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TECHNICAL SPECIFICATION

colour inside

Industrial electroheating and electromagnetic processing equipment – Requirements on touch currents, voltages and electric fields from 1 kHz to 6 MHz

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CONTENTS

FOREWORD 5
INTRODUCTION 7
1 Scope 9
2 Normative references 9
3 Terms and definitions 9
4 Organization and use of this document 11
5 Prospective source voltage limits 12
6 Assessment of the source impedance 12
7 Touching and access considerations 13
7.1 General 13
7.2 Primary contact areas 13
7.3 Special protective gloves, footwear and clothing 13
7.4 External metallic objects and tools 14
7.5 Considerations for the secondary contact area assessment 14
8 Impedances of parts of the body, and touch current densities 14
8.1 General 14
8.2 The equivalent circuit of skin and parts of the body 15
8.3 Touch current density consideration for large contact areas 16
9 Capacitively coupled currents in the body due to an external electric field or insulated live part 16
9.1 General and measurement frequency 16
9.2 Determination of the capacitance 16
9.3 Assessment of the electric field and use of reference level data 17
9.4 Measurement methods and limiting values 17
9.4.1 Simplified measurement of the prospective current in the parts of the body 17
9.4.2 More accurate method for determination of currents in the parts of the body 17
9.4.3 Limiting touch current values 17
10 Electric shock – immediate nerve and muscle reactions 17
10.1 General 17
10.2 Touch current limits – immediate nerve and muscle reactions 17
11 Electric shock – local overheating and burns of parts of the body 18
11.1 General and initial thermal conditions 18
11.2 Awareness, perception and withdrawal 19
11.2.2 Heat sensing nerves exist only in the skin region, and thus not in the interior of for example fingers. Conditions where such interior heating occurs while the skin sensing is insufficient for perception are dealt with in 11.3. 19
11.2.3 The perception conditions for hazard calculations are skin temperature rises of at least 3 K over 5 s to 10 s and 5 K over 20 s or less. These times then include the time for withdrawal. The high alternative value 10 s applies if the touching part of the body is large and less easy to withdraw (i.e. the upper arm, leg or torso) than a hand or finger for which 5 s applies. 19
11.3 Long-term tissue overheating 19
12 Requirements and risk group classification 20
12.1 General 20

12.2 Conditions for the touch current limits up to 100 kHz 20
12.3 Requirements related to skin temperature rises and times of awareness, perception and withdrawal 21
12.3.1 Skin heat capacity considerations 21
12.3.2 Skin temperature considerations 21
12.4 Risk level categorisation as function of the prospective contact voltage 22
12.5 Additional protection: residual current protective devices (RCDs) 22
13 Non-sinusoidal touch currents 22
14 Warning marking and risk group classifications 23
Annex A (informative) Examples of calculations 24
A.1 General 24
A.2 Skin heating 24
A.3 Examples of tissue heating conditions 29
A.3.1 With 1 500 mm^2 fingerskin area, i.e. gripping 29
A.3.2 With the maximal fingerskin area 230 mm^2 29
Annex B (informative) Rationales, references and volunteer studies in the non-thermal case 31
B.1 Background and observations 31
B.2 Discussion of Figure B.1 31
B.3 A volunteer study at 11 kHz sinusoidal conditions 33
B.3.1 Experimental setup and data 33
B.3.2 Discussion and analysis of the experimental data 33
B.4 Contact/touch current data from standards and other published documents 34
B.5 Reference levels for the external electric field 35
B.6 Prospective touch voltage limits 35
B.7 Perception and pain in relation to risk levels 35
B.8 Remarks on the slope of the curves for frequencies higher than 10 kHz 36
B.9 Remarks on the touch current levels above 100 kHz in ICNIRP and IEEE specifications 36
Annex C (informative) Additional information and rationales – skin data and impedances of parts of the body 37
C.1 Skin anatomy 37
C.2 Comparative calculation procedure for wet skin impedances 38
C.3 Some data for dry skin 38
C.4 Frequency dependence of the body tissue electrical conductivities 39
C.5 Calculations for Table 1 39
Bibliography 41

Figure 1 – Complex impedances of various parts of the body, 1 kHz to 6 MHz 15
Figure 2 – Maximum allowed touch and touch currents, 1 kHz to 100 kHz, immediate nerve and muscle electric shock 18
Figure 3 – Warning markings 23
Figure B.1 – Maximum allowed touch and touch currents in various standards, 1 kHz to 100 kHz, immediate nerve and muscle electric shock 32
Figure B.2 – Setup for touch current and voltage measurements with index and middle fingers on 50 mm^2 flat conductors 33
Figure B.3 – Current measuring circuit for unweighed touch current, from IEC 60990:2016 35
Figure C.1 – Human skin anatomy (from Wikipedia) 37

Figure C.2 – Average electrical conductivities for homogeneous body modelling from 10 Hz to 10 MHz (from EN 50444:2008) 39

Table 1 – Maximally allowed skin power density per surface area, under various conditions of withdrawal 22
Table A.1 – Comparison of impedances of parts of the body, using the equivalent circuits in IEC 60990:2016 and in this document 25
Table A.2 – Moist skin, finger and overall heating rate at 50 V overall effective voltage, using equivalent circuits in IEC 60990:2016 and this document 25
Table A.3 – Wet skin, finger and overall heating rate at 50 V overall effective voltage, using this document, with halved skin impedances compared with Table A.2 26
Table A.4 – Effective contact voltage limits for the moist skin examples in Table A.2 27
Table A.5 – Effective contact voltage limits for the wet skin examples in Table A.3 28
Table C.1 – Comparison of complex impedances of moist and wet fingers 39

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INDUSTRIAL ELECTROHEATING AND ELECTROMAGNETIC PROCESSING EQUIPMENT – REQUIREMENTS ON TOUCH CURRENTS, VOLTAGES AND ELECTRIC FIELDS FROM 1 kHz TO 6 MHz

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62996, which is a technical specification, has been prepared by IEC technical committee 27: Industrial electroheating and electromagnetic processing.

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

Draft TS	Report on voting
27/1005/DTS	27/1010/RVDTS

Full information on the voting for the approval of this document 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.

In this document, the following print types are used:

- terms defined in Clause 3: in bold type.
- in Table A.4 and Table A.5, the resulting voltage limits are bolded, for clarity.

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

- transformed into an International standard,
- reconfirmed,
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INTRODUCTION

Touch and touch currents and voltages constitute a very important category of electrical safety issues particularly for electroheating (EH) equipment and equipment for electromagnetic processing of materials (EPM). The equipment manufacturer is mandated to adequately reduce any hazard from touching live equipment parts. For being able to do so, assessments and verifications are necessary for determination of hazards.

During the drafting of IEC 60519-1:2015, it became apparent that there was a need for a technical specification providing an overview, a guidance and requirements for users of that standard, and dealing with the nearest higher frequency interval above that of IEC 61140 and IEC 60204 (all parts). A revised IEC 61140:2016 covers issues up to 1 kHz (up to 200 Hz in earlier editions). Thus, this document deals with touch and touch currents and voltages in the frequency range from 1 kHz to 6 MHz. This range was adopted due to deviating frequency dependence of skin impedances below 1 kHz.

In principle, cases with strong external electric fields where the person is not touching the live insulated or bare live conductor are closely related to cases where the person is actually touching an insulated live conductor. These cases of currents in parts of the body by capacitive coupling are therefore included in this document.

NOTE A parallel IEC technical specification IEC TS 62997:2017 is developed by TC 27, dealing with the magnetic nearfields from 1 Hz to 6 MHz.

The upper frequency limit 6 MHz is chosen due to

– higher frequencies not being expected in internal frequency converters for DC voltage transformation in equipment,
– the free space wavelength of 6 MHz being 50 m, which results in wave phenomena that essentially not exist with or at objects with less than 10 % spatial dimensions of this,
– the fact that the power penetration depth limitation by the equivalent complex permittivity of body tissues has not yet set in at 6 MHz, so currents can be considered to be the same across the two touch areas and their patterns are as with low frequencies, and
– industrial processing frequencies below this limit are typically low impedance; higher impedance dielectric heating has its lowest ISM frequency at 6,8 MHz and is dealt with in IEC 60519-9.

Separation of electric shock (by a current between two parts of the body, creating an internal electric field by the tissue impedance) and induced electric shock (by an internally induced electric field caused by an external alternating magnetic field) is generally possible in the frequency interval considered in this document, since the latter requires a very high current in the conductor generating the magnetic field and conductor resistive losses are low by design. However, touching of such a conductor can occur and both mechanisms will then have to be assessed.

Impedance considerations for skin and other parts of the body are usually not included in sufficient detail in most existing standards, technical specifications and guidelines. With the exception of IEC 60601 (all parts) for medical equipment, no IEC standards provide reasonably complete touch current and voltage specifications. Equivalent test circuits tend to be too general and in some instances even contradictory to established literature data. This specification includes references to relevant IEC, IEEE, ICNIRP, EN and scientific literature data. Additional inputs are from numerical calculations with model situations, and volunteer studies.

Local overheating of particularly skin regions can be the dominating hazard at frequencies higher than some tens of kilohertz. Hazard limits are then to be based on skin impedances, thermal properties and touch as well as current path cross section area considerations. In addition, awareness, perception and withdrawal considerations become crucial. All these factors are dealt with in this document, in a more detailed way than in any other IEC publication.

Even if the scope of IEC TC 27 is limited to industrial electroheating and electromagnetic processing of materials, this document can fill an important gap, with its generally applicable and detailed specifications for higher frequencies than alternating current. It is therefore expected to be of more general use. It should, however, be observed that in particular skin impedances behave non-linearly for frequencies below about 1 kHz.

INDUSTRIAL ELECTROHEATING AND ELECTROMAGNETIC PROCESSING EQUIPMENT – REQUIREMENTS ON TOUCH CURRENTS, VOLTAGES AND ELECTRIC FIELDS FROM 1 kHz TO 6 MHz

1 Scope

This document addresses the safety assessments in the frequency range between 1 kHz and 6 MHz and provides limits for touch and touch currents for industrial installations or equipment for electroheating (EH) and electromagnetic processing of materials (EPM). Indirect contact by capacitive currents to parts of an earthed human body in an open space are also included, since the current is then distributed analogously in the part of the body and differs from cases of induced electric shock.

