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Title: Draft BS IEC 60479-2 Effects of current on human beings and livestock. Part 2: Special aspects.

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



64/2450/CD

COMMITTEE DRAFT (CD)

PROJECT NUMBER: IEC 60479-2 ED2	
DATE OF CIRCULATION: 2020-05-29	CLOSING DATE FOR COMMENTS: 2020-07-24
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IEC TC 64 : ELECTRICAL INSTALLATIONS AND PROTECTION AGAINST ELECTRIC SHOCK	
SECRETARIAT: Germany	SECRETARY: Mr Wolfgang Niedenzu
OF INTEREST TO THE FOLLOWING COMMITTEES: TC 2,TC 7,TC 8,TC 9,TC 11,TC 13,TC 14,TC 17,TC 18,TC 22,TC 23,TC 26,TC 27,TC 29,TC 31,TC 32,TC 33,TC 34,TC 35,TC 36,TC 37,TC 38,TC 40,TC 42,TC 44,TC 45,TC 46,TC 47,TC 48,TC 49,TC 55,TC 57,TC 59,TC 61,TC 62,TC 65,TC 66,TC 69,TC 72,TC 76,TC 78,TC 79,TC 80,TC 81,TC 82,TC 85,TC 87,TC 88,TC 90,TC 91,TC 94,TC 95,TC 96,TC 97,TC 99,TC 100,TC 103,TC 104,TC 106,TC 107,TC 108,TC 109,TC 110,TC 112,TC 120,TC 121,ACOS,SyC LVDC	PROPOSED HORIZONTAL STANDARD: ☐ Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.
FUNCTIONS CONCERNED: ☐ EMC ☐ ENVIRONMENT ☐ QUALITY ASSURANCE ☒ SAFETY	

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TITLE:

Effects of current on human beings and livestock - Part 2: Special aspects

NOTE FROM TC/SC OFFICERS:

In this 1st Committee Draft of Edition 2 to IEC 60479-2, additions to the Edition 1.0 are marked in red while deleted text is hidden.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

Part 2: Special aspects

FOREWORD

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The International Standard IEC 60479-2 has been prepared by IEC technical committee 64: Electrical installations and protection against electric shock.

This second edition cancels and replaces the first edition published in 2019. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) Changes reflecting the change in applicability of frequency from 1 kHz to 150 kHz have been added.
- b) Further examination of short duration unidirectional pulses and the basis of their danger in charge rather than current is presented
- c) The handling of successive DC pulses has been clarified
- d) A full section on static electricity has been added.

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

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

FDIS	Report on voting
64/XXXX/FDIS	64/XXXX/RVD

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

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

A list of all parts in the IEC 60479 series, published under the general title *Effects of current on human beings and livestock*, can be found on the IEC website.

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

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

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

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

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

IEC 60479 consists of the following parts under the general title *Effects of current on human beings and livestock*

Part 1: General aspects

Part 2: Special aspects:

Part 3: void

Part 4: Effects of lightning strokes on human beings and livestock

EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

Part 2: Special aspects

1 Scope

This part of IEC 60479 describes the effects on the human body when a sinusoidal alternating current in the frequency range above 100 Hz passes through it.

The effects of current passing through the human body for:

- alternating sinusoidal current with DC components;
- alternating sinusoidal current with phase control;
- alternating sinusoidal current with multicycle control

are given but are only deemed applicable for alternating current frequencies from 15 Hz up to 100 Hz.

Means of extending the frequency of applicability of pure sinusoids to a frequency of 150 kHz are given, supplementing the data in IEC 60479-1.

Means of examining random complex irregular waveforms are given.

This document describes the effects of current passing through the human body in the form of single and multiple successive unidirectional rectangular impulses, sinusoidal impulses and impulses resulting from capacitor discharges.

Additionally, recent additions address the following items:

- *Special waveforms are documented including AC waveforms with DC components, and AC waveforms with phase control and multicycle control. AC waveforms of mixed frequency are examined.*
- *Single bursts of current pulses are documented along with the effect of repeated current pulses with repetition rates in two ranges within 10-70 pulses per second (PPS) regions.*
- *The immersed human body is considered.*
- *Unidirectional impulse currents form an important update to the document. Whereas energy, in various forms, of applied pulses has been postulated as the important injuring parameter in the past, re-evaluation of the research shows that charge transfer is the key parameter. Consequently, the standard has been made contemporary by documenting this re-orientation. The values specified are deemed to be applicable for impulse durations from 0,001 ms up to and including 10 ms.*
- .

- *A full discussion of static electricity, its effects on the human body and the safety of static discharge have been included.*

This document only considers conducted current resulting from the direct application of a source of current to the body, as does IEC TS 60479-1 and IEC 60479-3. It does not consider current induced within the body caused by its exposure to an external electromagnetic field.

