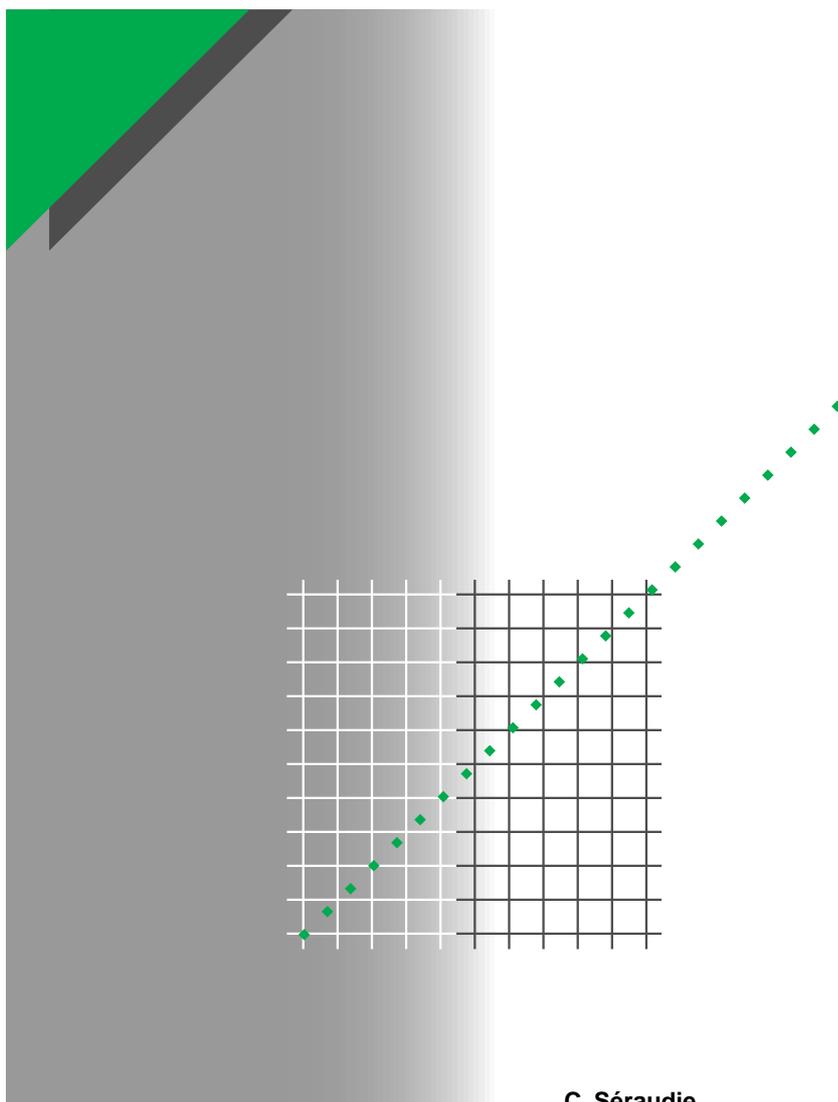


Cahier technique n° 179

LV surges and surge arresters LV insulation co-ordination



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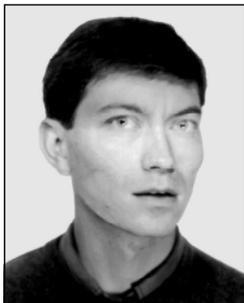
Foreword

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no. 179

LV surges and surge arresters LV insulation co-ordination



Christophe SERAUDIE

Having graduated from the Centre d'Etudes Supérieures des Techniques Industrielles (CESTI: Centre for the Advanced Study of Industrial Techniques) in 1986, he then obtained his PhD in ceramic materials in 1990 (thesis prepared at Limoges University under a Ceramics and Composites CNRS contract). He joined Merlin Gerin's "LV breaking" research group that same year, and then in 1992 assumed responsibility for development of surge arresters in the LV Final Distribution Division.

Lexicon

Common mode (disturbances):

which are applied and propagated between live conductors and frames or the earth.

Differential mode (disturbances):

which are superimposed on network voltage and propagated between the various live conductors.

Filter:

equipment particularly designed to eliminate switching and power frequency surges.

Holding current I_s :

current delivered by the network and which flows off via the surge arrester after passage of the discharge current (this phenomenon only exists for spark-gap-based technologies).

Leakage current I_f :

current flowing in the surge arrester when it is supplied at its maximum steady state voltage.

Level of protection:

the highest value of residual voltage and maximum arcing voltage.

Lightning rod:

a metal device designed to intercept lightning in order to flow it off to earth.

Maximum arcing voltage:

peak voltage in 1.2/50 μ s wave (characteristic specific to spark-gap type components).

Nominal I_n or maximum I_{max} discharge current:

peak value of the current in 8/20 μ s wave (see **fig. 9**) used for operating tests.

Residual voltage U_r :

voltage appearing at the terminals of a surge limiter (component or switchgear) during discharge current flow.

Surge limiter:

device used to attenuate or clip certain types of surge. In France this term is particularly reserved for MV surge protection devices in LV installations using IT earthing systems.

Surge arrester:

a device designed to limit transient surges, including lightning surges, and to redirect current waves. It contains at least one non-linear component (as per NF C 61-740).

LV surges and surge arresters

LV insulation co-ordination

Low voltage insulation co-ordination consists of matching the surge levels that may appear on an electrical network (or installation) with the surge withstand of the industrial or domestic equipment that it supplies, bearing in mind the possibility of including surge limiting devices in the network structure.

This discipline contributes to increased safety of equipment and increased availability of electrical power.

Insulation co-ordination control therefore requires:

- estimation of surge level and energy,
- knowledge of the characteristics and location of the devices installed,
- selection of appropriate protection devices, bearing in mind that for a device, there is only one surge withstand (normally defined by its construction standard).

This “Cahier Technique” deals with the aspects relating to standards and implementation of disturbances, protection devices and in particular surge arresters.

It mainly concerns LV installations (< 1000 V) in the industrial, tertiary and domestic sectors.

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1 Surges

There are four different types of surge:

- lightning,
- electrostatic discharge,
- switching,
- power frequency.

Their main characteristics are described in the table in **figure 1**, and are defined in the IEC 1000-4 publications.

These disturbances which are superimposed on network voltage can be applied in two modes:

- common mode, between the live conductors and the earth,
- differential mode, between the various live conductors.

In both cases the resulting damage comes from dielectric breakdown and leads to destruction of sensitive equipment and in particular of electronic components.

Installations are regularly subjected to a certain number of non-negligible surges (see **fig. 2**) which cause malfunctioning and

Surge	Duration	Steepness of rising edge, or frequency	Damping according to distance
Lightning	Very short (μs)	Very high (1000 kV/ μs)	Strong
Electrostatic discharge	Very short (ns)	High (≈ 10 MHz)	Very strong
Switching	Short (ms)	Average (1 to 200 kHz)	Average
At power frequency	Long (s), or very long (h)	Network frequency	Zero

Fig. 1: the four types of surge present on the electrical networks.

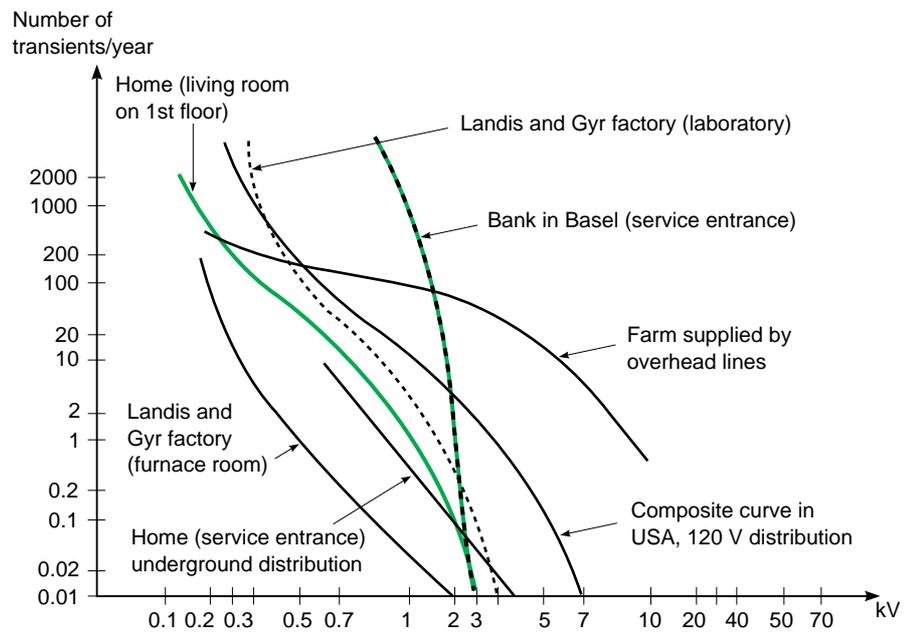


Fig. 2: frequencies of occurrence and peak values of surges (recorded by Landis and Gyr and published by the IEEE).

even destruction of equipment, resulting in downtime.

