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Effects of current on human beings and livestock – Part 1: General aspects

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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International Standard IEC 60479-1 has been prepared by IEC technical committee 64: Electrical installations and protection against electric shock.

This first edition cancels and replaces IEC TS 60479-1:2005, Amendment 1:2016 and IEC TR 60479-3:1998. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to IEC TS 60479-1 and IEC TR 60479-3:

- The contents of IEC TR 60479-3 relating to aspects unique to the effects of current passing through the bodies of livestock have been incorporated into a new Annex H (normative).

It has the status of a basic safety publication in accordance with IEC Guide 104.

The text of this International Standard is based on the following documents:

CDV	Report on voting
64/2275/CDV	64/2343/RVC

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

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

A list of all parts in the IEC 60479 series, published 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 document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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- withdrawn,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

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

In order to avoid errors in the interpretation of this document, it should be emphasized that the data given herein is mainly based on experiments with animals as well as on information available from clinical observations. Only a few experiments with shock currents of short duration have been carried out on living human beings.

On the evidence available, mostly from animal research, the values are so conservative that this document applies to persons of normal physiological conditions including children, irrespective of age and weight.

There are, however, other aspects which should be taken into account, such as probability of faults, probability of contact with live or faulty parts, ratio between touch voltage and fault voltage, experience gained, technical feasibilities, and economics. These parameters should be considered carefully when establishing safety requirements, for example, operating characteristics of protective devices for electrical installations.

The form of the document, as has been adopted, summarizes results so far achieved which are being used by technical committee 64 as a basis for establishing requirements for protection against shock. These results are considered important enough to justify an IEC publication which may serve as a guide to other IEC committees and countries having need of such information.

This document applies to the threshold of ventricular fibrillation which is the main cause of deaths by electric current. The analysis of results of recent research work on cardiac physiology and on the fibrillation threshold, taken together, has made it possible to better appreciate the influence of the main physical parameters and, especially, of the duration of the current flow.

This document contains information about body impedance and body current thresholds for various physiological effects. This information can be combined to derive estimates of AC and DC touch voltage thresholds for certain body current pathways, contact moisture conditions, and skin contact areas.

This document refers specifically to the effects of electric current. When an assessment of the harmful effects of any event on human beings and livestock is being made, other non-electric phenomena, including falls, heat, fire, or others should be taken into account. These matters are beyond the scope of this document, but may be extremely serious in their own right.

Further experimental data are under consideration, such as recent ongoing experimental work on "current induced heart fibrillation by excitation with discrete Fourier spectra" which is intended to contribute to frequency factor data.

The characteristics of the impedance of the body of livestock and the effects of sinusoidal alternating currents are described in Annex H.

EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

Part 1: General aspects

1 Scope

This part of IEC 60479 provides basic guidance on the effects of shock current on human beings and livestock.

For a given current path through the human body, the danger to persons depends mainly on the magnitude and duration of the current flow. However, the time/current zones specified in the following clauses are, in many cases, not directly applicable in practice for designing measures of protection against electrical shock. The necessary criterion is the admissible limit of touch voltage (i.e. the product of the current through the body called touch current and the body impedance) as a function of time. The relationship between current and voltage is not linear because the impedance of the human body varies with the touch voltage, and data on this relationship is therefore required. The different parts of the human body (such as the skin, blood, muscles, other tissues and joints) present to the electric current a certain impedance composed of resistive and capacitive components.

The values of body impedance depend on a number of factors and, in particular, on current path, on touch voltage, duration of current flow, frequency, degree of moisture of the skin, surface area of contact, pressure exerted and temperature.

The impedance values indicated in this document result from a close examination of the experimental results available from measurements carried out principally on corpses and on some living persons.

Knowledge of the effects of alternating current is primarily based on the findings related to the effects of current at frequencies of 50 Hz or 60 Hz which are the most common in electrical installations. The values given are, however, deemed applicable over the frequency range from 15 Hz to 100 Hz, threshold values at the limits of this range being higher than those at 50 Hz or 60 Hz. Principally the risk of ventricular fibrillation is considered to be the main mechanism of death of fatal electrical accidents.