NOTE 1 Induced electric shock phenomena are caused by the alternating magnetic field external to a current-carrying conductor, inducing an electric field in a part of the body in the vicinity of or directly contacting it. The causes are thus different from those causing electric shock phenomena and are dealt with in IEC TS 62997 on magnetic nearfield safety, developed by TC 27.

The overall safety requirements for the various types of EH or EPM equipment and installations in general result from the joint application of the general requirements specified in IEC 60519-1:2015 and related particular requirements covering specific types of installations or equipment. This document complements IEC 60519-1:2015.

NOTE 2 This document complements Annex B in IEC 60519-1:2015.

On contacting, this document is based primarily on a movement of the primary contact area in relation to the live part, resulting in a contact or **touch current**. The awareness, perception and reaction times differ in comparison with a situation where a person is, for example, leaning towards or holding a conductor which subsequently becomes live, or a similar fault condition. Different considerations are then applicable and are dealt with in a detailed way in this document.

Since high impedances for dry skin will result in the lowest **touch current** and the dryness is typically variable, data for only moist and wet skin are used in this document.

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 60417, *Graphical symbols for use on equipment* (available at http://www.graphical-symbols.info/equipment)

IEC 60519-1:2015, *Safety in installations for electroheating and electromagnetic processing – Part 1: General requirements*

3 Terms and definitions

For the purposes of this document the terms and definitions given in IEC 60519-1:2015 and the following 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.

NOTE General definitions are given in IEC 60050, the International Electrotechnical Vocabulary. Terms relating to industrial electroheating are defined in IEC 60050-841.

3.1
aversion
experience that is disliked but can be accepted for a short time before voluntary withdrawal

Note 1 to entry: Reactions to aversive stimuli are consciously controlled, as opposed to reactions to pain which can normally not.

Note 2 to entry: The strength of an internal electric field causing muscle or nerve pain is typically twice the strength of a field causing **aversion**.

3.2
awareness
mental preparedness regarding an unpleasant experience if an object is touched, or that it can become live while being held

Note 1 to entry: Lack of **awareness** will typically delay the action of withdrawal.

3.3
electric shock
pathophysiological effect resulting from an electric current passing through a human or animal body

Note 1 to entry: The effects in the frequency range below 100 kHz are essentially immediate, as muscle and nerve reactions. In the higher frequency range, these have vanished and time-dependent local overheating can occur.

Note 2 to entry: The definition requires two contact areas, or an area of the body near a voltage source and a contact area at another potential, between which the current flows. No induced currents are supposed to be created, as with induced electric shock dealt with in IEC TS 62997.

[SOURCE IEC 60050-195:1998, 195-01-04, modified – The notes have been added.]

3.4
pain
unpleasant experience such that it is not readily accepted a second time by the subject submitted to it

EXAMPLE A capacitor discharge corresponding to 50 to 100 × 10^{-6} A^2s between gripping hands, the sting of a bee, the burn of a cigarette.

Note 1 to entry: Agents at the **pain** level cause harm as defined in for example IEC 60050-903:2013, 903-01-01.

Note 2 to entry: The examples are objective statements for standardisation purposes. Subjective experiences vary.

[SOURCE: IEC TS 60479-2:2017, 3.13, modified – The example has been rephrased, and the notes have been added.]

3.5
primary capacitive current area
accessible but insulated live conductive 100 mm × 200 mm area, or the smaller area if the accessible area is smaller

3.6
primary contact area
live part which is advertently or inadvertently touched by a part of the body closing the **touch current** circuit

3.7
prospective primary capacitive current area
part of the body in its most onerous position facing the live source

3.8
prospective touch voltage
open circuit voltage between the prospective **primary contact area** and the secondary contact area

Note 1 to entry: The effective touch voltage that is between the two parts of the body, with the active **touch current**.

Note 2 to entry: The definition differs from 195-05-09 of IEC 60050-195:1998 by the introduction of more general contact area definitions (in 3.5, 3.6 and 3.10).

3.9
reference levels
RL
directly measurable quantities, derived from basic restrictions and provided for practical exposure assessment purposes

Note 1 to entry: The meaning of the term differs between some standards and guidelines, with regard to the considerations of safety factors.

Note 2 to entry: **Reference levels** are as such not referring to any levels of immediate nerve and muscle reactions, or sensations of any gradual heating of the tissue.

Note 3 to entry: Another term, used by IEEE and EU, is action level (AL).

3.10
secondary contact area
live part or ground, with or without protective insulation, through which the current flows when the **primary contact area** is being contacted or touched, or through the **prospective primary capacitive current area**

3.11
touch current
electric current passing between the **primary contact area** or **prospective primary capacitive current area**, and the **secondary contact area**

4 Organization and use of this document

It is recommended that this document be studied in the listed order below. The order of use then depends on what is deemed to be critical. However, this document is very detailed and there are many cross-references. They are important for determining the most significant hazard condition. In particular, Annex A with its Table A.4 and Table A.5 is helpful in this respect.

a) Clause 10 presents the basic **touch current** limitations as function of frequency up to 100 kHz, i.e. the non-thermal case of possible muscle and nerve reactions, with consideration of various situations where a **touch current** can occur. The three current level categories are shown in Figure 2. Further requirements including risk levels are given in 12.2 and Clause 14.

b) Hazardous heating of bodyparts including skin burns are possible, in particular at frequencies higher than 100 kHz where painful muscle and nerve reaction no longer occur. The basic requirements are in Clause 11. Thermal data and further requirements including risk levels are given in 12.3, with Table 1 being helpful. Clause 14 deals with risk levels and warning marking.

c) There are also source voltage limits for **touch currents**, for avoiding initiation of arcing effects upon touching. These are specified in Clause 5, with some important comments in Clause B.6.

d) The kinds of contact such as by a fingertip, gripping, and through protective means are crucial for the determination of the **touch current** and skin heating. Standardizing specifications of contacting geometries are given in Clause 7.

e) It is necessary to be able to assess and calculate the relevant bodypart and skin impedances for obtaining the possible **touch currents** and skin heating. These impedances are given in Clause 8, with its Figure 1. Both the moist skin (normal) and wet skin conditions are dealt with.

f) There is furthermore a need to know additional external impedances in the overall source circuit. The source internal impedance is dealt with in Clause 6, and capacitive impedances by insulating protection, gloves, etc. are dealt with in Clause 9.

g) Clause 9 also deals with capacitively coupled bodycurrents caused by the electric field from an inaccessible source.

Clause 13 is applicable in case of source voltage harmonics. Annex A contains a number of examples illustrating the different hazard-related criteria. Annex B provides rationales, references and volunteer studies in the non-thermal case, and Annex C provides additional informative material on skin anatomy, impedances for wet, moist and dry skin, and body impedances.

5 Prospective source voltage limits

NOTE 1 The limits set out in Clause 5 apply in addition to those in Clauses 10 and 11.

NOTE 2 Rationales are given in Annex B, which also provides details and data from the references which are used in this document.

Between the frequencies f = 1 kHz and 100 kHz, the peak source voltage U is reduced from 400 V peak to 200 V peak, by the formula $U = 400 \times f^{-0,15}$, with f in kHz. It is 140 V RMS between 100 kHz and 6 MHz.

This applies also for insulated live parts dealt with in 9.2, which specifies the measurement method.

A higher voltage is allowed if it can be shown for the specific situation via measurements that a higher **prospective touch voltage** can be tolerated without arcing.

NOTE 3 The formula for the voltage between 1 kHz and 100 kHz is linear in a log-log scale.

6 Assessment of the source impedance

Source impedances are in series with the other impedances addressed in Clauses 7, 8 and 9. If they are known beforehand to be insignificant for the assessments, no measurements are needed.

NOTE An overall source impedance less than approximately 25 Ω is typically considered to be insignificant.

For source impedances exceeding 25 Ω, voltage measurements across applied test resistors and capacitors are made in turn, in addition to the **prospective touch voltage** measurement, for determination of the equivalent series source complex impedance.

Any contact area insulation addressed in 9.2 is not a part of the source impedance. It is instead included as a series capacitance to the touch area.

7 Touching and access considerations

7.1 General

The primary area is the **primary contact area** or the **primary capacitive current area**. The **secondary contact area** is chosen to be a large and onerously but not unlikely located skin area of the nearest part of the body to the **primary contact area**.

The **touch current** will increase with increasing **primary contact area**, and the immediate nerve and muscle reactions dealt with in Clause 10 are a first limiting factor. The impedance of small skin areas can, however, result in too strong heating of these for lower **touch currents**, dealt with in Clause 11.

NOTE Examples of calculations are given in Annex A.

7.2 Primary contact areas

7.2.1 Unless limited by the requirements in 7.2.2 to 7.2.7, the most onerous accessible area shall be used in the calculations.

7.2.2 The impedances of parts of the body in Figure 1 are applicable to a smallest contact area of 3,1 mm^2, equivalent to a 2 mm diameter flat conductor contact area.

NOTE Smaller skin contact area impedances for flat areas, circularly cylindrical conductors, and hemispherical conductor tips are under consideration.

7.2.3 If the live conductor area is possible to grip by the hand and has a larger diameter than 10 mm and length than 100 mm, the gripping contact area is set to 1 500 mm^2. If the length or diameter is smaller, single or parallel finger contact areas are instead calculated as in 7.2.5 for diameters up to 12 mm, and as actual minimum contacting areas of the finger skin on the gripping side for still larger diameters or if flat. The internal finger impedance is then set to 0.

7.2.4 A fingertip contact area to a flat object with all diametric dimensions exceeding 8 mm is set to 8 mm in diameter, i.e. a 50 mm^2 contact area, unless the contacting finger papillary surface is possible to easily position in parallel to a larger live conductor surface area. The 50 mm^2 limit is also applicable to circularly cylindrical conductors and hemispherical tips with diameters larger than 12 mm and 10,5 mm, respectively.

7.2.5 If the **primary contact area** is smaller than 50 mm^2, the actual contact area is employed, with the limitations in 7.2.2 and 7.2.7.

7.2.6 If the contact area is larger than 50 mm^2 and fulfils the particular criterion in 7.2.4, the fingertip area is set up to a maximum of 230 mm^2.

NOTE This elliptical area with axes 20 mm and 15 mm represent the onerous case where a potentially hazardous internal finger heating is possible while no fingertop skin heating is perceived. The finger power density criterion in 12.3.2 is then applicable. Also see A.3.2.

