

Chapter J

Overvoltage protection

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J1

1 Overvoltage characteristics of atmospheric origin

1.1 Overvoltage definitions

1.1.1 Various types of overvoltage

An overvoltage is a voltage pulse or wave which is superimposed on the rated voltage of the network (see Fig. J1).

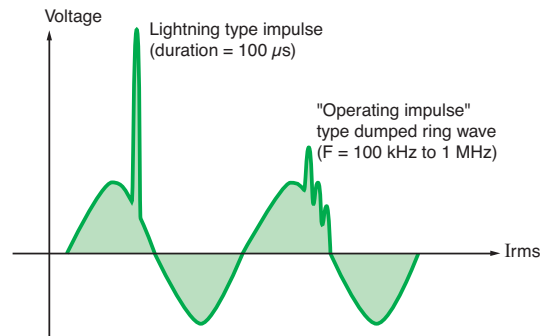


Fig. J1 : Examples of overvoltage

This type of overvoltage is characterized by (see Fig. J2):

- the rise time t_f (in μs);
- the gradient S (in $kV/\mu s$).

An overvoltage disturbs equipment and produces electromagnetic radiation. Moreover, the duration of the overvoltage (T) causes an energy peak in the electric circuits which could destroy equipment.

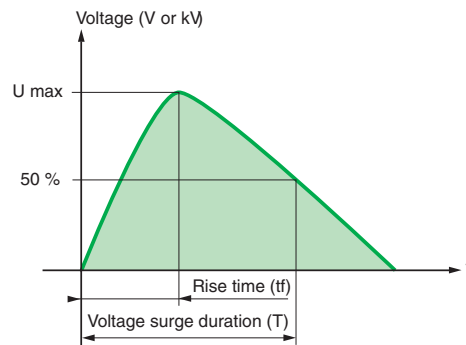


Fig. J2 : Main characteristics of an overvoltage

Four types of overvoltage can disturb electrical installations and loads:

- Switching surges: high-frequency overvoltages or burst disturbance (see Fig. J1) caused by a change in the steady state in an electrical network (during operation of switchgear).
- Power-frequency overvoltages: overvoltages of the same frequency as the network (50, 60 or 400 Hz) caused by a permanent change of state in the network (following a fault: insulation fault, breakdown of neutral conductor, etc.).
- Overvoltages caused by electrostatic discharge: very short overvoltages (a few nanoseconds) of very high frequency caused by the discharge of accumulated electric charges (for example, a person walking on a carpet with insulating soles is electrically charged with a voltage of several kilovolts).
- Overvoltages of atmospheric origin.

J2

1 Overvoltage characteristics of atmospheric origin

*Lightning strokes in a few figures:
Lightning flashes produce an extremely large quantity of pulsed electrical energy (see Fig. J4)*

- of several thousand amperes (and several thousand volts),
- of high frequency (approximately 1 megahertz),
- of short duration (from a microsecond to a millisecond).

1.2 Overvoltage characteristics of atmospheric origin

Between 2000 and 5000 storms are constantly undergoing formation throughout the world. These storms are accompanied by lightning strokes which represent a serious hazard for persons and equipment. Lightning flashes hit the ground at an average of 30 to 100 strokes per second, i.e. 3 billion lightning strokes each year.

The table in **Figure J3** shows the characteristic lightning strike values. As can be seen, 50% of lightning strokes have a current exceeding 33 kA and 5% a current exceeding 65 kA. The energy conveyed by the lightning stroke is therefore very high.

Cumulative probability (%)	Peak current (kA)	Gradient (kA/μs)
95	7	9.1
50	33	24
5	65	65
1	140	95
0	270	

Fig. J3 : Lightning discharge values given by the IEC 62305 standard

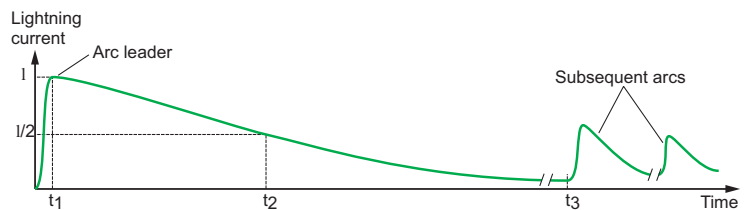


Fig. J4 : Example of lightning current

Lightning also causes a large number of fires, mostly in agricultural areas (destroying houses or making them unfit for use). High-rise buildings are especially prone to lightning strokes.

