IEC/TR 60479-4

Edition 2.0 2011-10

TECHNICAL REPORT

RAPPORT TECHNIQUE

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Effects of current on human beings and livestock – Part 4: Effects of lightning strokes

Effets du courant sur le corps humain et sur les animaux domestiques – Partie 4: Effets de la foudre

IEC/TR 60479-4:2011

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

PRICE CODE
CODE PRIX S

ICS 13.200; 29.020

ISBN 978-2-88912-694-1

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

Part 4: Effects of lightning strokes

FOREWORD

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IEC/TR 60479-4, which is a technical report, has been prepared by technical committee No.64: Electrical installations and protection against electric shock.

This second edition cancels and replaces the first edition, published in 2004 and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

– the report has been completed with additional information on the influences and effects of natural electricity in the form of lightning strokes during thunderstorms;

– the definitions and technical terms have been updated;

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– the explanation of the basic physical mechanisms for the dynamics of lightning where specified;
– the references to the relevant literature and the list of bibliography are updated;
– figures showing the current path during different interactions of lightning with the victim's body are updated.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
64/1772/DTR	64/1804/RVC

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

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

A list of all the parts in the IEC 60479 series, under the general title *Effects of current on human beings and livestock*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability 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,
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INTRODUCTION

IEC 60479-1, IEC 60479-2 and IEC 60479-3 deal with the effect of electric shock derived from electrical systems on the bodies of human beings and livestock. This part of IEC 60479, which is a technical report, describes the influence and effect of natural electricity in the form of lightning strokes during thunderstorms. Lightning current can consist of several uni-polar and/or bi-polar impulses with different peak values and durations; Clause 6 of IEC/TS 60479-2:2007[24][1] does not cover these effects.

The interaction of a lightning stroke with the victim's body is quite different from the usual experience with electric shock derived from electrical systems. The pathway often includes the head in lightning accidents. The importance of the cranial orifices as points of entry of lightning current has been noted, and from these the proximity of the pathway to the brainstem. The brain stem includes the respiratory centre, in contrast with pathways of shock current arising from electrical systems. In particular it should be pointed out that differences exist between accidents caused by a direct flash compared with those interactions which are caused by step voltages. Even very short single impulses of lightning can cause cardiopulmonary arrest [5], [6], [15] and [16].

The intense electric interactions with living organisms are very dangerous but, surprisingly in many cases, not always lethal. It is accepted that more than 90 % of lightning accidents involving humans are not fatal [1], [12]. Corresponding reliable data for livestock is not known. There is a large variation in outcome due to different environments, different activities of people and knowledge of first aid and quality of medical care [1], [5].

It has been necessary, therefore, to create a separate standard concerning the special effects of lightning strokes. The physical behaviour of lightning is shown as a basis. The interaction with a living body is then described, followed by the consequences for the life of the victim.

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[1] References in square brackets refer to the bibliography.

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EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

Part 4: Effects of lightning strokes

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1 Scope and object

This part of IEC 60479, which is a technical report, summarizes the basic parameters for lightning and their variability insofar as they apply to human beings and livestock.

The possible direct and indirect interactions of strikes with bodies of living beings are indicated and the resulting effects caused by lightning currents for the organism are described.

The object of this report is to show the differences of effects on human beings and livestock due to lightning strokes versus those effects of electric shocks derived from electrical systems.

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/TS 60479-1:2005, *Effects of current on human beings and livestock – Part 1: General aspects*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC/TS 60479-1, in addition to the following definitions, apply.

3.1 Definitions of technical terms

3.1.1
lightning flash
atmospheric discharge consisting of one or more strokes

3.1.2
lightning stroke
single electrical discharge in a lightning flash

3.1.3
lightning channel
conducting path of the lightning current

3.1.4
stepped and connecting leader
stepped leader stepping down from a cloud and a connecting leader stepping up from points of field concentration beneath, noting that they are low current non-luminous processes leading to the return stroke when the two connect

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3.1.5
main stroke
return stroke
bright lightened stroke with strong current discharge, which is initiated at that moment when the stepped and connecting leader comes into contact with the earth

3.1.6
downward flash
lightning flash initiated by a downward leader from a cloud to earth

3.1.7
upward flash
lightning flash initiated by an upward leader from earth to cloud; that part of a stroke when the leader grows from earth to cloud

3.1.8
continuing current
mean current of the long-lasting component of the lightning current

3.1.9
peak value of current
maximum value of the lightning current

NOTE Values are given in Table A.2 and Figure A.5 of IEC 62305-1:2010 [7].

