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TECHNICAL REPORT

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Assessment of contact current related to human exposure to electric, magnetic and electromagnetic fields

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ASSESSMENT OF CONTACT CURRENT RELATED TO HUMAN EXPOSURE TO ELECTRIC, MAGNETIC AND ELECTROMAGNETIC FIELDS

FOREWORD

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a Technical Report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 63167, which is a Technical Report, has been prepared by IEC technical committee 106: Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
106/422/DTR	106/436A/RVDTR

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

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

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

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- withdrawn,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

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

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

INTRODUCTION

In the guidelines limiting human exposure to electric, magnetic and electromagnetic fields (EMF guidelines), limits for the contact current are given to avoid adverse indirect effects, i.e. electric shocks and burn hazards caused by contact with a conductive object located in an electric and/or magnetic field, when the object has an electric potential owing to electric or magnetic induction to the object.

At the moment, no standardized method for evaluating the contact current, in the context of human exposures to the above fields has been well established. On the other hand, there is a huge amount of knowledge, as well as many standards and regulations on the issue of electrical safety (i.e. direct contact with live part of conductive object) to avoid severe electric shock hazards. Therefore, the evaluation methods used in the field of electrical safety might be useful references. This document summarizes general information on the assessment of contact current related to human exposure to electric, magnetic and electromagnetic fields.

ASSESSMENT OF CONTACT CURRENT RELATED TO HUMAN EXPOSURE TO ELECTRIC, MAGNETIC AND ELECTROMAGNETIC FIELDS

1 Scope

This document, which is a Technical Report, provides general information on the assessment of contact current related to human exposure to electric, magnetic and electromagnetic fields. The contact currents in this context occur when a human body comes into contact with a not electrified conductive object exposed to an electric and/or magnetic field at a different electric potential owing to electric and/or magnetic induction to the object. This is distinguished from the issue of electrical safety where contact with live parts of a conductive object is dealt with.

In reference to the international EMF guidelines [1]-[4] [1], the frequency range of contact current covered in this document is direct current to 110 MHz, and only steady-state (continuous) contact currents are covered. Transient contact currents (spark discharges) which may occur immediately before the contact with the object are not covered.

2 Normative references

There are no normative references in this document.

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
contact current
current flowing into the body resulting from contact with a conductive object in an electric, magnetic or electromagnetic field

3.2
electric field strength
magnitude of a field vector at a point that represents the force (F) on an infinitely small charge (q) divided by the charge

3.3
exposure
state that occurs when a person is subjected to an electric, magnetic or electromagnetic field, or to a contact current other than those originating from physiological processes in the body and other natural phenomena

1 Numbers in square brackets refer to the Bibliography.

3.4
indirect effect
effect resulting from physical contact between a person and a not electrified object, such as a metallic structure in an electric, magnetic or electromagnetic field, at an electric potential that is at least at a point of the object different from the potential of the person

3.5
touch current
electric current flowing through a human body when it touches one or more accessible parts of an installation or of equipment

Note 1 to entry: The term “leakage current” had also been used as a synonym for touch current in the field of electrical safety.

3.6
spark discharge
transfer of current through an air gap prior to making contact with another conductive object at a different potential

4 Abbreviated terms

AM	amplitude modulation
EMF	electric, magnetic or electromagnetic field
EV	electric vehicle
FM	frequency modulation
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
IH	induction heating
MPE	maximum permissible exposure
MRI	magnetic resonance imaging
PC	personal computer
RF	radio frequency
WPT	wireless power transfer

5 Contact current in EMF exposure guidelines

Clause 5 overviews contact currents described in the EMF guidelines [1]-[4].

In the frequency range up to approximately 10 MHz (dominantly up to 100 kHz), the flow of electric current from an object in a field to the body of an individual may result in the stimulation of muscles and/or peripheral nerves. With increasing current, this may be manifested as perception, pain from an electric shock and/or burn, the inability to release the object, difficulty in breathing and, at higher currents, cardiac ventricular fibrillation.

In the frequency range of about 100 kHz to 110 MHz, shocks and burns can result either from an individual touching an ungrounded metal object that has acquired a charge in a field or from contact between a charged individual and a grounded metal object.

