PD IEC/TS 61936-2:2015

BSI Standards Publication

Power installations exceeding 1 kV a.c. and 1,5 kV d.c.

Part 2: d.c.

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National foreword

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

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Power installations exceeding 1 kV a.c. and 1,5 kV d.c. –
Part 2: d.c.

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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POWER INSTALLATIONS EXCEEDING 1 kV a.c. and 1,5 kV d.c. –

Part 2: d.c.

FOREWORD

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- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 61936-2, which is a technical specification, has been prepared by technical committee 99: System engineering and erection of electrical power installations in systems with nominal voltages above 1 kV a.c. and 1,5 kV d.c., particularly concerning safety aspects.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

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

Enquiry draft	Report on voting
99/130/DTS	99/132/RVC

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

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

A list of all parts in the IEC 61936 series, published under the general title *Power installations exceeding 1 kV a.c. and 1,5 kV d.c.*, can be found on the IEC website.

The following differences exist in the countries indicated below:

7.2.4: For live parts without protective facilities, a minimum height $H = N + 2\ 440$ mm shall be maintained. (Australia)

7.2.6: Guidance reference construction can be found at ENA Doc 015. (Australia)

7.5.4: Space for evacuation shall always be at least 600 mm, even when removable parts or open doors, which are blocked in the direction of escape, intrude into the escape routes. (Australia)

8.7.1: Fire rating of barriers must be a minimum fire rating of 120 minutes. (Australia)

8.7.2: The dimensions G_1 and G_2 are to be measured from the inside edge wall of any bund wall rather than the measured point shown in Figure 7a) and 7b) of IEC 61936-1:2010/AMD1:2014 from the transformer where the bund wall is wider than the transformer. (Australia)

8.8: Spill containment should extend by 50% of the height of the transformer. (Australia)

10: For requirements on earthing, refer to AS 2067, Substations and High Voltage Installations. (Australia)

10.2.1: 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 10 of IEC TS 60479-1:2005. (United Kingdom)

10.2.1: Permissible touch and step voltages in power installations shall be in accordance with Federal law concerning electrical installations (High and low voltage) (SR 734.0) and Regulations for electrical power installations (SR 743.2 StV). (Switzerland)

10.2.1 and Annex B: Earthing requirements are based on probabilistic calculations and so much of the clause is not appropriate for Australia. (Australia)

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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

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

INTRODUCTION

There are few national laws, standards and internal rules dealing with the matter coming within the scope of this technical specification, and these practices have been taken as a basis for this work.

This part of IEC 61936 contains the minimum requirements valid for IEC countries and some additional information which ensures an acceptable reliability of an installation and its safe operation.

This part of IEC 61936 is published as a Technical Specification in order to welcome contribution and involvement from a wider audience. This may provide the basis for a future international standard.

The publication of this technical specification is believed to be a decisive step towards the gradual alignment all over the world of the practices concerning the design and erection of high voltage power installations.

Particular requirements for transmission and distribution installations as well as particular requirements for power generation and industrial installations are included in this technical specification.

The relevant laws or regulations of an authority having jurisdiction takes precedence.

POWER INSTALLATIONS EXCEEDING 1 kV a.c. and 1,5 kV d.c. –

Part 2: d.c.

1 Scope

This part of IEC 61936 provides, in a convenient form, common rules for the design and the erection of electrical power installations in systems with nominal voltages above 1,5 kV d.c., so as to provide safety and proper functioning for the use intended.

This technical specification does not apply to the design and erection of any of the following:

– overhead and underground lines between separate installations;
– electric railways;
– mining equipment and 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;
– valve hall.

This technical specification does not apply to the design of factory-built, type-tested switchgear for which separate IEC standards exist.