7.2.7 For finger or fingertip contact to circularly cylindrical conductors with diameters between 12 mm and 2 mm, 90° contact angle over 10 mm length is applied, resulting in 15 mm^2 contact area in the latter case. 90° contact angle is also used for hemispherical conductor tip diameters between 10,5 mm and 2,6 mm, resulting in 50 mm^2 and 3,1 mm^2 contact area, respectively.

7.3 Special protective gloves, footwear and clothing

In cases where wearing of special protective gloves or clothing are specified or required by the manufacturer or user, the **primary capacitive current area** shall be used in the measurements and calculations of the series impedance for the **touch current**.

NOTE 1 Such gloves or clothing are usually only applicable if their use does not in any way hamper the actions of manual operation, and the **primary contact area** can be completely covered by the gloves or clothing.

NOTE 2 Additional non-electrical safety requirements apply to gloves and clothing.

In the case that wearing of special protective footwear is specified or required by the manufacturer or user in areas of secondary contact, the capacitance calculated as for the **primary capacitive current area**, unless ascertained by particular measures, shall be used in the measurements and calculations of the series impedance for the **touch current**. The wetting is by 0,9 % saline solution.

NOTE 3 Such footwear is usually applicable only if the **secondary contact area** can be reached with the feet while another part of the body is contacting the **primary contact area**, and all other areas than the primary and **secondary contact areas** are either inaccessible or insulated such that the application of 7.4 and 7.5 does not result in a more onerous situation.

The capacitance or complex impedance shall be measured according to 9.2.

7.4 External metallic objects and tools

Metallic objects and tools can become part of a more onerous **touch current** path than any direct bodypart contact, and shall be considered unless clearly forbidden in user instructions and by warning signs.

NOTE A gripped metal object such as a tool contacting a live **primary contact area** will reduce the skin impedance, since the **primary contact area** of the skin specified in 7.2 becomes larger so that the **touch current** increases.

7.5 Considerations for the secondary contact area assessment

The **secondary contact area** is typically not a hand or a finger, except if the corresponding earthed or live object can be gripped by a hand or is likely to be used as support for maintaining the body posture or balance, or is a tool or a part of the equipment intended to be held in operation.

Cases where it is possible that the **touch current** path is between a hand or a finger, and a finger on the same hand, shall be investigated as an additional case to any other in this 7.5. The hand tissue impedance is then set to zero.

NOTE Different source impedances then typically apply when the source circuit has a galvanic separation from earth.

Secondary contact areas being an arm, leg or the torso are considered to be naked and providing the same skin contact impedance as a naked moistened bodypart as specified in 8.2, unless special clothing as specified in 7.3 is applicable.

If the **secondary contact area** is a conductor which is in practise reached by only the feet when the **primary contact area** is contacted:

– either zero skin impedance shall be considered, or
– special protective footwear be provided and applies, with the restrictions in 7.3.

8 Impedances of parts of the body, and touch current densities

8.1 General

The overall **touch current** path consists of not only the body between the primary and **secondary contact areas**, but also any protective or capacitive objects such as that of gloves or footwear (see 7.3), tools (see 7.4) and other live part insulation as well as the source impedance (see Clause 6). Due to the impedance variations with frequency and differences in primary and **secondary contact areas**, onerous but relevant impedances of the current path shall be used in the calculations of **touch currents**. More than one case is possible; see 7.5.

8.2 The equivalent circuit of skin and parts of the body

Figure 1 shows the overall equivalent reference circuit of moistened skin and parts of the body in the range 1 kHz to 6 MHz, to be used for calculations of **touch currents** and possible tissue overheating, including that of the skin. Modifications for wet skin conditions are made by the skin resistance R_s and the spread resistance R_t being halved and the skin capacitance C_s in Figure 1 being doubled; this is applied for humid environments at temperatures above normal ambient, or when workloads or parts of the processing equipment are wet or can easily become wetted in normal operation.

The reference moistening data are specified with rubbing the (finger) skin on a cloth moistened (not soaked) with a 0,9 % saline solution, and then quickly putting it on a metallic test conductor which is subsequently energised.

NOTE 1 The actual fingerskin impedance is higher in many practical situations such as dry environments and by fingerskin calluses. How to allow for this is not dealt with in this document, but some dry skin data are given in Clause C.3.

The skin impedance and spread resistance are used whenever there is a skin contact to a live conductor, except bare feet as dealt with in 7.5. It is set to zero where the contact areas are to insulated conductors larger than 200 cm^2, for which instead only the insulation impedance is employed. For smaller insulated conductors, the relevant insulator and skin impedances are added.

In cases where the **touch current** path is between a hand or finger and the arm, the whole arm tissue impedance is set to two thirds of that for the sum of arm, torso and leg in Figure 1.

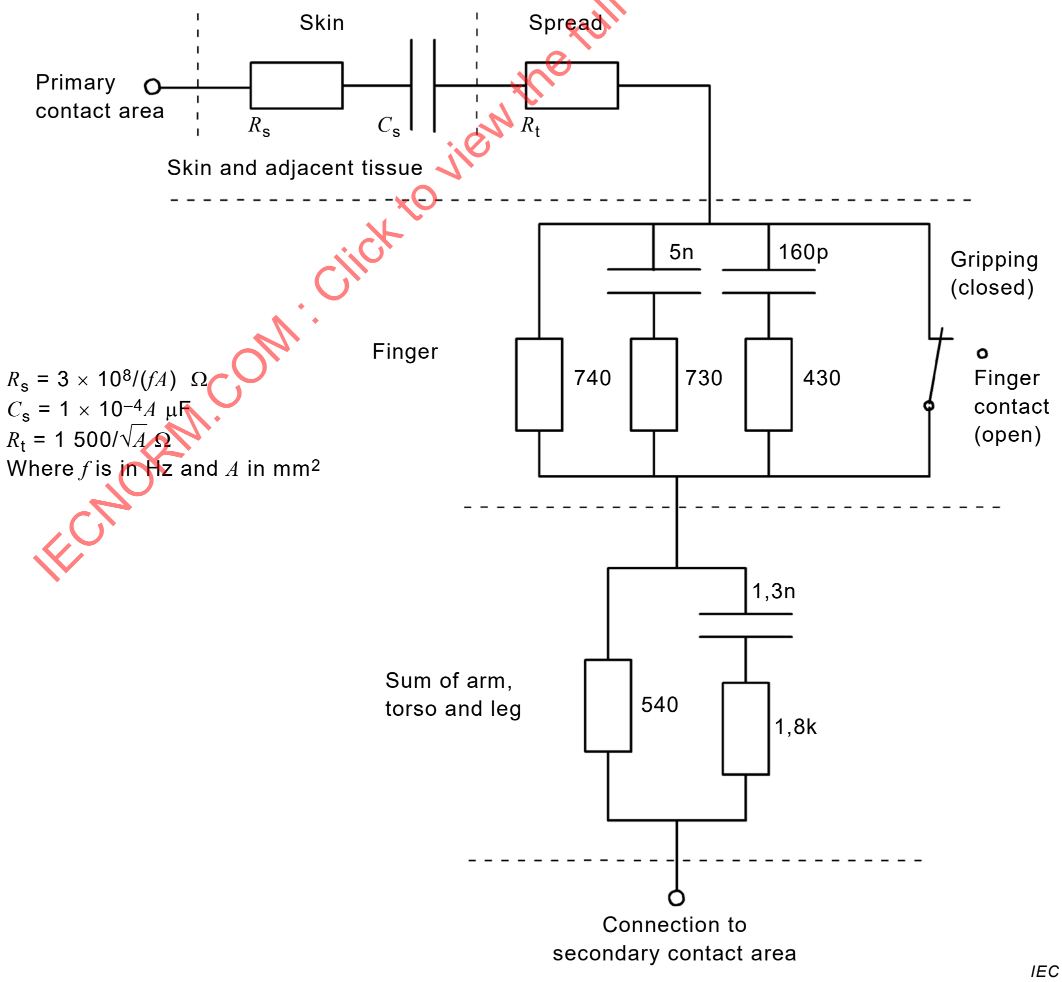

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Figure 1 – Complex impedances of various parts of the body, 1 kHz to 6 MHz

NOTE 2 The circuit is with minor modifications due to the upper frequency limit 6 MHz. It is for moistened skin. The variations of R_s and C_s with the extent of moistening are addressed in 8.2.

NOTE 3 The circuit differs significantly from those in IEC 60990:2016 and Annex A of IEC 61010-1:2010, in particular their Figures 3 and A.3, respectively. Those are stated for burns but do not consider skin impedances, and the frequency interval of applicability is not defined. Those standards are discussed in Annex B.

NOTE 4 Examples of calculations are in Annex A and further information on impedance data are in Annex C.

NOTE 5 The circuit diagram is used for calculations with inserted values of the area A and data obtained by 7.3. and 7.5, preferably with a small computer program.

8.3 Touch current density consideration for large contact areas

In many cases, the extent of the **primary contact area** is quite large. Such cases are gripping and where both contact areas are feet. A relaxation of the **touch current** limits is made in 10.2 due to the resulting reduced current density and by that reduced electric field strength for these cases. Data are shown in Figure 2.

9 Capacitively coupled currents in the body due to an external electric field or insulated live part

9.1 General and measurement frequency

The measurements are intended for only cases where one terminal of the source is earthed. 9.2. is applicable when contacting an insulating object covering the live part exists. 9.3 or 9.4 are applied in cases where there is a distance in air between the bodypart and the field source. Three methods for assessments and measurements are then specified for obtaining the current, in typically the whole upright body in an external electric field, typically with the field source above. The first method is simplistic and intended for verification of a clearly non-hazardous situation. It uses the live conductor voltage to earth. The second and third methods employ measurements using a metal foil substitute of the **prospective primary capacitive current area**.

The person is located in the most onerous position in relation to an adjacent but inaccessible electric field source.

The measurement frequency is the actual operating frequency, or such that a sufficiently accurate current is measured.

NOTE Clause 6 will be considered if the source impedance is significant.

9.2 Determination of the capacitance

A thin metal foil according to the definition in 3.5 is used to fit the insulated live area or any smaller area resulting in the highest current when connected to the nearest accessible earthed metal via a thin wire connected in its central region. The current is measured as in 9.4.1.

In cases where the design of the equipment and installation is such that no earthed metal can be accessed by any part of the body while another is contacting the **prospective primary capacitive current area**, a second thin metal foil with maximum dimensions as specified in 3.5 and with the wire length of maximally 2,5 m shall be used to find the position resulting in the highest current.

The insulation of the insulated areas being chosen for the tests shall have adequate mechanical and electrical properties and not be exposed to wear.