1.3 Effects on electrical installations

Lightning damages electrical and electronic systems in particular: transformers, electricity meters and electrical appliances on both residential and industrial premises.

The cost of repairing the damage caused by lightning is very high. But it is very hard to assess the consequences of:

- disturbances caused to computers and telecommunication networks;
- faults generated in the running of programmable logic controller programs and control systems.

Moreover, the cost of operating losses may be far higher than the value of the equipment destroyed.

J3

Lightning is a high-frequency electrical phenomenon which causes overvoltages on all conductive items, especially on electrical cabling and equipment.

1.3.1 Lightning stroke impacts

Lightning strokes can affect the electrical (and/or electronic) systems of a building in two ways:

- by direct impact of the lightning stroke on the building (see Fig. J5 a);
 - by indirect impact of the lightning stroke on the building:
 - A lightning stroke can fall on an overhead electric power line supplying a building (see Fig. J5 b). The overcurrent and overvoltage can spread several kilometres from the point of impact.
 - A lightning stroke can fall near an electric power line (see Fig. J5 c). It is the electromagnetic radiation of the lightning current that produces a high current and an overvoltage on the electric power supply network.
- In the latter two cases, the hazardous currents and voltages are transmitted by the power supply network.
- A lightning stroke can fall near a building (see Fig. J5 d). The earth potential around the point of impact rises dangerously.

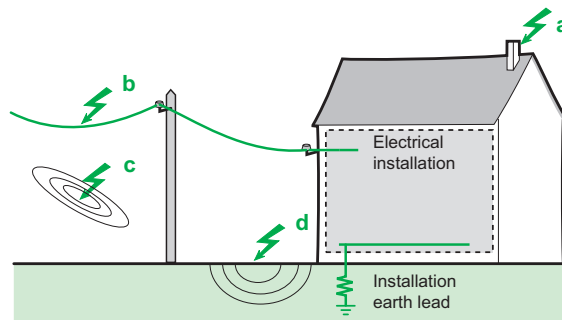


Fig. J5 : Various types of lightning impact

In all cases, the consequences for electrical installations and loads can be dramatic.

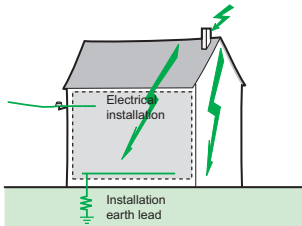
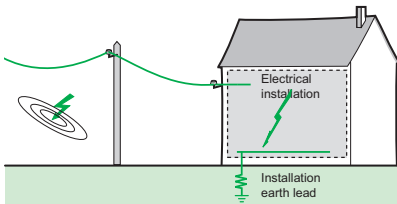
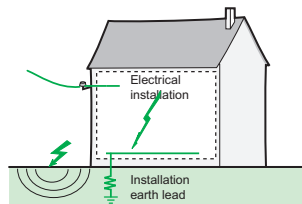
Lightning falls on an unprotected building.	Lightning falls near an overhead line.	Lightning falls near a building.
		