Protection devices, such as HV and LV surge arresters, are available. However, in order to

ensure correct protection against the surges occurring on the network, detailed knowledge of their nature and characteristics is necessary. This is the purpose of this chapter.

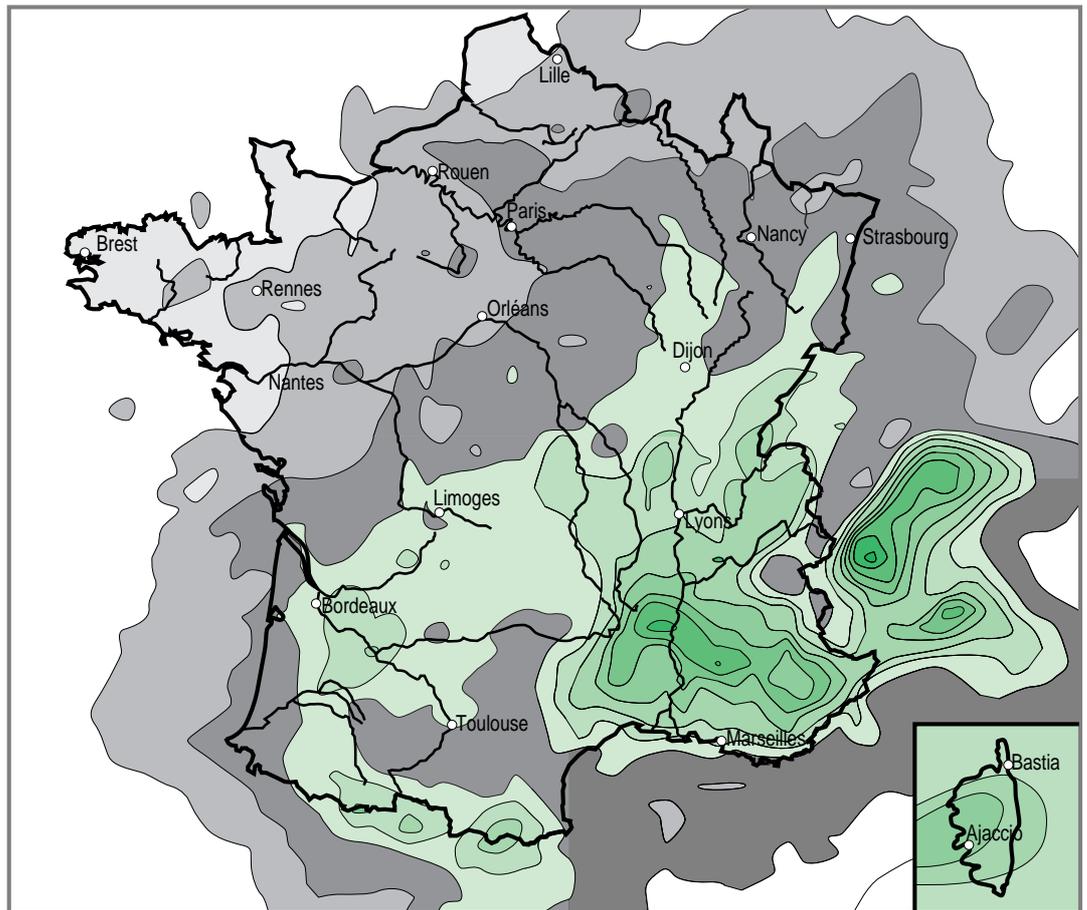
1.1 Lightning surges

Lightning is a natural phenomenon with spectacular and destructive consequences.

In France two million lightning strokes cause each year the death of 40 people and 20000 animals, 15000 fires, 50000 power cuts on electrical and telephone networks and the destruction of countless transformers and thousands of electronic household appliances. The total cost of the effects of lightning is estimated at around one thousand million francs a year. Not all regions have the same degree of exposure. Although a map normally exists

showing the lightning densities for each country, in order to determine in greater detail the exposure of a site, preference should be given to the maps published by firms specialising in the detection of storms and related phenomena (see **fig. 3**).

Lightning is linked to the formation of storm clouds which combine with the ground to form a genuine dipole. The electrical field on the ground may then reach 20 kV/m. A leader develops between the cloud and the ground in a series of



(© Copyright 1985 METEORAGE).

Fig. 3: reading of lightning impacts in France. Each colour corresponds to a lightning striking density.

leaps, creating the ionised channel in which the return arc or lightning stroke flows (see **fig. 4**). According to the polarity of the cloud with respect to the ground, the stroke is either negative (negative cloud) or positive (positive cloud), and according to the origin of the leader, the stroke is either ascending or descending.

It has been observed that in countries with a temperate climate (including France), the majority of lightning strokes are negative, but that the most energetic are positive. Their effects form the subject of two approaches: when the element studied is the one receiving the stroke, we refer to a direct lightning stroke, and when the element studied only suffers the effects of the stroke, we refer to an indirect lightning stroke. When lightning falls on a structure, the lightning current generates an impulse surge.

The direct lightning stroke

In the electrotechnical field, the “direct” lightning stroke is the one directly striking the electrical installations (overhead lines, substations, etc.). Its energy is considerable as 50 % of lightning strokes exceed 25 kA peak and 1 % exceed 180 kA (see table in **figure 5**). The steepness of these discharges can reach 100 kA/μs. Moreover, a lightning stroke is rarely unique, but several impulses (discharges), separated by dozens of milliseconds, can be detected (see **fig. 6**).

The destructive effects of a direct lightning stroke are well known: electrocution of living beings, melting of components and fires in buildings. The installation of a lightning rod on a construction limits these risks, as do also the guard wires protecting EHV lines.

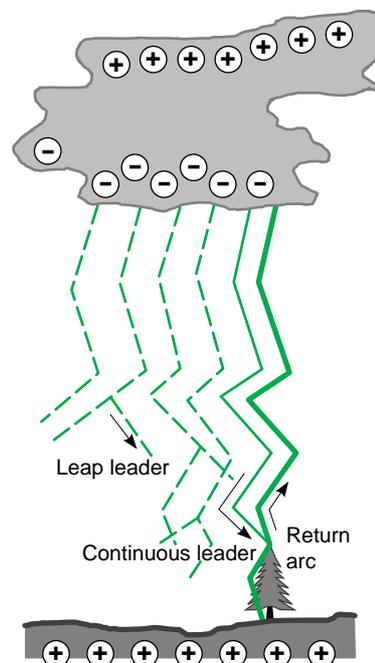


Fig. 4: diagram showing a lightning stroke.

Overrun possibility	Current peak	Load	Slope	$\int i^2 dt$	Total duration	Number of discharges
P (%)	I (kA)	Q (C)	S (kA/μs)	(KA ² .s)	T (s)	n
50	26	14	48	0.54	0.09	1.8
10	73	70	74	1.9	0.56	5
1	180	330	97	35	2.7	12

Fig. 5: main characteristics for lightning strokes (source: Soulé).

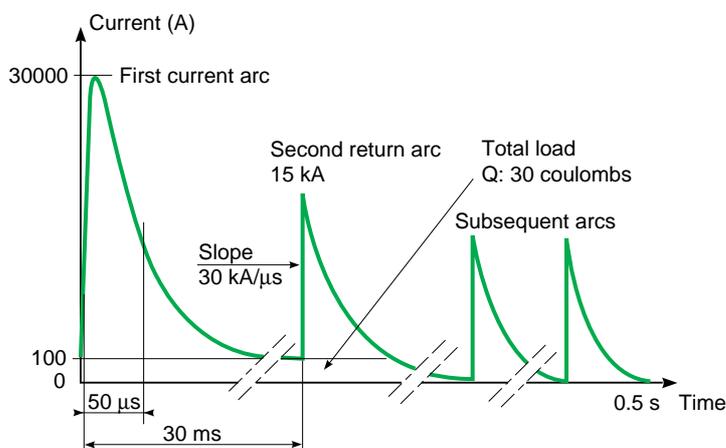


Fig. 6: form of the negative ground/cloud lightning current.

The indirect lightning stroke

This is the manifestation at a distance of a direct lightning stroke.

Three aspects of its effects are covered: conducted surges, rise in earthing potential and radiation.

■ Conducted surges are the result of an impact on overhead lines, and may reach several hundred kilovolts.