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

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

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC TS 60479-1:2005, *Effects of current on human beings and livestock – Part 1: General aspects*

IEC TS 60479-1:2005/AMD1:2016

IEC 60990, *Methods of measurement of touch-current and protective conductor current*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 60479-1 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>

3.1 frequency factor

F_f

ratio of the threshold current for the relevant physiological effects at the frequency f to the threshold current at 50/60 Hz.

Note 1 to entry. The frequency factor differs for perception, let-go and ventricular fibrillation.

3.2 phase control

process of varying the instant within the cycle at which current conduction in an electronic valve device or a valve arm begins

[SOURCE: IEC 60050-551:1998, 551-16-23]

3.3 phase control angle

current delay angle

time expressed in angular measure by which the starting instant of current conduction is delayed by phase control

[SOURCE: IEC 60050-551:1998, 551-16-32, modified — the term "phase control angle" has been added.]

3.4 multicycle control

process of varying the ratio of the number of cycles which include current conduction to the number of cycles in which no current conduction occurs

[SOURCE: IEC 60050-551:1998, 551-16-31]

3.5 multicycle control factor

p

ratio between the number of conducting cycles and the sum of conducting and non-conducting cycles in the case of multicycle control

SEE Figure 13.

[SOURCE: IEC 60050-551:1998, 551-16-37, modified — the symbol and reference to Figure 13 have been added.]

3.6 specific or unitary energy – deleted

3.7 specific fibrillating charge

F_q

minimum $I \cdot t$ value of unidirectional impulse of short duration which under given conditions (current-path, heart-phase) causes ventricular fibrillation with a certain probability

Note 1 to entry: F_q is determined by the form of the impulse as the integral

$$\int_0^{t_i} i dt$$

where t_i is defined in Figure 20 and Figure 21.

Note 2 to entry: F_q is expressed in C or As.

3.8 time constant

time required for the amplitude of an exponentially decaying quantity to decrease to

$$\frac{1}{e} = 0,3679$$

times an initial amplitude

[SOURCE: IEC 60050-801:1994, 801-21-45, modified — the definition has been revised.]

3.9 shock-duration of a capacitor discharge

t_i

time interval from the beginning of the discharge to the time when the discharge current has fallen to 5 % of its peak value

Note 1 to entry: When the time constant of the capacitor discharge is given by T , the shock-duration of the capacitor discharge is equal to $3T$, the time for the current to fall to 0.049 of its initial value. During the shock-duration of the capacitor discharge practically all the available current (~95%) from the impulse is dissipated.

Note 2 to entry: See Figure 20 and Figure 21.3.10 shock-duration for complex asymptotic waveform

t_i

shortest duration of that part of the impulse that contains 95 % of the energy over the total impulse

3.11 threshold of perception

minimum value for the charge of electricity which under given conditions causes any sensation to the person through whom it is flowing

3.12
threshold of pain

minimum value for the charge ($I \cdot t$) that can be applied as an impulse to a person holding a large electrode in the hand without causing pain

3.13
pain

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

EXAMPLE: Electric shock above the threshold of pain described in 11.3, the sting of a bee or burn of a cigarette.

3.14
antistatic material

material exhibiting properties which minimize charge generation when rubbed against or separated from the same or other similar materials

3.15
electromagnetic compatibility (EMC)

ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

3.16
electrostatic discharge (ESD)

transfer of electric charge between bodies of different electrostatic potential in proximity or through direct contact

3.17
energy storage capacitor

capacitor of the ESD-generator representing the capacity of a human body charged to the test voltage value

3.18
EUT

equipment under test

3.19
threshold of let-go

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

432 **3.20**

433

434 **Startle Reaction**

435 an extremely rapid psychophysiological response of an organism to a sudden and
436 unexpected stimulus

437

438

4 Effects of alternating currents with frequencies above 100 Hz

NOTE Values for 50/60 Hz are given in IEC TS 60479-1. For frequencies up to 100 Hz the provisions of IEC TS 60479-1 are used.

4.1 General

Electric power in the form of alternating current at frequencies higher than 50/60 Hz is increasingly used in modern electrical equipment, for example aircraft (400 Hz), power tools and electric welding (mostly up to 450 Hz), electrotherapy (using mostly 4000 Hz to 5000 Hz) and switching mode power supplies (20 kHz to 1 MHz).

Little experimental data is available for Clause 4, therefore the information given herein should be considered as provisional only but may be used for the evaluation of risks in the frequency ranges concerned (see Bibliography).

Recent experiments in governmental funded projects are ongoing to exploit and investigate the effects of higher frequencies using the latest technologies and methods to justify existing extrapolation of the frequency factor for ventricular fibrillation (VF) threshold.

Attention is also drawn to the fact that the impedance of human skin decreases approximately inversely proportional to the frequency for touch voltages in the order of some 10's of volts, so that the skin impedance at 500 Hz is only about 10% of the skin impedance at 50 Hz and may be neglected in many cases. This impedance of the human body at such frequencies is therefore reduced to its internal impedance Z_i (see IEC TS 60479-1).