In the EMF guidelines, reference levels for steady state (continuous) contact current are given for frequencies up to 110 MHz to avoid shock and burn hazards (see Annex A). The reference levels are not intended to avoid ventricular fibrillation, which is the basis of standards for electrical safety. The upper frequency of 110 MHz is the upper frequency limit of the FM broadcast band. Here, the transient currents resulting from spark discharges [5], which can occur when an individual comes into very close proximity with an object at a different electric potential, are not considered in the reference levels of contact current. Instead, the effect of spark discharge is considered in the reference levels of electric field exposure for the general public by including a sufficient margin to prevent surface electric-charge effects such as perception by most people.

It is noteworthy that different methods for evaluation of conformity to the guidelines are provided for multiple-frequency exposure for low-frequency (below 100 kHz) and high-frequency (above 10 kHz) ranges. In the frequencies between 10 kHz and 100 kHz, both evaluation methods are applied (see Annex A).

6 Consideration in evaluating contact currents

6.1 General

Clause 6 describes items to be considered in evaluating contact currents:

a) assumed situations of human exposure to a contact current (6.2);
b) methods for evaluating a touch current used in electrical safety standards for references (6.3);
c) some proposed methods for evaluating contact currents (6.4).

6.2 Assumed situations of human exposure to contact current

6.2.1 General

There are several situations to be considered for human exposure to a contact current. Different cases have to be considered depending on the type of coupling between fields (electric or magnetic) and human bodies/objects.

6.2.2 Capacitive coupling (power line)

An electric field induces, by capacitive coupling (electrostatic induction), a voltage in a person or a conductive object that is isolated from the ground. When a person touches an object having a different potential, a contact current flows so as to cancel the potential difference. This can be categorized into two cases: (a) an isolated person touches a grounded object and (b) a grounded person touches an isolated object (especially a large object such as a bus or a truck) [6]. Comprehensive studies have been carried out for typical cases encountered under overhead transmission lines [7].

6.2.3 Inductive coupling (power line)

By inductive coupling (electromagnetic induction), a magnetic field induces a voltage, especially in long conductive objects such as telecommunication lines, fences and gas pipelines, having at least one reasonable grounding, when they are installed close to and parallel to magnetic field sources such as overhead power lines [8]. When a person touches the object, a contact current flows. In particular, in the case of fault condition in overhead power lines, the limit values for the open-circuit voltage in telecommunication lines are set by an international regulation-setting body [9]. In contrast to the capacitive coupling, grounding a conductive object at a large distance from the point of contact will actually increase the amplitude of the open-circuit voltage, thereby increasing the contact current.

6.2.4 Induction heating equipment

Induction heating (IH) equipment is heating equipment using the Joule effect produced by magnetically induced currents. For a domestic IH cooker, a metal pan or pot is heated by a magnetic field, and when a person touches a conductive part of the pan or pot, a contact current can occur typically in the frequency ranges of around 20 kHz to 100 kHz. The method used to evaluate human exposure to magnetic fields produced by IH cookers is standardized in IEC 62233 [10]; however, the contact current is not mentioned in IEC 62233. Note that it may be appropriate to categorize this exposure situation as an issue of electrical safety.

For industrial IH equipment, a method of evaluating touch current in terms of electrical safety is being standardized in IEC TC 27 (industrial electroheating and electromagnetic processing) for the frequency ranges between 1 kHz and 6 MHz [11].

6.2.5 Wireless power transfer (WPT)

A wireless power transfer (WPT) system is a system capable of transferring power between a transmitter and receiver using wireless technologies including electromagnetic induction. They are used for wirelessly charging mobile phones, tablet PCs, electric vehicles (EV) and, so forth. There are several types of WPT, and the frequency range used is from tens of kilohertz to tens of megahertz. When a conductive object is placed in the immediate vicinity of a system and a person touches it, a contact current can occur. As touching the metal body of an EV when charging using a WPT charging system may be the case [12], it may be appropriate to categorize the exposure situation as an issue of electrical safety. Details regarding exposure assessment methods for WPT systems are reported in IEC TR 62905 [13]. In IEC TR 62905, contact currents are considered for the conditions where ungrounded or grounded metal object is placed in the vicinity of WPT systems.

