

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Protection against lightning –
Part 1: General principles**

**Protection contre la foudre –
Partie 1: Principes généraux**

Withdrawn



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PROTECTION AGAINST LIGHTNING –**Part 1: General principles****FOREWORD**

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International Standard IEC 62305-1 has been prepared by IEC technical committee 81: Lightning protection.

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The text of this first edition of IEC 62305-1 is compiled from and replaces

- IEC 61024-1-1, first edition (1993).

The text of this standard is based on the following documents:

FDIS	Report on voting
81/262/FDIS	81/267/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted, as close as possible, in accordance with the ISO/IEC Directives, Part 2.

IEC 62305 consists of the following parts, under the general title *Protection against lightning*:

Part 1: General principles

Part 2: Risk management

Part 3: Physical damage to structures and life hazard

Part 4: Electrical and electronic systems within structures

Part 5: Services¹

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

¹ To be published

INTRODUCTION

There are no devices nor methods capable of modifying the natural weather phenomena to the extent that they can prevent lightning discharges. Lightning flashes to, or nearby, structures (or services connected to the structures) are hazardous to people, to the structures themselves, their contents and installations as well as to services. This is why the application of lightning protection measures is essential.

The need for protection, the economic benefits of installing protection measures and the selection of adequate protection measures should be determined in terms of risk management. Risk management is the subject of IEC 62305-2.

The criteria for design, installation and maintenance of lightning protection measures are considered in three separate groups:

- the first group concerns protection measures to reduce physical damage and life hazard in a structure is given in IEC 62305-3,
- the second group concerns protection measures to reduce failures of electrical and electronic systems in a structure is given in IEC 62305-4,
- the third group concerns protection measures to reduce physical damage and failures of services connected to a structure (mainly electrical and telecommunication lines) is given in IEC 62305-5.

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PROTECTION AGAINST LIGHTNING –

Part 1: General principles

1 Scope

This part of IEC 62305 provides the general principles to be followed in the protection against lightning of

- structures including their installations and contents as well as persons;
- services connected to a structure.

The following cases are outside the scope of this standard:

- railway systems;
- vehicles, ships, aircraft, offshore installations;
- underground high pressure pipelines;
- pipe, power and telecommunication lines not connected to a structure.

NOTE Usually these systems are under special regulations made by various specific authorities.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62305-2, *Protection against lightning – Part 2: Risk management*

IEC 62305-3, *Protection against lightning – Part 3: Physical damage to structures and life hazard*

IEC 62305-4, *Protection against lightning – Part 4: Electrical and electronic systems within structures*

IEC 62305-5, *Protection against lightning – Part 5: Services*²

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

lightning flash to earth

electrical discharge of atmospheric origin between cloud and earth consisting of one or more strokes

² To be published.

3.2**downward flash**

lightning flash initiated by a downward leader from cloud to earth

NOTE A downward flash consists of a first short stroke, which can be followed by subsequent short strokes. One or more short strokes may be followed by a long stroke.

3.3**upward flash**

lightning flash initiated by an upward leader from an earthed structure to cloud

NOTE An upward flash consists of a first long stroke with or without multiple superimposed short strokes. One or more short strokes may be followed by a long stroke.

3.4**lightning stroke**

single electrical discharge in a lightning flash to earth

3.5**short stroke**

part of the lightning flash which corresponds to an impulse current

NOTE This current has a time to the half value T_2 typically less than 2 ms (see Figure A.1).

3.6**long stroke**

part of the lightning flash which corresponds to a continuing current

NOTE The duration time T_{long} (time from the 10 % value on the front to the 10 % value on the tail) of this continuing current is typically more than 2 ms and less than 1 s (see Figure A.2)

3.7**multiple strokes**

lightning flash consisting on average of 3-4 strokes, with typical time interval between them of about 50 ms

NOTE Events having up to a few dozen strokes with intervals between them ranging from 10 ms to 250 ms have been reported.

3.8**point of strike**

point where a lightning flash strikes the earth, or protruding object (e.g. structure, LPS, service, tree, etc.)

NOTE A lightning flash may have more than one point of strike.

3.9**lightning current**

i

current flowing at the point of strike

3.10**peak value**

I

maximum value of the lightning current

3.11**average steepness of the front of short stroke current**

average rate of change of current within a time interval $t_2 - t_1$

NOTE It is expressed by the difference $i(t_2) - i(t_1)$ of the values of the current at the start and at the end of this interval, divided by $t_2 - t_1$ (see Figure A.1).

3.12

front time of short stroke current

T_1

virtual parameter defined as 1,25 times the time interval between the instants when the 10 % and 90 % of the peak value are reached (see Figure A.1)

3.13

virtual origin of short stroke current

O_1

point of intersection with time axis of a straight line drawn through the 10 % and the 90 % reference points on the stroke current front (see Figure A.1); it precedes by 0,1 T_1 that instant at which the current attains 10 % of its peak value

3.14

time to half value of short stroke current

T_2

virtual parameter defined as the time interval between the virtual origin O_1 and the instant at which the current has decreased to half the peak value (see Figure A.1)

3.15

flash duration

T

time for which the lightning current flows at the point of strike

3.16

duration of long stroke current

T_{long}

time duration during which the current in a long stroke is between the 10 % of the peak value during the increase of the continuing current and 10 % of the peak value during the decrease of the continuing current (see Figure A.2)

3.17

flash charge

Q_{flash}

time integral of the lightning current for the entire lightning flash duration

3.18

short stroke charge

Q_{short}

time integral of the lightning current in a short stroke

3.19

long stroke charge

Q_{long}

time integral of the lightning current in a long stroke

3.20

specific energy

W/R

time integral of the square of the lightning current for the entire flash duration

NOTE It represents the energy dissipated by the lightning current in a unit resistance.

3.21

specific energy of short stroke current

time integral of the square of the lightning current for the duration of the short stroke

NOTE The specific energy in a long stroke current is negligible.

3.22**object to be protected**

structure or service to be protected against the effects of lightning

3.23**structure to be protected**

structure for which protection is required against the effects of lightning in accordance with this standard

NOTE A structure to be protected may be a part of a larger structure.

3.24**service to be protected**

service connected to a structure for which protection is required against the effects of lightning in accordance with this standard

3.25**lightning flash to an object**

lightning flash striking an object to be protected

3.26**lightning flash near an object**

lightning flash striking close enough to an object to be protected that it may cause dangerous overvoltages

3.27**electrical system**

system incorporating low voltage power supply components

3.28**electronic system**

system incorporating sensitive electronic components such as communication equipment, computer, control and instrumentation systems, radio systems, power electronic installations

3.29**internal systems**

electrical and electronic systems within a structure

3.30**physical damage**

damage to a structure (or to its contents) or to a service due to mechanical, thermal, chemical and explosive effects of lightning

3.31**injury of living beings**

injuries, including loss of life, to people or to animals due to touch and step voltages caused by lightning

3.32**failure of electrical and electronic systems**

permanent damage of electrical and electronic systems due to LEMP

3.33

lightning electromagnetic impulse

LEMP

electromagnetic effects of lightning current

NOTE It includes conducted surges as well as radiated impulse electromagnetic field effects.

3.34

surge

transient wave appearing as overvoltage and /or overcurrent caused by LEMP

NOTE Surges caused by LEMP can arise from (partial) lightning currents, from induction effects in installation loops and as remaining threat downstream of SPD.

3.35

lightning protection zone

LPZ

zone where the lightning electromagnetic environment is defined

NOTE The zone boundaries of an LPZ are not necessarily physical boundaries (e.g. walls, floor and ceiling).

3.36

risk

R

value of probable average annual loss (humans and goods) due to lightning, relative to the total value (humans and goods) of the object to be protected

3.37

tolerable risk

R_T

maximum value of the risk which can be tolerated for the object to be protected

3.38

lightning protection level

LPL

number related to a set of lightning current parameters values relevant to the probability that the associated maximum and minimum design values will not be exceeded in naturally occurring lightning

NOTE Lightning protection level is used to design protection measures according to the relevant set of lightning current parameters.

3.39

protection measures

measures to be adopted in the object to be protected to reduce the risk

3.40

lightning protection system

LPS

complete system used to reduce physical damage due to lightning flashes to a structure

NOTE It consists of both external and internal lightning protection systems.

3.41

external lightning protection system

part of the LPS consisting of an air-termination system, a down-conductor system and an earth-termination system

3.42**internal lightning protection system**

part of the LPS consisting of lightning equipotential bonding and/or electrical insulation of external LPS

3.43**air-termination system**

part of an external LPS using metallic elements such as rods, mesh conductors or catenary wires intended to intercept lightning flashes

3.44**down-conductor system**

part of an external LPS intended to conduct lightning current from the air-termination system to the earth-termination system

3.45**earth-termination system**

part of an external LPS which is intended to conduct and disperse lightning current into the earth

3.46**external conductive parts**

extended metal items entering or leaving the structure to be protected such as pipe works, cable metallic elements, metal ducts, etc. which may carry a part of the lightning current

3.47**lightning equipotential bonding**

bonding to LPS of separated metallic parts, by direct conductive connections or via surge protective devices, to reduce potential differences caused by lightning current

3.48**shielding wire**

metallic wire used to reduce physical damage due to lightning flashes to a service

3.49**LEMP protection measures system**

LPMS

complete system of protection measures for internal systems against LEMP

3.50**magnetic shield**

closed, metallic, grid-like or continuous screen enveloping the object to be protected, or part of it, used to reduce failures of electrical and electronic systems

3.51**surge protective device**

SPD

device intended to limit transient overvoltages and divert surge currents. It contains at least one non linear component

3.52**coordinated SPD protection**

set of SPD properly selected, coordinated and erected to reduce failures of electrical and electronic systems

3.53

rated impulse withstand voltage

U_w

impulse withstand voltage assigned by the manufacturer to the equipment or to a part of it, characterizing the specified withstand capability of its insulation against overvoltages

NOTE For the purposes of this standard, only withstand voltage between live conductors and earth is considered.
(IEC 60664-1:2002) [1]³

3.54

conventional earthing impedance

ratio of the peak values of the earth-termination voltage and the earth-termination current which, in general, do not occur simultaneously

4 Lightning current parameters

The lightning current parameters used in the IEC 62305 series are given in Annex A.