NOTE Use of peak measurements: at current levels that produce physiological responses of perception, startle reaction and inability of let-go, the physiological response from non-sinusoidal and mixed frequency periodic current is best indicated by the peak value of an output signal from measuring circuits containing a frequency-weighting network such as those described in IEC 60990.

These frequency weighting networks attenuate the signal according to the frequency factors given in IEC TS 60479-1:2005 and IEC TS 60479-1:2005/AMD1:2016, Clause 4 so that the output signal corresponds to a constant level of physiological response. Attenuation is provided for narrow impulses of current that would produce less physiological response because of the short duration of their peak value. The network output allows a fixed value to be read independent of waveshape or mix of frequencies to be provided for ease of determination of the leakage current and evaluation of the level of hazard present.

Comparable physiological effects are produced by non-sinusoidal and sinusoidal current producing the same peak value by this measurement method.

A representative network can be found in IEC 60990 and in bibliographic reference. [1]

4.2 Effects of alternating current in the frequency range above 100 Hz up to and including 1 kHz

4.2.1 Threshold of perception

For the threshold of perception, the frequency factor is given in Figure 1.

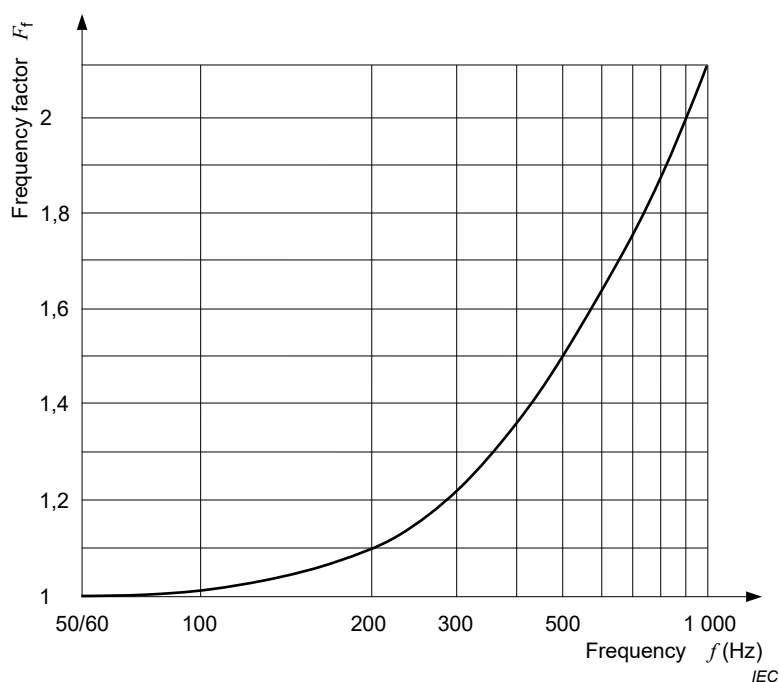


Figure 1 – Variation of the threshold of perception within the frequency range 50/60 Hz to 1 kHz

4.2.2 Threshold of let-go

For the threshold of let-go the frequency factor is given in Figure 2.

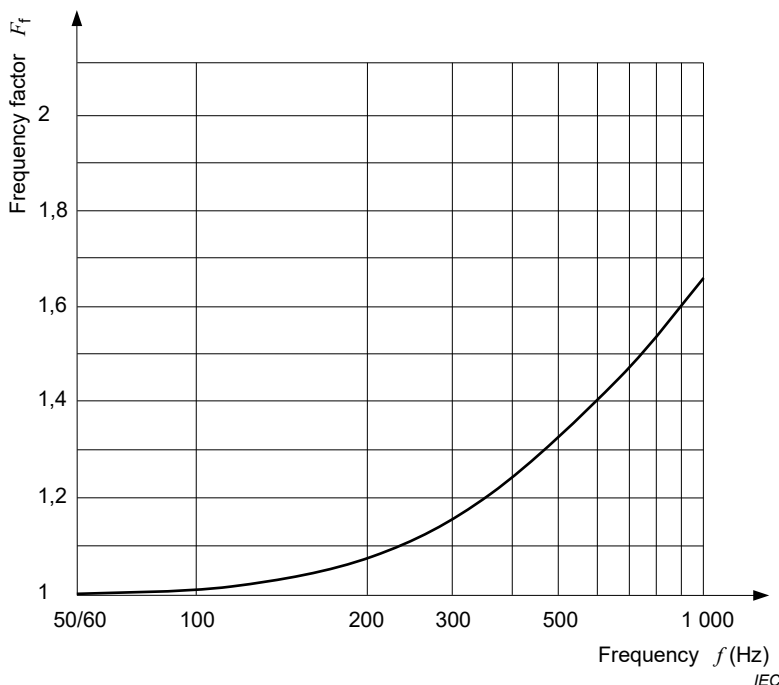
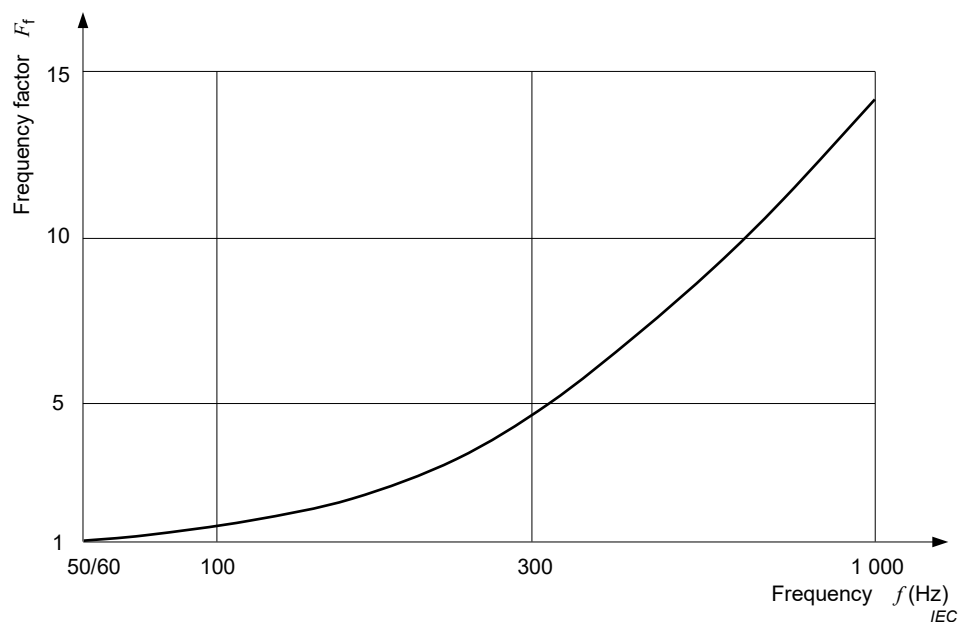


