BS EN 50522:2022+A1:2024



BSI Standards Publication

Earthing of power installations exceeding 1 kV a.c.

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National foreword

This British Standard is the UK implementation of EN 50522:2022+A1:2024. It supersedes BS EN 50522:2022, which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to CENELEC text carry the number of the CENELEC amendment. For example, text altered by CENELEC amendment A1 is indicated by ⟩A1⟨.

The UK participation in its preparation was entrusted to Technical Committee PEL/99, Erection and operation of power installations.

A list of organizations represented on this committee can be obtained on request to its committee manager.

The UK committee draws users' attention to National Annexes NA, NB and NC, which provide further guidance to assist users in the application of this standard.

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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 50522:2022+A1

September 2024

ICS 29.120.50

Supersedes EN 50522:2010 and all of its amendments and corrigenda (if any)

English Version

Earthing of power installations exceeding 1 kV a.c.

Prises de terre des installations électriques de puissance en courant alternatif de tension supérieure à 1 kV

Erdung von Starkstromanlagen mit Nennwechselspannungen über 1 kV

This European Standard was approved by CENELEC on 2022-01-10. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

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European foreword

This document (EN 50522:2022) has been prepared by CLC/TC 99X “Power installations exceeding 1 kV AC (1,5 kV DC)”.

The following dates are fixed:

• latest date by which this document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2023-01-10
• latest date by which the national standards conflicting with this document have to be withdrawn	(dow)	2025-01-10

This document will supersede EN 50522:2010 and all of its amendments and corrigenda (if any).

EN 50522:2022 includes the following significant technical changes with respect to EN 50522:2010:

— Text sections in italic which were indicating that the section is a copy of an IEC 61936-1 text replaced by reference note to IEC 61936-1 due to copyright reasons.

— Clause 3 is updated regarding touch voltages.

— Improved figures in Clause 3 for distribution of earth fault currents.

— The process of designing earthing system is clarified in 5.4 and Figure 9.

— Rearranged Annex A and B including prospective permissible touch voltage and permissible step voltage.

— Introduction of stainless steel in Annex C and Annex D.

— More details and figures regarding fences in Annex G.

— Enlarged table of reduction factors and application on cables in Annex I.

— New figures in Annex J (J.4 and J.5).

— Details on soil resistivity measurements and touch voltage measurements including flow chart in Annex L.

— Clause 10 was Annex M in previous version.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC shall not be held responsible for identifying any or all such patent rights.

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European foreword to Amendment 1

This document (EN 50522:2022/A1:2024) has been prepared by CLC/TC 99X “Power installations exceeding 1 kV a.c. (1,5 kV d.c.)”.

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1 Scope

This document is applicable to specify the requirements for the design and erection of earthing systems of electrical installations, in systems with nominal voltage above 1 kV AC and nominal frequency up to and including 60 Hz, so as to provide safety and proper functioning for the use intended.

NOTE 1 The technical and procedural principles of this document can be applied when third parties' installations and facilities are planned and/or erected in the vicinity of HV electrical power installations.

For the purpose of interpreting this document, an electrical power installation is considered to be one of the following:

a) substation, including substation for railway power supply;

b) electrical power installations on mast, pole and tower;

switchgear and/or transformers located outside a closed electrical operating area;

c) one (or more) power station(s) located on a single site;

the electrical power installation includes generators and transformers with all associated switchgear and all electrical auxiliary systems. Connections between generating stations located on different sites are excluded;

d) the electrical system of a factory, industrial plant or other industrial, agricultural, commercial or public premises;

e) electrical power installations on offshore facilities for the purpose of generation, transmission, distribution and/or storage of electricity;

f) transition towers/poles between overhead lines and underground lines.

The electrical power installation includes, among others, the following equipment:

— rotating electrical machines;

— switchgear;

— transformers and reactors;

— converters;

— cables;

— wiring systems;

— batteries;

— capacitors;

— earthing systems;

— buildings and fences which are part of a closed electrical operating area;

— associated protection, control and auxiliary systems;

— large air core reactor.

NOTE 2 In general, a standard for an item of equipment takes precedence over this document.

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This document does not apply to the design and erection of earthing systems of any of the following:

— overhead and underground lines between separate installations;

— electrified railway tracks and rolling stock;

— mining equipment and installations;

— fluorescent lamp installations;

— installations on ships according to IEC 60092 (all parts) and offshore units according to IEC 61892 (all parts), which are used in the offshore petroleum industry for drilling, processing and storage purposes;

— electrostatic equipment (e.g. electrostatic precipitators, spray-painting units);

— test sites;

— medical equipment, e.g. medical X-ray equipment.

NOTE 3 The standard EN 50341 series, Overhead lines exceeding AC 1 kV, specifies requirements for the design and erection of earthing systems in overhead lines.

NOTE 4 The scope of this document does not include the requirements for carrying out live working on electrical power installations.

NOTE 5 The scope of this document considers safety requirements for HV installations and its influences on LV installations. For electrical installation up to 1 kV, the standard HD 60364 series applies.

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.

EN 60909 (series), *Short-circuit currents in three-phase a.c. systems* (IEC 60909 series)

EN IEC 62561-2, *Lightning protection system components (LPSC) - Part 2: Requirements for conductors and earth electrodes (IEC 62561-2)*

HD 60364-1, *Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions (IEC 60364-1)*

IEC 60479-1:2018, *Effects of current on human beings and livestock – Part 1: General aspects*

〖A1〗 IEC 61936-1:2021, *Power installations exceeding 1 kV AC and 1,5 kV DC - Part 1: AC* 〈A1〗

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61936-1:2010 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
earth ring electrode
earth electrode embedded in the soil around a building or pole as a closed ring

3.2
〚A1〛 **touch voltage** 〚A1〛
U_T
〚A1〛 <effective> 〚A1〛 voltage between conductive parts when touched simultaneously

Note 1 to entry: The value of the effective touch voltage could be appreciably influenced by the impedance of the person in electric contact with these conductive parts.

Note 2 to entry: The person is touching the conductive parts with bare skin.

〚A1〛 [SOURCE: IEC 60050-195:2021, 195-05-11, modified – The symbol UT has been added. In the definition, “by a human being or livestock” has been deleted. In Note 1 to entry, “of the human being or livestock” has been replaced by “of the person”.]

[SOURCE: IEC 61936-1:2021, 3.7.12, modified – Note 2 added] 〚A1〛

3.3
permissible touch voltage
U_{Tp}
limit value of touch voltage U_T

Note 1 to entry: See Figure 8.

〚A1〛 [SOURCE: IEC 61936-1:2021, 3.7.13, modified – Note 1 added] 〚A1〛

3.4
prospective touch voltage
U_{vT}
voltage between simultaneously accessible conductive parts when those conductive parts are not being touched

Note 1 to entry: See Figure 1.

〚A1〛 [SOURCE: IEC 60050-195:2021, 195-05-09, modified]

[SOURCE: IEC 61936-1:2021, 3.7.14, modified – Note 1 added] 〚A1〛

3.5
prospective permissible touch voltage
U_{vTp}
limit value of prospective touch voltage U_{vT}

〚A1〛 [SOURCE: IEC 61936-1:2021, 3.7.15] 〚A1〛

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3.6
transferred potential
potential rise of an earthing system caused by a current to earth transferred by means of a connected conductor (for example a metallic cable sheath, PEN conductor, pipeline, rail) into areas with low or no potential rise relative to reference earth, resulting in a potential difference occurring between the conductor and its surroundings

Note 1 to entry: See Figure 1.

[SOURCE: ▌A1⟩ IEC 61936-1:2021 ⟨A1▌, 3.7.17, modified – reference Figure 1 added]

3.7
global earthing system
equivalent earthing system created by the interconnection of local earthing systems that ensures, by the proximity of the earthing systems, that there are no touch voltages exceeding permissible limit values

Note 1 to entry: Such systems permit the division of the earth fault current in a way that results in a reduction of the earth potential rise at the local earthing system. Such a system could be said to form a quasi equipotential surface.

Note 2 to entry: The existence of a global earthing system may be determined by sample measurements or calculation for typical systems. Typical examples of global earthing systems are in city centres; urban or industrial areas with distributed low- and high-voltage earthing (see Annex N).

[SOURCE: ▌A1⟩ IEC 61936-1:2021 ⟨A1▌, 3.7.19, modified "that there are no touch voltages exceeding permissible limit values" and Note 2 reference to Annex added]

3.8
system with isolated neutral
system in which the neutrals of transformers and generators are not intentionally connected to earth, except for high impedance connections for signalling, measuring or protection purposes

[SOURCE: IEV 601-02-24, modified]

3.9
system with resonant earthing
system in which at least one neutral of a transformer or earthing transformer is earthed via an arc suppression coil and the combined inductance of all arc suppression coils is essentially tuned to the earth capacitance of the system for the operating frequency

Note 1 to entry: In case of no self-extinguishing arc fault there are two different operation methods used:

— automatic disconnection;

— continuous operation during fault localization process.

In order to facilitate the fault localization and operation there are different supporting procedures:

— short term earthing for detection;

— short term earthing for tripping;

— operation measures, such as disconnection of coupled busbars;

— phase earthing.

