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INTERNATIONAL STANDARD

BASIC SAFETY PUBLICATION

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

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

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EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

Part 1: General aspects

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.

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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

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- withdrawn,
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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.

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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.

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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.

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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

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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

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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.

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

4.5 Factors affecting initial resistance of the human body (R_0)

At the moment when the touch voltage occurs, capacitances in the human body are not charged. Therefore skin impedances Z_{S1} and Z_{S2} are negligible and the initial resistance R_0 is approximately equal to the internal impedance of the human body Z_i (see Figure 1). The initial resistance R_0 depends mainly on the current path and to a lesser extent on the surface area of contact.

The initial resistance R_0 limits the current peaks of short impulses (e.g. shocks from electric fence controllers).

4.6 Values of the total impedance of the human body (Z_T)

4.6.1 Total body impedance dependence for large, medium and small surface areas of contact

The dependence of the total body impedance Z_T for the 50th percentile of a population of living human beings for large, medium and small surface areas of contact (order of magnitude 10 000 mm^2, 1 000 mm^2 and 100 mm^2 respectively) in dry, water-wet and saltwater-wet conditions at touch voltages U_T = 25 V AC to 200 V AC is shown in Figures 7, 8 and 9.

4.6.2 Sinusoidal alternating current 50/60 Hz for large surface areas of contact

The values of the total body impedances in Tables 1, 2 and 3 are valid for living human beings and a current path hand to hand for large surface areas of contact (order of magnitude 10 000 mm^2) in dry (Table 1), water-wet (Table 2) and saltwater-wet (Table 3) conditions.

The range of the total body impedances for touch voltages up to 700 V for large surface areas of contact in dry, water-wet and saltwater-wet conditions for a percentile rank of 50 % of the population is presented in Figure 4.

The values for Tables 1, 2 and 3 represent the best knowledge on the total body impedances Z_T for living adults. On the knowledge at present available, the total body impedance Z_T for children is expected to be somewhat higher but of the same order of magnitude.

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Table 1 – Total body impedances Z_T for a current path hand to hand AC 50/60 Hz, for large surface areas of contact in dry conditions

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	1 750	3 250	6 100
50	1 375	2 500	4 600
75	1 125	2 000	3 600
100	990	1 725	3 125
125	900	1 550	2 675
150	850	1 400	2 350
175	825	1 325	2 175
200	800	1 275	2 050
225	775	1 225	1 900
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value = internal impedance	575	775	1 050

NOTE 1 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 %).

NOTE 2 For living persons the values of Z_T correspond to a duration of current flow of about 0,1 s. For longer durations Z_T values can decrease (about 10 % to 20 %) and after complete rupture of the skin Z_T approaches the internal body impedance Z_i.

NOTE 3 For the standard value of the voltage 230 V (network-system 3N ~ 230/400 V) it can be assumed that the values of the total body impedance are the same as for a touch voltage of 225 V.

NOTE 4 Values of Z_T are rounded to 25 Ω.

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Table 2 – Total body impedances Z_T for a current path hand to hand AC 50/60 Hz, for large surface areas of contact in water-wet conditions

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	**50 % of the population**	**95 % of the population**
25	1 175	2 175	4 100
50	1 100	2 000	3 675
75	1 025	1 825	3 275
100	975	1 675	2 950
125	900	1 550	2 675
150	850	1 400	2 350
175	825	1 325	2 175
200	800	1 275	2 050
225	775	1 225	1 900
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value = internal impedance	575	775	1 050

NOTE 1 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 %).

NOTE 2 For living persons the values of Z_T correspond to a duration of current flow of about 0,1 s. For longer durations Z_T values can decrease (about 10 % to 20 %) and after complete rupture of the skin Z_T approaches the internal body impedance Z_i.

NOTE 3 For the standard value of the voltage 230 V (network-system 3N ~ 230/400 V) it can be assumed that the values of the total body impedance are the same as for a touch voltage of 225 V.

NOTE 4 Values of Z_T are rounded to 25 Ω.

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Table 3 – Total body impedances Z_T for a current path hand to hand AC 50/60 Hz, for large surface areas of contact in saltwater-wet conditions

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	960	1 300	1 755
50	940	1 275	1 720
75	920	1 250	1 685
100	880	1 225	1 655
125	850	1 200	1 620
150	830	1 180	1 590
175	810	1 155	1 560
200	790	1 135	1 530
225	770	1 115	1 505
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value = internal impedance	575	775	1 050

NOTE 1 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 %).

NOTE 2 Due to low skin impedances in this case it can be assumed that Z_T depends little on the duration of current flow; Z_T approaches the internal body impedance Z_i.