Figure 2 – Variation of the threshold of let-go within the frequency range 50/60 Hz to 1 kHz

4.2.3 Threshold of ventricular fibrillation

For shock durations longer than the cardiac cycle, the frequency factor for the threshold of fibrillation for longitudinal current paths through the trunk of the body is given in Figure 3.

489 For shock durations shorter than the cardiac cycle no experimental data is available on the
490 effects of frequency.



491
492 **Figure 3 – Variation of the threshold of ventricular fibrillation within the frequency range**
493 **50/60 Hz to 1 kHz, shock durations longer than one heart period and longitudinal current paths**
494 **through the trunk of the body**

495
496 **4.3 Effects of alternating current in the frequency range above 1 kHz up to and**
497 **including 10 kHz**

498 **4.3.1 Threshold of perception**

499 For the threshold of perception the frequency factor is given in Figure 4.

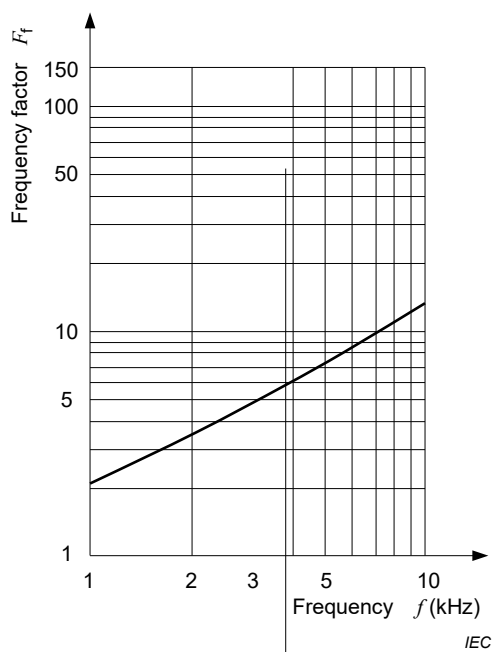


Figure 4 – Variation of the threshold of perception within the frequency range 1 kHz to 10 kHz

4.3.2 Threshold of let-go

For the threshold of let-go the frequency factor is given in Figure 5.

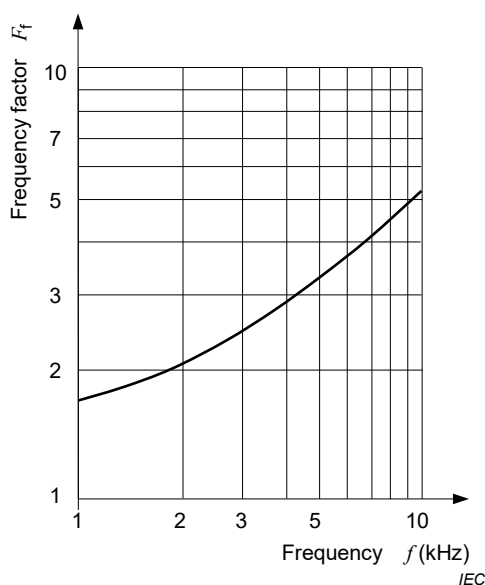


Figure 5 – Variation of the threshold of let-go within the frequency range 1 kHz to 10 kHz

4.3.3 Threshold of ventricular fibrillation

For frequencies between 1 kHz and 10 kHz the provisions of 4.4.4 are used.