Note 2 to entry: Arc suppression coil may have high ohmic resistor in parallel to facilitate fault detection.

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3.10
system with low-impedance neutral earthing
system in which at least one neutral of a transformer, earthing transformer or generator is earthed directly or via an impedance designed such that due to an earth fault at any location the magnitude of the fault current leads to a reliable automatic tripping due to the magnitude of the fault current

[SOURCE: IEV 601-02-25, modified, 601-02-26, modified]

3.11
earth fault current
I_F
current which flows from the main circuit to earth or earthed parts at the fault location [A1] *Text deleted.* [A1]

[A1] *Text deleted.* [A1]

Note [A1] 1 [A1] to entry: For single earth faults, this is [A1] in systems with [A1]:

— [A1] *Text deleted.* [A1] isolated neutral, the capacitive earth fault current,

— [A1] *Text deleted.* [A1] high resistive earthing, the RC composed earth fault current,

— [A1] *Text deleted.* [A1] resonant earthing, the earth fault residual current,

— [A1] *Text deleted.* [A1] solid or low impedance neutral earthing, the line-to-earth short-circuit current.

Note [A1] 2 [A1] to entry: Further earth fault current could result from double earth fault and line to line to earth fault according to EN 60909 (all parts).

[A1] Note 3 to entry: See Figures 2 to 7. [A1]

[A1] [SOURCE: IEC 61936-1:2021, 3.7.25, modified – in Note 2 reference to EN 60909 series added, Note 3 with reference to Figures added] [A1]

3.12
current to earth
I_E
current flowing to earth via the impedance to earth

Note 1 to entry: See Figure 2.

Note 2 to entry: The current to earth is the part of the earth fault current I_F, which causes the potential rise of the earthing system. For the determination of I_E see also Annex L.

3.13
reduction factor
r
factor r of a three-phase line is the ratio of the current to earth over the sum of the zero sequence currents in the phase conductors of the main circuit ($r = I_E / 3\ I_0$) at a point remote from the short-circuit location and the earthing system of an installation

3.14
horizontal earth electrode
electrode which is generally buried at a depth of up to approximately 1 m. It can consist of strip, round bar or stranded conductor and can be laid out to form a radial, ring or mesh earth electrode or a combination of these

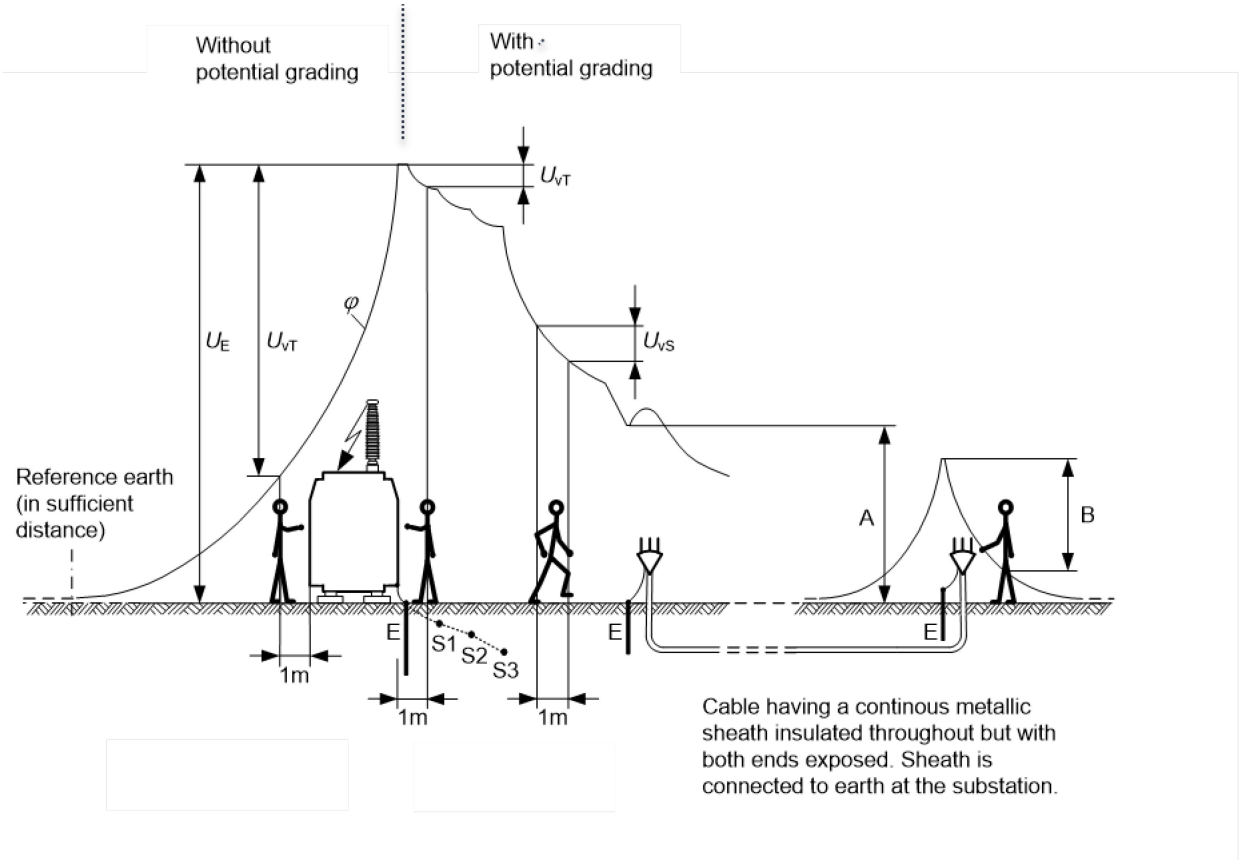
3.15
cable with earth electrode effect
cable whose sheaths, screens or armourings have the same effect as a horizontal electrode consisting of bare round earth-wire

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3.16
foundation earth electrode
conductive structural embedded in concrete which is in conductive contact with the earth via a large surface

[SOURCE: IEV 826-13-08, modified]

3.17
potential grading earth electrode
conductor which due to shape and arrangement is principally used for potential grading rather than for establishing a certain resistance to earth

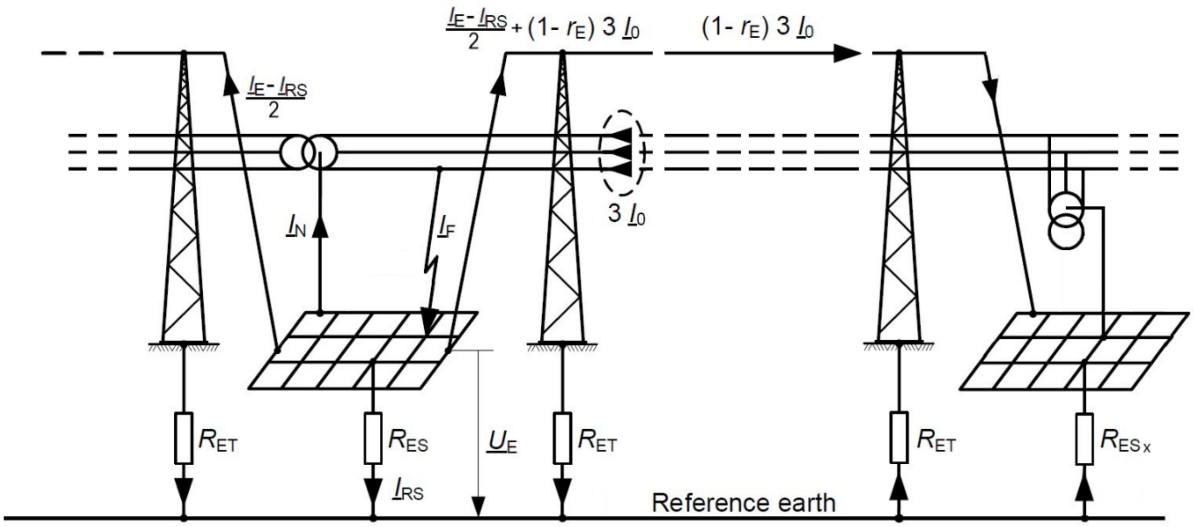


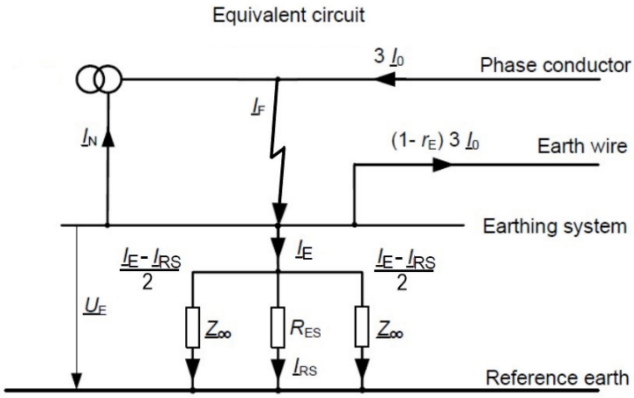
Key

E	Earth electrode
S1, S2, S3	Potential grading earth electrodes (e.g. ring earth electrodes), connected to the earth electrode E
U_E	Earth potential rise
U_{vS}	Prospective step voltage
U_{vT}	Prospective touch voltage
A	Prospective touch voltage resulting from transferred potential in case of single side cable sheath earthing
B	Prospective touch voltage resulting from transferred potential in case of cable sheath earthed on both sides
φ	Earth surface potential