6.2.6 Broadcasting

Burns can occur at a point of contact between a human body and a metallic structure that is exposed to RF electromagnetic fields from nearby sources such as AM broadcast antennas. The contact point between the body and the structure often has a small area and the current injected into the body is concentrated near this point. This can result in a current density near the contact sufficiently strong to raise the local temperature and cause surface or deep burns [13].

6.3 Methods of measurement of touch current used in electrical safety standards

6.3.1 General

When considering the evaluation method for contact currents in the context of human exposure to electric, magnetic and electromagnetic fields, existing IEC standards related to electrical safety may be useful inputs.

6.3.2 IEC standards related to electrical safety

There are several IEC technical committees in charge of electrical safety. These include:

– TC 64: Electrical installations and protection against electric shock;

– TC 108: Safety of electronic equipment within the field of audio/video, information technology and communication technology;

– TC 61: Safety of household and similar electrical appliances;

– TC 99: System engineering and erection of electrical power installations in systems with nominal voltages above 1 kV AC and 1,5 kV DC, particularly concerning safety aspects;

– TC 66: Safety of measuring, control and laboratory equipment;

– TC 62/SC 62A: Common aspects of electrical equipment used in medical practice.

Table 1 summarizes the selected standards related to the electrical safety and the committees in which they were created [14]-[26]. Note that the “touch voltage”, the product of the touch current and the assumed body impedance, is commonly used as a parameter for setting limits for touch currents.

In IEC TS 60479-1 [20], a diagram of physiological effects for different touch currents and durations is shown (reproduced in Figure 1 and Table 2), which is commonly referenced in electrical safety standards as a basis for limiting touch currents.

Table 1 – Selected IEC technical committees and standards related to electrical safety

IEC TC	IEC standards related to electrical safety	Notes
TC 108, Safety of electronic equipment within the field of audio/video, information technology and communication technology	IEC 60065:2014, Audio, video and similar electronic apparatus – Safety requirements [14]	Stipulates touch voltage limits
	IEC 60950-1:2005, Information technology equipment – Safety – Part 1: General requirements IEC 60950-1:2005/AMD1:2009 IEC 60950-1:2005/AMD2:2013 [15]	Stipulates touch current limits
	IEC 60990:2016, Methods of measurement of touch current and protective conductor current [16]	Stipulates measuring method of touch current
	IEC 62368-1:2014, Audio/video, information and communication technology equipment – Part 1: Safety requirements [17]	"Hazard based safety engineering (HBSE)" is adopted
TC 61, Safety of household and similar electrical appliances	IEC 60335-1:2010, Household and similar electrical appliances – Safety – Part 1: General requirements IEC 60335-1:2010/AMD1:2013 IEC 60335-1:2010/AMD2:2016 [18]	Stipulates touch current limits
TC 64, Electrical installations and protection against electric shock	IEC 60364-4-41:2005, Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock IEC 60364-4-41:2005/AMD1:2017 [19]	
	IEC TS 60479-1:2005, Effects of current on human beings and livestock – Part 1: General aspects IEC TS 60479-1:2005/AMD1:2016 [20]	A diagram of physiological effects for different body currents and durations is shown
	IEC TS 60479-2:2017, Effects of current on human beings and livestock – Part 2: Special aspects [21]	
	IEC 61140:2016, Protection against electric shock – Common aspects for installation and equipment [22]	
	IEC TS 61201:2007, Use of conventional touch voltage limits – Application guide [23]	
TC 99, Insulation coordination and system engineering of high voltage electrical power installations above 1,0 kV AC and 1,5 kV DC	IEC 61936-1:2010, Power installations exceeding 1 kV a.c. – Part 1: Common rules IEC 61936-1:2010/AMD1:2014 [24]	Stipulates touch voltage limits
TC 66, Safety of measuring, control and laboratory equipment	IEC 61010-1:2010, Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 1: General requirements IEC 61010-1:2010/AMD1:2016 [25]	Stipulates touch current limits
TC 62/SC 62A, Common aspects of electrical equipment used in medical practice	IEC 60601-1:2005, Medical electrical equipment – Part 1: General requirements for basic safety and essential performance IEC 60601-1:2005/AMD1:2012 [26]	Stipulates "leakage current" limits

