IEC/TR 60479-5

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TECHNICAL REPORT

RAPPORT TECHNIQUE

Effects of current on human beings and livestock –
Part 5: Touch voltage threshold values for physiological effects

Effets du courant sur l'homme et les animaux domestiques –
Partie 5: Valeurs des seuils de tension de contact pour les effets physiologiques

IEC/TR 60479-5:2007

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FOREWORD

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IEC/TR 60479-5, which is a technical report, has been prepared by IEC technical committee 64: Electrical installations and protection against electric shock.

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

Enquiry draft	Report on voting
64/1585/DTS	64/1611/RVC

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

A list of all the parts in the IEC 60479 series, 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 publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

INTRODUCTION

This technical report provides a methodology for estimating voltage thresholds which are intended to give guidance to IEC technical committees on the selection and application of voltage limits with regard to protection against electric shock. Technical committees may use this methodology to recalculate proposed voltage thresholds or to determine new voltage threshold values based on different pathways, other current threshold values, different alternating current frequencies, other skin capacitances values, etc.

To estimate the type and severity of physiological effects that might be caused by electricity, the magnitude and pathway of current through a person's body needs to be determined. However, from an equipment design point of view, it is advantageous to be able to predict whether unwanted physiological effects are possible or probable, given only information about voltage levels on accessible conductive surfaces. If the maximum available voltage is sufficiently low under the expected circumstances to be unable to cause enough touch current to cause unwanted physiological effects, then the safeguards normally required to avoid the occurrence of these physiological effects may be reduced or eliminated. Voltages below critical levels that are unlikely to be hazardous in this respect have normally been called extra-low voltage (ELV). Based on this information technical committees may wish to review their defined values of extra-low voltage.

The objective of this technical report being to derive touch voltage threshold values corresponding to zones of physiological effects (as presented in Figures 20 and 22 of IEC/TS 60479-1), the introduction of such techniques gives designers the ability to provide a larger variety of circuits that give the expected level of user protection under a broader set of circumstances than previously considered.

The physiological effects corresponding to the threshold voltage values should be the same as those for touch current that appear in IEC/TS 60479-1. Physiological effects considered in this technical report are startle reaction of current, effects involving muscular contractions such as inability to let-go and ventricular fibrillation. Current thresholds are based on curves a, b and c_1 in IEC/TS 60479-1 which remains the prime standard. The touch voltage thresholds are related to the touch current thresholds by the body impedance according to Ohm's law. However, in this case, the application of Ohm's law is not straightforward. Body impedance is a function of a number of variables including the voltage across the body, the current pathway, the area of contact between the skin and the conductive surface, the level of moisture in the contact area, and the duration of voltage across (or current through) the body. When voltage is applied to the body and current begins to flow, the resistive component of the skin impedance changes to a lower value within a few tens of milliseconds.

This technical report discusses 50/60Hz sinusoidal alternating voltage and pure direct voltage having no significant alternating component. Higher frequency alternating voltage is not included in this type of analysis as this would require a more complex body impedance model and would require the use of frequency factors for the current thresholds for the unwanted physiological effects. As this technical report does not cover frequencies above 50/60Hz, technical committees are requested to inform IEC/TC 64 about experience gained on this subject. Suggestions for modifications and additions to the report should be submitted to IEC/TC 64.

This work does not relieve the responsibility of IEC technical committees to consider the usual touch current commonly measured in product evaluations.

EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

Part 5: Touch voltage threshold values for physiological effects

1 Scope

IEC/TR 60479-5, which is a technical report, provides touch voltage-duration combination thresholds based on analysis of information concerning body impedances and current thresholds of physiological effects, as given in IEC/TS 60479-1. Such threshold combinations relate to specific environmental and contact conditions that determine body impedance for particular current pathways.

This technical report considers only

(i) 50/60 Hz sinusoidal alternating voltage having no other frequency components and no significant direct voltage component, and

(ii) direct voltage with no significant alternating component.

This technical report provides thresholds as a result of calculations based on values from IEC/TS 60479-1, with uncertainties. Therefore thresholds proposed in this report also correspond to values with uncertainties.

This technical report does not consider immersion of body parts and medical application.

Touch voltage-duration combination thresholds are for use by technical committees as guidance for the determination of limits for touch voltage and touch voltage durations in various environmental situations.