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

This technical specification does not apply to the design of factory-built, type-tested thyristor valves, VSC valves and switchgear for which separate IEC standards exist.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60071-1, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60071-2:1996*, Insulation co-ordination – Part 2: Application guide*

IEC 60071-5, *Insulation co-ordination – Part 5: Procedures for high voltage direct current (HVDC) converter stations*

IEC 60079-10-1, *Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres*

IEC 60079-10-2, *Explosive atmospheres – Part 10-2: Classification of areas – Combustible dust atmospheres*

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

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

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

IEC 61936-1:2010, *Power installations exceeding 1 kV a.c. – Part 1: Common rules*
IEC 61936-1:2010/AMD1:2014

IEC 62271-1:2007, *High-voltage switchgear and controlgear – Part 1: Common specifications*
IEC 62271-1:2007/AMD1:2011

3 Terms and definitions

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

3.1
valve
complete operative controllable or non-controllable valve device assembly, normally conducting in only one direction (the forward direction), which can function as a converter arm in a converter bridge

Note 1 to entry: An example of a non-controllable valve device assembly is a semiconductor diode valve. An example of a controllable valve device assembly is a thyristor valve.

[SOURCE: IEC 60633:1998, 6.3]

3.2
electronic valve device
indivisible electronic device for electronic power conversion or electronic power switching, comprising a single non-controllable or bistably controlled unidirectionally conducting current path

Note 1 to entry: Typical electronic valve devices are thyristors, power rectifier diodes, power switching bipolar and field effect transistors and insulated-gate bipolar transistors (IGBT).

Note 2 to entry: Two or more electronic valve devices may be integrated on a common semiconductor chip (examples: a thyristor and a rectifier diode in a reverse conducting thyristor, a power switching field effect transistor with its inverse diode) or packaged in a common case (semiconductor power module). These combinations are to be considered as separate electronic valve devices.

[SOURCE: IEC 60050-551:1998, 551-14-02]

3.3
nominal voltage, <of a system>
suitable approximate value of voltage used to designate or identify a system

[SOURCE: IEC 60050-601:1985, 601-01-21]

3.4
highest voltage, <of a d.c. system>
U_{dm}
highest mean or average pole d.c. voltage to earth, excluding harmonics and commutation overshoots, for which the installation is designed in respect of its insulation

3.5
d.c. neutral point
common point of two monopoles forming a bipole converter or the earthed point of a monopole converter

3.6
d.c. electrode line
electrical connection between a d.c. earth electrode and the d.c. installation

3.7
high voltage
d.c. voltage exceeding 1 500V d.c.

3.8
low voltage
d.c. voltage not exceeding 1 500V d.c.

3.9
converter station
part of a power system which interconnects an a.c. system to a d.c. system or two d.c. systems with different voltages enabling power transfer from one system to the other and/or vice versa

3.10
d.c. earth electrode
d.c. ground electrode
array of conductive elements placed in the earth, or the sea, which provides a low resistance path between a point in the d.c. circuit and the earth and is capable of carrying continuous current for some extended period

Note 1 to entry: An earth electrode may be located at a point some distance from the HVDC substation.

Note 2 to entry: Where the electrode is placed in the sea it may be termed as sea electrode.

[SOURCE: IEC 60633:1998, 8.14, modified – The indication "d.c." has been added to the term and a synonym, d.c. ground electrode, has been added.]

3.11
pole
part of an HVDC system consisting of all the equipment in the HVDC substations and interconnecting transmission lines, if any, which during normal operation, exhibit a common direct voltage polarity with respect to earth.

[SOURCE: IEC 60633:1998, 8.5]

3.12
lightning impulse protective level, <of a protective device>
U_{pl}
maximum permissible peak voltage value, on the terminals of a protective device subjected to lightning impulses under specific conditions

[SOURCE: IEC 60050-604:1987, 604-03-56]

3.13
switching impulse protective level, <of a protective device>
U_{ps}
maximum permissible peak voltage value, on the terminals of a protective device subjected to switching impulses under specific conditions

[SOURCE: IEC 60050-604:1987, 604-03-57]

4 Fundamental requirements

4.1 General

4.1.1 General requirements

See 4.1.1 of IEC 61936-1:2010.

4.1.2 Agreements between supplier (manufacturer) and user

See 4.1.2 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

4.2 Electrical requirements

4.2.1 Methods of d.c. neutral point earthing

The method of d.c. neutral point earthing of a system 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.

