BS EN 50522:2010

Incorporating corrigendum October 2012

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 50522:2010. Together with BS EN 61936-1:2010, it partially supersedes BS 7354:1990. Where conflict exists between BS EN 50522:2010 and BS 7354:1990 the provisions of BS EN 50522:2010 take precedence.

The UK participation in its preparation was entrusted to Technical Committee PEL/99, Erection and operation of power installations. Preparation of this National Foreword and the National Annexes was entrusted to both PEL/99 and Technical Committee GEL/600, Earthing. A list of organizations represented on these committees can be obtained on request to their secretaries.

NOTE To ensure wide participation in the process, GEL/600, in particular, has strengthened its membership to include more representation from the UK Electricity Supply industry (TSOs and DNOs) and an earthing test equipment manufacturer. Furthermore, detailed consultation has been carried out with The Energy Networks Association (ENA) through its Earthing Co-ordination Group.

National Annexes NA, NB and NC have been appended to this standard.

Background and developments to IEC/CENELEC documents

In recent years, two documents have existed side-by-side covering, among other things, the earthing of high voltage installations. The first was HD 637 S1, Power installations exceeding 1kV, published in 1999 while the other was IEC 61936-1, of the same title, published in 2002. These documents were produced by working groups of the committees CENELEC TC/99X and IEC TC/99, respectively. As these documents were not published at the same time and the composition of the working groups was to some extent different, a situation arose such that significant discrepancies existed between these two documents, notably, concerning the fundamental safety criterion of allowable human body current and body impedance values under step and touch voltage conditions. This situation was not ideal, and an initiative was taken to develop a revision to IEC 61936-1 under maintenance team IEC TC/99 MT4 and to release it as a European standard. At the same time, a working group CENELEC TC/99X WG1 was formed to extract the earthing content of HD 637 S1 and bring to publication a new European standard on earthing (EN 50522). Parallel voting of EN 61936-1 and EN 50522 was arranged, in order to achieve harmonization of the adopted electrocution safety criteria and both documents were published in 2010.

Background and development of UK earthing design standards

Over a similar period, within the UK, there were three important concurrent documents concerning the earthing of HV power installations. The first, BS 7354:1990, Code of practice for design of high-voltage open-terminal stations, prepared by Technical Committee PEL/92, covered similar topics to IEC 61936-1, with Section 7 devoted to earthing. The other two documents, exclusively concerning earthing, were published by the Energy Networks Association, and can be considered as a set. These are Technical Specification 41/24 Issue 1 – 1992, Guidelines for the installation, testing and maintenance of main earthing systems in substations and Engineering Recommendation S34, Amendment 2 – 1988, A guide for assessing the rise of earth potential at substation sites.

Differences in the UK approach to earthing design

In the period of the preparation of EN 61936-1 and EN 50522, the BSI committees GEL/600 and PEL/99 coordinated activities with the aim to:

a) achieve pro-active representation of UK interests on CENELEC TC/99X and IEC TC/99 working groups; and

b) bring about a harmonization of the criteria for station earthing design in the UK.

From this work, the following important aspects of the National Annexes in this document that differ from the EN 50522 are worth highlighting.

1) Recognition of the probabilistic nature of electrical system safety

There has been a reaffirmation in BS EN 61936-1:2010 of the explicit recognition that the parameters involved in assessing safety are probabilistic in nature, with regard to the fault current magnitude and duration, as well as the probability of the fault occurrence, and the presence probability of a human being. This has led to the introduction of a new additional approach to earthing system design in the UK based on probabilistic methods, which is outlined in National Annex NA using a design flow chart and developed with case studies in National Annex NB.

2) Deviations of UK safety limits compared to IEC/CENELEC limits

The release of DD IEC/TS 60479-1:2005, Effects of current on human beings and livestock – Part 1: General aspects, provided new data on human electrocution safety parameters; specifically new and lower values of human body impedances. The CENELEC and IEC working groups were concerned that this would result in lower maximum tolerable values of touch voltages, and as a result, proposed a modified method for calculating such voltages based on an 'average' of different shock scenarios and based on body impedances not exceeded for 50% of the population (note, the first edition of IEC 61936-1 was based on left-hand to feet body impedances not exceeded for 5% of the population). However, as a result of advice obtained from the UK Health and Safety Executive (HSE), consensus was reached between PEL/99 and GEL/600 that UK HV earthing systems have to be designed according to tolerable voltages based on body impedances not exceeded for 5% of the population, as given in DD IEC/TS 60479-1:2005, Table 1 (Column 2) rather than the 50% values (Column 3). Also worth noting has been the consensus among PEL/99 and GEL/600 to move away from using the tolerable body current curve 'c1' to curve 'c2' from DD IEC/TS 60479-1:2005, again, based on advice from the UK HSE. This marks a departure from the very strict deterministic limits observed previously under ENATS 41-24. However, the reduction in values of IEC published body impedances means that the resultant values of tolerable voltages are not greatly affected and certainly not reduced.

Accordingly, the UK obtained a variation to the new CENELEC and IEC standards which has been recognized in the foreword of BS EN 61936-1:2010 and BS EN 50522:2010, Annex Q (A-Deviations). Hence, these documents specify the required difference in approach to earthing design in the UK, based on the 5% body impedance values. This variation affects the fundamental design parameters and in National Annex NA, a revised set of tolerable voltage curves has been produced to replace EN 50522:2010, Figure 4 (Section 5.4.3) and Figure B.2 (Annex B). The new UK tolerable touch voltage figures are given in National Annex NA.

3) Additional guidance on assessing fault current distribution, earth potential rise, design and testing of earthing systems

BS EN 61936-1:2010 partially supersedes BS 7354:1990, and in particular it supersedes the earthing section of BS 7354. However, EN 50522:2010 does not provide sufficient detailed guidance on specific aspects of design and testing of earthing systems. In view of this, the committees PEL/99 and GEL/600 have decided to recommend that reference is made to ENAS 34 for recommendations and guidance on assessing rise of earth potential and to ENATS 41-24 for recommendations and guidance for the design, installation, testing and maintenance of earthing systems in substations. It should be emphasised that the tolerable safety limits contained in ENAS 34 and ENATS 41-24 are not applicable and it is noted that both ENAS 34 and ENATS 41-24 are expected to be revised in the near future to take into account the new safety limits, as given in Annex A of this document.

4) Recognition of the use of computer-aided earthing design tools

Over the past 20 years, UK power companies and consultants have increasingly relied on the use of computer-aided earthing design tools. It is recognized that computation of earth impedances and prospective safety voltages for complex earthing systems and soils using simplified equations may lead to inaccurate safety assessments. Accordingly, modern computation software tools may be employed. It is advisable to verify calculated values through direct testing of the installation on commissioning and periodically throughout its lifetime. Additional guidance on earth system testing is given in National Annex NC.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Amendments/corrigenda issued since publication

Date	Text affected
31 October 2012	National foreword / national annex correction

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 50522

November 2010

ICS 29.120.50

Supersedes HD 637 S1:1999 (partially)

English version

Earthing of power installations exceeding 1 kV a.c.

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

Erdung von Starkstromanlagen mit Nennwechselspannungen über 1 kV

This European Standard was approved by CENELEC on 2010-11-01. 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.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
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Foreword

This European Standard was prepared by the Technical Committee CENELEC TC 99X, Power installations exceeding 1 kV a.c. (1,5 kV d.c.). It was submitted to formal vote and was accepted by CENELEC as EN 50522 on 2010-11-01.

Together with EN 61936-1:2010 this document supersedes HD 637 S1:1999.

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

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2011-11-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2013-11-01

NOTE *The text identical with IEC 61936-1 is written in italics.*

Contents

1 Scope

This European Standard 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 a.c. and nominal frequency up to and including 60 Hz, so as to provide safety and proper functioning for the use intended.

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

a) substation, including substation for railway power supply;

b) electrical 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 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.

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

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

– overhead and underground lines between separate installations;
– electric railways;
– mining equipment and installations;
– fluorescent lamp installations;
– installations on ships and off-shore installations;
– electrostatic equipment (e.g. electrostatic precipitators, spray-painting units);
– test sites;
– medical equipment, e.g. medical X-ray equipment.

This European Standard does not apply to the requirements for carrying out live working on electrical installations.

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.

EN 60529, *Degrees of protection provided by enclosures (IP Code)* (IEC 60529)

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

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

HD 60364-4-41, *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock* (IEC 60364-4-41, modified)

IEC 60050(151):2001, *International Electrotechnical Vocabulary (IEV) – Part 151: Electrical and magnetic devices*

IEC 60050(195):1998, *International Electrotechnical Vocabulary (IEV) – Part 195: Earthing and protection against electric shock*

IEC 60050(601):1985, *International Electrotechnical Vocabulary (IEV) – Part 601: Generation, transmission and distribution of electricity – General*

IEC 60050(602):1983, *International Electrotechnical Vocabulary (IEV) – Part 602: Generation, transmission and distribution of electricity – Generation*

IEC 60050(604):1987, *International Electrotechnical Vocabulary (IEV) – Part 604: Generation, transmission and distribution of electricity – Operation*

IEC 60050(605):1983, *International Electrotechnical Vocabulary (IEV) – Part 605: Generation, transmission and distribution of electricity – Substations*

IEC 60050(826):2004, *International Electrotechnical Vocabulary (IEV) – Part 826: Electrical installations*

IEC 60287-3-1, *Electric cables – Calculation of the current rating – Part 3-1: Sections on operating conditions – Reference operating conditions and selection of cable type*

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

IEC 60949:1988, *Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects*

IEC/TS 61000-5-2, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 2: Earthing and cabling*

3 Terms and definitions

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

3.1 General definitions

3.1.1
electrical equipment
item used for such purposes as generation, conversion, transmission, distribution or utilization of electric energy, such as electric machines, transformers, switchgear and controlgear, measuring instruments, protective devices, wiring systems, current-using equipment

[IEV 826-16-01]

3.1.2
rated value
value of a quantity used for specification purposes, established for a specified set of operating conditions of a component, device, equipment, or system

[IEV 151-16-08]

3.1.3
high voltage
voltage exceeding 1 000 V a.c.

3.1.4
low voltage
voltage not exceeding 1 000 V a.c.

3.1.5
operation
all activities, including both electrical and non-electrical work activities, necessary to permit the power installation to function

NOTE These activities include switching, controlling, monitoring and maintenance

3.2 Definitions concerning installations

3.2.1
closed electrical operating area
room or location for operation of electrical installations and equipment to which access is intended to be restricted to skilled or instructed persons or to lay personnel under the supervision of skilled or instructed persons, e.g. by opening of a door or removal of protective barrier only by the use of a key or tool, and which is clearly marked by appropriate warning signs

3.2.2
substation
part of a power system, concentrated in a given place, including mainly the terminations of transmission or distribution lines, switchgear and housing and which may also include transformers. It generally includes facilities necessary for system security and control (e.g. the protective devices)

NOTE According to the nature of the system within which the substation is included, a prefix may qualify it.

EXAMPLES: transmission substation (of a transmission system), distribution substation, 400 kV substation, 20 kV substation.

[IEV 605-01-01]

3.2.3
power station
installation whose purpose is to generate electricity and which includes civil engineering works, energy conversion equipment and all the necessary ancillary equipment

[IEV 602-01-01]

3.2.4
installations of open design
installations where the equipment does not have protection against direct contact

3.2.5
installations of enclosed design
installations where the equipment has protection against direct contact

NOTE For degrees of enclosure protection see EN *60529.*

3.3 Definitions concerning safety measures against electric shock

3.3.1
protection against direct contact
measures which prevent persons coming into hazardous proximity to live parts or those parts which could carry a hazardous voltage, with parts of their bodies or objects (reaching the danger zone)

3.3.2
protection in case of indirect contact
protection of persons from hazards which could arise, in event of fault, from contact with exposed conductive parts of electrical equipment or extraneous conductive parts

3.3.3
enclosure
part providing protection of equipment against certain external influences and, in any direction, protection against direct contact

3.4 Definitions concerning earthing

3.4.1
(local) earth
part of the Earth which is in electric contact with an earth electrode and the electric potential of which is not necessarily equal to zero

NOTE The conductive mass of the earth, whose electric potential at any point is conventionally taken as equal to zero.

[IEV 195-01-03, modified]

3.4.2
reference earth
(remote earth)
part of the Earth considered as conductive, the electric potential of which is conventionally taken as zero, being outside the zone of influence of the relevant earthing arrangement

NOTE The concept "Earth" means the planet and all its physical matter.

[IEV 195-01-01, modified]

3.4.3
earth electrode
conductive part, which may be embedded in a specific conductive medium, e.g. in concrete or coke, in electric contact with the Earth

[IEV 195-02-01]

3.4.4
earthing conductor
conductor which provides a conductive path, or part of the conductive path, between a given point in a system or in an installation or in equipment and an earth electrode

[IEV 195-02-03]

NOTE Where the connection between part of the installation and the earth electrode is made via a disconnecting link, disconnecting switch, surge arrester counter, surge arrester control gap etc., then only that part of the connection permanently attached to the earth electrode is an earthing conductor.

3.4.5
protective bonding conductor
protective conductor for ensuring equipotential bonding

3.4.6
earthing system
arrangement of connections and devices necessary to earth equipment or a system separately or jointly

[IEV 604-04-02]

3.4.7
earth rod
earth electrode consisting of a metal rod driven into the ground

[IEV 604-04-09]

3.4.8
structural earth electrode
metal part, which is in conductive contact with the earth or with water directly or via concrete, whose original purpose is not earthing, but which fulfils all requirements of an earth electrode without impairment of the original purpose

NOTE Examples of structural earth electrodes are pipelines, sheet piling, concrete reinforcement bars in foundations and the steel structure of buildings, etc.

3.4.9
electric resistivity of soil, ρ_E
resistivity of a typical sample of soil

3.4.10
resistance to earth, R_E
real part of the impedance to earth

3.4.11
impedance to earth, Z_E
impedance at a given frequency between a specified point in a system or in an installation or in equipment and reference earth

NOTE The impedance to earth is determined by the directly connected earth electrodes and also by connected overhead earth wires and wires buried in earth of overhead lines, by connected cables with earth electrode effect and by other earthing systems which are conductively connected to the relevant earthing system by conductive cable sheaths, shields, PEN conductors or in another way.

3.4.12
earth potential rise (EPR), U_E
voltage between an earthing system and reference earth

3.4.13
potential
voltage between an observation point and reference earth

3.4.14
(effective) touch voltage, U_T
voltage between conductive parts when touched simultaneously

NOTE The value of the effective touch voltage may be appreciably influenced by the impedance of the person in electric contact with these conductive parts.

[IEV 195-05-11, modified]

3.4.15
prospective touch voltage, U_{vT}
voltage between simultaneously accessible conductive parts when those conductive parts are not being touched

[IEV 195-05-09, modified]

3.4.16
step voltage, U_S
voltage between two points on the earth's surface that are 1 m distant from each other, which is considered to be the stride length of a person

[IEV 195-05-12]

3.4.17
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 (Figure 1).

NOTE The definition also applies where a conductor, which is connected to reference earth, leads into the area of the potential rise.

3.4.18
stress voltage
voltage appearing during earth fault conditions between an earthed part or enclosure of equipment or device and any other of its parts and which could affect its normal operation or safety

3.4.19
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 dangerous touch voltages

NOTE 1 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 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 O).

3.4.20
multi-earthed HV neutral conductor
neutral conductor of a distribution line connected to the earthing system of the source transformer and regularly earthed

3.4.21
exposed-conductive-part
conductive part of equipment which can be touched and which is not normally live, but which can become live when basic insulation fails

[IEV 826-12-10]

3.4.22
extraneous-conductive-part
conductive part not forming part of the electrical installation and liable to introduce an electric potential, generally the electric potential of a local earth

[IEV 826-12-11, modified]

3.4.23
PEN conductor
conductor combining the functions of both protective earthing conductor and neutral conductor

[IEV 826-13-25]

3.4.24
earth fault
fault caused by a conductor being connected to earth or by the insulation resistance to earth becoming less than a specified value

[IEV 151-03-40:1978]

NOTE Earth faults of two or several phase conductors of the same system at different locations are designated as double or multiple earth faults.

3.4.25
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

[IEV 601-02-24, modified]

3.4.26
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 In case of no self-extinguishing arc fault there are two different operation methods used:

- automatic disconnection;
- continuous operation during fault localisation process.
  In order to facilitate the fault localisation 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 Arc suppression coil may have high ohmic resistor in parallel to facilitate fault detection.

3.4.27
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

[IEV 601-02-25, 601-02-26]

3.4.28
earth fault current, I_F
current which flows from the main circuit to earth or earthed parts at the fault location (earth fault location) (Figure 2 and Figure 3)

NOTE 1 For single earth faults, this is,
– *in systems with isolated neutral, the capacitive earth fault current;*
– *in systems with high resistive earthing, the RC composed earth fault current;*
– *in systems with resonant earthing, the earth fault residual current;*
– *in systems with solid or low impedance neutral earthing, the line-to-earth short-circuit current.*

NOTE 2 Further earth fault current may result from double earth fault and line to line to earth.

3.4.29
current to earth, I_E
current flowing to earth via the impedance to earth (see Figure 2)

NOTE 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.

3.4.30
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

3.4.31
circulating transformer neutral current
portion of fault current which flows back to the transformer neutral point via the metallic parts and/or the earthing system without ever discharging into soil

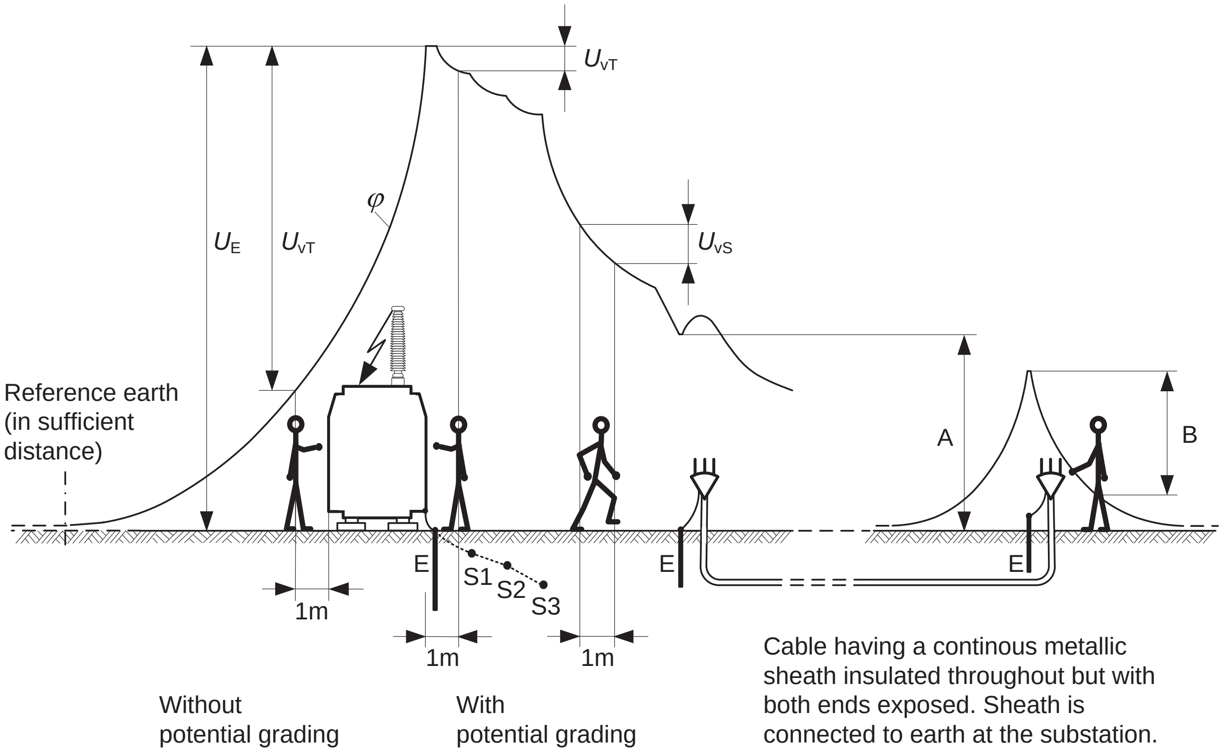
3.4.32
horizontal earth electrode
electrode which is generally buried at a depth of up to approximately 1 m. It can consist of strip, round bar or stranded conductor and can be laid out to form a radial, ring or mesh earth electrode or a combination of these

3.4.33
cable with earth electrode effect
cable whose sheaths, screens or armourings have the same effect as a strip earth electrode

3.4.34
foundation earth electrode
conductive structural embedded in concrete which is in conductive contact with the earth via a large surface

[IEV 826-13-08, modified]

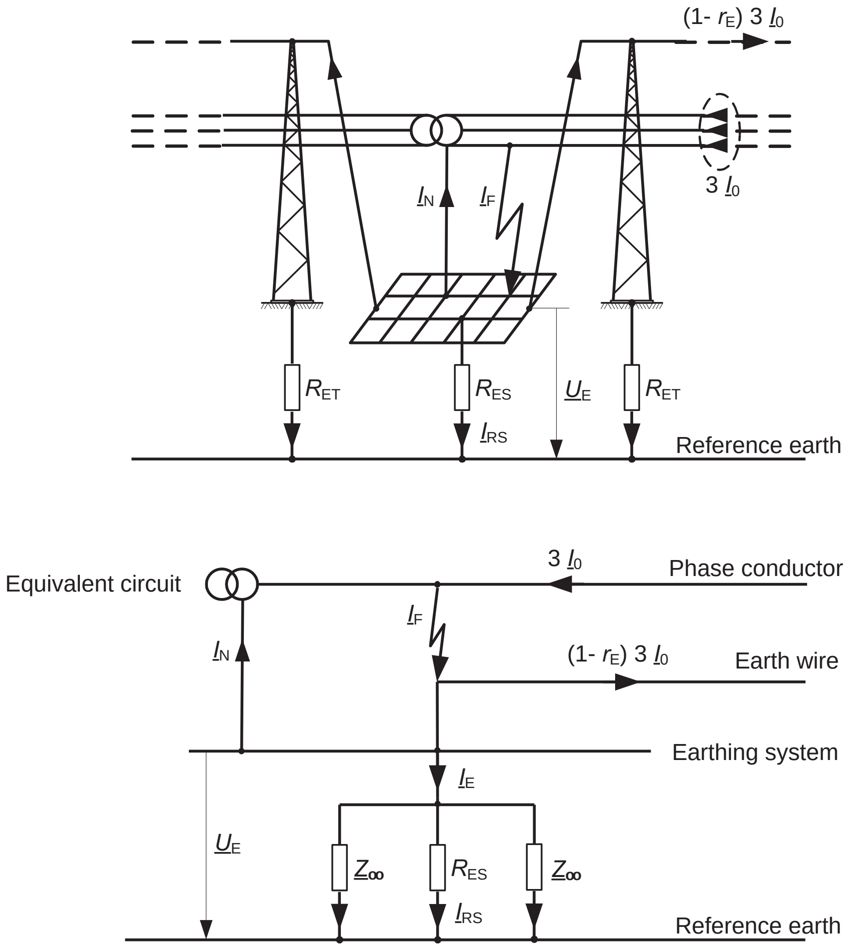
3.4.35
potential grading earth electrode
conductor which due to shape and arrangement is principally used for potential grading rather than for establishing a certain resistance to earth



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



$\underline{I}_F = 3\,\underline{I}_0 + \underline{I}_N$

$\underline{I}_E = r_E \cdot (\underline{I}_F - \underline{I}_N)$

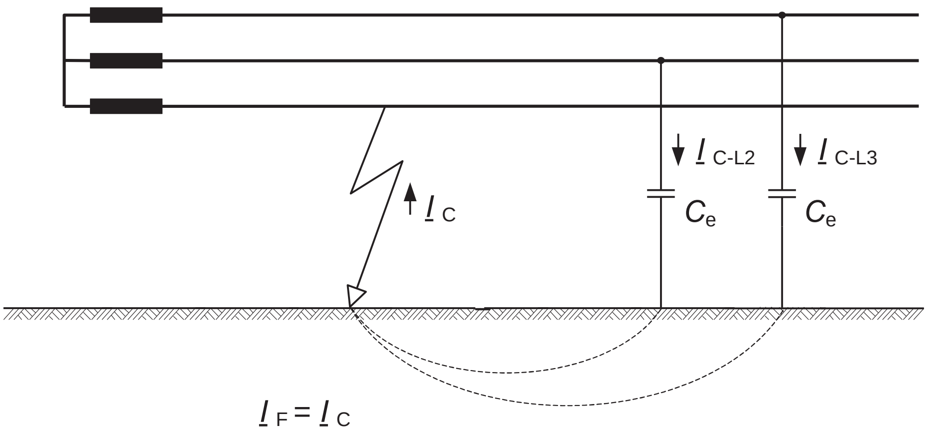
$\underline{U}_E = \underline{I}_E \cdot \underline{Z}_E$

$$\underline{Z}_E = \frac{1}{\dfrac{1}{R_{ES}} + n\,\dfrac{1}{\underline{Z}_\infty}}$$

For equal earth wire tower footing impedances of the overhead lines

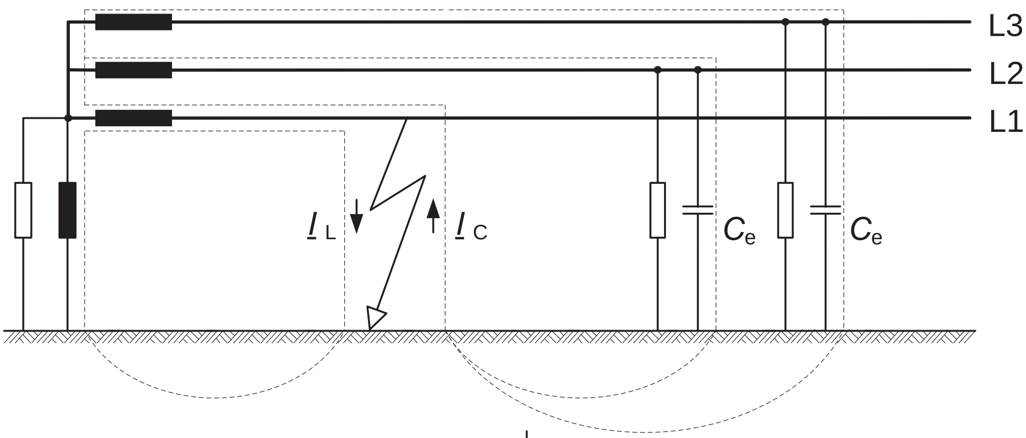
3 $\underline{I}_0$	Three times zero sequence current of the line
$\underline{I}_N$	Current via neutral earthing of the transformer
$\underline{I}_F$	Earth fault current
$\underline{I}_E$	Current to earth (cannot be measured directly)
$\underline{I}_{RS}$	Current via the resistance to earth of the mesh earth electrode
r_E	Reduction factor of the overhead line
R_{ES}	Resistance to earth of the mesh earth electrode
R_{ET}	Resistance to earth of the tower
$\underline{Z}_\infty$	Chain impedance (earth wire/tower footing) of the overhead line assumed to be infinite
$\underline{Z}_E$	Impedance to earth
$\underline{U}_E$	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



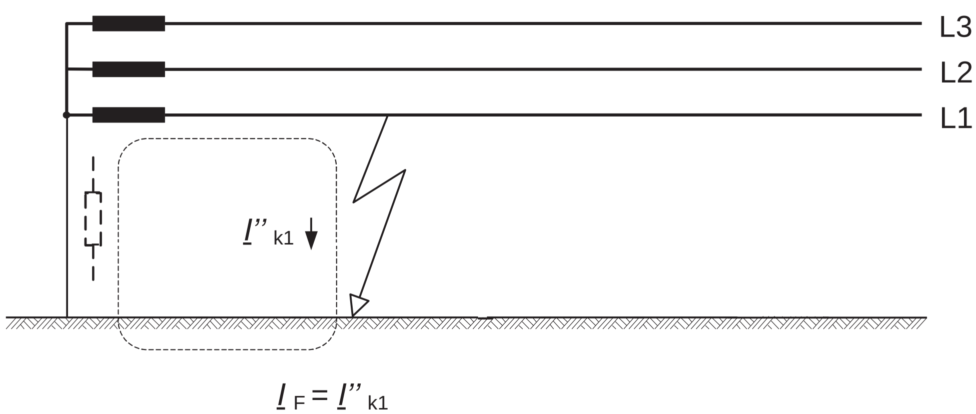
NOTE $\underline{I}_C$ may include ohmic component.

a) Earth fault current in a system with isolated neutral



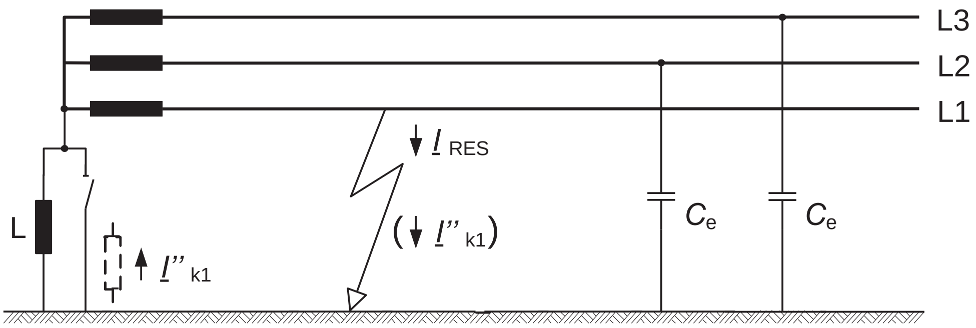
$$/\underline{I}_F/ = /\underline{I}_{RES}/ = \sqrt{\left|\underline{I}_C + \underline{I}_L\right|^2 + \left|\underline{I}_H\right|^2}$$

b) Earth fault current in a system with resonant earthing



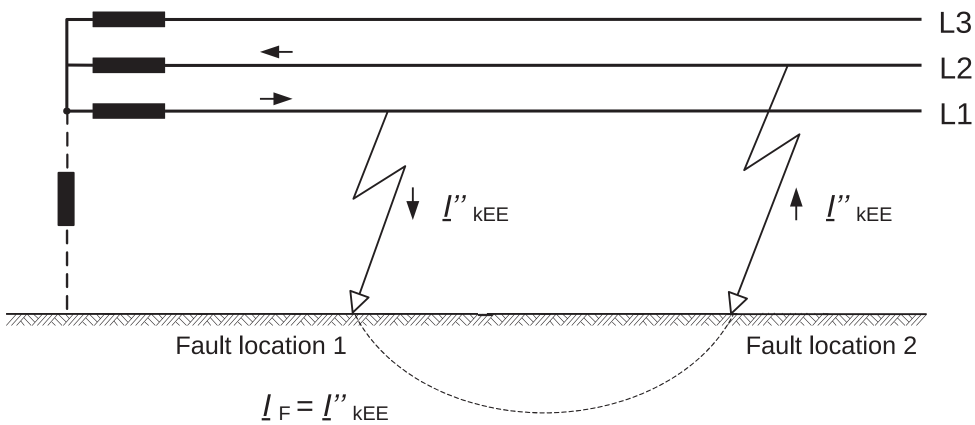
c) Earth fault current in a system with low impedance neutral earthing

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



$\underline{I}_F = \underline{I}_{RES}$ after a short time $\underline{I}''_{k1}$

d) Earth fault current in a system with resonant earthing and temporary low impedance neutral earthing



$\underline{I}_F = \underline{I}''_{kEE}$

e) Double earth fault current in a system with isolated neutral or resonant earthing

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

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

Figure 3 - Essential components of earth fault currents in high voltage systems

4 Fundamental requirements

4.1 General requirements

This standard 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.

