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Effets du courant sur l'homme et les animaux domestiques –

Partie 1:
Aspects généraux

Effects of current on human beings and livestock –

Part 1:
General aspects

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

Part 1: General aspects

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international cooperation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of the IEC on technical matters, prepared by technical committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.
3) They have the form of recommendations for international use published in the form of standards, technical reports or guides and they are accepted by the National Committees in that sense.
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The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical report of one of the following types:

- type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;
- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

Technical reports of types 1 and 2 are subject to review within three years of publication to decide whether they can be transformed into International Standards. Technical reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

IEC 479-1, which is a technical report of type 2, has been prepared by IEC technical committee 64: Electrical installations of buildings.

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

Committee drafts	Reports on voting
64(CO)211 64(CO)234	64(CO)235 64(CO)241

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

This document is issued in the type 2 technical report series of publications (according to G.4.2.2 of part 1 of the IEC/ISO Directives) as a "prospective standard for provisional application" in the field of electrical installations in buildings (and the effects of current on human beings and livestock) because there is an urgent requirement for guidance on how standards in this field should be used to meet an identified need.

This document is not to be regarded as an "International Standard". It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the IEC Central Office.

A review of this type 2 technical report will be carried out not later than three years after its publication, with the options of either extension for a further three years or conversion to an International Standard or withdrawal.

This third edition cancels and replaces the second edition of IEC 479-1 published in 1984.

This technical report has the status of a basic safety publication in accordance with IEC Guide 104.

Annexes A, B, C and D form an integral part of this technical report.

Annex E is for information only.

INTRODUCTION

This Technical Report is intended to provide basic guidance on the effects of shock currents on human beings and livestock, for use in the establishment of electrical safety requirements.

In order to avoid errors in the interpretation of this report it is to 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 the report applies to persons under normal physiological conditions, including children irrespective of age and weight.

There are, however, other aspects to 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 have to be considered carefully when fixing safety requirements, for example, operating characteristics of protective devices for electrical installations.

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

The first edition of IEC 479 was issued in 1974 and was based on an extensive search in literature and on the evaluation of replies received to a questionnaire. However, since that date, new research work has been conducted on this subject. The study of this work and a more precise analysis of preceding publications have allowed a better understanding of the effects of electric current on living organisms and, in particular, on human beings and livestock.

This specifically applies to the limits of ventricular fibrillation which is the main cause of deaths by electric current, and the analysis of all 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.

Recent research work has also been conducted on the other physical accident parameters, especially the waveform and frequency of the current and the impedance of the human body. This revision of IEC 479 was therefore considered necessary and should be viewed as the logical development and evolution of the second edition.

EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

Part 1: General aspects

1 General

1.1 *Scope and object*

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 protection against electrical shock, the necessary criterion being the admissible limit of touch voltage (i.e. the product of the current through the body 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 these impedances depend on a number of factors and, in particular, on the current path, on the touch voltage, the duration of the current flow, the frequency, the degree of moisture of the skin, the surface area of contact, the pressure exerted and on the temperature.

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

Clause 3 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. It is considered principally the risk of ventricular fibrillation which is the main cause of fatal accidents in that range of frequencies.

Accidents with direct current are much less frequent than would be expected from the number of d.c. applications, and fatal 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 remains considerably higher than for alternating current.

The main differences between the effects of a.c. and d.c. on the human body result from the fact that excitatory actions of the current (stimulation of nerves and muscles, induction of cardiac atrial or ventricular fibrillation) are linked to the changes of the current magnitude especially when making and breaking the current. To produce the same excitatory effects the magnitude of direct current flow of constant strength is two to four times greater than that of alternating current.

1.2 *Normative reference*

The following normative document contains provisions which, through reference in this text, constitutes provisions of this Technical Report. At the time of publication, the edition indicated was valid. All normative documents are subject to revision, and parties to agreements based on this Technical Report are encouraged to investigate the possibility of applying the most recent editions of the normative document indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 479-2: 1987, *Effects of current passing through the human body – Part 2: Special aspects*

1.3 *Definitions*

For the purpose of this Technical Report the following definitions apply.

1.3.1 *Electrical impedance of the human body*

1.3.1.1 **internal impedance of the human body (Z_i):** Impedance between two electrodes in contact with two parts of the human body, neglecting skin impedances.

1.3.1.2 **impedance of the skin (Z_p):** Impedance between an electrode on the skin and the conductive tissues underneath.

1.3.1.3 **total impedance of the human body (Z_T):** Vectorial sum of the internal impedance and the impedance of the skin (see figure 1).

1.3.1.4 **initial resistance of the human body (R_o):** Resistance limiting the peak value of the current at the moment when the touch voltage occurs.

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

1.3.2.1 **threshold of perception:** Minimum value of current which causes any sensation for the person through which it is flowing.

1.3.2.2 **threshold of reaction:** Minimum value of current which causes involuntary muscular contraction.