3.1.10
flash charge
time integral of the lightning current for the entire lightning duration

NOTE This value ranges from 0,2 °C to 350 °C for the majority of positive and negative lightning strokes [7].

3.1.11
impulse charge
short stroke charge
time integral of the lightning current for the impulse part of the lightning duration

NOTE This value ranges from 0,22 °C to 150 °C for the majority of positive and negative lightning strokes [7].

3.1.12
specific energy
energy dissipated by the lightning current in a unit resistance

NOTE It is the integral of the square of the lightning current for the duration of the lightning. This value ranges from 6×10^3 J/Ω to $1,5 \times 10^7$ J/Ω for the majority of positive and negative lightning strokes [7].

3.1.13
average steepness of current wave front
average rate of change of current calculated over 10 % to 90 % of peak amplitude of the wave front [7]

NOTE This value ranges from 0,2 kA/µs to 99 kA/µs for the majority of positive and negative lightning strokes.

3.1.14
stroke duration
Time from the initiation of an atmospheric discharge until the time that particular stroke has been extinguished (the range of 3.1.5) and is 15 µs to 2000 µs for the majority of positive and negative lightning strokes [7]

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3.1.15
stroke interval
time interval between the beginnings of successive strokes

3.1.16
total flash duration
Time from the beginning the first stroke to the end of the last stroke with a time range of 0,1 ms to 1100 ms for the majority of positive and negative lightning flashes [7]

NOTE 1 Experience shows that the statistical distribution of the parameters of total flash duration as expressed by Definition 3.1.16, can be assumed to have a logarithmic normal distribution.

NOTE 2 A flash is made up of a number of strokes. A continuing current may result and continue for some time. The duration of the flash is therefore dependent on the stroke duration, the number of strokes of the flash and the duration of any continuing current. All of these are variable and statistically described.

3.2 Definitions of interactions

3.2.1
direct stroke
interaction whereby the tip of the stepped and connecting leader attaches directly to the living being (see Figure 2)

3.2.2
contact voltage
potential difference between accessible points when touched simultaneously by a living being (see Figure 3)

NOTE In some texts this has been erroneously referred to as “contact potential” or “touch voltage”

3.2.3
side flash
electric arc between two objects, at least one of which is contacted by lightning (see Figures 4 and 7))

3.2.4
step voltage
voltage on the earth’s surface between two points

[IEC 60050-195:1998, 195-05-12, modified] [25]

NOTE The possible resulting currents are shown in Figures 5 and 7. .

3.2.5
streamer current
current flowing through an individual as that individual serves as the starting point for an upward streamer which ultimately does not join a stepped leader to form a conducting channel (see Figure 8)

3.2.6
flashover
electric arc over the surface of the body carrying a significant proportion of the current

NOTE It may occur with the other combinations above (see Figure 2).

3.3 Definitions of effects on organisms

3.3.1
physiological effects
reaction due to external electrical stimulation of excitable cells, such as all kinds of skeletal muscle, smooth muscle of arteries and veins, cardiac muscle, nerves and all the structures of the brain

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NOTE These effects are transient and stimulate the tissue within the limits of physiological function.

3.3.2
pathophysiological effects
stimulatory or inhibitory effects which lead to reversible or irreversible dysfunction of the affected structures of the organism

NOTE 1 These effects are of long duration and are produced by stimuli outside usual physiological magnitudes

NOTE 2 This group of effects includes keraunoparalysis which is a transient paralysis of the muscular structures in the line of the current. Its cause is uncertain.

3.3.3
thermal effect
pathophysiological effect of electrical current which results from local and transient heating of the affected structures up to temperatures where parts of cells and organelles become denatured

NOTE The effect of evaporation remains to be proved [17].