Installations and equipment shall be capable of withstanding electrical, mechanical, climatic and environmental influences anticipated on site.

The design shall take into account

- *the purpose of the installation,*
- *the users requirements such as power quality, reliability, availability, and ability of the electrical network to withstand the effects of transient conditions such as starting of large motors, short power outages and re-energization of the installation,*
- *the safety of the operators and the public,*
- *the environmental influence,*
- *the possibility for extension (if required) and maintenance.*

4.2 Electrical requirements

4.2.1 Methods of neutral earthing

The method of neutral earthing strongly influences the fault current level and the fault current duration. Further more the neutral earthing method is important with regard to the following:

- *selection of insulation level;*
- *characteristics of overvoltage limiting devices such as spark gaps or surge arresters;*
- *selection of protective relays;*
- *design of earthing system.*

The following are examples of neutral earthing methods:

- *isolated neutral;*
- *resonant earthing;*
- *high resistive earthing;*
- *solid (low impedance) earthing.*

The choice of the type of neutral earthing is normally based on the following criteria:

- *local regulations (if any);*
- *continuity of supply required for the network;*
- *limitation of damage to equipment caused by earth faults;*
- *selective elimination of faulty sections of the network;*
- *detection of fault location;*
- *touch and step voltages;*
- *inductive interference;*
- *operation and maintenance aspects.*

One galvanically connected system has only one method of neutral earthing. Different galvanically independent systems may have different methods of neutral earthing. If different neutral earthing configurations can occur during normal or abnormal operating conditions, equipment and protective system shall be designed to operate under these conditions.

4.2.2 Short-circuit current

Installations shall be designed, constructed and erected to safely withstand the mechanical and thermal effects resulting from short-circuit currents.

The objective is to determine the worst case fault scenario for every relevant aspect of the functional requirements, as these may differ. The following types of fault shall be examined at each voltage level present in the installation:

a) three phases to earth;

b) two phases to earth;

c) single phase to earth;

d) phase to phase via earth (cross country earth fault).

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.

Installations shall be protected with automatic devices to disconnect three-phase and phase-to-phase short-circuits.

Installations shall be protected either with automatic devices to disconnect earth faults or to indicate the earth fault condition. The selection of the device is dependent upon the method of neutral earthing.

The standard value of rated duration of the short-circuit is 1,0 s.

NOTE 1 *If a value other than 1 s is appropriate, recommended values would be 0,5 s, 2,0 s and 3,0 s.*

NOTE 2 *The rated duration should be determined taking into consideration the fault switching time.*

4.3 Safety criteria

The hazard to human beings is that a current will flow through the region of the heart which is sufficient to cause ventricular fibrillation. The current limit, for power-frequency purposes is derived from the appropriate curve in IEC/TS 60479-1. This body current limit is translated into voltage limits for comparison with the calculated step and touch voltages taking into account the following factors:

- *proportion of current flowing through the region of the heart;*
- *body impedance along the current path;*
- *resistance between the body contact points and e.g. metal structure to hand including glove, feet to remote earth including shoes or gravel;*
- *fault duration.*

It must also be recognized that fault occurrence, fault current magnitude, fault duration and presence of human beings are probabilistic in nature.

For installation design, the curve shown in Figure 4 is calculated according to the method defined in Annex A and Annex B*.*

NOTE *The curve is based on data extracted from IEC/TS 60479-1:*

- *body impedance from Table 1 of IEC/TS 60479-1(not exceeded by 50 % of the population);*
- *permissible body current corresponding to the c2 curve in Figure 20 and Table 11 of IEC/TS 60479-1 (probability of ventricular fibrillation is less than 5 %);*
- *heart current factor according to Table 12 of IEC/TS 60479-1.*

The curve in Figure 4, which gives the permissible touch voltage, should be used.

As a general rule meeting the touch voltage requirements satisfies the step voltage requirements, because the tolerable step voltage limits are much higher than touch voltage limits due to the different current path through the body.

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 used to prevent touch voltages resulting from HV faults exceeding the low voltage limits given in HD *60364-4-41 (e.g. 50 V).*

4.4 Functional requirements

The earthing system, its components and bonding conductors shall be capable of distributing and discharging the fault current without exceeding thermal and mechanical design limits based on backup protection operating time.

The earthing system shall maintain its integrity for the expected installation lifetime with due allowance for corrosion and mechanical constraints.

Earthing system performance shall avoid damage to equipment due to excessive potential rise, potential differences within the earthing system and due to excessive currents flowing in auxiliary paths not intended for carrying parts of the fault current.

The earthing system, in combination with appropriate measures, shall maintain step, touch and transferred potentials within the voltage limits based on normal operating time of protection relays and breakers.

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 earthing system performance shall contribute to ensuring electromagnetic compatibility (EMC) among electrical and electronic apparatus of the high-voltage system in accordance with IEC/TS 61000-5-2.

5 Design of earthing systems

5.1 General

Parameters relevant to earthing system dimensioning are:

- value of fault current [1)];
- fault duration [1)];
- soil characteristics.

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 have to 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 Annex C. If a different material, for example stainless steel, is used, this material and its dimensions shall meet the functional requirements.

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1) These parameters mainly depend on the method of earthing the neutral of the high voltage system.

5.2.2 Earthing conductors

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

- copper: 16 mm² (but see also G.5)
- aluminium: 35 mm²
- steel: 50 mm²

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.

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 1 In some cases steady-state zero-sequence currents must be taken into account for the dimensioning of the relevant earthing system.

NOTE 2 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 standard 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 have to be considered.

NOTE The current carrying capability of the type of joints used (especially bolted joints) is to be taken into account.

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]

[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 has to be sized according to the maximum coil current.

[d] It has to 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 can not be applied. The reactive/capacitive component of residual current has to 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 has to be considered. In case of further coils external to the substation they may be considered.

Legend:

I_C Calculated or measured capacitive earth fault current
I_{RES} Earth fault residual current (see Figure 3b)
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 IEC 60909.
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 EN 60909
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 has to be determined (in accordance with Annex L).

5.4 Dimensioning with regard to touch voltages

5.4.1 Permissible values

Touch voltage limits are given in Figure 4, as stated in 4.3 (safety criteria).

However Figure 4 is based only on bare hand to hand or hand to feet contact. It is allowable to use the calculations given in Annex A to take account of additional resistances e.g. footwear, superficial high resistivity materials.

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

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 has to 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 4 shall be used. These permissible values are considered to be satisfied if

- either one of the conditions C is satisfied:

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

  C2: The earth potential rise, determined by measurement or calculation does not exceed double the value of the permissible touch voltage in accordance with Figure 4.

- or 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 Annex E.

Additional resistances can be taken into account to determine the prospective permissible touch voltage U_{vTp} according to Annex A and Annex B.

A flowchart of this design process is given in Figure 5.

If neither the conditions C are satisfied nor the recognized specified measures M are carried out, then the stipulation for the permissible touch voltage U_{Tp} of Figure 4 has to be proved, generally by measurements.

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

NOTE As an alternative to using the conditions C and the recognized specified measures M 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.

NOTE In the case of more than four routes their mutual influence must not 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) has to be considered.

5.4.3 Design procedure

Design of an earthing system can be accomplished as follows:

a) *data collection e.g. earth fault current, fault duration and layout;*

b) *initial design of the earthing system based on the functional requirements;*

c) *determine if it is part of a global earthing system;*

d) *if not, determine soil characteristics e.g. specific soil resistivity of layers;*

e) *determine based on earth fault current the current discharged into soil from earthing system;*

f) *determine based on layout, soil characteristics and parallel earthing systems the overall impedance to earth;*

g) *determine earth potential rise;*

h) *determine permissible touch voltage;*

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

   NOTE The design is also complete if EPR is less then 2 U_{Tp} according to 5.4.2.

j) *if not, determine if touch voltages inside and in the vicinity of the earthing system are below the tolerable limits;*

k) *determine if transferred potentials present a hazard outside or inside the electrical power installation. If yes, proceed with mitigation at exposed location;*

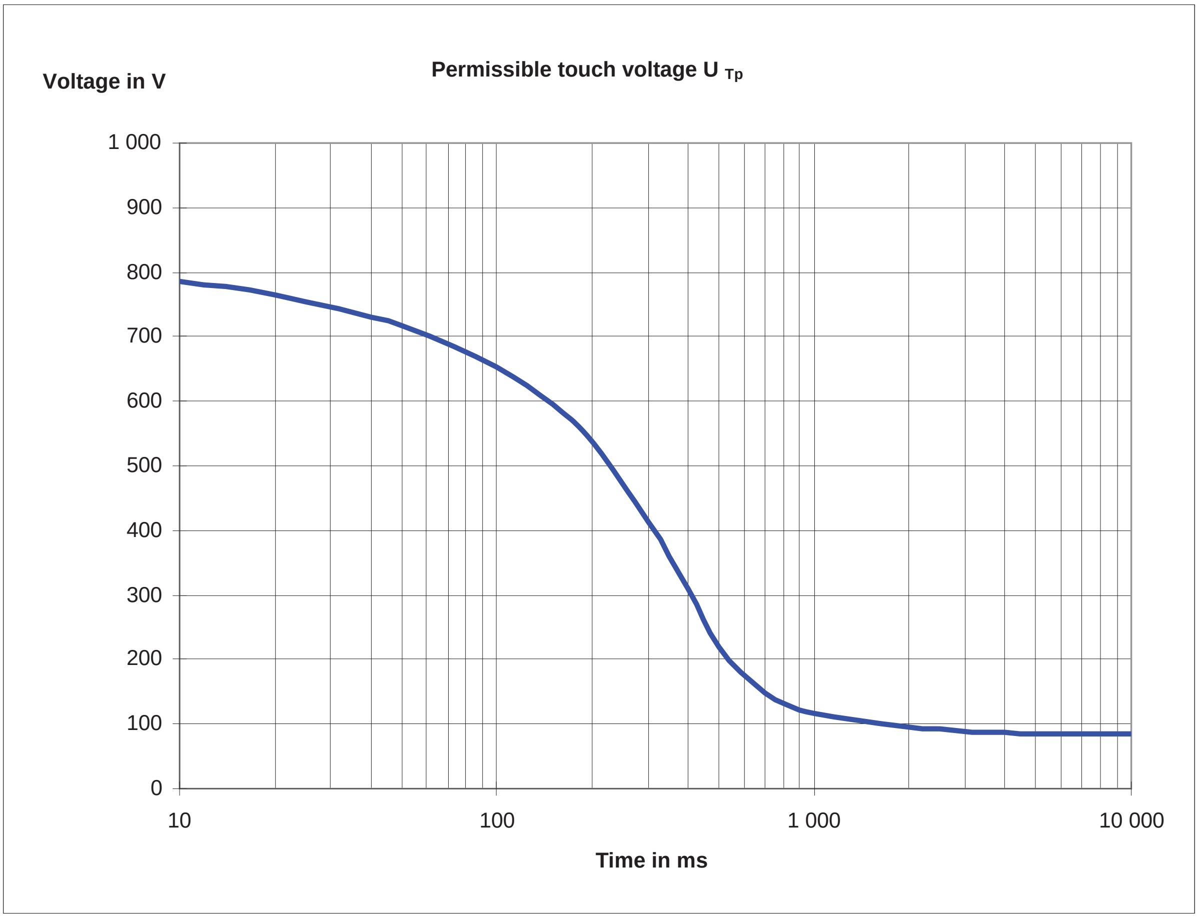
l) *determine if low voltage equipment is exposed to excessive stress voltage. If yes, proceed with mitigation measures, which can include separation of HV and LV earthing systems;*

m) *determine if the circulating transformer neutral current can lead to excessive potential differences between different parts of the earthing system. If yes, proceed with mitigation measures;*

Once the above criteria have been met, the design can be refined, if necessary, by repeating the above steps. Detailed design is necessary to ensure that all exposed conductive parts, are earthed. Extraneous conductive parts shall be earthed, if appropriate.

The structural earth electrode shall be bonded and form part of the earthing system. If not bonded, verification is necessary to ensure that all safety requirements are met.

Metallic structures with cathodic protection may be separated from the earthing system. Precautions such as labelling shall be taken to ensure that when such measures are taken, maintenance work or modifications will not inadvertently nullify them.



Fi

Figure 4 - Permissible touch voltage

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}.

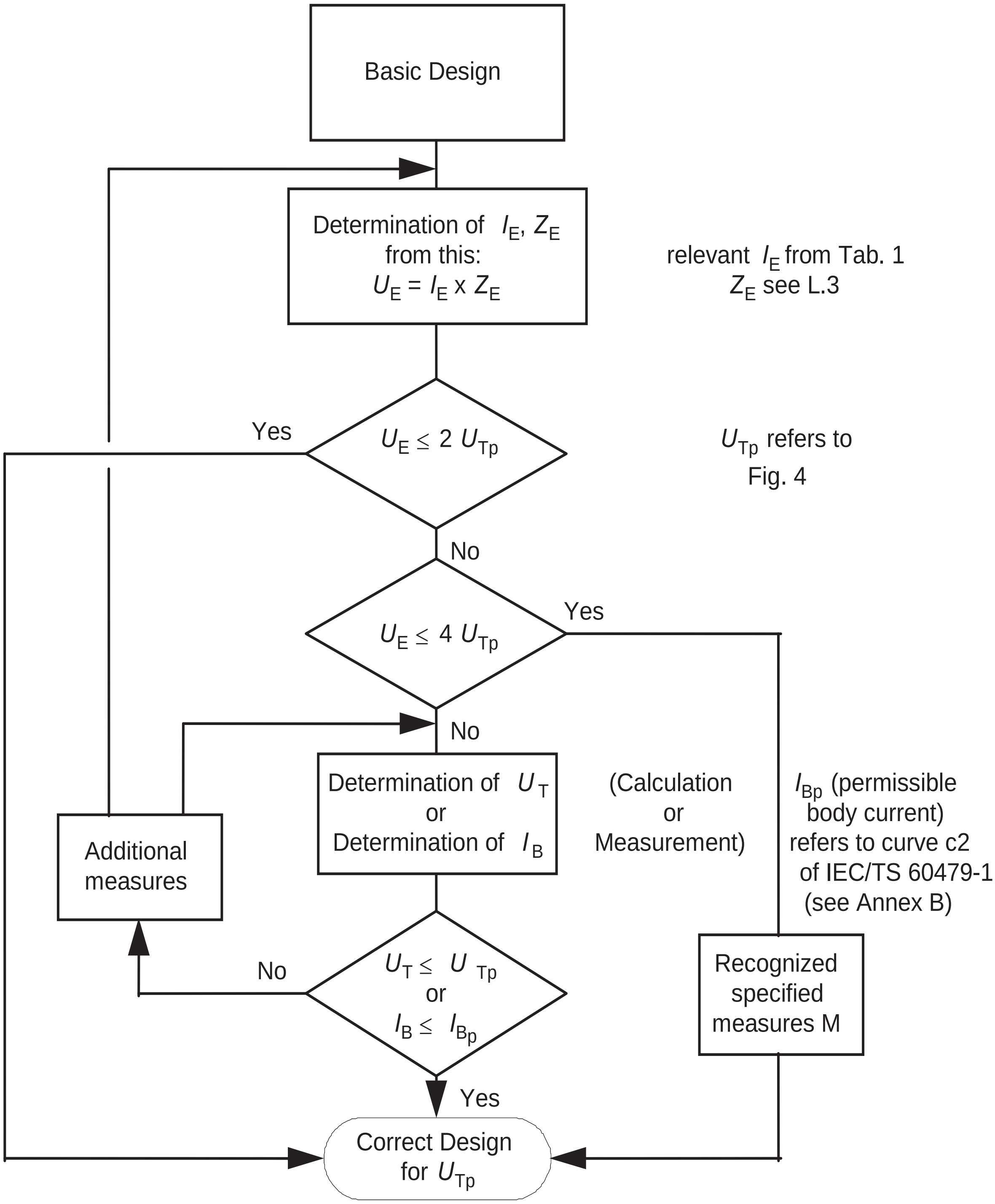


Figure 5 - Design of earthing systems, if not part of a global earthing system (C1 of 5.4.2), with regard to permissible touch voltage U_{Tp} by checking the earth potential rise U_E or the touch voltage U_T

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

Where high and low voltage earthing systems exist in proximity to each other and do not form a global earthing system, part of the EPR from the HV system can be applied on the LV system. Two practices are presently used:

a) interconnection of all HV with LV earthing systems;

b) separation of HV from LV earthing systems.

In either case, the relevant requirements concerning step, touch and transfer potentials specified below shall be complied with within a substation and at a LV installation supplied from that substation.

NOTE *Interconnection is preferred when practicable.*

6.1.2 LV supply only within HV substations

Where the LV system is totally confined within the area covered by the HV earthing system both earthing systems shall be interconnected, even if there is no global earthing system.

6.1.3 LV supply leaving or coming to HV substations

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

If high voltage and low voltage earthing systems are separate, the method of separating earth electrodes shall be chosen such that no danger to persons or equipment can occur in the low voltage installation. This means that step, touch and transfer potentials and stress voltage in the LV installation caused by a high voltage fault are within the appropriate limits.

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 may be appropriate.

6.1.4 LV in the proximity of HV substation

Special consideration should be given to LV systems which are located in the zone of influence of the HV substation earthing system.

For industrial and commercial installations a common earthing system can be used. Due to the close proximity of equipment it is not possible to separate earthing systems.

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

<table>
<tr><th colspan="2" rowspan="3">Type of LV system [a, b]</th><th colspan="3">EPR Requirements</th></tr>
<tr><th rowspan="2">Touch Voltage</th><th colspan="2">Stress Voltage [c]</th></tr>
<tr><th>Fault duration $t_f \leq 5$ s</th><th>Fault duration $t_f > 5$ s</th></tr>
<tr><td colspan="2">TT</td><td>Not applicable</td><td>EPR ≤ 1 200 V</td><td>EPR ≤ 250 V</td></tr>
<tr><td colspan="2">TN</td><td>$EPR \leq F \cdot U_{Tp}$ [d, e]</td><td>EPR ≤ 1 200 V</td><td>EPR ≤ 250 V</td></tr>
<tr><td rowspan="2">IT</td><td>Distributed protective earth conductor</td><td>As per TN system</td><td>EPR ≤ 1 200 V</td><td>EPR ≤ 250 V</td></tr>
<tr><td>Protective earth conductor not distributed</td><td>Not applicable</td><td>EPR ≤ 1 200 V</td><td>EPR ≤ 250 V</td></tr>
</table>

[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 EPR may be replaced by local potential differences based on measurements or calculations*

[d] *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.*

[e] U_{Tp} *is derived from Figure* 4.

NOTE The typical value for F is 2. Higher values of F may be applied where there are additional connections of the PEN conductor to earth. For certain soil structures, the value of F may be up to 5. Caution is necessary when this rule is applied in soils with high resistivity contrast where the top layer has a higher resistivity. The touch voltage in this case can exceed 50 % of the EPR.

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 standard. 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 may occur. The insulation of cables or pipes has to 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;
- suitable potential grading;
- limiting overvoltages by using suitable devices.

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 have to be taken.

A general distance cannot be specified, the degree of danger has to 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 standard, 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.

Where construction work involves an existing earthing system, protective measures shall be taken to ensure the safety of persons during fault conditions.

General installation details can be found in Annex K.

7.2 Lightning and transients

Lightning and switching operations are sources of high and low frequency currents and voltages. Surges typically occur when switching long cable sections, operating GIS disconnectors or carrying out back-to-back capacitor switching. Successful attenuation requires sufficient electrode density at injection points to deal with high frequency currents, together with an earthing system of sufficient extent to deal with low frequency currents. The HV earthing system shall form part of the lightning protection system and additional earthing conductors may be required at injection points.

Relevant electromagnetic compatibility and lightning standards shall be used to address specific aspects related to the transient performance of the earthing system and its components.

When an industrial or commercial installation includes more than one building or location, the earthing system of each shall be interconnected. Since during surges such as lightning strokes, there will be a large difference in potential between the earthing systems of each building and location in spite of the interconnection, measures shall be taken to prevent damage to sensitive equipment connected between different buildings or locations. Where possible, non-metallic media, such as fibre optic cable, should be used for the exchange of low-level signals between such locations.

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.

8 Measurements

Measurements shall be carried out after construction, where necessary, to verify the adequacy of the design. Measurements may include the earthing system impedance, prospective touch and step voltages at relevant locations and transferred potential, if appropriate. When measuring touch and step voltages under test conditions, e.g. current injection test, two choices are possible. Either measure the prospective touch and step voltages using a high impedance voltmeter or measure the effective touch and step voltages appearing across an appropriate resistance which represents the human body.

Details are given in Annexes H, L and M.

9 Maintainability

9.1 Inspections

The construction of the earthing system shall be carried out in a way that the condition of the earthing system can be examined periodically by inspection. Excavating at selective locations and visual inspection are appropriate means which shall be considered.

9.2 Measurements

Design and installation of the earthing system shall allow measurements to be carried out periodically or following major changes affecting fundamental requirements, or even for continuity tests.

Annex A
(normative)

Method of calculating permissible touch voltages

Formula:

$$U_{\mathrm{Tp}} = I_{\mathrm{B}}(t_{\mathrm{f}}) \cdot \frac{1}{HF} \cdot Z_{\mathrm{T}}(U_{\mathrm{T}}) \cdot BF$$

Factors:

Touch voltage	U_{T}	
Permissible touch voltage	U_{Tp}	
Fault duration	t_{f}	
Body current limit	$I_{\mathrm{B}}(t_{\mathrm{f}})$	*c2 in Figure 20 and Table 11 of IEC/TS 60479-1, where probability of ventricular fibrillation is less than 5 %.* *I_B depends on fault duration*
Heart current factor	HF	*Table 12 of IEC/TS 60479-1,* *i.e. 1,0 for left hand to feet,* *0,8 for right hand to feet,* *0,4 for hand to hand*
Body impedance	$Z_{\mathrm{T}}(U_{\mathrm{T}})$	*Table 1 and Figure 3 of IEC/TS 60479-1* *Z_T not exceeded by 50 % of the population* *Z_T depends on touch voltage. Therefore first calculation has to start with assumed level*
Body factor	BF	*Figure 3 of IEC/TS 60479-1,* *i.e. 0,75 for hand to both feet,* *0,5 for both hand to feet*

NOTE 1 Different touch voltage conditions, e.g. left hand to feet, hand to hand, lead to different tolerable touch voltages. Figure 4 of this standard is based on a weighted average taken from four different touch voltage configurations. 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) and touch voltage hand to hand (weighted 0,7).

NOTE 2 Different parameter values are applicable for some countries (see A-deviations).

For specific consideration of additional resistances the formula to determine prospective permissible touch voltage becomes:

$$U_{\mathrm{vTp}} = I_{\mathrm{B}}(t_{\mathrm{f}}) \cdot \frac{1}{HF} \cdot \left(Z_{\mathrm{T}}(U_{\mathrm{T}}) \cdot BF + R_{\mathrm{H}} + R_{\mathrm{F}}\right)$$

Additional factors:

Prospective permissible touch voltage	U_{vTp}
Additional hand resistance	R_{H}
Additional foot resistance	R_{F}

Annex B
(normative)

Touch voltage and body current

B.1 Calculation of permissible touch voltage

For the calculation of permissible values of touch voltages for high voltage installations the following assumptions were made:

- current path one hand to feet;
- 50 % probability of body impedance;
- 5 % probability of ventricular fibrillation;
- no additional resistances.

NOTE These assumptions lead to a touch voltage curve 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.

Assuming that the basis of body current calculation is IEC/TS 60479-1, and taking into account as permissible limit of current the curve c_2 of Figure 20 and Table 11 of IEC/TS 60479-1 (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 s	**Body current** mA
0,05	900
0,10	750
0,20	600
0,50	200
1,00	80
2,00	60
5,00	51
10,00	50

In order to obtain the relevant permissible touch voltage, it is necessary to determine the total human body impedance. 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/TS 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

Touch voltage V	**Total human body impedance** 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

Taking into account a hand to feet current path a correction factor of 0,75 for the body impedance has to be applied (Figure 3 of IEC/TS 60479-1). By combining the two tables considering this correction factor, it is possible, by means of an iterative process, to calculate a touch voltage limit for each value of the fault duration. The result given in Figure 4 is based on a weighted average (NOTE in Annex A). In Table B.3 the values of some points of the curve in Figure 4 are shown.

Table B.3 - Calculated values of the permissible touch voltage U_{Tp} as a function of the fault duration t_f

Fault duration t_f s	**Permissible touch voltage U_{Tp}** V
0,05	716
0,10	654
0,20	537
0,50	220
1,00	117
2,00	96
5,00	86
10,00	85

NOTE 1 For specific conditions touch voltages based on actual current path may be determined.

NOTE 2 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.2 Calculation of prospective permissible touch voltage

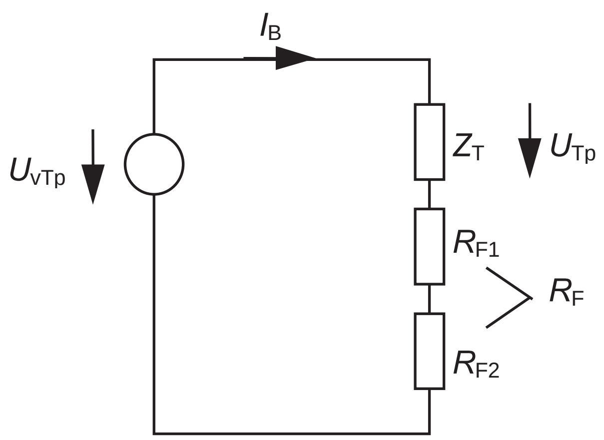
Table B.4 - Assumption for calculations with additional resistances

Type of contact	Different touch voltage conditions weighted
Probability factor for the value of Z_T	50 %
Curve I_B = f (t_f)	c_2 in Figure 20 of IEC/TS 60479-1
Circuit impedance	Z_T (50 %) + R_F
Additional resistance	$R_F = R_{F1} + R_{F2} = R_{F1} + 1{,}5\ m^{-1} \cdot \rho_S$
Legend: See Figure B.1.	

Calculation method:

t_f		(Fault duration)
$\Downarrow$		
U_{Tp}	$= f(t_f)$	in accordance with B.1, Table B.3 or Figure 4
$\Downarrow$		
Z_T	$= f(U_T)$	in accordance with B.1, Table B.2 With $U_T = U_{Tp}$ for the start
I_B	$= \frac{U_T}{Z_T}$	per definition
$\Downarrow$		
$U_{Tp}(t_f)$	$= U_T(t_f) + (R_{F1} + R_{F2}) \cdot I_B$	
	$= U_T(t_f) \cdot (1 + \frac{R_F}{Z_T})$	

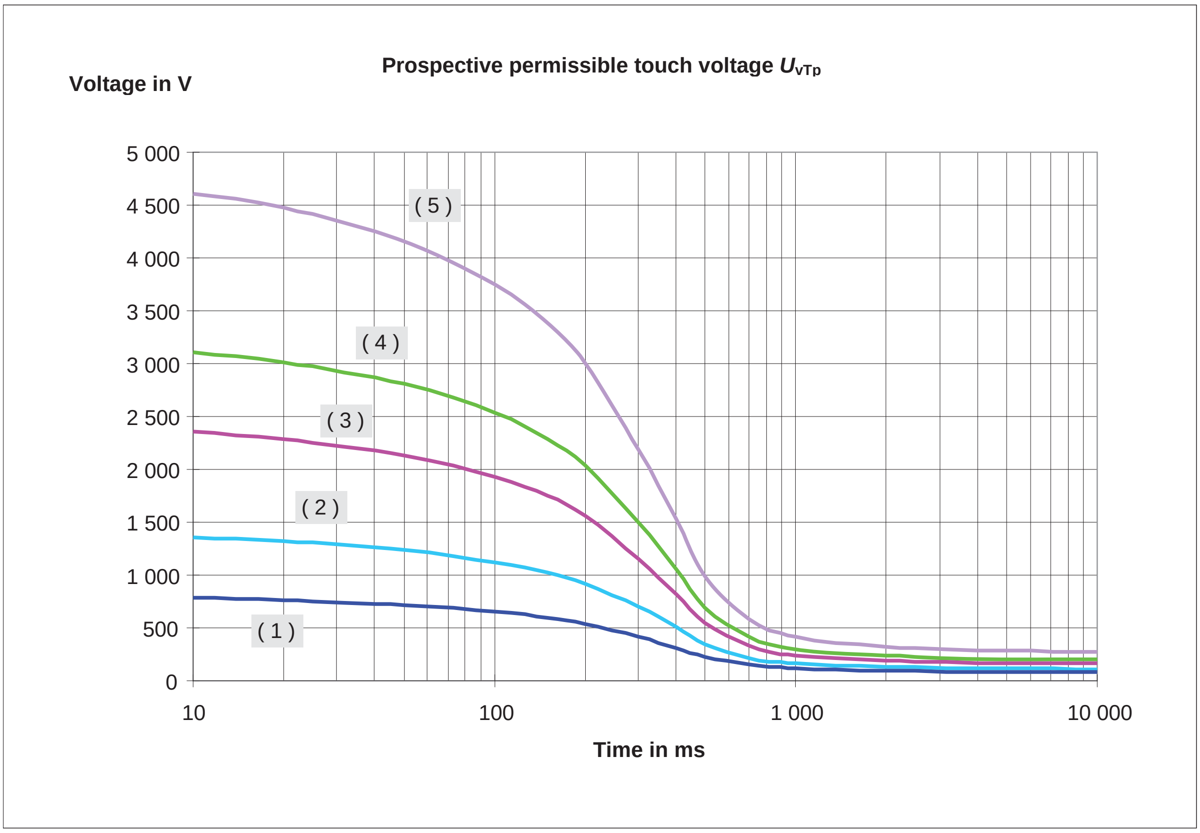
Figure B.2 shows curves $U_{Tp} = f(t_f)$ for 4 values of R_F.