The time function of the lightning current to be used for analysis purposes is given in Annex B.

Information for simulation of lightning current for test purposes is given in Annex C.

The basic parameters to be used in laboratory to simulate the effects of lightning on LPS components are given in Annex D.

Information on surges due to lightning at different installation points is given in Annex E.

5 Damage due to lightning

5.1 Damage to a structure

Lightning affecting a structure can cause damage to the structure itself and to its occupants and contents, including failure of internal systems. The damages and failures may also extend to the surroundings of the structure and even involve the local environment. The scale of this extension depends on the characteristics of the structure and on the characteristics of the lightning flash.

5.1.1 Effects of lightning on a structure

The main characteristics of structures relevant to lightning effects include:

- construction (e.g. wood, brick, concrete, reinforced concrete, steel frame construction);
- function (dwelling house, office, farm, theatre, hotel, school, hospital, museum, church, prison, department store, bank, factory, industry plant, sports area);
- occupants and contents (persons and animals, presence of combustible or non-combustible materials, explosive or non-explosive materials, electrical and electronic systems with low or high withstand voltage);

³ References in square brackets refer to the bibliography.

- connected services (power lines, telecommunication lines, pipelines);
- existing or provided protection measures (e.g. protection measures to reduce physical damage and life hazard, protection measures to reduce failure of internal systems);
- scale of the extension of danger (structure with difficulty of evacuation or structure where panic may be created, structure dangerous to the surroundings, structure dangerous to the environment).

Table 1 reports the effects of lightning on various types of structures.

Table 1 – Effects of lightning on typical structures

Type of structure according to function and/or contents	Effects of lightning
Dwelling-house	Puncture of electrical installations, fire and material damage Damage normally limited to objects exposed to the point of strike or to the lightning current path Failure of electrical and electronic equipment and systems installed (e.g. TV sets, computers, modems, telephones, etc.)
Farm building	Primary risk of fire and hazardous step voltages as well as material damage Secondary risk due to loss of electric power, and life hazard to livestock due to failure of electronic control of ventilation and food supply systems, etc.
Theatre, Hotel, School Department store Sports area	Damage to the electrical installations (e.g. electric lighting) likely to cause panic Failure of fire alarms resulting in delayed fire fighting measures
Bank Insurance company Commercial company, etc.	As above, plus problems resulting from loss of communication, failure of computers and loss of data
Hospital Nursing home Prison	As above, plus problems of people in intensive care, and the difficulties of rescuing immobile people
Industry	Additional effects depending on the contents of factories, ranging from minor to unacceptable damage and loss of production
Museums and archeological sites Church	Loss of irreplaceable cultural heritage
Telecommunications Power plants	Unacceptable loss of services to the public
Firework factory Munition works	Consequences of fire and explosion to the plant and its surroundings
Chemical plant Refinery Nuclear plant Biochemical laboratories and plants	Fire and malfunction of the plant with detrimental consequences to the local and global environment

5.1.2 Sources and types of damage to a structure

The lightning current is the source of damage. The following situations shall be taken into account, depending on the position of the point of strike relative to the structure considered:

- S1: flashes to the structure;
- S2: flashes near the structure;
- S3: flashes to the services connected to the structure;
- S4: flashes near the services connected to the structure.

Flashes to the structure can cause:

- immediate mechanical damage, fire and/or explosion due to the hot lightning plasma arc itself, due to the current resulting in ohmic heating of conductors (over-heated conductors), or due to the charge resulting in arc erosion (melted metal);
- fire and/or explosion triggered by sparks caused by overvoltages resulting from resistive and inductive coupling and to passage of part of the lightning currents;
- injury to people by step and touch voltages resulting from resistive and inductive coupling;
- failure or malfunction of internal systems due to LEMP.

Flashes near the structure can cause:

- failure or malfunction of internal systems due to LEMP.

Flashes to a service connected to the structure can cause:

- fire and/or explosion triggered by sparks due to overvoltages and lightning currents transmitted through the connected service;
- injury to people due to touch voltages inside the structure caused by lightning currents transmitted through the connected service;
- failure or malfunction of internal systems due to overvoltages appearing on connected lines and transmitted to the structure.

Flashes near a service connected to the structure can cause:

- failure or malfunction of internal systems due to overvoltages induced on connected lines and transmitted to the structure.

NOTE 1 Malfunctioning of internal systems is not covered by the IEC 62305 series. Reference should be made to IEC 61000-4-5 [2].

NOTE 2 Only the sparks carrying lightning current (total or partial) are regarded as able to trigger fire.

NOTE 3 Lightning flashes, direct to or near the incoming pipelines, do not cause damages to the structure, provided that they are bonded to the equipotential bar of the structure (see IEC 62305-3).

As result, the lightning can cause three basic type of damages:

- D1: injury of living beings due to touch and step voltages;
- D2: physical damage (fire, explosion, mechanical destruction, chemical release) due to lightning current effects including sparking;
- D3: failure of internal systems due to LEMP.

5.2 Damage to a service

Lightning affecting a service can cause damage to the physical means itself (line or pipe) used to provide the service, as well as to connected electrical and electronic equipment.

NOTE The service to be considered is the physical connection between

- the switch telecommunication building and the user's building or two switch telecommunication buildings or two users' buildings, for the telecommunication (TLC) lines,
- the switch telecommunication building or the user's building and a distribution node, or two distribution nodes for the telecommunication (TLC) lines,
- the high voltage (HV) substation and the user's building, for the power lines,
- the main distribution station and the user's building, for pipes.

The scale of this extension depends on the characteristics of the service, on the type and extension of the electrical and electronic systems and on the characteristics of the lightning flash.

5.2.1 Effects of lightning on a service

The main characteristics of services relevant to lightning effects include:

- construction (line: overhead, underground, screened, unscreened, fibre optic; pipe: above ground, buried, metallic, plastic);
- function (telecommunication line, power line, pipeline);
- structure supplied (construction, contents, dimensions, location);
- existing or provided protection measures (e.g. shielding wire, SPD, route redundancy, fluid storage systems, generating sets, uninterruptible power systems).

Table 2 reports the effects of lightning on various types of services.

Table 2 – Effects of lightning on typical services

Type of service	Effects of lightning
Telecommunication line	Mechanical damage to line, melting of screens and conductors, breakdown of insulation of cable and equipment leading to a primary failure with immediate loss of service Secondary failures on the optical fibre cables with damage of the cable but without loss of service
Power lines	Damages to insulators of low voltage overhead line, puncturing of insulation of cable line, breakdown of insulation of line equipment and of transformers, with consequential loss of service
Water pipes	Damages to electrical and electronic control equipments likely to cause loss of service
Gas pipes Fuel pipes	Puncturing of non-metallic flange gaskets likely to cause fire and/or explosion. Damage to electrical and electronic control equipments likely to cause loss of service

5.2.2 Sources and types of damage to a service

The lightning current is the source of damage. The following situations shall be taken into account, depending on the position of the point of strike relative to the service considered:

- S1: flashes to the supplied structure;
- S3: flashes to the service connected to the structure;
- S4: flashes near the service connected to the structure.

Flashes to the supplied structure can cause:

- melting of metallic wires and of cable screens due to parts of the lightning current flowing into the services (resulting from resistive heating);
- breakdown of insulation of lines and of the connected equipments (due to the resistive coupling);
- puncturing of non-metallic gaskets in flanges of pipes, as well as gaskets in insulating joints.

NOTE 1 Optical fibre cable without metallic conductor are not affected by lightning flashes striking the supplied structure.

Flashes to a service connected to the structure can cause:

- immediate mechanical damage of metallic wires or piping due to electrodynamic stress or heating effects caused by lightning current (breaking and/or melting of metallic wires, screens or piping), and due to the heat of the lightning plasma arc itself (puncturing of plastic protective cover);
- immediate electrical damage of lines (breakdown of insulation) and of connected equipment;
- puncturing of thin overhead metallic pipes and of non-metallic gaskets in flanges, where consequences may extend to fire and explosion depending on the nature of conveyed fluids.

Flashes near a service connected to the structure can cause:

- breakdown of insulation of lines and of the connected equipments due to inductive coupling (induced overvoltages).

NOTE 2 Optical fibre cable without metallic conductors are not affected by lightning flashes striking the ground.

As a result, the lightning can cause two basic type of damage:

- D2: physical damage (fire, explosion, mechanical destruction, chemical release) due to thermal effects of lightning current
- D3: failure of electrical and electronic systems due to overvoltages.

5.3 Types of loss

Each type of damage, alone or in combination with others, may produce different consequential loss in the object to be protected. The type of loss that may appear depends on the characteristics of the object itself.