4 Physics of lightning

The explanation of the basic physical mechanisms for the onset and the dynamics of lightning is very complicated. Recent explanation takes into account that a tripolar layered cloud is generated by microscopic charge transfer between soft hail particles (also called graupel) and ice crystals [3].

Lightning is a transient, high-current discharge whose path length is measured in kilometres. Well over half of all flashes occur wholly within the cloud and are called intra-cloud (IC) discharges. Cloud-to-ground (CG) lightning has been studied more extensively than other forms of lightning because of its practical importance (for instance, as a cause for injuries and death, disturbances in power and communication systems and the ignition of forest fires) and because lightning below a cloud is more easily studied with optical techniques. Cloud-to-cloud and cloud-to-air discharges occur less frequently than either IC or CG lightning. All discharges other than CG are often combined under the general term "cloud discharges".

Four different types of discharges between cloud and earth have been identified (Figure 1). Negative CG flashes probably account for about 90 % of the CG discharges world-wide (Figure 1a), and less than 10 % of lightning discharges are initiated by a downward-moving positive leader (Figure 1c) [4]. Ground-to-cloud discharges are initiated by leaders that move upward from the earth (Figurse 1b et 1d). These upward-initiated flashes are relatively rare and usually occur from mountain peaks and tall man-made structures [3].

Other important physical parameters are the specific energy per stroke, the average steepness of current rise within a stroke, as well as the stroke duration and total flash duration where there is more than one stroke in a flash.

The mechanical effects are related to the peak value of the current and specific energy. The thermal effects are related to the specific energy when resistive coupling is involved and to the total charge or impulse charge when arcs develop. The highest peak values, specific energy and impulse energy occur in positive lightning strokes.

The inductive coupling is related to the steepness of the lightning current front. The highest value of this parameter occurs in subsequent negative strokes [5].

Thunder accompanies lightning and is generated by super-heated air at the channel, which causes air pressure waves.

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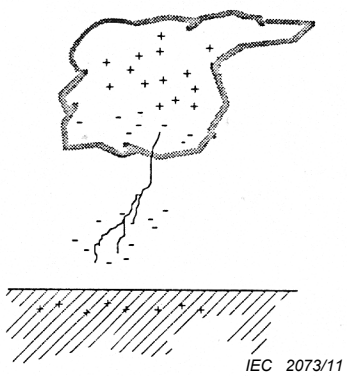

Figure 1a – Lightning begins with a negative charged leader moving downwards

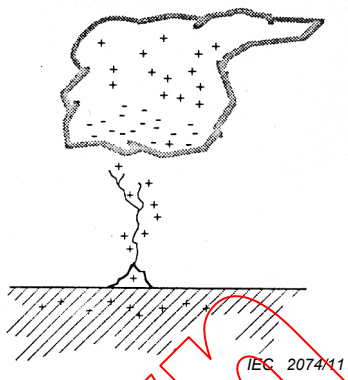

Figure 1b – Lightning has a positively charged leader, and hence this type effectively lowers negative charge to earth

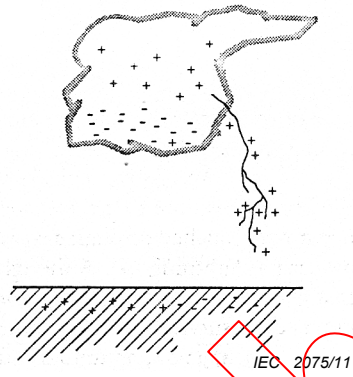

Figure 1c – Discharges are initiated by a downward moving positive leader

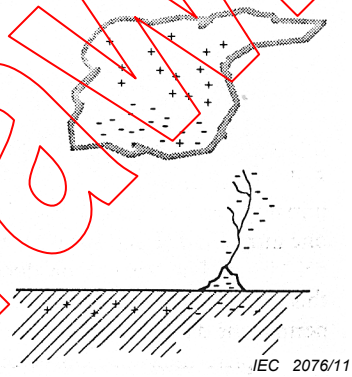

Figure 1d – The leader is charged negatively and effectively lowers positive charge (reprinted from [4])

Figure 1 – Categorization of lightning [4]

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5 Interaction of strokes with human beings and livestock

5.1 General

The possible interaction of lightning with human beings and livestock depends on the resulting time course and pathway of the current in the body and on its surface. As the temporal and spatial current distribution of strokes varies, so the effects on living organisms are different. The effects of magnetic fields derived from the lighting stroke upon a living organism are not thought to be significant [23].