If the impact occurs on an MV network, the transmission by the transformer to LV takes place by capacitive coupling (see **fig. 7**). As a rule less than 4 % of surge amplitude on the MV side is found on the LV side. A statistical study carried out in France shows that 91 % of surge amplitude on the MV side is found on the LV side. A statistical study carried out in France shows that 91 % of surges at a LV consumer do not exceed 4 kV and 98 % do not exceed 6 kV.

■ A rise in earthing potential occurs when the lightning current flows off through the ground. This variation in earthing potential affects installations when the lightning strikes the

ground near their earthing connections (see **fig. 8**). Thus, at a given distance D from the point of impact of the lightning, the potential U is expressed by the equation:

$$U \approx 0.2 I \rho_s / D$$

where

I : lightning current,
 ρ_s : ground resistivity.

If this formula is applied to the case of **figure 8** where

$I = 20 \text{ kA}$,

$\rho_s = 1000 \text{ Ohm.m}$,

$D_{\text{neutral}} = 100 \text{ m}$,

$D_{\text{installation}} = 50 \text{ m}$,

the potential of the neutral earthing connection rises to 40 kV, whereas that of the installation earthing connection is 80 kV, i.e. a potential difference -pd- between the neutral and installation earthing connections of 40 kV. However, this example is purely academic since in reality the values attained in the installation seldom exceed 10 kV.

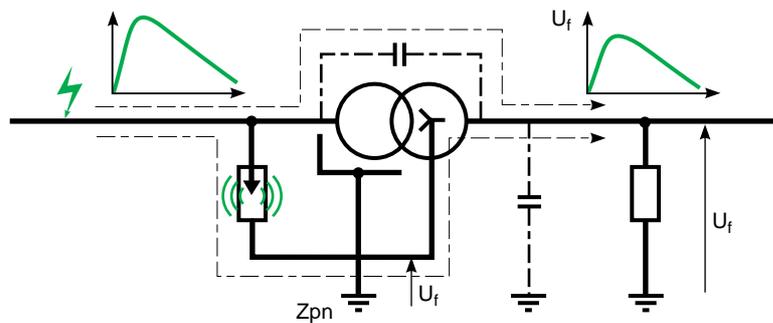


Fig. 7: transmission of a lightning surge, from MV to LV, takes place by capacitive coupling of the transformer windings.

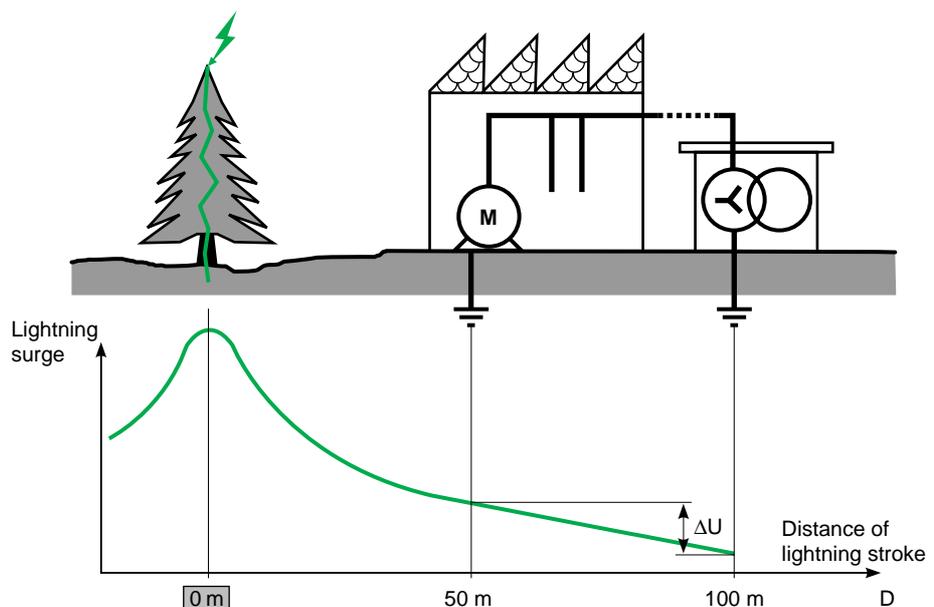


Fig. 8: diagram explaining the rises and differences in potential of the earths of an electrical installation.

Naturally this surge also depends on ground resistivity.

This often accounts for the phenomenon of animals that are indirectly struck by lightning: even 100 m away from the point of impact, a horse in a meadow may receive a difference in potential of 500 V between his rear and forelegs.

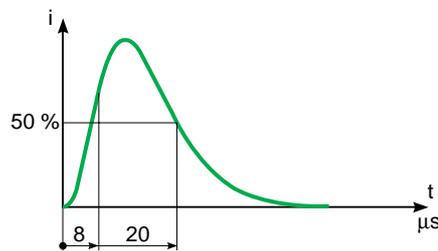
■ Radiation is another effect, as an indirect lightning stroke can generate an extremely rapid variation in the electromagnetic field, responsible for the voltages induced in the loops. Consequently, it is common to find, in the vicinity of storms, induced voltages of some hundred volts per square metre of loop.

The associated electric fields, radiated by the flash, may reach 50 kV/m, and can induce high voltages in the open circuits which act like aerials. A very steep front and a rapid damping are characteristic of such phenomena. A statistical study of surges and overcurrents due to lightning has resulted in the standardisation of the waves shown in **figure 9**.

Characterisation of equipment according to this wave type is a reference for its lightning withstand.

The answer to these various effects of lightning is dealt with in a "protection device" approach developed in chapter 3.

a) "Current" 8/20 μ s wave



b) "Voltage" 1.2/50 μ s wave

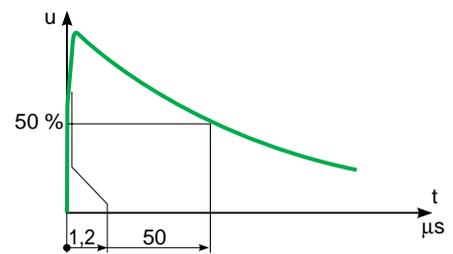


Fig. 9: standardised lightning waveforms.

1.2 Surges by electrostatic discharges

In a very dry environment, human beings electrostatically charged by friction (particularly on a synthetic carpet) frequently attain a voltage of several dozen kilovolts. Its discharge is an impulse current of a few dozen amperes.

Perforation of electronic components has been observed after such discharges, whose rising edges are extremely steep (a few nanoseconds at most).

1.3 Switching surges

This type of phenomenon occurs on electrical networks undergoing rapid modifications to their structure (opening of protection devices, opening and closing of control devices). The surges generated are normally propagated in the form of high frequency waves with rapid damping.

Switching of inductive currents

On making or breaking of inductive currents, impulses with a high amplitude and a very small rise time may occur. Thus, a switch controlling an electric motor, an LV/LV transformer, a contactor, or even a simple relay, etc. generates a differential mode surge whose amplitude may exceed 1000 V with rising edges of a few microseconds.

Switching surges caused by the switching of inductive currents may also stem from MV.

Switching of capacitive circuits

Whereas electrical networks tend to be more inductive, the presence of capacitances (capacitor banks or simply off-load lines) forms an LC resonant circuit. Switching then causes surges of the oscillating kind. A surge factor of three can be observed in the event of re-arcing after breaking.

Breaking a strong current by a breaking device

The breaking of a short-circuit current generates surges if breaking is very quick and without energy consumption by the arc. Surges may be great when certain fuses are blown

(of around 1.5 kV). A similar well known case is the current breaking accompanying arc welding: the surges observed reach a dozen kilovolts. A statistical study of switching surges has resulted in standardisation of the waves shown in **figure 10**.

Characterisation of equipment according to this wave type is a reference for its switching surge withstand.