For the purposes of this standard the following types of loss are considered:

- L1: loss of human life;
- L2: loss of service to the public;
- L3: loss of cultural heritage;
- L4: loss of economical value (structure and its content, service and loss of activity).

Loss of type L1, L2 and L3 may be considered as loss of social values, whereas loss of type L4 may be considered as purely economical loss.

Losses which may appear in a structure are as follows:

- L1: loss of human life;
- L2: loss of service to the public;

- L3: loss of cultural heritage
- L4: loss of economic value (structure and its content).

Losses which may appear in a service are as follows:

- L2: loss of service to the public;
- L4: loss of economic value (service and loss of activity).

NOTE In a service, loss of human life is not considered in this standard.

The relationship between source of damage, type of damage and loss is reported in Table 3 for structures and in Table 4 for services.

Table 3 – Damages and loss in a structure according to different points of strike of lightning

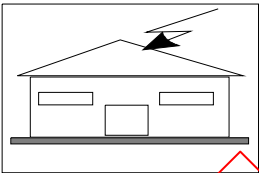
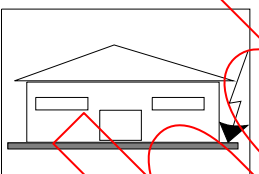
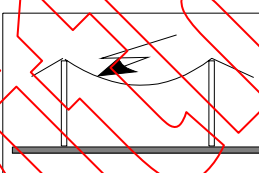
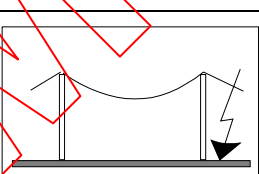
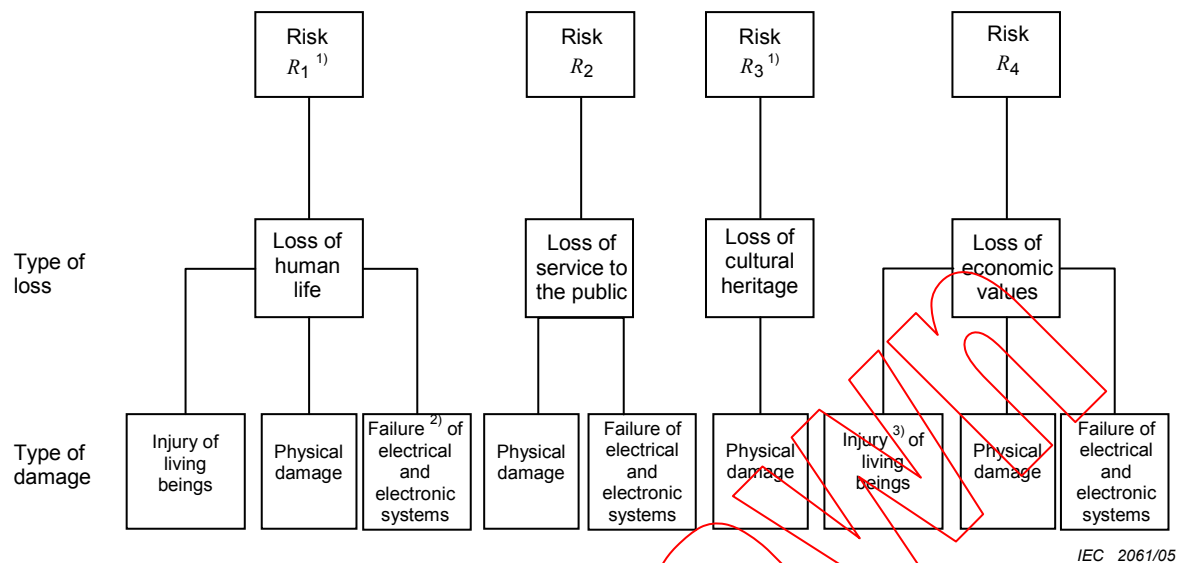
Point of strike		Source of damage	Type of damage	Type of loss
Structure		S1	D1 D2 D3	L1, L4** L1, L2, L3, L4 L1*, L2, L4
Near a structure		S2	D3	L1*, L2, L4
Service connected to the structure		S3	D1 D2 D3	L1, L4** L1, L2, L3, L4 L1*, L2, L4
Near a service		S4	D3	L1*, L2, L4
* Only for structures with risk of explosion and for hospitals or other structures where failure of internal systems immediately endangers human life. ** Only for properties where animals may be lost.				

Table 4 – Damages and loss in a service according to different points of strike of lightning

Point of strike	Source of damage	Type of damage	Type of loss
Service	S3	D2 D3	L2, L4
Near the service	S4	D3	
Supplied structure	S1	D2 D3	

Types of loss resulting from types of damage and the corresponding risks are reported in Figure 1.



¹⁾ Only for structures.

²⁾ Only for hospitals or other structures where failure on internal systems immediately endanger human life.

³⁾ Only for properties where animals may be lost.

Figure 1 – Types of loss and corresponding risks resulting from different types of damage

6 Need and economic convenience for lightning protection

6.1 Need for lightning protection

The need for lightning protection of an object to be protected in order to reduce the loss of social values L1, L2 and L3 shall be evaluated.

In order to evaluate whether or not lightning protection of an object is needed, a risk assessment in accordance with the procedures contained in IEC 62305-2 shall be made. The following risks shall be taken into account, corresponding to the types of loss reported in 5.3:

- R_1 : risk of loss of human life;
- R_2 : risk of loss of services to the public;
- R_3 : risk of loss of cultural heritage.

Protection against lightning is needed if the risk R (R_1 to R_3) is higher than the tolerable level R_T

$$R > R_T$$

In this case, protection measures shall be adopted in order reduce the risk R (R_1 to R_3) to the tolerable level R_T

$$R \leq R_T$$

If more than one type of loss could appear in the object to be protected, the condition $R \leq R_T$ shall be satisfied for each type of loss (L1, L2 and L3).

The values of tolerable risk R_T where lightning could result in the loss of items of social value should be under the responsibility of a competent national body.

NOTE 1 An authority having jurisdiction may specify the need for lightning protection for specific applications without requiring a risk assessment. In these cases, the required lightning protection level will be specified by the authority having jurisdiction. In some cases, a risk assessment may be performed as a technique by which to justify a waiver to these requirements.

NOTE 2 Detailed information on risk assessment and on the procedure for selection of protection measures is reported in IEC 62305-2.

6.2 Economic convenience of lightning protection

Besides the need for lightning protection for the object to be protected, it may be useful to evaluate the economic benefits of providing protection measures in order to reduce the economic loss L4.

In this case, the risk R_4 of loss of economic values should be assessed. The assessment of risk R_4 allows the evaluation of the cost of the economic loss with and without the adopted protection measures.

Lightning protection is cost effective if the sum of the cost C_{RL} of residual loss in presence of protection measures and the cost C_{PM} of protection measures is lower than the cost C_L of total loss without protection measures:

$$C_{RL} + C_{PM} < C_L$$

NOTE Detailed information on the evaluation of economic convenience of lightning protection is reported in IEC 62305-2.

7 Protection measures

Protection measures may be adopted in order to reduce the risk according to the type of damage.

7.1 Protection measures to reduce injury of living beings due to touch and step voltages

Possible protection measures include:

- adequate insulation of exposed conductive parts;
- equipotentialization by means of a meshed earthing system;
- physical restrictions and warning notices.

NOTE 1 Equipotentialization is not effective against touch voltages.

NOTE 2 An increase of the surface resistivity of the soil inside and outside the structure may reduce the life hazard (see Clause 8 of IEC 62305-3).

7.2 Protection measures to reduce physical damage

Possible protection measures include:

- a) for structures
 - lightning protection system (LPS)

NOTE 1 When a LPS is installed, equipotentialization is a very important measure to reduce fire and explosion danger and life hazard. For more details see IEC 62305-3.

NOTE 2 Provisions limiting the development and propagation of the fire such as fire-proof compartments, extinguishers, hydrants, fire alarm and fire extinguishing installations, may reduce physical damage.

NOTE 3 Protected escape routes provide protection for personnel.

b) for services

- shielding wire

NOTE 4 For buried cables, a very effective protection is given by metal ducts.

7.3 Protection measures to reduce failure of electrical and electronic systems

Possible protection measures include:

a) for structures

- LEMP protection measures system (LPMS) consisting of the following measures to be used alone or in combination:
 - earthing and bonding measures;
 - magnetic shielding;
 - line routing;
 - “coordinated SPD protection” .

b) for services

- surge protective devices (SPDs) at different locations along the length of the line and at the line termination;
- magnetic shields of cables.

NOTE 1 For buried cables, very effective protection is provided by a continuous metallic screen of adequate thickness.

NOTE 2 Route redundancy, redundant equipment, autonomous power generating sets, uninterruptible power systems, fluid storage systems, and automatic failure detection system are effective protection measures to reduce the loss of activity of the service.

NOTE 3 An increased withstand voltage of insulation of equipment and cables is an effective protection measure against failure due to overvoltages.

7.4 Protection measures selection

The selection of the most suitable protection measures shall be made by the designer and the owner according to the type and the amount of each kind of damage, and according to the technical and economical aspects of the different protection measures.

The criteria for risk assessment and for selection of the most suitable protection measures are given in IEC 62305-2.

Protection measures are effective provided that they comply with the requirements of relevant standards and are able to withstand the stress expected in the place of its installation.