Accidents with direct current are much less frequent than would be expected from the number of DC applications, and fatal electrical accidents occur only under very unfavourable conditions, for example, in mines. This is partly due to the fact that with direct current, the let-go of parts gripped is less difficult and that for shock durations longer than the period of the cardiac cycle, the threshold of ventricular fibrillation is considerably higher than for alternating current.

This basic safety publication is primarily intended for use by technical committees in the preparation of standards in accordance with the principles laid down in IEC Guide 104 and ISO/IEC Guide 51. It is not intended for use by manufacturers or certification bodies.

One of the responsibilities of a technical committee is, wherever applicable, to make use of basic safety publications in the preparation of its publications. The requirements, test methods or test conditions of this basic safety publication will not apply unless specifically referred to or included in the relevant publications.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 Guide 104:2010, *The preparation of safety publications and the use of basic safety publications and group safety publications*

ISO/IEC Guide 51:2014, *Safety aspects – Guidelines for their inclusion in standards*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 General definitions

3.1.1
longitudinal current
current flowing lengthwise through the trunk of the human body such as from hand to feet

3.1.2
transverse current
current flowing across the trunk of the human body such as from hand to hand

3.1.3
internal impedance of the human body
Z_i
impedance between two electrodes in contact with two parts of the human body, neglecting skin impedances

Note 1 to entry: For the body of livestock, the impedance of the hooves, if any, are also neglected.

3.1.4
impedance of the skin
Z_s
impedance between an electrode on the skin and the conductive tissues underneath

3.1.5
total impedance of the human body
Z_T
vectorial sum of the internal impedance and the impedances of the skin

Note 1 to entry: For the body of livestock, Z_T is the vectorial sum of the internal impedance and the impedances of the hide, skin and hooves, if any (see Figure H.1).

SEE: Figure 1.

3.1.6
impedance of the hide and skin
Z_P
impedance between an electrode on the hide and/or skin and the conductive tissues underneath

3.1.7
impedance of the hoof
Z_h
impedance between an electrode under the hoof and the conductive tissues above it

3.1.8
initial resistance of the human body
R_0
resistance limiting the peak value of the current at the moment when the touch voltage occurs

Note 1 to entry: For the body of livestock the resistance of the hide, if any, is neglected, but the resistance of the hooves, if any, are included.

3.1.9
dry condition
condition of the skin of a surface area of contact with regard to humidity of a living person being at rest under normal indoor environmental conditions

3.1.10
water-wet condition
condition of the skin of a surface area of contact being exposed for 1 min to water of public water supplies (average resistivity ρ = 3 500 Ωcm, pH = 7 to 9)

3.1.11
saltwater-wet condition
condition of the skin of a surface area of contact being exposed for 1 min to a 3 % solution of NaCl in water (average resistivity ρ = 30 Ωcm, pH = 7 to 9)

Note 1 to entry: It is assumed that saltwater-wet condition simulates the condition of the skin of a sweating person or a person after immersion in seawater. Further investigations are necessary.

3.1.12
deviation factor
F_D
total body impedance Z_T for a given percentile rank of a population divided by the total body impedance Z_T for a percentile rank of 50 % of a population at a given touch voltage

$$F_D\left(X\%,\ U_T\right) = \frac{Z_T\left(X\%,\ U_T\right)}{Z_T\left(50\%,\ U_T\right)}$$

3.2 Effects of sinusoidal alternating current in the range 15 Hz to 100 Hz

3.2.1
threshold of perception
minimum value of touch current which causes any sensation for the person through which it is flowing

3.2.2
threshold of reaction
minimum value of touch current which causes involuntary muscular contraction

3.2.3
threshold of let-go
maximum value of touch current at which a person holding electrodes can let go of the electrodes

3.2.4
threshold of immobilization
minimum value of current through the body of the influenced human being or livestock (or part of the human body or livestock) which causes such muscular reaction that the person or livestock cannot move voluntarily, as long as the current flows

3.2.5
threshold of ventricular fibrillation
minimum value of touch current through the body of the human being or livestock which causes ventricular fibrillation

3.2.6
heart-current factor
F
factor which relates the electric field strength (current density) in the heart for a given current path to the electric field strength (current density) in the heart for a touch current of equal magnitude flowing from left hand to feet

Note 1 to entry: In the heart, the current density is proportional to the electric field strength.