NOTE 3 For the standard value of the voltage 230 V (network-system 3N ~ 230/400 V) it can be assumed that the values of the total body impedance are the same as for a touch voltage of 225 V.

NOTE 4 Values of Z_T are rounded to 5 Ω.

The values indicated in Tables 1 to 3 have been derived from measurements carried out on corpses and on living persons (adults, males and females) as described in Annex A.

At voltages higher than approximately 125 V for water-wet conditions and 400 V for saltwater-wet conditions the values for the total body impedance are the same as for dry conditions (see Figure 4).

4.6.3 Sinusoidal alternating current 50/60 Hz for medium and small surface areas of contact

The value of the internal body impedances Z_i and of the initial body resistance R_0 (see 4.6) depend only to a small extent on the surface areas of contact.

However, when the surface area of contact is very small, in the order of a few square millimetres, the values are increased.

After the skin has broken down (for touch voltages over approximately 100 V and after longer durations of current flow), the total body impedance Z_T approaches values of the internal body impedance Z_i and depends only to a small extent on the surface area of contact and its condition of dampness.

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The measurements of the dependence of the total body impedance Z_T on the surface area of contact for AC 50 Hz in dry, water-wet and saltwater-wet conditions which have been carried out on living persons at touch voltages of U_T = 25 V to 200 V are described in Annex A.

NOTE No data on Z_T for surface areas in water-wet and saltwater-wet conditions of persons or corpses is available for touch voltages above 200 V.

The dependence of the total body impedance Z_T for a current path hand to hand on the surface area of contact (from 1 mm^2 up to approximately 8 000 mm^2) in dry conditions for a touch voltage range of 25 V to 200 V, AC 50 Hz, measured on one person is shown in Figure 5. For touch voltages below 100 V and small surface areas of contact in the order of a few mm^2, deviations in the measurements can easily reach about +50 % of the average, depending on temperature, pressure, location within the palm of the hand, etc.

The dependence of the total body impedance Z_T between the tips of the right forefinger and the left forefinger (surface area of contact approximately 250 mm^2) on the touch voltage for AC 50/60 Hz for a voltage range from 25 V to 200 V is shown in Figure 6.

From Figure 6 one can calculate that the partial impedance of one forefinger at a touch voltage of 200 V is in the order of 1 000 Ω.

The measurements of the total body impedance Z_T shown in Figures 5 and 6 have been carried out on one living person only.

For a percentile rank of 5 %, 50 % and 95 % of a population of living human beings on the knowledge at present available, the following presentation is given for the total body impedance Z_T for large, medium and small surface areas of contact (order of magnitude 10 000 mm^2, 1 000 mm^2 and 100 mm^2 respectively) in dry, water-wet and saltwater-wet conditions:

- for large surface areas of contact, the values have been presented in Tables 1, 2 and 3 for dry, water-wet and saltwater-wet conditions for touch voltages U_T = 25 V to 1 000 V, AC 50/60 Hz;
- for medium surface areas of contact, the values are presented in Tables 4, 5 and 6 for dry, water-wet and saltwater-wet conditions for touch voltages U_T = 25 V to 200 V AC 50/60 Hz;
- for small surface areas of contact, the values are presented in Tables 7, 8 and 9 for dry, water-wet and saltwater-wet conditions for touch voltages U_T = 25 V to 200 V AC 50/60 Hz.

Table 4 –Total body impedances Z_T for a current path hand to hand for medium surface areas of contact in dry conditions at touch voltages U_T = 25 V to 200 V AC 50/60 Hz (values rounded to 25 Ω)

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	11 125	20 600	38 725
50	7 150	13 000	23 925
75	4 625	8 200	14 750
100	3 000	5 200	9 150
125	2 350	4 000	6 875
150	1 800	3 000	5 050
175	1 550	2 500	4 125
200	1 375	2 200	3 525

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Table 5 – Total body impedances Z_T for a current path hand to hand for medium surface areas of contact in water-wet conditions at touch voltages U_T = 25 V to 200 V AC 50/60 Hz (values rounded to 25 Ω)

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	5 050	9 350	17 575
50	4 100	7 450	13 700
75	3 400	6 000	10 800
100	2 800	4 850	8 525
125	2 350	4 000	6 875
150	1 800	3 000	5 050
175	1 550	2 500	4 125
200	1 375	2 200	3 525

Table 6 – Total body impedances Z_T for a current path hand to hand for medium surface areas of contact in saltwater-wet conditions at touch voltages U_T = 25 V to 200 V AC 50/60 Hz (values rounded to 5 Ω)