Figure 1 — Example for the surface potential profile and for the voltages in case of current carrying earth electrodes

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$$I_F = 3\, I_0 + I_N$$
$$I_E = r_E \cdot (I_F - I_N)$$
$$U_E = I_E \cdot Z_E$$

$$Z_E = \frac{1}{\frac{1}{R_{ES}} + n\,\frac{1}{Z_\infty}}$$

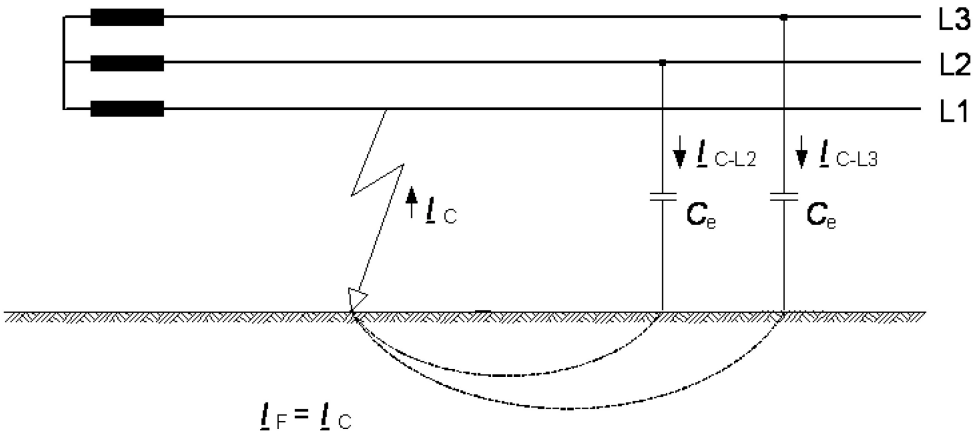
For equal earth wire tower footing impedances of the overhead lines

Key

$3\, I_0$	Three times zero sequence current of the line
I_N	Current via neutral earthing of the transformer
I_F	Earth fault current
I_E	Current to earth (cannot be measured directly)
I_{RS}	Current via the resistance to earth of the mesh earth electrode
r_E	Reduction factor of the overhead line
R_{ES}, R_{ESx}	Resistance to earth of the mesh earth electrode
R_{ET}	Resistance to earth of the tower
Z_∞	Chain impedance (several number of towers with resistance to earth, R_{ET}) represents a value of the overhead line assumed to be infinite
Z_E	Impedance to earth
U_E	Earth potential rise
n	Number of overhead lines leaving the substation (here: n = 2)

Figure 2 — Example for currents, voltages and resistances for an earth fault in a transformer substation with low impedance neutral earthing

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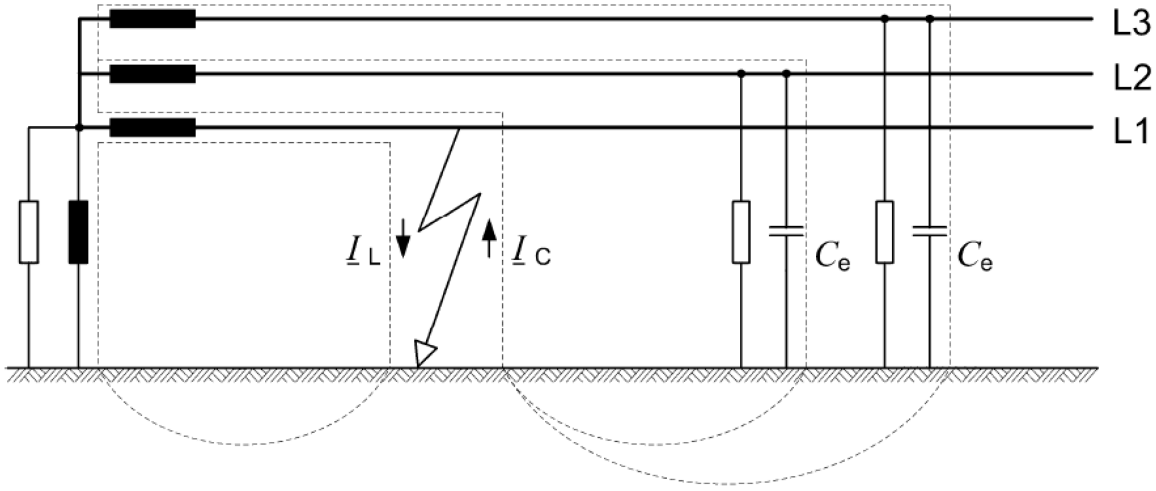
Key

$\underline{I}_F$ Earth fault current

$\underline{I}_C$ Capacitive earth fault current (complex value, including ohmic component)

NOTE $\underline{I}_C$ may include ohmic component.

Figure 3 — Earth fault current in a system with isolated neutral



Key

$\underline{I}_F$ Earth fault current

$\underline{I}_C$ Capacitive earth fault current (complex value, including ohmic component)

$\underline{I}_L$ Sum of the currents of the parallel arc-suppression coils (complex value, including ohmic component)

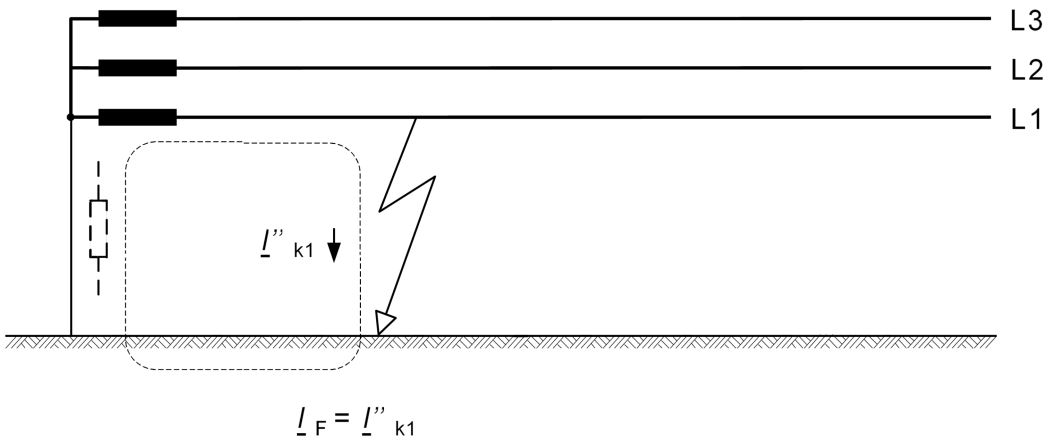
$\underline{I}_H$ Harmonic current (different frequencies)

$\underline{I}_{RES}$ Earth fault residual current

NOTE $\underline{I}_R$ is the ohmic part of the complex value of ($\underline{I}_C + \underline{I}_L$).

Figure 4 — Earth fault current in a system with resonant earthing

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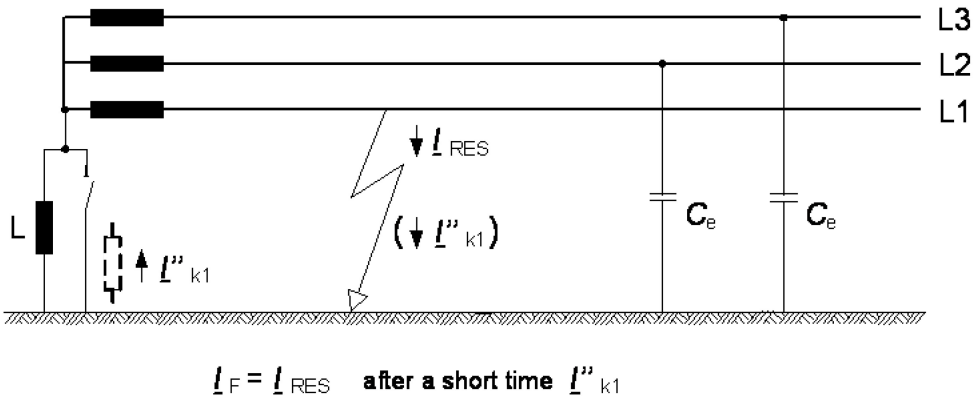
Key

$\underline{I}_F$ Earth fault current

$\underline{I}''_{k1}$ Initial symmetrical short-circuit current for a line-to-earth short circuit

NOTE If $\underline{I}_C$ is in the same order as $\underline{I}''_{k1}$ this current shall be considered additionally.