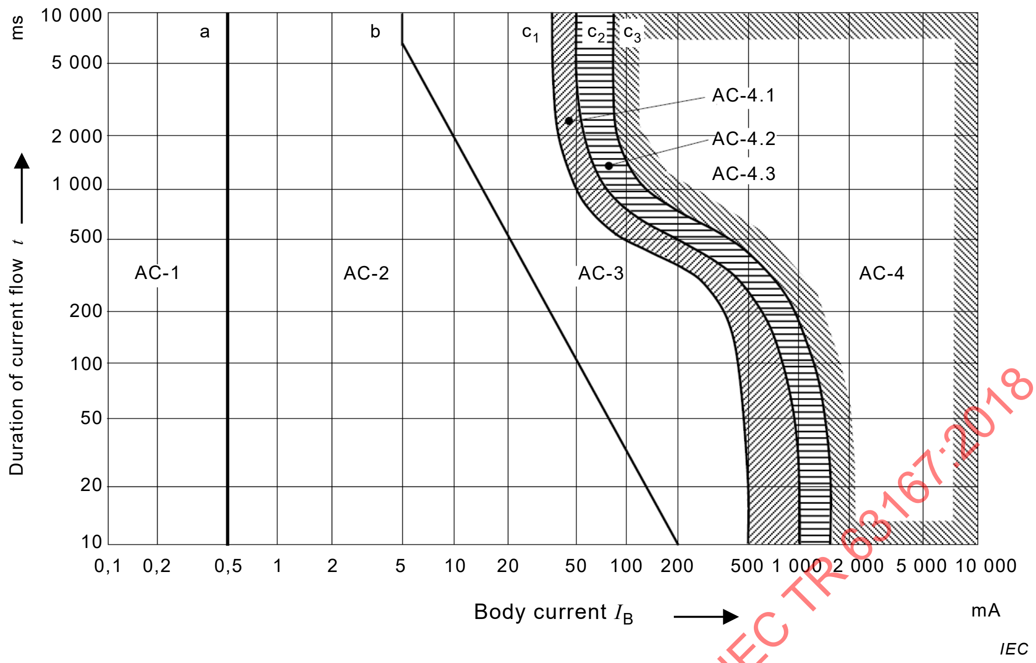


Figure 1 – Time/current zones of effects of alternating currents (15 Hz to 100 Hz) on persons for a current path corresponding to left hand to feet (for explanation see Table 2)

Table 2 – Time/current zones for alternating current 15 Hz to 100 Hz for hand to feet pathway – Summary of zones in Figure 1

Zones	Boundaries	Physiological effects
AC-1	Up to 0,5 mA curve a	Perception possible but usually no ‘startled’ reaction
AC-2	0,5 mA up to curve b	Perception and involuntary muscular contractions likely but usually no harmful electrical physiological effects
AC-3	Curve b and above	Strong involuntary muscular contractions. Difficulty in breathing. Reversible disturbances of heart function. Immobilization may occur. Effects increasing with current magnitude. Usually no organic damage to be expected
AC-4 [a]	Above curve c_1	Patho-physiological effects may occur such as cardiac arrest, breathing arrest, and burns or other cellular damage. Probability of ventricular fibrillation increasing with current magnitude and time
AC-4.1	c_1-c_2	Probability of ventricular fibrillation increasing up to about 5 %
AC-4.2	c_2-c_3	Probability of ventricular fibrillation up to about 50 %
AC-4.3	Beyond curve c_3	Probability of ventricular fibrillation above 50 %

[a] For durations of current flow below 200 ms, ventricular fibrillation is only initiated within the vulnerable period if the relevant thresholds are surpassed. As regards ventricular fibrillation, Figure 1 relates to the effects of current which flows in the path left hand to feet. For other current paths, the heart current factor has to be considered.

6.3.3 Modelling human body impedance

6.3.3.1 General

An impedance or an equivalent circuit of the human body is needed when deriving a touch voltage from a permissible touch current. In addition, when measuring touch or contact current, an appropriate circuit should be standardized. The following considerations have been made regarding the standardization of electrical safety.