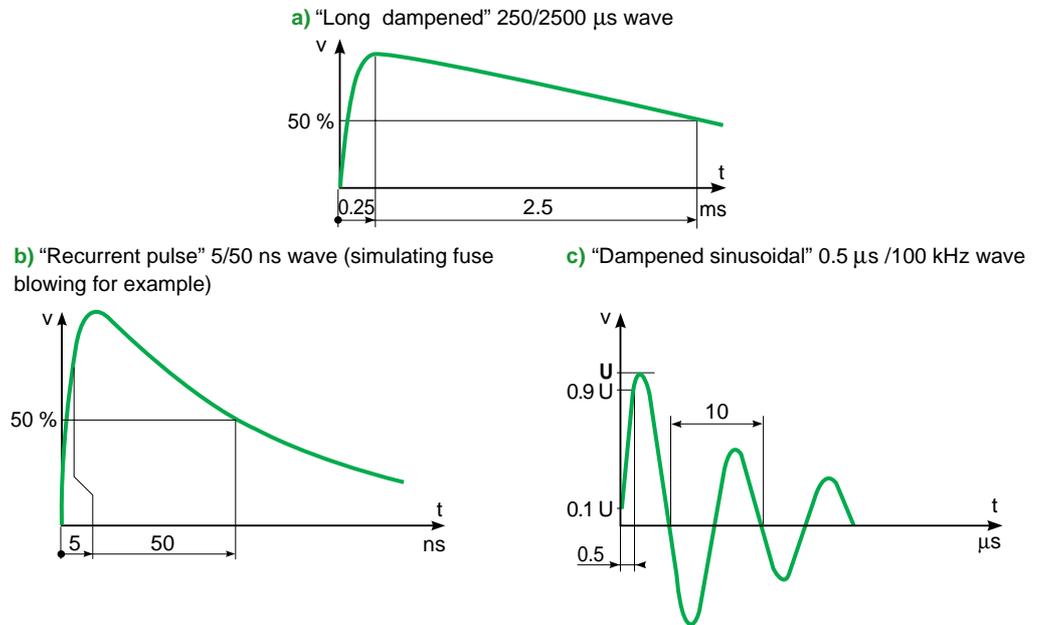


Fig. 10: standardised waveforms representing switching surges.

1.4 Surges at power frequency

The main characteristic of these surges is their frequency which assumes that of the network: generally 50, 60 or 400 Hz.

MV spark-gap holding current

Lightning falling on an MV line causes arcing of the spark-gaps which then flow off to earth a current, at network frequency, until the protection devices of the main substation trip. This current generates, for a fraction of a second, a rise in earthing potential of the LV network as well as a risk of breakdown in return of the LV equipment if the earthing connection of the spark-gaps is the same as that of the LV neutral.

This surge may appear several times in succession, for example during re-energisation attempts while the insulation fault is still present (case of automatic reclosing cycles on overhead networks in rural distribution). This risk is not present with zinc oxide surge arresters which do not have a holding current.

Such a rise in earthing potential of the LV network also occurs in the event of MV/frame breakdown

of an MV/LV transformer if the frame of the transformer is connected to the neutral earth.

Breaking of neutral continuity

Although distribution networks are normally three-phase, many switchgear items are single-phase. Depending on the needs of each LV consumer, voltage unbalances may occur. The most problematic case is breaking of the neutral which may generate a rise in potential that is harmful for devices programmed to operate at single-phase voltage and which then find themselves operating at a voltage close to phase-to-phase voltage.

The insulation fault

In the case of a three-phase network with unearthed or impedant neutral, one earthed phase subjects the two other phases to phase-to-phase voltage with respect to earth. The most dangerous of all these surges are those which are propagated in common mode, either lightning or power frequency, when the MV zero phase-sequence current is strong.

2 Surge protection devices

In order to ensure safety of people, protection of equipment and, to a certain extent, continuity of supply, insulation co-ordination aims at reducing the likelihood of equipment dielectric failure. Several components can be used to limit and/or

eliminate the surges described earlier. These components, used to manufacture the surge protection devices, are sometimes included in certain LV devices, particularly of the electronic kind.

2.1 The protection principles

The level of surge that a device is able to withstand depends on its two main electrical characteristics which are:

- clearance in air,
- length of creepage distance on the insulators or tracking.

The surge protection devices are classed according to their function:

- the primary protection devices which deal with direct lightning strokes,
- the secondary protection devices which complete the first kind and deal with all other surge phenomena.

It should be noted that all these devices and their installation must also take account of the electromagnetic disturbances due to currents of high strength and/or high di/dt (e.g. lightning discharge currents).

Clearance

Clearance is the shortest distance between two conductors. This distance, in air, plays an important role in the breakdown phenomenon. The risk of arcing depends on the voltage applied and the degree of pollution. For this reason electrical devices must satisfy standards (see [fig. 11](#))

Degree of pollution	Construction requirement	Surge category			
		I For devices connected to circuits in which measurements are taken to limit transient surges to an appropriate low level	II For energy consuming devices, supplied from the fixed installation	III For devices in fixed installations and if reliability and availability of the device are covered by specific specifications	IV For devices used at the installation origin
	Rated impulse withstand voltage (kV)	1.5	2.5	4	6
	1.2/50 μ s test voltage at sea level (kV)	1.8	2.9	4.9	7.4
1 = No pollution, or only dry non-conductive pollution	Minimum clearance in air (mm)	0.5	1.5	3	5.5
2 = Normal presence of non-conductive pollution only	Minimum clearance in air (mm)	0.5	1.5	3	5.5
3 = Presence of conductive pollution or of a dry non-conductive pollution which becomes conductive as a result of condensation	Minimum clearance in air (mm)	0.8	1.5	3	5.5
4 = Persistent high conductivity due to pollution caused, for example, by conductive dust or by snow and rain	Minimum clearance in air (mm)	1.6	1.6	3	5.5

Fig. 11: impulse withstand voltages and clearances (as in IEC 947-1) applicable for equipment installed on LV 230/400 V networks.

Degree of pollution	1	2			3			4			
Comparative tracking index	≥ 100	≥ 600 to 600	≥ 400 to 400	≥ 100	≥ 600 to 600	≥ 400 to 400	≥ 100	≥ 600 to 600	≥ 400 to 400	≥ 175	
Rated insulation voltage (V)	400	1	2	2.8	4	5	5.6	6.3	8	10	12.5
	500	1.3	2.5	3.6	5	6.3	7.1	8	10	12.5	16
	630	1.8	3.2	4.5	6.3	8	9	10	12.5	16	20

Fig. 12: lengths in millimetres of creepage distances for electrical devices (extracted from publication IEC 947-1).

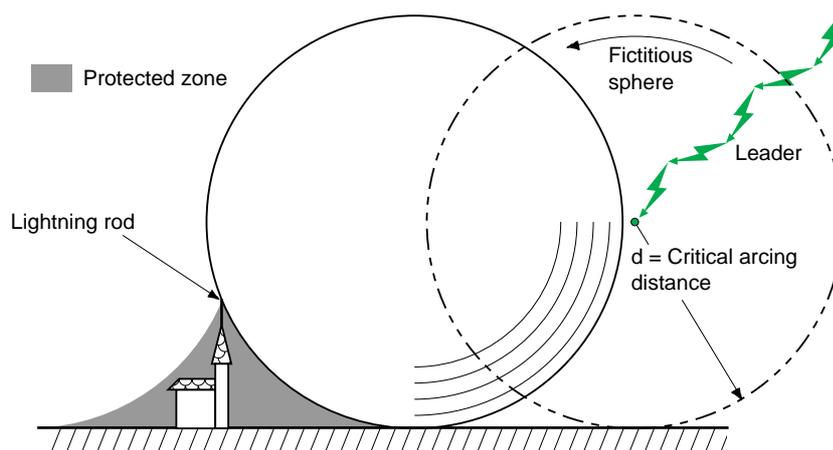


Fig. 13: principle of the electrogeometrical model used to define the zone protected by a surge arrester.

which particularly define four categories of surge and four degrees of pollution.

Assessment of the degree of “normal pollution” varies according to the application:

- for industrial applications, unless otherwise specified in the relevant equipment standard, devices for industrial applications are normally designed to be used in an environment with a degree of pollution 3,
- for domestic applications, unless otherwise specified in the relevant equipment standard, devices for domestic and similar applications are normally designed to be used in an environment with a degree of pollution 2.

Length of creepage distance on the insulators

Creepage distance is the shortest distance, along the surface of an insulating material, between two conductive parts.

Electrical devices must also satisfy standards in this area (see fig. 12).

However, in an electrical installation these construction arrangements (clearance and creepage distance) may prove insufficient, particularly for loads. The use of the protection devices described below is thus often advisable.

The primary protection devices

These devices consist of a sensor, a specific electrical conductor and an earth. They perform

three functions: intercepting lightning strokes, flowing them off to earth and dissipating them in the ground.

The interception devices are the lightning rods which are available in different forms such as guard wires on HV overhead lines or Franklin antennae at the top of steeples. They are earthed in order to flow off the lightning currents, either by one conductor (often a copper strip) or by several (which is preferable). The earth, which must be particularly well made, is often formed by several, separately buried, copper conductors.

Installation and choice of a lightning rod are determined on the basis of a maximum acceptable lightning current for the installation and the area to be protected. According to this maximum current (or peak current of the first impulse), the electrogeometrical model is used to calculate critical arcing distance. This distance is used as the radius of a fictitious sphere rolling along the ground and which knocks up against the buildings to be protected. Only the area under the sphere is protected for lightning currents of a strength greater than or equal to the reference value. All elements in contact with this sphere are exposed to being directly struck by lightning (see fig. 13).