Legend to Figure B.1, Table B.3 and Table B.4:

U_{vTp}	Voltage difference acting as a source voltage in the touching circuit with a limited value that guarantees the safety of a person when using additional known resistances (for example footwear, standing surface insulating material).
Z_T	Total body impedance
I_B	Current flowing through the human body
U_{Tp}	Permissible touch voltage, the voltage across the human body
R_F	Additional resistance ($R_F = R_{F1} + R_{F2}$) R_{F1} For example resistance of the footwear R_{F2} Resistance to earth of the standing point
ρ_S	Resistivity of soil near the surface in an installation (in Ωm)
t_f	Fault duration

Figure B.1 - Scheme of the touching circuit



(1):	Permissible touch voltage according Figure 4					
(2):	R_F =	750 Ω	(R_{F1} =	0 Ω,	ρ_s =	500 Ωm)
(3):	R_F =	1 750 Ω	(R_{F1} =	1 000 Ω,	ρ_s =	500 Ωm)
(4):	R_F =	2 500 Ω	(R_{F1} =	1 000 Ω,	ρ_s =	1 000 Ωm)
(5):	R_F =	4 000 Ω	(R_{F1} =	1 000 Ω,	ρ_s =	2 000 Ωm)

NOTE R_{F1} = 1 000 Ω represents an average value for old and wet shoes. Higher values of footwear resistance may be used where appropriate.

Figure B.2 - Examples for curves $U_{vTp} = f\ (t_f)$ for different additional resistances $R_F = R_{F1} + R_{F2}$

Annex C
(normative)

Type and minimum dimensions of earth electrode materials ensuring mechanical strength and corrosion resistance

Material		Type of electrode	Minimum size				
			Core			Coating/sheath	
			Dia-meter mm	Cross-section mm²	Thick-ness mm	Single values µm	Average values µm
Steel	Hot-galvanised	Strip [b]		90	3	63	70
		Profile (incl. plates)		90	3	63	70
		Pipe	25		2	47	55
		Round bar for earth rod	16			63	70
		Round wire for horizontal earth electrode	10				50
	With lead sheath [a]	Round wire for horizontal earth electrode	8			1 000	
	With extruded copper sheath	Round bar for earth rod	15			2 000	
	With electrolytic copper sheath	Round bar for earth rod	14,2			90	100
Copper	Bare	Strip		50	2		
		Round wire for horizontal earth electrode		25 [c]			
		Stranded cable	1,8 [d]	25			
		Pipe	20		2		
	Tinned	Stranded cable	1,8 [d]	25		1	5
	Galvanised	Strip		50	2	20	40
	With lead sheath [a]	Stranded cable	1,8 [d]	25		1 000	
		Round wire		25		1 000	

[a] Not suitable for direct embedding in concrete. Use of lead is not recommended due to environmental reasons.
[b] Strip, rolled or cut with rounded edges.
[c] In extreme conditions where experience shows that the risk of corrosion and mechanical damage is extremely low 16 mm² can be used.
[d] For single wire.

Annex D
(normative)

Current rating calculation of earthing conductors and earth electrodes

For fault currents which are interrupted in less than 5 s the cross-section of the earthing conductor or earth electrode shall be calculated from the following formula D.1 (see IEC 60949:1988):

$$A = \frac{I}{K}\sqrt{\frac{t_f}{\ln\frac{\Theta_f + \beta}{\Theta_i + \beta}}} \tag{D.1}$$

Where:

- A is the cross-section in mm²
- I is the conductor current in amperes (RMS value)
- t_f is the duration of the fault current in seconds
- K is a constant depending on the material of the current-carrying component; Table D.1 provides values for the most common materials assuming an initial temperature of 20 °C
- $ß$ is the reciprocal of the temperature coefficient of resistance of the current-carrying component at 0 °C (see Table D.1)
- Θ_i is the initial temperature in degrees Celsius. Values may be taken from IEC 60287-3-1. If no value is laid down in the national tables, 20 °C as ambient ground temperature at a depth of 1 m should be adopted.
- Θ_f is the final temperature in degrees Celsius

Table D.1 - Material constants

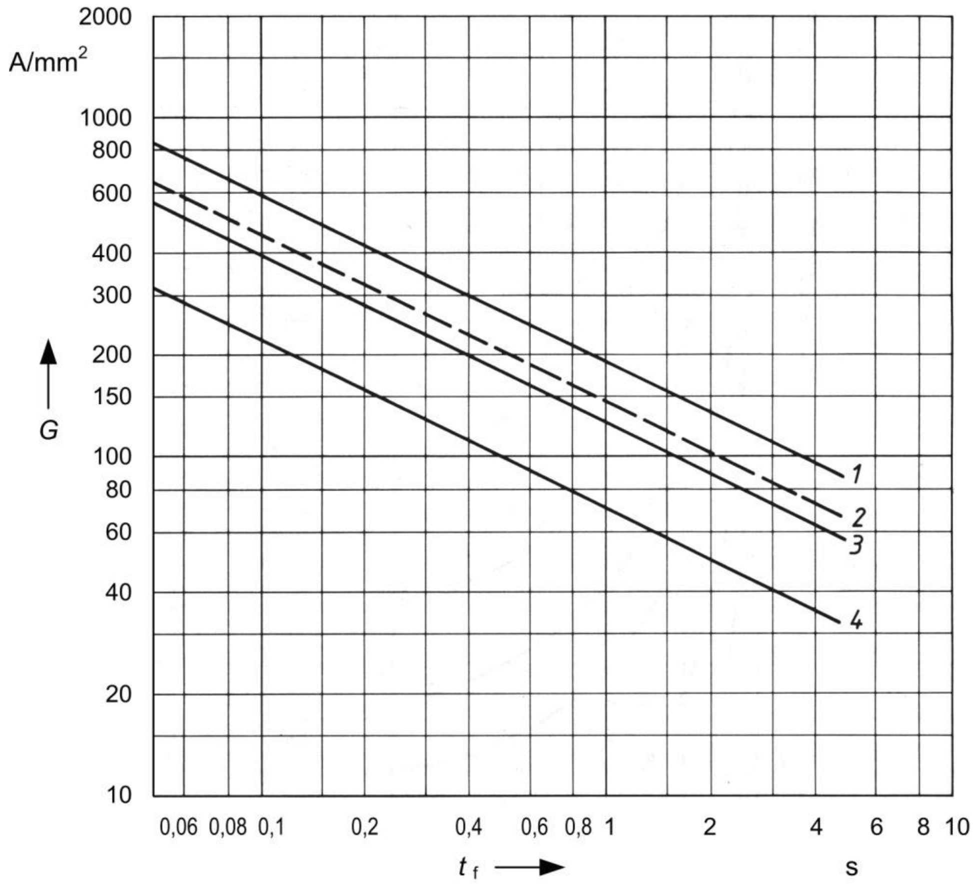
Material	β in °C	K in $A \cdot \sqrt{s} / mm^2$
Copper	234,5	226
Aluminium	228	148
Steel	202	78

For common conditions where the earthing conductor is in air and the earth electrode is in soil the short-circuit current density G (= I / A) may be taken from Figure D.1 for initial temperatures of 20 °C and for final temperatures up to 300 °C.

For fault currents flowing for a longer time (as in systems with isolated neutral or with resonant earthing) the permissible cross-sections are shown in Figure D.2. If a final temperature other than 300 °C (see Figure D.2a and Figure D.2b, lines 1, 2 and 4) is chosen the current may be calculated with a factor selected from Table D.2. For example lower final temperatures are recommended for insulated conductors and conductors embedded in concrete.

Table D.2 - Factors for conversion of continuous current from 300 °C final temperature to another final temperature

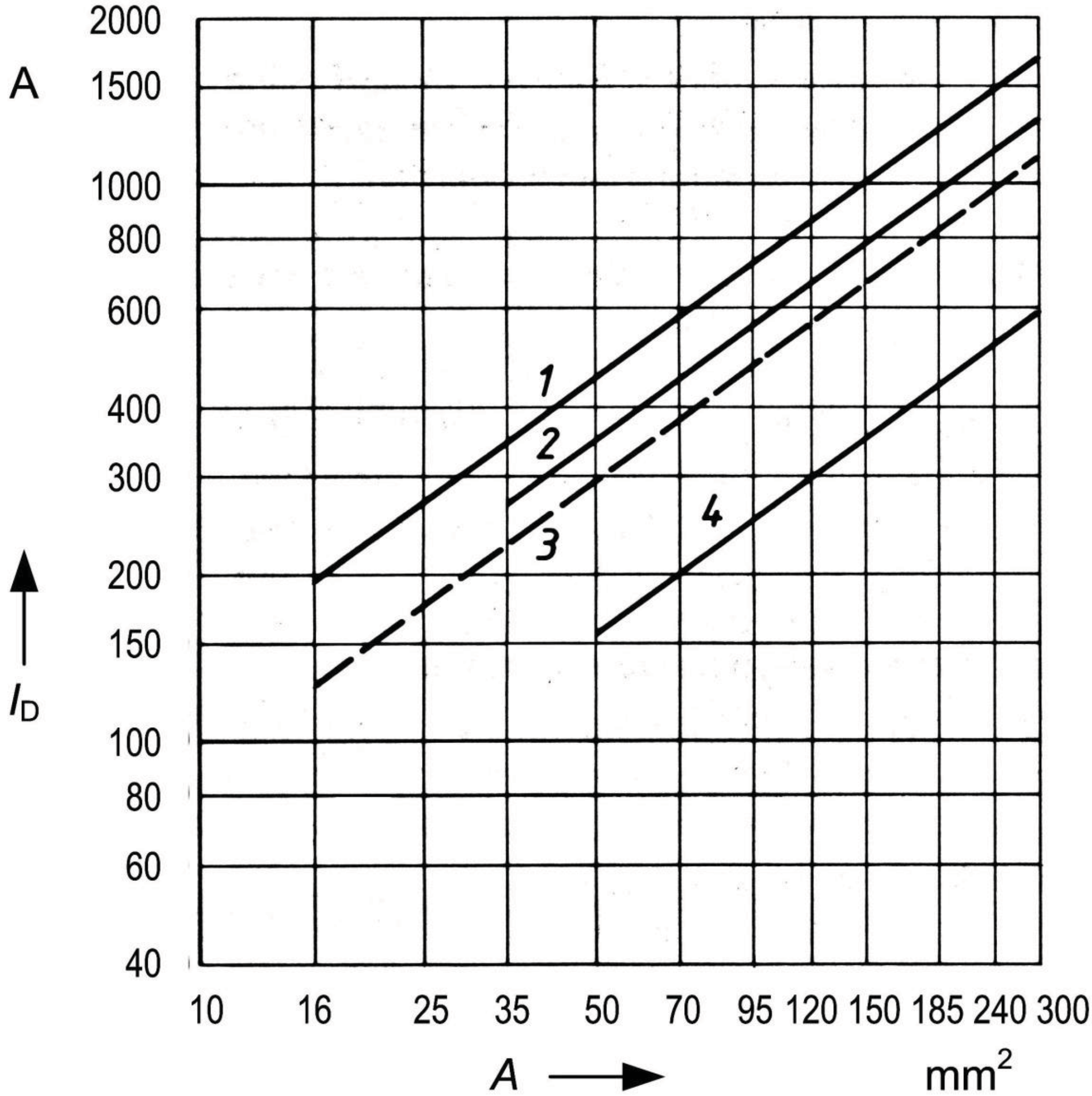
Final temperature °C	Conversion factor
400	1,2
350	1,1
300	1,0
250	0,9
200	0,8
150	0,7
100	0,6



Lines 1, 3 and 4 apply for a final temperature of 300 °C, line 2 applies for 150 °C.

1 Copper, bare or zinc-coated
2 Copper, tin-coated or with lead sheath
3 Aluminium, only earthing conductors
4 Galvanized steel

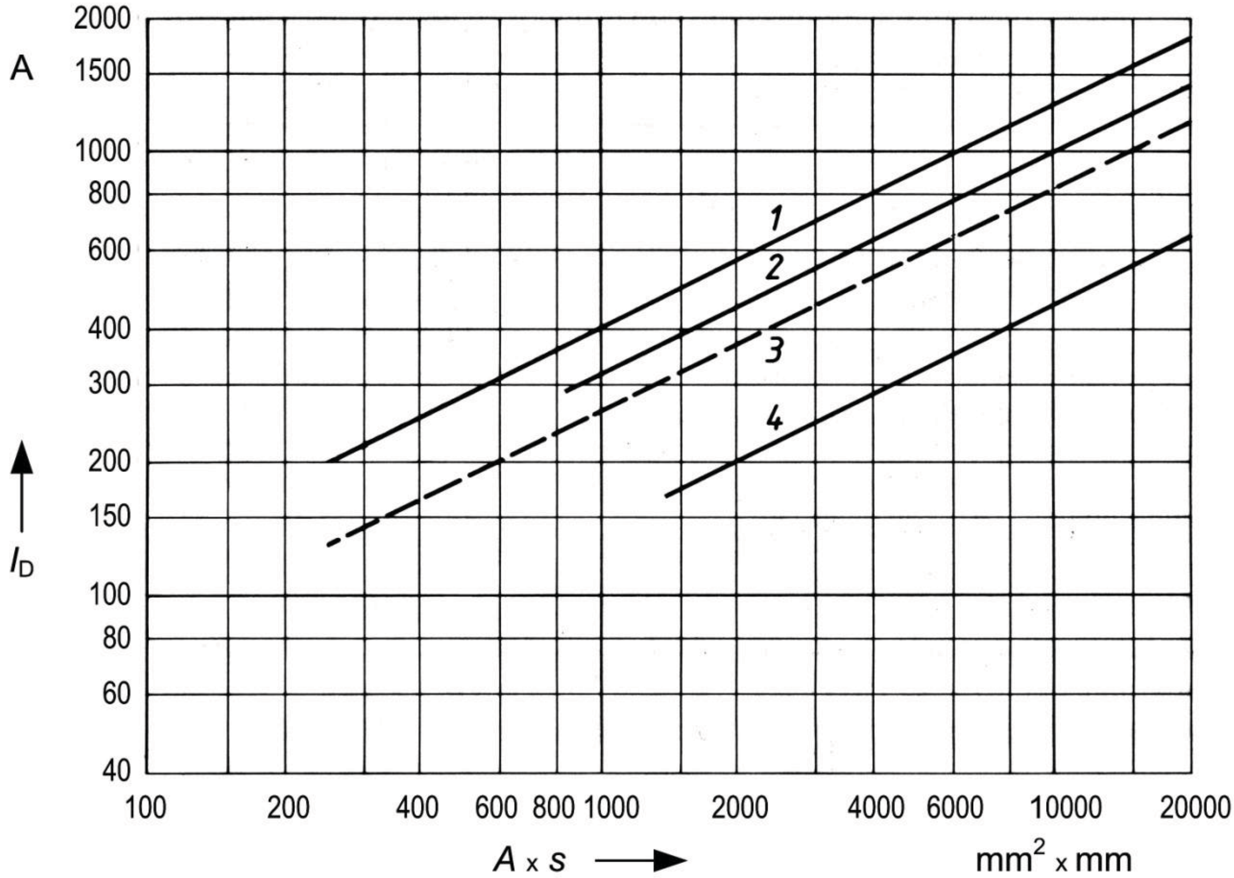
Figure D.1 - Short circuit current density *G* for earthing conductors and earth electrodes relative to the duration of the fault current t_f



Lines 1, 2 and 4 apply for a final temperature of 300 °C, line 3 applies for 150 °C. Table D.2 contains factors for conversion to other final temperatures.

1 Copper, bare or zinc-coated
2 Aluminium
3 Copper, tin-coated or with lead sheath
4 Galvanized steel

a) Continuous current I_D for earthing conductors with circular cross-section (A)



Lines 1, 2 and 4 apply for a final temperature of 300 °C, line 3 applies for 150 °C. Table D.2 contains factors for conversion to other final temperatures.

1 Copper, bare or zinc-coated
2 Aluminium
3 Copper, tin-coated or with lead sheath
4 Galvanized steel

b) Continuous current I_D for earthing conductors with rectangular cross-section versus the product of cross-section and profile-circumference ($A * s$)

Figure D.2 - Continuous current I_D for earthing conductors

Annex E
(normative)

Description of the recognized specified measures M

Table E.1 - Conditions for the use of recognized specified measures M to ensure permissible touch voltages U_{Tp} (see Figure 4)

Fault duration t_f	Earth potential rise U_E	On outer walls and fences around installations	Inside the installations	
			Indoor installation	Outdoor installation
$t_f > 5$ s	$U_E \leq 4 \times U_{Tp}$	M1 or M2	M3	M4.1 or M4.2
	$U_E > 4 \times U_{Tp}$	Proof $U_T \leq U_{Tp}$	M3	M4.2
$t_f \leq 5$ s	$U_E \leq 4 \times U_{Tp}$	M1 or M2	M3	M4.2
	$U_E > 4 \times U_{Tp}$	Proof $U_T \leq U_{Tp}$		

M 1: Recognized specified measures for the outer walls of buildings with indoor installations. One of the recognized specified measures M 1.1 to M 1.3 may be applied as protection against external touch voltage.

M 1.1: Use of non-conductive material for the outer walls (for example masonry or wood) and avoidance of earthed metal parts which can be touched from outside.

M 1.2: Potential grading by a horizontal earth electrode which is connected to the earthing system, at a distance of approximately 1 m outside the outer wall and at a maximum depth of 0,5 m.

M 1.3: Insulation of the operating location: The layers of insulating material shall be of sufficient size, so that it is impossible to touch the earthed conductive parts with the hand from a location outside the insulating layer. If touching is possible only in lateral direction, an insulating layer width of 1,25 m is sufficient.

The insulation of the operating location is considered to be sufficient in the following cases:

- a layer of crushed stones with a thickness of at least 100 mm,
- a layer of asphalt with adequate base (for example gravel),
- an insulating mat with a minimum area of 1 000 mm x 1 000 mm and a thickness of at least 2,5 mm or a measure ensuring equivalent insulation.

M 2: Recognized specified measures for external fences at outdoor installations

One of the recognized specified measures M 2.1 to M 2.3 may be applied as protection against external touch voltage; at gates in external fences recognized specified measure M 2.4 also has to be considered.

M 2.1: Use of fences of non-conductive material or of plastic-covered wire mesh (also with bare conductive slats).

M 2.2: When using fences of conductive material, potential grading by a horizontal earth electrode, which is connected to the fence, at a distance of approximately 1 m outside the fence and at a maximum depth of 0,5 m. The connection of the fence to the earthing system is optional (however see recognized specified measure M 2.4).

M 2.3: Insulation of the operating location in accordance with recognized specified measure M 1.3 and earthing of the fence either in accordance with Annex G or by connection with the earthing system.

M 2.4: If gates in external fences are connected directly to the earthing system or via protective conductors or metal sheaths of cables for staff locator systems etc., then at the opening area of the gates a potential grading or insulation of the operating location in accordance with recognized specified measure M 1.3 has to be applied.

When the gates in a separately earthed conductive fence are to be connected to the main earthing system, the gates shall be isolated from the conductive parts of the fence in a way that establishes an electrical separation of at least 2,5 m. This may be achieved by using a fence section of non-conductive material or by using conductive fencing with insulated inserts at the end. Care must be taken to ensure the electrical separation is maintained when the gates are fully opened.

M 3: Recognized specified measures in indoor installations

Within indoor installations one of the recognized specified measures M 3.1 to M 3.3 may be applied.

M 3.1: Equipotential grading by embedding grid-type electrodes in the building foundations (for example of a minimum cross-section of 50 mm² and maximum mesh widths of 10 m or structural steel mats) and connection to the earthing system at a minimum of two separate locations.

If concrete steel reinforcement is also used for dissipating the fault current, the capability of the steel reinforcement shall be checked by calculation.

If structural steel mats are used, then the adjacent mats have to be interconnected at least once and all the mats together have to be connected to the earthing system at a minimum of two locations.

At existing buildings a horizontal earth electrode may be used, which has to be buried in the soil near the outside walls and connected to the earthing system.

M 3.2: Construction of the operating locations from metal (for example a metal grid or metal plate) and connection to any metal parts which have to be earthed and which can be touched from the operating location.

M 3.3: Insulation of the operating locations for the earth potential rise in accordance with recognized specified measure M 1.3. For equipotential bonding the metal parts which have to be earthed and which can be simultaneously touched from the operating location, have to be interconnected.

M 4: Recognized specified measures in outdoor installations

M 4.1: At operating locations:

Potential grading by a horizontal earth electrode at a depth of approximately 0,2 m and a distance of approximately 1 m from the equipment to be operated. This horizontal earth electrode has to be connected to all metal parts which have to be earthed and which can be touched from the operating location.

or

Construction of the operating locations from metal (for example metal grid or metal plate) and connection to the metal parts which have to be earthed and which can be touched from the operating location.

or

Insulation of the location in accordance with recognized specified measure M 1.3. For equipotential bonding the metal parts which have to be earthed and which can be simultaneously touched from the operating location, have to be interconnected.

M 4.2: Burying a horizontal earth electrode surrounding the earthing system in the form of a closed ring. Inside this ring, a meshed earth grid has to be buried, whose individual meshes have a maximum size of 10 m x 50 m. At individual parts of the installation, which are situated outside of the ring and which are connected to the earthing system, a grading earth electrode at a distance of approximately 1 m and a depth of approximately 0,2 m has to be provided (for example lightning masts, which are connected to the earthing system via protective conductors).

Annex F
(normative)

Measures on earthing systems to reduce the effects of high frequency interference

Although an earthing system is primarily designed to fulfil requirements based on power frequency currents, requirements based on high-frequency currents also have to be taken into consideration. Such currents may primarily arise from lightning or from switching operations in high voltage installations. The resulting transient currents or the corresponding voltages may disturb, for example, the functioning of control and protection devices. Reducing the interference by modifying an existing earthing system is only possible at very high expense, therefore the following points have to be taken into consideration when designing and constructing an earthing system:

a) Current paths have to be of as low an inductance as possible:

- earth electrodes and earthing conductors shall be significantly meshed;
- the density of the earthing mat mesh in areas where high transient currents are more likely to occur should be increased. This applies mainly to lightning arresters, voltage transformers, current transformers and GIS installations;
- the earthing terminals of high voltage equipment, control cubicles, relays, kiosks etc. should be connected to a mesh;
- the connection to the earthing system shall be made by an earthing conductor of as short a length as possible;
- at crossover points, the earthing conductors shall be connected;
- the resulting loops shall be short-circuited;
- the mutual impedance may be reduced by separating parallel earth electrodes or earthing conductors by at least 0,5 m, or by dividing a conductor and laying the sub-conductors separated;
- in cable trenches, earthing conductors should be laid parallel to the cable. The screens of the cables should be connected to the earthing system at both ends. The screen shall be capable of carrying the relevant part of the earth fault current.

b) For the purpose of a better electromagnetic shielding and a low-inductive current path metallic construction parts of buildings and steel embedded in concrete should be connected to the earthing system.

NOTE 1 In addition to their gradient effects and/or earthing purpose, steel reinforcement and metallic structures can have a screen effect between sensitive areas and radiating areas (as an example, junctions between GIS and cable). In this case the screen effect can be improved by reducing the size of the steel reinforced mesh and interconnecting this steel reinforced grid with metallic parts of GIS or screens of control cables going through the concrete slabs. Earthing conductors, which would have to be interconnected by conducting connections, are only necessary, if the flow of higher currents has to be taken into account or if the armouring represents part of the earthing conductor grid. Normally the multiple connection of the armouring with wires is sufficient. So many terminals shall be provided that all parts can be interconnected to each other and to the earthing system at several locations.

NOTE 2 To avoid local discharge from switching of bus charging currents it is necessary to have low-impedand HF-connections between GIS and connected cable-boxes and cable screens with HF-earthing.

Annex G
(normative)

Detailed measures for earthing of equipment and installations

G.1 Fences around substation installations

Bare metallic fences shall be earthed. A number of earth points shall be used, for example at each corner. In accordance with local conditions (fence inside or outside the earthing system) the earth connection should be made either to the high voltage earthing system or to separate earth electrodes.

Bare metallic parts of the fence coated with insulating material need not be earthed.

All physical breaks in the fencing surrounding a substation installation, for example the gates, shall be bonded in such a way as to ensure that dangerous potentials do not arise between the parts of the fence.

G.2 Pipes

Metallic pipes within the substation site should be connected to the substation earthing system.

The use of metallic pipes, for example water supplies, from outside the substation perimeter, should be avoided and non-metallic materials or isolating joints should be used instead.

G.3 Traction rails

The rails of non-electric tracks that cross into the substation site shall be connected to the substation earthing system.

Suitable insulating rail joints should be included at the boundary of the substation site such that the electrical separation is maintained to the remaining parts of the traction system. In some cases two insulating rail joints may be required to prevent short-circuiting by the traction unit. Special attention has to be paid at traction operating locations. For the determination of measures, the owner of the railway system shall be consulted and the stipulations of 6.2 should be taken into account.

G.4 Pole mounted transforming and/or switching installations

In general all pole mounted transforming equipment combined with switching equipment, or not, shall be earthed.

In cases, where at the pole only a transformer is situated, a minimum earthing system (e. g. an earth rod or a ring earth electrode or the footing of a conductive pole) fulfils the earthing requirements of the transformer.

In general, switching equipment mounted on poles made of steel or other conductive material or made of reinforced concrete shall be earthed. At the operating position the permissible touch voltage according to 5.4 must be met. This can be accomplished by, e.g.:

- the design of the earthing system, or
- an equipotential bonding by means of an earth mat, or
- using insulation of operating location, or
- using insulating equipment (e.g. insulating tools, gloves or mat) when the switching operation is done, or
- by a combination of the measures described.

Switching equipment mounted on poles made of non-conductive material need not be earthed. If it is not earthed, mechanically reliable insulators (for example unsplit core insulators) have to be installed in operating linkages outside the normal arm's reach. These shall be designed for the nominal voltage of the system. The part of the actuator which can be touched from the ground has to be earthed to dissipate possible leakage currents. An earth rod of at least 1 m length or a horizontal earth electrode around the pole at a distance of approximately 1 m is sufficient. Earth electrodes and earthing conductors shall satisfy the minimum cross sections in accordance with Annex C, 5.2 and 5.3.

G.5 Secondary circuits of instrument transformers

The secondary circuits of all instrument transformers shall be earthed as close as possible to the instrument transformer's secondary terminals.

The minimum cross-section of 5.2.2 does not apply to this type of equipment. A minimum cross-section of 2,5 mm² copper is required; if the earthing conductor is mechanically unprotected then 4,0 mm² copper is necessary.

If, however, it is necessary to earth at some other points, then there shall be no possibility of the earth being inadvertently disconnected.

Annex H
(normative)

Measuring touch voltages

For touch voltage measurements a current injection method shall be used (see Annex L).

The touch voltage has to be determined by taking into account the human body with a resistance of 1 kΩ.

The measuring electrode(s) for simulation of the feet shall have a total area of 400 cm^2 and lie on the earth with a minimum total force of 500 N.

If no additional resistances are to be taken into account, a probe, driven at least 20 cm into the soil, may be used instead of the measuring electrode. For the measurement of the touch voltage in any part of the installation the electrode shall be placed at a distance of 1 m from the exposed part of the installation, for concrete or dried soil it shall be on a wet cloth or water film. A tip-electrode for the simulation of the hand shall be capable of piercing a paint coating (not insulation) reliably. One terminal of the voltmeter is connected to the hand electrode, the other terminal to the foot electrode. It is sufficient to carry out such measurements in a substation as a sampling test.

NOTE In order to get a rapid overview the prospective touch voltage, which is always higher than the touch voltage, can be measured by a voltmeter with a high internal resistance and a probe driven 10 cm deep is often sufficient.

Annex I
(informative)

Reduction factors related to earth wires of overhead lines and metal sheaths of underground cables

I.1 General

Earth wires of overhead lines and metal sheaths of underground cables participate in carrying fault currents returning to earth. They take over a part of the earth current of the corresponding circuit in accordance with Figure 2 of this standard. By this effect the earthing system of a high voltage installation affected by an earth fault will be discharged effectively in respect of the earth fault current. The extent of this relief is described by the reduction factor.