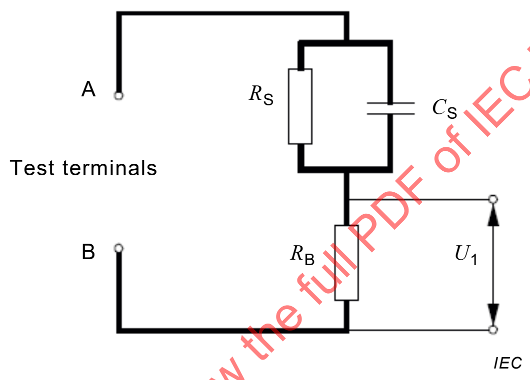
6.3.3.2 Dependence of human impedance on touch voltage

In IEC TS 60479-1 [20], it is shown that the impedance of the human body varies with the touch voltage, and data on this relationship are provided. In addition, the impedance of the human body for different current paths is also considered.

6.3.3.3 Frequency characteristics

In IEC 60990 [16], circuits that simulate the frequency characteristics of human body impedance are shown for the measurement of touch currents to be used for frequencies up to 1 MHz. The circuit shown in Figure 2 is for an "unweighted" touch current to be adopted for burns, while the circuit shown in Figure 3, which includes a weighting circuit, considers the human response of perception or reaction.

A similar circuit is also shown in IEEE C95.3 [27] (Figure 4). In IEEE C95.3, a simulated body impedance (standard load) that can be inserted in the measurement circuit when measuring the contact current is shown.



Key

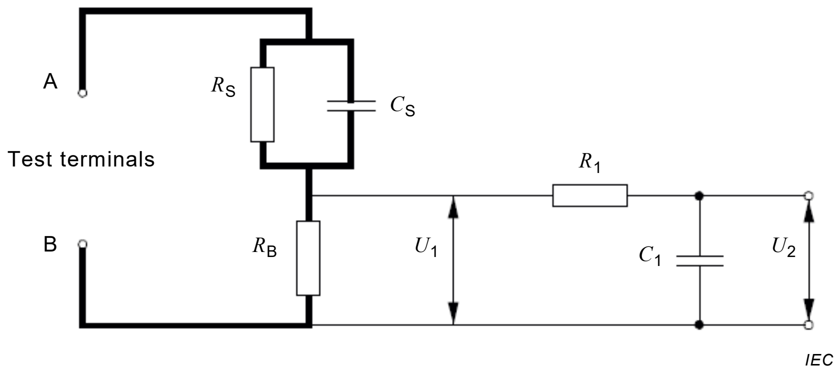
R_S 1 500 Ω

R_B 500 Ω

C_S 0,22 µF

Unweighted touch current = $\frac{U_1}{500}$ (RMS value)

Figure 2 – Measuring network for unweighted touch current [16]



Key

R_S	1 500 Ω	R_1	10 000 Ω
R_B	500 Ω	C_1	0,022 µF
C_S	0,22 µF		

Weighted touch current (perception or startle-reaction) = $\frac{U_2}{500}$ (peak value)

Figure 3 – Measuring network for touch current weighted for perception or startle-reaction [16]

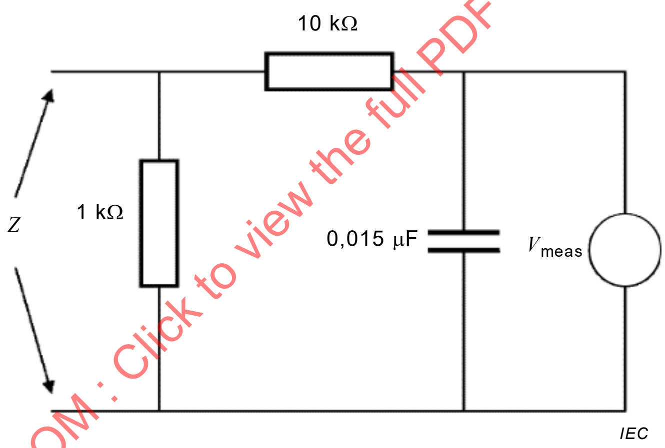


Figure 4 – Simulated body impedance for contact current measurements shown in IEEE C95.3 [27]

6.3.3.4 Consideration of touching boundary (skin impedance and contact area)

Well-investigated circuits for the human body impedance considering electrodes, skin impedances and spreading impedances have also been proposed for the frequency ranges from 10 kHz to 10 MHz [28] and from 75 kHz to 15 MHz [29] based on measurements made on human subjects. In IEC TS 62996 [11], which deals with the electrical safety of industrial electroheating and electromagnetic processing equipment, the circuit proposed in [28] was adopted with minor modification for frequencies from 1 kHz to 6 MHz.