The secondary protection devices

These devices provide protection against the indirect effects of lightning and/or switching and power frequency surges.

This category contains:

- surge arresters for LV networks,
- filters,
- wave absorbers.

Under some conditions, other devices may also perform this function:

- transformers,
- surge limiters,
- network conditioners and static Uninterruptible Power Supplies (UPS).

In practice these devices have two effects: either they limit the impulse voltage (these are the “parallel” protection devices) or they limit the power transmitted (these are the “serial” protection devices).

■ Surge arresters

In LV, this type of switchgear has considerably progressed in terms of safety with reinforced standardised tests: nominal withstand to 20 lightning impulses instead of the previous 3, and specific tests at power frequency surges.

Furthermore, with the latest standards, surge arresters can be forgotten once installed, since any deterioration due to serious faults must be reported (remote transfer, technical alarm, etc.).

An entire range of surge arresters is thus available: modular arresters for mounting on a symmetrical rail, arresters that can be installed in a main LV board or in a subdistribution enclosure and even “flush-mountable” models placed in socket boxes. They all enable flow off of various currents (from 1 to 65 kA) with a varying protection level (from 1500 to 2000 V).

■ Filters and transformers

A filter uses the RLC circuit principle, and is easily calculated once the disturbance to be filtered has been properly identified. It is particularly used to attenuate switching surges. A transformer can also act as a filter: its reactor attenuates surges and reduces the steepness of their wave front.

■ Wave absorbers

A wave absorber is a “super” surge arrester/filter in that it can dissipate important energies (due to surge) and that its protection level is ideal for electronic equipment.

However, these devices have one major defect, namely their filters which, due to their serial-connection, impose a sizing directly linked to the nominal current which will pass through them. They are therefore used more in final distribution.

■ Surge limiters

These devices defined in French standard NF C 63-150 are used on unearthed or impedant networks (IT earthing system) and installed at the MV/LV transformer outlet (see fig. 14). They enable the flow off to earth of high energy surges and withstand the “earth” fault current of the MV network.

■ The network conditioners and the Static Uninterruptible Power Supplies

These devices sometimes contain several of the devices described above, and as such are part of the secondary protection devices.

The other protection types

Telephony and switched networks are affected by surges like LV, the only difference being that the acceptable surge level is normally lower.

There are two types of telephone protection devices:

- modules plugged into boards for telephone exchanges,
- modular cases to be mounted on symmetrical rail, designed to protect one or more telephone pairs (see fig. 15) for users (tertiary and domestic),
- mixed “LV supply/telephony” extensions for Minitel type applications.

In actual fact all information transmission equipment can be affected and disturbed by surges. Therefore suitable surge arresters must be specified for domestic installations (of the BatiBUS type) as well as for computer and audiovisual equipment.

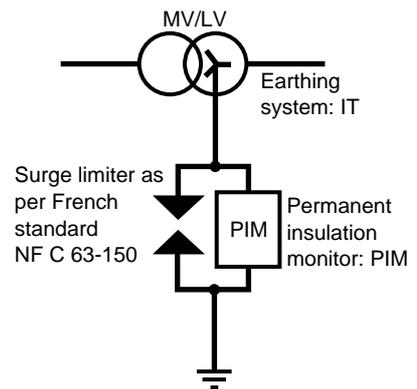


Fig. 14: installation diagram of a surge limiter.



Fig. 15: a surge arrester for telephone network (Merlin Gerin PRC surge arrester).

2.2 The components

Protection devices are designed with a variety of components, some of which, such as reactors, resistors and capacitors are already well known to electricians, and others, such as varistors, spark-gaps and silicon components, whose behaviour is described below. These explanations are given, for LV surge arresters, for devices with virtually identical volumes (as a guideline of the size of modular switchgear), as overall dimension is also an important choice criterion for the user.

The varistor

This component is also known as MOV which stands for "Metal Oxide Varistor" (GEMOV for the General Electric brand and SIOV for the Siemens brand), or simply variable resistor as it has a non-linear behaviour. Presented most commonly in the form of a cylindrical lozenge, it is a ceramic solid originally made of silicon carbide (SiC) and today made of zinc oxide (ZnO). Lozenge thickness defines its voltage characteristic, and its surface the amount of energy that it can dissipate. Its main advantage is its energy loss / cost ratio which makes it an essential component in the manufacture of surge arresters.

The main problem stems from its implementation as:

- a series of low energy impulses causes temperature rise and speeds up the ageing process,
- excessive energy implies destruction of the component by short-circuiting,
- a very high energy may in some cases result in explosion of the varistor.

Today, these disadvantages are minimised by the know-how of surge arrester manufacturers:

- a disconnection system prevents thermal runaway and cuts out the faulty component,
- coating with a fireproof resin is used to contain the high energies to be dissipated.

The spark-gap

The following types are available: air (such as the former horn gap placed on MV overhead

networks), insulator bypass by surface tracking of a dielectric, or gas within a sealed tube. Its advantages are that it allows high energies to flow through, combined with a very small stray capacitance.

Its disadvantages are as follows:

- its high conduction voltage dependent on wave front steepness,
- its long response time linked to wave front steepness,
- the existence of a holding current (hard to extinguish),
- potential drift of its threshold voltage.

In the case of air spark-gaps (LV indoor), arcing voltage also depends on atmospheric conditions (degree of hygrometry and pressure) and thus on the installation site (damp premises and altitude): variations of 40 % have been observed.

Silicon components

This designation covers a variety of electronic components (diode, thyristor, triac, etc.).

Their low energy withstand means that these components are mainly used in LV and particularly on telephone lines. Their response time and residual voltage are low.

As a rule destruction of these components takes the form of a short-circuit, which is an easily detectable electrical fault.

How to choose a component

Surge arrester manufacturers base their choice on a variety of characteristics:

- threshold voltage U_s or conduction voltage,
- residual voltage U_r when the disturbance occurs,
- leakage current I_f at mains voltage,
- response time,
- stray capacitance,
- energy withstand,
- failure mode, etc.

For information, some of these are quoted in the table in **figure 16**.

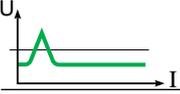
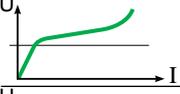
Characteristic U/I	Component	Leakage current I_f	Holding current I_s	Residual voltage U_r	Conducted energy E	Conduction time t
	Ideal device	0	0	Weak	High	Weak
	Spark-gap	0	Strong	Weak but strong U_s	High	Strong
	Varistor	Weak	0	Weak	High	Medium
	Diode	Weak	0	Weak	Weak	Weak

Fig. 16: the main characteristics of the components for surge protection devices.

These characteristics are evaluated by tests according to various constraints (voltage, current, energy).

Standardised waves reproducing the disturbances and surges described in the previous chapter are used for this purpose. In particular, for studying varistor ageing, the 10/1000 μs wave, applied several times, has been chosen (see **fig. 17**).

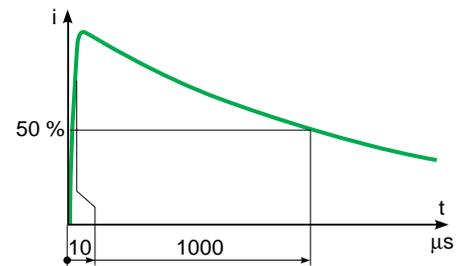


Fig. 17: 10/1000 μs wave, particularly used to study varistor ageing.

2.3 Implementation of components

In order to benefit from the various advantages of these components, the obvious solution is to combine them.

A diagram is thus required to implement them within devices designed to be placed simply on electrical installations. However there is no standard diagram, and only a diagram tailored to a specific need can satisfy the operator. In practice, well designed and properly tested assemblies are able to suitably combine the advantages described above, taking account of input data (lightning, etc.) and output data (low residual voltage, etc.).

This diagram is also used to make the technical/economic compromise able to satisfy the user in terms of value for money.

The main surge protection devices on LV networks are:

- filters,
- surge arresters,

- wave absorbers,
- and, for telephone networks, specific surge arresters.

Filter

Based on combinations of reactors and capacitors, a large number of diagrams are possible (see **fig. 18**).

Its attenuation varies according to the diagram, in L, T or π .

To ensure proper adaptation of the device, choice of components, based on a calculation using the pass-bands of the disturbances to be controlled, therefore requires sound knowledge of installation impedances.