Determination of limits needs to be based on risk assessment. Factors that are part of risk assessment include voltage threshold values (taking into account contact area, skin moisture condition, body current pathway) provided by this technical report, as well as other factors not covered such as:

– reduction of the likelihood of contact (by obstacles, barriers, warnings, placing out of reach, training, etc.); or
– reduction of touch voltage compared to the fault voltage (such as by equipotential bonding); or
– additional resistance in series with the human body (such as gloves, shoes, carpet, etc.).

2 Normative references

The following referenced documents are indispensable for the application 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 60050-195, *International Electrotechnical Vocabulary – Part 195: Earthing and protection against electric shock*

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

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

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
touch current
electric current passing through a human body or through an animal body when it touches one or more accessible parts of an installation or of equipment

[IEV-195-05-21]

3.2
touch voltage
voltage between conductive parts when touched simultaneously by a person or an animal

[IEV 195-05-11]

NOTE The touch voltage may be different from the open-circuit voltage between those conductive parts.

3.3
threshold
level of stimulus just strong enough to produce a response

NOTE A threshold is not the same as a limit which includes risk assessment, safety margins, etc.

3.3.1
voltage threshold for startle reaction
minimum derived value of touch voltage for a population for which a current flowing through the body is just enough to cause involuntary muscular contraction to the person through which it is flowing

3.3.2
voltage threshold for strong muscular reaction
minimum derived value of touch voltage for a population for which a current flowing through the body is just enough to cause involuntary contraction of a muscle, such as inability to let-go from an electrode (a.c.), but not including startle reaction

3.3.3
voltage threshold for ventricular fibrillation
minimum derived value of touch voltage for a population for which a current flowing through the body is just enough to cause ventricular fibrillation

3.4
long duration
duration corresponding to the vertical asymptote of the “b” and “c_1” curves of IEC/TS 60479-1 (e.g. 10 s)

3.5
short duration
any duration less than long duration

4 Conditions and threshold values

4.1 General

Physiological effects of electricity through the human body are caused by current passing through the body. In order to estimate the type and severity of physiological effects that might be caused by electricity, the magnitude and pathway of current through a person’s body must be determined. However, from an equipment design point of view, it is advantageous to be able to predict whether unwanted physiological effects are possible or probable, armed only with information concerning voltage levels on accessible conductive surfaces. If the maximum available voltage is sufficiently low to be unable to cause enough touch current to cause unwanted physiological effects, then the safeguards normally required to avoid the occurrence of these physiological effects may be reduced or eliminated.

NOTE This technical report only estimates the touch voltage and not the effect of the source impedance. This results in the worst case situation. In this report the prospective touch voltage is considered as equal to the effective touch voltage, as defined in IEC 60050-195.

4.2 Physiological effects of touch current

Thresholds for the physiological effects associated with electric current through a human body are reported in IEC/TS 60479-1.

This technical report addresses startle reaction from current, strong involuntary muscular reaction such as inability to let go an electrode in a.c. and ventricular fibrillation. Other effects, such as perception of current, might be important for some applications but are not addressed. It should be noted that current thresholds corresponding to strong muscular reaction and to ventricular fibrillation depend on touch current magnitude, while current threshold corresponding to startle reaction depends more on current density. Nevertheless, IEC/TS 60479-1 addresses a current startle reaction threshold in mA which contributes to considerations in this report that the current startle reaction threshold only depends on the current magnitude.

For the purposes of this report, the threshold of physiological effects of greatest interest are curves a, b and c_1. Curve a is the level beyond which startle reaction of current becomes possible. Curve b is the lower boundary of current levels beyond which more serious and undesirable physiological effects begin to occur. Curve c_1 is the level beyond which the likelihood of ventricular fibrillation begins to become a concern.