<p>The lightning current flows to earth via the more or less conductive structures of the building with very destructive effects:</p> <ul style="list-style-type: none"> ■ thermal effects: Very violent overheating of materials, causing fire, ■ mechanical effects: Structural deformation, ■ thermal flashover: Extremely dangerous phenomenon in the presence of flammable or explosive materials (hydrocarbons, dust, etc.). 	<p>The lightning current generates overvoltages through electromagnetic induction in the distribution system.</p> <p>These overvoltages are propagated along the line to the electrical equipment inside the buildings.</p>	<p>The lightning stroke generates the same types of overvoltage as those described opposite.</p> <p>In addition, the lightning current rises back from the earth to the electrical installation, thus causing equipment breakdown.</p>
<p>The building and the installations inside the building are generally destroyed</p>	<p>The electrical installations inside the building are generally destroyed.</p>	

Fig. J6 : Consequence of a lightning stroke impact

1 Overvoltage characteristics of atmospheric origin

1.3.2 The various modes of propagation

■ Common mode

Common-mode overvoltages appear between live conductors and earth: phase-to-earth or neutral-to-earth (see **Fig. J7**). They are dangerous especially for appliances whose frame is connected to earth due to risks of dielectric breakdown.

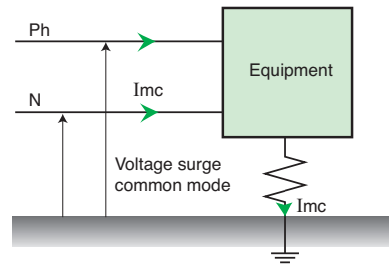


Fig. J7 : Common mode

■ Differential mode

Differential-mode overvoltages appear between live conductors: phase-to-phase or phase-to-neutral (see **Fig. J8**). They are especially dangerous for electronic equipment, sensitive hardware such as computer systems, etc.

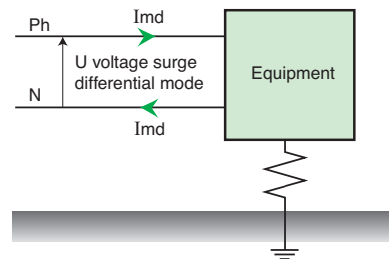


Fig. J8 : Differential mode

J5

1 Overvoltage characteristics of atmospheric origin

1.4 Characterization of the lightning wave

Analysis of the phenomena allows definition of the types of lightning current and voltage waves.

- 2 types of current wave are considered by the IEC standards:
- 10/350 μs wave: to characterize the current waves from a direct lightning stroke (see Fig. J9);

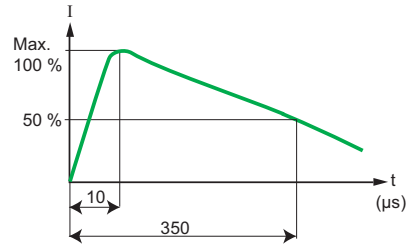


Fig. J9 : 10/350 μs current wave

- 8/20 μs wave: to characterize the current waves from an indirect lightning stroke (see Fig. J10).

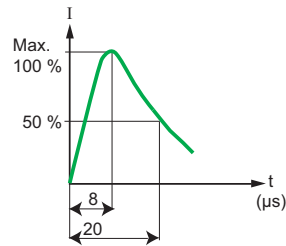


Fig. J10 : 8/20 μs current wave

These two types of lightning current wave are used to define tests on SPDs (IEC standard 61643-11) and equipment immunity to lightning currents. The peak value of the current wave characterizes the intensity of the lightning stroke.

- **The overvoltages** created by lightning strokes are characterized by a 1.2/50 μs voltage wave (see Fig. J11). This type of voltage wave is used to verify equipment's withstand to overvoltages of atmospheric origin (impulse voltage as per IEC 61000-4-5).

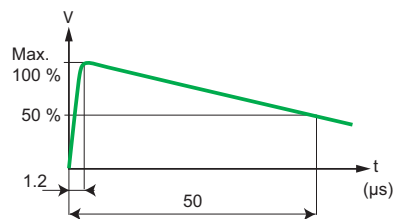


Fig. J11 : 1.2/50 μs voltage wave

2 Principle of lightning protection

2.1 General rules

The system for protecting a building against the effects of lightning must include:

- protection of structures against direct lightning strokes;
- protection of electrical installations against direct and indirect lightning strokes.