NOTE Clause 5 also applies.

9.3 Assessment of the electric field and use of reference level data

The live conductor working voltage to earth is divided with the shortest distance between it and the nearest earthed part of the body in an accessible location, to obtain the averaged electric field strength. The whole body is considered to be at earth potential. The resulting field strength value is then compared with the reference level value from a relevant standard.

NOTE Reference level values are given in Clause B.5.

9.4 Measurement methods and limiting values

9.4.1 Simplified measurement of the prospective current in the parts of the body

The prospective current is measured as the voltage across a 500 Ω resistor having one terminal at earth voltage. The part of the body in its most onerous position (i.e. closest to the live conductor but away from other conductive parts/components) is used, with the **prospective primary capacitive current area** being replaced by a thin metal foil of corresponding geometry to the nearest bodypart. The foil is facing the live conductor and has a thin wire contacting the rim in its location closest to earth. The other end of the wire is contacting the resistor. Shields and barriers are in place. The current is measured with a current probe near the earthed end of the resistor.

9.4.2 More accurate method for determination of currents in the parts of the body

Instead of a 500 Ω resistor, a network with zero skin impedance is used. The combination and posture of the parts of the body in their most onerous positions is used, with the torso, head (its impedance set to zero), arm, hand or finger, or combination of these, replaced by one or several metal foils of corresponding geometry and with the respective part of the network between them. The network ends with a thin wire connected to earth, at which the current is measured with a current probe. The number and directions of the metal foils in relation to the live conductor are those which result in the highest current. All other specifications are as in 9.4.1.

9.4.3 Limiting touch current values

The limits for perception of **touch currents** up to 100 kHz are applied. The 100 kHz value 50 mA applies for frequencies higher than 100 kHz, unless it is shown that 11.3 is applicable.

NOTE 1 It is assumed that no immediate nerve or muscle reaction perception occurs for frequencies higher than 100 kHz, so no withdrawal takes place due to the current as such. Furthermore, which bodyparts will carry the highest current density is left unspecified.

NOTE 2 Clause 14 provides information on an additional current limit under the conditions in 9.2 for an insulated live part and on risk groups, and Clause B.9 on some rationales.

10 Electric shock – immediate nerve and muscle reactions

10.1 General

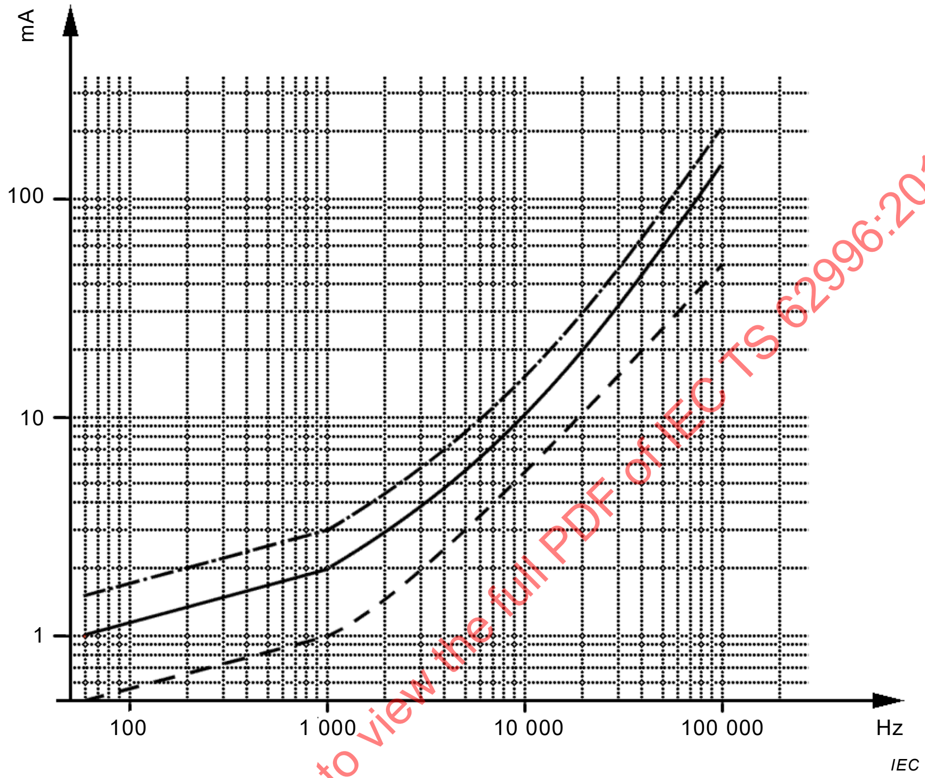
Clause 10 deals with only the immediate and direct nerve and muscle reactions caused by the internal electric field intensity as such, resulting from a current path between two defined separate parts of the body. Descriptions of the phenomena are given in Clause A.1, and examples of calculations using the numerical data in Clause 10 are given in Clauses A.2 and A.3.

10.2 Touch current limits – immediate nerve and muscle reactions

Additional requirements and descriptions are given in Clause 12. Rationales for the **touch current** limits are given in Annex B.

The following formulas are applicable and the resulting graphs are shown in Figure 2. With f being the frequency in Hz and the stationary RMS **touch current** in mA:

– for inadvertent touching at the **aversion** level: $I_{\text{inadv}} = -80{,}1 + 81{,}3\exp(f / 96\ 100)$;
– for gripping or between the feet: $I_{\text{gripp}} = 1{,}5 \times I_{\text{inadv}}$;
– inadvertent touching in critical environments possibly causing **aversion**, and approximate perception level in normal environments: $I_{\text{percep}} = 0{,}49 + f \times 4{,}95 \cdot 10^{-4}$.



Key

—— (full line): I_{inadv}; inadvertent touching causing **aversion**, occupational

– – – (dashes): I_{percep}; corresponds to approximate perception level in normal environments

—·—· (dots/dashes): $I_{\text{gripp}} = 1{,}5 \times I_{\text{inadv}}$; gripping or between the feet, occupational.

NOTE 1 The graphs are projected between 60 Hz and 1 kHz, for showing the connection to mains AC requirements in other standards and similar.

NOTE 2 No specifications are provided above 100 kHz, since local overheating (burns) are assumed to then be the determining **electric shock** mechanism, and thus additionally being dependent on tissue impedances. This is in line also with IEC TS 60479-2:2017.

Figure 2 – Maximum allowed touch and touch currents, 1 kHz to 100 kHz, immediate nerve and muscle electric shock

11 Electric shock – local overheating and burns of parts of the body

11.1 General and initial thermal conditions

Clause 11 deals with the physical and pathophysiological aspects of local overheating and burns of mainly the skin caused by high local power densities and resulting from a continuous current path over time between two defined separate parts of the body. The detailed safety requirements including risk level categorisation are in Clause 12, which also contains a summary in its Table 1. Examples of calculations using the numerical data are given in Annex A.

It is assumed that the initial temperature of the skin and surface regions of fingers, hands, and arms is 32 °C, on which the calculations are typically based. Overheating of inner parts of the body typically begins at a higher initial temperature. An initial temperature of 40 °C is then set and shall also be used for the initial skin temperature in situations with elevated ambient temperatures.

NOTE At frequencies of several kilohertz and higher, thermal injuries by local overheating of the skin are possible with the higher currents allowed than at lower frequencies and also, in particular cases, at still higher frequencies of inner parts of the body such as finger joints.

11.2 Awareness, perception and withdrawal

NOTE Rationales for the following specifications are given in Annex C.

11.2.1 Subclause 11.2 applies to only non-repetitive **touch currents** leading to perception followed by withdrawal. Cases of contact with the **primary contact area** of a case is assumed to occur maximally three times over one minute or more, then followed by no contacting over the remainder of any six minute period.

NOTE 1 The contacting assumed to result in withdrawal is not a normal procedure in equipment operation but instead a result of inadvertence or a result of conscious decision of gripping for maintaining body posture control.

NOTE 2 It is assumed that any finger overheating has ceased after the totally six minutes, due to normal cooling effects, but that there has been no such cooling effects during the first minute of repeated contacts.

11.2.2 Heat sensing nerves exist only in the skin region, and thus not in the interior of for example fingers. Conditions where such interior heating occurs while the skin sensing is insufficient for perception are dealt with in 11.3.

11.2.3 The perception conditions for hazard calculations are skin temperature rises of at least 3 K over 5 s to 10 s and 5 K over 20 s or less. These times then include the time for withdrawal. The high alternative value 10 s applies if the touching part of the body is large and less easy to withdraw (i.e. the upper arm, leg or torso) than a hand or finger for which 5 s applies.

NOTE The 3 K over 5 s to 10 s or 5 K over 20 s or less is considered to inevitably result in the heating to be perceived.

The withdrawal reaction in this case is set to be completed 1,0 s to 1,5 s after the actual sensing, where the shorter time is to be expected if the person is informed by, for example, a warning sign and there is thus an **awareness** of the risk of being exposed to a **touch current**. If another part of the body than a finger, hand and lower arm is the contacting part of the body, the reaction time between actual sensing until completion of the withdrawal is set to 1,5 s.

11.3 Long-term tissue overheating

11.3.1 Subclause 11.3 applies to cases where excessive internal tissue heating at the end of 20 s continuous contacting is not assumed.

NOTE The skin heating perception criterion is in 11.2.3, with numerical data in Table 1 top entry.

The person then typically thinks he/she "knows" that the (live) conductor surface is actually not hot, but since the tissue is heated up while the conductor surface as such is actually still cold, some contradictory sensing signals will be given to the brain. This potentially results in a delayed "surprise effect" **awareness** resulting in a delayed or no withdrawal reaction.

The criterion is in practice applicable to only fingers. The finger dimensions are set to a diameter of 17 mm and a length of 110 mm, i.e. a volume of 25 cm^3. Its impedance is according to Figure 1.

11.3.2 The summed local power density in a continuously contacting extremities including arms and fingers over any 6 min shall not exceed 20 W/kg, and 10 W/kg in the trunk. No long-term head contact is applicable.

NOTE 1 A homogeneous SAR value of 20 W·kg^{-1} constitutes the basic restriction for instructed person fingers in many standards. This will result in a temperature rise rate of about 0,5 K/min, i.e. about 3 K over any 6 min specified in the standards. A continuous heating rate at this level is thus allowed, since it is assumed that there is an ongoing temperature rise equilibration/reduction by heat conduction, blood convection and sweating, until the person eventually feels an overall discomfort and withdraws.