The reduction factor r for an earth wire of a 3-phase overhead line is the ratio of the return current in the earth to sum of the zero sequence current of the 3-phase circuit.

$$r = \frac{\boldsymbol{I}_{\mathrm{E}}}{3\,\boldsymbol{I}_0} = \frac{3\,\boldsymbol{I}_0 - \boldsymbol{I}_{\mathrm{EW}}}{3\,\boldsymbol{I}_0}$$

Where:

I_{EW}	current in the earth wire (in balanced stage)
I_{E}	earth return current
$3\,I_0$	sum of zero sequence currents

The same definition is relevant to the reduction factor r of an underground cable with metal sheath, screen, armouring or an enveloping steel pipe. Instead of the current in the earth wire I_{EW} the current in the metal sheath etc. has to be used.

For the balanced current distribution of an overhead line the reduction factor of an earth wire can be calculated on the basis of the self impedances of the phase conductors $Z_{\mathrm{L\text{-}E}}$ and the earth wire $Z_{\mathrm{EW\text{-}E}}$ and the mutual impedance between phase conductors and earth wire $Z_{\mathrm{ML\text{-}EW}}$.

$$r = \frac{Z_{\mathrm{EW\text{-}E}} - Z_{\mathrm{ML\text{-}EW}}}{Z_{\mathrm{EW-E}}} = 1 - \frac{Z_{\mathrm{ML\text{-}EW}}}{Z_{\mathrm{EW\text{-}E}}}$$

The most influencing term for $Z_{\mathrm{ML\text{-}EW}}$ is the mean distance between phase conductors and earth wire, for $Z_{\mathrm{EW\text{-}E}}$ the resistance of the earth wire. By this the reduction effect of an earth wire in respect of the earth current is increasing (r shows a tendency reducing) with lower distance of phase conductor and earth wire and with lower resistance of the earth wire.

I.2 Typical values of reduction factors of overhead lines and cables (50 Hz)

Earth wires of overhead lines (110 kV)

Steel 50...70 mm²	$r = 0{,}98$
ACSR 44/32 mm²	$r = 0{,}77$
ACSR 300/50 mm²	$r = 0{,}61$

Paper-insulated cables (10 kV and 20 kV)

Cu 95 mm²/1,2 mm lead sheath	$r = 0{,}20 – 0{,}60$
Al 95 mm²/1,2 mm aluminium sheath	$r = 0{,}20 – 0{,}30$

Single-core XLPE cables (10 kV and 20 kV)

Cu 95 mm²/16 mm² copper screen	$r = 0{,}50 – 0{,}60$

Single-core oil filled cables (110 kV)

Cu 300 mm²/2,2 mm aluminium sheath $r = 0,37$

Gas-pressure cables in steel pipe (110 kV)

Cu 300 mm²/1,7 mm steel $r = 0,01 – 0,03$

Single-core XLPE cables (110 kV)

Cu 300 mm²/35 mm² copper screen $r = 0,32$

Single-core XLPE cables (150 kV)

Cu 800 mm²/700 mm² lead screen $r = 0,2$

Single-core oil filled cables (400 kV)

Cu 1 200 mm²/1 200 mm² aluminium sheath $r = 0,01$

NOTE The reduction factor of cables links can be further reduced by installing extra bonding cables of suitable section (e.g. 150 mm² copper) in the same trench and by earthing them at the locations where the screens are earthed

Annex J
(informative)

Basis for the design of earthing systems

J.1 Soil resistivity

The soil resistivity ρ_E varies considerably at different locations with the type of soil, grain size, density and moisture (see Table J.1).

Table J.1 - Soil resistivities for frequencies of alternating currents (Range of values, which were frequently measured)

Type of soil	Soil resistivity ρ_E Ωm
Marshy soil	5 to 40
Loam, clay, humus	20 to 200
Sand	200 to 2 500
Gravel	2 000 to 3 000
Weathered rock	mostly below 1 000
Sandstone	2 000 to 3 000
Granite	up to 50 000
Moraine	up to 30 000

Up to some meters of depth changes of moisture can cause temporary variations of the soil resistivity. Furthermore it has to be considered, that the soil resistivity can change considerably with the depth because of usually present distinct different layers of soil.

J.2 Resistance to earth

The resistance to earth R_E of an earth electrode depends on the soil resistivity as well as on the dimensions and the arrangement of the earth electrode. It depends mainly on the length of the earth electrode, less on the cross-section. Figure J.1 and Figure J.2 show the values of the resistance to earth for horizontal earth electrodes and earth rods relative to the total length.

In case of very long horizontal earth electrodes (for example cables with earth electrode effect) the resistance to earth decreases with the length, but approaches a final value (see Figure J.3).

Foundation earth electrodes may be regarded as earth electrodes buried in the surrounding soil.

The resistance to earth of a meshed earth electrode is approximately

$$R_E = \frac{\rho_E}{2\,D}$$

D is the diameter of a circle with the same area as the meshed earth electrode.

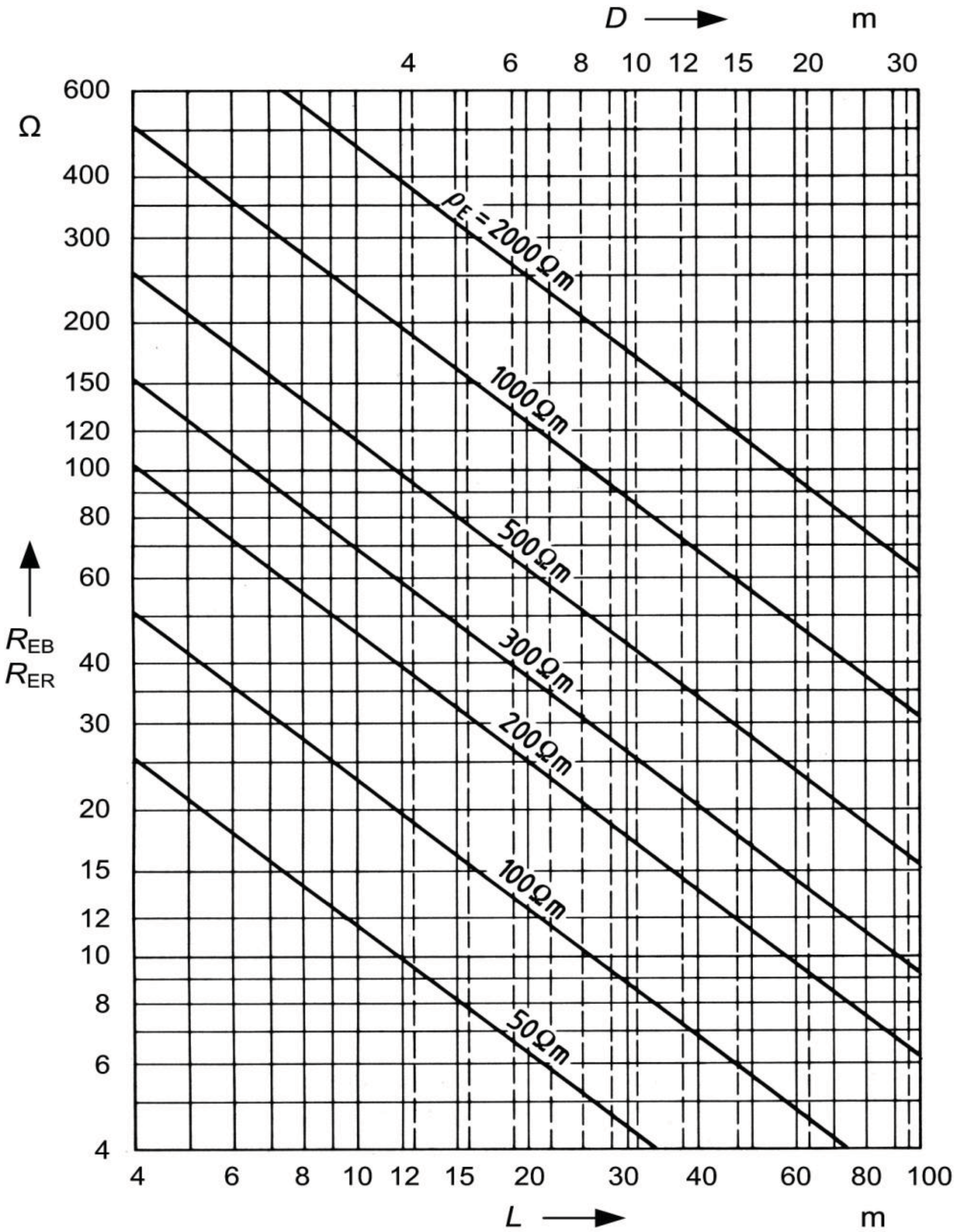


Figure J.1 - Resistance to earth of horizontal earth electrodes (made from strip, round material or stranded conductor) for straight or ring arrangement in homogeneous soil

Calculated values in accordance with the following formulas:

Strip earth electrode: $R_{EB} = \frac{\rho_E}{\pi L} \ln \frac{2L}{d}$

Ring earth electrode: $R_{ER} = \frac{\rho_E}{\pi^2 D} \ln \frac{2\pi D}{d}$

L	Length of the earth strip in m
$D = \frac{L}{\pi}$	Diameter of the ring earth electrode in m
d	Diameter of the stranded earth electrode or half width of an earth strip in m (here 0,015 m assumed)
ρ_E	soil resistivity in Ωm

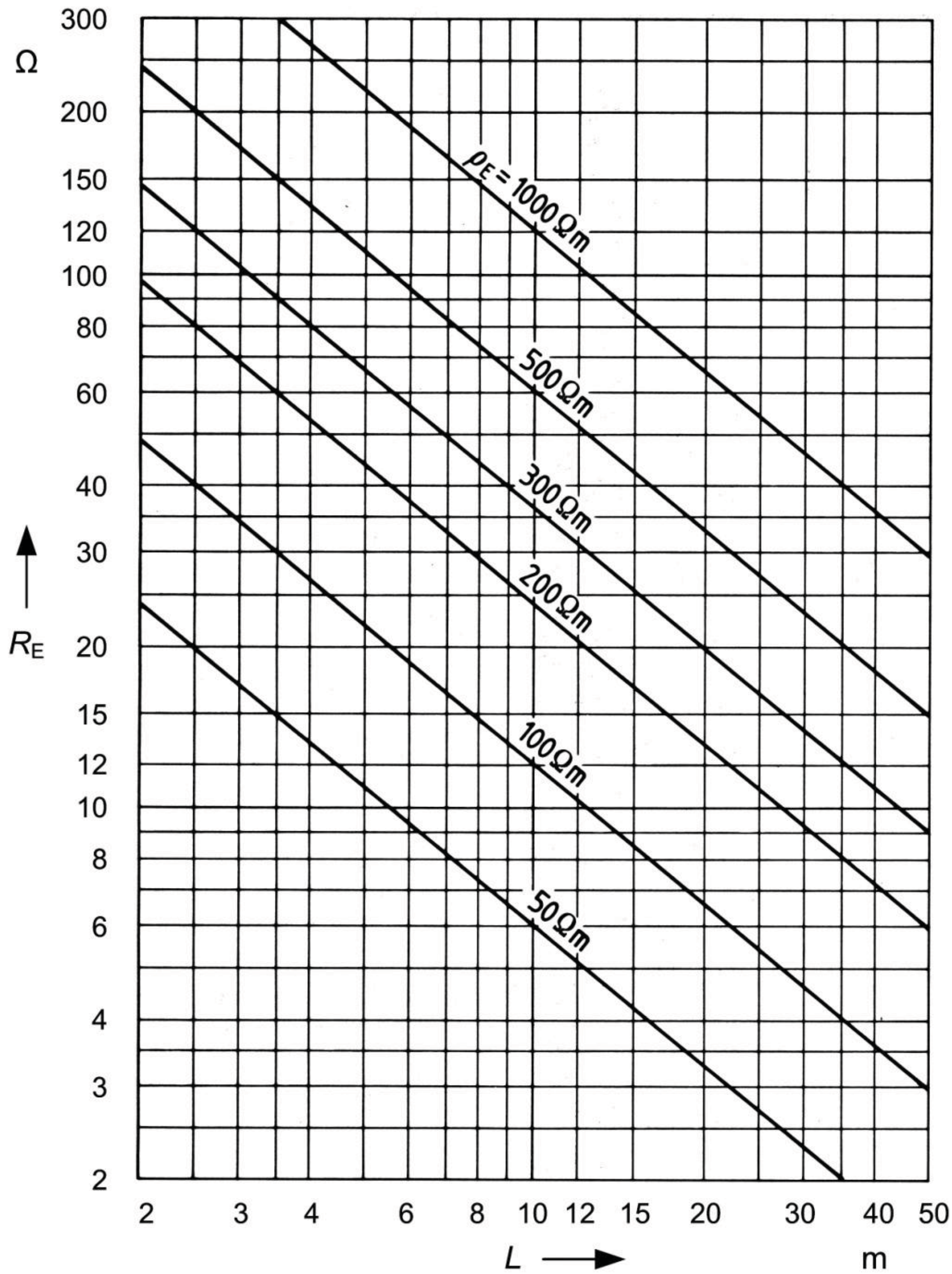


Figure J.2 - Resistance to earth of earth rods, vertically buried in homogeneous soil

Calculated values in accordance with the following formula:

$$R_E = \frac{\rho_E}{2\pi L} \ln \frac{4L}{d}$$

L Length of the earth rod in m
d Diameter of the earth rod in m (here 0,02 m assumed)
ρ_E Soil resistivity in Ωm

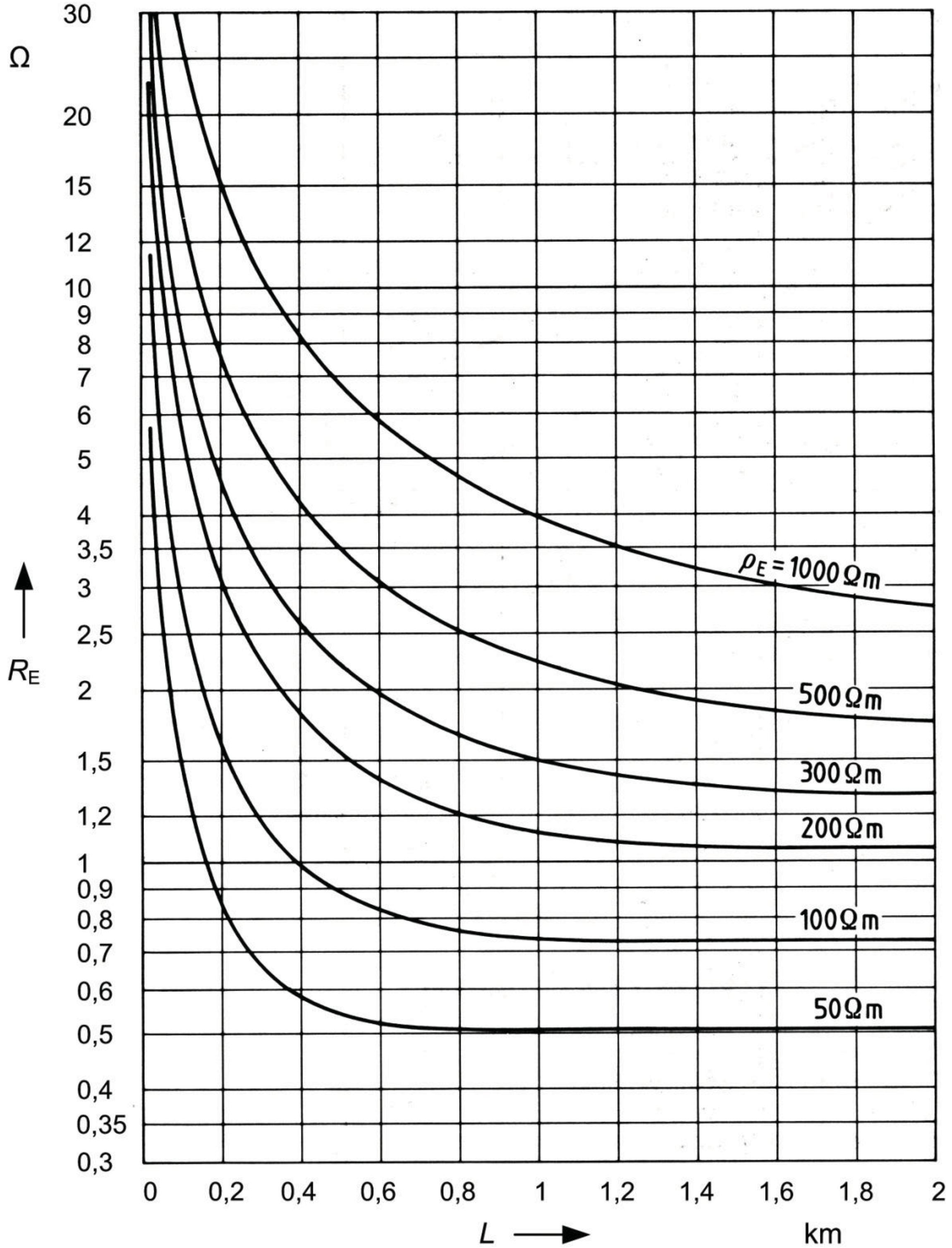


Figure J.3 - Typical values for the resistance to earth of a cable with earth electrode effect depending on the length of the cable and the soil resistivity

Annex K
(informative)

Installing the earth electrodes and earthing conductors

K.1 Installation of earth electrodes

K.1.1 Horizontal earth electrodes

Horizontal earth electrodes are usually laid at the bottom of a trench or a foundation excavation.

It is recommended that

- they are surrounded with lightly tamped soil,
- stones or gravel should not be in direct contact with the buried earth electrodes,
- indigenous soil, which is hostile to the electrode metal used, should be replaced by a suitable backfill.

K.1.2 Vertical or inclined driven rods

Vertical or inclined driven rods are driven into the soil by force and should be separated by a distance not less than the length of the rod.

Appropriate tools shall be used to avoid any damage to the electrodes when driving them in.

K.1.3 Jointing the earth electrodes

The joints used to connect conductive parts of an earth electrode network (grid) within the network itself shall have adequate dimensions to ensure an electrical conductance and mechanical and thermal strength equivalent to the electrodes themselves.

The earth electrodes have to be resistant to corrosion and should not be liable to contribute to galvanic cells.

The joints used to assemble rods shall have the same mechanical strength as the rods themselves and should resist mechanical stresses during driving. When different metals, which form galvanic cells that might cause galvanic corrosion, have to be connected, joints shall be protected by durable means against contact with electrolytes in their surroundings.

K.2 Installation of earthing conductors

In general the path of the earthing conductors shall be as short as possible.

K.2.1 Installing the earthing conductors

The following installation methods may be considered.

- Buried earthing conductors: Protection against mechanical damage may be required.
- Accessible installed earthing conductors: Above the ground the earthing conductors shall be installed in such a way that they remain accessible. If there is a risk of mechanical damage, the earthing conductor should be adequately protected.
- Concrete embedded earthing conductors: Earthing conductors may also be embedded in concrete. Easily accessible terminals shall be available at both ends.

Special attention shall be taken to avoid corrosion where the bare earthing conductor enters the soil or concrete.

K.2.2 Jointing the earthing conductors

The joints shall have good electrical continuity to prevent any unacceptable temperature rise under fault current conditions.

Joints shall not become loose and shall be protected against corrosion. When different metals, forming galvanic cells that can cause galvanic corrosion, have to be connected, joints shall be protected by durable means against any contact with electrolytes in their surroundings.

Suitable connectors shall be used to connect the earthing conductor to the earth electrode, to the main earth terminal and to any metallic part. The use of test link chambers can be helpful.

It shall be impossible to disassemble joints without special tools.

Annex L
(informative)

Measurements for and on earthing systems

L.1 Measurement of soil resistivities

Measurements of the soil resistivity for the pre-determination of the resistance to earth or the impedance to earth have to be carried out using a four probe method (for example Wenner-method), whereby the soil resistivity for different depths can be determined.

L.2 Measurement of resistances to earth and impedances to earth

L.2.1 These resistances and impedances may be determined in different ways. Which method is suitable depends on the extent of the earthing system and the degree of interference (see Clause L.4).

NOTE Attention has to be given to the fact that while the measurements and preparations are carried out, even when disconnected, but especially during the measurement, on and between earthed parts (for example between tower and lifted-off earth wire) dangerous touch voltages may occur.

L.2.2 Examples for suitable methods of measurements and types of instruments are:

a) Fall-of-potential method with the earth tester

   This instrument is used for earth electrodes and earthing systems of small or medium extent, for example single rod earth electrodes, strip earth electrodes, earth electrodes of overhead line towers with lifted off or attached earth wires, medium voltage earthing systems and separation of the low-voltage earthing systems. The frequency of the used alternating voltage should not exceed 150 Hz.

   Earth electrode under test, probe and auxiliary electrode shall lie on a straight line as far apart as possible. The distance of the probe from the earth electrode under test should be at least 2,5 times the maximum extension of the earth electrode under test (in measuring direction), but not less than 20 m; the distance of the auxiliary electrode must be at least 4 times the maximum extension, but not less than 40 m.

b) High frequency earth tester

   This instrument facilitates without lifting-off the earth wire the measurement of the resistance to earth of a single tower. The frequency of the measuring current shall be so high that the chain impedance of the earth wire and the neighbouring towers becomes high, representing a practically negligible shunt circuit to the earthing of the single overhead line tower.

c) Heavy-current injection method (see Figure L.1)

   This method is used particularly for the measurement of the impedance to earth of large earthing systems.

   By applying an alternating voltage of approximately system frequency between the earthing system and a remote earth electrode, a test current I_M is injected into the earthing system, leading to a measurable potential rise of the earthing system.

   Earth wires and cable sheaths with earth electrode effect, which are operationally connected to the earthing system, shall not be disconnected for the measurement.

The modulus of the impedance to earth is given by

$$Z_E = \frac{U_{EM}}{I_M \cdot r}$$

Where:

U_{EM} is the measured voltage between the earthing system and a probe in the area of the reference earth (remote earth) in Volts

I_M is the measured test current in Amperes

r is the reduction factor of the line to the remote earth electrode (see Annex I). The reduction factor may be determined by calculation or by measurement. For the reduction factor for overhead lines without earth wires and cables without shield or armouring is $r = 1$.

Earth wires of lines which run on a separated support parallel to the test line between earthing system and remote earth electrode, have to be taken into account, if they are connected to the earthing system under test and the remote earth electrode. If a cable with low-resistance metal sheath, earthed on both sides, is provided, then the greatest part of the test current will return via the sheath. If there is an insulating covering around the sheath it can be suitable to disconnect the earthings of the sheath.

However, for cables which perform the function of an earth electrode, the earthing of the metal sheaths shall not be disconnected.

The distance between the tested earthing system and the remote earth electrode should be large enough to ensure separate zones of influence, e.g. 1 to 5 km for extended earthing systems. The test current should be, as far as possible, selected at least so high that the measured voltages (earth potential rise as well as touch voltages, referred to the test current) are greater than possible interference and disturbance voltages. This is generally ensured for test currents above 50 A. The internal resistance of the voltmeter should be at least 10 times the resistance to earth of the probe.

NOTE For small earthing systems smaller distances can be sufficient.

Possible interference and disturbance voltages have to be eliminated (see Clause L.4).

d) Determination from the individual resistances

If the earthing system consists of separate earth electrodes, which practically do not interfere with each other, but which are interconnected via connecting conductors, for example earthing conductors or earth wires of overhead lines, then the impedance to earth Z_E can be determined in the following way:

The resistance to earth of each earth electrode is determined for disconnected connecting conductors by the fall-of-potential method, the impedance of the connecting conductors are calculated, and the impedance to earth is determined from the equivalent circuit of the resistance to earth and the impedances of the connecting conductors.

L.3 Determination of the earth potential rise

The earth potential rise $\underline{U}_E$ is (see Figure L.1) given by:

$$\underline{U}_E = \underline{Z}_E \cdot \underline{I}_E$$

Where:

$\underline{Z}_E$ is the impedance to earth, for example from the measurement in accordance with L.2.2 c) or from the calculation in accordance with L.2.2 d)

$\underline{I}_E$ is the current to earth in accordance with 3.4.29

The current to earth during measurement is given by

$$\underline{I}_{EM} = r \cdot \underline{I}_M$$

The impedance to earth is given by

$$\underline{Z}_E = \frac{\underline{U}_{EM}}{\underline{I}_{EM}}$$

The earth potential rise in case of fault is given by

$$\underline{U}_E = \underline{I}_E \cdot \underline{Z}_E = \underline{U}_{EM} \cdot \frac{\underline{I}_E}{r \cdot \underline{I}_M}$$

For an earth fault in a three-phase system and for a similar earth wire reduction factor of all overhead lines leaving the substation, the current to earth can be determined by:

$$\underline{I}_E = r \cdot \Sigma\, 3\, \underline{I}_0$$

Where:

r is the earth wire reduction factor

$\Sigma\, 3\, \underline{I}_0$ is the vector sum of the currents of all phase conductors of this system flowing to the substation

For a fault in the substation $\Sigma\, 3\, \underline{I}_0$ is the difference between the earth fault current and the transformer neutral current.

If the earth wire reduction factors of the lines A, B, C ... leaving the substations are different, the current to earth is given by:

$$\underline{I}_E = r_A \cdot 3\, \underline{I}_{0A} + r_B \cdot 3\, \underline{I}_{0B} + r_C \cdot 3\, \underline{I}_{0C} + ...$$

Where:

$\underline{I}_{0A}$ is the zero sequence current of a phase conductor (for example phase L1) of the line A, $\underline{I}_{0B}$ accordingly of the line B, etc.

r_A is the earth wire reduction factor of the line A, r_B of the line B, etc.

NOTE This equivalent circuit is based on the effect that in practice the chain impedance $\underline{Z}_\infty$ is almost achieved after a few spans. For overhead lines longer than a few spans the effect of magnetic coupling results in an earth wire current, which can be additionally considered by the reduction factor.

For a cable leaving the substation, instead of the earth wire reduction factor the cable sheath reduction factor has to be used in the equation above for $\underline{I}_E$.

For cables with insulated sheath which lead fault current to the substation the cable sheath reduction factor is the primary effect. In addition the chain impedance (cable sheath/neighbouring earth grids) can be considered if the cable is significantly longer than the sections forming the chain impedance.

L.4 Elimination of interference and disturbance voltages for earthing measurements

For the determination of the earth potential rise in accordance with the L.2.2 c) distortions of the measured values due to interference and disturbance voltages of every type (for example inductive interference of the test circuit by parallel systems in operation) may occur.

Examples for methods proved useful in practice for the elimination of such disturbing effects are:

a) Beat method

In this case a voltage source (for example emergency generating set) is used, whose frequency deviates some tenth of a Hertz from the system frequency. The voltages caused by the test current are added vectorially to possible disturbance voltages U_d', whose modulus and phase angle for sufficiently short duration of a measuring cycle may be regarded as constant. Due to the asynchronous superposition the pointer or the display of the voltmeter swings between a maximum value U_1 and a minimum value U_2. The voltage caused by the test current is determined by

$$U = \frac{U_1 + U_2}{2} \qquad \text{for } 2 \cdot U_d' < U_1$$

$$U = \frac{U_1 - U_2}{2} \qquad \text{for } 2 \cdot U_d' > U_1$$

$$U = \frac{U_1}{2} \qquad \text{for } 2 \cdot U_d' = U_1$$

b) Polarity reversal method

For this purpose a system synchronous voltage source (transformer) is used, whose voltage is reversed 180° electrically in the phase angle after a dead interval. During the flow of the test current the occurring voltages U_a before the reversal, U_b after the reversal and the disturbance voltage U_d for the test current switched off are measured. Because of vectorial relations the voltage caused by the test current is calculated by

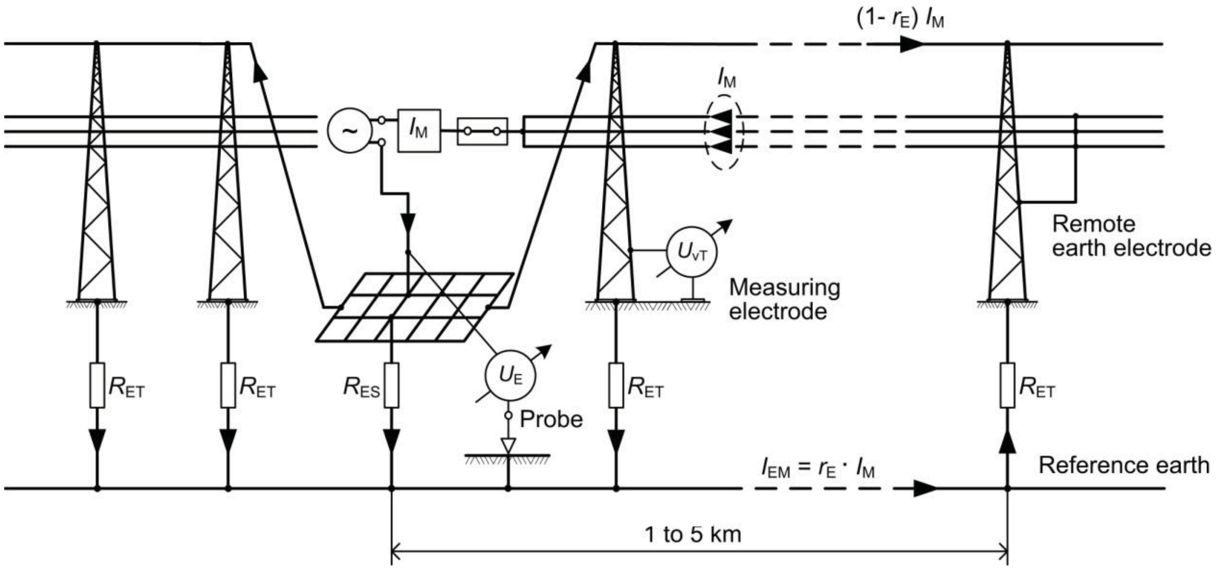
$$U = \sqrt{\frac{U_a^2 + U_b^2}{2} - U_d^2}$$

c) Vector measurement

Long measuring leads should be laid rectangularly to the test line, as far as possible. If this is not possible because of space conditions, the part of the voltage induced in the measuring line by the test current can partly be eliminated by vector measurement equipment.

d) Blocking of direct currents

If the disturbance voltages have high direct voltage contents, a voltmeter which blocks the direct voltage may be required.