4.4 Effects of alternating current in the frequency range above 10 kHz

4.4.1 General

In 4.4, changes have not been made to the threshold of perception, or the threshold of let-go for higher frequencies. While these are important thresholds, the most dangerous is that of

ventricular fibrillation. The fibrillation threshold is therefore given up to 150 kHz. The remaining thresholds may be considered as in the paragraphs below up to the frequency limits shown.

4.4.2 Threshold of perception

For frequencies between 10 kHz and 100 kHz the threshold rises approximately from 10 mA to 100 mA (RMS values).

For frequencies above 100 kHz the tingling sensation characteristic for the perception at lower frequencies changes into a sensation of warmth for current intensities in the order of ~100 milliamperes.

4.4.3 Threshold of let-go

For frequencies above 100 kHz there is neither experimental data nor reported incidents concerning the threshold of let-go.

4.4.4 Threshold of ventricular fibrillation

For shock durations longer than the cardiac cycle, the frequency factor for the threshold of fibrillation for longitudinal current paths through the trunk of the body for the frequency range above 1 kHz up to and including 150 kHz is given in Figure 6.

For frequencies above 1 kHz, thermal effects are more likely to become dominant.

For shock durations shorter than the cardiac cycle, no experimental data is available.

Figure 6 – Variation of the frequency factor of the threshold of ventricular fibrillation for continuous sinusoidal current for use from 1 kHz to a maximum of 150 kHz

4.4.5 Other effects

Burns may occur at frequencies above 100 kHz and current magnitudes in the order of amperes depending on the duration of the current flow.

5 Effects of special waveforms of current

5.1 General

As is to be expected, the effects of such currents on the human body are between those caused by direct and by alternating current; therefore equivalent current magnitudes with regard to ventricular fibrillation can be established.

Clause 5 describes the effects of current passing through the human body for:

- alternating sinusoidal current with DC components,
- alternating sinusoidal current with phase control,
- alternating sinusoidal current with multicycle control.

NOTE Other waveforms are under consideration.

The information given is deemed applicable for alternating current frequencies from 15 Hz up to 100 Hz.

5.2 Equivalent magnitude, frequency and threshold

In 5.2 the hazard may be taken as being approximately the same effect as with an equivalent pure alternating sinusoidal current I_{ev} having the following characteristics:

- Magnitude equivalence:

The following current magnitudes have to be distinguished:

I_{RMS} = RMS value of the current of the proposed waveform,

I_p = peak value of the current of the proposed waveform,

I_{pp} = peak-to-peak value of the current of the proposed waveform,

I_{ev} = RMS value of a sinusoidal current presenting the same effect as the waveform concerned.

NOTE The current I_{ev} is used instead of the current I_B in Figures 20 and 22 of IEC TS 60479-1:2005 to estimate the risk of ventricular fibrillation.

Most physiological effects are related to the filtered peak current (in magnitude and in duration) with the natural body filter defined by the frequency factor F . The peak value of the current should be used in all cases except where there is a known relationship between the RMS value and the peak value, i.e. pure sinusoidal current.

- Frequency equivalence

The waveform under study has a time period equal to the period of the equivalent sinusoidal waveform.

- Threshold equivalence

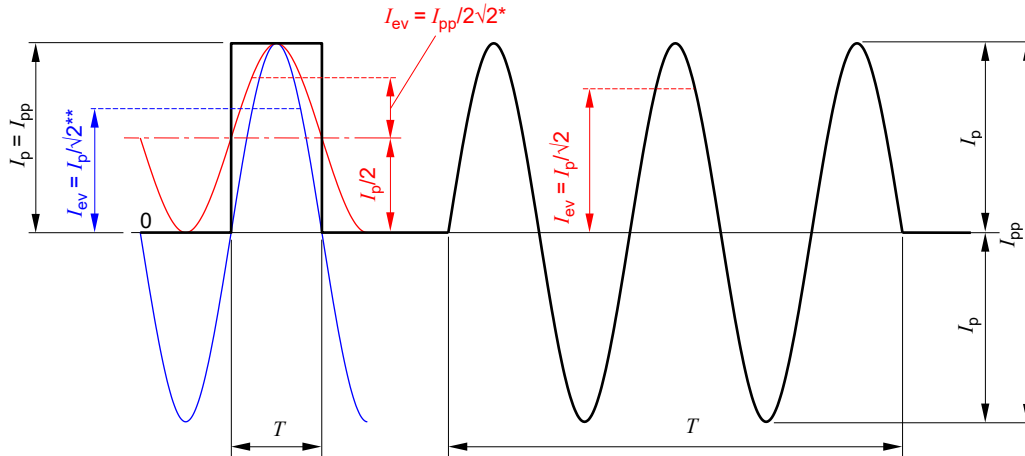
The different current thresholds (perception, inability of let-go and ventricular fibrillation) for waveforms consisting of specific ratio of alternating to direct current is equivalent as for a pure sinusoidal alternating current with a current having the characteristic equal to I_{ev} .