NOTE 2 No warning marking is needed; see Table 1 top entry.

NOTE 3 The rationales for not specifying **touch current** limits are given in Clause B.9.

NOTE 4 The EU Directive 2013/35/EU specifies maximum 40 mA for higher frequencies than 100 kHz, but does not consider any particular skin heating. IEEE Std C95.1-2005 specifies between 50 mA and 200 mA under different conditions.

11.3.3 The 20 W/dm^3 value is allowed to be temporarily exceeded in cases where continuous contacting is excluded by equipment design and/or operating procedures, or when skin heating is perceived. With 11.3.1, the maximally 20 s contacting time during any 6 min results in an allowed 360 W/dm^3. This is also the ceiling value under any conditions.

A warning marking and instructions shall be provided by the manufacturer in cases where exceeding the momentaneous 20 W/dm^3 value is allowed.

EXAMPLE The criterion is used with 20 W/dm^3 value in the 25 cm^3 finger volume resulting in 3 K temperature rise over 20 s. The allowed value 360 W/dm^3 then results in 9 W in the finger.

NOTE 1 Other examples of calculations are given in Table A.4 and Table A.5, and in Clause A.3.

NOTE 2 Finger heating conditions with very similar intermittency conditions are dealt with in AA.2 of IEC 60519-6:2011.

12 Requirements and risk group classification

12.1 General

Subclause 12.2 contains requirements on application of the three **touch current** limits in 10.2 and Figure 1, and 12.3 contains requirements related to skin temperature rises and times of **awareness**, perception and withdrawal. Risk group classifications are also given.

Risk group classification as function of contact voltages are in 12.4, and on residual current protective devices (RCDs) in 12.5.

NOTE Risk assessment and categorisation is dealt with in IEC 60519-1:2015. Especially the concepts provided in its Clause 4 are relevant also for contact voltages and for **touch currents** addressed in Clause 11 in this document.

12.2 Conditions for the touch current limits up to 100 kHz

Three levels of **touch current** are specified in 10.2:

– I_{percep}, approximate perception level in normal environments;
– I_{inadv}, inadvertent touching level causing **aversion**, occupational;
– $I_{\text{gripp}} = 1{,}5 \times I_{\text{inadv}}$, gripping or between the feet, occupational.

I_{percep} is also the level for intentional contacting in operation, provided the **prospective touch voltage** is about the same as the effective contact voltage, i.e. the series impedance of the source circuit is low; see Clause 6. The level applies in cases where contacting of a live part occurs as a part of procedures such as maintenance and inspections, or with long intervals in normal operation. No warning signs or particular instructions are needed.

I_{percep} also applies for inadvertent touching in critical environments such as being damp or wet, or with elevated ambient temperatures. Warning marking and particular instructions shall then be provided by the manufacturer.

I_{inadv} in normal environments represents startling followed by **aversion** but no **pain**. Reactions such as involuntary movements of the whole or part of the body which can cause secondary hazards are not foreseen. Warning marking and particular instructions shall then be provided by the manufacturer.

I_{gripp} represents situations where there is **awareness** of the **electric shock** risk and mentally preparedness for it, but the person consciously chooses gripping or contacting feet for avoiding or stopping damages to the equipment or workload, or a personal hazard by stabilising body posture.

I_{gripp} also applies in normal environments when the **primary contact area** conductor is possible to become energised by a single fault condition during contacting. Warning marking with additional information on the risks of gripping or energising shall be located at the object that can be gripped, and particular instructions shall also be provided.

I_{percep} corresponds to risk group 0 or 1. I_{inadv} corresponds to risk group 1. I_{gripp} corresponds to risk group 1 or 2.

Touch currents higher than those specified above are considered hazardous and shall be protected against.

12.3 Requirements related to skin temperature rises and times of awareness, perception and withdrawal

12.3.1 Skin heat capacity considerations

NOTE The skin anatomy is illustrated in Figure C.1. Numerical data are provided in Annexes A and C.

For the epidermis and dermis, 2,0 $J \cdot cm^{-3} \cdot K^{-1}$ is used. For the subcutis, the value becomes 2,8 $J \cdot cm^{-3} \cdot K^{-1}$. Thus, the epidermis + dermis (1 mm thickness) heat capacity becomes 0,2 $J\ cm^{-2}\ K^{-1}$, and for the subcutis (1,5 mm thickness) one obtains 0,42 $J \cdot cm^{-2} \cdot K^{-1}$. The total becomes 0,62 $J \cdot cm^{-2} \cdot K^{-1}$ (= 6,2 $mJ \cdot mm^{-2} \cdot K^{-1}$).

12.3.2 Skin temperature considerations

There will be no **pain** when the short term overall skin temperature does not exceed 50 °C. This case thus applies if the withdrawal is completed before a temperature rise of 18 K can occur, under the typical ambient conditions in 11.1. The situation is in risk group 0.

NOTE 1 Additional information is in IEC Guide 117.

If the skin temperature has reached 65 °C, there will be a **pain** and subsequent damage to only the epidermis and dermis, resulting in a later skin rejection without complications. This case thus applies when the withdrawal is completed before a temperature rise of 33 K can occur. The situation is in risk group 1.

A lasting **pain** occurs If the temperature has reached 70 °C, and the burn will heal more slowly than a burn caused by surface heating. A fingertop papillary pattern can remain slightly modified after healing. This condition is acceptable only on small areas, less than 50 mm^2. The situation is still in risk group 1.

Further information on limited skin areas is provided in 7.2.4, 7.2.6, and the examples in Table A.4 and Table A.5. An example with larger skin area is dealt with in A.3.2.

Table 1 summarises the requirements. For conditions in the skin power density gaps in the table, the lower skin power density values apply. Risk groups are also included.

Table 1 – Maximally allowed skin power density per surface area, under various conditions of withdrawal

Part of the body	**Warning type**	**Maximum temp. rise rate**	**Withdrawal within**	**Skin power density per surface area** mW/mm^2	**Risk group**
Any	None	5 K over > 20 s	> 20 s (i.e. none; see 11.3)	≤ 1,55	0
Other than hand and finger	Yes; sign	3 K over 5 s	10 s	≤ 3,7	0
Hand and finger	Yes; sign	5 K over 5 s	10 s	≤ 6,2	0
Hand and finger	Yes; sign	≤ 13 K over 1,5 s	1,5 s after 5 K rise	≤ 54	1
Other parts of the body	Yes; sign + instructions	≤ 13 K over 1,5 s	1,5 s after 5 K rise	≤ 54	1
Hand and finger	Yes; sign + instructions	≤ 13 K over 1 s	1 s after 5 K rise	≤ 81	1
Hand and finger	Yes; sign + instructions	> 20 K/s ≤ 50 K/s	0,75 s	> 125 < 310	1

NOTE 2 The gap in skin power density between low and medium high heating rates is related to possible delays in **awareness**, perception and withdrawal in cases with low temperature rise rate. Ascertaining shorter such times necessitates quite high temperature rise rate.

NOTE 3 The gap in skin power density between medium high and very high heating rates is related to a quite immediate reaction in the latter case, in contrast to sensing followed by intentional withdrawal in the former case.

NOTE 4 Examples of calculations are given in Annex A and the method for calculating the skin power is in Clause C.5.

12.4 Risk level categorisation as function of the prospective contact voltage

Prospective contact voltages higher than 100 V RMS shall lead to the determination of risk groups in 12.2 to be increased by one, except for risk group 2 in 12.2, which remains. This applies only if the **primary contact area** is a conductor. Additional warnings and instructions are then thus needed.

12.5 Additional protection: residual current protective devices (RCDs)

The use of RCDs is recognised in AC systems as a provision against carelessness by users, but are not recognised as a sole means of protection. The same applies for the source frequencies in this document.

Protection by RCDs are considered effective only in the sense that they will reduce risk level 2 to 1 if their intended action cuts out the active circuit faster than the respective withdrawal times in Table 1. Additionally, their proper action will reduce the discomfort caused by the **touch current**. Their use is therefore recommended if practical with respect to overall reliability, but they are not to replace other means of protection or warnings/instructions.

13 Non-sinusoidal touch currents

The combination of a DC and sinusoidal current is outside the scope of this document. Information for frequencies below 1 kHz exist in IEC TS 60479-2:2017.

Only harmonics are now considered. These are separated out by recording the curve form of the source voltage and then applying known spectrum analysis techniques, to obtain the amplitudes of the frequency components. For each of these, separate calculations are then made using the impedance data obtainable with Clauses 8 and 9, for obtaining the **touch**

current data by Clauses 8 and 9. The resulting currents are then compared with the applicable limits and calculated as percentages of the allowed maximal values. The added percentages shall not exceed 100.

14 Warning marking and risk group classifications

Warning marking shall be according to 19.4 and Annex F of IEC 60519-1:2015:

– Symbol IEC 60417-6206:2013-07 "Caution, electric field hazard", shown in Figure 3 a), shall be used in cases with a significant electric field strength but less than that in 9.3 in accessible locations (risk group 0), and higher than that in 9.3 but fulfilling 9.4.1 or 9.4.2 (risk group 1). It is also used with the conditions in 9.2 for an insulated live part, if the measured current is higher than 2/3 of the limit in 9.4.3.

  NOTE The reasons for the lower current value from an insulated live part is that a lower actual impedance than 500 Ω is possible, and that operating personnel is typically not aware of any significant current being possible to extract from the surface.

– Symbol IEC 60417-6208:2013-07 "Caution, **touch current** or voltage", shown in Figure 3 b), shall be used in cases where it is possible in normal environments that the **touch current** exceeds I_{percep} but not I_{inadv} in 10.2. Risk group 0 then applies. Risk group 1 applies in critical environments and for higher **touch currents**. If other parts of the body than hands and fingers are likely to be the **primary contact area** under the risk group 1 conditions, instructions shall also be provided.

– Symbol IEC 60417-6207:2013-07 "Caution, **touch current** that can cause burns", shown in Figure 3 c), shall be used as specified in Table 1. Additionally, it shall be used in cases where 11.3.3 is applied.

a) IEC 60417-6206 b) IEC 60417-6208 c) IEC 60417-6207

Figure 3 – Warning markings

Annex A
(informative)

Examples of calculations

A.1 General

The following criteria are used for determination of the allowable effective touch voltages:

– skin heating rates, with levels depending on several conditions as summarised in Table 1;
– finger internal tissue heating, as addressed in Clause 11;
– allowed overall **touch currents** with regard to immediate nerve and muscle **electric shock** effects;
– allowed prospective contact voltage and the effective contact voltage, as addressed in Clause 5.