8 Basic criteria for protection of structures and services

An ideal protection for structures and services would be to enclose the object to be protected within an earthed and perfectly conducting continuous shield of adequate thickness, and by providing adequate bonding, at the entrance point into the shield, of the services connected to the structure.

This would prevent the penetration of lightning current and related electromagnetic field into the object to be protected and prevent dangerous thermal and electrodynamic effects of current, as well as dangerous sparkings and overvoltages for internal systems.

In practice, it is often neither possible nor cost effective to go to such lengths to provide such optimum protection.

Lack of continuity of the shield and/or its inadequate thickness allows the lightning current to penetrate the shield causing:

- physical damage and life hazard
- failure of internal systems
- failure of the service and of the connected systems.

Protection measures, adopted to reduce such damages and relevant consequential loss, shall be designed for the defined set of lightning current parameters against which protection is required (lightning protection level).

8.1 Lightning protection levels (LPL)

For the aim of this standard, four lightning protection levels (I to IV) are introduced. For each LPL a set of maximum and minimum lightning current parameters is fixed.

NOTE 1 Protection against lightning whose maximum and minimum lightning current parameters exceed those relevant to LPL I is not considered in this standard.

NOTE 2 The probability of occurrence of lightning with minimum or maximum current parameters outside the range of values defined for LPL I is less than 2 %.

The maximum values of lightning current parameters relevant to LPL I will not be exceeded, with a probability of 99 %. According to the polarity ratio assumed (see Clause A.2), values taken from positive flashes will have probabilities below 10 %, while those from negative flashes will remain below 1 % (see Clause A.3).

The maximum values of lightning current parameters relevant to LPL I are reduced to 75 % for LPL II and to 50 % for LPL III and IV (linear for I , Q and di/dt , but quadratic for W/R). The time parameters are unchanged.

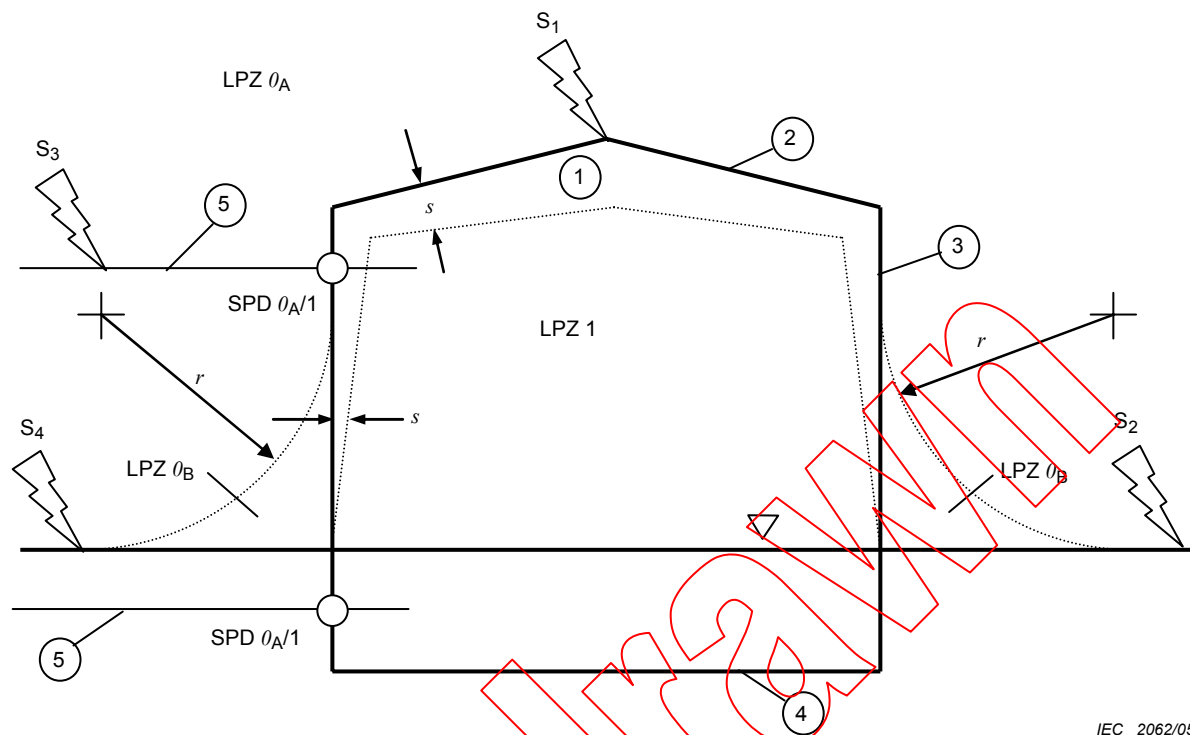
The maximum values of lightning current parameters for the different lightning protection levels are given in Table 5 and are used to design lightning protection components (e.g. cross-section of conductors, thickness of metal sheets, current capability of SPDs, separation distance against dangerous sparking) and to define test parameters simulating the effects of lightning on such components (see Annex D).

The minimum values of lightning current amplitude for the different LPL are used to derive the rolling sphere radius (see Clause A.4) in order to define the lightning protection zone LPZ 0_B which cannot be reached by direct strike (see 8.2 and Figures 2 and 3). The minimum values of lightning current parameters together with the related rolling sphere radius are given in Table 6. They are used for positioning of the air-termination system and to define the lightning protection zone LPZ 0_B (see 8.2).

Table 5 – Maximum values of lightning parameters according to LPL

First short stroke			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Peak current	I	kA	200	150	100	
Short stroke charge	Q_{short}	C	100	75	50	
Specific energy	W/R	MJ/ Ω	10	5,6	2,5	
Time parameters	T_1/T_2	$\mu\text{s}/\mu\text{s}$	10 / 350			
Subsequent short stroke			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Peak current	I	kA	50	37,5	25	
Average steepness	di/dt	kA/ μs	200	150	100	
Time parameters	T_1/T_2	$\mu\text{s}/\mu\text{s}$	0,25 / 100			
Long stroke			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Long stroke charge	Q_{long}	C	200	150	100	
Time parameter	T_{long}	s	0,5			
Flash			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Flash charge	Q_{flash}	C	300	225	150	

Withhold

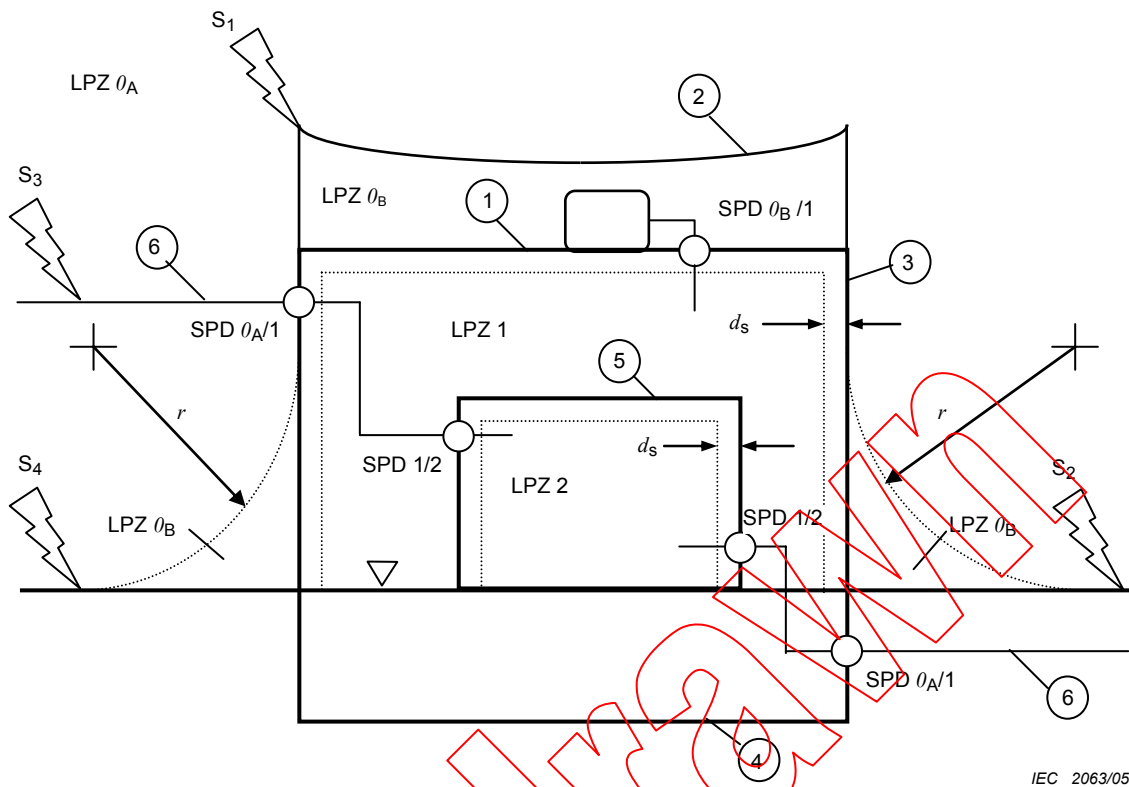


- | | | | |
|---|--------------------------|-----|---|
| 1 | Structure | S1 | Flash to the structure |
| 2 | Air termination system | S2 | Flash near to the structure |
| 3 | Down conductor system | S3 | Flash to a service connected to the structure |
| 4 | Earth termination system | S4 | Flash near a service connected to the structure |
| 5 | Incoming services | r | Rolling sphere radius |
| | | s | Separation distance against dangerous sparking |