In addition, the area of contact is stipulated in the safety standards to properly simulate the touching condition in measurements. In the proposed circuits in [28], [29] and [11] (Figure 5), “grip” and “finger” contacts can be considered. In the EMF guidelines (see Annex A), the assumed conditions of contact are “point contact” (area not specified) in ICNIRP guidelines [1], [2], and “touch contact” with a contact area of 1 cm^2 and “grasping contact” (applicable only for a controlled environment) with a contact area of 15 cm^2 for IEEE safety standards [3], [4].

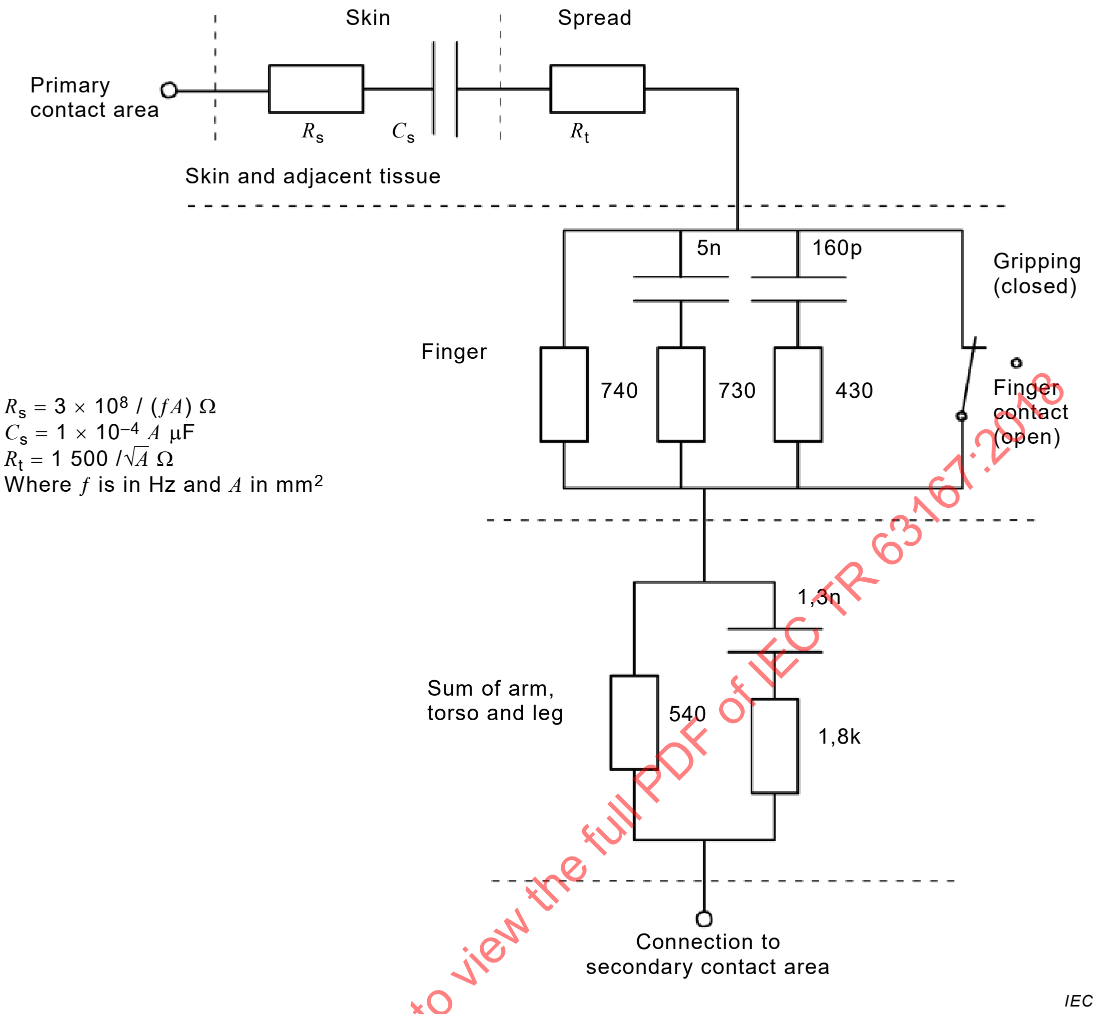


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Figure 5 – Impedances of various parts of the body proposed in IEC TS 62996 for 1 kHz to 6 MHz [11]