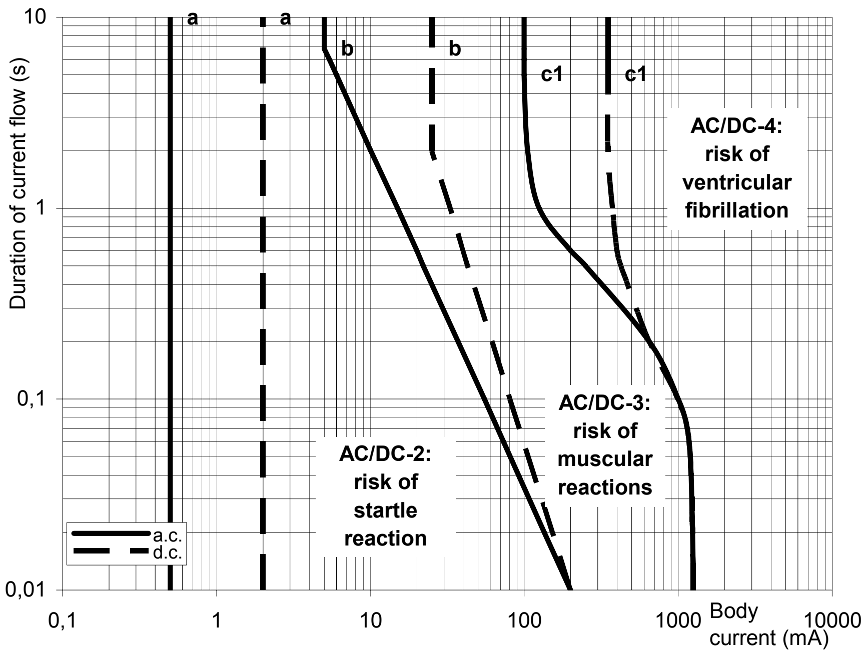
Figures 1 to 3 below show the thresholds for touch current on which the voltage thresholds are based. These figures are based only on information from IEC/TS 60479-1. Figures 1, 2 and 3 respectively show the threshold current values for hand-to-hand; both-hands-to-feet or hand-to-seat (longitudinal) current.

Figure 2 directly reproduces Figures 20 and 22 from IEC/TS 60479-1. Other figures are derived from IEC/TS 60479-1 using the appropriate factors of Table 5 to adapt the threshold current to the hand-to-hand pathway.

The values in Table 1 refer to long duration current passing through the torso. For a.c., the main concern is the inability to let go with reference to current passing through each arm. Therefore, the a.c. current value in Table 1 and in Figure 2 has been doubled for the 'both-hands-to-feet' pathway for longer current duration (only above the intersection with the d.c. line). For d.c. and for shorter a.c. duration, the value is not doubled because continuous d.c. and short duration a.c. current do not cause inability to let go (which results in coincidence of both lines) (see note 1 of Table 1).

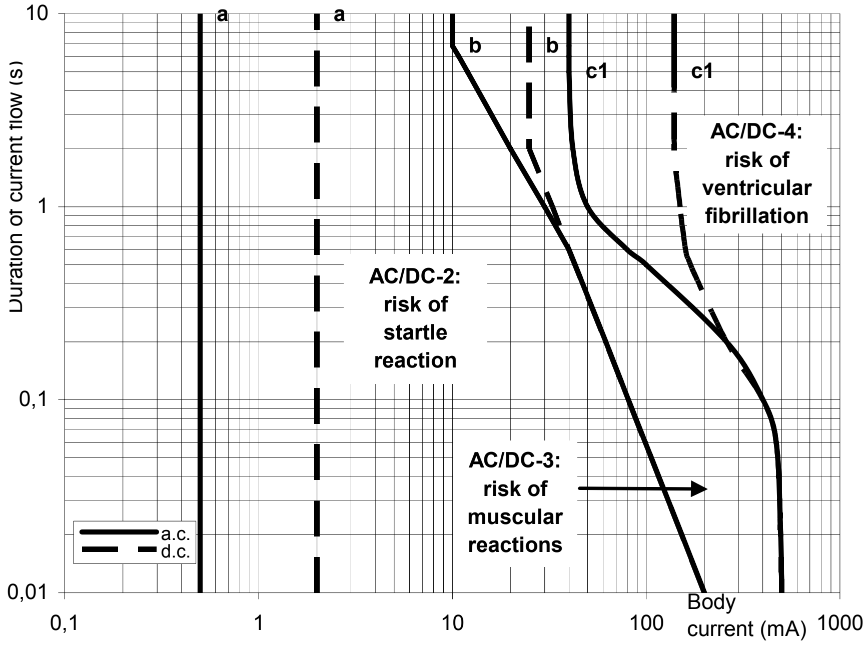
For direct current, a lower magnitude of current is needed to produce ventricular fibrillation when the current flows upward from feet to hands (feet positive with respect to the upper body) through the torso rather than downward. This technical report assumes upward current in all cases involving direct current. The ventricular fibrillation current threshold for a d.c. downwards current is about twice that of the current threshold corresponding to the upward current.