- ▽ Ground level
 ○ Lightning equipotential bonding by means of SPD
 Direct flash, full lightning current

- LPZ 0_A Direct flash, full lightning current
 LPZ 0_B No direct flash, partial lightning or induced current
 LPZ 1 No direct flash, limited lightning or induced current
 Protected volume inside LPZ 1 must respect separation distance s

Figure 2 – LPZ defined by an LPS (IEC 62305-3)



- | | | | |
|---|-------------------------------------|-------|---|
| 1 | Structure (shield of LPZ 1) | S1 | Flash to the structure |
| 2 | Air termination system | S2 | Flash near to the structure |
| 3 | Down conductor system | S3 | Flash to a service connected to the structure |
| 4 | Earth termination system | S4 | Flash near a service connected to the structure |
| 5 | Room (shield of LPZ 2) | r | Rolling sphere radius |
| 6 | Services connected to the structure | d_s | Safety distance against too high magnetic field |

-  Ground level
 Lightning equipotential bonding by means SPD

LPZ 0A Direct flash, full lightning current, full magnetic field

LPZ 0B No direct flash, partial lightning or induced current, full magnetic field

LPZ 1 No direct flash, limited lightning or induced current, damped magnetic field

LPZ 2 No direct flash, induced currents, further damped magnetic field

Protected volumes inside LPZ 1 and LPZ 2 must respect safety distances d_s

**Figure 3 – LPZ defined by protection measures against LEMP
(IEC 62305-4)**

Table 6 – Minimum values of lightning parameters and related rolling sphere radius corresponding to LPL

Interception criteria			LPL			
	Symbol	Unit	I	II	III	IV
Minimum peak current	I	kA	3	5	10	16
Rolling sphere radius	r	m	20	30	45	60

From the statistical distributions given in Figure A.5, a weighted probability can be determined that the lightning current parameters are smaller than the maximum values and respectively greater than the minimum values defined for each protection level (see Table 7).

Table 7 – Probabilities for the limits of the lightning current parameters

Probability that lightning current parameters	LPL			
	I	II	III	IV
Are smaller than the maximum values defined in Table 5	0,99	0,98	0,97	0,97
Are greater than the minimum values defined in Table 6	0,99	0,97	0,91	0,84

The protection measures specified in IEC 62305-3, IEC 62305-4 and IEC 62305-5 are effective against lightning whose current parameters are in the range defined by the LPL assumed for design. Therefore the efficiency of a protection measure is assumed equal to the probability with which lightning current parameters are inside such range.

8.2 Lightning protection zones (LPZ)

Protection measures such as LPS, shielding wires, magnetic shields and SPD determine lightning protection zones (LPZ).

LPZ downstream of the protection measure are characterized by significant reduction of LEMP than that upstream of the LPZ.

With respect to the threat of lightning, the following LPZs are defined (see Figures 2 and 3):

- LPZ O_A zone where the threat is due to the direct lightning flash and the full lightning electromagnetic field. The internal systems may be subjected to full or partial lightning surge current;
- LPZ O_B zone protected against direct lightning flashes but where the threat is the full lightning electromagnetic field. The internal systems may be subjected to partial lightning surge currents;
- LPZ 1 zone where the surge current is limited by current sharing and by SPDs at the boundary. Spatial shielding may attenuate the lightning electromagnetic field;
- LPZ 2, ..., n zone where the surge current may be further limited by current sharing and by additional SPDs at the boundary. Additional spatial shielding may be used to further attenuate the lightning electromagnetic field.

NOTE 1 In general, the higher the number of an individual zone, the lower the electromagnetic environment parameters.

As a general rule for protection, the object to be protected shall be in a LPZ whose electromagnetic characteristics are compatible with the capability of the object to withstand stress causing the damage to be reduced (physical damage, failure of electrical and electronic systems due to overvoltages).

NOTE 2 For most electrical and electronic systems and apparatus, information about withstand level can be supplied by manufacturer.

8.3 Protection of structures

8.3.1 Protection to reduce physical damage and life hazard

The structure to be protected shall be inside an LPZ 0_B or higher. This is achieved by means of a lightning protection system (LPS).

An LPS consists of both external and internal lightning protection systems (see Figure 2).

The functions of the external LPS are

- to intercept a lightning flash to the structure (with an air-termination system),
- to conduct the lightning current safely to earth (with a down-conductor system),
- to disperse it into the earth (with an earth-termination system).

The function of the internal LPS is to prevent dangerous sparking within the structure, using either equipotential bonding or a separation distance, s , (and hence electrical isolation) between the LPS components and other electrically conducting elements internal to the structure.

Four classes of LPS (I, II, III, IV) are defined as a set of construction rules, based on the corresponding LPL. Each set includes level-dependent (e.g. rolling sphere radius, mesh width etc.) and level-independent (e.g. cross-sections, materials etc.) construction rules.

Where surface resistivity of the soil outside, and of the floor inside the structure is not sufficiently high, life hazard due to touch and step voltages is reduced:

- outside the structure, by insulation of the exposed conductive parts, by equipotentialization of the soil by means of a meshed earthing system, by warning notice and by physical restrictions;
- inside the structure, by equipotential bonding of services at entrance point into the structure.

LPS shall comply with requirements of IEC 62305-3.

8.3.2 Protection to reduce the failure of internal systems

The protection against LEMP to reduce the risk of failure of internal systems shall limit:

- overvoltages due to lightning flashes to the structure resulting from resistive and inductive coupling;
- overvoltages due to lightning flashes near the structure resulting from inductive coupling;

- overvoltages transmitted by lines connected to the structure due to flashes to or near the lines;
- magnetic field directly coupling with internal systems.

NOTE Failure of apparatus due to electromagnetic fields directly radiated into the equipment are negligible provided that apparatus comply with radio frequency (RF) radiated emission and immunity tests defined by relevant EMC product standards (see IEC 62305-2 and IEC 62305-4).

The system to be protected shall be located inside a LPZ 1 or higher. This is achieved by means of magnetic shields attenuating the inducing magnetic field and/or suitable routing of wiring reducing the induction loop. Bonding shall be provided at the boundaries of LPZ for metal parts and systems crossing the boundaries. This bonding may be accomplished by means of bonding conductors or, when necessary, by surge protective devices (SPDs).

Protection measures for LPZ shall comply with IEC 62305-4.

Effective protection against overvoltages, causing failures of internal systems, may also be achieved by means of a “coordinated SPD protection”, limiting overvoltages below the rated impulse withstand voltage of the system to be protected.

SPDs shall be selected and installed according to the requirements of IEC 62305-4.

8.4 Protection of services

The service to be protected shall be

- inside an LPZ 0_B or higher to reduce physical damage. This is achieved by selecting underground instead of aerial routing or by using adequately positioned shielding wire, where effective according to the line characteristics or, in the case of pipes, by increasing the pipe thickness to an adequate value and ensuring the metallic continuity of pipes;
- inside an LPZ 1 or higher for protection against overvoltages causing failure of the service. This is achieved by reducing the level of the overvoltages induced by lightning by means of adequate magnetic shielding of cables, diverting overcurrent and limiting overvoltages by means of adequate SPDs.

Annex A (informative)

Parameters of lightning current

A.1 Lightning flashes to earth

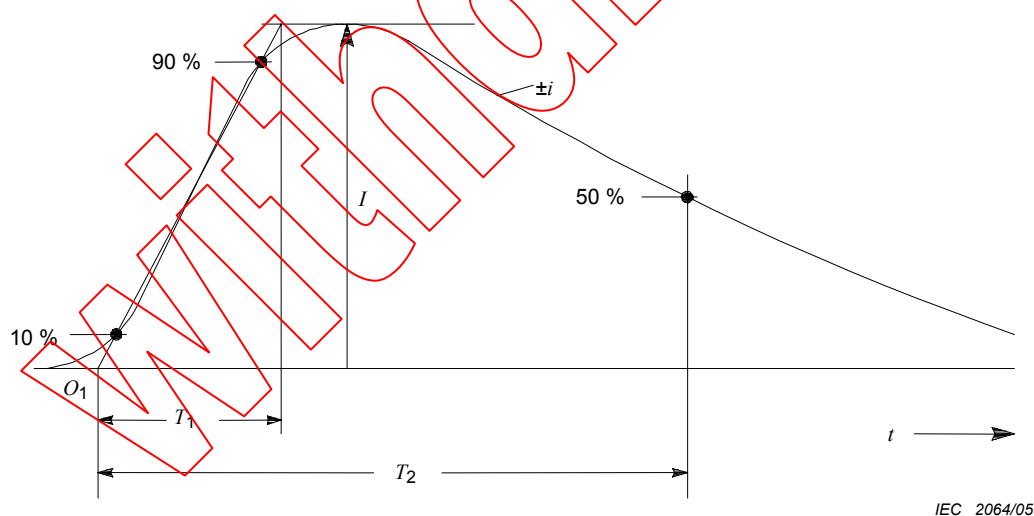
Two basic types of flashes exist:

- downward flashes initiated by a downward leader from cloud to earth;
- upward flashes initiated by an upward leader from an earthed structure to cloud.

Mostly downward flashes occur in flat territory, and to lower structures, whereas for exposed and/or higher structures upward flashes become dominant. With effective height, the probability of a direct strike to the structure increases (see IEC 62305-2, Annex A) and the physical conditions change.