The following are examples of d.c. neutral point earthing methods:

– isolated neutral;
– high impedance earthing;
– high resistive earthing;
– solid (low impedance) earthing.

The choice of the type of d.c. neutral point earthing is normally based on the following criteria:

– local regulations (if any);
– continuity of service 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 d.c. system has only one method of d.c. neutral point earthing. Different galvanically independent d.c. systems may have different methods of d.c. neutral point earthing, so the earthing point could be located in one or both converter stations.

The a.c. and d.c. systems may be either galvanically separated or not. The d.c. neutral point earthing method of an a.c. system not galvanically separated from the d.c. one has an effect on the d.c. neutral point earthing and vice versa. Design of equipment and protective system shall take into account this feature.

If different d.c. neutral point 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 Voltage classification

The nominal voltage and the maximum operating voltage of the system shall be agreed between user and manufacturer.

Based on the maximum operating voltage the highest voltage of a d.c. system (U_{dm}) shall be selected.

4.2.3 Current in normal operation

Every part of an installation shall be designed and constructed to withstand currents under defined operating conditions.

4.2.4 Short-circuit current

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

For the purposes of this standard, all applicable types of short-circuits, which may happen, shall be considered, e.g.:

- pole-to-earth;
- pole-to-pole;
- double pole-to-earth;
- converter arm.

Installations shall be protected with automatic devices or functions to disconnect or switch off the d.c. system in case of pole-pole or pole-pole-earth short circuit.

In case of pole-earth or metallic return or d.c. electrode line to earth, installations shall be protected with automatic devices or functions to disconnect or switch off the d.c. system or with a device to indicate the earth fault condition.

The selection of the device or function is dependent upon the method of d.c. neutral point earthing.

Selection of magnitude and duration of short circuit current shall be agreed between manufacturer and user.

Methods for the calculation of the effects of short-circuit current are given, for power cables, in IEC 60949.

4.2.5 Rated frequency

The provision of IEC 61936-1:2010, 4.2.5 is not applicable.

4.2.6 Corona

The design of installations shall be such that radio interference due to electromagnetic fields, e.g. caused by corona effects, will not exceed a specified level.

When the acceptable value is exceeded, the corona level may be controlled, for example, by the installation of corona rings or the recessing of fasteners on bus fittings for high-voltage suspension insulator assemblies, bus support assemblies, bus connections and equipment terminals.

Maximum permissible levels of radio interference are given by national or local authorities in some countries.

Guidance on acceptable levels of radio interference voltage for a.c. switchgear and controlgear can be found in IEC 62271-1 in which the emission tests are recommended from a.c. voltages of 123 kV and above. In absence of other criteria, it is proposed that emission tests as per IEC 62271-1:2007, 6.9.1 is performed on equipment subjected to a direct voltage (to earth) U_{dm} of 123 × √2/√3 = 100 kV or higher. The test voltage shall be corrected to 1,1/√2 × U_{dm}.

NOTE Recommendations for minimizing the radio interference of high-voltage installations are reported in CISPR 18-1, CISPR 18-2 and CISPR 18-3 [1,2,3] [1].

4.2.7 Electric and magnetic fields

The design of an installation shall be such as to limit the electric and magnetic fields generated by energized equipment to an acceptable level for exposed people.

National and/or international regulations may specify acceptable levels.

4.2.8 Overvoltages

See 4.2.8 of IEC 61936-1:2010.

4.2.9 Harmonics

See 4.2.9 of IEC 61936-1:2010.

4.2.10 Galvanic separation between a.c. and d.c. systems

The a.c. and d.c. systems may be either galvanically separated or not. Galvanic separation between a.c. and d.c. systems is generally obtained by means of converter transformers.

NOTE Regardless of galvanic separation between a.c. and d.c. systems there is always a portion of a.c. system comprised within the converter transformer and the electronic valve devices which is not galvanically insulated from the d.c. system.

4.3 Mechanical requirements

See 4.3 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

4.4 Climatic and environmental conditions

4.4.1 General

Installations, including all devices and auxiliary equipment which form an integral part of them, shall be designed for operation under the climatic and environmental conditions listed below.