Figure 5 — Earth fault current in a system with low impedance neutral earthing



Key

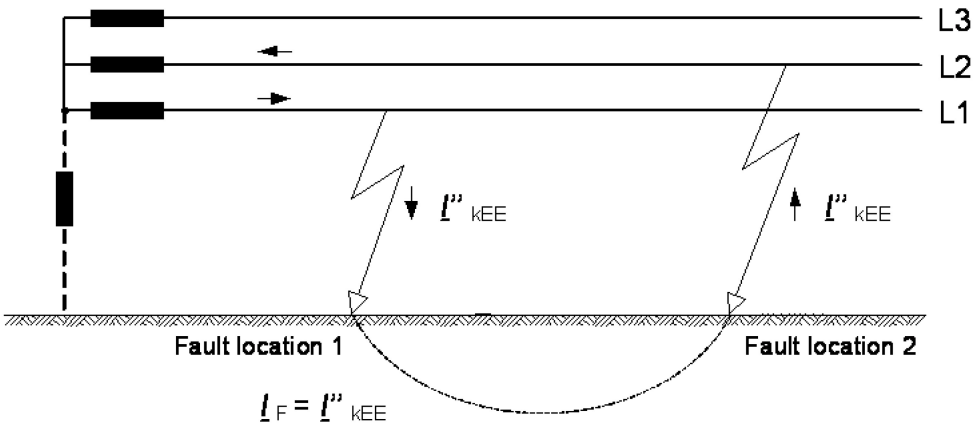
$\underline{I}_F$ Earth fault current

$\underline{I}_{RES}$ Earth fault residual current

$\underline{I}''_{k1}$ Initial symmetrical short-circuit current for a line-to-earth short circuit

Figure 6 — Earth fault current in a system with resonant earthing and temporary low impedance neutral earthing

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Key

I_F Earth fault current

I''_{kEE} Double earth fault current

Figure 7 — Double earth fault current in a system with isolated neutral or resonant earthing

4 Fundamental requirements

4.1 General requirements

This document provides the criteria for design, installation, testing and maintenance of an earthing system such that it operates under all conditions and ensures the safety of human life in any place to which persons have legitimate access. It also provides the criteria to ensure that the integrity of equipment connected and in proximity to the earthing system is maintained.

〚A1〛 The requirements of IEC 61936-1:2021, 4.1.1 first and third paragraph only apply. 〚A1〛

4.2 Electrical requirements

4.2.1 Methods of neutral earthing

The requirements of 〚A1〛 IEC 61936-1:2021 〚A1〛, 4.2.1 apply.

4.2.2 Short-circuit current

〚A1〛 The requirements of IEC 61936-1:2021, 4.2.4 paragraph 1 and 2 and Note 1 apply.

Faults within and outside the installation site shall be examined to determine the worst fault location.

Simultaneous faults in different voltage systems are not considered.

The requirements of IEC 61936-1:2021, 4.2.4 paragraph 3, 4, 5, 6 and Note 2 apply. 〚A1〛

The rated duration should be determined taking into consideration the fault clearance time described in IEV 448-13-15.

〚A1〛 The requirements of IEC 61936-1:2021, 4.2.4 paragraph 7 and 8 apply. 〚A1〛

4.3 Safety criteria

〚A1〛 The requirements of IEC 61936-1:2021, 10.2.1 paragraph 1, 2 and 3 apply. 〚A1〛

For installation design, the curve shown in Figure 8 is calculated according to the method defined in Annex A and Annex B.

〚A1〛 The requirements of IEC 61936-1:2021, 10.2.1 NOTE apply. 〚A1〛

The curve in Figure 8, which gives the permissible touch voltage, shall be used.

〚A1〛 The requirements of IEC 61936-1:2021, 10.2.1 paragraph 6 apply. 〚A1〛

See A.3.

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For installations where high voltage equipment is not located in closed electrical operating areas, e.g. in an industrial environment, a global earthing system should be applied to prevent touch voltages exceeding permissible limit values.

[A1] [SOURCE: IEC 61936-1:2021, 10.2.1, modified – intolerable touch voltage is replaced by touch voltages exceeding permissible limit values] [A1]

4.4 Functional requirements

The requirements of [A1] IEC 61936-1:2021 [A1], 10.2.2 paragraph 1, 2, 3 and 4 apply.

NOTE The requirement to keep step and touch voltages within permissible levels does not apply to temporary earth connections (portable earthing equipment) at work locations.

The requirements of [A1] IEC 61936-1:2021 [A1], 10.2.2 paragraph 5 apply.

5 Design of earthing systems

5.1 General

Parameters relevant to earthing system dimensioning are:

— value of fault current;

— fault duration;

— soil characteristics.

NOTE The value of fault current and fault duration mainly depend on the method of neutral earthing of the high voltage system.

5.2 Dimensioning with respect to corrosion and mechanical strength

5.2.1 Earth electrodes

The electrodes, being directly in contact with the soil, shall be of materials capable of withstanding corrosion (chemical or biological attack, oxidation, formation of an electrolytic couple, electrolysis, etc.). They shall resist the mechanical influences during their installation as well as those occurring during normal service. It is acceptable to use steel embedded in concrete foundations and steel piles or other natural earth electrodes as a part of the earthing system. Mechanical strength and corrosion considerations dictate the minimum dimensions for earth electrodes given in Table C.1 of Annex C. If a different material is used, this material and its dimensions shall meet the functional requirements.

5.2.2 Earthing conductors

Due to mechanical strength and stability against corrosion minimum cross-sections are:

— copper: 16 mm^2 (but see also G.5)

— aluminium: 35 mm^2

— steel: 50 mm^2

5.2.3 Bonding conductors

It is recommended that the sizing of bonding conductors is in line with 5.2.2.

NOTE Earthing and bonding conductors made of steel need appropriate and suitable protection against corrosion.

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5.3 Dimensioning with respect to thermal strength

5.3.1 General

The currents to be taken into account for earthing conductors and earth electrodes are specified in Table 1.

NOTE In some cases, steady-state zero-sequence currents are taken into account for the dimensioning of the relevant earthing system.

For design purposes, the currents used to calculate the conductor size should take into account the possibility of future growth.

The fault current is often subdivided in the earth electrode system; it is, therefore, feasible to dimension each electrode and earthing conductor for only a fraction of the fault current.

Final temperatures involved in the design and to which reference is made in Annex D shall be chosen in order to avoid reduction of the material strength and to avoid damage of the material surrounding, for example concrete or insulating materials. No permissible temperature rise of the soil surrounding the earth electrodes is given in this document because experience shows that soil temperature rise is usually not significant.

5.3.2 Current rating calculation

The calculation of the cross-section of the earthing conductors or earth electrodes depending on the value and the duration of the fault current is given in Annex D. There is discrimination between fault duration lower than 5 s (adiabatic temperature rise) and greater than 5 s. The final temperature is to be chosen taking into account the material and the surroundings. Nevertheless, the minimum cross-sections of 5.2.2 shall be considered.

The current carrying capacity of the connecting elements, e.g. joints, as a function of the short-circuit current duration and the current intensity should be taken into account. (e.g. 4 kA (50 Hz) / 1 s / 300 °C).

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Table 1 — Relevant currents for the design of earthing systems

Type of high voltage system		Relevant for thermal loading [a] [e]		Relevant for earth potential rise and touch voltages
		Earth electrode	Earthing conductor	
Systems with isolated neutral				
		I''_{kEE}	I''_{kEE}	$I_E = r \cdot I_C$ [b]
System with resonant earthing Includes short time earthing for detection				
	Substations without arc-suppression coils [f]	I''_{kEE}	I''_{kEE}	$I_E = r \cdot I_{RES}$ [b]
	Substations with arc-suppression coils	I''_{kEE}	I''_{kEE} [c]	$I_E = r \cdot \sqrt{I_L^2 + I_{Res}^2}$ [b h]
Systems with low-impedance neutral earthing Includes short time earthing for tripping [g]				
	Substation without neutral earthing	I''_{k1}	I''_{k1}	$I_E = r \cdot I''_{k1}$
	Substation with neutral earthing	I''_{k1}	I''_{k1}	$I_E = r \cdot (I''_{k1} - I_N)$ [d]

Legend:

I_C Calculated or measured capacitive earth fault current.

I_{RES} Earth fault residual current (see Figure 4).
If the exact value is not available, 10 % of I_C may be assumed.

I_L Sum of the rated currents of the parallel arc-suppression coils in the relevant substation.

I''_{kEE} Double earth fault current calculated in accordance with the IEC 60909 series.
For I“kEE 85 % of the initial symmetrical short-circuit current may be used as a maximum value.

I''_{k1} Initial symmetrical short-circuit current for a line-to-earth short-circuit, calculated in accordance with the EN 60909 series.

I_E Current to earth (see Figure 2).

I_N Current via neutral earthing of the transformer (see Figure 2).

r Reduction factor (see Annex I).

If the lines and cables leaving the substation have different reduction factors, the relevant current shall be determined (in accordance with Annex L).

[a] If several current paths are possible a split up may be considered.

[b] If there is no automatic disconnection of earth faults, the need to consider double earth faults depends on operational experience.

[c] The earthing conductor of the Petersen coil shall be sized according to the maximum coil current.

[d] It shall be checked if external fault may be decisive.

[e] The minimum cross-sections of Annex C are to be considered.

[f] In case of not well compensated system the general approach of 10 % I_C cannot be applied. The reactive/capacitive component of residual current shall be considered additionally.