A lightning current consists of one or more different strokes:

- short strokes with duration less than 2 ms (Figure A.1)
- long strokes with duration longer than 2 ms (Figure A.2).



Key

- O_1 virtual origin
- I peak current
- T_1 front time
- T_2 time to half value

Figure A.1 – Definitions of short stroke parameters (typically $T_2 < 2$ ms)

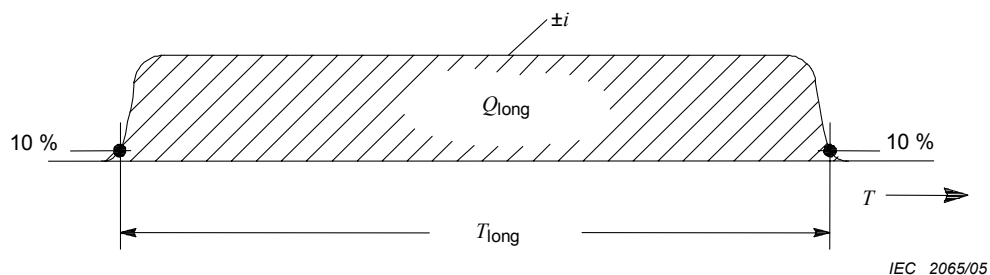
**Key** T_{long} duration time Q_{long} long stroke charge

Figure A.2 – Definitions of long stroke parameters
(typically $2 \text{ ms} < T_{\text{long}} < 1 \text{ s}$)

Further differentiation of strokes comes from their polarity (positive or negative) and from their position during the flash (first, subsequent, superimposed). The possible components are shown in Figure A.3 for downward flashes and in Figure A.4 for upward flashes.

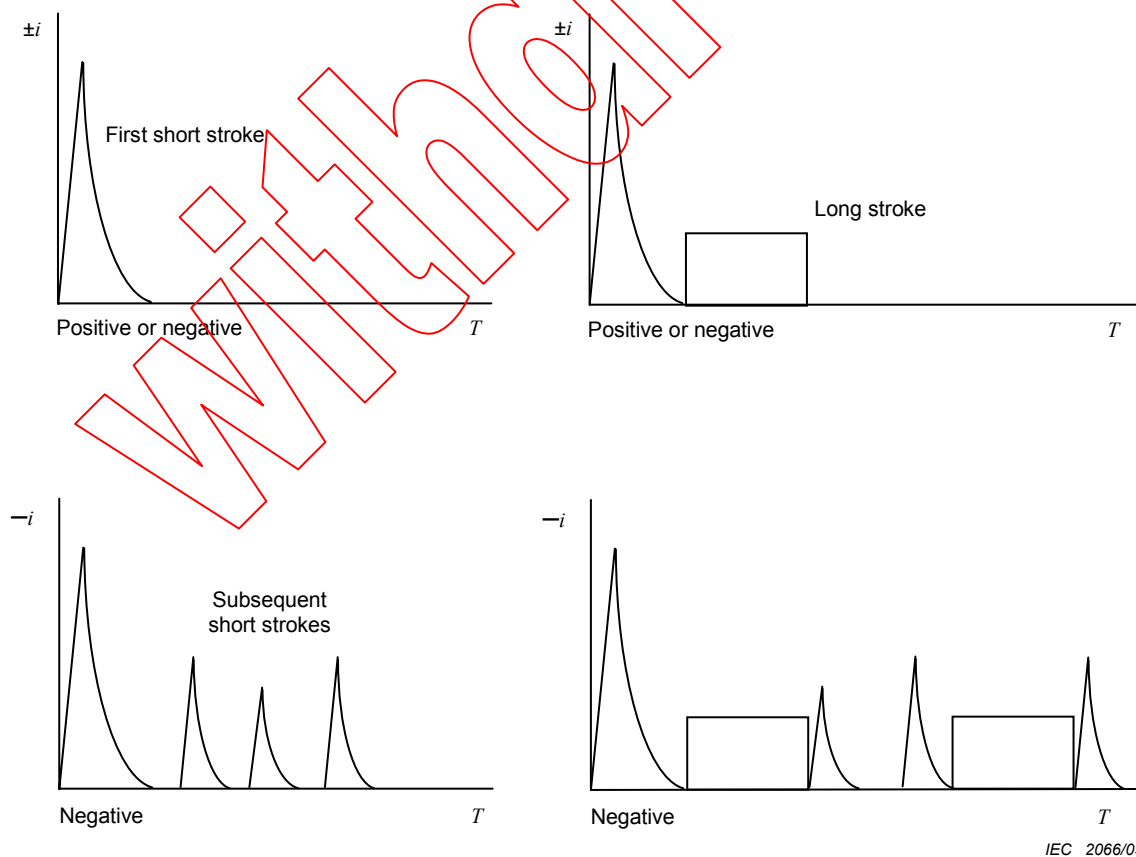
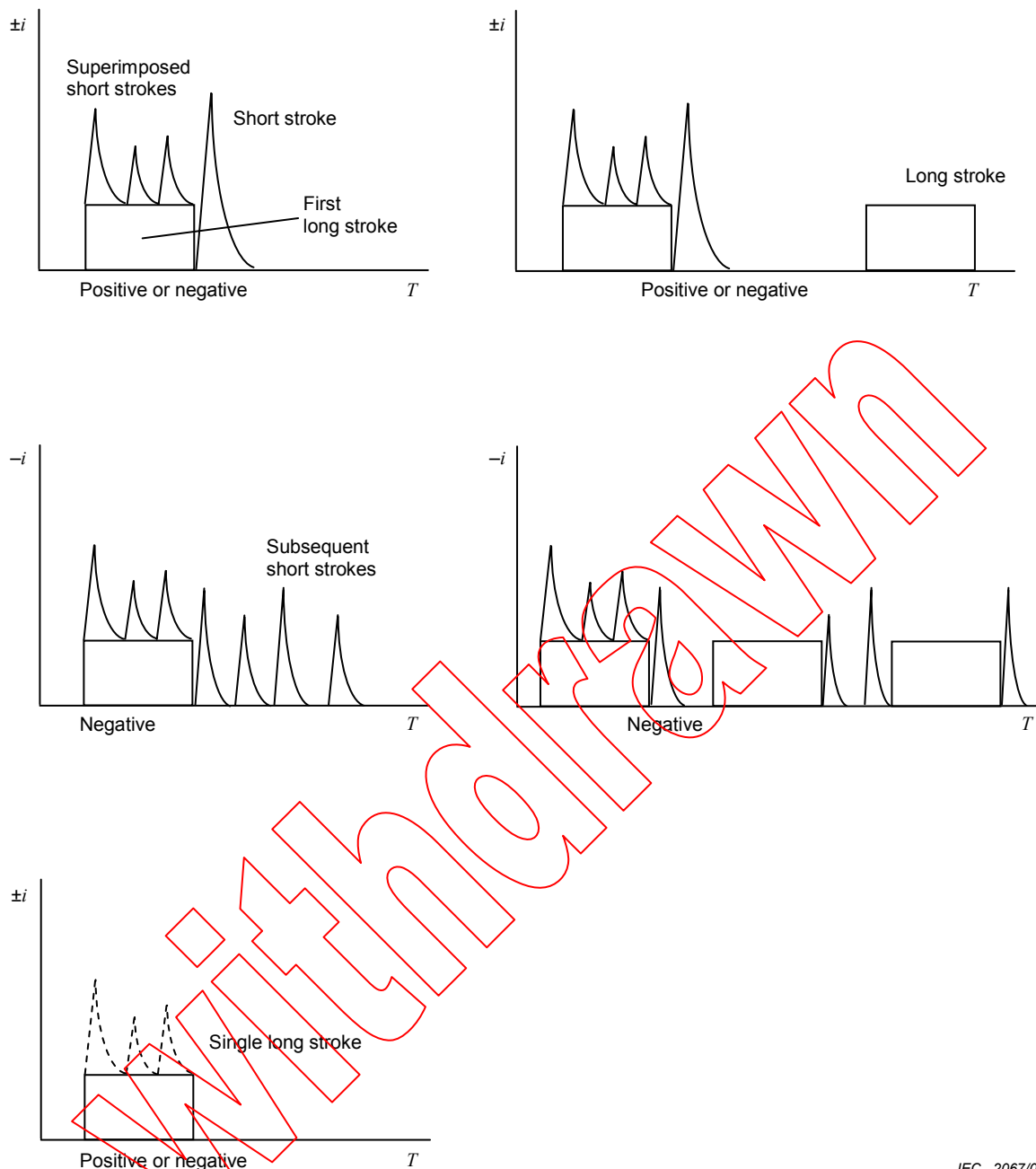


Figure A.3 – Possible components of downward flashes
(typical in flat territory and to lower structures)



IEC 2067/05

**Figure A.4 – Possible components of upward flashes
(typical to exposed and/or higher structures)**

The additional component in upward flashes is the first long stroke with or without up to some ten superimposed short strokes. But all short stroke parameters of upward flashes are less than those of downward flashes. A higher long stroke charge of upward flashes is not yet confirmed. Therefore the lightning current parameters of upward flashes are considered to be covered by the maximum values given for downward flashes. A more precise evaluation of lightning current parameters and their height dependency with regard to downward and upward flashes is under consideration.