3.2.7
vulnerable period
comparatively small part of the cardiac cycle during which the heart fibres are in an inhomogeneous state of excitability and ventricular fibrillation occurs if they are excited by an electric current of sufficient magnitude

Note 1 to entry: The vulnerable period corresponds to the first part of the T-wave in the electrocardiogram which is approximately 10 % of the cardiac cycle (see Figures 17 and 18).

3.3 Effects of direct current

3.3.1
total body resistance
R_T
sum of the internal resistance of the human body and the resistances of the skin

3.3.2
DC/AC equivalence factor
k
ratio of direct current to its equivalent RMS value of alternating current having the same probability of inducing ventricular fibrillation

Note 1 to entry: As an example for shock durations longer than the period of one cardiac cycle and 50 % probability for ventricular fibrillation, the equivalence factor for 10 s is approximately:

$$k = \frac{I_{\text{DC-fibrillation}}}{I_{\text{AC-fibrillation (RMS)}}} = \frac{300\ \text{mA}}{80\ \text{mA}} = 3{,}75 \quad \text{(see Figures 20 and 22).}$$

3.3.3
upward current
direct touch current through the human body for which the feet represent the positive polarity

3.3.4
downward current
direct touch current through the human body for which the feet represent the negative polarity

4 Electrical impedance of the human body and livestock

4.1 General

The values of body impedance depend on a number of factors and, in particular, on current path, on touch voltage, duration of current flow, frequency, degree of moisture of the skin, surface area of contact, pressure exerted and temperature.

A schematic diagram for the impedance of the human body is shown in Figure 1.

NOTE A modelling circuit for the human body is given in Annex G.

4.2 Internal impedance of the human body (Z_i)

The internal impedance of the human body can be considered as mostly resistive. Its value depends primarily on the current path and, to a lesser extent, on the surface area of contact.

NOTE 1 Measurements indicate that a small capacitive component exists (dashed lines in Figure 1).

Figure 2 shows the internal impedance of the human body for its different parts expressed as percentages of that related to the path hand to foot.

For current paths hand to hand or hand to feet, the impedances are mainly located in the limbs (arms and legs). If the impedance of the trunk of the body is neglected, a simplified circuit diagram can be established which is shown in Figure 3.

NOTE 2 In order to simplify the circuit diagram, it is assumed that the impedance of arms and legs have the same values.

4.3 Impedance of the skin (Z_S)

The impedance of the skin can be considered as a network of resistances and capacitances. Its structure is made up of a semi-insulating layer and small conductive elements (pores). The skin impedance falls when the current is increased. Sometimes current marks are observed (see 4.7).

The value of the impedance of the skin depends on voltage, frequency, duration of the current flow, surface area of contact, pressure of contact, the degree of moisture of the skin, temperature and type of skin.

For lower touch voltages the value of the impedance of the skin varies widely, even for one person, with surface area of contact and condition (dry, wet, perspiration), temperature, rapid respiration, etc. For higher touch voltages the skin impedance decreases considerably and becomes negligible when the skin breaks down.

As regards the influence of frequency, the impedance of the skin decreases when the frequency increases.

4.4 Total impedance of the human body (Z_T)

The total impedance of the human body consists of resistive and capacitive components.

For lower touch voltages, there are considerable variations in the impedance of the skin Z_S and the total impedance of the human body Z_T similarly varies widely. For higher touch voltages, the total impedance depends less and less on the impedance of the skin and its value approaches that of the internal impedance Z_i. See Figures 4 to 9.