The presence of condensation, precipitation, particles, dust, corrosive elements and hazardous atmospheres shall be specified in such a manner that appropriate electrical equipment can be selected. Zone classification for hazardous areas shall be performed in accordance with IEC 60079-10-1 and IEC 60079-10-2.

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1 Figures in square brackets refer to the bibliography.

Dust accumulates constantly on insulators and conductive surfaces immersed in a d.c. electric field. In installations with high levels of d.c. electric fields special care shall be paid either to creapage lengths or air treatment (indoor installations).

In cases with heavy pollution levels, the indoor air could be treated and overpressurized.

4.4.2 Normal conditions

See 4.4.2 of IEC 61936-1:2010.

4.4.3 Special conditions

See 4.4.3 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

4.5 Special requirements

See 4.5 of IEC 61936-1:2010.

5 Insulation

5.1 General

As conventional (air insulated) d.c. installations are normally not impulse tested, the d.c. installation requires minimum clearances between live parts and earth and between live parts of poles in order to avoid flashover below the impulse withstand level selected for the installation.

Insulation coordination shall be in accordance with IEC 60071-5 and IEC 60071-1 as far as principal definitions and rules are concerned.

5.2 Selection of insulation level

The insulation level shall be chosen according to the established highest d.c. voltage for equipment U_{dm} and/or impulse withstand voltage.

5.2.1 Consideration of methods of neutral earthing

The choice should be made primarily to ensure reliability in service, taking into account the method of d.c. neutral point earthing in the system and the characteristics and the locations of overvoltage limiting devices to be installed.

In installations in which a high level of safety is required, or in which the configuration of the system, the adopted method of d.c. neutral point earthing or the protection by surge arresters make it inappropriate to lower the level of insulation, one of the higher alternative values of Annex A may be chosen.

In installations in which the configuration of the system, the adopted method of d.c. neutral point earthing or the protection by surge arresters make it appropriate to lower the level of insulation, the lower alternative values of Annex A may be sufficient.

5.2.2 Consideration of rated withstand voltages

In the voltage range I (1,5 kV d.c. $< U_{dm} <$ 500 kV d.c.), the choice is generally based on the rated lightning impulse withstand voltages given in Annex A; in the voltage range II ($U_{dm} >$ 500 kV d.c.), the choice is generally based on the rated switching impulse withstand voltages and the rated lightning impulse withstand voltages given in Annex A.

5.3 Verification of withstand values

5.3.1 If the minimum clearances calculated according to 5.4 are maintained, it is not necessary to apply dielectric tests.

5.3.2 If the minimum clearances referred to in 5.4 are not maintained, the ability to withstand the test voltages of the chosen insulation level shall be established by applying the appropriate dielectric tests in accordance with IEC 60060-1 for the specified withstand voltage values or by exact calculation of possible overvoltages in the HVDC system and deriving clearances based on IEC 60071-1 and 60071-2.

5.3.3 If the minimum clearances referenced to in 5.4 are not maintained in parts or areas of an installation, dielectric tests restricted to these parts or areas will be sufficient.

In accordance with IEC 60071-2:1996, Annex B, minimum clearances may be lower if this has been proven by tests or by operating experience of lower overvoltages.

5.4 Minimum clearances of live parts

5.4.1 The minimum clearance N shall be chosen as the maximum of the two following clearances:

– Switching impulse withstand clearance d_{sw}
– Lightning impulse withstand clearance d_{lw}

Switching impulse pole-to-earth withstand clearances in air, in meters, are given by the following Formula (1), based on negative switching impulse withstand, which results from Formula G.3 of IEC 60071-2:1996 and applies for altitudes up to 1 000 m above sea level. For higher altitudes, see 4.4.3.2 of IEC 61936-1:2010.

$$d_{sw} = K \frac{-1 + e^{\left(\frac{U_{dm} K_a [u_S]_{p,u.}}{1080 k \cdot (1 - 2\sigma_S)}\right)}}{0{,}46} \qquad (1)$$