A.2 Lightning current parameters

The lightning current parameters in this standard are based on the results of the International Council on Large Electrical Systems (CIGRE) data given in Table A.1. Their statistical distribution can be assumed to have a logarithmic normal distribution. The corresponding mean value μ and the dispersion $\sigma_{\log}$ are given in Table A.2 and the distribution function is shown in Figure A.5. On this basis, the probability of occurrence of any value of each parameter can be determined.

A polarity ratio of 10 % positive and 90 % negative flashes is assumed. The polarity ratio is a function of the territory. If no local information is available, the ratio given herein should be used.

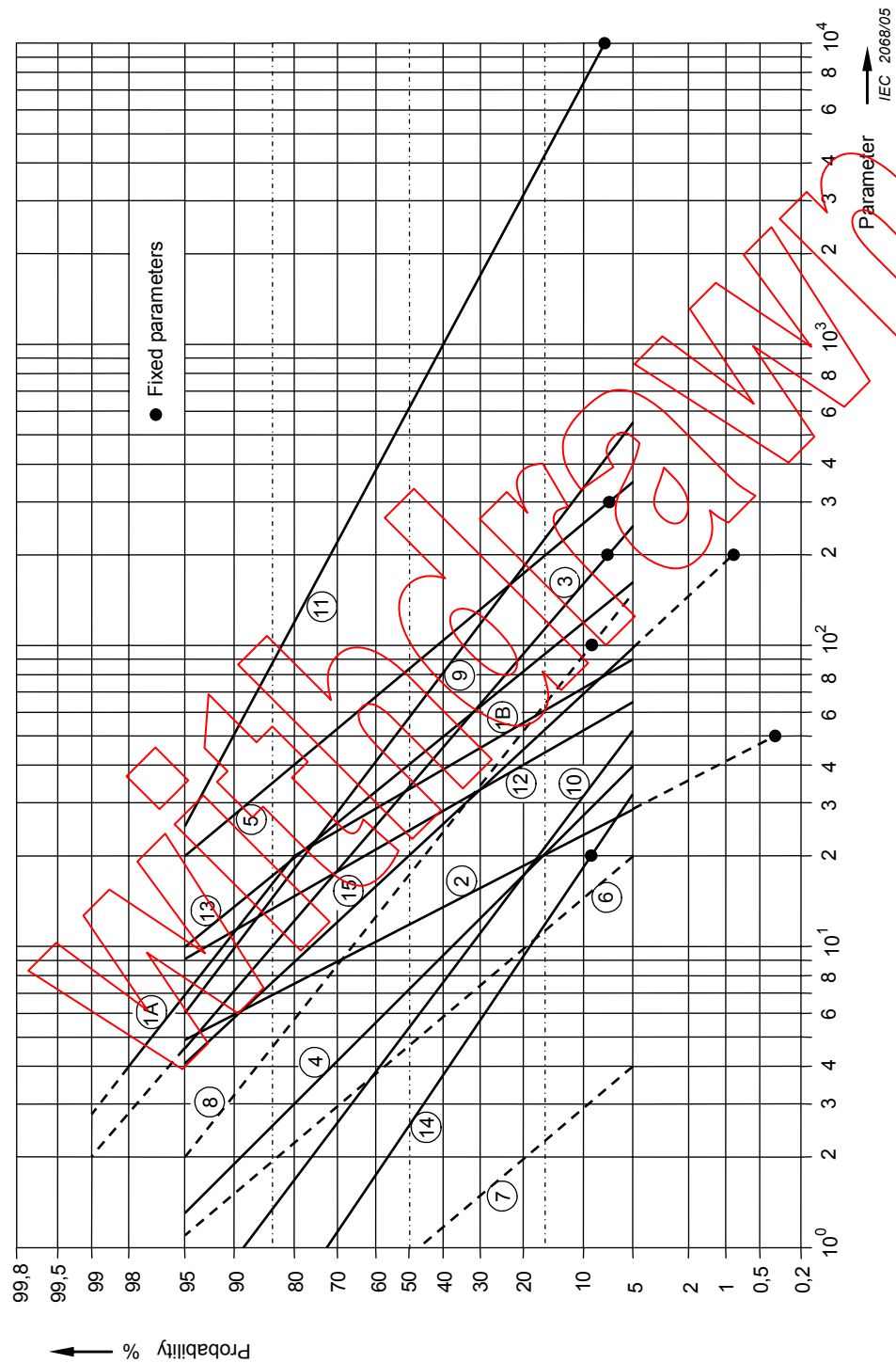
Table A.1 – Tabulated values of lightning current parameters taken from CIGRE (Electra No. 41 or No. 69*) [3], [4]

Parameter	Fixed values for LPL I	Values			Type of stroke	Line in Figure A.5
		95 %	50 %	5 %		
I (kA)	50 200	4(98 %)	20(80 %)	90	*First negative short	1A+1B
		4,9	11,8	28,6	*Subsequent negative short	2
		4,6	35	250	First positive short (single)	3
Q_{flash} (C)	300	1,3	7,5	40	Negative flash	4
		20	80	350	Positive flash	5
Q_{short} (C)	100	1,1	4,5	20	First negative short	6
		0,22	0,95	4	Subsequent negative short	7
		2	16	150	First positive short (single)	8
W/R (kJ/ Ω)	10 000	6	55	550	First negative short	9
		0,55	6	52	Subsequent negative short	10
		25	650	15 000	First positive short	11
di/dt_{max} (kA/ μs)	20	9,1	24,3	65	*First negative short	12
		9,9	39,9	161,5	*Subsequent negative short	13
		0,2	2,4	32	First positive short	14
$di/dt_{30/90\%}$ (kA/ μs)	200	4,1	20,1	98,5	*Subsequent negative short	15
Q_{long} (C)	200				Long	
t_{long} (s)	0,5				Long	
Front duration (μs)		1,8	5,5	18	First negative short	
		0,22	1,1	4,5	Subsequent negative short	
		3,5	22	200	First positive short (single)	
Stroke duration (μs)		30	75	200	First negative short	
		6,5	32	140	Subsequent negative short	
		25	230	2 000	First positive short (single)	
Time interval (ms)		7	33	150	Multiple negative strokes	
Total flash duration (ms)		0,15	13	1 100	Negative flash (all)	
		31	180	900	Negative flash (without single)	
		14	85	500	Positive flash	

NOTE The values of $I = 4$ kA and $I = 20$ kA correspond to a probability of 98 % and 80 %, respectively.

Table A.2 – Logarithmic normal distribution of lightning current parameters – Mean μ and dispersion $\sigma_{\log}$ calculated from 95 % and 5 % values from CIGRE (Electra No. 41 or No. 69) [3], [4]

Parameter	Mean μ	Dispersion $\sigma_{\log}$	Stroke type	Line in Figure A.5
I (kA)	(61,1)	0,576	*First negative short (80 %)	1A
	33,3	0,263	*First negative short (80 %)	1B
	11,8	0,233	*Subsequent negative short	2
	33,9	0,527	First positive short (single)	3
Q_{flash} (C)	7,21	0,452	Negative flash	4
	83,7	0,378	Positive flash	5
Q_{short} (C)	4,69	0,383	First negative short	6
	0,938	0,383	Subsequent negative short	7
	17,3	0,570	First positive short (single)	8
W/R (kJ/ Ω)	57,4	0,596	First negative short	9
	5,35	0,600	Subsequent negative short	10
	612	0,844	First positive short	11
di/dt_{max} (kA/ μ s)	24,3	0,260	*First negative short	12
	40,0	0,369	*Subsequent negative short	13
	2,53	0,670	First positive short	14
$di/dt_{30/90\%}$ (kA/ μ s)	20,1	0,420	*Subsequent negative short	15
Q_{long} (C)	200		Long	
t_{long} (s)	0,5		Long	
Front duration (μ s)	5,69	0,304	First negative short	
	0,995	0,398	Subsequent negative short	
	26,5	0,534	First positive short (single)	
Stroke duration (μ s)	77,5	0,250	First negative short	
	30,2	0,405	Subsequent negative short	
	224	0,578	First positive short (single)	
Time interval (ms)	32,4	0,405	Multiple negative strokes	
Total flash duration (ms)	12,8	1,175	Negative flash (all)	
	167	0,445	Negative flash (without single)	
	83,7	0,472	Positive flash	



NOTE For numbering of curves see Tables A.1 and A.2.

Figure A.5 – Cumulative frequency distribution of lightning current parameters (lines through 95 % and 5 % value)

All values fixed for LPL given in this standard relate to both downward and upward flashes.

NOTE The value of lightning parameters is usually obtained from measurement taken on tall objects. Statistical distribution of estimated lightning current peak values that does not consider the effect of tall objects is also available from lightning location systems.

A.3 Fixing the maximum lightning current parameters for LPL I

The mechanical effects of lightning are related to the peak value of the current (I), and to the specific energy (W/R). The thermal effects are related to the specific energy (W/R) when resistive coupling is involved and to the charge (Q) when arcs develop to the installation. Overvoltages and dangerous sparking caused by inductive coupling are related to the average steepness (di/dt) of the lightning current front.

Each of the single parameters (I , Q , W/R , di/dt) tend to dominate each failure mechanism. This shall be taken into account in establishing test procedures.