Short duration currents (less than one heart cycle) are always assumed to coincide with the vulnerable portion of the heart beat cycle.



NOTE The "c_1" curve is modified according to Table 12 of IEC/TS 60479-1; see also last paragraph of 4.1 of that standard.

Figure 1 – Physiological thresholds for a.c. (50/60 Hz) and d.c. flowing hand-to-hand (transversely) through the human body



NOTE Modifications to Figures 20 and 22 of IEC/TS 60479-1 include:

– doubling of threshold corresponding to curve "b" for a.c., explained in note 1 of Table 1;

– below the intersection of the double a.c. curve and the d.c. curve, both curves were made coincident with the more conservative d.c. curve; see explanation in the 4th paragraph of 4.1 of IEC/TS 60479-1.

Figure 2 – Physiological thresholds for a.c. (50/60 Hz) and d.c. flowing from both hands to both feet (longitudinally) through the human body

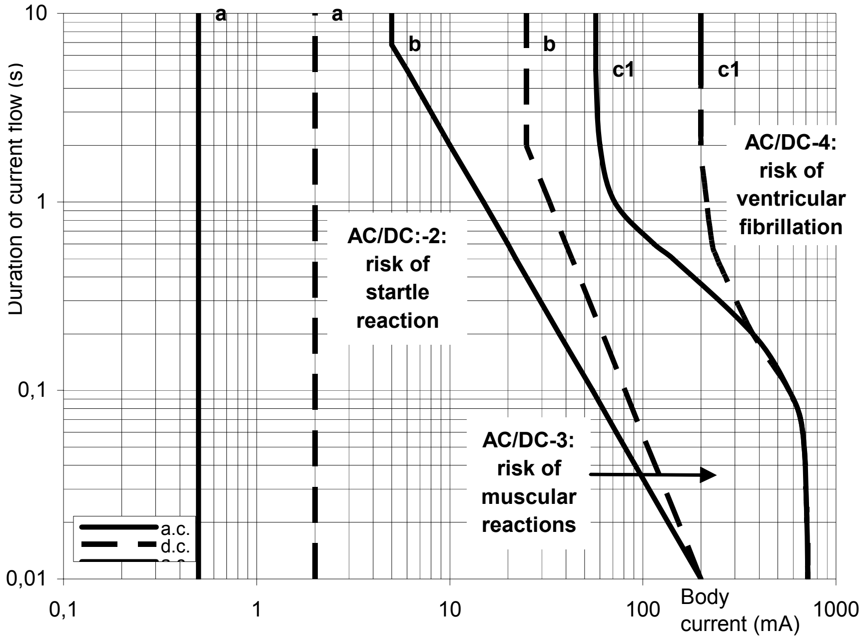


Figure 3 – Physiological thresholds for a.c. (50/60 Hz) and d.c. flowing from hand-to seat (longitudinal) through the human body

For the determination of voltage threshold, the following long duration current thresholds have been considered. They have been determined from Figures 20 and 22 and Table 12 of IEC/TS 60479-1 which correspond to the upper end of the b or c_1 curves in Figures 1 to 3 above.

Table 1 – Current threshold values for each condition and for long duration

Type of threshold	Current	Current path	mA
Current of startle reaction	a.c.	Hand-to-hand	0,5
		Both-hands-to-feet	0,5
		One-hand-to-seat	0,5
	d.c.	Hand-to-hand	2
		Both-hands-to-feet	2
		One-hand-to-seat	2
Strong muscular reactions	a.c.	Hand-to-hand	5
		Both-hands-to-feet (Note 1)	10
		One-hand-to-seat	5
	d.c.	Hand-to-hand	25
		Both-hands-to-feet	25
		One-hand-to-seat	25
Ventricular fibrillation (Note 3)	a.c.	Hand-to-hand	100
		Both-hands-to-feet	40
		One-hand-to-seat	57
	d.c.	Hand-to-hand	350
		Feet-to-both-hands (Note 2)	140
		Seat-to-one-hand (Note 2)	200

NOTE 1 The values in this table refer to current through the torso. For a.c. the main concern is the inability to let go which refers to the current through each arm. Therefore, the total touch current value in the table has been doubled for longer current durations.

NOTE 2 Current path in the direction of feet-to-both-hands is referred to as upward current. The ventricular fibrillation current threshold for a d.c. downwards current is about twice that of the current threshold corresponding to the upward current.