This I_{ev} value is different for each of these thresholds.

5.3 Effects of alternating current with DC components

5.3.1 Waveforms and frequencies and current thresholds

Figure 7 shows typical waveforms which are dealt with in 5.3.1. Pure DC and pure AC are represented as well as combined waveforms of various ratios AC to DC.

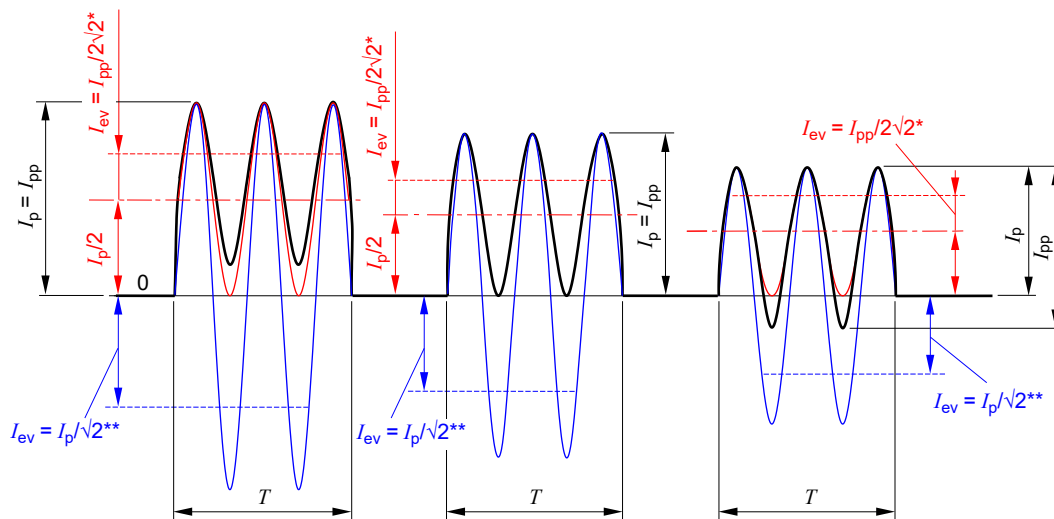


* for shock duration >1,5 cardiac cycle

** for shock duration <0,75 cardiac cycle

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a) Combined waveforms of various ratios AC to DC together with rectangle pulse for shock duration >1,5 and <0,75 of the cardiac cycle



* for shock duration >1,5 cardiac cycle

** for shock duration <0,75 cardiac cycle

IEC

b) Combined waveforms of various ratios AC to DC of mixed frequencies for shock duration >1,5 and <0,75 of the cardiac cycle

Figure 7 – Waveforms of currents

5.3.2 Threshold of startle reaction

The threshold of startle reaction depends on several parameters such as the area of the body in contact with an electrode (contact area), the conditions of contact (dry, wet, pressure, temperature) and also on the physiological characteristics of the individual.

These effects are related to the peak value of the current and the currents have to be combined frequency by frequency to estimate the total effect.[2,3] A measurement circuit is described in IEC 60990.

5.3.3 Threshold of let-go

The threshold of let-go depends on several parameters, such as the contact area, the shape and the size of the electrodes and also on the physiological characteristics of the individual.

From the standpoint of let-go (hand contacts with energized circuitry that can last a few seconds), this document uses the Dalziel research to determine the let-go current threshold for combinations of alternating current and direct current.[4,5] The frequency of the alternating current in this case was 60 Hz and 7,07 mA peak AC (5 mA RMS for a sinusoidal current) and 30 mA DC were used as the touch current thresholds for pure AC and DC respectively. These thresholds are considered to be adequate to represent the entire population (including children) from inability to let-go.

The equation, $I_{AC\ peak} = 7,176 \times \exp(-0,143 \times DC) - 0,106$, represents this combined AC and DC case and may be used to calculate the result of any combination of AC and DC in the range specified.

The following Figure 8 illustrates the Dalziel information.

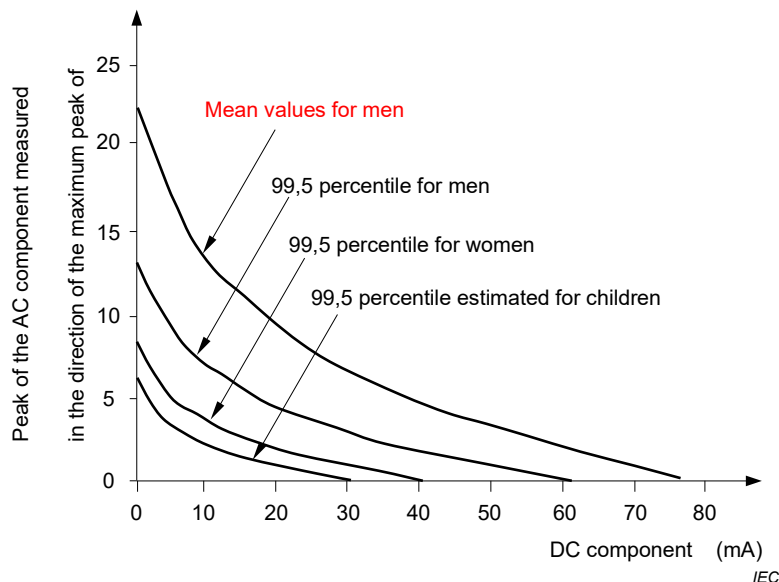


Figure 8 – Let-go thresholds for men, women and children

The above curves can be described by an equation fitted to the data.