I_M	Test current (generally only the modulus of the voltage and the current is determined)
I_{EM}	Current to earth during the measurement (in this case not directly measurable)
r_E	Reduction factor of the line to the remote earth electrode
R_{ES}	Resistance to earth of the mesh earth electrode
R_{ET}	Resistance to earth of the tower
U_E	Earth potential rise during measurement
U_{vT}	Prospective touch voltage during measurement

Figure L.1 - Example for the determination of the impedance to earth by the heavy-current injection method

Annex M
(normative)

Details on site 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 standard 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.

Annex N
(informative)

The use of reinforcing bars in concrete for earthing purpose

The steel reinforcing bars can be used for several purposes:

a) as a part of the earthing system, in which case the size of the steel reinforcing bars must be in accordance with 5.2.2;

b) as the potential grading for the protection of the operator, in which case all relevant parts of the steel reinforcing shall be connected together to ensure that no differences in potential exist. The connections must be dimensioned in accordance with 5.2.3;

c) as an electromagnetic shield associated with high frequency currents, in which case all relevant parts of the steel reinforcing shall be connected together to form a very low impedance path for high frequency currents. Many connection points will be provided to the steel reinforcing to unable equipment connections to be kept as short as possible to minimize the electromagnetic influences;

When steel reinforcing bars are used for any of these purposes, care must be taken to ensure that the possibility of corrosion is kept to a minimum. The connection to the steel reinforcing bars shall be in accordance with Annex K.

Annex O
(informative)

Global Earthing System

The definition of the global earthing system is based on the fact that in an area no or hardly any potential differences occur.

In order to identify such areas, no simple or stand-alone rule is available.
In general:

- a low overall resistance is helpful, but is not a guarantee. Therefore, the standard is not stating a minimum requirement based on resistance.
  Moreover, also in installations with high soil resistivity and overall resistances, safety requirements can be fulfilled thanks to the increase of the additional resistances and adequate potential grading;
- a low fault current level is helpful as the total earth potential rise will be limited;
- a suitable cable sheath reduction factor or earth wire reduction factor distributes the fault current in such a way that the total earth potential rise is limited;
- a short fault duration is increasing the permissible touch voltages and in consequence difference referred to permissible limits are smaller.

There are different measures available to meet safety requirements. In order to specify measures for a certain area local conditions have to be considered. The verification can be done by typical means based on measurements or calculations.

Typical cases where a global earthing system exists could be:

- substation is surrounded by buildings with foundation earth electrodes and the earthing systems are interconnected e.g. by cable sheath or low voltage protective earth conductors;
- substation is feeding city centre or densely built up areas;
- substation is feeding suburban area with many distributed earth electrodes interconnected by protective earth conductors of low voltage system;
- substation with given number of nearby substations;
- substation with given number and length of outgoing earth electrodes;
- substation connected via cables with earth electrode effect;
- substation is feeding extended industrial area;
- substations are part of system with multi earthed high voltage neutral conductor.

Annex P
(normative)

Special national conditions

Special national condition: National characteristic or practice that cannot be changed even over a long period, e.g. climatic conditions, electrical earthing conditions.

NOTE If it affects harmonization, it forms part of the European Standard.

For the countries in which the relevant special national conditions apply these provisions are normative, for other countries they are informative.

Clause	Special national condition
5.3.2	**Finland**
	For systems with isolated neutral and system with resonant earthing I_C and I_{res} can be used for dimensioning of thermal loading of earth electrodes and earthing conductor if disconnection time is within 1 s.

Annex Q
(informative)

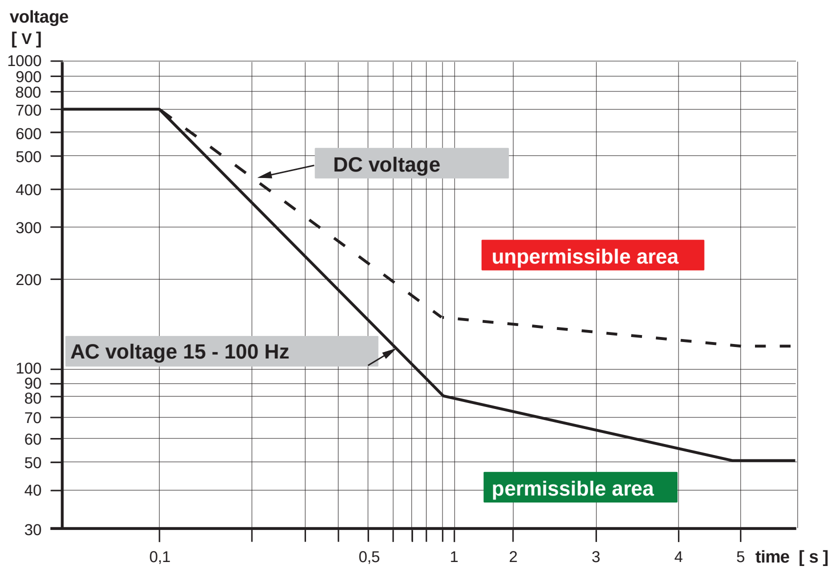
A-deviations

A-deviation: National deviation due to regulations, the alteration of which is for the time being outside the competence of the CENELEC national member.

This European Standard does not fall under any Directive of the EC.

In the relevant CENELEC countries these A-deviations are valid instead of the provisions of the European Standard until they have been removed.

Clause	Deviation
General	**France**
	In France many laws and decrees are mandatory for the design, the construction, the verification and the control of HV installations. All the French safety and legal requirements, mainly driven by the ministry of industry (arrêté du 17 mai 2001), the ministery of labour (décret du 14 novembre 1988) and the grid codes for HV and MV public networks, are incorporated in two National standards; NFC 13-100 and NFC 13-200. Both NFC 13-100 and NFC 13-200 are globally in line with EN 50522. Their application is mandatory in France and they can not by superseded by the EN, which is providing only general rules.
	EN 50522 does not cover a large part of the field of the French regulation. It cannot be used in France as a contracting basis between various players involved in HV installation business, since it may create difficulties, interpretation problems, and confused situations.
	The main additional rules and deviations from EN 50522 are covered by NFC 13-100 and NFC 13-200.
5.4.1 +	**United Kingdom** (Health & Safety Executive (HSE))
Annex A	HV earthing systems should be designed according to tolerable voltages based on body impedances not exceeded by 5 % of the population, as given in Table 1 of IEC 60479-1:2005.
5.4.1	**Sweden** (ELSÄK-FS 2008: 1, kap 5, §§ 3, 6, 7 and 8)
	Earth faults shall automatically be disconnected within 5 seconds for non low impedance earthed systems. An exception applies to non low impedance earthed systems with a system voltage not exceeding 25 kV and not including overhead lines, where a single pole earth fault is permitted to only initiate an alarm automatically.
	Earth faults for low impedance earthed systems shall automatically be disconnected within 0,5 seconds.
5.4.1	**Switzerland** (Federal law concerning electrical installations (High and low voltage) (SR 734.0), Regulation for electrical power installations (SR 734.2))
	Dimensioning with regard to touch and step voltages permissible values, SR 734.2: Art. 54 *(Permissible touch and step voltages in power installations),* Art. 55 *(Permissible touch voltages in low voltage installations)* and Art. 57 *(Earthing in high voltage installations)*
	(Appendix 4 (Art. 54, 55 and 57) Permissible touch voltages)



Permissible touch voltages and step voltages

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5.4.2 **Sweden** (ELSÄK-FS 2008: 1, kap 2, § 2 and kap 5, §§ 6, 7 and 8. ELSÄK-FS 2008: 3, §§ 3 and 6)

Measures for observance of permissible touch voltages shall be proved by measurements.

6.1 **France**

Table 2 According to the French regulation (arrêté technique du 17 mai 2001 – Article 45), in case of a single phase HV faults, the overvoltage induced in reference to local earth of a BT installation shall not exceed 1 500 V rms.

6.1.4 **Sweden** (ELSÄK-FS 2008: 1, kap 5, § 6)

For non low impedance earthed systems with a system voltage not exceeding 25 kV, where a single pole earth fault is only initiating an automatic alarm, touch voltage for TN system in table 2 shall fulfill EPR ≤ 50 V.

Annex E **France**

M3.1 In public networks substation, the connection of the building foundation to the earthing system must be achieved at least every 10 m in the three direction (x,y,z). While for industrial buildings, earthing should be achieved according to Article 412 of NFC 13-200.

National Annex NA (informative)
UK earthing safety limits and design methodology

NA.1 UK earthing design safety limits

As a result of the adoption of the '5%' values of body impedance from DD IEC/TS 60479-1, Table 1 (large surface-areas of contact in dry conditions) different tolerable levels of touch voltage are applicable for earthing design in the UK.

Note: See Annex Q of BS EN 50522:2010, which details the related UK A-deviations.

These have been calculated on the basis of the left-hand to both feet shock scenario. Therefore, Figure NA.1 should be used instead of BS EN 50522:2010, Figure 4 and Figures NA.2 to NA.5 should be used instead of BS EN 50522:2010, Figure B.2. These curves are applicable for simple assessments of earthing safety and where more detailed consideration of alternative specific shock scenarios is required, e.g. hand-to-hand, or if different contact conditions are assumed, e.g. wet rather than dry, the limits may be modified taking into account the appropriate heart current factor and path/contact-specific body impedance according to DD IEC/TS 60479-1.

Permissible touch and step voltages for typical fault clearance times and additional resistances, based on a typical minimum value for footwear resistance of 4 kΩ per foot within a substation where the public are excluded, are provided in Table NA.1 and Table NA.2 respectively. It should be noted, however, that touch and step voltage scenarios outside enclosed substations might require adoption of other values of footwear resistance, and neglection of additional resistances due to chippings.

Figure NA.1 – Permissible touch voltage – no additional resistances

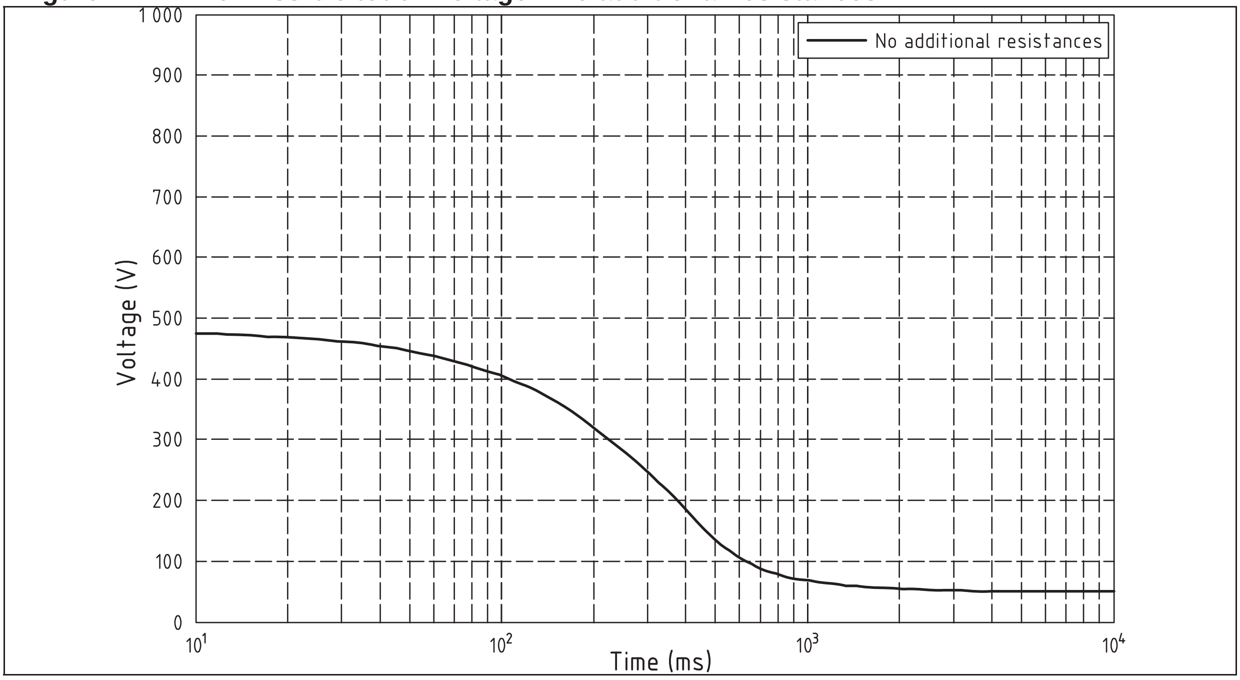
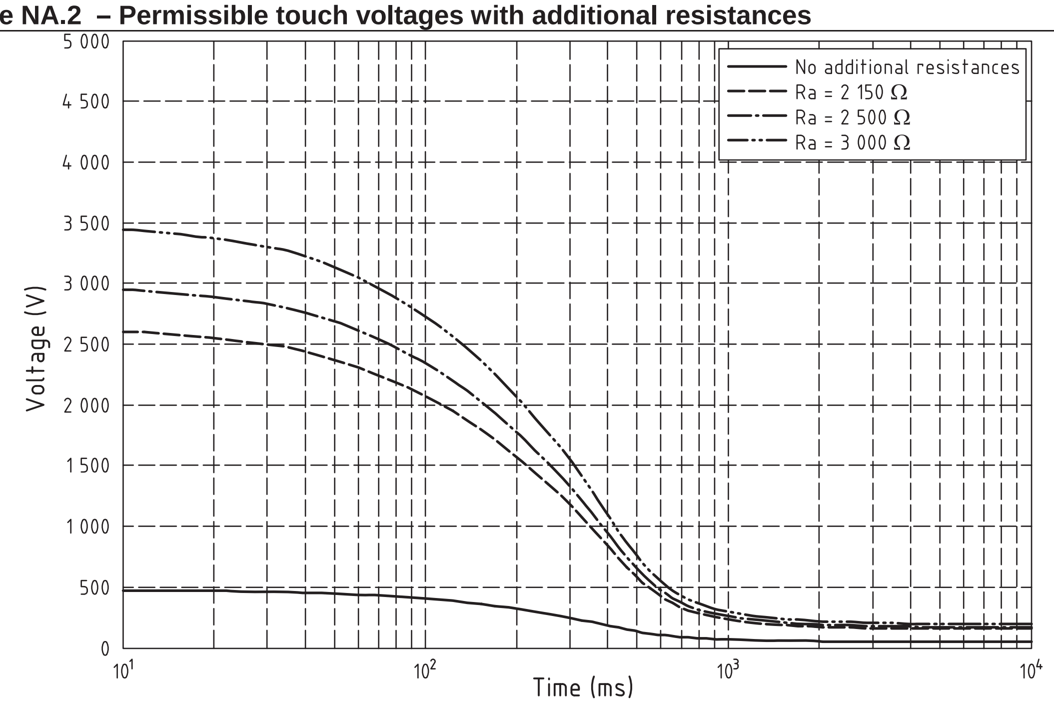
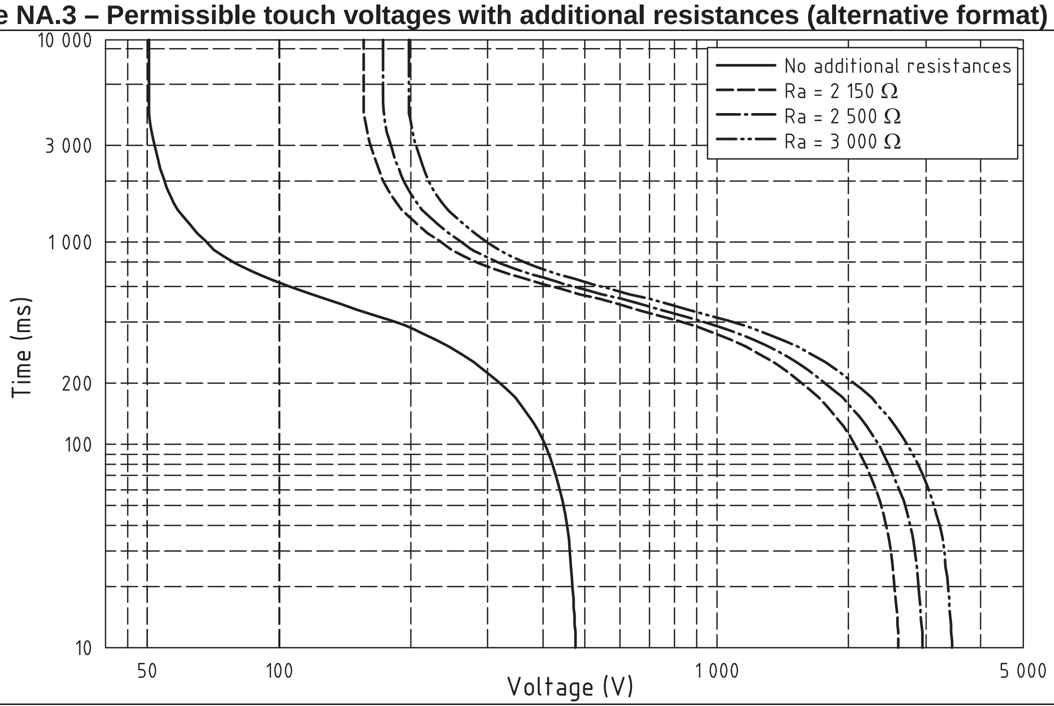


Figure NA.2 – Permissible touch voltages with additional resistances



NOTE 1 Tolerable touch voltage without additional resistances as Figure NA.1 (Left hand to both feet)
NOTE 2 R_a = 2150 Ω (Footwear resistance: 4 kΩ, earth foot resistance of 300 Ω based on ρ_s = 100 Ωm)
NOTE 3 R_a = 2500 Ω (Footwear resistance: 4 kΩ, effective chippings resistance 1000 Ω per foot based on 75 mm chippings thickness)
NOTE 4 *R*a = 3000 Ω (Footwear resistance: 4 kΩ, effective chippings resistance 2000 Ω per foot based on 150 mm chippings thickness)

Figure NA.3 – Permissible touch voltages with additional resistances (alternative format)



Permissible step voltage levels with additional resistances are presented in Figure NA.4.

Figure NA.4 – Permissible step voltages – no additional resistances

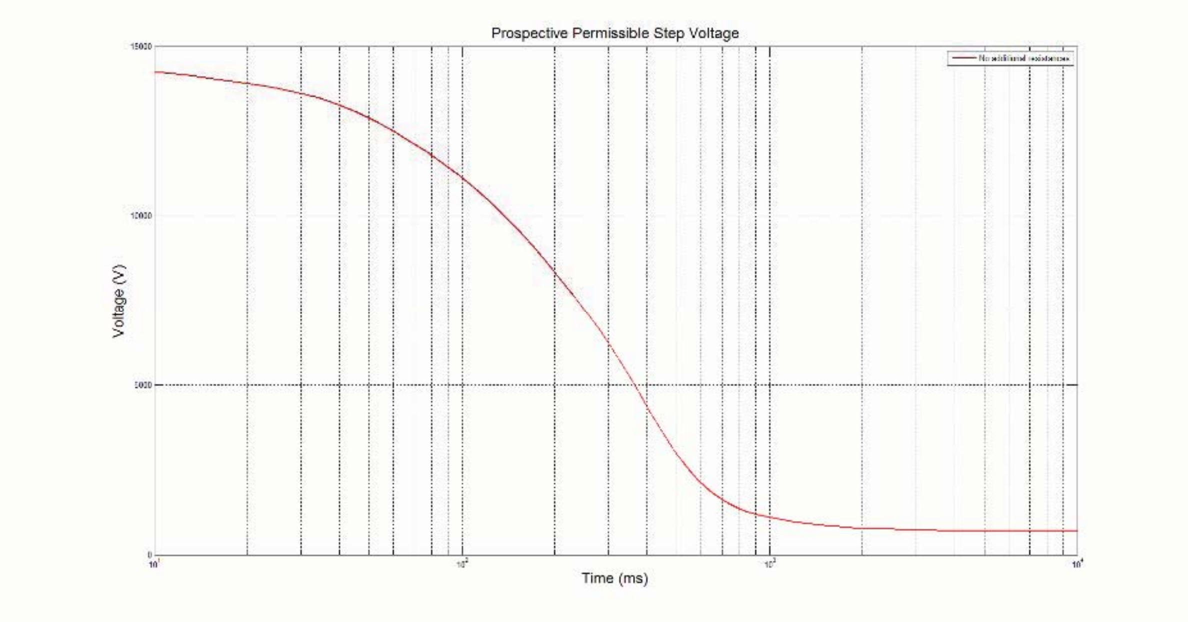
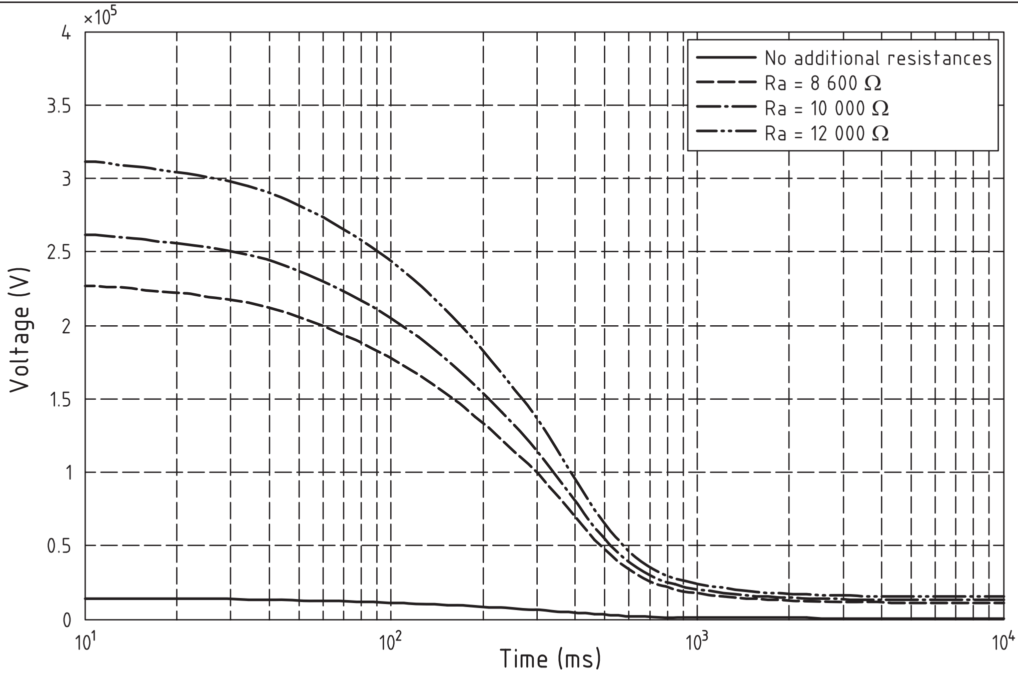


Figure NA.5 – Permissible step voltages with additional resistances



NOTE 1 Tolerable step voltage without additional resistances (foot to foot path)' as Figure NA.4 (foot to foot)
NOTE 2 R_a = 8600 Ω (Footwear resistance: 4 kΩ, earth foot resistance of 300 Ω based on ρ_s = 100 Ωm)
NOTE 3 R_a = 10000 Ω (Footwear resistance: 4 kΩ, effective chippings resistance 1000 Ω per foot based on 75 mm chippings thickness)
NOTE 4 *Ra* = 12000 Ω (Footwear resistance: 4 kΩ, effective chippings resistance 2000 Ω per foot based on 150 mm chippings thickness)

Figure NA.6 – Permissible step voltages with additional resistances (alternative format)

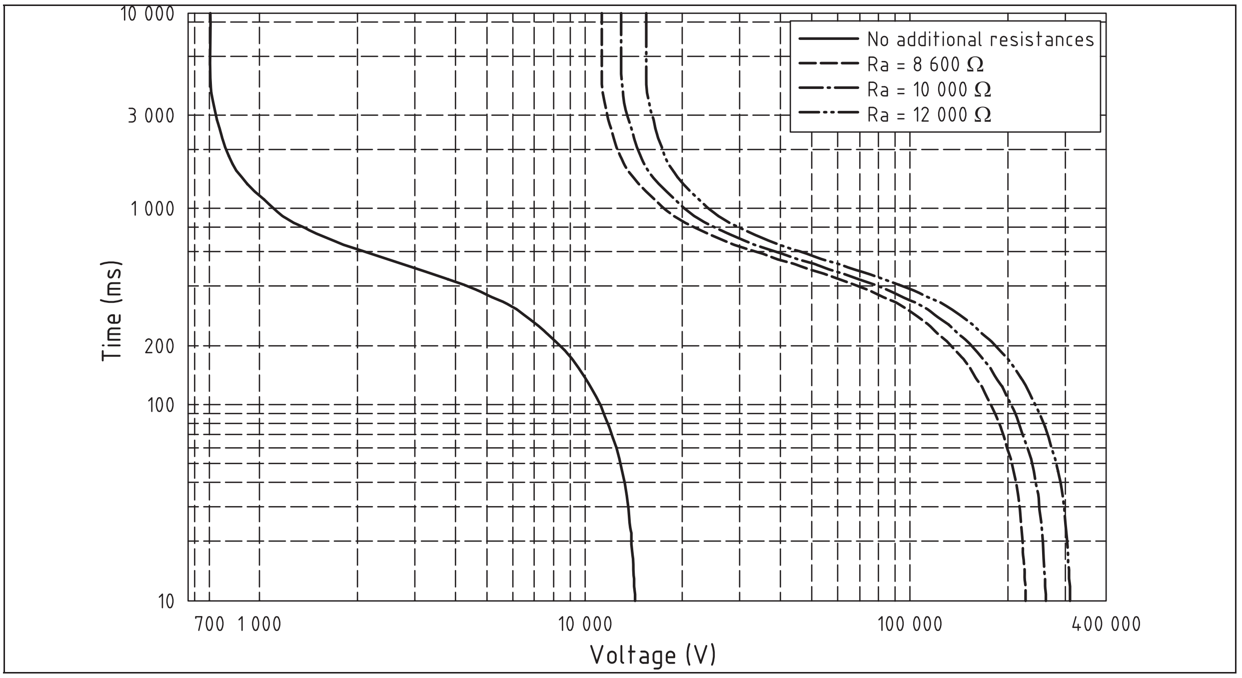


Table NA.1 – Permissible touch voltages for typical fault clearance times

Permissible touch voltages V		Fault clearance time, s					
		0.1	**0.15**	**0.2**	**0.5**	**1**	**3**
Additional resistance, Ω	**0**	405	362	320	135	68	52
	2 150	2 070	1 808	1 570	578	233	162
	2 500	2 341	2 043	1 773	650	259	180
	3 000	2 728	2 379	2 064	753	298	205

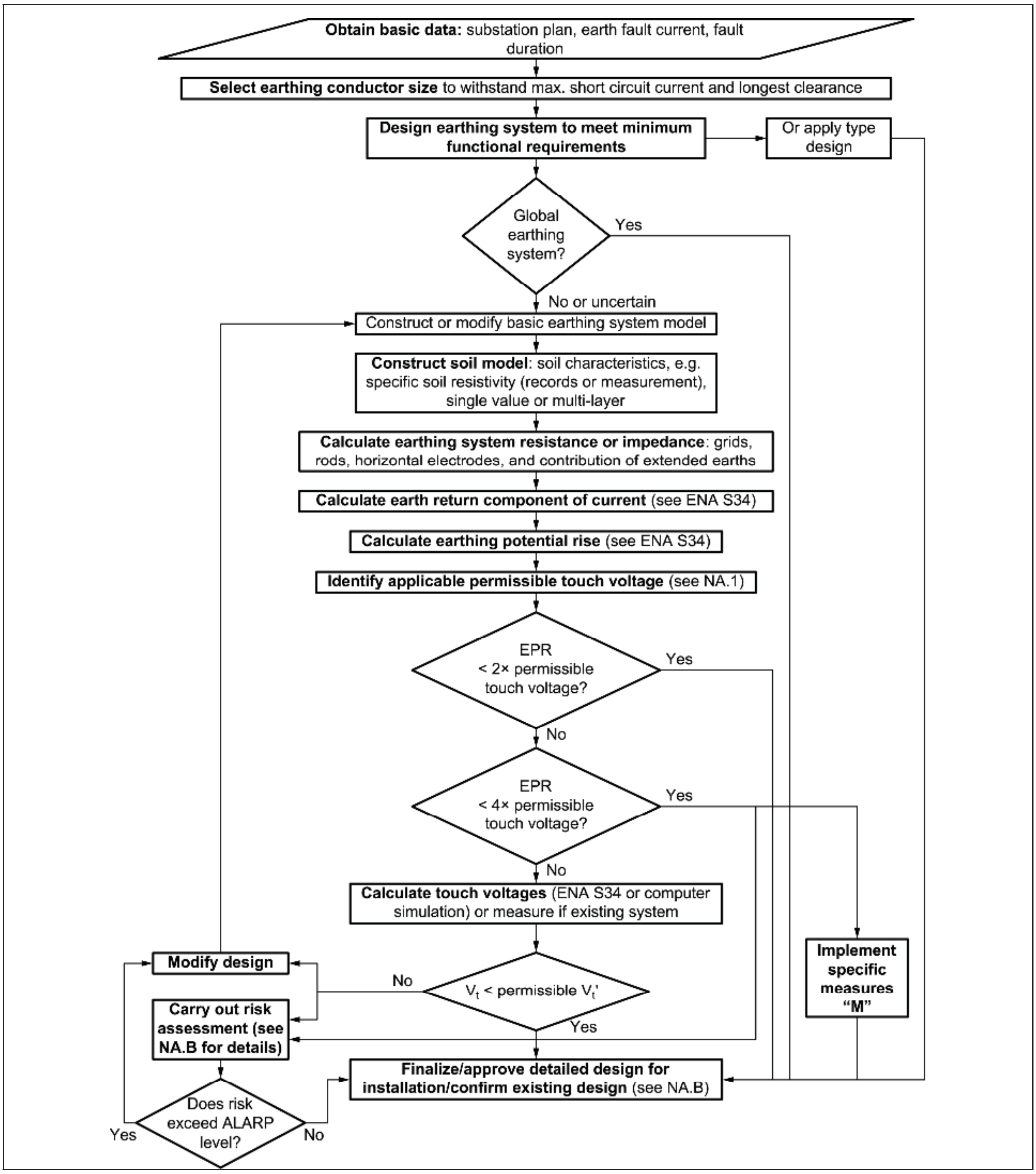
Table NA.2 – Permissible step voltages for typical fault clearance times

Permissible step voltages V		Fault clearance time, s					
		0.1	**0.15**	**0.2**	**0.5**	**1**	**3**
Additional resistance, Ω	**0**	11 131	9 663	8 357	2959	1 101	733
	8 600	A)	A)	A)	A)	17 571	11 727
	10 000	A)	A)	A)	A)	20 253	13 517
	12 000	A)	A)	A)	A)	24 083	16 074
	A) Limits could not foreseeably be exceeded.						