[g] Short-term earthing of system with resonant earthing starts automatically within 5 s after earth fault detection.

[h] In case of a fault in the substation the capacitive earth fault current I_C shall be considered. In case of further coils external to the substation they may be considered.

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5.4 Dimensioning with regard to touch voltages

5.4.1 Permissible values

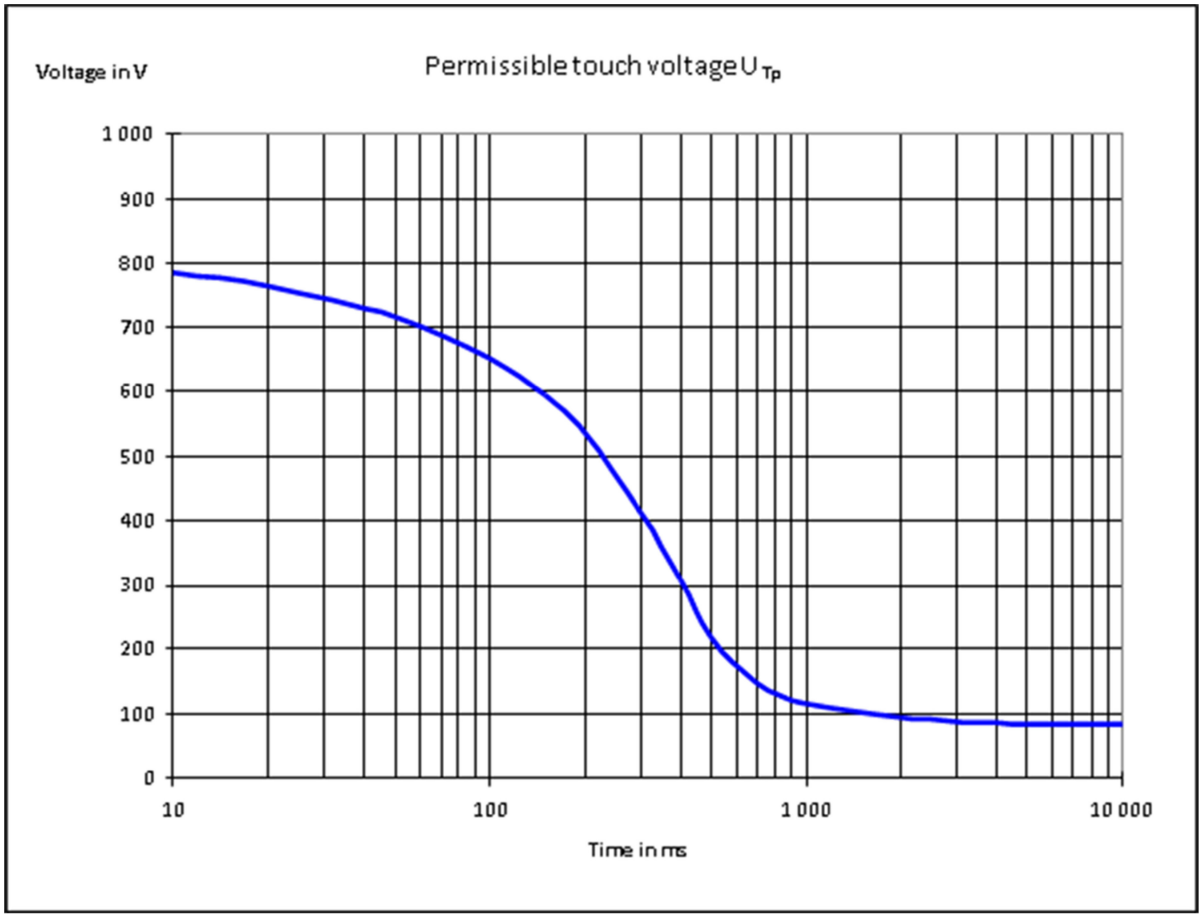
The limit value of the touch voltage (U_T) is the permissible touch voltage (U_{Tp}) and is given in Figure 8 as stated in 4.3 (safety criteria). The Figure 8 represents the limit values of this permissible touch voltage U_{Tp} depending on the fault duration.

Step voltage limits can be derived according to A.3, but are only needed in exceptional cases.

Any voltage over the human body (bare skin to bare skin) due to the simultaneous touching of two conductive parts shall be lower than or equal to the values of the curve in Figure 8.

Figure 8 is based only on bare hand to hand or hand to feet contact (direct skin contact). It is allowable to use the calculations given in Annex A and B to take account of additional resistances e.g. footwear, gloves and surface materials of higher resistivity.

Every earth fault will be disconnected automatically or manually. Thus, touch voltages of very long or indefinite duration do not appear as a consequence of earth faults.



[SOURCE: A1 IEC 61936-1:2021 A1, Figure 12]

NOTE For duration of current flow considerably longer than 10 s a value of 80 V may be used as permissible touch voltage U_{Tp}.

Figure 8 — Permissible touch voltage

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5.4.2 Measures for the observance of permissible touch voltages

Application of the fundamental requirements will give the basic design of the earthing system. This design shall be checked with respect to touch voltages and could then be considered as a type design for similar situations.

For the values of the permissible touch voltages U_{Tp} Figure 8 shall be used. These permissible values are considered to be satisfied

C1: if the relevant installation becomes a part of a global earthing system.

C2: if C1 is not satisfied and the earth potential rise, determined by measurement or calculation does not exceed double the value of the permissible touch voltage U_{Tp} in accordance with Figure 8.

C3: if C2 is not satisfied and the earth potential rise, determined by measurement or calculation does not exceed four times the value of the permissible touch voltage in accordance with Figure 8 and the relevant recognized specified measures M are carried out in accordance with the magnitude of the earth potential rise and the fault duration. These measures are described in Table E.1 of Annex E.

C4: if C3 is not satisfied the criteria for the permissible touch voltage (U_{Tp}) of Figure 8 shall be proved by calculation and/or measurement of touch voltage (U_T). Additional resistances may be taken into account to determine the prospective permissible touch voltage (U_{vTp}) according to Annex A and Annex B and proved by calculation and/or measurement of U_{vT}. Generally, the verification of the criteria of permissible voltages (U_{Tp} or U_{vTp}) is done by measurements. If the criteria for U_T or U_{vT} are still not satisfied, the design shall be improved and steps C2 to C4 shall be reconsidered.

A flowchart of the design process from C2 to C4 is given in Figure 9.

Alternatively, a type design may be used that ensures the requirements in 5.4.1 are fully met.

NOTE 1 Examples of high earth potential rise where step voltages could be necessary to be considered at the boundaries of the earthing system are e.g. when $U_E > 20 \times U_{Tp}$

NOTE 2 As an alternative to using one of the conditions C1 to C4, the values of the touch voltages can be checked by field measurements.

Transferred potentials are always to be checked separately.

The earth potential rise and touch voltages of an earthing system may be calculated from available data (soil resistivity, impedance to earth of existing earthing systems, see Annex J). For the calculation all earth electrodes and other earthing systems, which are reliably connected to the relevant earthing system with sufficient current carrying capacity, may be considered. In particular, this applies to connected overhead earth wires, wires buried in earth and cables with earth electrode effect. This also applies to earthing systems, which are conductively connected to the relevant earthing system via sheaths or screens of cables, PEN-conductors or in another way.

For the proof by calculation with the help of Figure J.3 all cables with earth electrode effect can be considered, unless they are laid on more than four routes. These cables may belong to systems of different voltages.

In the case of more than four routes their mutual influence cannot be neglected; therefore, out of the existing routes only four have to be selected. In case several cables are laid in a certain route, the length may be included only once.

For the determination of the earth potential rise and touch voltages the currents of Table 1 are relevant.

For proof by measurement, Clause 8 (with reference to Annex H and Annex L) shall be considered.

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5.4.3 Design procedure

The requirements of [A1] IEC 61936-1:2021 [A1], 10.3.1 paragraph 1 the steps a) – f) apply.

g) determine earth potential rise, U_E, see Figure 1;

h) determine the permissible touch voltage value from Figure 8 for the relevant fault duration;

i) if the earth potential rise is below the permissible touch voltage and the requirements of Table 2 are met, the design is complete;

The design is also complete if U_E is less than 2 U_{Tp} according to 5.4.2 and the requirements of Table 2 are met.

The design is also complete if U_E is less than 4 U_{Tp} according to 5.4.2 with specified measures M applied and the requirements of Table 2 are met.

The requirements of [A1] IEC 61936-1:2021 [A1], 10.3.1 paragraph 1 the step j) apply.

NOTE 1 See calculation methods in Annex A and B.

The requirements of [A1] IEC 61936-1:2021 [A1], 10.3.1 paragraph 1 the steps k) – l) apply.

Table 2 shall be taken into account regarding transferred potentials to low voltage systems.

[A1] *Text deleted.* [A1]

The requirements of [A1] IEC 61936-1:2021 [A1], 10.3.1 paragraph 1 the step m) apply.

The requirements of [A1] IEC 61936-1:2021 [A1], 10.3.1 paragraph 2 apply.