Five frequencies are chosen to illustrate the procedures of applying these criteria: 1 kHz, 10 kHz, 20 kHz, 100 kHz, 1 MHz, and 6 MHz. Using the formulas in 10.2, the following maximum allowed currents with regard to immediate nerve and muscle **electric shock** effects are obtained:

– at 1 kHz – gripping: 3 mA, inadvertent touching: 2 mA;
– at 10 kHz – gripping: 15 mA, inadvertent touching: 10 mA;
– at 20 kHz – gripping: 30 mA, inadvertent touching: 20 mA
– at 100 kHz – gripping: 225 mA, inadvertent touching: 150 mA;

NOTE Muscle and nerve reactions are not supposed to occur for frequencies above 100 kHz; see 10.2, Note 2.

The inadvertent touching is at the level of **aversion**. Table A.1 provides the equivalent series impedances of the various parts of the body, with two alternative **primary contact area**s, both at the high **touch current** limits for gripping:

– gripping by hand, i.e. using 1 500 mm^2 contact area;
– fingertip touching, i.e. using 50 mm^2 contact area.

The **secondary contact area** is supposed to be an earthed foot, so the sum of arm, torso and leg in Figure 1 are included.

For comparison, circuit data from IEC 61010-1:2010 are also used.

Table A.2 and Table A.3 provide the resulting overall **touch current** and skin heating rates for the two cases with moist and wet skin, respectively, and using 50 V overall contact voltage as reference. The corresponding finger tissue heating rates are provided and discussed in Clause A.3.

Table A.4 and Table A.5 show the selection procedure for obtaining the maximum allowed effective contact voltage in each case.

NOTE Another example combined with volunteer studies at 11 kHz is described in Clause B.2.

A.2 Skin heating

Finger power density data at 50 V effective contact voltage are provided in Table A.2, using the thermal data in 11.3.2. The criterion is applicable only if the skin heating rate is so low that the less than 3,1 mW/mm^2 power per skin surface area criterion also applies.

Table A.1 – Comparison of impedances of parts of the body, using the equivalent circuits in IEC 60990:2016 and in this document

	IEC 60990:2016	This document		
Frequency (Hz)	**Equiv. series impedance of the circuit (Figure B.3)** Ω	**Equiv. series impedance of the circuit: one finger; arm/torso/one leg** Ω	**Equiv. series impedance of** 1 500 mm^2 **moist skin area (gripping);** $R_s+C_s+R_t$ Ω	**Equiv. series impedance of moist fingertip skin:** 50 mm^2 **area** $R_s+C_s+R_t$ Ω
1 k	783 – j587	≈ 740; 540	200 – j1 061 + 39	6000 – j31 800 + 212
10 k	503 – j72	673 – j146; 536 – j22	20 – j106 + 39	600 – j3 180 + 212
20 k	501 – j36	564 – j191; 524 – j42	10 – j53+39	300 – j1 590 +212
100 k	500 – j7,2	377 – j91; 442 – j51	2 – j11 + 39	60 – j318 + 212
1 M	500 – j0,7	298 – j88; 416 – j7	0 – j11 + 39	6 – j32 + 212
6 M	500	205 – j34; 415 – j1	0 – j0 + 39	1 – j5 + 212

For wet finger skin, the equivalent series impedances in the right column are halved.

Table A.2 – Moist skin, finger and overall heating rate at 50 V overall effective voltage, using equivalent circuits in IEC 60990:2016 and this document

Frequency (Hz)	**IEC 60990:2016 Overall current and power (Figure B.3)** mA; W	**Gripping** (1 500 mm^2 **skin)**		**Fingertip contact** (50 mm^2 **skin)**	
		Overall complex impedance (Ω) **Overall current** (mA) **Moist skin power** (mW)	**Finger power density**[1]	**Overall complex impedance** (Ω) **Overall current** (mA) **Moist skin power** (mW)	**Finger power density** W/dm^3
1 k	51 mA; 2,0 W	|779 – j1 061|Ω = 1318 Ω; 38 mA; 344 mW	0	|7490 – j31 800| Ω = 3 670 Ω; 1,53 mA; 14,5 mW	0,6
10 k	98 mA; 4,9 W	|594 – j129|Ω = 608 Ω; 82 mA; 397 mW	0	|2020 – j3 350|Ω = 3914 Ω; 13 mA; 135 mW	4,4
20 k	100 mA; 5,0 W	|573 – j95|Ω = 581 Ω; 82 mA; 361 mW	0	|1600 – j1 823 Ω| = 2 427 Ω; 21 mA; 215 mW	9,6
100 k	100 mA; 5,0 W	|483 – j62|Ω = 487 Ω; 103 mA; 430 mW	0	|1091 – j460|Ω = 1184 Ω; 42 mA; 485 mW	27
1 M	100 mA; 5,0 W	|455 – j18|Ω = 455 Ω; 110 mA; 471 mW	0	|932 – j126|Ω = 941 Ω; 53 mA; 615 mW	34
6 M	100 mA; 5,0 W	|454 – j1|Ω = 454 Ω;110 mA; 470 mW	0	|833 – j41|Ω = 834 Ω; 60 mA; 765 mW	30

[1] The fingers are not included in gripping; see Figure 1.

Table A.3 – Wet skin, finger and overall heating rate at 50 V overall effective voltage, using this document, with halved skin impedances compared with Table A.2

Frequency (Hz)	**Gripping** (1 500 mm^2 **skin**)	**Fingertip contact** (50 mm^2 **skin**)	
	Complex impedance (Ω) **Overall current** (mA) **Wet skin power** (mW)	**Complex impedance** (Ω) **Overall current** (mA) **Wet skin power** (mW)	**Finger power density** (W/dm^3)
1 k	|660 – j530|Ω = 846 Ω; 59 mA; 417 mW	|4385 – j15 900| Ω = 16 500 Ω; 3,03 mA; 28,5 mW	2,7
10 k	|566 – j75|Ω = 571 Ω; 88 mA; 228 mW	|1615 – j1758|Ω = 2 387 Ω; 20,9 mA; 177 mW	12,0
20 k	|549 – j68|Ω = 553 Ω; 90 mA; 198 mW	|1344 – j1029 Ω| = 1 692 Ω; 29,6 mA; 224 mW	20
100 k	|462 – j56|Ω = 465 Ω; 107 mA; 235 mW	|955 – j251|Ω = 987Ω; 51 mA; 354 mW	39
1 M	|436 – j13|Ω = 436 Ω; 115 mA; 258 mW	|823 – j111|Ω = 830Ω; 60 mA; 392 mW	43
6 M	|434 – j1|Ω = 434 Ω; 115 mA; 258 mW	|726 – j38|Ω = 727Ω; 69 mA; 507 mW	39

Table A.4 – Effective contact voltage limits for the moist skin examples in Table A.2

Frequency	**Gripping** (1 500 mm^2 **skin)**		**Fingertip inadvertent contact** (50 mm^2 **skin)**	
Hz	**Reason**	**Limit**[1] V	**Reason**	**Limit** V
1 k	38 mA total current at 50 V (no skin heating limit)	50 × 3/38 = **3,9** due to current limit	1,54 mA total current at 50 V (the fingertip skin power density is < 1,55 mW/mm^2 at that current; 2 mA is allowed	50 × 2/1,54 = **65** due to overall current limit
10 k	82 mA total current at 50 V (no skin heating limit)	50 × 15/82 = **9,1** due to current limit	13 mA total current at 50 V (the fingertip skin power density is 2,5 < 6,2 mW/mm^2 at that current). 10 mA is allowed	50 × 10/13 = **38** due to overall current limit, but withdrawal < 10 s needed
20k	86 mA total current at 50 V (no skin heating limit)	50 × (30/86) = **17,4** due to current limit	21 mA total current at 50 V (the fingertip skin power density is 4,6 < 6,2 mW/mm^2 at that current). 20 mA is allowed	50 × 20/21 = **48** due to overall current limit, but withdrawal < 10 s needed
100 k	The skin heating is 430/1 500 < 6,2 mW/mm^2, i.e non-limiting; at 109 V, it becomes 1,36 (< 1,55) mW/mm^2 so the overall current 225 mA is the limiting factor.	**109** due to overall current limit	Fingertop power density is 9,6 mW/mm^2 at 50 V, so finger value 54 with 1,5 s withdrawal applies, and allows up to 50 × sqrt(54/9,6) = 119 V. At that voltage, the overall current becomes 42 × (119/50)=100 mA, and 150 mA is allowed. The finger SAR value at 119 V becomes 27 × (119/50)^2) = 153 W/dm^3. which is less than 360 W/dm^3; see 11.3.3.	**119** due to fingertop heating with 1,5 s withdrawal time
1 M	The skin heating is 0,31 mW/mm^2 at 50 V overall and 110 mA overall current. Increasing the contact voltage to the maximum 140 V increases the skin heating to 0,31 × (140/50)^2 = 2,4 mW/mm^2. This is above the 1,55 limit but below the 6,2 limit.	**140** due to maximal voltage limit in Clause 5, but withdrawal < 10 s needed	Fingertop power density is 12,3 mW/mm^2 at 50 V, so finger value 54 with 1,5 s withdrawal applies, and allows up to 50 × sqrt(54/12,3) = 105 V. At that voltage, the overall current becomes 53 × (105/50) = 111 mA. The finger SAR value at 105 V becomes 34 × (105/50)^2) =150 W/dm^3, which is less than 360 W/dm^3; see 11.3.3. With special warnings, 81 mW/mm^2 is allowed, increasing the allowed voltage to 50 × sqrt(81/12,3) = 128 V. This is below the 130 V RMS limit in Clause 4. The finger SAR value at 128 V becomes 27 × (128/50)^2) = 177 W/dm^3. Since the contact time is now significantly shorter than 5 s, there is no voltage limit due to SAR values.	**105** due to fingertop heating with 1,5 s withdrawal time ------- **128** due to fingertop heating with 1,0 s withdrawal time

Frequency	Gripping (1 500 mm^2 skin)		Fingertip inadvertent contact (50 mm^2 skin)	
Hz	Reason	Limit[1] V	Reason	Limit V
6 M	Data are unchanged, compared with those at 1 MHz	**140** due to maximal voltage limit in Clause 5, but withdrawal < 10 s needed	Fingertop power density is 15,3 mW/mm^2 at 50 V, so finger value 54 with 1,5 s withdrawal applies, and allows up to 50 × sqrt(54/15,3) = 94 V. At that voltage, the overall current becomes 60 × (94/50) = 113 mA. With special warnings, 81 mW/mm^2 is allowed, increasing the allowed voltage to 50 × sqrt(81/15,3) = 115 V. This is below the 130 V RMS limit in Clause 4. The voltages and finger power at 50 V are now lower, so there is no voltage limit due to SAR values.	**94** due to fingertop heating with 1,5 s withdrawal time ----- **115** due to fingertop heating with 1,0 s withdrawal time

[1] The source voltage limit in Clause 5 is given for the sinusoidal case, as RMS values.