The minimum pole-to-pole clearance in meters is given by the following Formula (2), based on negative switching impulse withstand, which results from Formula G.3 of IEC 60071-2:1996 and applies for altitudes up to 1 000 m above sea level. For higher altitudes, see 4.4.3.2 of IEC 61936-1:2010.

$$d_{sw} = K \frac{-1 + e^{\left(\frac{2U_{dm} K_a [u_S]_{p,u.}}{1080 k \cdot (1 - 2\sigma_S)}\right)}}{0{,}46} \qquad (2)$$

Where

U_{dm} is the established highest d.c. voltage for equipment (pole to earth) in kV;

K is a factor based on IEC 60071-2;

K_a is an atmospheric correction factor according to IEC 60071-2, and

$[u_S]_{p.u.}$ is the required per unit switching impulse withstand voltage and σ_S is assumed to be 0,06.

Normally, for d.c. systems with solid earth reference, $[u_S]_{p.u.}$ = 2 p.u. can be conservatively assumed for switching impulse withstand voltage. In case of protection with surge arresters, the $[u_S]_{p.u}$ value can be reduced according to the switching impulse protective level U_{ps} of the surge arresters with a proper safety margin as shown in Formula (3) below:

$$[u_S]_{p,u.} = 1{,}15 \frac{U_{ps}}{U_{dm}} \quad (3)$$

The lightning impulse withstand (both the pole-to-ground and the pole-to-pole) clearance in meters can be calculated with the following Formula (4):

$$d_{lw} = s + \frac{U_L}{K_t} \cdot \frac{1}{1-2\sigma_L} \cdot \frac{1}{530} \quad (4)$$

Where

U_L is the required lightning impulse withstand voltage in kV;

K_t is an atmospheric correction factor according to IEC 60060-1;

s is a safety margin for taking into account dust deposit and humidity that can be assumed to be 0,015 m and σ_L is assumed to be 0,03.

In case of protection with surge arresters, the $[u_L]_{p.u}$ value can be reduced according to the lightning impulse protective level U_{pl} of the surge arresters with a proper safety margin as shown in the following Formula (5):

$$U_L = 1{,}25 \cdot U_{pl} \quad (5)$$

The safety margin could be further reduced for special installations with controlled electric field configuration and atmosphere as in converter valve hall.

In installations in which a high level of safety is required, or in which the configuration of the system, the adopted method of d.c. neutral point earthing or the protection by surge arresters make it inappropriate to lower the level of insulation, the safety margin can be increased.

In installations in which the configuration of the system, the adopted method of d.c. neutral point earthing or the protection by surge arresters make it appropriate to lower the level of insulation, the safety margin can be decreased.

In voltage range (U_{dm} > 450 kV d.c.), the pole-to-earth clearances in air are determined by the rated switching impulse withstand voltage (SIWV). They substantially depend on the electrode configurations. In cases of difficulty in classifying the electrode configuration, it is recommended to make a choice based on the phase-to-earth clearances of the most unfavourable configuration such as, for example, the arm of an isolator against the tower construction (rod-structure).

5.4.2 If parts of an installation can be separated from each other by a disconnector, they shall be tested at the rated impulse withstand voltage for the isolating distance. If between such parts of an installation the minimum clearances calculated with the formulae of 5.4 are increased by 25 % or more, it is not necessary to apply dielectric tests.

5.5 Minimum clearances between parts under special conditions

5.5.1 Minimum clearances between parts of an installation, which are assigned to different insulation levels, shall be at least 125 % of the clearances of the higher insulation level.

5.5.2 If conductors swing under the influence of short-circuit forces, 50 % of the minimum clearances calculated with the formulae of 5.4 shall be maintained as a minimum.

5.5.3 If conductors swing under the influence of wind, 75 % of the minimum clearances calculated with the formulae of 5.4 shall be maintained as a minimum.

5.5.4 In case of rupture of one sub-chain in a multiple insulator chain, 75 % of the minimum clearances calculated with the formulae of 5.4 shall be maintained as a minimum.

5.6 Tested connection zones

Information on mounting and service conditions of type tested equipment supplied by the manufacturer shall be observed on site.