A.3.1 First short stroke and long stroke

The values of I , Q and W/R related to mechanical and thermal effects are determined from positive flashes (because their 10 % values are much higher than the corresponding 1 % values of the negative flashes). From Figure A.5 (lines 3, 5, 8, 11 and 14) the following values with probabilities below 10 % can be taken:

$$\begin{aligned} I &= 200 \text{ kA} \\ Q_{\text{flash}} &= 300 \text{ C} \\ Q_{\text{short}} &= 100 \text{ C} \\ W/R &= 10 \text{ MJ}/\Omega \\ di/dt &= 20 \text{ kA}/\mu\text{s} \end{aligned}$$

For a first short stroke according to Figure A.1, these values give an first approximation for the front time:

$$T_1 = I / (di/dt) = 10 \mu\text{s} \text{ (} T_1 \text{ is of minor interest)}$$

For an exponentially decaying stroke, the following formula for approximate charge and energy values applies ($T_1 \ll T_2$):

$$\begin{aligned} Q_{\text{short}} &= (1/0,7) \cdot I \cdot T_2 \\ W/R &= (1/2) \cdot (1/0,7) \cdot I^2 \cdot T_2 \end{aligned}$$

These formulas, together with the values given above, lead to a first approximation for the time to half value:

$$T_2 = 350 \mu\text{s}$$

For the long stroke, its charge can be approximately calculated from:

$$Q_{\text{long}} = Q_{\text{flash}} - Q_{\text{short}} = 200 \text{ C}$$

Its duration time, according to Figure A.2, may be estimated from the flash duration time as:

$$T_{\text{long}} = 0,5 \text{ s}$$

A.3.2 Subsequent short stroke

The maximum value of average steepness di/dt related to the dangerous sparking caused by inductive coupling is determined from subsequent short strokes of negative flashes (because their 1 % values are much higher than the 1 % values from first negative strokes or the corresponding 10 % values of the positive flashes). From Figure A.5 (lines 2 and 15) the following values with probabilities below 1 % can be taken:

$$I = 50 \text{ kA}$$

$$di/dt = 200 \text{ kA}/\mu\text{s}$$

For a subsequent short stroke according to Figure A.1 these values give an first approximation for its front time of:

$$T_1 = I / (di/dt) = 0,25 \mu\text{s}$$

Its time to half value may be estimated from the stroke duration of negative subsequent short strokes:

$$T_2 = 100 \mu\text{s} \text{ (} T_2 \text{ is of minor interest).}$$

A.4 Fixing the minimum lightning current parameters

The interception efficiency of an LPS depends on the minimum lightning current parameters and on the related rolling sphere radius. The geometrical boundary of areas which are protected against direct lightning flashes can be determined using the rolling sphere method.

Following the electro-geometric model, the rolling sphere radius r (final jump distance) is correlated with the peak value of the first short stroke current. In an IEEE working group report [5], the relation is given as

$$r = 10 \cdot I^{0,65} \quad (\text{A.1})$$

where

r is the rolling sphere radius (m);

I is the peak current (kA).

For a given rolling sphere radius r it can be assumed that all flashes with peak values higher than the corresponding minimum peak value I will be intercepted by natural or dedicated air terminations. Therefore, the probability for the peak values of negative and positive first strokes from Figure A.5 (lines 1A and 3) is assumed to be the interception probability. Taking into account the polarity ratio of 10 % positive and 90 % negative flashes, the total interception probability can be calculated (see Table 7).

Annex B (informative)

Time functions of the lightning current for analysis purposes

The current waveshapes of:

- the first short stroke 10/350 µs
- the subsequent short strokes 0,25/100 µs

may be defined as:

$$i = \frac{I}{k} \cdot \frac{(t/\tau_1)^{10}}{1 + (t/\tau_1)^{10}} \cdot \exp(-t/\tau_2) \quad (\text{B.1})$$

where

I is the peak current;

k is the correction factor for the peak current;

t is the time;

τ_1 is the front time constant;

τ_2 is the tail time constant.

For the current waveshapes of the first short stroke and the subsequent short strokes for different LPL, the parameters given in Table B.1 apply. The analytic curves are shown in Figures B.1 to B.4.

Table B.1 – Parameters for Equation B.1

Parameters	First short stroke			Subsequent short stroke		
	LPL			LPL		
	I	II	III-IV	I	II	III-IV
I (kA)	200	150	100	50	37,5	25
k	0,93	0,93	0,93	0,993	0,993	0,993
τ_1 (µs)	19	19	19	0,454	0,454	0,454
τ_2 (µs)	485	485	485	143	143	143

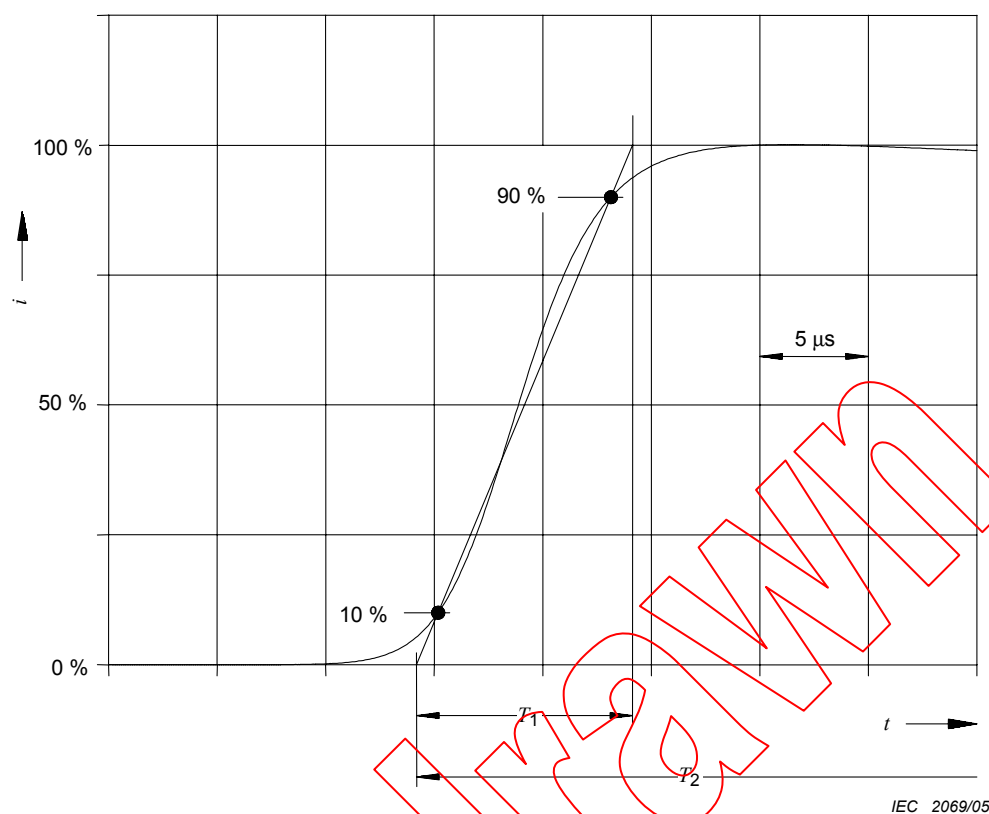


Figure B.1 – Waveshape of the current rise of the first short stroke

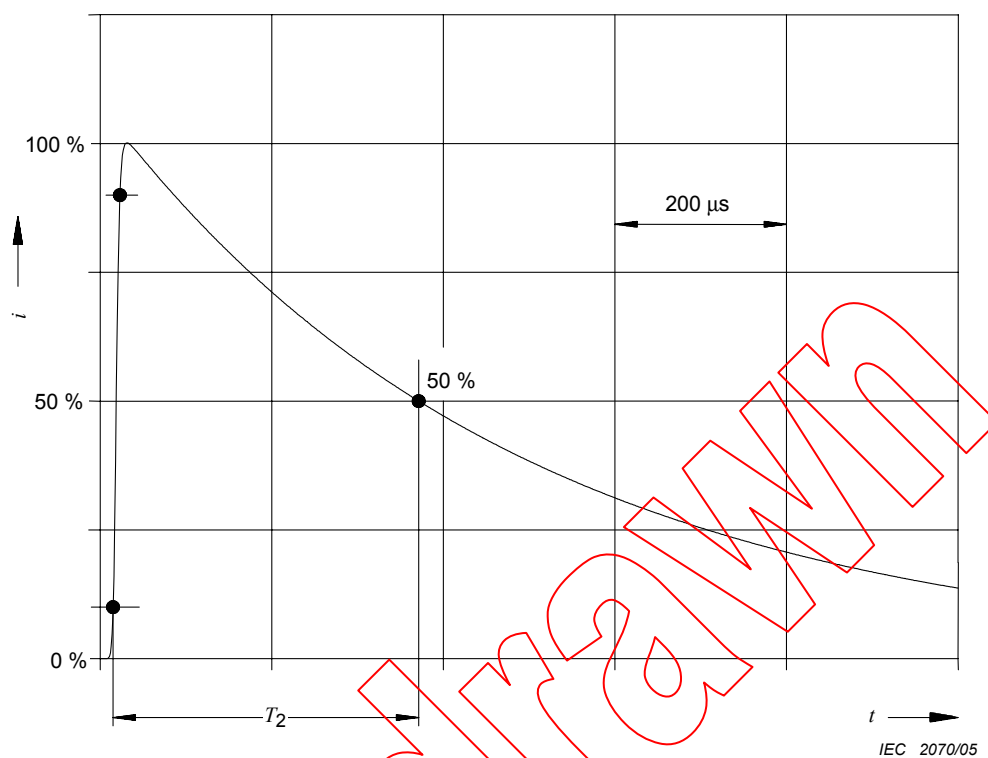


Figure B.2 – Waveshape of the current tail of the first short stroke