1.3.2.3 **threshold of let-go:** Maximum value of current at which a person holding electrodes can let go of the electrodes.

1.3.2.4 **threshold of ventricular fibrillation:** Minimum value of current through the body which causes ventricular fibrillation.

1.3.2.5 **heart-current factor *F*:** 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 current of equal magnitude flowing from left hand to feet.

NOTE – In the heart, the current density is proportional to the electric field strength.

1.3.2.6 **vulnerable period:** Covers a 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 – 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 12 and 13).

1.3.3 *Effects of direct current*

1.3.3.1 **d.c./a.c. equivalence factor (*k*):** Ratio of direct current to its equivalent r.m.s. value of alternating current having the same probability of inducing ventricular fibrillation.

NOTE – As an example for shock durations longer than the period of one cardiac cycle and 50 % probability for ventricular fibrillation, the equivalence factor is approximately:

$$k = \frac{I_{\text{d.c.-fibrillation}}}{I_{\text{a.c.-fibrillation (r.m.s.)}}} = \frac{300\text{ mA}}{80\text{ mA}} = 3{,}75$$

1.3.3.2 **longitudinal current:** Current flowing lengthwise through the trunk of the human body such as from hand to feet.

1.3.3.3 **transverse current:** Current flowing crosswise through the trunk of the human body such as from hand to hand.

1.3.3.4 **upward current:** Direct current through the human body for which the feet represent the positive polarity.

1.3.3.5 **downward current:** Direct current through the human body for which the feet represent the negative polarity.

2 Electrical impedance of the human body

This clause indicates values for the electric impedance of the human body as a function of the touch voltage, the frequency, the degree of moisture of the skin, the current path, and the surface area of contact.

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

2.1 *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 the contact.

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

2.2 *Impedance of the skin* (Z_p)

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 2.5.4).

The value of the impedance of the skin depends on the 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 the skin.

For touch voltages up to approximately a.c. 50 V, the value of the impedance of the skin varies widely with surface area of contact, temperature, perspiration, rapid respiration, etc., even for one person.

For higher touch voltages over approximately 50 V, 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.

2.3 *Total impedance of the human body* (Z_T)

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

For touch voltages up to approximately 50 V, on account of considerable variations in the impedance of the skin Z_p, 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.

As regards the influence of frequency, taking into account the frequency dependence of the skin, the total impedance of the human body is higher for direct current and decreases when the frequency increases.

2.4 *Initial resistance of the human body* (R_o)

At the moment when the touch voltage occurs, capacitances in the human body are not charged. Therefore skin impedances Z_{p1} and Z_{p2} are negligible and the initial resistance R_o is approximately equal to the internal impedance of the human body Z_i (see figure 1). The initial resistance R_o depends mainly on the current path and to a lesser extent on the surface area of contact.

The initial resistance R_o limits the current peaks of short impulses (e.g. shocks from electric fence controllers).

2.5 *Values of the total impedance of the human body (Z_T)*

2.5.1 *Sinusoidal alternating current 50/60 Hz*

The values of the total body impedance given in table 1 are valid for living human beings and a current path hand to hand for large surface areas of contact (5 000 mm^2 to 10 000 mm^2) and dry conditions.

At voltages up to 50 V, values measured with contact areas wetted with fresh water, are 10 % to 25 % lower than in dry conditions and conductive solutions decrease the impedance considerably down to half of values measured in dry conditions.

At voltages higher than approximately 150 V, the total body impedance depends less and less on humidity and on the surface area of contact.

The measurements have been made on adults, males and females. They are described in annex A. The range of the total body impedance for touch voltages up to 5 000 V is presented in figure 4 and for touch voltages up to and including 220 V in figure 5 (dashed line).

The values of table 1 and figures 4 and 5 represent the best knowledge on the total body impedance for living adults. On the knowledge at present available the total body impedance for children is expected to be somewhat higher but of the same order of magnitude.

Table 1 – Total body impedance Z_T for a current path hand to hand a.c. 50/60 Hz, for large surface areas of contact

Touch voltage V	Values for the total body impedance (Ω) that are not exceeded for a percentage (percentile rank) of		
	5 % of the population	50 % of the population	95 % of the population
25	1 750	3 250	6 100
50	1 450	2 625	4 375
75	1 250	2 200	3 500
100	1 200	1 875	3 200
125	1 125	1 625	2 875
220	1 000	1 350	2 125
700	750	1 100	1 550
1 000	700	1 050	1 500
Asymptotic value	650	750	850

NOTE – Some measurements indicate that the total body impedance for the current path hand to foot is somewhat lower than for a current path hand to hand (10 % to 30 %).

2.5.2 *Sinusoidal alternating current with frequencies up to 20 kHz*

The values of the total body impedances for 50/60 Hz decrease at higher frequencies due to the influence of the capacitances of the skin and approach for frequencies above 5 kHz the internal body impedance Z_i.