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	1 795	2 425	3 275
50	1 765	2 390	3 225
75	1 740	2 350	3 175
100	1 715	2 315	3 125
125	1 685	2 280	3 075
150	1 660	2 245	3 030
175	1 525	2 210	2 985
200	1 350	2 175	2 935

Table 7 – Total body impedances Z_T for a current path hand to hand for small surface areas of contact in dry conditions at touch voltages U_T = 25 V to 200 V AC 50/60 Hz (values rounded to 25 Ω)

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	91 250	169 000	317 725
50	74 800	136 000	250 250
75	42 550	74 000	133 200
100	23 000	40 000	70 400
125	12 875	22 000	37 850
150	7 200	12 000	20 225
175	4 000	6 500	10 725
200	3 500	5 400	8 650

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Table 8 – Total body impedances Z_T for a current path hand to hand for small surface areas of contact in water-wet conditions at touch voltages U_T = 25 V to 200 V AC 50/60 Hz (values rounded to 25 Ω)

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	39 700	73 500	138 175
50	29 800	54 200	99 725
75	22 600	40 000	72 000
100	17 250	30 000	52 800
125	12 875	22 000	37 850
150	7 200	12 000	20 225
175	4 000	6 500	10 725
200	3 500	5 400	8 650

Table 9 – Total body impedances Z_T for a current path hand to hand for small surface areas of contact in saltwater-wet conditions at touch voltages U_T = 25 V to 200 V AC 50/60 Hz (values rounded to 5 Ω)

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	5 400	7 300	9 855
50	5 105	6 900	9 315
75	4 845	6 550	8 840
100	4 590	6 200	8 370
125	4 330	5 850	7 900
150	4 000	5 550	7 490
175	3 700	5 250	7 085
200	3 400	5 000	6 750

4.6.4 Sinusoidal alternating current with frequencies up to 20 kHz and above

The values of the total body impedance 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.

The measurements of the total body impedance with frequencies up to 20 kHz at touch voltages of 10 V and 25 V are described in Annex B.

Figure 10 shows the frequency dependence of the total body impedance Z_T for a current path hand to hand and large surface areas of contact for a touch voltage of 10 V and frequencies from 25 Hz to 20 kHz.

Figure 11 shows the frequency dependence of the total body impedance Z_T for a current path hand to hand and large surface areas of contact for a touch voltage of 25 V and frequencies from 25 Hz to 2 kHz. From the results, curves have been derived giving the dependence of the total body impedance Z_T of a population for the 50th percentile rank for touch voltages from 10 V to 1 000 V and a frequency range from 50 Hz to 150 kHz for a current path hand to hand or hand to foot for large surface areas of contact in dry conditions. The curves are shown in Figure 12.

NOTE No measurements have been carried out in water-wet and saltwater-wet conditions.

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4.6.5 Direct current

The total body resistance R_T for direct current is higher than the total body impedance Z_T for alternating current for touch voltages up to approximately 200 V due to the blocking effect of the capacitances of the human skin.

The measurements of the total body impedance which have been carried out with direct current for large surface areas of contact in dry conditions are described in Annex C.

NOTE No measurements have been carried out in water-wet and saltwater-wet conditions.

The values for the total body resistance R_T for direct current determined in the way described in Annex C are presented in Table 10 (see Figure 13, continuous lines).

For large surface areas of contact in water-wet and saltwater-wet conditions the total body resistance R_T may be determined with sufficient accuracy from Tables 2 and 3, while neglecting small differences of Z_T between alternating current and direct current which may exist in the voltage range below 100 V. For all other cases, the tables for alternating current can be used for a conservative estimate.

Table 10 – Total body resistances R_T for a current path hand to hand, direct current, for large surface areas of contact in dry conditions

Touch voltage V	Values for the total body resistance R_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	2 100	3 875	7 275
50	1 600	2 900	5 325
75	1 275	2 275	4 100
100	1 100	1 900	3 350
125	975	1 675	2 875
150	875	1 475	2 475
175	825	1 350	2 225
200	800	1 275	2 050
225	775	1 225	1 900
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value	575	775	1 050

NOTE 1 Some measurements indicate that the total body resistance R_T for the current path hand to foot is somewhat lower than for a current path hand to hand (10 % to 30 %).

NOTE 2 For living persons, the values of R_T correspond to a duration of current flow of about 0,1 s. For longer durations R_T values can decrease (about 10 % to 20 %) and after complete rupture of the skin R_T approaches the initial body resistance R_O.

NOTE 3 Values of R_T are rounded to 25 Ω.

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