NOTE In tested connection zones, the minimum clearances according to 5.4 and Annex A need not to be maintained because the ability to withstand the test voltage is established by a dielectric type test.

6 Equipment

6.1 General requirements

See 6.1 of IEC 61936-1:2010.

6.2 Specific requirements

6.2.1 Switching devices

See 6.2.1 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

6.2.2 Reactors

The reactors are classified taking into account the dielectric in contact with the winding and the type of internal or external cooling medium, as described in Clause 3 of IEC 60076-2:2011.

When designing the reactor installation, the possibility of fire propagation (see 8.7) shall be considered. Similarly, means shall be implemented to limit, if necessary, the acoustic noise level (see 4.5.2 of IEC 61936-1:2010).

For reactors installed indoors, suitable ventilation shall be provided (see 7.5.7).

Water (ground water, surface water and waste water) shall not be polluted by reactors installations. This shall be achieved by the choice of the design of reactors type and/or site provisions. For measures, see 8.8.

If it is necessary to take samples (oil sampling) or to read monitoring devices (such as fluid level, temperature, or pressure), which are important for the operation of the reactor whilst the reactor is energized, it shall be possible to perform this safely and without damage to the equipment.

Air-core reactors shall be installed in such a way that the minimum design magnetic clearance to other reactors and metallic parts is fulfilled to minimize induced losses.

In general metallic parts should be located where the effect of the magnetic field does not cause harmful effects.

Air-core reactors shall be installed in such a way that the magnetic field of the short-circuit current will not be capable of drawing objects into the coil. Adjacent equipment shall be designed to withstand the resulting electromagnetic forces.

Air core reactors shall be designed to prevent hazardous ferromagnetic objects attraction due to their magnetic flux density. Rotational forces may be noticeable above 6 mT and cause difficulty around 60 mT. Translational forces may be noticeable above 10^{-4} T^2/m and equal to gravity above 10^{-3} T^2/m.

6.2.3 Prefabricated type-tested switchgear

See 6.2.3 of IEC 61936-1:2010.

6.2.4 Surge arresters

See 6.2.5 of IEC 61936-1:2010.

6.2.5 Capacitors

See 6.2.6 of IEC 61936-1:2010.

6.2.6 Line traps

See 6.2.7 of IEC 61936-1:2010.

6.2.7 Insulators

The minimum specific creepage distance of insulators shall comply with the level of pollution specified by the user.

The requirements of the wet test procedure of IEC 62271-1 shall apply for all external insulation.

Insulator profiles and/or requirements for performance of outdoor insulators in polluted or heavy wetting conditions may be specified by the user.

6.2.8 Insulated cables

6.2.8.1 Temperature

See 6.2.9.1 of IEC 61936-1:2010.

6.2.8.2 Stress due to temperature changes

See 6.2.9.2 of IEC 61936-1:2010.

6.2.8.3 Flexible reeling and trailing cables

See 6.2.9.3 of IEC 61936-1:2010.

6.2.8.4 Crossings and proximities

See 6.2.9.4 of IEC 61936-1:2010.

6.2.8.5 Installation of cables

See 6.2.9.5 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

6.2.8.6 Bending radius

See 6.2.9.6 of IEC 61936-1:2010.

6.2.8.7 Tensile stress

See 6.2.9.7 of IEC 61936-1:2010.

6.2.9 Conductors and accessories

See 6.2.10 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

6.2.10 Rotating electrical machines

See 6.2.11 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

6.2.11 Static converters

See 6.2.14 of IEC 61936-1:2010.

6.2.12 Fuses

6.2.12.1 Clearances

See 6.2.15.1 of IEC 61936-1:2010.

6.2.12.2 Fuse replacement

See 6.2.15.2 of IEC 61936-1:2010.

6.2.13 Electrical and mechanical Interlocking

See 6.2.16 of IEC 61936-1:2010.

6.2.14 Electronic valve devices

In cases where use of parallel electronic valve devices is necessary, consideration shall be given to potential uneven current distribution in parallel currents.

In case of series connection of electronic valve devices, consideration to uneven voltage distribution shall be given.