LV surge arrester

The diagram of a simple, effective LV surge arrester is described in **figure 19**: the three

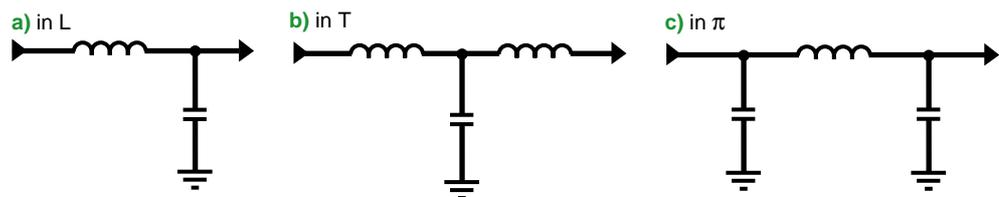


Fig. 18: standard diagrams of filters used in LV.

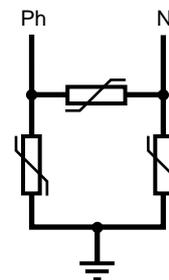


Fig. 19: diagram and photograph of a single-phase LV surge arrester (Merlin Gerin PF15 middle-range surge arrester).

varistors thus combined protect the installation in the common and differential modes.

To obtain a better energy withstand/residual voltage ratio, another combination of the components is used, performed for a single phase (as shown in the diagram in **figure 20**):

- the spark-gap dissipates the energy,
- the serial-connected reactors “flatten” the wave fronts: the “sensitive” components are thus separated with reduced electrical stresses when surges occur,
- and the varistor fixes the residual voltage.

The reactors are sized according to the characteristics of the components and the nominal current of the line to be protected. This last point often results in a large volume and high cost for these protection devices.

Wave absorber

Based on combined filter/surge arrester diagrams, it effectively eliminates energy surges. It may also contain an earthed screen transformer in order to block differential mode HF disturbances and common mode LF voltages.

Reserved for sensitive installations, it normally takes the form of a large-sized enclosure.

Surge arrester for information and telephone circuits

The gas discharge tube is ideal for the protection of telephone lines:

- the permanent supply voltage is sufficiently low to prevent holding current on the discharge tube after a surge,
- its clipping voltage is greater than ringing generator voltage.

In this area, the devices used have recourse to several electronic diagrams. A distinction must be made between:

- those used in information exchange centres, for example in radio relays,
- those designed for installation in telephone exchanges,
- those designed for the protection of simple telephone lines, for example implemented on the telephone incoming line in a home.

All these devices have virtually the same electrical characteristics (conduction voltage, response time, leakage current), as the operating voltages on these networks are small. However their installation and energy flow off capacity are different.

In a home, a surge arrester designed to protect a telephone incoming line can be installed in the consumer switchboard and may use the earthing connection of the electrical installation.

Figure 21 shows two internal diagrams of this type of surge arrester for a simple telephone line, one grouping three spark-gaps and the other showing their integration in a “3 terminal” version. The latter is preferable, as it allows better balancing of common mode protection devices and a reduction in arcing voltage by bringing the electrodes closer together.

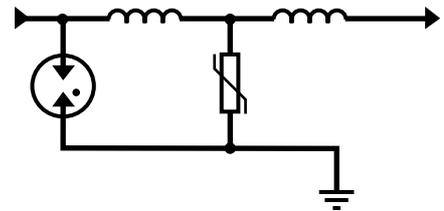


Fig. 20: complete diagram of a LV surge arrester with serial-mounted reactors: more than just a filter.

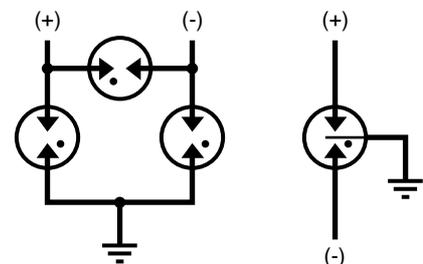


Fig. 21: use of gas discharge tubes on a telephone network, either from 2P devices or from a single 3P device.

3 Standards and applications

The increasing need for availability of electrical power together with the upgrading of electrical equipment and installations (strong currents and in particular weak currents) are responsible for the development of surge arresters. These lightning protection devices were first standardised in France, but European and international standards should be published before the end of the century.

The standards dealing with this subject can be divided into three main categories:

- product standards, for the design and manufacture of surge arresters,
- horizontal standards, which concern the design and/or implementation of various devices,
- implementation guides, specific to LV surge arresters.

A global approach to the above texts, followed by some implementation examples, complete this chapter.

3.1 “Product” standards

Product approval is a guarantee for its user in terms of operation and safety.

The vast majority of electrical switchgear have to satisfy specific manufacturing standards. Consequently, for electrical power distribution, circuit-breakers satisfy standard IEC 947-2 (NF C 63-120) for industry and standard IEC 898 (NF C 61-410) for domestic applications. Contactors and switches have to satisfy other parts of standard IEC 947. Likewise, switchboards and cubicles also have to comply with standards, such as IEC 439-1.

These texts specify all components of electrical networks, right down to loads, with respect to insulation and surge withstand (see [fig. 22](#)).

The purpose of the surge arresters is protection of the various electrical equipment.

A “product” standard specific to LV surge arresters has been available in France since 1987: the NF C 61-740. The requirement to conform to this standard increases dependability of installations and safety of the people operating them.

The 1995 version of standard NF C 61-740 defines the normal operating conditions, the rated characteristics, the classification, etc. This standard particularly describes certain tests guaranteeing safety. In addition to the “conventional” tests (connection, case, etc.), other more specific tests are scheduled:

- verification of the level of residual voltage U_r at nominal discharge current I_n (8/20 μ s wave) and of maximum impulse arcing voltage (1.2/50 μ s wave). The highest of these values forms the protection level of the surge arrester (for example 1500 V);
- proper operation after 20 impulses at nominal discharge current I_n , for example 20 kA (without

disconnection or any changes in surge arrester characteristics);

- proper operation after 1 impulse at maximum discharge current I_{max} , for example 65 kA (a rechargeable disconnection can take place but without any changes in surge arrester characteristics);
- verification of disconnection in event of surge arrester thermal runaway;
- testing withstand to disconnection fault currents in the event of surge arrester short-circuiting. This disconnection can be performed by fuses or circuit-breakers external to the surge arresters;
- testing withstand to transient surges at power frequency (50 Hz, 1500 V, 300 A, 200 ms): no phenomena external to the surge arrester should be generated (flames, projections, etc.);
- testing ageing by verification for 1000 hours of equipment withstand at maximum steady state voltage U_c ;

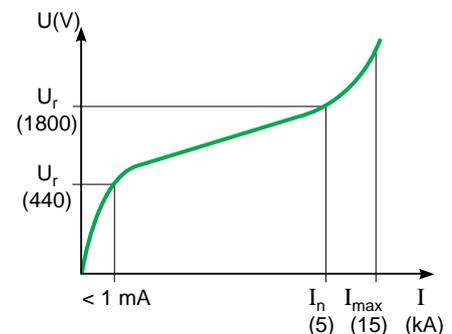


Fig. 22: representation of curve $U = f(I)$ of a surge arrester

- testing temperature rise, necessary when the surge arrester contains components such as resistors or reactors.

The above tests have been defined to guarantee the dependability of all conform surge arresters. These tests will normally form part of the international standard currently being drafted.

3.2 Horizontal standards

This category of standard texts contains two “reference” texts: the IEC 364 (NF C 15-100) and IEC 664. Standard IEC 364 concerns the electrical installations of buildings, and IEC 664 insulation co-ordination of LV equipment.

IEC 364

This standard only defines two situations, a “natural” and a “controlled” situation:

- the “natural” situation concerns installations supplied by a fully underground LV network where impulse withstand of devices conforming to their manufacturing standard is sufficient,
- the “controlled” situation concerns installations supplied by bare or twisted overhead LV lines in which devices have a withstand compatible with foreseeable surges.

However, in both cases, surge arresters need to be installed as:

- in “natural” situations, surges may occur as a result of a rise in earthing potential further to an indirect lightning stroke (see [fig. 8](#)) or a fault in the MV/LV transformer,
- the “controlled” situation is not always feasible as a result of the diversity in equipment withstand levels, and nor is it lasting as additions are always possible.

In France, standard NF C 15-100 uses these definitions. In particular paragraph 443 also uses the definition of surge categories, referring readers to paragraph 534 for choice of equipment and its installation.

IEC 664

For general application in low voltage, this standard is divided into four parts:

- part 1: principles, specifications and tests,
- part 2: specifications for clearances, creepage distances and solid insulation,
- part 3: use of coating of electronic device printed circuit boards,
- part 4: application guide.

All the tests and measures guaranteeing fully safe operation of the equipment are described in this standard.

The table in [figure 11](#) gives the values fixed by standard IEC 664 for clearance in air, for the manufacture of the different types of electrical switchgear. This table shows that surge withstand varies according to the position of the devices in the installation.