2.1.1 Procedure to prevent risks of lightning strike

The basic principle for protection of an installation against the risk of lightning strikes is to prevent the disturbing energy from reaching sensitive equipment. To achieve this, it is necessary to:

- capture the lightning current and channel it to earth via the most direct path (avoiding the vicinity of sensitive equipment);
- perform equipotential bonding of the installation; This equipotential bonding is implemented by bonding conductors, supplemented by Surge Protection Devices (SPDs) or spark gaps (e.g., antenna mast spark gap).
- minimize induced and indirect effects by installing SPDs and/or filters.

Two protection systems are used to eliminate or limit overvoltages: they are known as the building protection system (for the outside of buildings) and the electrical installation protection system (for the inside of buildings).

2.2 Building protection system

The role of the building protection system is to protect it against direct lightning strokes.

The system consists of:

- the capture device: the lightning protection system;
- down-conductors designed to convey the lightning current to earth;
- "crow's foot" earth leads connected together;
- links between all metallic frames (equipotential bonding) and the earth leads.

When the lightning current flows in a conductor, if potential differences appear between it and the frames connected to earth that are located in the vicinity, the latter can cause destructive flashovers.

2.2.1 The 3 types of lightning protection system

Three types of building protection are used:

■ The simple lightning rod

The lightning rod is a metallic capture tip placed at the top of the building. It is earthed by one or more conductors (often copper strips) (see **Fig. J12**).

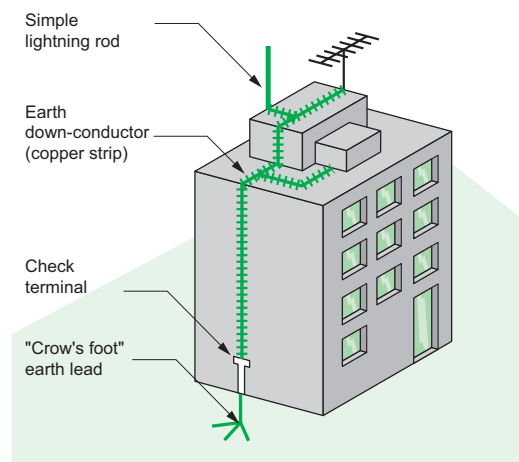


Fig. J12 : Simple lightning rod

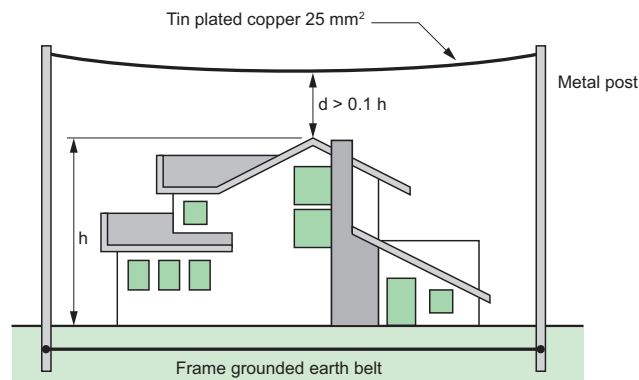


Fig. J13 : Taut wires

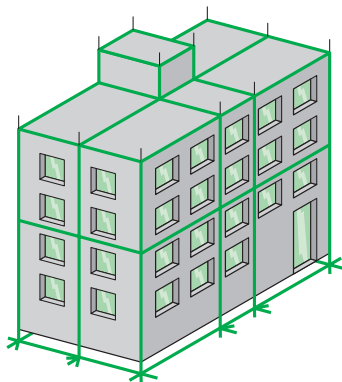


Fig. J14 : Meshed cage (Faraday cage)

■ The lightning rod with taut wires

These wires are stretched above the structure to be protected. They are used to protect special structures: rocket launching areas, military applications and protection of high-voltage overhead lines (see Fig. J13).

■ The lightning conductor with meshed cage (Faraday cage)

This protection involves placing numerous down conductors/tapes symmetrically all around the building. (see Fig. J14).

This type of lightning protection system is used for highly exposed buildings housing very sensitive installations such as computer rooms.