6.4 Proposed methods of measuring contact current

6.4.1 General

In 6.4, possible evaluation methods by the measurement of contact currents (or contact voltages) are described. To estimate the contact current, the following methods can be applied.

6.4.2 Contact current measurement using a human subject

It is straightforward to measure a contact current directly using a human subject itself for an exposure situation to be tested; however, special care must be taken to ensure the safety of the subject to avoid electric shock. This method is considered in Annex D of IEC 62311:2007, a generic IEC standard for EMF exposure [30]. For this case, a clamp-on current sensor (current transformer) can be used to measure the contact current flowing into a hand in contact with a conductive object. Another proposed method is measurement of the voltage difference between points of concern on a human body [31]. In this case, the contact current can be calculated from the obtained voltage difference and information on the impedance of the body between the points.

6.4.3 Contact current measurement using a human equivalent impedance/circuit

Considering the safety of human subjects and the repeatability of measurements, it is more suitable to use an impedance or a circuit that simulates the human body as a standardized measurement method for contact currents. The human-equivalent circuits shown in 6.3.3 can be used for this purpose.

In addition, for standardization, the area of the contact and the grounding condition should also be specified to ensure repeatability.

There are some products that are commercially available, for frequencies of 3 kHz to 3 MHz and for frequencies from 40 Hz to 110 MHz, for example. These instruments have a human equivalent circuit and provide a flat metal plate used as a ground plane. One of these instruments is capable of choosing a grasp or touch contact, while the other can measure the contact current through a real human body.

6.4.4 Contact current calculated from measurement of open-circuit voltage

An alternative method is to measure the open-circuit voltage (contact voltage) of a conductive object to be touched instead of the measurement of a contact current. The contact current can then be obtained by a calculation using the obtained voltage and information on the human-equivalent circuit.

For the calculation, the human-equivalent circuits shown in 6.3.3 can be used. In addition, more realistic human models with a few millimetre resolution have been developed for numerical calculation [32]-[35], and these models can be applied for this purpose. The realistic computational three-dimensional (3D) human body model is derived from 3D imaging technology such as MRI and CT scans, and the images are then meshed into voxels for numerical analysis. Such model and methodology can provide much more precise results than the simple circuit model. A typical human body model grasping an energized metal electrode is shown in Figure 6. The figure also shows the current density plots and current pathways that result through the computational human body using typical numerical electromagnetic simulation tools. When including such kind of a realistic human model into a standard, the model should be transparent.