The requirements of [A1] IEC 61936-1:2021 [A1], 10.3.1 paragraph 4 and 5 apply.

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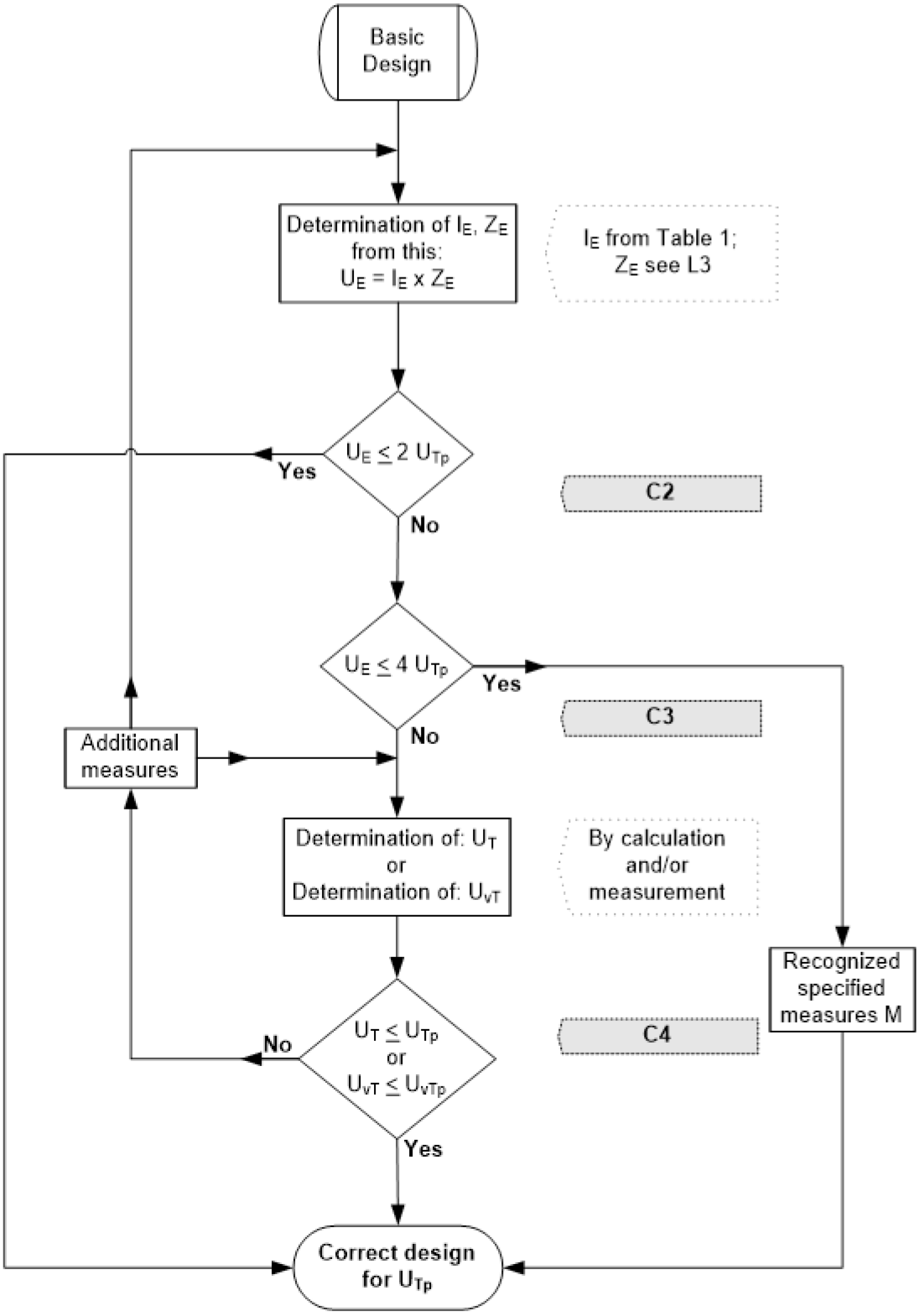


Figure 9 — Design of earthing systems, if not part of a global earthing system (C1 of 5.4.2), with regard to permissible touch voltage U_{Tp} by checking the earth potential rise U_E or the touch voltage U_T and without consideration of transferred potential

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6 Measures to avoid transferred potential

6.1 Transferred potential from high voltage systems to low voltage systems

6.1.1 High and low voltage earthing systems

The requirements of [A1] IEC 61936-1:2021, 10.2.3.1 [A1] apply.

6.1.2 LV supply only within HV substations

The requirements of [A1] IEC 61936-1:2021 [A1], 10.2.3.2 apply.

6.1.3 LV supply leaving or coming to HV substations

[A1] Full compliance is ensured if the earthing system of the electrical power installation is part of a global earthing system or connected to a multi-earthed HV neutral conductor in a balanced system.

[SOURCE: IEC 61936-1:2021, 10.2.3.3, modified – reference to Table 2] [A1]

If there is no global earthing system, the minimum requirements of Table 2 shall be used to identify those situations where interconnection of earthing systems with low voltage supply outside the high voltage installation is feasible.

The requirements of [A1] IEC 61936-1:2021, 10.2.3.3 [A1] paragraph 2 apply.

NOTE For installations with rated voltages below 50 kV, a distance of 20 m between separated earthing systems has been used in many cases. For certain soil structures other values could be appropriate.

6.1.4 LV in the proximity of HV substation

The requirements of [A1] IEC 61936-1:2021, 10.2.3.4 [A1] paragraph 1 and 2 apply.

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Table 2 — Minimum requirements for interconnection of low voltage and high voltage earthing systems based on U_E limits

Type of LV system [a, b]		U_E Requirements		
		Touch Voltage	Stress Voltage [c]	
			Fault duration $t_f \leq 5$ s	Fault duration $t_f > 5$ s
TT		Not applicable	$U_E \leq 1\,200$ V	$U_E \leq 250$ V
TN		$U_E \leq F \cdot U_{Tp}$ [d, e]	$U_E \leq 1\,200$ V	$U_E \leq 250$ V
IT	Distributed protective earth conductor	As per TN system	$U_E \leq 1\,200$ V	$U_E \leq 250$ V
	Protective earth conductor not distributed	Not applicable	$U_E \leq 1\,200$ V	$U_E \leq 250$ V

[a] For definitions of the type of LV systems, see HD 60364-1.

[b] For telecommunication equipment, the ITU recommendations should be used.

[c] Limit may be increased if appropriate LV equipment is installed or U_E may be replaced by local potential differences based on measurements or calculations

[d] A1 The typical value for F is 2, indicating the touch voltage is 50 % of UE. Higher values of F (up to 5) may be applied where there are additional connections of the PEN conductor to earth which therefore may reduce the touch voltage as a percentage of UE. For certain soil structures, caution is necessary in soils with high contrast of top layer resistivity and underlying lower resistivity. In this case F is closer to 1 as the touch voltage can exceed 50 % of the UE. If the PEN or neutral conductor of the low-voltage system is connected to earth only at the HV earthing system, the value of F shall be 1. A1

[e] U_{Tp} is derived from Figure 8.

A1 [SOURCE: IEC 61936-1:2021, Table 6, modified reference to Figure 8] A1

6.2 Transferred potentials to telecommunication and other systems

Rules for telecommunication systems in or in the vicinity of high voltage earthing systems are outside the scope of this document. Existing international documents (e.g. ITU recommendations and directives) are to be taken into account when dealing with transferred potentials to telecommunication systems.

Cables and insulated metallic pipes going into or out of a substation can be exposed to voltage differences during an earth fault inside the substation.

Depending on the way the cable screen and/or armouring are earthed (at one or both ends) significant stress voltages or currents in the screen and/or armouring could occur. The insulation of cables or pipes shall be dimensioned accordingly.

In case of earthing at one end this may be done inside or outside the substation. Attention is to be paid to the possible touch voltages at the insulated other end.

Precautions, as shown by the following examples, may be taken where necessary:

— interruption of the continuity of metallic parts where they leave the area of the earthing system;

— insulation of conductive parts or areas;

— installation of suitable barriers around conductive parts or areas to prevent their being touched;

— installation of an insulated barrier between parts connected to different earthing systems;

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— suitable potential grading;

— limiting overvoltages by using suitable devices;

— metallic structures, e.g. metallic fences, vineyard wires and guard rails, installed outside but in the proximity of the power installation.

If a high voltage earthing system becomes part of a global earthing system, where normally no dangerous potential differences appear, problems may arise if conductive parts of insulated pipes, cables, etc. connected to a remote earth potential and earthed conductive parts of the high voltage installation are simultaneously accessible.

It is therefore necessary for this equipment to be placed at a sufficient distance from the areas influenced by earth electrodes. If this is not possible, suitable measures shall be taken.

A general distance cannot be specified, the degree of danger shall be determined for each individual case.

7 Construction of earthing systems

7.1 Installation of earth electrodes and earthing conductors

An earthing system is generally composed of several horizontal, vertical or inclined electrodes, buried or driven into the soil by force.

The use of chemicals to reduce soil resistivity is not recommended.

Horizontal earth electrodes are preferably buried at a depth of 0,5 m to 1 m below ground level. This gives sufficient mechanical protection. It is recommended that the earth electrode is situated below the frost line.