Table A.5 – Effective contact voltage limits for the wet skin examples in Table A.3

Frequency	Gripping (1 500 mm^2 skin)		Fingertip contact (50 mm^2 skin)	
Hz	Reason	Limit[1] V	Reason	Limit V
1 k	59 mA total current at 50 V (no skin heating limit)	50 × 3/59 = **2,5** due to current limit	3,03 mA total current at 50 V; the fingertip skin power density is < 1,55 mW/mm^2 at that current; 2 mA is allowed	50 × 2/3,03 = **33** due to overall current limit
10 k	88 mA total current at 50 V (no skin heating limit)	50 × 15/88 = **8,5** due to current limit	20,9 mA total current at 50 V; the fingertip skin power density is 177/50 = 3,5 (< 6,2) mW/mm^2 at that current). 10 mA is allowed, i.e. 24 V, which gives 0,8 < 1,55 mW/mm^2	50 × 10/20,9 = **24** due to overall current limit
20 k	90 mA total current at 50 V (no skin heating limit)	50 × 30/90 = **16,7** due to current limit	29,5 mA total current at 50 V (the fingertip skin power density is 4,5 (< 6,2) mW/mm^2 at that current). 20 mA is allowed, i.e 34 V, which gives 3,7 < 6,2 mW/mm^2	50 × 20/29,5=**34** due to overall current limit, but withdrawal < 10 s needed
100 k	The skin heating is 235/1500 mW/mm^2; at 105 V, it beco-mes 0,69 (< 1,55) mW/mm^2,so the overall current 225 mA is the limiting factor	50 × 225/107 **= 105** due to overall current limit	Fingertop power density is 7,1 mW/mm^2 at 50 V, so finger value 54 mW/mm^2 with 1,5 s withdrawal then applies, and allows up to 50 × sqrt(54/7,1) = 138 V. At that voltage, the overall current becomes 51 × (138/50) = 141 mA, and 150 mA is allowed. The finger tissue power at 141 mA becomes 0,141^2 × 377 = 7,5 W, so the SAR values becomes 7,5 × 40 = 300 W/dm^3. This is less than 360 W/dm^3; see the example in 11.3.2.	**138** due to fingertop heating with 1,5 s withdrawal time

Frequency	Gripping (1 500 mm^2 skin)		Fingertip contact (50 mm^2 skin)	
Hz	Reason	Limit[1] V	Reason	Limit V
1 M	The skin heating is 0,17 mW/mm^2 at 50 V overall and 115 mA overall current. Increasing the contact voltage to the maximum 140 V increases the skin heating to 0,17 × (140/50)^2= 1,3 mW/mm^2. This is below the 1,55 limit.	**140** due to maximal voltage limit in Clause 5	Fingertop power density is 7,8 mW/mm^2 at 50 V, so finger value < 54 with 1,5 s withdrawal applies, and allows up to 50 × sqrt(54/7,8) = 131 V. At that voltage, the overall current becomes 60 × (131/50) = 157 mA. < 81 mW/mm^2 is allowed with a shorter withdrawal time. However, the overall voltage limit is 140 V. The overall current becomes 60 × (140/50) = 168 mA and the finger tissue power becomes 0,168² × 377 = 10,6 W, so the SAR values becomes 10,6 × 40 = 425 W/dm^3. This is less than 360 W/dm^3, so the voltage has to be reduced to 129 V.	**131** due to fingertop heating with 1,5 s withdrawal time ------- **140** due to maximum voltage with fingertop heating with 1,0 s withdrawal time. **129** due to maximally allowed finger tissue momentaneous power density.
6 M	Data are unchanged, compared with those at 1 MHz	**140** due to maximal voltage limit in Clause 5	Fingertop power density is 10,1 mW/mm^2 at 50 V, so finger value 54 with 1,5 s withdrawal applies, and allows up to 50 × sqrt(54/10,1) = 115 V. At that voltage, the overall current becomes 60 × (94/50) = 113 mA. With special warnings, 81 mW/mm^2 is allowed, increasing the allowed voltage to 50 × sqrt (81/10,1) = 141 V. This is above the 140 V RMS limit in Clause 4. The overall current at 140 V becomes 138 mA, and the finger tissue power becomes 0,138^2 × 377 = 6,4 W, so the SAR values becomes 256 W/dm^3. This is less than 360 W/dm^3, so no SAR restriction applies.	**115** due to fingertop heating with 1,5 s withdrawal time ----- **140** due to maximum voltage, and with fingertop heating with 1,0 s withdrawal time

[1] The source voltage limit in Clause 5 is given for the sinusoidal case, as RMS values.

A.3 Examples of tissue heating conditions

A.3.1 With 1 500 mm^2 fingerskin area, i.e. gripping

It is seen in Table A.5 that the most onerous condition is with wet skin at 1 MHz. However, the skin temperature rise rate is then so high that the 20 s criterion in 11.2.3 (i.e. maximally 1,55 mW/mm^2 skin area) is not fulfilled.

NOTE The finger is not included in the calculations for gripping.

A.3.2 With the maximal fingerskin area 230 mm^2

A possibility to achieve a higher power density in the finger tissue is to increase the fingertip contact area as specified in 7.2.6.

Calculations at 1 MHz for wet finger then results in the following case of no perception.

– R_s becomes 6/2 (wet) / 4,6 (area increase) = < 1 Ω.

– The capacitive complex impedance becomes, in analogy j32/(3 × 4,6) = j3,3 Ω.

– The spread resistance becomes $\frac{212}{\sqrt{50/230}} = 99\ \Omega$.

– The overall complex impedance becomes 298 – j88 (whole finger) + 416 – j7 (body) + 99 – j3 (fingerskin) Ω. The total becomes |813 – j98| = 819 Ω (to be compared with 823 – j111 in Table A.3).

– The overall current at 50 V becomes 61 mA, i.e very much the same as with the wet 50 mm^2 fingerskin.

– However, the fingerskin power (compare with Table A.5, where it is 7,8 W/mm^2) becomes $0{,}061^2 \times 99$ = 33,5 mW, i.e. 33,5/230 = 0,145 mW/mm^2.

– Since the maximum allowed skin power density without perception is set to 1,55 mW/mm^2, a somewhat higher voltage 52 V is allowed.

– The finger power then becomes $0{,}061^2 \times 298$ = 1,1 W, i.e. 44 W/dm^3.

– This is allowed only under the conditions in 11.3.3, then with a total relative contacting time during 6 min (= 360 s) of 20/44 = 45 %, i.e. 164 s.

NOTE In the very special case of very large skin area hand or lower arm contact, the arm impedance can be set to two thirds of the total of that for the arm, torso and one leg (see 8.2).

Annex B
(informative)

Rationales, references and volunteer studies in the non-thermal case

B.1 Background and observations

The basically immediate and direct nerve and muscle reactions are very different from local overheating effects, since the former gradually disappear with increasing frequency and thus makes it possible to allow higher **touch currents** so that the latter effect can occur. Burns are caused by the temperature rise in the part of the body acting over a time without withdrawal. Some medical studies reported in the literature to not sufficiently differentiate between these two effects, which has resulted in unclear recommendations and difficulties in interpretation.

The actual reaction of a low frequency **electric shock** is known to most persons. With currents in the kilohertz range, a tingling effect in the tissue volume with the highest current density is instead felt. There is no reduction of control of movement of the touching part such as a finger, and the effect can be tolerated for a short time at the **aversion** level. Higher current densities are needed for **pain** reactions, with a local "quick sting" effect and an unpleasant and involuntary muscle reaction when contacting a live part with a small area of the part of the body such as a fingertip. At frequencies about 100 kHz, the muscle reaction has essentially vanished, and a tingling effect in parts of the body is instead felt for higher currents. A small contact area spark effect, such as when discharging a capacitor, can also occur at elevated touch voltages, due to surface charge redistribution effects.

Usually, the spread between individuals regarding the subjective level of perceived **touch current** is low. The spread between individuals with **touch currents** causing subjective **pain** is much higher. For this and ethical reasons, volunteer studies are preferably made with perception and **aversion** as targets. An example is in Clause B.3. The only practical way is to define the levels by objective agents, an example being the harm by actual injuries as is the case with the **pain** definition. Until an objective agent for the non-harmful **aversion** is developed, the somewhat subjective definition of **aversion** is provided in this document.