2.2.2 Consequences of building protection for the electrical installation's equipment

50% of the lightning current discharged by the building protection system rises back into the earthing networks of the electrical installation (see Fig. J15): the potential rise of the frames very frequently exceeds the insulation withstand capability of the conductors in the various networks (LV, telecommunications, video cable, etc.). Moreover, the flow of current through the down-conductors generates induced overvoltages in the electrical installation.

As a consequence, the building protection system does not protect the electrical installation: it is therefore compulsory to provide for an electrical installation protection system.

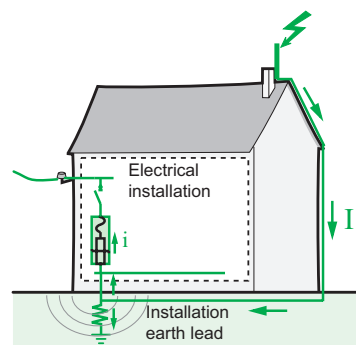


Fig. J15 : Direct lightning back current

2 Principle of lightning protection

2.3 Electrical installation protection system

The main objective of the electrical installation protection system is to limit overvoltages to values that are acceptable for the equipment.

The electrical installation protection system consists of:

- one or more SPDs depending on the building configuration;
- the equipotential bonding: metallic mesh of exposed conductive parts.

2.3.1 Implementation

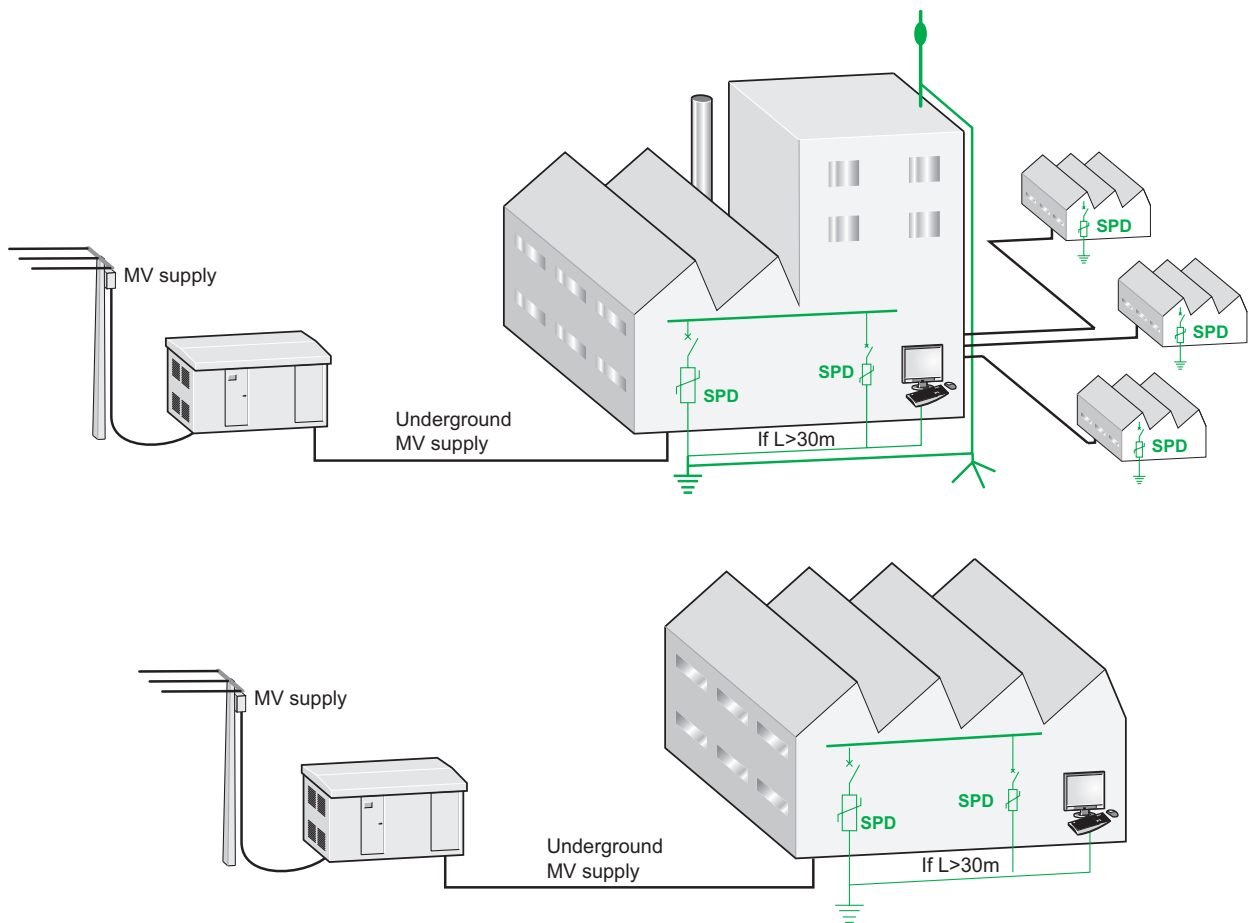
The procedure to protect the electrical and electronic systems of a building is as follows.