The needed redundancy in valves shall be agreed between supplier (manufacturer) and user.

6.2.15 Valve cooling system

If it is necessary to take samples (water sampling,) or to read monitoring devices (such as fluid level, temperature, conductivity or pressure), which are important for the operation of the valve whilst the converter is energized, it shall be possible to perform this safely and without damage to the equipment.

When designing the cooling system, the possibility of fire propagation (see 8.7) shall be considered. Similarly, means shall be implemented to limit, if necessary, the acoustic noise level (see 4.5.2 of IEC 61936-1:2010).

For room of cooling equipment installed indoors, suitable ventilation shall be provided (see 7.5.7).

7 Installations

7.1 General requirements

This Clause 7 specifies only general requirements for the installations regarding choice of circuit arrangement, circuit documentation, transport routes, lighting, operational safety and labelling.

Distances, clearances and dimensions specified are the minimum values permitted for safe operation. They are generally based on the minimum values given in the former national standards of the IEC members. A user may specify higher values if necessary.

For minimum clearances (N) of live parts, refer to 5.4.

National standards and regulations may require the use of higher clearance values.

Where an existing installation is to be extended, the requirements applicable at the time of its design and erection may be specified as an alternative.

The relevant standards for operation of electrical (power) installations shall additionally be taken into account. Operating procedures shall be agreed upon between manufacturer and user (see 7.1.2).

7.1.1 Circuit arrangement

See 7.1.1 of IEC 61936-1:2010.

7.1.2 Documentation

See 7.1.2 of IEC 61936-1:2010.

7.1.3 Transport routes

See 7.1.3 of IEC 61936-1:2010.

7.1.4 Aisles and access areas

See 7.1.4 of IEC 61936-1:2010.

7.1.5 Lighting

See 7.1.5 of IEC 61936-1:2010.

7.1.6 Operational safety

See 7.1.6 of IEC 61936-1:2010.

7.1.7 Labelling

See 7.1.7 of IEC 61936-1:2010.

7.2 Outdoor installations of open design

The layout of open type outdoor installations shall take into account the minimum pole-to-pole and pole-to-earth clearances given in 5.4.

The design of the installation shall be such as to restrict access to danger zones, taking into account the need for operational and maintenance access. External fences shall therefore be provided and, where safety distances cannot be maintained, permanent protective facilities shall be installed. For electrical installations on mast, pole and tower external fences may not be required, if the installation is inaccessible from ground level to the general public and meet the safety distances given in 7.7.

A separation shall be provided between bays or sections by appropriate distances, protective barriers or protective obstacles.

7.2.1 Protective barrier clearances

Within an installation, the following minimum protective clearances shall be maintained between live parts and the internal surface of any protective barrier (N is defined in 5.4):

– for solid walls, without openings, with a minimum height of 1 800 mm, the minimum protective barrier clearance is $B_1 = N$;

– for equipment, where U_{dm} is greater than 45 kV d.c., a wire mesh, screen or solid wall, with openings, with a minimum height of 1 800 mm and a degree of protection of IP1XB (see IEC 60529) shall be used. The minimum protective barrier clearance is $B_2 = N +$ 100 mm;

– for equipment where U_{dm} is up to 45 kV d.c., a wire mesh, screen or solid wall, with openings, with a minimum height of 1 800 mm and a degree of protection of IP2X (see IEC 60529), shall be used. The minimum protective barrier clearance is $B_3 = N +$ 80 mm.

For non-rigid protective barriers and wire meshes, the clearance values shall be increased to take into account any possible displacement of the protective barrier or mesh.

7.2.2 Protective obstacle clearances

Within installations, the following minimum clearance shall be maintained from live parts to the internal surface of any protective obstacle (see Figure 1 of IEC 61936-1:2010/AMD1:2014):

– for solid walls or screens less than 1 800 mm high, and for rails, chains or ropes, the minimum protective obstacle clearance is $O_2 = N +$ 300 mm (minimum 600 mm);

– for chains or ropes, the values shall be increased to take into account the sag.

Where appropriate, protective obstacles shall be fitted at a minimum height of 1 200 mm and a maximum height of 1 400 mm.