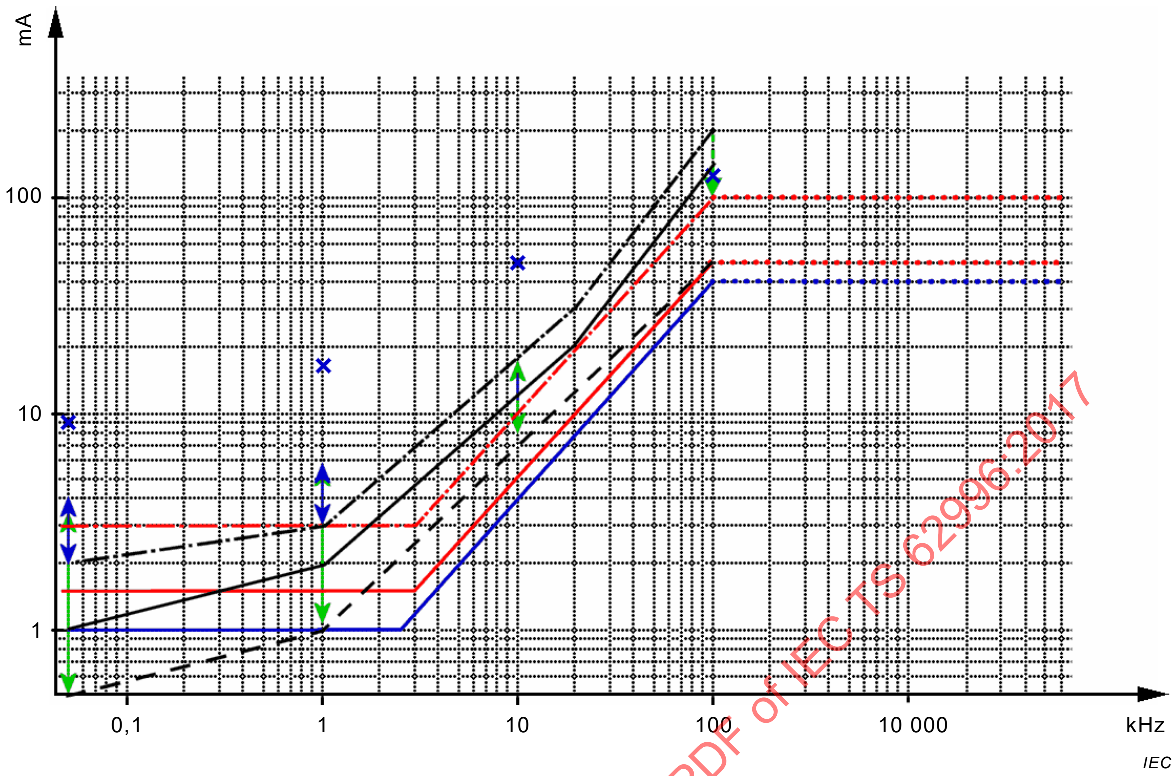
B.2 Discussion of Figure B.1

NOTE Ventricular fibrillation effects diminish very rapidly with increasing frequency, as shown in Figure 3 of IEC TS 60479-2:2017, and are excluded from this analysis.

The basis for the choices of current levels are perception and **pain** reactions; between these there is a current interval with startling followed by an increasingly uncomfortable experience with increased current level. **Aversion** as defined in this document is at a level between that of perception and **pain**. There are then no involuntary muscle contractions, or let-go situations for even higher currents, which typically occur for at least 10 times higher currents than those at the perception limit; see Figure B.1 and IEC 61140:2016 with regard to 50/60 Hz.

The 50/60 Hz point at 1 mA is at the level of **aversion** and is in accordance with for example ICNIRP guidelines. IEC 61140:2016 specifies 0,5 mA at 60/60 Hz as a likely level of perception, and 3,5 mA for **pain**.

The level factor ½ for intentional occupational touching represents the level of acceptable leakage current at 50/60 Hz alternating current according to several publications, for example IEC 60335-1:2010, IEC 60335-1:2010/AMD1:2013 and IEC 60335-1:2010/AMD2:2016, 13.2. The level factor 2 for gripping, etc. is in accordance with IEEE Std C95.1-2005 and IEC 61140:2016 with regard to 50/60 Hz, but with a slightly lower quotient. The reason for the higher current limit is the larger cross section area throughout, reducing concentrations of the electric field strength which is the primary hazard agent.



Key

(blue crosses): Let-go old data for 50 % percentile of males; from ICNIRP:1998, p 503.

(blue arrows): ¼ of let-go thresholds; from ICNIRP:2008.

(blue line): **Reference levels** of **touch current**, occupational exposure; from ICNIRP:2010, Table 5, and 2013/35/EU.

(green arrows): At 50 Hz: levels of perception and **pain**; from IEC 61140:2016. At higher frequencies: from IEC TS 60479-2:2017, using several of its tables.

(red full line): Touching **touch currents** in controlled environments; from IEEE Std C95.6-2002.

(red dot/dash): Grasping **touch current** in controlled environments; from IEEE Std C95.6-2002. Values at 10 kHz and 100 kHz also for perception according to IEC TS 60479-2:2017, 4.1.1.

(black full line): Inadvertent touching causing **aversion**.

– – – (black dashes): Inadvertent touching in critical environments possibly causing **aversion** and approximate perception level in normal environments.

—·— (black dots/dashes): Gripping or both feet; this document.

NOTE 1 The graphs are projected between 50 Hz and 1 kHz, for showing the connection to mains AC requirements. The factor 2 for perception is in line with also Figure 1 in IEC TS 60479-2:2017. However, the perception current increase as function of frequency between 10 kHz and 100 kHz is stated in IEC TS 60479-2:2017 to be approximately 10 times.

NOTE 2 No specifications are provided above 100 kHz, since local overheating (burns) are assumed to then be the determining **electric shock** mechanism.

NOTE 3 The definition in the Directive 2013/35/EU of exposure limit values (ELV) for **touch current** is assumed to correspond to the **aversion** level.

NOTE 4 There is no correspondence to the definition of maximum permissible exposure (MPE) in the IEEE Std C95.6-2002 standard and unchanged **touch current** values between 0 and 3 kHz.

Figure B.1 – Maximum allowed touch and touch currents in various standards, 1 kHz to 100 kHz, immediate nerve and muscle electric shock

The curves in Figure B.1 are from the initial considerations, and shown as piecewise linear in log-log scale, with breakpoints for the inadvertent touching curve at (200; 1,4), (1 000; 2), (20 000; 20), and (100 000; 150) (Hz; mA).

The *dI/df* (i.e. **touch current** as function of frequency) breakpoint at 1 kHz corresponds well to the references provided in the key to Figure B.1.

The 20 mA breakpoint at 20 kHz is chosen in accordance with industry experience by some persons having worked with systems producing appropriate data for assessments. It should firstly be observed that only hand or finger contact normally occurs, and that mainly a sting effect corresponding to **pain** occurs with a small such contact area. With larger area finger or hand contact, only a strong tingling effect occurs in the hand and arm, with a much weaker such effect in the body or legs, due to the larger cross section area for the **touch current** flow. Any let-go issues do not occur, and the level is typically less than that of **pain**, even if it is quite uncomfortable.

The upwards slope from the 20 kHz points in Figure B.1 is discussed in Clause B.7. Additional details on perception and **pain** in the references are given in Clause B.4.

Rather than employing a number of piecewise linear formulas in log-log scale, those in 10.2 are applicable.

B.3 A volunteer study at 11 kHz sinusoidal conditions

B.3.1 Experimental setup and data

The study was initiated and carried out by members of the IEC TC 27 Working Group 32, responsible for the IEC technical specification project. Two flat circular 50 mm^2 conductor tips (see Figure B.2) were touched by the index and middle fingers. The fingerskin conditioning was by rubbing the dry fingers for about 5 s on a cloth moistened but not wetted by a 0,9 % saline solution, and then quickly putting the fingertips on the conductors.

The resulting levels of perception were between 5,6 mA and 6,8 mA, for the four persons. The touch voltage for perception was 26 V to 30 V for all persons. The **aversion** levels were between 11 mA and 14 mA, with no correlation between low/high perception and low/high **aversion** currents for each individual. The **aversion** voltage was close to 60 V for all persons.

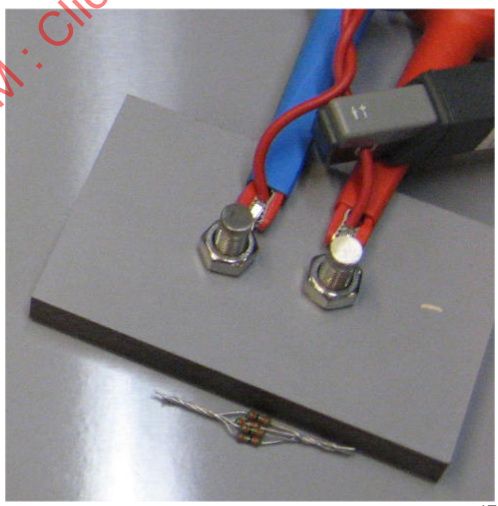


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Figure B.2 – Setup for touch current and voltage measurements with index and middle fingers on 50 mm^2 flat conductors

B.3.2 Discussion and analysis of the experimental data

Touch current data on perception and **aversion** are in very good agreement with those calculated from 10.2: 5,9 mA and 11 mA, respectively. The touch voltage as calculated from Figure 1 and using 6 mA **touch current** with the assumption of the equivalent of totally three fingerlengths, as current path based on the finger and hand region where tingling was felt, becomes 29,5 V, again in good agreement.

The extent of finger moistening is quite sensitive with the small contact area 50 mm^2; a 30 % reduction of the series resistance R_s and increase of the series capacitance C_s results in a touch voltage 31,7 V at the level of perception, instead of the 26 V to 30 V. This sensitivity is also pointed out in the Kanai *et al* reference. The tingling effect is a tissue volume effect and seemingly not very dependent on the skin impedance properties.

The experimentally obtained quotient between the **aversion** and perception currents of about 2 is in very good agreement with the quotient 1,9 by the formulas in 10.2.

NOTE The analysis in B.3.2 are of general importance also for IEC TS 62997, developed by TC 27.

B.4 Contact/touch current data from standards and other published documents

The symptoms of **electric shock** are immediate and the following terms are invariably used in IEC, ICNIRP and IEEE publications, in approximate order of severity:

– perception,
– startling,
– threshold of **pain**,
– let-go,
– ventricular fibrillation.

Reference is made to the following tables in IEEE standards:

h) IEEE Std C95.6-2002 – Table 5;
i) IEEE Std C95.1-2005 – Table 5;
j) IEEE Std C95.1-2005 – Table 7.

These and additional data from ICNIRP references and IEC TS 60479-2:2017 are collected in the graphs in Figure B.1.

NOTE 1 IEC TS 60479-2:2017 does not deal with skin impedances or other influences by the contact areas, neither does it deal with tissue heating, since the times of **touch current** is limited to 10 ms in the scope, but times up to 100 ms and even 2 s are mentioned. Furthermore, it does not deal with any prospective source voltage limits due to risk of arcing or flashover to the tissue.

A measuring network for unweighted **touch current** is in Figure 3 of IEC 60990:2016. It is stated to be for assessing electrical burns and is reproduced here as Figure B.3.

A comparison using the data in Figure B.3 is shown in Table A.1.

NOTE 2 Figure A.3 in IEC 61010-1:2010 is a measuring circuit for alternating current and frequencies up to 1 MHz, for physiological response.

NOTE 3 6.3.1 in IEC 61010-1:2010 and IEC 61010-1:2010/AMD1:2016 specifies a maximally allowed 70 mA RMS when measured with the measuring circuit of its Figure A.3, which is the same as Figure B.3 in this document. This is stated to relate to possible burns at higher frequencies. The statement is not in line with the conclusions in this document.