Search for information

- Identify all sensitive loads and their location in the building.
- Identify the electrical and electronic systems and their respective points of entry into the building.
- Check whether a lightning protection system is present on the building or in the vicinity.
- Become acquainted with the regulations applicable to the building's location.
- Assess the risk of lightning strike according to the geographic location, type of power supply, lightning strike density, etc.

Solution implementation

- Install bonding conductors on frames by a mesh.
- Install a SPD in the LV incoming switchboard.
- Install an additional SPD in each subdistribution board located in the vicinity of sensitive equipment (see Fig. J16).



J9

Fig. J16 : Example of protection of a large-scale electrical installation

Surge Protection Devices (SPD) are used for electric power supply networks, telephon networks, and communication and automatic control buses.

2.4 The Surge Protection Device (SPD)

The Surge Protection Device (SPD) is a component of the electrical installation protection system. This device is connected in parallel on the power supply circuit of the loads that it has to protect (see Fig. J17). It can also be used at all levels of the power supply network. This is the most commonly used and most efficient type of overvoltage protection.

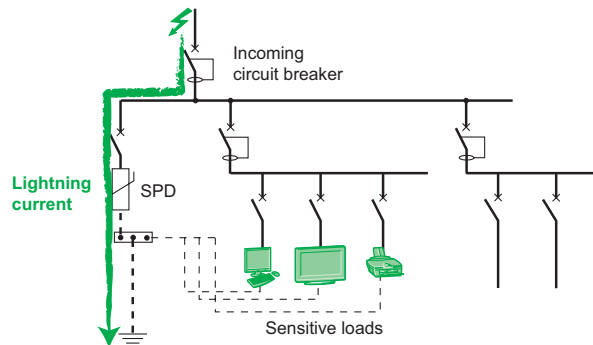


Fig. J17 : Principle of protection system in parallel

Principle

SPD is designed to limit transient overvoltages of atmospheric origin and divert current waves to earth, so as to limit the amplitude of this overvoltage to a value that is not hazardous for the electrical installation and electric switchgear and controlgear.

SPD eliminates overvoltages:

- in common mode, between phase and neutral or earth;
 - in differential mode, between phase and neutral.
- In the event of an overvoltage exceeding the operating threshold, the SPD
- conducts the energy to earth, in common mode;
 - distributes the energy to the other live conductors, in differential mode.

The three types of SPD:

■ Type 1 SPD

The Type 1 SPD is recommended in the specific case of service-sector and industrial buildings, protected by a lightning protection system or a meshed cage. It protects electrical installations against direct lightning strokes. It can discharge the back-current from lightning spreading from the earth conductor to the network conductors. Type 1 SPD is characterized by a 10/350 μ s current wave.