The equation, $I_{AC\ peak} = 12,891 \times \exp(-0,069 \times DC) - 0,191$ represents the 99,5-percentile curve for men.

The equation, $I_{AC\ peak} = 8,523 \times \exp(-0,105 \times DC) - 0,126$ represents the 99,5-percentile curve for women.

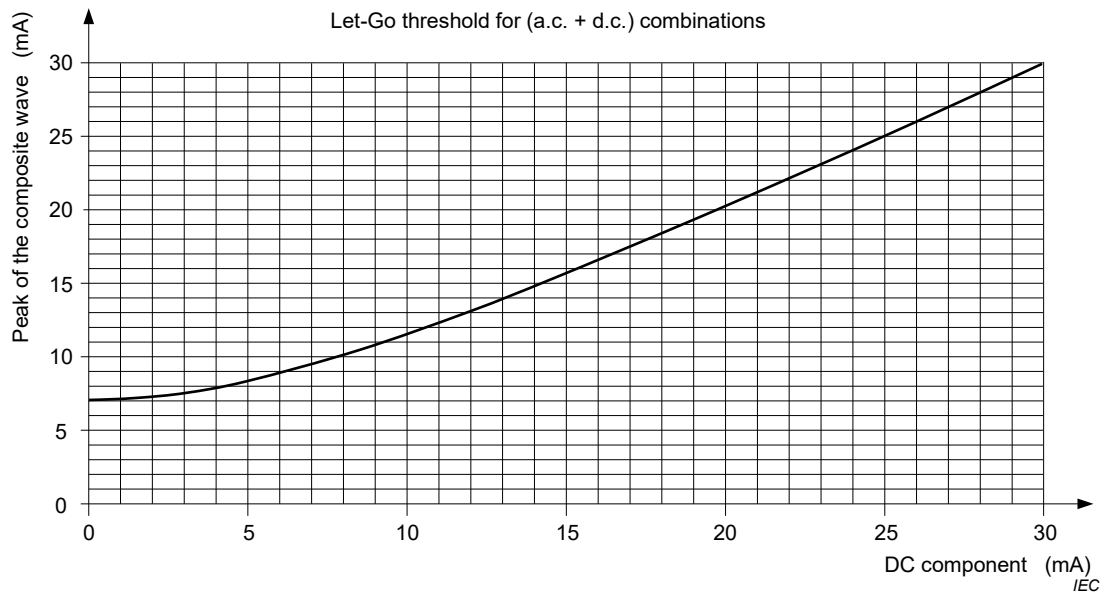
The equation, $I_{AC\ peak} = 6,395 \times \exp(-0,139 \times DC) - 0,095$ represents the 99,5-percentile estimated curve for children.

For practical considerations, some standards allow for some ripple (e.g. up to 10 %) on a DC supply as an exception.

Figure 9 shows the let-go threshold expressed in peak mA for combinations of 50/60 Hz sinusoidal alternating current and direct current. The peak of the composite AC and DC wave in mA at the let-go threshold estimated for the population of humans, including children, is shown as a function of the direct current component in mA.

Figure 9 is represented by the equation for the composite current:

623 $I_{AC \text{ peak}} + I_{DC} = 7,176 \times \exp(-0,143 \times DC) - 0,106 + DC$



624

625 **Figure 9 – 99,5 percentile let-go threshold for combinations**
 626 **of 50/60 Hz sinusoidal alternating current and direct current**

627 These effects are related to the peak value of the current **and the currents have to be combined**
 628 **frequency by frequency to estimate the total effect.** [7] A measurement circuit is described in
 629 IEC 60990.

630 5.3.4 Threshold of ventricular fibrillation

631 5.3.4.1 Waveforms consisting of specific ratios of alternating to direct 632 current

633 The fibrillation hazard may be taken as being approximately the same as with an equivalent
 634 alternating sinusoidal current I_{ev} having the following characteristics:

- 635 a) For shock durations longer than approximately 1,5 times the period of the cardiac cycle, I_{ev} is the
 636 RMS value of the sinusoidal alternating current having the same peak-to-peak value I_{pp} as the
 637 current of the waveform concerned.