This standard also stipulates certain creepage distance lengths in order to verify the tracking withstand required for manufacture of the various electrical switchgear types (see [fig. 12](#)).

Although the standard takes account of the risk of pollution (various levels are scheduled), the climatic effects, combined with equipment and component ageing, reduce equipment withstand with time.

Today, the withstand of electronic and computer devices does not always correspond to the minimum level given by class I (1500 V).

Moreover, these devices may be connected to the electrical network at the installation origin, a place where only class III and IV devices should be installed. Surge arresters therefore need to be fitted at the installation origin.

3.3 Surge arrester installation guides

A variety of documents deal with the subject of surge arrester installation: in France, standard NF C 15-531 focuses on the installation rules of LV surge arresters, and standard NF C 15-100 covers all the LV electrical installations.

At international level, a standard is currently being drafted. Its equivalent will be standard NF C 15-443 (to be published in replacement of standard NF C 15-531) which treats three main subjects differently:

- evaluation of the risk of lightning,
- selection of surge arresters,
- implementation of surge arresters.

To evaluate the risk, a formula based on scientific criteria is proposed to engineering and design departments. This formula takes account of the characteristics of the site and the environment:

- lightning density,
- type of distribution network,
- site topography,
- presence of lightning rods, if any.

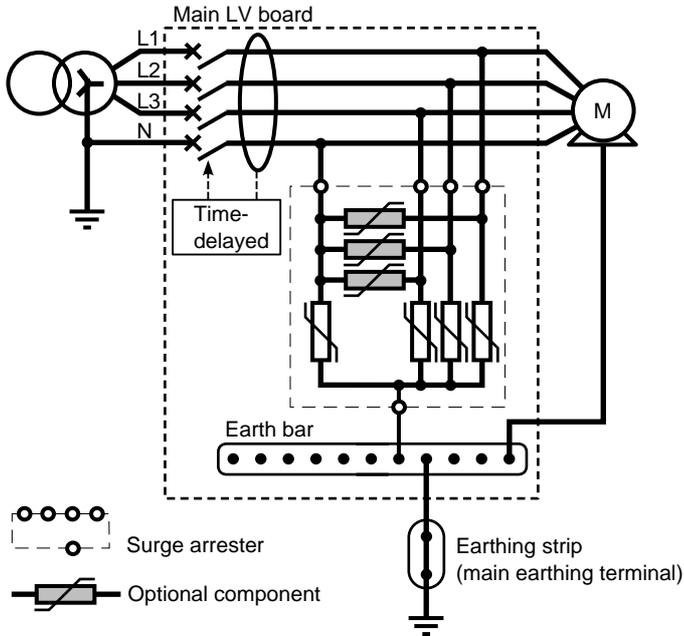
Selection of surge arresters depends on:

- the importance of the risk,
- the susceptibility of the devices,

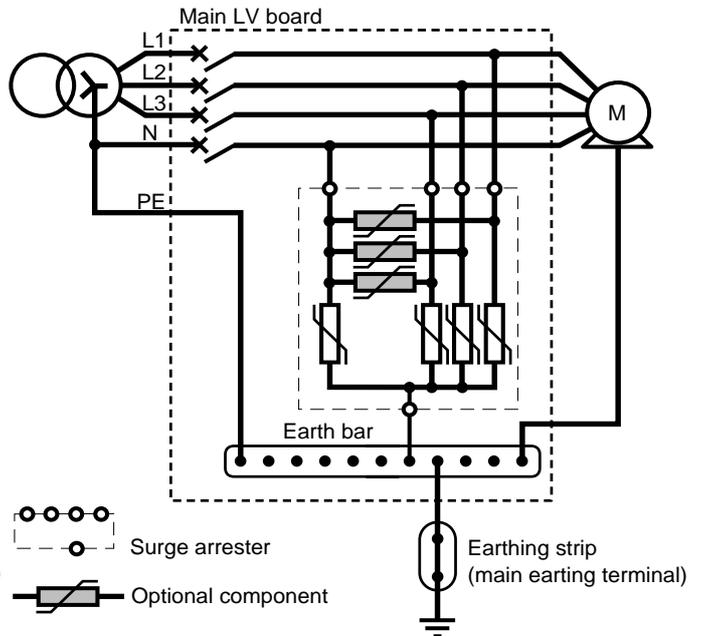
■ the earthing system of the electrical network. Whatever system is used, if a lightning risk is present, all electrical installations must be fitted

with surge arresters (see **fig. 23**), whose composition may vary according to the type of earthing system.

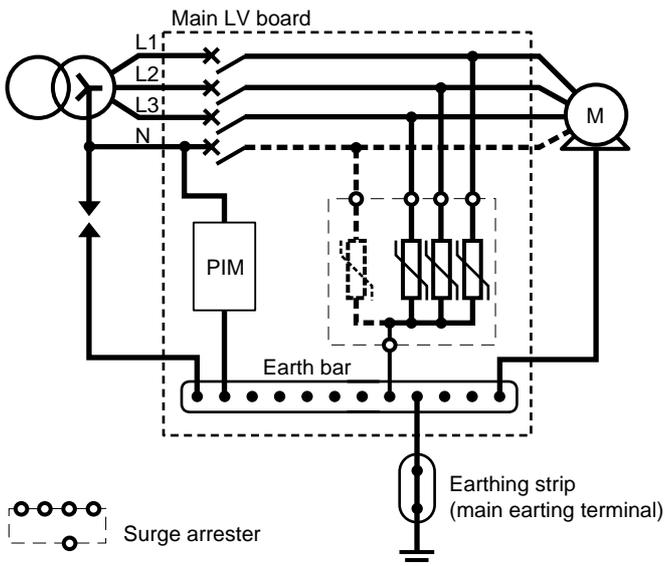
a) TT system



c) TN-S system



b) IT system



d) TN-C system

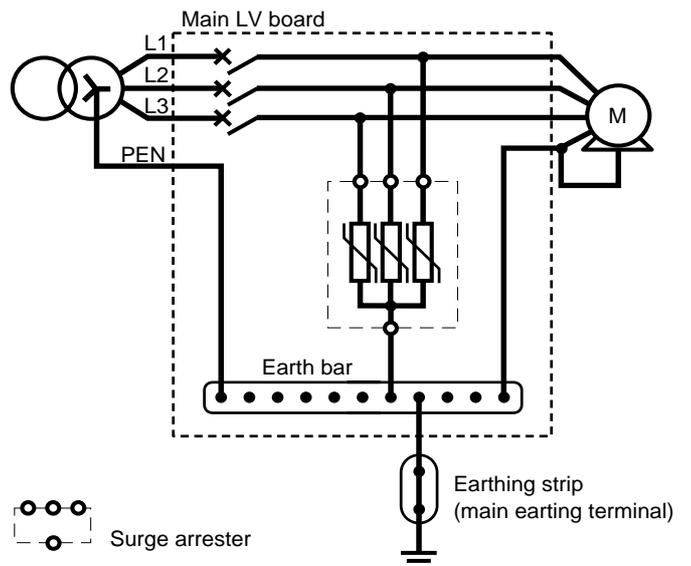


Fig. 23: choice of surge protection mode (common or differential) according to the electrical installation earthing system as per NF C 15-443 .

These differences are due to:

- whether or not differential mode surges are treated,
- the maximum steady state voltage U_c :
 - between live conductors and the earth:
 - $U_c > 1.5 U_n$ in the TT and TN earthing systems,
 - $U_c > \sqrt{3} U_n$ in the IT earthing system;
 - between phases and neutral, $U_c > 1.1 U_n$ whatever earthing system is used.

Note 1: Earthing the neutral does not prevent surges from affecting the phase conductors.

Note 1: Surge limiters, use of which is compulsory in the IT earthing system, replace surge arresters for protection against 50 Hz MV surges. As these two devices do not have the same functions, surge arresters continue to be required for lightning surges.

3.4 Implementation of surge arresters

A variety of rules are defined (importance of equipotential bonding, staggered or cascading protection devices, use of residual current devices), application of which may sometimes vary according to the installation sector (tertiary and industrial or domestic).