■ Type 2 SPD

The Type 2 SPD is the main protection system for all low voltage electrical installations. Installed in each electrical switchboard, it prevents the spread of overvoltages in the electrical installations and protects the loads. Type 2 SPD is characterized by an 8/20 μ s current wave.

■ Type 3 SPD

These SPDs have a low discharge capacity. They must therefore mandatorily be installed as a supplement to Type 2 SPD and in the vicinity of sensitive loads. Type 3 SPD is characterized by a combination of voltage waves (1.2/50 μ s) and current waves (8/20 μ s).

2 Principle of lightning protection

■ SPD normative definition

	Direct lightning stroke	Indirect lightning stroke	
IEC 61643-1	Class I test	Class II test	Class III test
IEC 61643-11/2007	Type 1 : T1	Type 2 : T2	Type 3 : T3
EN/IEC 61643-11	Type 1	Type 2	Type 3
Former VDE 0675v	B	C	D
Type of test wave	10/350	8/20	1.2/50 + 8/20

Note 1: There exist **T1** + **T2** SPD (or Type 1 + 2 SPD) combining protection of loads against direct and indirect lightning strokes.

Note 2: some **T2** SPD can also be declared as **T3**.

Fig. J18 : Table of SPD normative definition

2.4.1 Characteristics of SPD

International standard IEC 61643-1 Edition 2.0 (03/2005) defines the characteristics of and tests for SPD connected to low voltage distribution systems (see Fig. J19).

■ Common characteristics

□ **U_c**: Maximum continuous operating voltage

This is the a.c. or d.c. voltage above which the SPD becomes active. This value is chosen according to the rated voltage and the system earthing arrangement.

□ **U_p**: Voltage protection level (at I_n)

This is the maximum voltage across the terminals of the SPD when it is active. This voltage is reached when the current flowing in the SPD is equal to I_n. The voltage protection level chosen must be below the overvoltage withstand capability of the loads (see section 3.2). In the event of lightning strokes, the voltage across the terminals of the SPD generally remains less than U_p.

□ **I_n**: Nominal discharge current

This is the peak value of a current of 8/20 μs waveform that the SPD is capable of discharging 15 times.

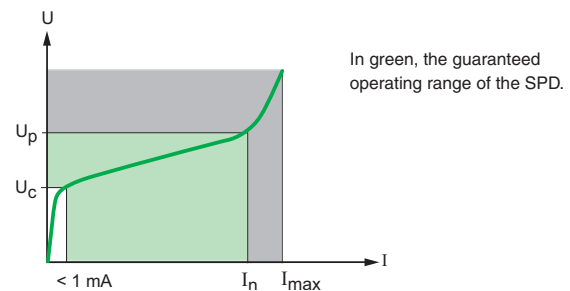


Fig. J19 : Time/current characteristic of a SPD with varistor

■ Type 1 SPD

□ **I_{imp}**: Impulse current

This is the peak value of a current of 10/350 μs waveform that the SPD is capable of discharging 5 times.

□ **I_{fi}**: Autoextinguish follow current

Applicable only to the spark gap technology.

This is the current (50 Hz) that the SPD is capable of interrupting by itself after flashover. This current must always be greater than the prospective short-circuit current at the point of installation.

■ Type 2 SPD

□ **I_{max}**: Maximum discharge current

This is the peak value of a current of 8/20 μs waveform that the SPD is capable of discharging once.

■ Type 3 SPD

□ **U_{oc}**: Open-circuit voltage applied during class III (Type 3) tests.

J11

2.4.2 Main applications

■ Low Voltage SPD

Very different devices, from both a technological and usage viewpoint, are designated by this term. Low voltage SPDs are modular to be easily installed inside LV switchboards.

There are also SPDs adaptable to power sockets, but these devices have a low discharge capacity.

■ SPD for communication networks

These devices protect telephon networks, switched networks and automatic control networks (bus) against overvoltages coming from outside (lightning) and those internal to the power supply network (polluting equipment, switchgear operation, etc.).

Such SPDs are also installed in RJ11, RJ45, ... connectors or integrated into loads.

J12