In the case of vertical driven rods, the top of each rod will usually be situated below ground level. Vertical or inclined driven rods are particularly advantageous when the soil resistivity decreases with depth.

Metal frameworks, earthed in accordance with this document, which form a construction unit, may be used as an earthing conductor to earth parts which are directly fixed to this framework. Consequently, the whole framework shall have a sufficiently conductive cross-section and the joints shall be conductively and mechanically reliable. Precautions shall be taken to avoid part of the framework becoming disconnected from the earthing system when temporary dismantling takes place. Large frameworks shall be connected to the earthing system in a sufficient number of points.

The requirements of ⟦A1⟧ IEC 61936-1:2021 ⟨A1⟩, 10.4 apply.

General installation details can be found in Annex K and Annex M.

7.2 Lightning and transients

The requirements of ⟦A1⟧ IEC 61936-1:2021 ⟨A1⟩, 10.3.3 apply.

Annex F gives information for the design and construction of earthing systems to reduce the effects of high frequency interference.

7.3 Measures for earthing on equipment and installations

All exposed conductive parts which are part of the electrical system shall be earthed; in special cases insulated zones shall be created.

Extraneous conductive parts shall be earthed if appropriate, e.g. due to arcing, mechanical failures, capacitive and inductive coupling.

Detailed measures for earthing on fences, pipes, traction rails, etc. can be found in Annex G.

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8 Measurements

The requirements of [A1] IEC 61936-1:2021 [A1], 10.5 apply.

Details are given in Annexes H and L.

9 Maintainability

9.1 Inspections

The requirements of [A1] IEC 61936-1:2021 [A1], 10.6.1 apply.

9.2 Measurements

The requirements of [A1] IEC 61936-1:2021 [A1], 10.6.2 apply.

10 Inspection and documentation of earthing systems

A plan of the earthing system should exist which shows the material and the position of the earth electrodes, their branching points and the depth of burial.

Before taking over a site, a report should be made showing that all the requirements of this document have been observed.

The resistance to earth of every installation outside of the global earthing system areas shall be calculated or measured systematically (details of the measuring technique are given in Annex L) and the earth potential rise calculated or measured. Proof of touch voltage, if necessary, is to be made by measurement or calculation.

Inside the global earthing system areas there is no need to verify the resistance to earth or the earth potential rise because a basic design of earthing system is sufficient.

If recognized specified measures are needed to achieve permissible touch voltages, they shall be included in the site plan and shall be described in the documentation.

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Annex A
(normative)

Methods of calculating permissible touch voltages

A.1 Method of calculating permissible touch voltages U_{Tp}

Figure 8 shows the limit values of the permissible touch voltage U_{Tp}. This curve represents the values of touch voltage that shall not be exceeded by measured or calculated touch voltages, for any configuration in any condition.

Formula (A.1) of this Annex A gives the equation to evaluate the permissible touch voltage U_{Tp} for any configuration depending on four specific conditions:

1) the fault duration t_f, which determines the Body current limit $I_B(t_f)$

2) the sensitivity of human heart to fibrillate (*HF* = Heart Factor)

3) the body impedance Z_T, that depends on the touch voltage U_T

4) the touching condition (〚A1〛 e.g., 〚/A1〛 hand-hand, hand-to-feet; considering the body factor *BF*)

Formula (A.1):

$$U_{\mathrm{Tp}} = \mathrm{I_B}\left(t_f\right) \cdot \frac{1}{\mathrm{HF}} \cdot \mathrm{Z_T}\left(U_{\mathrm{T}}\right) \cdot BF \qquad \text{(A.1)}$$

[SOURCE: 〚A1〛 IEC 61936-1:2021 〚/A1〛, Annex B, first formula]

〚A1〛 where:

U_T	Touch voltage	bare skin to bare skin
U_{Tp}	Permissible touch voltage	
t_f	Fault duration	
$I_B(t_f)$	Body current limit	*c*2 in IEC 60479-1:2018, Figure 20 and Table 11, where probability of ventricular fibrillation is less than 5 %. I_B depends on fault duration
HF	Heart current factor	IEC 60479-1:2018, Table 12 i.e., 1,0 for left hand to feet, 0,8 for right hand to feet, 0,4 for hand to hand

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$Z_T(U_T)$	Body impedance	IEC 60479-1:2018, Table 1 and Figure 3 Z_T not exceeded by 50 % of the population Z_T depends on touch voltage. Therefore first calculation shall start with assumed level
BF	Body factor	IEC 60479-1:2018, Figure 3 i.e. 0,75 for hand to both feet,

[SOURCE: IEC 61936-1:2021, Annex B, modified, “bare skin to bare skin” added to touch voltage] A1

Different touching situations lead to different tolerable touch voltage. The limit values of the permissible touch voltages U_{Tp} of this document (see Figure 8) are based on the average of weighted values taken from four different permissible touch voltage calculation with Formula (A.1), corresponding to four different touching A1 solutions A1. These four situations are:

— touch voltage, U_{Tp1}, left hand to feet (weighted 1,0),

— touch voltage, U_{Tp2}, right hand to feet (weighted 1,0),

— touch voltage, U_{Tp3}, both hand to feet (weighted 1,0) and

— touch voltage, U_{Tp4}, hand to hand (weighted 0,7).

$U_{Tp} = (U_{Tp1} + U_{Tp2} + U_{Tp3} + U_{Tp4} * 0{,}7) / 4$

A.2 Method of calculating prospective permissible touch voltages U_{vTp}

Additional resistances ($R_A = R_H + R_F$) are introduced in Formula (A.1) giving Formula (A.2), that calculated the prospective permissible touch voltage. These additional resistances may represent e.g. gloves, shoes. The aim is to compare the calculated or measured value of the prospective touch voltage U_{vT} to its limit value prospective permissible touch voltage U_{vTp}.

Formula (A.2):

$$U_{\mathrm{vTp}} = \mathrm{I_B}\left(t_f\right) \cdot \frac{1}{\mathrm{HF}} \cdot \left(\mathrm{Z_T}\left(U_{\mathrm{T}}\right) \cdot BF + R_H + R_F\right) \qquad \text{(A.2)}$$

[SOURCE: IEC 61936-1:2010, Annex B, second formula]

For specific conditions touch voltages based on actual current path may be determined.

Another suitable formula to calculate the prospective permissible touch voltage is Formula (3), where $I_B(t_f)$ is the body current for a current path hand left hand to the feet (heart current factor $HF = 1$) and $U_{TP}(t_f)$ is the permissible touch voltage according to Figure 8.

Formula (A.3):

$$U_{\mathrm{vTp}}\left(t_f\right) = \mathrm{U_{Tp}}\left(t_f\right) + \frac{I_B\left(t_f\right)}{\mathrm{HF}} \cdot \left(R_H + R_F\right) \qquad \text{(A.3)}$$

This simplified formula includes additional resistances in accordance with the requirements of 5.4.1.

Additional factors:

R_H Hand resistance (e.g. gloves)

R_F Foot resistance ($R_F = R_{F1} + R_{F2}$)

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R_{F1} Resistance of the footwear

R_{F2} Resistance to earth of the standing point, where R_{F2} = 1,5 m^{-1} *ρ_S

ρ_S Specific soil resistivity of surface

A.3 Method of calculating permissible step voltages

Touch and step voltages shall always to be considered. As a general rule, the touch voltage requirements satisfy the step voltage requirements, because the tolerable step voltage limits are much higher than the touch voltage limits due to the different current path through the body (heart current factor *HF* = 0,04).

In special cases with high U_E (earth potential rise) step voltage limits shall be considered. In this case the permissible step voltage is derived similar to the method in A.1 and taking into account Formula (A.1) with the following factors, but without weighing.

Step voltage should be considered at the boundaries of the earthing system when e.g. U_E > 20 x U_{Tp} depending on fault duration.

Body current limit	$I_B(t_f)$	c2 in IEC 60479-1:2018, Figure 20 and Table 11 where probability of ventricular fibrillation is less than 5 %
Heart current factor	*HF*	IEC 60479-1:2018, Table 12 i.e. 0,04 for one foot to the other
Body impedance	$Z_T(U_T)$	IEC 60479-1:2018, Table 1 and Figure 3, Z_T not exceeded by 50 % of the population
Body factor	*BF*	IEC 60479-1:2018, Figure 3, i.e. 1 for one foot to the other

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Annex B
(normative)

Calculation of Permissible touch voltage U_{Tp}, Prospective permissible touch voltage U_{vTp}

B.1 General

Annex B gives in Table B.1, B.2 and B.3 the values of the body current and the body impedance to use for calculating the permissible touch voltage U_{Tp} of Figure 8. Furthermore, it shows two options of calculating the prospective permissible touch voltage U_{vTp}.

B.2 Calculation of permissible touch voltage

For the calculation of permissible values of touch voltages for high voltage installations that are represented by the values of U_{Tp} in Figure 8 the method of Annex A is used, considering the following formula and assumptions:

— Formula (A.1) of A.1

— the weighted configurations regarding current paths of A.1;

— 50 % probability of body impedance;

— 5 % probability of ventricular fibrillation;

— no additional resistances.