Importance of the equipotential bondings

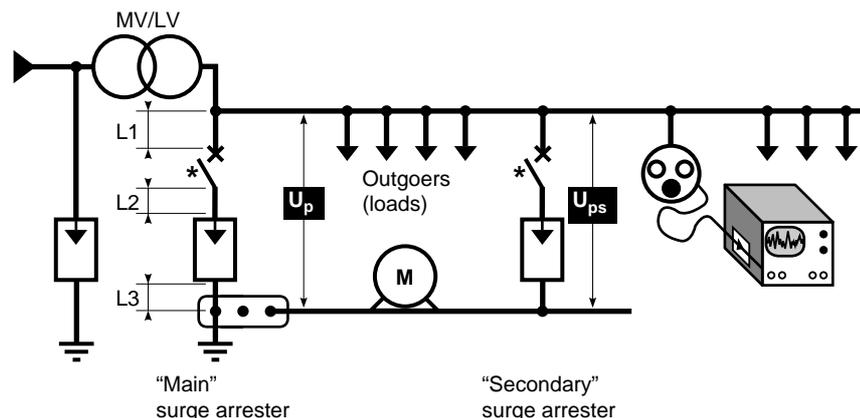
EMC principles state that LV installations must have only one earthing connection for their loads. This connection is close to the origin of the installation, and it is at this level that the "main" surge arrester must be installed (see fig. 24): care must be taken to minimise the impedance of its circuit (reduction of its connections to the live conductors and earth, as well as the impedance of the disconnection device). In this manner, if the surge arrester begins to conduct, the loads are subjected at most to the protection voltage U_p equal to the residual voltage of the surge arrester plus the voltage drop in its connections

and in the disconnection device. Hence the importance of a properly constructed installation conform to proper practices.

Reminder: one metre of cable has an inductance of $1 \mu\text{H}$: application of the formula $\Delta U = L di/dt$ with the $8/20 \mu\text{s}$ wave and a 10 kA current results in a voltage of approximately 1000 volts peak/metre: hence the importance of minimising surge arrester connecting cable length.

Cascading protection devices

When a high amplitude lightning stroke occurs, the importance of the current flown off by the surge arrester means that protection voltage may exceed the withstand voltage of sensitive devices. These devices must therefore be protected by use of "secondary" surge arresters (see fig. 24). To ensure their effectiveness, these "secondary" surge arresters must be installed more than 10 metres away from the "main" surge arrester. This connection is



NB: For increased efficiency of protection, the cable lengths $L_1+L_2+L_3$ must be reduced when installing a surge arrester.

U_p = protection voltage downstream of the main surge arrester.

U_{ps} = protection voltage after the secondary surge arrester.

* = surge arrester disconnection device at end of life (in short-circuit).

Fig. 24: positions of surge arresters in an LV installation.

important as cable impedance performs a decoupling between the two protection levels (as shown in **figure 25**).

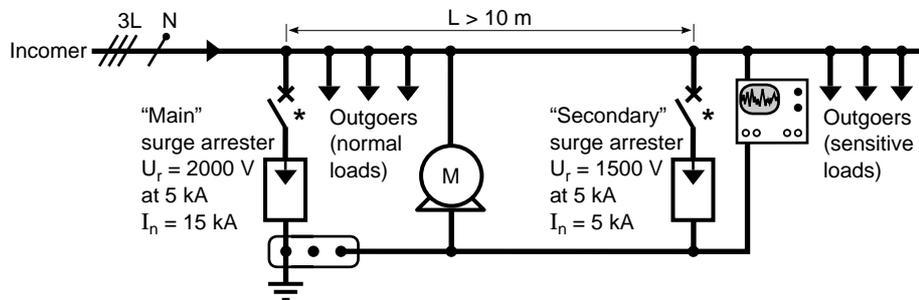
It is important to bear in mind that the supply of many electrical devices, and in particular electronic devices, is protected against surge by differential mode varistors. "Cascading" is thus also applied between the surge arrester of the installation responsible for protecting the sensitive device and the latter, and calls for a study of the protection levels.

Note 1: presence of surge arresters on the MV close to those placed on the LV is another case of "cascading" using the differences in arcing voltage of MV and LV surge arresters and the decoupling performed by the MV/LV transformer.

Note 2: when electronic devices containing common or differential mode filters are connected near the installation origin, these filters must be able to withstand the protection voltage U_p (see **fig. 24**).

Cohabitation of residual current devices and surge arresters

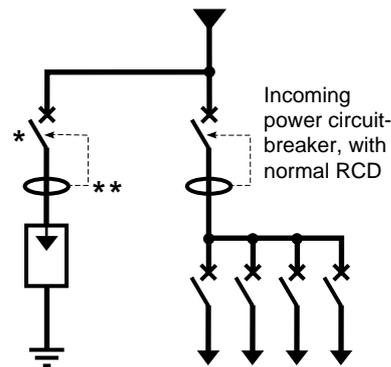
In installations whose origin is equipped with an RCD, it is preferable to place the surge arrester upstream of the latter (see **fig. 26a**). However, some electrical utilities do not allow intervention at this distribution level: this is the case of LV consumers in France. A time-delayed or selective RCD is then necessary to prevent current flow off via the surge arrester from causing nuisance tripping (see **fig. 26b**).



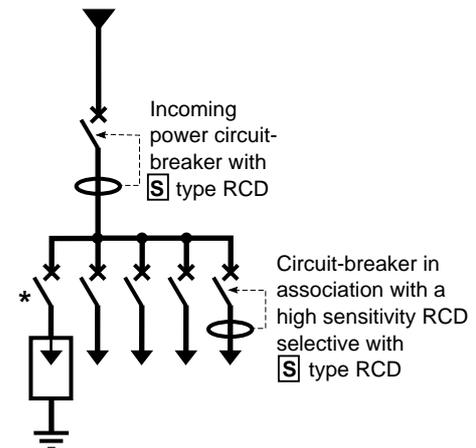
This length was defined for surge arresters equipped with varistors
* = surge arrester disconnection device at end of life (in short-circuit).

Fig. 25: example of two surge arresters installed in cascade.

a) Simplest connection
(forbidden in France by EDF)



b) Recommended connection: also enables discrimination with high sensitivity RCDs placed on the outgoers



* = surge arrester disconnection device at end of life (in short-circuit)

** = residual current device for protection of people, in this case associated with the disconnection device.

Fig. 26: position of a surge arrester on the installation of a LV consumer, for electrical distribution in TT earthing system.

Likewise, if surge arresters have to be installed near high sensitivity RCDs (10 or 30 mA), they must be placed just upstream of them.

In short

In tertiary, industry and the domestic sector, installation of a surge arrester must always comply with the following requirements:

- all surge arresters must be equipped with a disconnection device (de-energised when it is short-circuited): a fuse or a circuit-breaker. This device must be adapted to the surge arrester and its connections (by its rating and tripping or blowing curve) as well as to its installation point (by its breaking capacity). As a rule,

manufacturers specify the characteristics of the device to be provided for each type of surge arrester;

- the connections from the surge arrester to the live conductors and from the surge arrester to the main equipotential bonding must be as short as possible: 50 cm is the maximum value (see chapter 2 and **fig. 24**);

- surge arrester cabling must not create a loop surrounding devices sensitive to electromagnetic phenomena (electronic clocks, programmers, etc.).

Note: Both for initial choice of surge arrester and for its installation requirements, it is vital to consult the manufacturers' technical documents.

4 Conclusion

Nowadays, maximum availability of electrical power is required for a variety of reasons, whether purely economic (search for maximum productivity) or for safety purposes, or yet again simply for comfort in domestic applications. It is thus obvious that the ability to eliminate or at least greatly reduce the risks and hence the consequences of surges has become a professional reference.

This reference calls for control of insulation co-ordination in low voltage, first by applying a simple investigation method resulting in combination and choice of devices and surge arresters. The latter (the surge arresters) must limit the foreseeable surges on the network to a level acceptable by the former (the devices).

This calls for the following:

- estimation of surges (lightning, switching or power frequency) which may appear on the electrical network (see chapter 1),
- knowledge of the characteristics of the devices installed and more particularly of their impulse withstand (see chapter 2),
- selection of protection devices, taking these two points into account, as well as the earthing system of the electrical network.

However, this “theoretical approach” must be completed by the contractor’s know-how. As we explained earlier in this document, failure

to respect a few basic rules will make even the best surge arresters useless (see chapter 4). In this context, it is important to recall the importance of:

- shortening surge arrester connections,
- having a single earthing connection for all loads,
- respecting the minimum distance between two surge arresters,
- choosing a selective or time-delayed RCD when it is placed upstream of a surge arrester.

Surge arrester standards have been stabilised, and standards concerning insulation co-ordination in LV electrical installations should shortly be so also. Consequently, there is no escaping the fact that electricity-related professions need to quickly adapt if they are to satisfy operators.

To ensure the success of this adaptation, the importance of surge arrester manufacturers’ documents should be emphasised (see the Merlin Gerin Surge Arrester Guide), as they contain both:

- simplified explanations of surge and electromagnetic disturbance phenomena,
- the technical information essential for making the right choices and combinations (as described above).

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- Lightning and HV electrical installations
Cahier Technique no 168
B. DE METZ-NOBLAT

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