NA.2 UK earthing design methodology

Figure NA.6 reproduces the main elements of the earthing design methodology of BS EN 50522. However, the flowchart includes an additional option for carrying out a probabilistic risk assessment. The detailed methodology of applying the probabilistic risk assessment approach is given in National Annex NB.

Figure NA.7 – Earthing design methodology including the option for probabilistic risk assessment



NA.3 Bibliography

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Zhao H., Griffiths H., Haddad A., and Ainsley A., 'Safety-limit curves for earthing system designs: Appraisal of standard recommendations', *Proc. Inst. Elect. Eng., Gen., Transm. Distrib.*, vol. 152, no. 6, pp. 871–879, 2005.

National Annex NB (informative) Probabilistic based risk assessment of earthing systems

NB.1 Introduction

In the UK, legislation that covers the duties of employers to their employees and third parties is set out in The Health and Safety at Work etc. Act 1974 [1]. This act requires that 'it shall be the duty of every employer to conduct his (her) undertaking in such a way as to ensure, so far as is reasonably practicable, that persons… are not thereby exposed to risks to their health and safety'. More recently, the Management of Health and Safety at Work Regulations 1999 [2], which were enacted as a result of European Union Framework Directive 89/391/EEC, states that 'Every employer shall make a suitable and sufficient assessment of… the risks to the health and safety of persons not in his employment arising out of or in connection with the conduct by him (her) of his (her) undertaking'.

What is reasonably practicable has been established by a number of legal test cases and more comprehensively by the Health & Safety Executive (HSE) [4], and this concept is referred to as the as low as reasonably practicable (ALARP) principle. An individual fatality risk of 1 in 10 million per person per year is considered broadly acceptable for members of the public. Between 1 in 1 million and 1 in 10 000 per person per year, the ALARP principle must be applied; which means that unless the expense undertaken is in gross disproportion to the risk, the employer must undertake the expense to reduce the level of risk to the lowest level practicable. The HSE have attempted to reflect the price people are prepared to pay to secure a certain averaged risk reduction and advise a benchmark value for preventing a fatality of £1m (2001 figures: should be adjusted to current prices).

In carrying out such a cost benefit analysis (CBA), balancing risk against the cost of mitigation, it is necessary to consider the number of individuals exposed to a risk, i.e. the greater the number exposed, the greater the justifiable spend. It should also be noted that the outcome of a CBA is only one of a number of factors which may need to be taken into account in the decision making process.

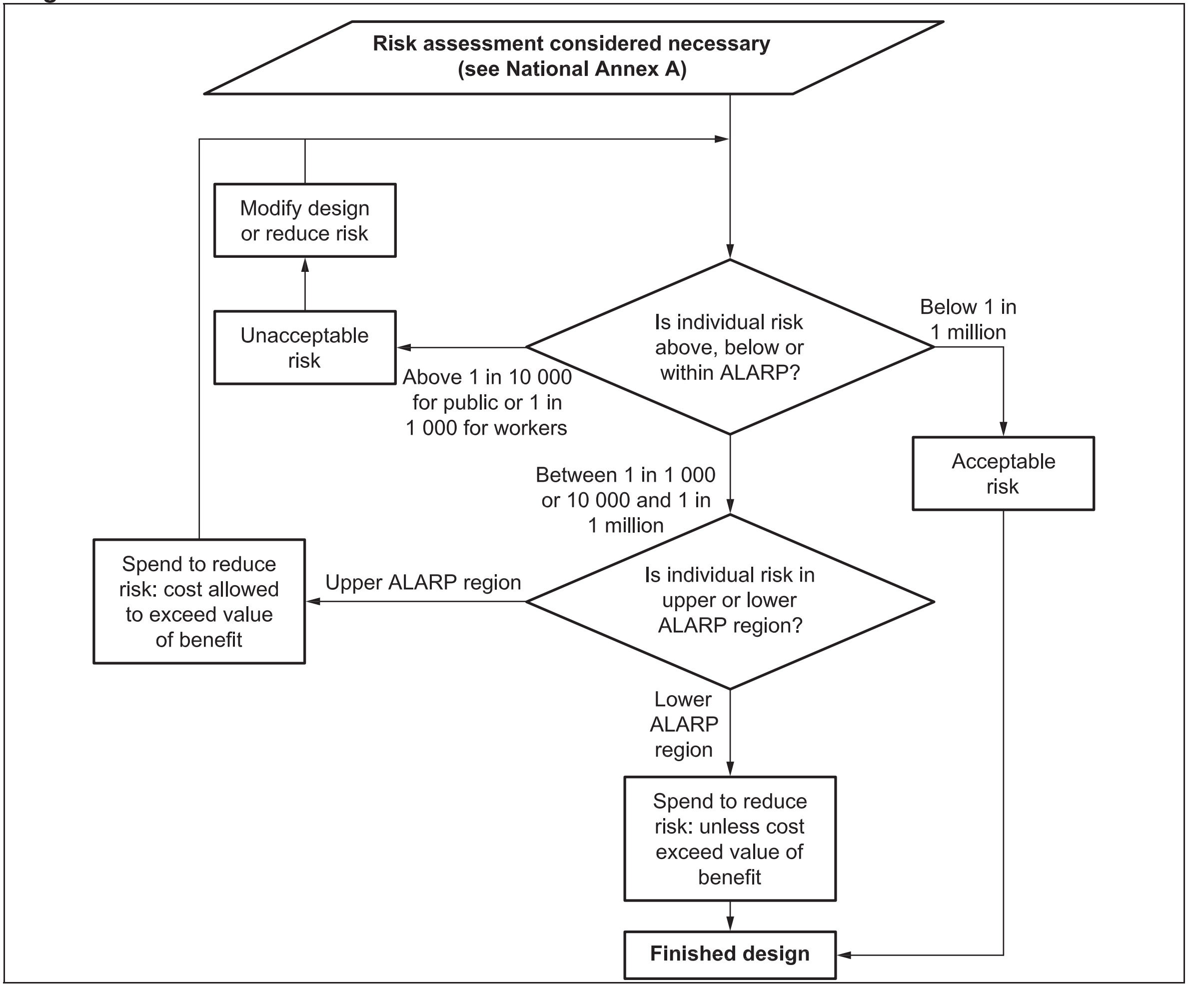
The risk management approach starts by recognizing the probabilistic nature of exposure to earth potential rise. In simple terms, this means that account should be taken of the likelihood of the occurrence of an earth fault at the same time as an individual being in a position which bridges a dangerous potential.

The procedure for carrying out a probabilistic risk assessment is outlined in Figure NB.1, which also supports Figure NA.6.

It should be noted that assessed risks may need to be reviewed in the future to take into account any changes in circumstances.

In this Annex, five case studies are provided to illustrate the application of a simplified probabilistic risk assessment to earthing system design problems. These case studies use typical data for the probability of an earth fault event but this data should not be taken as generically applicable: site-specific reliable data should be sourced by the designer for each particular case.

Figure NB.1 – Probabilistic risk assessment



NB.2 Case study 1

The following example will serve to illustrate the main steps involved in probabilistic risk assessment. Assume that a person is present at an electrical installation and it has been calculated that they could be exposed to a transferred 'touch' potential of 2 150 V for 200 ms, as a result of an earth fault on power system. If typical values of resistances in the accidental circuit were assumed, this voltage would be higher than the levels specified in National Annex NA. Therefore, if a deterministic approach were applied, this hazard would require mitigation. However, the alternative probabilistic approach considers the probability that the individual will experience this fatal electric shock. This overall probability P can be determined as the product of three separate probabilities,

$$P = P_F P_{FB} P_E$$

where

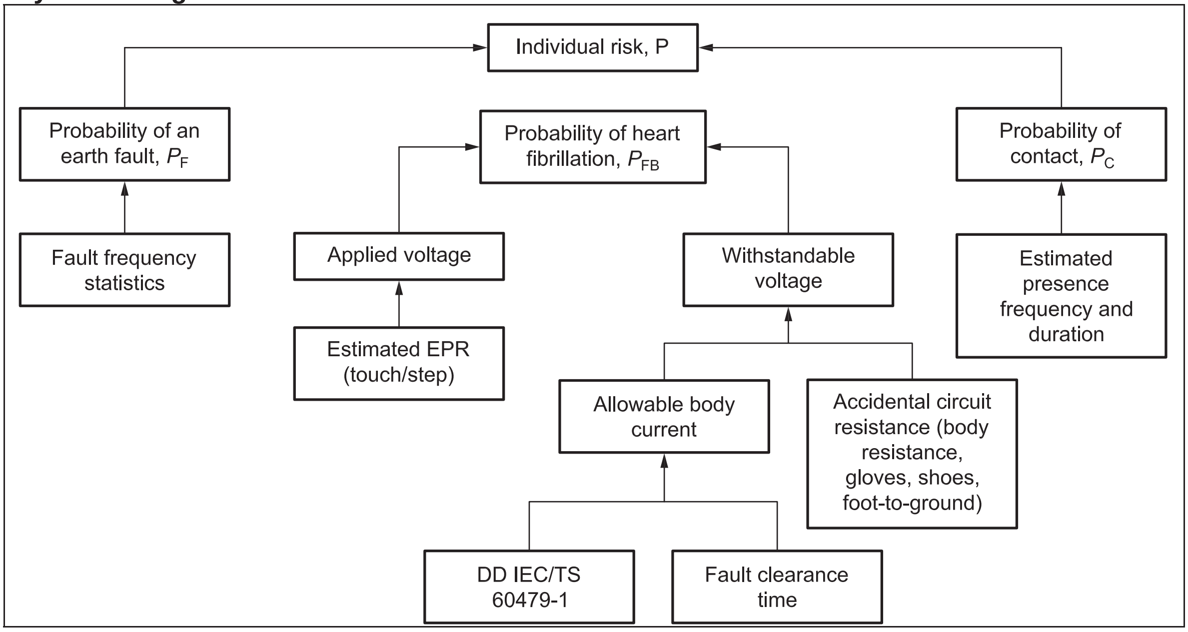
P_F is the probability of an earth fault on the power system,

P_{FB} is the probability of heart fibrillation, and

P_E is the probability of exposure or contact of the individual across the prospective earth potential rise,

as shown in Figure NB.2.

Figure NB.2 – Outline of probabilistic risk assessment approach applied to earthing system design



P_F may be estimated from historical fault records. A typical probability of an earth fault occurring, which results in a significant earth potential at a transmission substation, is 0.2 per annum; i.e. one significant earth fault every five years on average.

P_{FB} is the likelihood that, if a person were exposed to the earth potential rise, heart fibrillation would occur. Probabilities of heart fibrillation corresponding to current magnitude and duration (in this case 200 ms) are given in DD IEC/TS 60479-1. The current magnitude can be estimated from the accidental touch circuit and, in this example, a body resistance R_b of 431 Ω (hand to feet current path) will be assumed to cover at least 95% of the population. The 'additional' circuit resistances will depend upon the specific exposure scenario, such as what the individual is wearing and doing at the time of exposure. For example, it might be reasonable to assume that a person would be wearing footwear whilst outdoors. The ITU Directives Volume VI [3] specifies a combined additional resistance of 3 000 Ω for the hand-to-feet scenario for damp elastomer-soled shoes on loose soil, and this value is adopted in our example. Also included is the earth resistance of each foot (300 Ω per foot). All other circuit resistances and the source impedance are considered to be negligible in this case. In many exposure scenarios there will be additional insulation in the accidental circuit such as where an individual is using an insulated power tool. In this example, such insulation is neglected. The total resistance of the accidental circuit is calculated to be 3 581 Ω, which would result in a current of 0.6 A flowing through the body for a touch voltage of 2 150 V. At this current magnitude, DD IEC/TS 60479-1 predicts a probability of fibrillation of 10% which is greater than the 'c2' 5% threshold value from DD IEC/TS 60479-1 upon which the thresholds in National Annex NA are based.

Finally, it is necessary to estimate P_E, which is the likely time the person is present in the accidental circuit. This will again depend upon the activity undertaken by the exposed individual; in particular the proportion of time in contact with the circuit elements. Let us assume that in this example the person is in contact with the exposed metalwork, on average, for five minutes per day for 20 days. Therefore, the probability of contact over one year is 1.9×10^{-4}. The estimated annual probability that this person will experience a fatal electric shock as a result of their presence at an electrical installation can be estimated as the product of the probabilities P_F, P_{FB} and P_C, viz., $0.2 \times 0.1 \times 1.9 \times 10^{-4} = 3.8 \times 10^{-6}$ or 1 in 262 800. This level of individual risk falls within the lower ALARP region, where the cost of mitigation has to be balanced against the risk. If mitigation in this case were not prohibitively expensive, it may be considered worthwhile.

It should be noted that the above example covers one exposure scenario only. To cover the total individual risk, all reasonably foreseeable scenarios should be considered and all risk probabilities added together.

NOTE In many cases, it is expected that although the exposure voltages may exceed the limits prescribed in the standards, the level of individual risk might not warrant significant expenditure on mitigation. However, it is worth noting that, in general, it is not prohibitively expensive to design an earthing system to control touch and step voltages inside a substation to within the levels specified in the standards, and consequently, this approach is normally adopted.

NB.3 Case study 2 – Small substation with a separately earthed perimeter fence

A site earthing assessment found an earthed structure within 2m of the separately earthed perimeter fence as shown in Figure NB.3. This presents a transfer voltage hazard and is not in accordance with ENA TS 41-24. Risk assessment was used to quantify the risk presented by the transfer voltage hazard and the results are shown in Table NB.1.

Figure NB.3 – Earthed Structure within 2 m of separately earthed perimeter fence

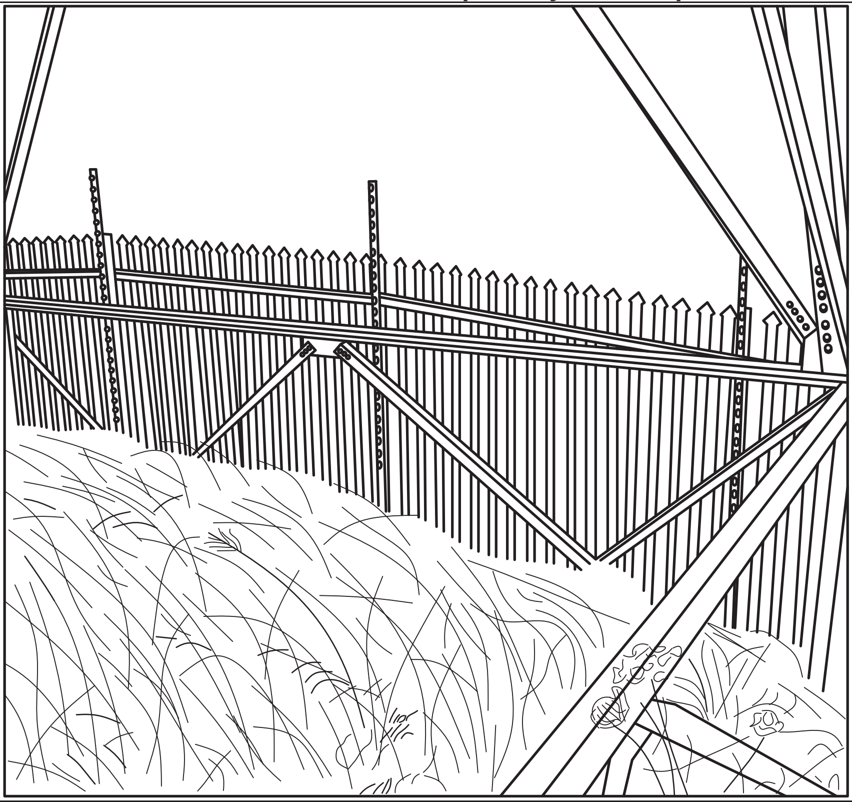


Table NB.1 – Risk assessment summary for Site A (132 kV substation)

Defect	P_F	P_{FB}	P_E	Risk	Remedial action
Earthed structure	0,25	0,5	$1,14 \times 10^{-5}$	$1,43 \times 10^{-6}$	Calculate justifiable spend

The parameters in Table NB.1 were determined as follows.

The individual risk is calculated using the formula:

$$\text{Risk} = P_F \times P_{FB} \times P_E$$

where

P_F = probability of an earth fault event,

P_{FB} = probability of heart fibrillation,

P_E = probability of exposure

The probability of an earth fault P_F is site specific and is dependent upon the type of installation, its location and the likelihood of faults on the incoming networks. In this example for a typical air-insulated substation of this size with two incoming overhead lines and no cabled circuits

P_F = 0.25 has been assumed.

The probability of heart fibrillation P_{FB} is dependent upon the magnitude of current flowing through the body and the duration of the shock. This current magnitude is determined by the specific shock scenario and the difference in potential that would be experienced. The duration of fault was understood to be less than 200 ms. The hand-hand potential between the earthed structure and the independently earthed fence was calculated by computer simulation to be 900 V. The probability of heart fibrillation according to DD IEC/TS 60479-1 is therefore no greater than 50%.

The probability of exposure P_E quantifies the amount of time that a person could be in a position that will expose them to a touch, step or transfer potential hazard. In this case, the transfer voltage scenario exists between the earthed structure and the separately earthed fence. Persons envisaged to be most at risk are those carrying out painting/maintenance of the structure and/or fence. It is estimated in this example that these activities collectively occupy approximately 10 hours per year per person and the person will only be 'in circuit' 1% of the time. Therefore

$P_E = 1.14 \times 10^{-5}$.

The risk to an individual is therefore:

Risk = $0.25 \times 0.5 \times 1.14 \times 10^{-5} = 1.43 \times 10^{-6}$

This risk is within the 'lower tolerable' ALARP region. This risk should then be evaluated taking into account the expected lifetime of the installation and the HSE's present value for the prevention of a fatality (VPF) to determine the justifiable spend for mitigation. Where this is less than the cost of mitigation (say relocating the fence) risk assessment may justify the decision to take no mitigating action.

NB.4 Case study 3 – Large substation

Case study 3 involves a larger substation to that of Case study 2 with four overhead connections. Therefore the probability of an earth fault at this location is slightly higher than for Case study 2, and assumed to have a probability of fault P_F = 0.3.

A site earthing assessment found several earthed structures within 2 m of the separately-earthed perimeter fence, which is not permitted under ENA TS 41-24. Risk assessment was used to quantify the transfer voltage hazard and the results are shown in Table NB.2.

The probability of heart fibrillation P_{FB} is dependent upon the magnitude of current flowing through the body and the duration of the shock. This current magnitude is determined by the specific shock scenario and the difference in potential that would be experienced. The fault duration at this substation was understood to be greater than 200 ms. For the hand-hand potentials calculated for this example the probability of heart fibrillation according to DD IEC/TS 60479-1 is shown to be 100%.

The first example in Table NB.2 concerns a security unit within the compound, as shown in Figure NB.4. A transfer voltage scenario exists between the security unit and the separately earthed fence. Persons envisaged to be most at risk are those carrying out painting/maintenance of the units and/or fence. It is estimated that these activities collectively occupy approximately 1 hour per year per person and the person will only be in circuit 1% of the time. Therefore $P_E = 1.14 \times 10^{-6}$.

Table NB.2 – Risk assessment summary for Case study 3

Defect	P_F	P_{FB}	P_E	Risk	Remedial action
Two security units	0.3	1	1.14×10^{-6}	3.42×10^{-7}	None
Floodlight	0.3	1	6.85×10^{-6}	2.05×10^{-6}	Calculate justifiable spend
Security camera	0.3	1	2.28×10^{-6}	6.85×10^{-7}	None
Tower B1	0.3	1	1.14×10^{-5}	3.42×10^{-6}	Calculate justifiable spend

The second example in Table NB.2 concerns floodlights within the compound. A transfer voltage scenario exists between floodlights and the separately earthed fence, as shown in Figure NB.5. Persons envisaged to be most at risk are those carrying out painting/maintenance of the floodlights and/or fence. It is estimated that these activities collectively occupy approximately 6 hours per year per person and the person will only be in circuit 1% of the time. Therefore $P_E = 6.85 \times 10^{-6}$.

The third example in Table NB.2 involves a security camera that has been constructed very close to the perimeter fence and actually passes through the barbed wire at the top. A transfer voltage scenario exists between a security camera and the separately earthed fence, as shown in Figure NB.6. Persons envisaged to be most at risk are those carrying out painting/maintenance of the camera and/or fence. It is estimated that these activities collectively occupy approximately 2 hours per year per person and the person will only be in circuit 1% of the time. Therefore $P_E = 2.28 \times 10^{-6}$.

The fourth example in Table NB.2 is associated with Terminal Tower B1, which is located outside the site but within 2 m of the perimeter fence, as shown in Figure NB.7. A transfer voltage scenario exists between a terminal tower and the separately earthed fence. Persons envisaged to be most at risk are those carrying out painting/maintenance of the tower and/or fence. It is estimated that these activities collectively occupy approximately 10 hours per year per person and the person will only be in circuit 1% of the time. Therefore $P_E = 1.14 \times 10^{-5}$.

Figure NB.4 – Security control units within 2m of the perimeter fence

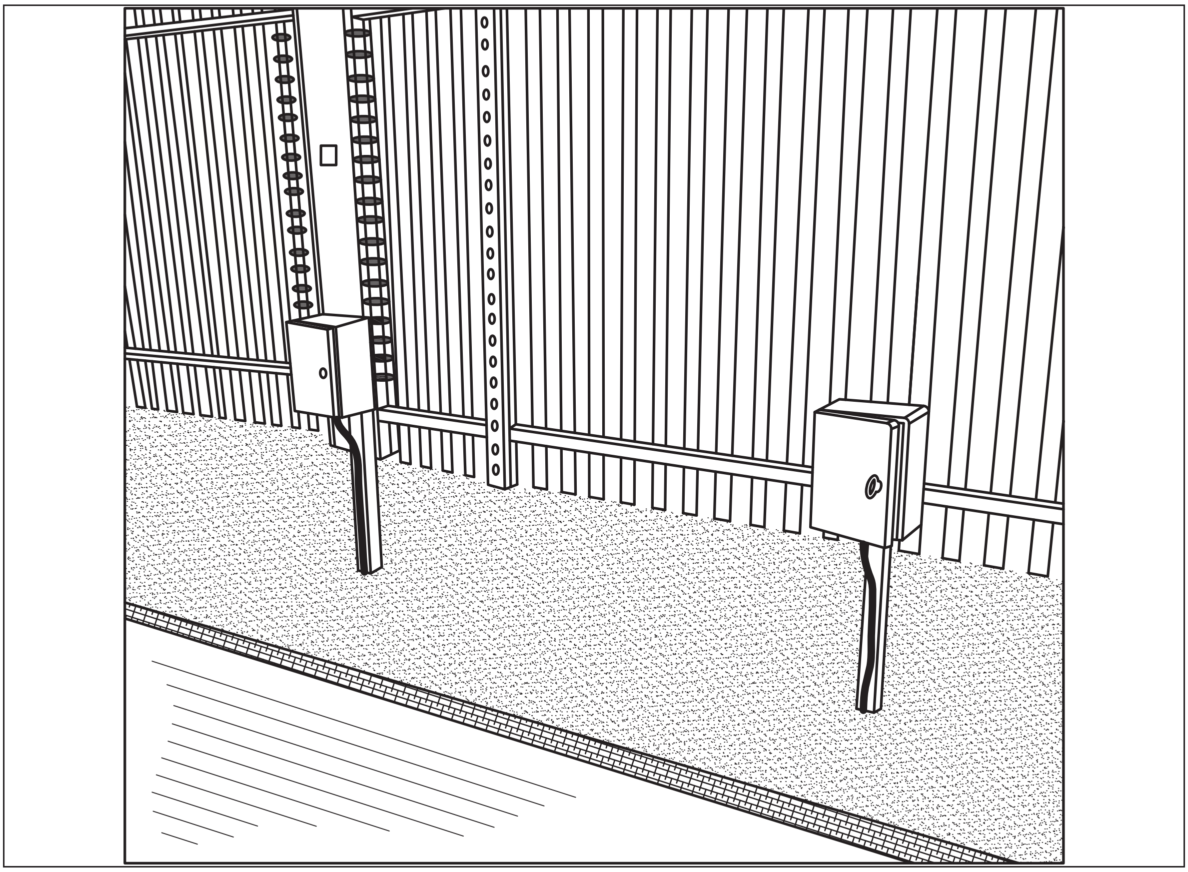


Figure NB.5 – Floodlight within 2m of the perimeter fence

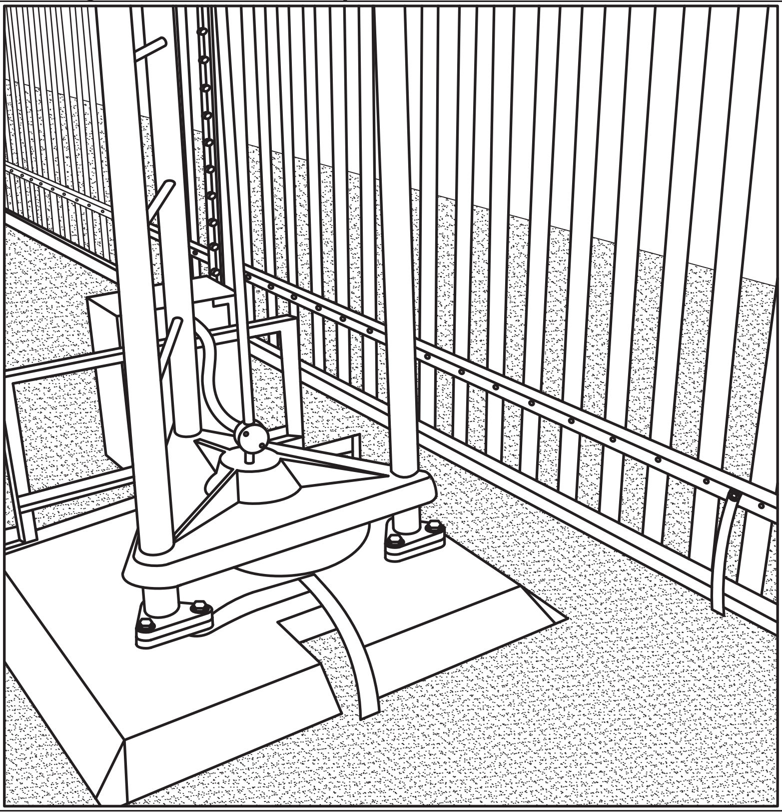


Figure NB.6 – Security camera and support through the perimeter fence

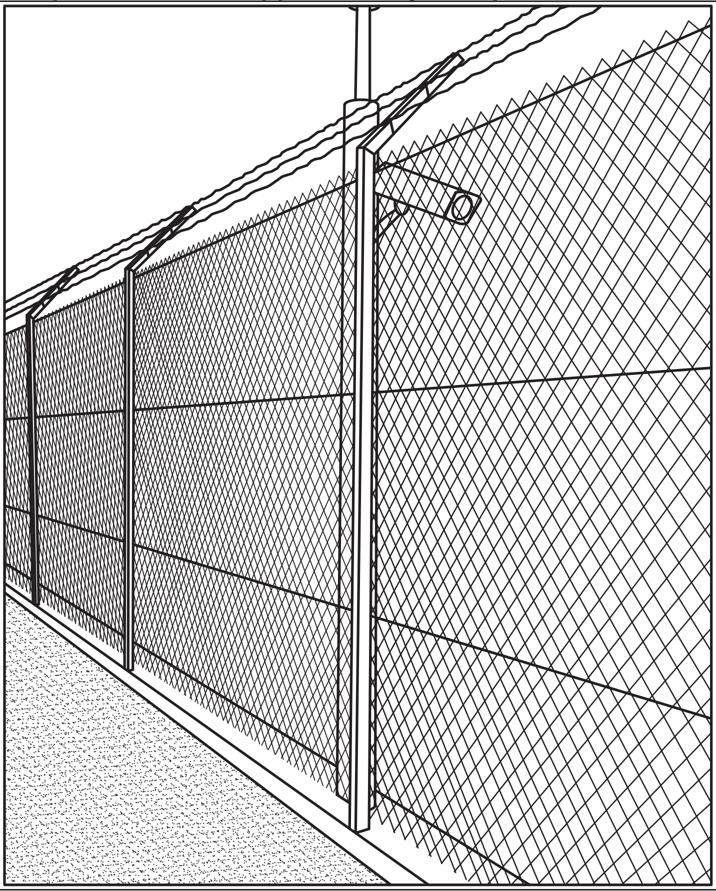
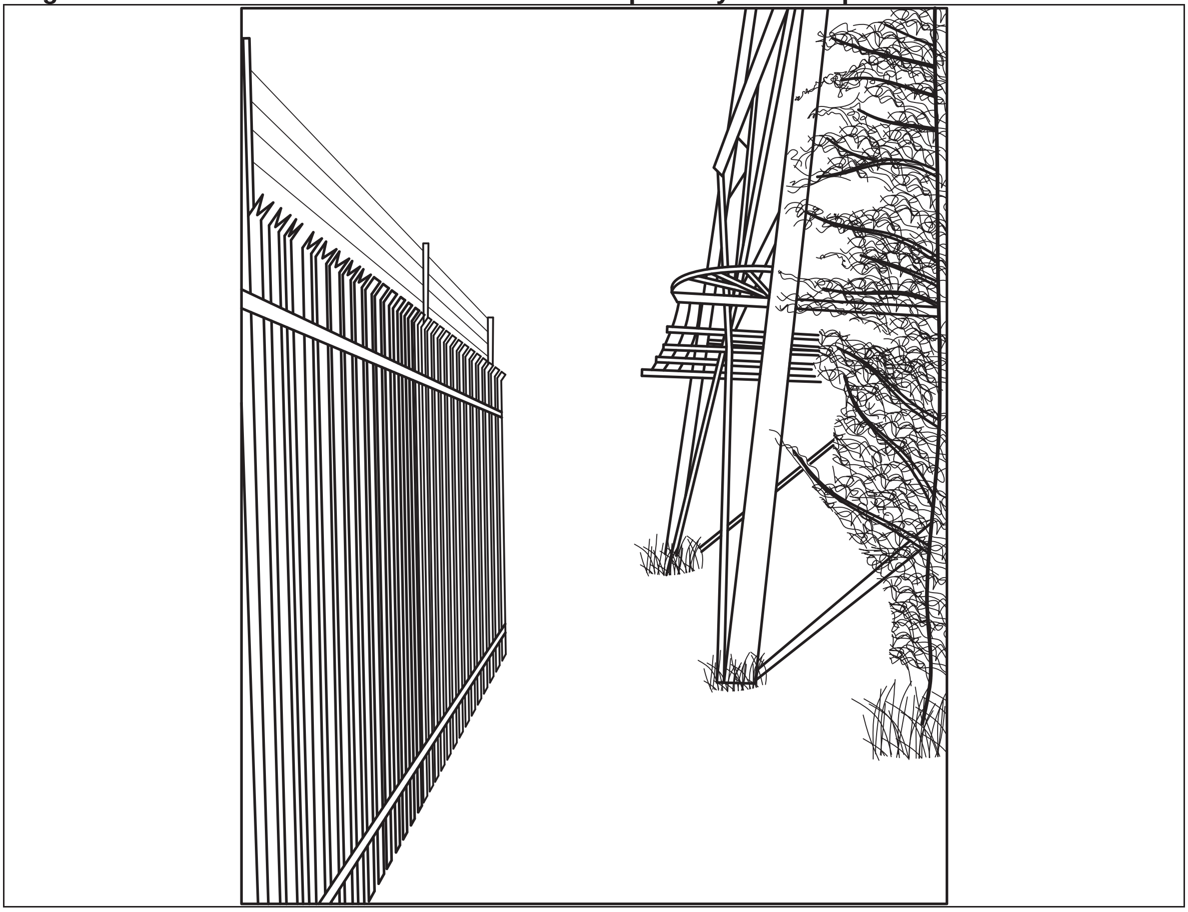


Figure NB.7 – Terminal tower B1 within 2m of separately earthed perimeter fence



The risks associated with the floodlight and Terminal Tower B1 are within the 'Lower Tolerable' ALARP region. These risks should be evaluated, taking into account the expected lifetime of the installation and the HSE's present VPF to determine the justifiable spend for mitigation. Where this is less than the cost of mitigation (for example relocating the fence or the floodlights), as is likely the case, risk assessment justifies the decision to take no mitigating action.