NOTE These assumptions lead to a touch voltage curve, U_{Tp} curve visualized by Figure 8, with an estimated risk due to experience, specific trained personnel, arguable expense etc. which is acceptable in case of earth faults in high voltage installations.

B.3 Calculation of the permissible touch voltage U_{Tp} curve values of Figure 8

Assuming that the basis of body current calculation is IEC 60479-1, and taking into account as permissible limit of current the curve c2 of IEC 60479-1:2018, Figure 20 and Table 11 (probability of ventricular fibrillation less than 5 %, left hand to both feet current path), the following Table B.1 results:

Table B.1 — Permissible body current I_B depending on the fault duration t_f

Fault duration, t_f s	Body current I_B (t_f) mA
0,05	900
0,10	800
0,20	600
0,50	200
1,00	80
2,00	60
5,00	51
10,00	50

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In order to obtain the relevant permissible touch voltage, it is necessary to determine the total human body impedance, which include internal body impedance and the impedances of the skin. This impedance depends on touch voltages and on the current path; values for a hand to hand or hand to foot current path are indicated in IEC 60479-1, from which Table B.2 is drawn (probability of 50 % that body impedances are less than or equal to the given value):

Table B.2 — Total human body impedance Z_T related to the touch voltage U_T for a current path hand to hand (values of Z_T are rounded to 25 Ω)

Touch voltage, U_T V	Total human body impedance, $Z_T(U_T)$ Ω
25	3 250
50	2 500
75	2 000
100	1 725
125	1 550
150	1 400
175	1 325
200	1 275
225	1 225
400	950
500	850
700	775
1 000	775

For the calculation of $U_T = f(t_f)$ Table B.2 is transformed into Table B.3 as U_T is defined by $U_T = I_B \cdot Z_B$:

Table B.3 — Total human body impedance Z_T related to the body current I_B for a current path hand to hand

Body current, I_B mA	Total human body impedance, $Z_T(U_T)$ Ω
8	3 250
20	2 500
38	2 000
58	1 725
81	1 550
107	1 400
132	1 325
157	1 275
184	1 225
421	950
588	850
903	775
1 290	775

Figure B.1 shows the dependence of the body impedance from the body current for a current path hand to hand:

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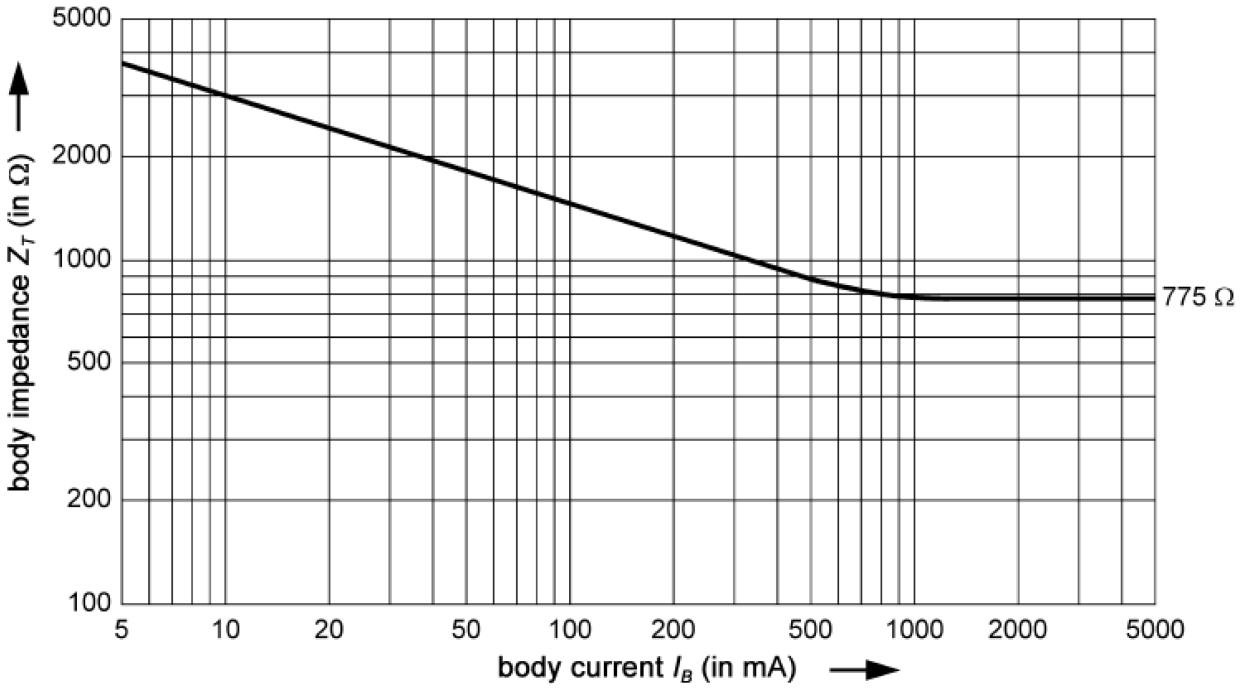


Figure B.1 — Total human body impedance Z_T related to the body current I_B for a current path hand to hand

The weighting conditions:

Each value in Figure 8 is based on a weighted average of four calculations due to four touching conditions:

— touch voltage left hand to feet (weighted 1,0),
— touch voltage right hand to feet (weighted 1,0),
— touch voltage both hand to feet (weighted 1,0),
— touch voltage hand to hand (weighted 0,7).

Resulting values of permissible touch voltages:

In Table B.4 the values of some points of the curve in Figure 8 are shown.

Table B.4 — Calculated values of the permissible touch voltage U_{Tp} as a function of the fault duration t_f (values of U_{Tp} are rounded to 5 V)

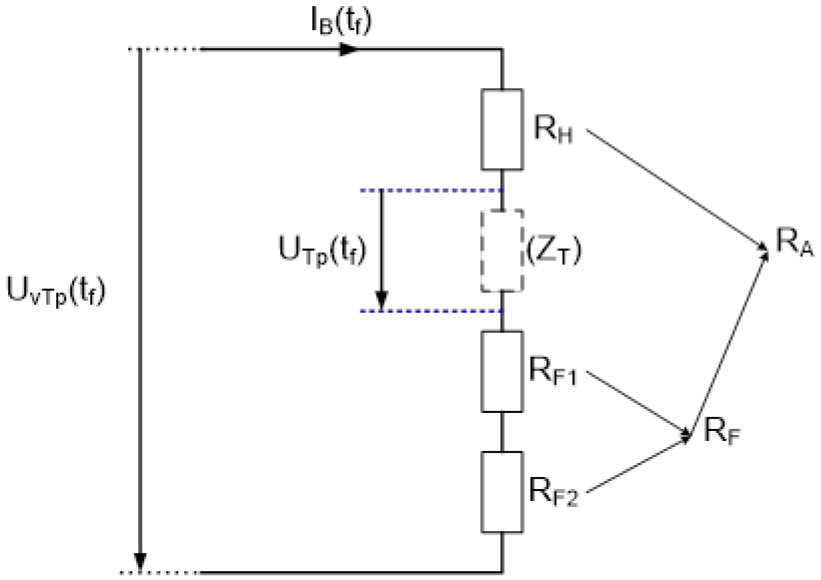
Fault duration t_f s	Permissible touch voltage U_{Tp} V
0,05	725
0,10	655
0,20	525
0,50	225
1,00	115
2,00	95
5,00	85
10,00	85

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For duration of current flow considerably longer than 10 s a value of 80 V may be used as permissible touch voltage U_{Tp}.

B.4 Calculation of prospective permissible touch voltage

A suitable method to calculate values of the prospective permissible touch voltage U_{vTp} is to consider a circuit diagram according to Figure B.2, where $I_B(t_f)$ is the body current for a current path hand left hand to the feet (heart current factor HF = 1) and $U_{Tp}(t_f)$ is the permissible touch voltage according to Figure 8.



Key

U_{vTp} (t_f)	Prospective permissible touch voltage
$I_B(t_f)$	Current flowing through the human body according to Table B.1
$U_{Tp}(t_f)$	Permissible touch voltage according to Table B.4
(Z_T)	Representation of the human body
R_A	Additional resistances $R_A = R_H + R_{F1} + R_{F2}$
R_H	Hand resistance (e.g. gloves)
R_F	Foot resistance
R_{F1}	Resistance of the footwear
R_{F2}	Resistance to earth of the standing point by using a simplified formula where $R_{F2} = 1{,}5\ m^{-1} * \rho_S$
t_f	Fault duration
ρ_S	specific soil resistivity of surface

Figure B.2 — Circuit diagram for the calculation of values of U_{vTp} depending on fault duration t_f

According to the circuit diagram Formula (A.3) is used to calculate values of U_{vTp}:

$$U_{vTp}\left(t_f\right) = U_{Tp}\left(t_f\right) + \frac{I_B\left(t_f\right)}{HF} \cdot \left(R_H + R_F\right)$$

Figure B.3 shows examples for curves $U_{vTp} = f(t_f)$ for different foot resistances R_F.

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