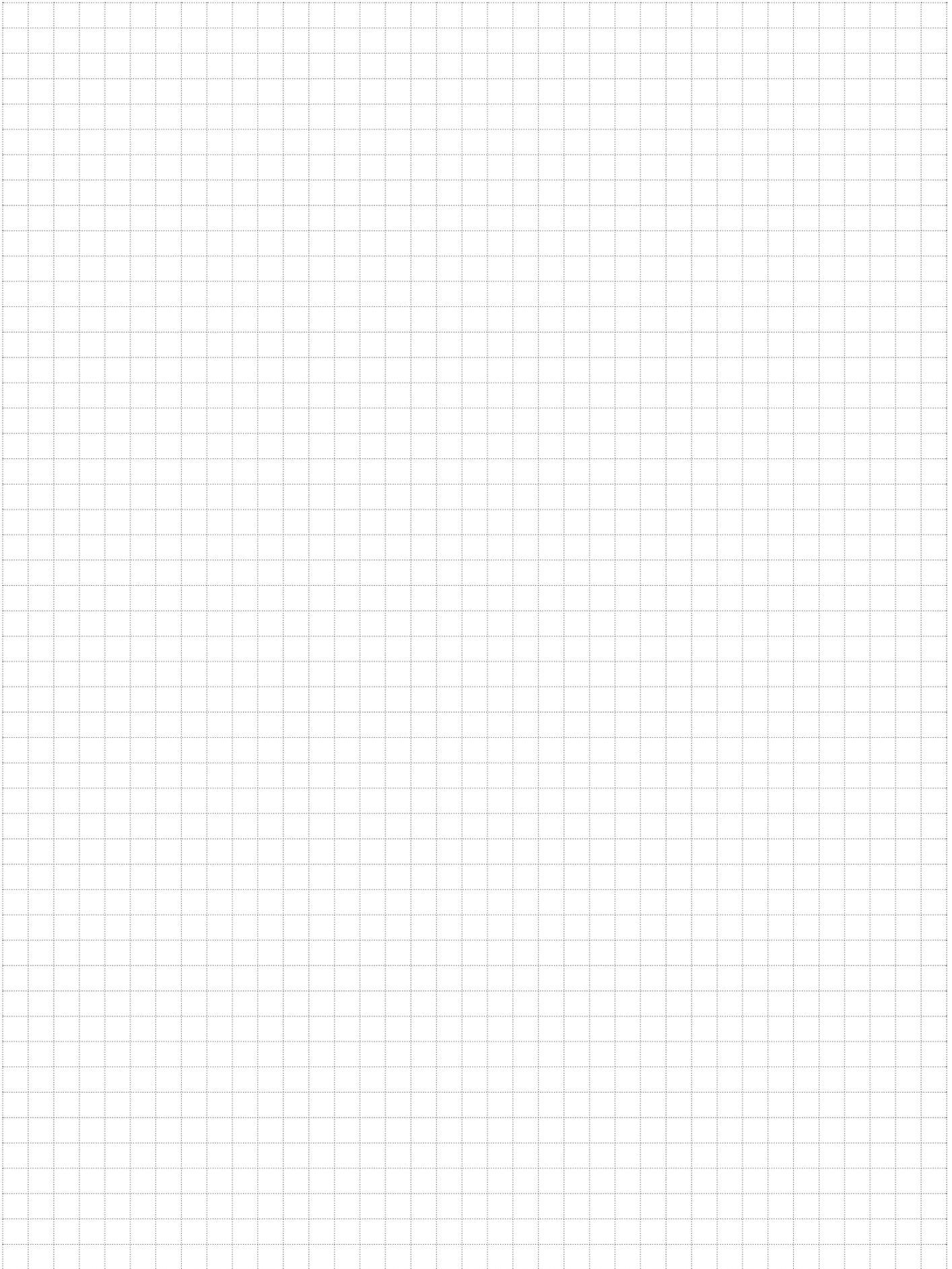
• **Fixed type – Delta configuration**
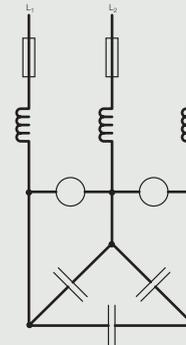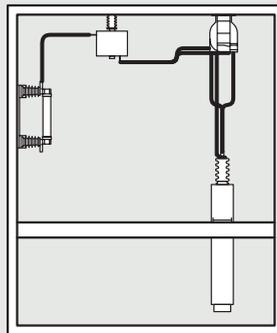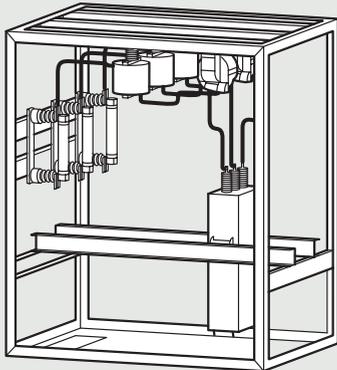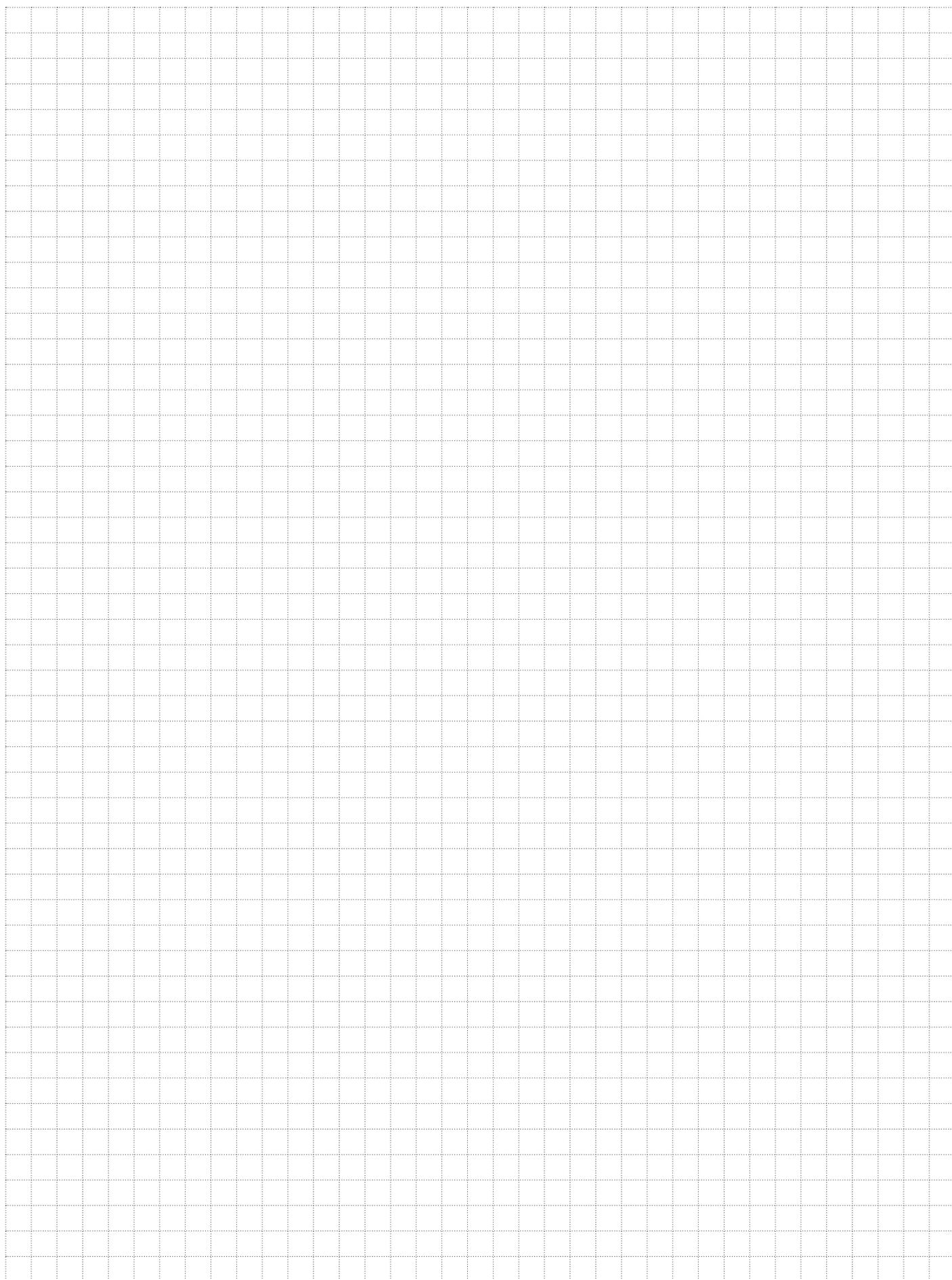

• **Fixed type with contactors – Delta configuration**
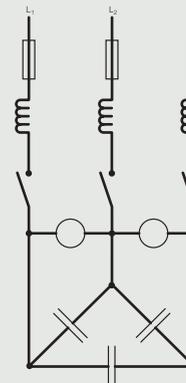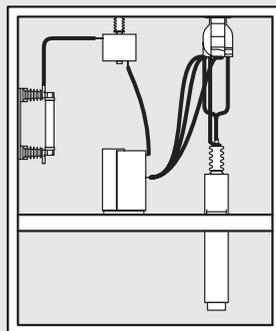
• **Fixed type – Double star configuration**

To unbalance relay

POWER GUIDE:
A complete set of technical documentation

01 | Sustainable development

02 | Power balance and choice of power supply solutions

03 | Electrical energy supply

04 | Sizing conductors and selecting protection devices

05 | Breaking and protection devices

06 | Electrical hazards and protecting people

07 | Protection against lightning effects

08 | Protection against external disturbances

09 | Operating functions

10 | Enclosures and assembly certification

11 | Cabling components and control auxiliaries

12 | Busbars and distribution

13 | Transport and distribution inside an installation

Annexes Glossary Lexicon

EX29007

L legrand

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