The risks calculated for electrocution at the locations of the security camera and the two security units are within the 'Tolerable' region, so no mitigating action is needed.

NB.5 Case study 4 – Street lighting close to substation

A site earthing assessment found a metal street light close to a substation as shown in Figure NB.8. Assuming that the light has an LV supply referenced to remote earth, it will present a touch voltage hazard. Risk assessment was used to quantify the risk presented by the touch voltage hazard and the results are shown in Table NB.1.

Figure NB.8 – Street light close to substation

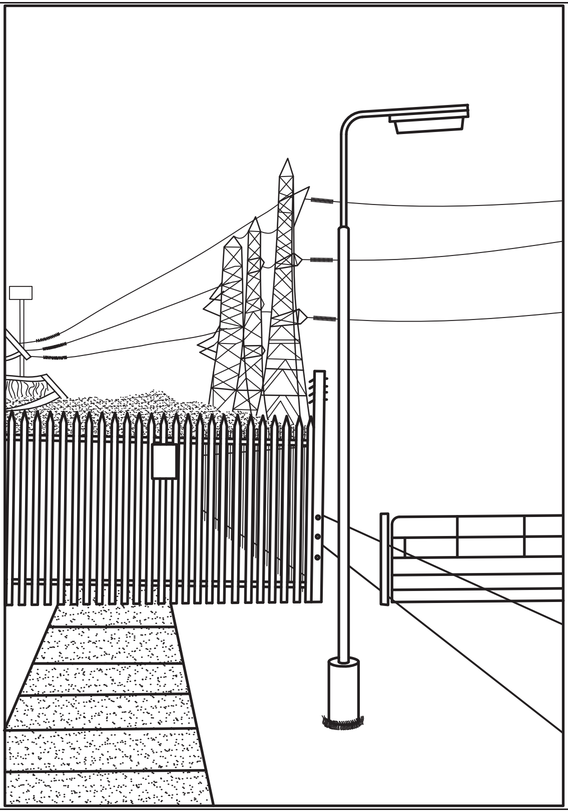


Table NB.3 – Risk assessment summary for Site A (132 kV substation)

Defect	P_F	P_{FB}	P_E	Risk	Remedial action
Earthed structure	0,25	1.0	$1,9 \times 10^{-5}$	4.75×10^{-7}	None

The parameters in Table NB.3 were determined as follows.

The individual risk is calculated using the formula:

Risk = $P_F \times P_{FB} \times P_E$

where

P_F = probability of an earth fault event,

P_{FB} = probability of heart fibrillation,

P_E = probability of exposure

The probability of an earth fault P_F is site specific and is dependent upon the type of installation, its location and the likelihood of faults on the incoming networks. In this example for a typical air-insulated substation with two incoming overhead lines and no cabled circuits

P_F = 0.25 has been assumed.

The probability of heart fibrillation P_{FB} is dependent upon the magnitude of current flowing through the body and the duration of the shock. This current magnitude is determined by the specific shock scenario and the difference in potential that would be experienced. The duration of fault was understood to be less than 1 000 ms. The hand-feet potential between the lighting column and the ground was calculated by computer simulation to be 590 V, i.e. above the permissible limits (Table NA.1). The step potential level was shown to be below the permissible limits (Table NA.2). Since members of the public can access the light, and the ground surface around it is loose material, a footwear resistance of 250 Ω has been applied in this case (ITU Directives Volume VI [3] specify a combined additional resistance of 250 Ω for damp leather soled shoes on loose soil). The hand-feet body resistance in this case is 525 Ω, which corresponds to a hand-hand resistance of 700 Ω (touch voltage 400V, 5% of population from Table 1 of DD IEC/TS 60479-1). The total resistance of the accidental circuit is therefore calculated to be 775 Ω, which would result in a current of 0.76 A flowing through the body for a touch voltage of 590 V. At this current magnitude, and for a fault duration of 1 000 ms, DD IEC/TS 60479-1 predicts a probability of fibrillation of 100%. The light is not in a location which would be conducive to people touching it for a prolonged period, e.g. as opposed to being adjacent to a bus shelter. Therefore, the highest probability of exposure P_E for any individual has therefore been estimated as 1 minute per year. Therefore

$$P_E = 1.9 \times 10^{-6}.$$

The risk to an individual is therefore:

$$\text{Risk} = 0.25 \times 1.0 \times 1.9 \times 10^{-6} = 4.75 \times 10^{-7}$$

This risk is considered 'Acceptable' and therefore no mitigating action is required in respect of members of the public.

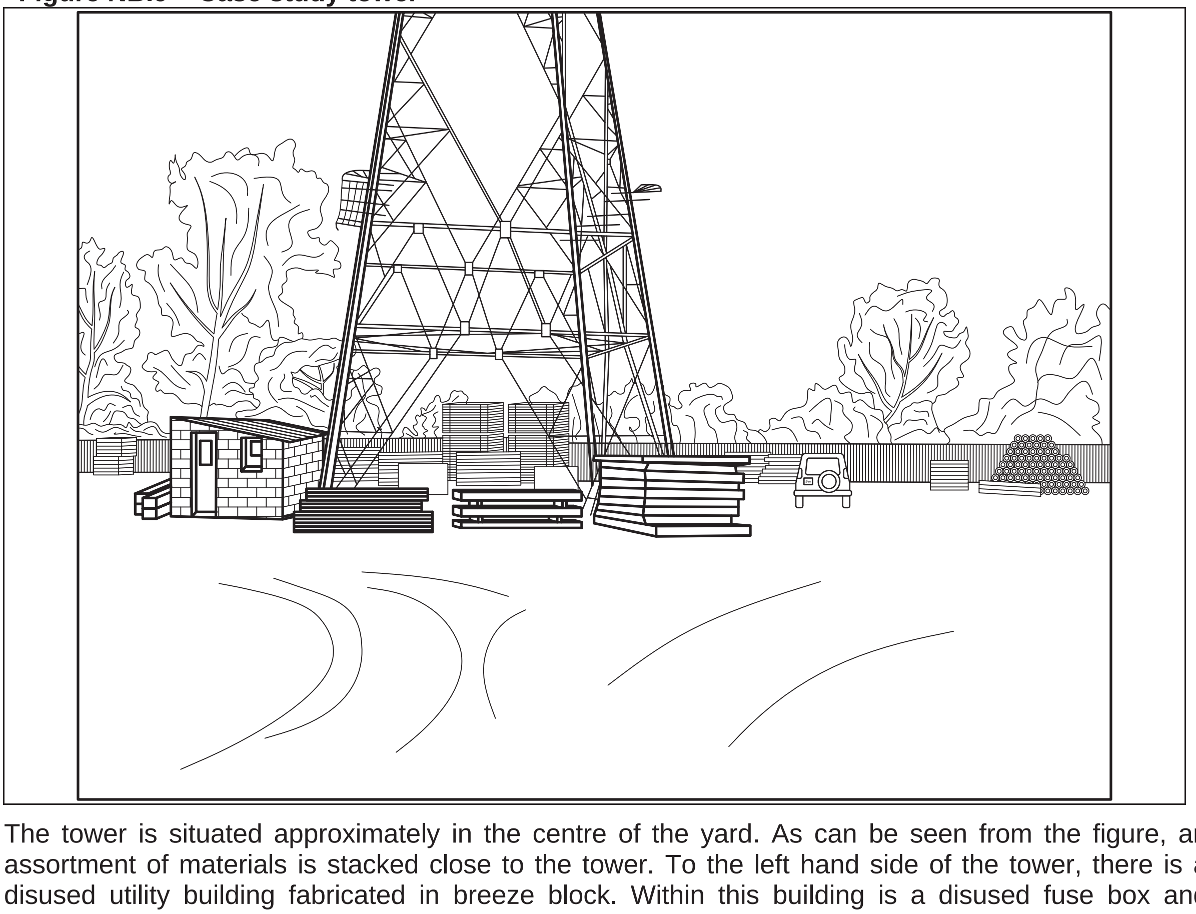
It should however be noted that the foregoing assessment covers only members of the public: The risks to maintenance personnel should also be considered.

NB.6 Case study 5 –Tower in industrial yard

NB.6.1 Background

An earthing risk assessment is required on a steel transmission line tower mid-route to ascertain the impact on third parties in the area. The tower is situated within the yard of an industrial materials storage depot as shown in Figure NB.9.

Figure NB.9 – Case study tower



The tower is situated approximately in the centre of the yard. As can be seen from the figure, an assortment of materials is stacked close to the tower. To the left hand side of the tower, there is a disused utility building fabricated in breeze block. Within this building is a disused fuse box and contactor which at one time provided power to floodlights installed on the tower. It is likely that the low voltage a.c. supply earth is still connected, presenting a hazard from transferred potentials, i.e. the earth potential rise from the tower under fault conditions would be transferred into the LVAC supply network. As a first stage of mitigation, it is required that the floodlights and associated cabling are removed and therefore this particular transferred potential hazard is eliminated. Therefore, the detailed probabilistic risk assessment focuses on the risks to people standing/working near to the tower base. The three probabilities, viz. the probability of the EPR event P_F, the probability of exposure P_E, and the probability of heart fibrillation P_{FB} are determined in the following sections, in order to assess the individual risk levels.

NB.6.2 Calculation of P_F

Total number of earth faults affecting the transmission system from all causes: 200 per annum

Total number of towers on system: 20 000.

Approximate breakdown of earth faults by cause: 59% lightning, 20% high wind, 20% pollution, 1% other cause.

The case study tower is not in a coastal or other location that is likely to result in pollution flashover so these faults can be excluded, therefore the number of faults is 160.

Total number of towers affected by single fault: 40 (i.e. 20 towers either side of a fault).

Based on the above, the EPR event rate for the tower during all weather conditions is 160/20 000 × 40 = 0.32 per annum.

It is possible to de-correlate some of these events with the presence of people, i.e. a person would not normally linger outside during lightning or high wind. However, bearing in mind that workers at the site will not stop work completely in such conditions it is not possible to assume complete de-correlation. Also, lightning activity can be some distance away but still result in an EPR at the case study tower. It is therefore assumed that 25% of events cannot be de-correlated.

Therefore, the de-correlated fault rate for tower $P_F = 0.25 \times 0.32 = 0.08$ per annum

NB.6.3 Calculation of P_E

Step potential from tower legs affecting site workers: it is not considered necessary to estimate the probability of exposure to step potential; see the calculation of P_{FB}, which follows.

Touch potential from tower legs affecting site workers: the likelihood of a site worker touching a tower leg is considered as follows:

Most materials stored close to the tower are packaged into heavy bundles, which would normally be moved by mechanically assisted means, thereby reducing the likelihood of workers touching the tower legs.

However, Figure NB.10 shows that one of the tower legs is being used as a rest for lighter materials, which will result in higher exposure.

The maximum individual exposure duration is therefore estimated to be 25 seconds per day.

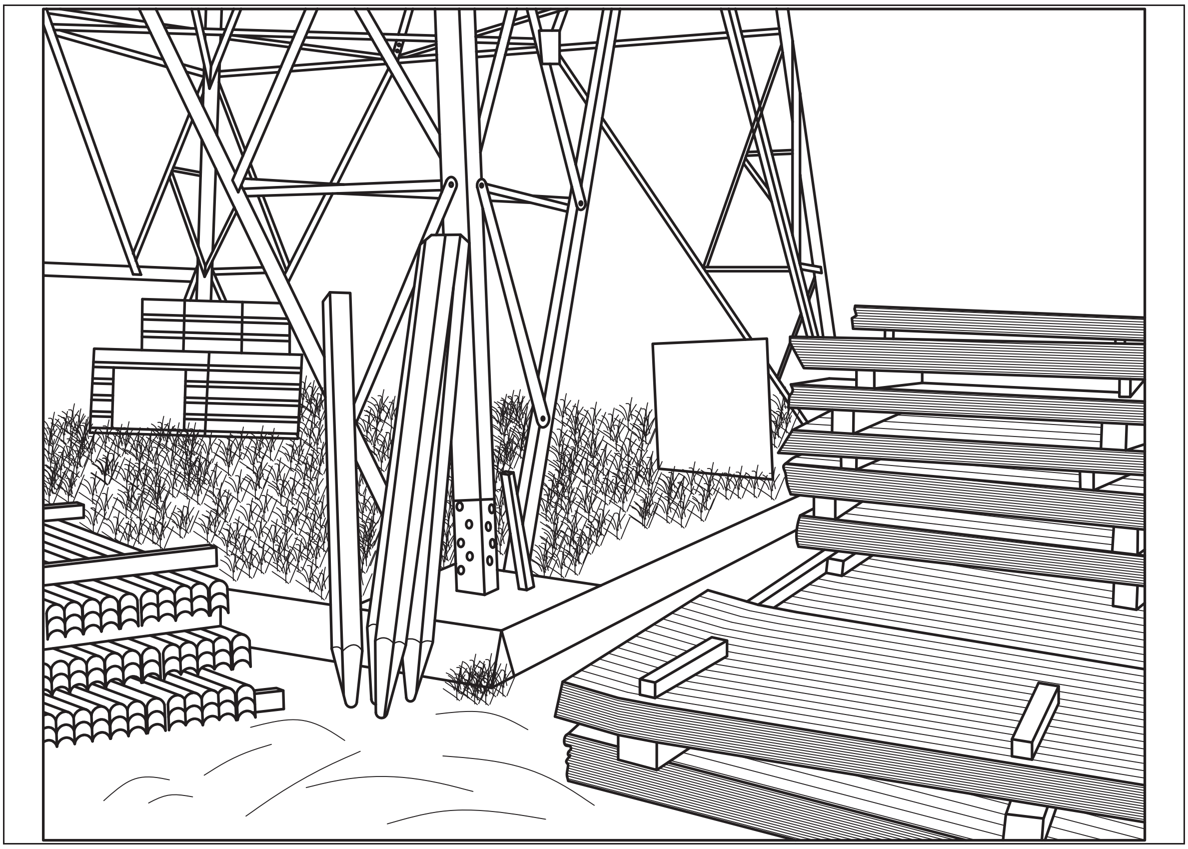
Taking into account the working year will be around 200 days the exposure can be calculated as follows:

$$P_E = \text{number of seconds per year exposed/number of seconds per year}$$

$$P_E = 200 \text{ days} \times 25 \text{ s per day} / 60 \times 60 \times 24 \times 365$$

P_E is therefore equal to 1.58×10^{-4}.

Figure NB.10 – Tower leg used to rest materials



NB.6.4 Calculation of P_{FB}

Step potential from tower legs affecting site workers: the maximum EPR (rms) at the tower is estimated to be 10 kV. At this value, it is possible to conclude that step potentials will not exceed conventionally established safe limits and therefore do not require further consideration. That is, the full EPR value does not exceed the permissible step voltage, and no further consideration this scenario is required.

Touch potential from tower legs affecting site workers: the circuit resistances are as follows:

Body resistance, R_B = 487 Ω (hand to two feet [1]);

Footwear resistance, R_{BE} = 3 000/ Ω (damp leather soled shoes, hard soil);

Total circuit resistance = 3 487 Ω.

With the tower EPR to be 10 kV, the touch potential was calculated to be approximately 5 kV.

The resulting body current will be 5 000/3 487 = 1.43 A.

Assuming a 200 ms fault clearance time, this current will result in 100% probability of heart fibrillation.

Therefore, P_{FB} = 1.0

NB.6.5 Calculation of resultant individual risk levels *IR*

The resultant individual risk levels are determined by multiplying the estimated probabilities in **NB.6.2**, **NB.6.3** and **NB.6.4**.

$IR = P_F \times P_E \times P_{FB}$

$IR = 0.08 \times 1.58 \times 10^{-4} \times 1.0 = 1.25 \times 10^{-5}$, or 1 in 80 000 approximately

Therefore the individual risk level to the workers lies in the upper ALARP region.

With an *IR* of 1 in 80 000, and assuming that the design life of the tower is 100 years, the chance of there being a fatality during this time is 1 in 800 for every individual exposed.

Therefore eliminating the touch potential hazard will prevent 0.001 25 fatalities per exposed individual during the life of the tower.

However, this assumes only one person is exposed at any one time but it is known that several people work in the yard. If the number of people exposed is increased to five, eliminating the touch potential hazard will prevent 0.006 25 fatalities during the life of the tower.

The HSE [4] advise that the value for preventing a fatality (VPF) is £1M (2001 figure).

Therefore it is worth spending at least £6 250 (based on 2001 figures) to eliminate touch potentials at this tower.

NB.6.6 Practical mitigation

It is evident from the assessment that the touch potential hazard at the tower should be controlled.

The touch potential hazard could be controlled or eliminated by several methods, e.g. by erecting a barrier around the legs to prevent access, by coating the legs with an insulating paint/material or by fitting insulating material on the ground around the legs, both of which will add resistance into the exposure circuit.

NB.7 Bibliography

Standards publications

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

ENA TS 41-24, *Guidelines for the design, installation, testing and maintenance of main earthing systems in substations* (www.energynetworks.org)

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National Annex NC (informative) Periodic inspection and testing

NC.1 General

Advice on frequency of inspection and testing may be found in ENA TS 41-24[1].

Inspection should include an assessment of the integrity of the earthing conductors, connections and joints where accessible or liable to damage. Attention should be paid to any visible features which might indicate deterioration of the conductors e.g. the presence of corrosion or physical distortion. Measurements should include electrode resistances and earth conductor connection and joint resistances.

It is advisable to measure the resistance of electrodes both on installation and at regular intervals thereafter. In the case of new installations, measurements provide important confirmation of the efficacy of the earthing system: Measurements of overall earthing system resistance/impedance should be compared with calculated values. Good agreement between measured and calculated values improves confidence in results, and validates installation for new systems.

For existing installations, where disconnection of earth electrodes is necessary for testing, consideration should be given to the effect this may have on the overall performance of the system. Many earth testing instruments however now provide advanced facilities allowing the resistance of a connected electrode to be established without disconnection (see **NC.5.5**).

Earthing system parameters can be difficult to establish accurately by measurement primarily because the system cannot be evaluated independently of its environment. The accuracy of measurement will be affected by the nature of the system under test and the test procedure (differences between theory and practice) and the prevailing environment and therefore it is normally appropriate to allow some margin for error. Conversely, overly pessimistic results may lead to over-engineered systems or unnecessary alterations being made to an installed system.

Inspection and testing should only be carried out by suitably trained and knowledgeable personnel. An appropriate level of skill and judgement is required to correctly perform measurements and interpret results.

NC.2 Safety

NC.2.1 Adequacy of the earthing system

The correct performance of an earthing system is essential to ensure the safe operation of the associated power network. Where a system is or has become deficient, safety may be compromised. Periodic inspection and testing is necessary to establish the condition of the earthing system and to determine any required remedial actions.

NC.2.2 Testing

A suitable and sufficient risk assessment should be carried out before carrying out work on earth systems. Measures used to manage risks should be documented in a method statement.

It is a common misconception that earth systems are inherently safe. Whilst this is generally true for systems that are well designed, installed and maintained, systems which are in some way deficient may present a variety of hazards under both fault and sometimes steady-state conditions.

Particular hazards may arise where it is necessary to disconnect parts of an earthing system to enable testing. Hazardous voltages may be present across open disconnections. Substantial currents may also be present in earthing conductors which can result in arcing when disconnected.

Power networks may often be subject to large transient over voltages (many kV) due to the effects of local switching on adjacent systems or lightning strikes elsewhere on the system. Such transients can carry a great deal of energy and it is essential to ensure that the chosen equipment is capable of surviving these without endangering users. Induced currents and voltages from nearby energized systems may also couple hazardous levels of energy into even de-energized and/or earthed systems.

NC.3 Established earth testing techniques

A number of earth resistance measurement techniques have been developed over the years of which the most popular are described below. Each technique has advantages and limitations and should be assessed for suitability in line with knowledge of the installation to be tested. Table NC.1 summarizes the considerations. For each technique a fuller description is provided below.

Table NC.1 – Established earth testing techniques

Method	Advantages	Limitations
Fall of potential including 61.8% method	Reliable; conforms to IEEE 81	Requires long distances (long test leads) to the test probes
Slope	Knowledge of electrical centre not necessary; long distances to test probes not necessary	Less accurate in non-homogeneous soil conditions; requires mathematical interpretation
Intersecting curves	Knowledge of electrical centre not necessary; long distances to test probes not necessary	Requires numerous calculations and drawing of curves
Star-delta	Provides validation evidence of correct measurement	Resistance areas should not overlap. A number of calculations are required. Three test electrode locations disposed at 120^{o} required
Clamp-on	Inherently safe. Quick, easy. Includes bonding and overall connection resistance. No requirement for disconnections	Effective only in situations with multiple grounds in parallel. Requires current return path.

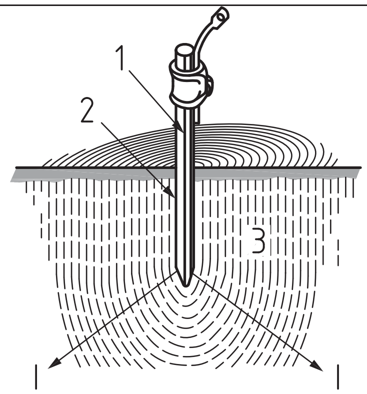
It should be noted that these methods, with the exception of the fall of potential method, are intended only for measuring earth resistance, not impedance. Where the earthing system is expected to have a significant inductance, the impedance rather than resistance should be used to calculate the EPR (see **NC.6**).

It should also be noted that, apart from the Fall of Potential Method, all the techniques in Table NC.1 are subject to simplifying assumptions, which can introduce appreciable error should the theory upon which they are based differ from the actual test environment. Further details on earth resistivity and earth resistance testing are given in IEEE 80-1983

NC.4 Earth coupling

In an earthing circuit, the current path is rapidly expanding with distance from the electrode, as illustrated in Figure NC.1.

Figure NC.1 – Ground current distribution at an electrode



Key

I Current

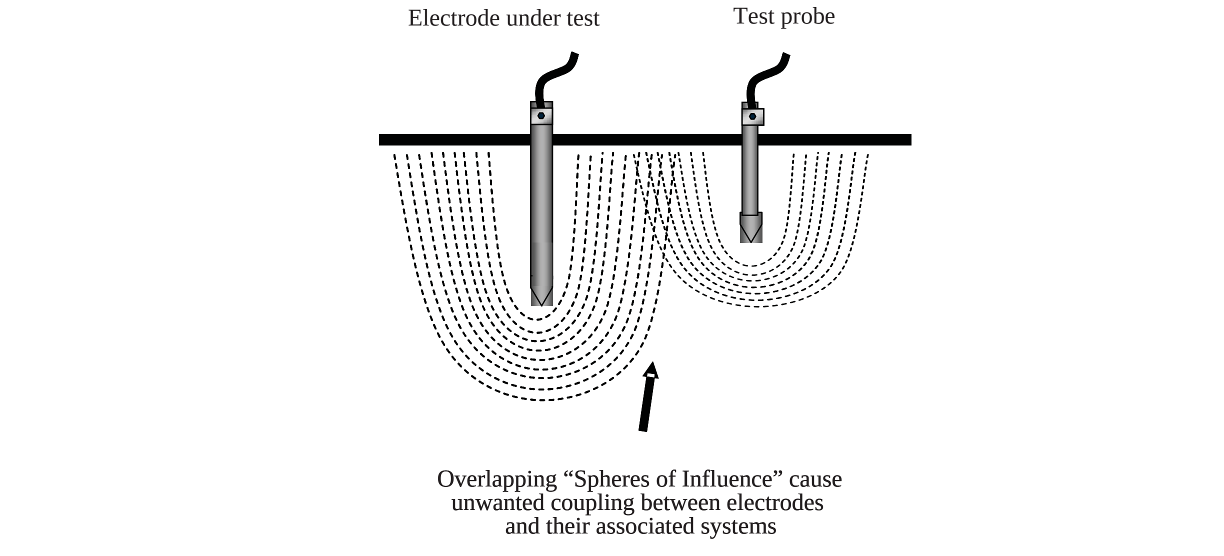
1 Electrode above ground

2 Electrode below ground

3 Current distribution

The net effect is that any significant resistance is concentrated in the area immediately around the buried electrode, its 'sphere of influence'. Beyond a critical distance, the rest of the earth offers so little additional resistance as to be of no practical consequence. A critical volume of soil surrounding the electrode determines its capabilities. In environments with moist, water-retentive soil, this volume is small, perhaps of the order of several metres. However in higher resistivity areas, with dry, sandy or rocky soil, it can extend to hundreds of meters. Furthermore, a temporal effect superimposes upon the basic relationship of electrode design to surrounding soil, see **NC.7.5**.

Figure NC.2 – Earth coupling example



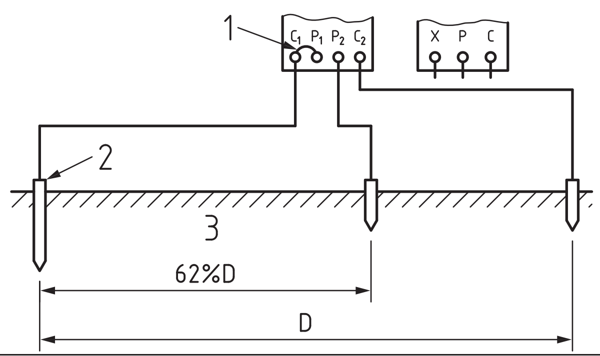
Earth coupling is an electrical relationship between separate grounds in proximity to each other, where the electrode's spheres of influence overlap, as illustrated in Figure NC.2. Coupling distorts the conventional measurement curve which would otherwise be obtained with say the fall of potential method. Some techniques, for example the slope method, attempt to overcome this problem by compensating mathematically.

NC.5 Measurement techniques

NC.5.1 Fall of potential method

A fall of potential test may be conducted using either a three or a four terminal instrument as shown in Figure NC.3. If a three pole instrument is used the connecting lead resistance will add to the measured resistance. Three points of contact are made with the soil. One is the connection to the electrode under test. The other two are probes, one for supplying test current, (connected to C_2 in the diagram), and one for measuring potential at a given position in the soil, (connected to P_2). The current probe is normally placed a considerable distance from the electrode under test, ideally outside its sphere of influence. The tester acts as a current source and circulates a current through the soil between the current probe and the electrode under test. The potential probe is used to make voltage measurements at multiple locations along a test route between the current probe and the electrode under test. The tester uses Ohm's Law to calculate and display the resistance at each voltage measurement location.