638
$$I_{ev} = \frac{I_{pp}}{2\sqrt{2}}$$

- 639 b) For shock durations shorter than approximately 0,75 times the period of the cardiac cycle, I_{ev} is
 640 the RMS value of the sinusoidal alternating current having the same peak value I_p as the current
 641 of the waveform concerned.

642
$$I_{ev} = \frac{I_p}{\sqrt{2}}$$

643 NOTE 1 This correlation is the least applicable the smaller the ratio AC to DC becomes. For pure DC shocks of a duration
 644 less than 0,1 s the threshold is equal to the corresponding RMS value of the alternating current (see Figure 20 and Figure
 645 22 in IEC TS 60479-1:2005 respectively).

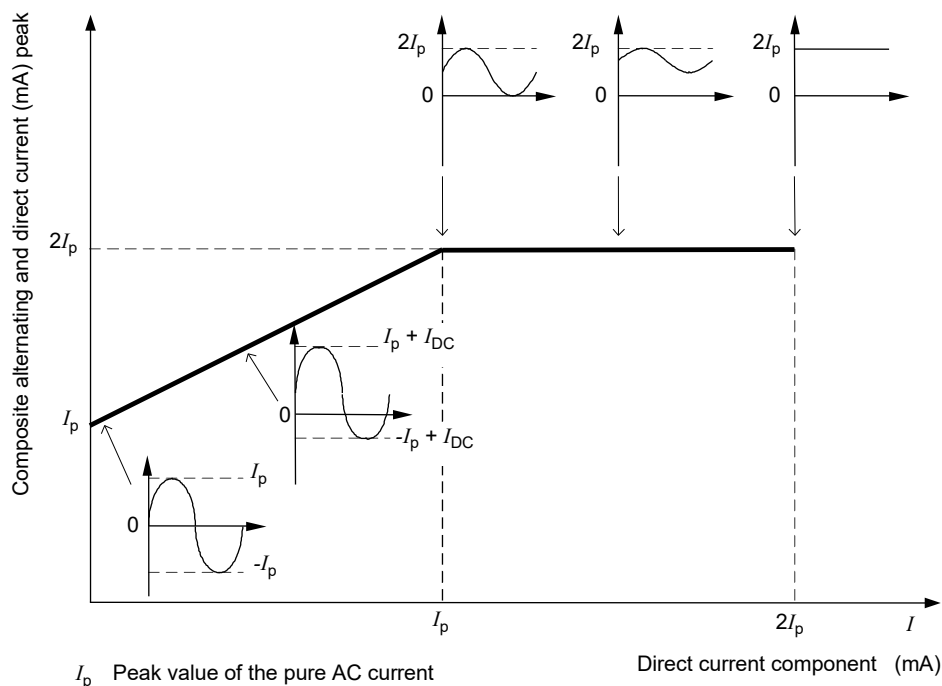
- 646 c) In the duration range from 0,75 to 1,5 times the period of the cardiac cycle, the amplitude
 647 parameter changes from peak value to peak-to-peak value.

648 NOTE 2 The details of the nature of the transition that takes place are subject to further studies.

According to Knickerbocker's findings, the likelihood of ventricular fibrillation for a combination of 50/60 Hz sinusoidal alternating and direct current lasting a few seconds or more is the same for a purely sinusoidal current of the same duration if the following is true.[6] The pure 50/60 Hz sinusoidal alternating current has the same peak-to-peak value as the peak-to-peak value of the combination current waveform provided that the direct current component is not large enough to preclude reversal of the instantaneous current (to prevent zero crossing) during each cycle. For example, the combination of a 40 mA RMS 50/60 Hz sinusoidal current combined with direct current up to $40 \cdot \sqrt{2}$ mA has approximately the same likelihood of causing ventricular fibrillation as a 40 mA RMS 50/60 Hz sinusoidal current alone.

Where the exposure is a few seconds or more and the direct current component is large enough so that the instantaneous current does not reverse during each cycle, then the composite of alternating plus direct current has the same likelihood of ventricular fibrillation when the peak value of the composite current is the same as the peak-to-peak value of the 50/60 Hz purely sinusoidal alternating current. For example, the combination of a 50/60 Hz sinusoidal current and direct current with a peak value of $80 \cdot \sqrt{2}$ mA ($2 \cdot I_p$) (with no reversal of the instantaneous current during each cycle) has approximately the same likelihood of causing ventricular fibrillation as a 40 mA RMS 50/60 Hz sinusoidal current with no direct current added.

Figure 10 illustrates an example in which the likelihood of ventricular fibrillation for sinusoidal alternating current (including 20 Hz, 50 Hz, and 60 Hz) combined with direct current is the same.



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NOTE The peak to peak value I_{pp} remains constant up until the I_p value and then the peak value of the composite remains constant at a value of two times the peak of the AC with no DC component.

Figure 10 – Composite alternating and direct current with equivalent likelihood of ventricular fibrillation

5.3.4.2 Examples of rectified alternating current

Figure 11 shows the waveforms for half wave and full wave rectification. For these waveforms the peak value of the current is identical to its peak-to-peak value.