NOTE 3 Current values other than values corresponding to ventricular fibrillation may cause other severe effects such as respiratory arrest as described in IEC/TS 60479-1.

4.3 Body impedance

Touch voltage thresholds are related to touch current thresholds by the body's impedance according to Ohm's law. However, the application of Ohm's law is not straightforward because the appropriate value of body impedance to use is a function of many factors. The selection of the proper value should include consideration of

- the type of power source (a.c. or d.c.), and
- the magnitude of the touch voltage, and
- the pathway of the current through the body (hand-to-hand or both-hands-to-feet or hand-to-seat), and

NOTE 1 These different pathways have been selected for their characteristics. The reason comes from the body impedance model described in Annex A. The voltage thresholds determined for the current path both-hands-to-feet may be generally considered conservative compared to the current path one hand-to-feet.

- the area of contact with the skin, and
- the condition of the skin contact area (saltwater-wet, water-wet, dry), and
- duration of the current flow.

The body impedance only includes skin impedance and internal tissue impedance.

Skin resistance changes as a function of the voltage applied to it. At low voltages, the change is reversible. The value quickly changes back to the original resistance once the voltage is removed. At high voltage, permanent injury to the skin can occur. In this case, the change in skin resistance that results from the applied voltage is not reversible.

NOTE 2 A finger can be assumed to have a resistance of approximately 1 000 Ω. Therefore, contact with a finger tip rather than with the palm of the hand will significantly increase the body impedance. The conditions described by the contact with the palm of the hand are therefore conservative.

IEC/TS 60479-1 contains information about body impedance that was obtained from measurements of live human volunteers and from measurements of cadavers. Annex A provides more details about body impedances and body impedance models. There are variations in impedance between different individuals and this is shown in the tables of Annex A by the percentile values.

Typically, physically large people have lower internal body resistance because of their larger cross-sectional area. Physically small people generally have higher internal body resistance. Some measurements [1][1] of body impedances show that the body impedance is not greatly influenced by the body weight. Therefore, there is not sufficient correlation between the body weight (children or adults) and the physiological current values corresponding to a particular effect. Three percentiles of the population are considered in IEC/TS 60479-1 (5^{th}, 50^{th} and 95^{th}). This report only considers the values of body impedance corresponding to the 5^{th} percentile of the population which covers more than 95 % of the population.

4.4 Impedance external to the body

It is assumed that the voltage source applied to the body has a low output impedance relative to the body impedance (which is the worst case). The magnitude of the touch current is determined solely by the combination of the applied voltage and the human body impedance. Consideration of any significant circuit impedance that might be in series with the body, and that can affect the available touch current from the voltage source, is outside the scope of this technical report.

NOTE In some instances, with large inductive impedance in series with the body, the touch voltage might be higher than the open-circuit voltage of the source. This effect can become significant for 50/60Hz at inductances larger than 100 mH.

External impedance from clothing, including gloves or shoes, is not considered in this report.

4.5 Other factors affecting voltage thresholds

The factors considered are as follows:

- Source: 50/60 Hz alternating sinusoidal voltage with no d.c. component or direct voltage with no alternating component.
- Skin condition: saltwater-wet, water-wet and dry.

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1 Figures in square brackets refer to the bibliography.

NOTE 'Dry' skin condition corresponds to normal indoor condition, water-wet skin condition corresponds to skin that has been immersed for more than 1 min in normal water (average value ρ = 35 $\Omega \times$ m, pH = 7,7 - 9), and a saltwater-wet skin condition is considered as skin that has been immersed for more than 1 min in a solution of 3 % NaCl in water (average value ρ = 0,25 $\Omega \times$ m, pH = 7,5 - 8,5).

Perspiration may be considered as lying between a water-wet and saltwater-wet condition. The conductivity of some sea water is slightly higher than the saltwater-wet condition.

- Pathway: hand-to-hand contact or both-hands-to-feet contact or hand-to-seat contact with accessible conductive parts.
- Contact area: large area contact, medium area contact, or small area contact with accessible conductive parts.

For the purposes of calculation, a large, full hand contact (L) is considered to have a surface contact hand area of 82 cm². A medium contact area (M) is considered to be 12,5 cm^2 and might represent touching a conductive part in the palm of each hand. A small contact area (S) is considered to be 1 cm^2 and might represent touching a small conductive part with the hand. All contacts, except for hand-to-seat, are assumed to be symmetrical for the purposes of this analysis. It is assumed that contact between each foot and a conductive supporting surface will be the same size as for each hand surface contact.