5.2 Description of direct strike

When the tip of the downward stepped leader has reached a height of some tens of metres above ground level, the resulting field strength attains a critical value so that a short upward streamer can be initiated from a conductive object or victim. The flow of current of the whole discharge goes direct via the victim's body (Figure 2).

A description of direct lightning stroke interaction is given in 5.6.

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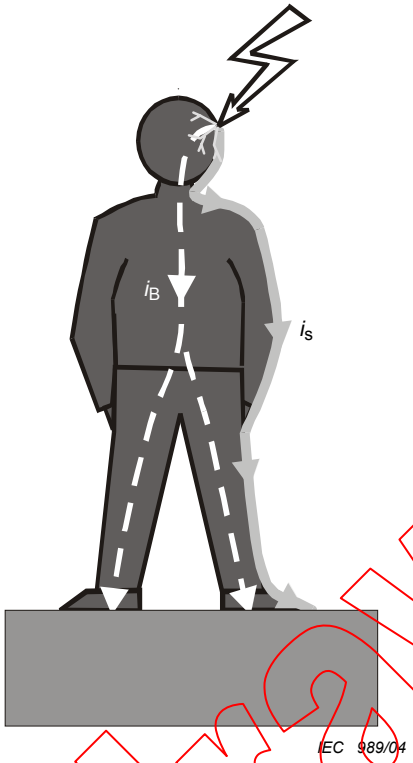

Key

i_B body current

i_s surface flashover current

Figure 2 – Direct stroke

5.3 Description of contact voltage

When an object, not necessarily metallic, is struck by lightning, points on its surface are raised in potential. When a person contacts one of these points and another, possibly earth, to complete a circuit, partial lightning current will flow through that person. This contact voltage is determined by a resistive and an inductive component [5] (Figure 3).

$$u = i_L R + L \mathrm{d}i_L/\mathrm{d}t$$

where

u is the resulting contact voltage;

i_L is the current through a vertical structure;

R is the resistance between the points of contact;

L is the inductance between the points of contact.

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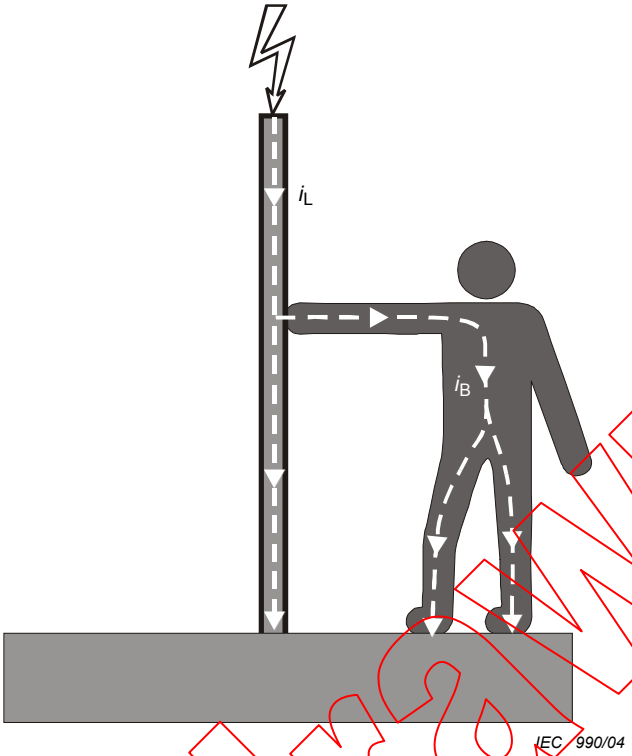

Key

i_L lightning current

i_B body current

Figure 3 – Contact voltage

5.4 Description of side flash

When a vertical structure conducts lightning current and a person is near, but not touching it, the potential builds up on the object in the same way as with contact voltage. The resulting potential difference may exceed the electrical breakdown strength of the gap between the object and a person standing nearby. Then a side flash occurs (Figure 4)

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