Figure NC.3 – Fall of potential test



Key

1 Jumper wire (if lead between 1 and 2 is short and of negligible resistance)

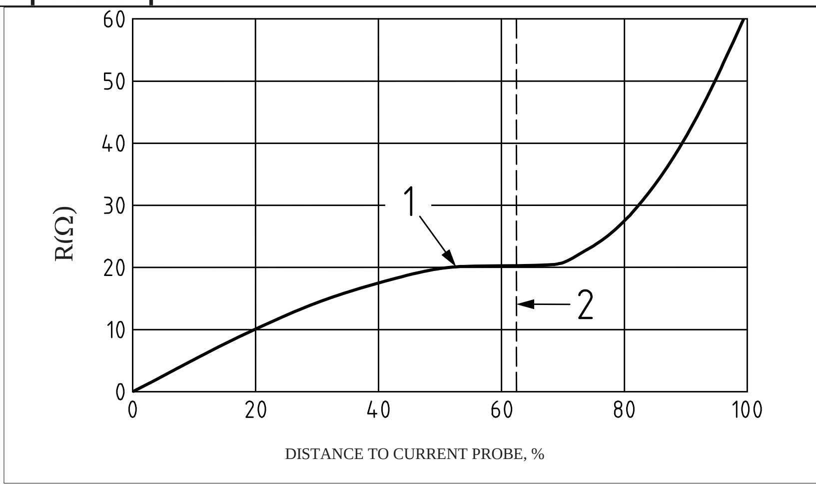
2 Earth electrode

3 Earth

The measurements are used to plot resistance against distance from the electrode under test. The result should be a rising curve where the probe is within the influence of the electrode under test, followed by a plateau region. When approaching the influence of the current probe, an additional resistance is superimposed, so the curve will rise again (as shown in Figure NC.4). The value recorded at the plateau is the measured resistance of the electrode under test.

A major consideration with this test is that if the current probe is not located at a sufficient distant from the electrode under test, their two spheres of influence will coincide, and therefore there will be no appreciable plateau region. If this occurs the current probe has to be moved farther out and the procedure repeated. In certain locations space constraints will make this impractical or difficult to achieve and alternatives such as the slope method below should be considered. According to IEEE 81.2, the auxiliary current return probe should be located at least 6.5 times the maximum dimension of the test earthing system dimension away. However, this should be regarded as a guide, not as a rule. If a definite plateau region is not obtained, the earth resistance can be estimated using the 61.8% rule.

Figure NC.4 – Fall of potential plot



Key

1 Earth resistance

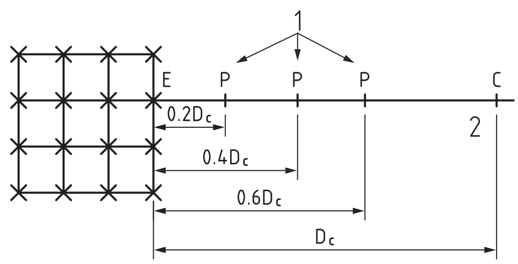
2 61.8% line.

NC.5.2 Slope method

The larger the substation, the larger the earthing system and consequently the larger the zone of influence in the soil. Locating the current test probe sufficiently far away can be impractical. The slope method [Tagg 1970] provides a means of dealing with these situations by working with shorter separation distances but requires additional potential measurements along the fall of potential line.

The critical measurement points are made with the potential probe placed at 0,2, 0,4, and 0,6 times the distance to the current probe, as shown in Figure NC.5. The resistance calculated at these points are referred to as R_1, R_2, and R_3, respectively. The current probe is positioned as far away as site conditions will allow.

Figure NC.5 – Critical data points for current probe distance



Key

1 potential spike, P

2 current spike, C

Next, the slope coefficient μ showing the rate of change of slope on the fall of potential curve is calculated from the formula:

$$\mu = \frac{R_3 \quad R_2}{R_2 \quad R_1}$$

A relationship can be derived between the slope coefficient, the distance to the current probe D_c and the distance at which the potential probe would measure the true earth resistance D_{pt}. A table is given in [Tagg 1970] which gives the value of D_{pt}/ D_c for a range of μ values (note that determining the correct value of μ is critical to obtaining an accurate result and it is recommended to carry out more than one test to obtain greater confidence in the R values; see below). From this, a simple equation [Tagg 1970] yields the distance at which the potential probe should be placed, using the known distance to the current probe. Therefore, if the potential probe were placed at this distance, the reading would indicate the measurement of ground resistance. This could be accomplished by physically moving the probe to that point, or, if a partial graph has been constructed, the reading could be taken from the graph.

If the calculated μ value is not found in the table [Tagg 1970], the current probe should be placed further away and the test repeated. Experience has shown that it is not reliable to rely on a single test and it is recommended that additional tests are taken in other directions and at greater probe distances, so as to eliminate localized effects and uncharacteristic readings. With increasing current probe distances readings will begin to align, and such agreement provides assurance that the measurement is reliable.

NC.5.3 Intersecting curves method [Tagg 1969]

The generic fall-of-potential plot (Figure NC.4) is typically shown starting from the junction of the X and Y axes; that is to say, the test electrode is taken to be a point ground. From this, it is relatively easy to measure out the distances to the test probes. However, practical HV earthing systems can be large, with numerous individual elements interconnected, and have highly irregular configurations. Therefore, it is difficult to define the centre of the electrical systems which is not necessarily coincident with the geometric centre. The standard practice is to connect the test lead(s) to a convenient access point, and work from there.

For the intersecting curves method to work, the distance to the current probe should be no more than twice the maximum dimension of the earth grid. Otherwise, the plot tends to be too flat, and the point of intersection will be indefinite.

The procedure involves connecting the earth tester at any convenient point to produce a partial fall of potential curve. The correct reading will be situated somewhere on this curve. Next, reposition the test setup, and construct a second curve. This can be done by moving off at another angle or the current probe can be moved out further. For clarity, it is best to make a third plot from yet another position.

The correct value of resistance can be read at 0,618 times the distance from the true electrical centre to the current probe (61,8% Rule). The true electrical centre is not known, but can be designated an unknown distance x from the point of attachment of the test lead(s). Therefore, if the known distance to the current probe is designated as D_c and the known distance to the potential probe as D_p:

$$x + D_p = 0{,}618(x + D_c)$$

Solving for D_p:

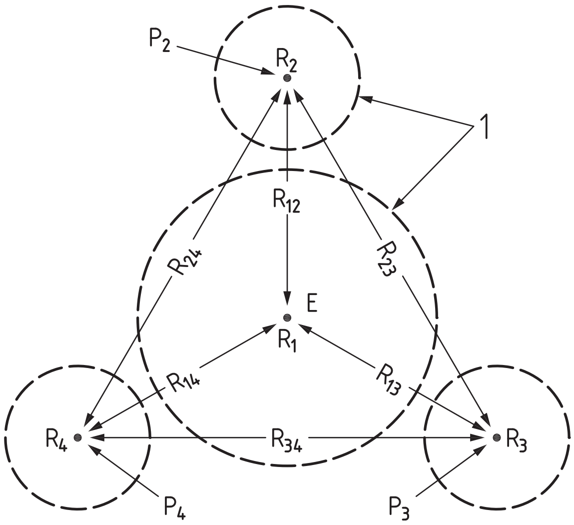
$$D_p = 0{,}618D_c - 0{,}382x$$

Upon assigning x, a number of arbitrary but plausible values can be obtained for D_p, and the corresponding resistances can be taken from the three curves described above. These are used to construct a second set of curves. The various values for x are plotted against their corresponding resistances, one plot for each of the three fall of potential curves described above. Where these new curves intersect is the true earth resistance value. It is the only point they hold in common, while the others drift according to the arbitrary selection of incorrect values for x. In theory, only two curves are necessary, but a third is added as a check. The line of the third curve should also intersect at the same point, but this is not likely in practice because of the non-homogeneous nature of most soil composition. More likely, a triangle will be formed by the three curves, and the centre of the triangle is taken as the correct value. The smaller the triangle, the more accurate the test result.

NC.5.4 Delta or star-delta method

The star-delta method (as illustrated in Figure NC.6) is a procedure that combines elements of two and three-point methods in an attempt to eliminate uncertainty. The electrode under test is denoted R_1, and three test probes are spaced equidistantly around it at angles of 120°. These are identified as R_2, R_3, and R_4. A series of two-point measurements are made between each pair, creating a total of six measurements.

Figure NC.6 – Star-delta method



Key

1 Resistance areas

The series measurements between the various pairs of electrodes can be made from a two-point configuration, and then evaluated mathematically to calculate the resistance of the electrode under test.

If the distances between R_1 and the surrounding probes are adequate, then:

$$R_1 = \frac{1}{3}\frac{(R_{12} + R_{13} + R_{14}) - (R_{23} + R_{34} + R_{42})}{2}$$

and:

$$R_1 = \frac{1}{2}(R_{12} + R_{13} - R_{23}) = \frac{1}{2}(R_{12} + R_{14} - R_{42}) = \frac{1}{2}(R_{13} + R_{14} - R_{34})$$

The procedure contains a proof of validity: The result obtained from the first equation above should be within acceptable limits when checked against the other three equations. If not, that indicates that the conditions required for the test to be effective have not been met; i.e. probe location has resulted in overlapping spheres of influence.

Furthermore, the star-delta method not only reveals if there is an error in the test set-up, but also affords a means of locating the source. One can calculate the resistances of R_2, R_3, and R_4 by adapting the equations above:

$$R_2 = \frac{1}{2}(R_{12} + R_{23} - R_{13}) = \frac{1}{2}(R_{12} + R_{42} - R_{14}) = \frac{1}{2}(R_{23} + R_{42} - R_{34})$$

$$R_3 = \frac{1}{2}(R_{13} + R_{23} - R_{12}) = \frac{1}{2}(R_{13} + R_{34} - R_{14}) = \frac{1}{2}(R_{23} + R_{34} - R_{42})$$

$$R_4 = \frac{1}{2}(R_{14} + R_{42} - R_{12}) = \frac{1}{2}(R_{14} + R_{34} - R_{13}) = \frac{1}{2}(R_{42} + R_{34} - R_{23})$$

Comparison of the results provides the necessary cross-check of the validity of the test set-up and procedure.

NC.5.5 Clamp-on test methods

NC.5.5.1 General

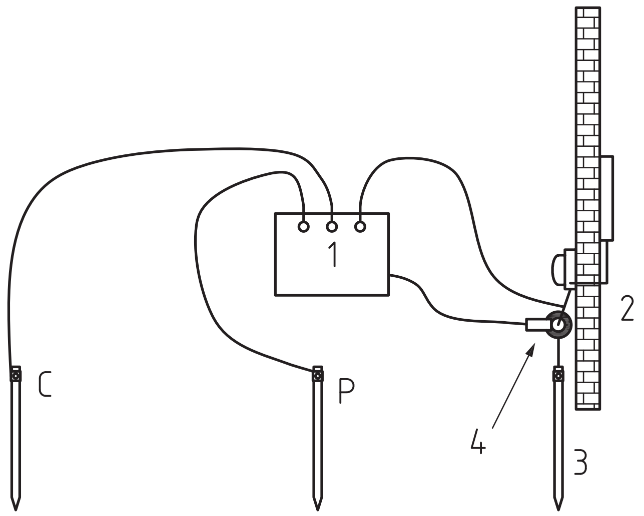
Clamp-on earth testing is a technique which can provide significant benefits enabling electrodes to remain connected and in an application of the technique sometimes known as 'stakeless testing' can eliminate the need for earth probes to be driven into the ground providing significant benefits in built up areas where concrete surfaces may prevail. It also obviates the need to disconnect electrodes in order to measure their resistance which is inherently safer and also quicker.

In many situations clamp-on testing brings the added advantage of testing the bonding and overall connection of the system whereas the fall of potential method considers only the earth electrode. Like most measurement techniques clamp-on testing has a number of advantages but its limitations have to be understood for correct application.

NC.5.5.2 Electrode testing without system disconnection

Here, a three or four terminal earth tester equipped with clamp-on current measuring transducer should be used. The transducer is placed just above the electrode to be measured, which may remain connected to and therefore protecting the installed system. Connections are made as in Figure NC.7 and the standard procedure for fall of potential measurement should be followed. Since the clamp is placed between the injection point of current from the earth tester and the electrode being tested the effect of any current path into the installation is ignored. The test instrument should be able to filter out any supply frequency earth leakage current flowing from the installation into the electrode.

Figure NC.7 – Electrode testing without system disconnection



Key

1 Earth tester
2 Installation
3 Electrode
4 Current measuring clamp

NC.5.5.3 Stakeless testing

Where driving spikes into the ground is impractical, e.g. in inner city locations or cable cellars beneath sub stations, an alternative clamp-on technique known as stakeless testing may be beneficial.

Stakeless testing may be performed using either accessory clamp meters for a traditional three or four terminal earth tester or by employing a stand alone hand held unit. Such devices incorporate two coils encapsulated within a purpose designed measurement head. Opening jaws enable the instrument to be attached to a variety of earth conductors, cables, tapes, etc. without the need for electrical disconnection or disturbance to the installed system.

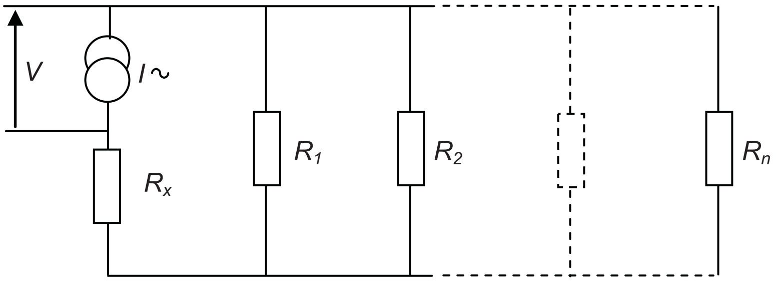
One of the two coils induces a high frequency a.c. signal into the conductor to be measured whilst the second measures the resultant current flow. The instrument interprets the signals using Ohm’s Law, applying filtering and noise cancelling techniques to display an accurate reading of conductor resistance.

Clamp-on testers are also usually able to measure additional parameters such as the system leakage current flowing through the electrode.

For stakeless testing to work, there has to be a complete circuit already in place in which the induced current can flow. An individual unconnected electrode cannot be measured since there is no return path for the current. Where the circuit is complete the tester measures the complete resistance of the circuit loop. All elements of the loop are measured in series.

In Figure NC.8 the clamp tester is clamped over R_x, the electrode under test. The current also travels through the parallel paths R_1, R_2, R_n, etc. but divides between them.

Figure NC.8 – Clamp on resistance testing



$$\frac{V}{I} = R_x + \frac{1}{\sum_1^n \frac{1}{R_n}} \text{ where, normally } R_x \gg \frac{1}{\sum_1^n \frac{1}{R_n}}$$

The electrode R_x should be much greater than the sum of the parallel resistances. In a multiple ground system, the circuit can be considered a simple loop consisting of the individual electrode under test, and a return path via the mass of earth and all the other electrodes.

A practical example of where the clamp-on method is highly effective is shown in Figure NC.9. The application is an interconnected parallel ground, like a lighting string. The system neutral completes the return. The resistance of the loop can be calculated by:

$$R_{\text{loop}} = R_6 + \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}}$$

For six similar electrodes with a resistance of 10 Ω, the loop resistance measured when testing each electrode would be:

$$R_{\text{loop}} = 10\Omega + 2\Omega = 12\Omega$$

For sixty similar electrodes with a resistance of 10 Ω, the loop resistance measured when testing each electrode would be:

$$R_{\text{loop}} = 10\Omega + 0{,}17\Omega = 10{,}17\Omega$$

If one of six electrodes has a resistance of 100 Ω, and the rest have a resistance of 10 Ω, the loop resistance measured when testing the high resistance electrode would be:

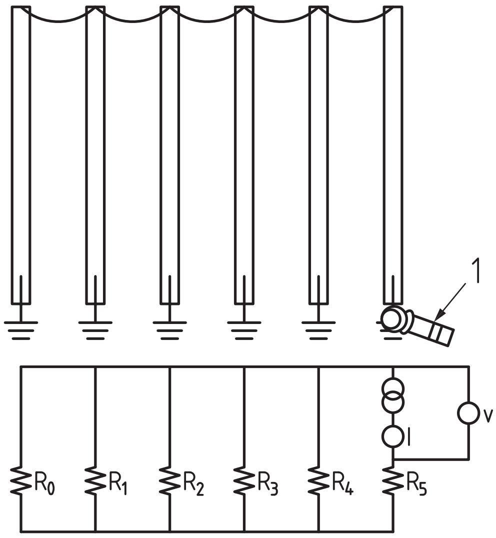
$$R_{\text{loop}} = 100\Omega + 2\Omega = 102\Omega$$

The loop resistance measured when testing each of the five other electrodes would be:

$$R_{\text{loop}} = 10\Omega + 2{,}4\Omega = 12{,}4\Omega$$

The more return paths, the smaller the contribution of extraneous elements to the reading and, therefore, the greater the accuracy. Even a high resistance element among many low resistance returns is not enough to defeat the measurement. But, if the return paths are few or all the elements 'high', the error is large. It should be noted that the method is not suitable where the return path has comparable or greater resistance compared to the electrode under test. The operator has to therefore be aware of such limitations. Generally speaking the clamp-on earth tester should not be the only instrument employed but it forms a useful part of an effective tool kit.

Figure NC.9 – Clamp on resistance testing example



Key

1 Clamp-on ground tester

NC.6 Measuring resistance and impedance

Depending on the design and voltage level, transmission and distribution earthing systems may exhibit significant inductance (reactance) as well as resistance. Where the earthing system is expected to have a significant inductance, e.g. at large installations such as a power station or transmission substation, or where there is a substantial interconnected cable system or earthed overhead line network, the impedance rather than resistance should be used to calculate the EPR.

It is recommended that for these types of installation, the earthing system impedance should be determined through measurement using a.c. test current [Griffiths, Jones, Harid and Haddad 2010]. IEEE 81.2 [ref] contains detailed information concerning the methods suitable for conducting such measurements. The fall of potential method can, in principle, be used but plateau regions are unlikely to develop in the apparent impedance magnitude and phase plots. Interpretation is further complicated by mutual coupling between test leads, and to the earthing system under test.

Impedance measurements are frequency dependent, so, measurements should be made with a test instrument working near to the supply frequency and have suitable noise rejection capability.

NC.7 Soil resistivity measurements

NC.7.1 Introduction

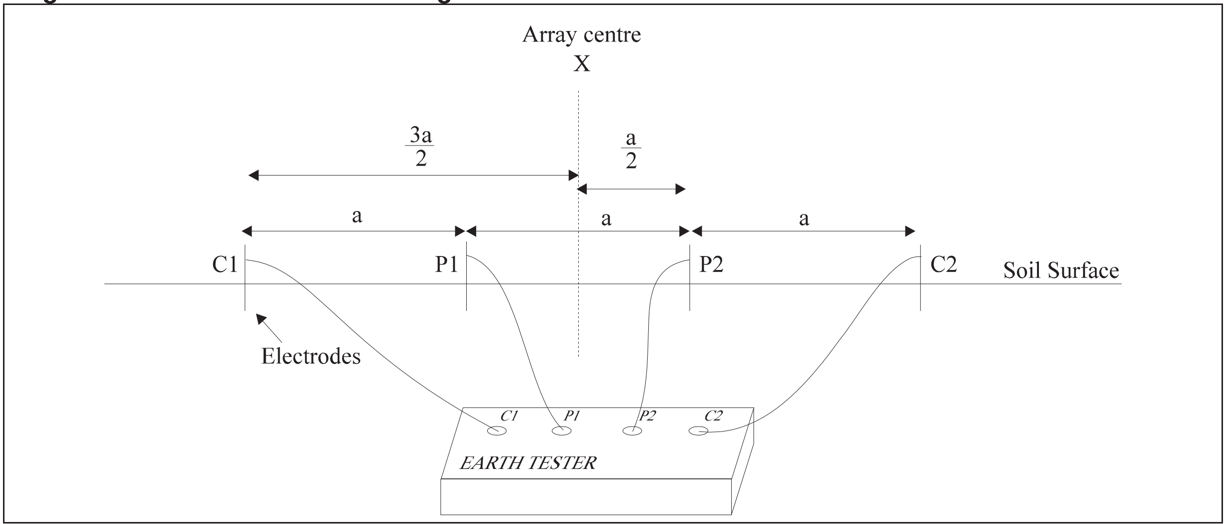
The earth impedance of an earthing system is dependent upon the surface area enclosed by the buried, bare earth electrode and the resistivity of the soil surrounding it. It is desirable to use the minimum area that will achieve a safe earthing design and this can only be determined from an accurate assessment of the local soil conditions.

Industry standards provide equations for the calculation of earth resistance and surface potentials of simple earthing systems that use a single resistivity parameter. These equations assume the soil has constant resistivity both laterally and with depth. Modern computer software provides the capability to simulate complex earthing geometries in 'soil models' having several layers of different resistivity and thickness [IEEE 80, IEEE 81]. The ability to use more complex representations of the soil demands a higher level of site-specific investigation and analysis.

NC.7.2 Wenner method

The electrical properties of a soil can be measured using an electrical sounding technique. The Wenner method (developed by Dr Frank Wenner of the U.S. Bureau of Standards, now NIST) is commonly used and is characterized by four electrodes arranged in a straight line, separated by a common spacing ‘a’ as shown in Figure NC.10.

Figure NC.10 – The Wenner configuration



A four-pole earth tester is used to circulate electrical current between two outer electrodes (C1 and C2). The resulting potential difference (P1 to P2) is then measured by the test instrument. The ratio of the measured potential difference divided by the current circulated provides the measured apparent resistance. The apparent resistivity is then calculated using:

$$\rho = 2\pi R a$$

where:

ρ	is the apparent resistivity (Ωm)
R	is the apparent resistance (Ω)
a	is the Wenner spacing (m)

A soil resistivity survey should determine the change of resistivity with depth. This is achieved by making a series of measurements over a range of Wenner spacings. As a rule of thumb, the depth of soil having the most influence on the measurement is approximately equal to the Wenner spacing *a*.

The test engineer should endeavour to achieve a maximum depth of investigation or Wenner spacing appropriate to the size of the earthing system. Experience has shown that Wenner spacings of several hundred metres are desirable to achieve good accuracy in subsequent calculations even for relatively small earthing systems. However, sites that permit these large spacings will rarely be available.

Table NC.2 provides a series of suggested Wenner spacings that minimize the number of electrode movements during a sounding and provide an even distribution of data points along the log x-axis of a sounding results graph. The latter is important due to the curve fitting procedure used in soil modelling. The 80m and 100m spacings can be omitted for smaller earthing systems.

Table NC.2 – Recommended Wenner spacings *a* in metres

1,0	1,5	2,0	3,0	4,5	6,0	9,0	13,5	18,0	27,0	36,0	54,0	81,0	100,0

Soil resistivity is related to geology, soil temperature, electrolyte salt content and moisture level, all of which can vary considerably across a site area both laterally and with depth. It is therefore important to conduct Wenner soundings at a number of locations to evaluate the range of soil resistivity in the vicinity of the earthing system. This is particularly important at existing sites where the installed earthing system necessitates soundings at areas remote from the bare earth conductors.

When planning a Wenner sounding, locations should be sought that have:

- An unobstructed route that will accommodate a good range of Wenner spacings;
- Adequate separation from buried metallic objects which could affect the results;
- Similar geology, elevation and soil moisture level to the earthing system location.

Finding sounding locations in urban areas can be particularly difficult as open spaces are limited and interference from unknown buried metallic objects is more likely. In these cases, soundings at multiple locations are very important. It is also likely that available space will limit the range of spacings achievable.

Lateral changes in soil resistivity mean that sounding results generally become less representative with increasing distance from the earthing system. This is particularly the case for the smaller-spacing measurements as lateral variation occurs most readily in the surface soil layers.

NC.7.3 Soil modelling

If equations that contain only a single resistivity parameter are to be used, for initial design purposes or where earthing design software is unavailable, the resistivity parameter can be taken as the 'best-fit' horizontal line through the plotted sounding data.

The representation of a complex three-dimensional soil structure with a 'soil model' presents a significant challenge. However, due to the present capability of earthing design software, the soil model type almost exclusively used is a horizontally layered one with each layer having different resistivity and thickness.

Soil model parameters are estimated from inspection of the plotted curves, then are optimized to achieve the 'best fit' between computed and measured apparent resistivity curves. A common misconception is that the 'best fit' is simply the lowest root-mean-square fit through the measured data and this is the method used by software that automatically provides a soil model for the user. However, whilst this approach provides a 'mathematical' solution, the soil model may be far from representative of the actual soil conditions. Instead, the test engineer should determine the optimum trend for the 'best fit' curve through the measured data after considering the influence of the soil at each sounding location on the earthing system, similarities in geology, hydrology and elevation, earthing system geometry, separation distances and sources of error.

NC.7.4 Sources of error

At most sites, the measured soil resistivity from each sounding locations will show disagreement. The test engineer should aim to determine whether the readings obtained are true reflections of the soil at each sounding location or if errors have occurred.

Measurement system errors or other factors such as buried metallic objects or in-ground electrical noise (naturally occurring or introduced by transmission masts, cathodic protection systems or railway traction systems) can all influence the measured value.

Conducting soundings at multiple locations using the recommended spacings in Table NC.2 is one of the best ways of identifying and discounting erroneous readings. However, where disagreement occurs between the maximum or minimum Wenner spacing readings it can difficult to distinguish between erroneous and accurate data points. The options in these circumstances are to extend the spacing range, conduct measurements at additional locations or model to the worst-case results.

Disagreement in the measured values between sounding location may not be erroneous at all, instead due to geological influences such as dipping layers, fault lines or voids. If this is suspected, the measurements should not be discounted from the soil modelling procedure.

Borehole surveys or trial pit excavations are commonly conducted by civil works contractors during site construction and provide information about soil type and structure although generally only to limited depth. Correlation with these records and geological maps can help reduce the uncertainty in soil model parameters.

NC.7.5 Seasonal variations

Soil resistivity fluctuates with soil moisture content and soil temperature. Higher soil resistivity conditions (worst case for earthing systems) will generally occur during the colder months, especially following a period of little rainfall. As it will frequently not be practicable to conduct soil resistivity measurements under these 'worst-case' conditions, it is advisable that an earthing system is not designed close to the limits of acceptable touch voltage or third-party interference. If soil conditions were optimistic during testing (warm and high soil moisture content), a limited, repeat soil resistivity investigation, planned during worse-case conditions can help to confirm that the earthing system design is satisfactory under all soil conditions.

NC.8 Other matters

NC.8.1 Test instruments

Testing is used to certify systems as being safe and therefore instruments have to be reasonably accurate and reliable.

Almost all earth testing is performed using purpose designed commercially available earth testers of which there are many. The choice of a suitable unit requires careful consideration to the modes of use and required accuracy so that a sensible investment can be made.

Connection to a wide range of earthing systems has to be carried out efficiently and safely across often unexpected and unfavourable ground conditions. The equipment has to be both physically and electrically capable of withstanding the adverse environment and electrical transients present during connection to installed networks. Additionally the equipment should have adequate immunity to electrical interference which could otherwise adversely influence measurement accuracy. Most commercially available earth testers utilize a square wave signal with measurements made bi-directionally to avoid polarization effects (this should not be confused with a.c. testing of impedance). Often such instruments will be capable of applying a number of alternative frequencies (offset from multiples of the power system frequency) so as to ensure the effects of local interference can be avoided.

Modern digital earth resistance testers can operate with high probe resistances meaning that testing may be practicable even in difficult ground conditions. In urban situations, where ground conditions make it impossible to insert probes, successful results can be achieved by laying temporary electrodes on the ground surface even when this is concrete, tarmac or similar. Water can be poured over them to improve electrical contact with ground surface. With modern instruments, any problem with probe contact is normally indicated to show that a reading may not be valid.

Many composite digital earth resistance test meters are suitable for testing of small-area earthing system where the effect of inductance can be neglected. However, for large area earthing systems or for earthing systems with extended connection to cable sheaths or overhead line earth wires, a.c. earth impedance testers are required. [IEEE 80, 81, 81.2, Griffiths, Jones, Harid, Haddad)

NC.8.2 Test leads

The wide variety of differing site and interconnection needs dictate that virtually no one set of test leads will suit all situations so whilst alternative options and lengths are available from instrument manufacturers, testing will inevitably require a degree of improvisation from time to time. In order to ensure accurate measurements are made it is vital that care is taken to ensure that test leads used are suitable. If in doubt advice should be sought from the instrument manufacturer.

Care should be taken to maintain safety in operation by regularly inspecting leads for cuts and signs of chafing and ensuring that leads are not used if damaged.

NC.8.3 Calibration

Maintaining correct calibration of an earth tester is essential to ensure valid measurements. As with most instruments, calibration should be checked periodically during the life of the product and adjusted if necessary. It is not uncommon for large customers to request that sub-contractors to provide a proof of a calibration for the test equipment used on a given installation. A manufacturer’s or third party calibration certificate provides proof of the instrument’s performance on the day it was tested.

For most test equipment, there is no fixed calibration interval since many factors outside of the instrument manufacturers control will affect the optimum period. It is neither necessary nor desirable to have an instrument calibrated more frequently than necessary since costs will increase for little or no gain. An instrument which is used constantly and is subjected to repeated mechanical and environmental changes is likely to need calibrating more frequently than one which spends most of its life on the shelf. An approach to be recommended is to set-up reference circuits employing fixed resistors against which the instrument is checked.

NC.8.4 Agricultural voltages

When tests are to be performed in open field conditions where animals/livestock are present care should be taken to ensure they are not exposed to hazardous voltages. Of particular significance is the output voltage from the tester, and it is not uncommon for instruments to be offered with reduced output voltages such as 25 V for use in such conditions. See BS EN 61557 for more details.

NC.8.5 Documentation

Any documentation resulting from the design, installation and testing of any earthing systems should be retained for future reference and comparison with future tests.

A plan of the earthing system should be defined and maintained that shows the material and the position of the earth electrodes, their branching points and the depth of burial.

NC.9 Bibliography

BS EN 61557/IEC 61557 (all parts), *Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c – Equipment for testing, measuring or monitoring of protective measures*

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