It should be noted that contact area may be affected by the use of conductive tools or interconnected equipment (accessible conductive parts).

- Duration: 10 ms to 10 s.

The worst case presented in this report corresponds to the following situation: a.c. current, long duration, saltwater-wet condition and large contact area.

4.6 Touch voltage thresholds as a function of duration

Based on human body impedances and on current-time curves as provided in IEC/TS 60479-1, a set of diagrams (see Figures 5 to 22) provide the maximum time acceptable for a given touch voltage applied to a human body. These curves have been established by using the method described in Annex B and with the model described in Annex A.

These curves should be used as a guide by IEC technical committees when prescribing the disconnecting time of the protective device used for the automatic disconnection of supply. The limits chosen for the disconnecting time may differ from the threshold values of this technical report because of safeguards, uncertainties, tolerances, risk assessment, etc., that may be included. For more details, see Figures 5 to 22.

The following flow-chart is provided to direct the reader to the appropriate figure showing voltage threshold information based on the situation of interest:

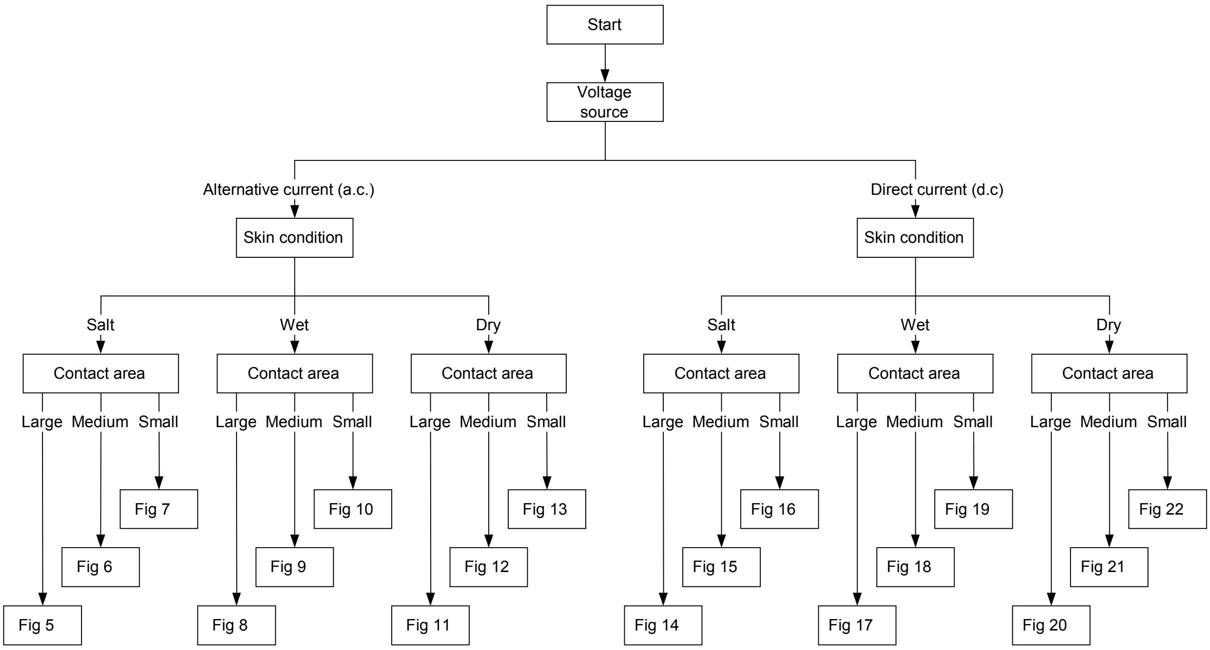

Figure 4 – Flow chart to be used for the selection of the appropriate figure providing the maximum duration for each touch voltage threshold

Annex B illustrates the method used to calculate touch voltages based on touch currents and body impedances.

4.7 Touch voltage thresholds for long durations

The following tables, (Tables 2a to 2f), represent an extract of the figures in Clause 5 for lengthy durations (longer than a few seconds corresponding to vertical asymptote for each curve in Clause 5). Annex B illustrates the method used to calculate touch voltages based on touch currents and body impedances.

Technical committees may use these voltage thresholds to set voltage limits in their product standards using appropriate risk factors.