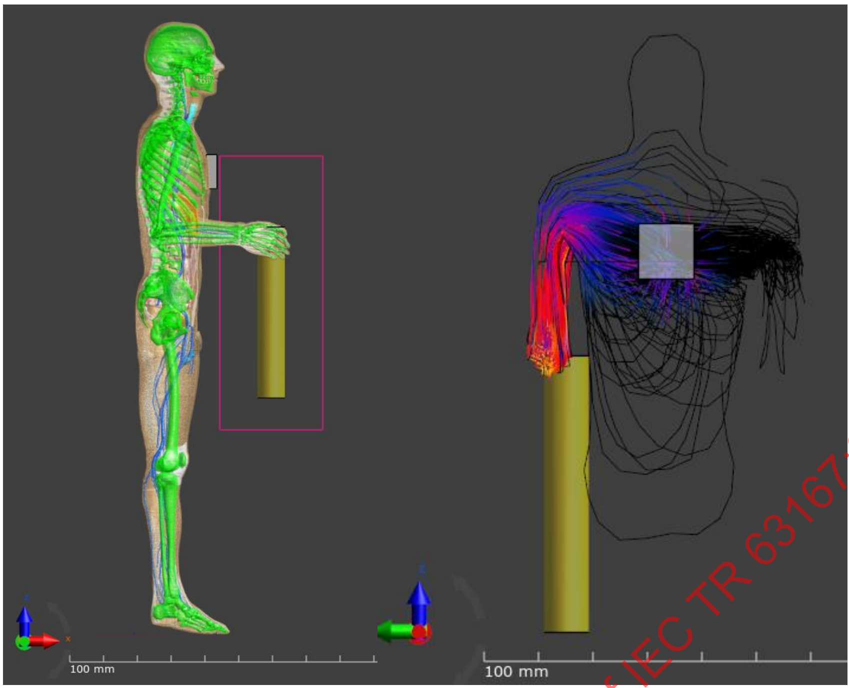

Figure 6 – Realistic computational 3D human body model and results of calculation of current density and pathway

7 Consideration in standardization of evaluation method for contact current

At the moment, there are no standardized methods for evaluating the contact currents in the context of human exposure to electric, magnetic and electromagnetic fields. In Clause 7, items to be considered in future standardization are discussed.

a) Scope: A future standard should clarify its scope, i.e. it should be limited to the issue of contact current related to the indirect effect of human exposure to electromagnetic fields, and exclude electrical safety issues. In addition, it should be clearly stated that only steady-state contact current as shown in international EMF guidelines is dealt with and that spark discharge is excluded.

b) Method of measuring contact current: A future standard should clearly specify the measuring method(s) for the contact current including:

- parameter to be measured (current or open-circuit voltage);
- experimental setup;
- human-equivalent circuit;
- type of contact (touch contact, grasping contact);
- specification of area of contact;
- condition of grounding;
- specifications of instrumentation used in the measurement.

Annex A
(informative)

Contact current limits in international EMF guidelines

There are two major international EMF guidelines limiting contact currents caused by exposure to electric, magnetic and electromagnetic fields. These are guidelines published by ICNIRP (International Commission on Non-Ionizing Radiation Protection) [1], [2] and EMF standards published by IEEE (Institute of Electrical and Electronics Engineers) [3], [4].

The limit values applied to steady-state (continuous) contact currents are shown in Table A.1 for ICNIRP (reference levels), and in Table A.2 for IEEE (MPE: maximum permissible exposure). The basic rationale for limiting the contact current for frequencies up to 110 MHz for two assumed exposure categories (general public and occupational/controlled environment) is identical, although there are slight differences in the limit values between them.

Table A.1 – Reference levels in ICNIRP guidelines for time varying contact current from conductive object [1], [2]

Exposure characteristics	Frequency range	Maximum contact current (mA)
Occupational exposure	up to 2,5 kHz	1,0
	2,5 kHz to 100 kHz	0,4 f
	100 kHz to 110 MHz	40
General public exposure	up to 2,5 kHz	0,5
	2,5 kHz to 100 kHz	0,2 f
	100 kHz to 110 MHz	20
NOTE f is frequency in kilohertz.		

Table A.2 – Maximum permissible exposure (MPE) levels of contact current in IEEE safety standards [3], [4]

Condition	Frequency range	Action level (mA-RMS)	Controlled environment (mA-RMS)
Contact, grasp (contact area: 15 cm^2)	0 Hz to 3 kHz	-	3,0
	3 kHz to 100 kHz	-	1,0 f
	100 kHz to 110 MHz	-	100
Contact, touch (contact area: 1 cm^2)	0 Hz to 3 kHz	0,5	1,5
	3 kHz to 100 kHz	0,167 f	0,5 f
	100 kHz to 110 MHz	16,7	50
NOTE f is expressed in kilohertz. The term “action level” is equivalent to the term “general public”.			

Regarding the type of contact, the ICNIRP guidelines assume “point contact”, while the IEEE standards assume both “touch contact” (with a contact area of 1 cm^2), and “grasping contact” (with a contact area of 15 cm^2, applicable only for a controlled environment). In the IEEE standards, it is stated that “the grasping contact limit pertains to controlled environments where personnel are trained to make grasping contact and to avoid touch contacts with conductive objects that present the possibility of painful contact”.

As the averaging time for the determination of compliance, the IEEE standards specify times of 0,2 s for frequencies less than 5 MHz and 6 min for frequencies above 100 kHz, while the ICNIRP guidelines do not explicitly specify the averaging time.