NOTE Rails, chains and ropes are not acceptable in certain countries.

7.2.3 Boundary clearances

The external fence of outdoor installations of open design shall have the following minimum boundary clearances in accordance with Figure 2 of IEC 61936-1:2010/AMD1:2014:

– solid walls (height see 7.2.6) $C = N +$ 1 000 mm;

– wire mesh/screens (height see 7.2.6) $E = N +$ 1 500 mm.

The degree of protection of IP1X (see IEC 60529) shall be used.

7.2.4 Minimum height over access area

The minimum height of live parts above surfaces or platforms where only pedestrian access is permitted shall be as follows:

– for live parts without protective facilities, a minimum height $H = N + 2\ 250$ mm (minimum 2 500 mm) shall be maintained (see Figure 3 of IEC 61936-1:2010). The height H refers to the maximum conductor sag (see Clause 4);
– the lowest part of any insulation, for example the upper edge of metallic insulator bases, shall be not less than 2 250 mm above accessible surfaces unless other suitable measures to prevent access are provided.

Where the reduction of safety distances due to the effect of snow on accessible surfaces needs to be considered, the values given above shall be increased.

7.2.5 Clearances to buildings

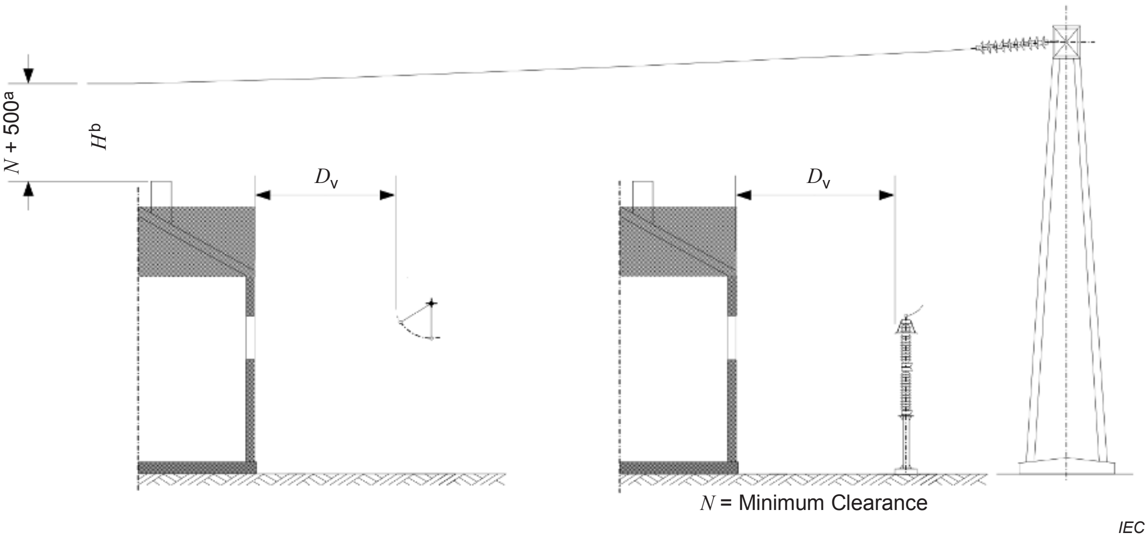
Where bare conductors cross buildings which are located within closed electrical operating areas, the following clearances to the roof shall be maintained at maximum sag (see Figure 1):

– the clearances specified in 7.2.4 for live parts above accessible surfaces, where the roof is accessible when the conductors are live;
– $N + 500$ mm where the roof cannot be accessed when the conductors are live;
– O_2 in lateral direction from the end of the roof if the roof is accessible when the conductors are live.

Where bare conductors approach buildings which are located within closed electrical operating areas, the following clearances shall be maintained, allowing for the maximum sag/swing in the case of stranded conductors:

– outer wall with unscreened windows: minimum clearance given by D_V;
– outer wall with screened windows (screened in accordance with 7.2.2): protective barrier clearances B_2 in accordance with 7.2.2;
– outer wall without windows: N.

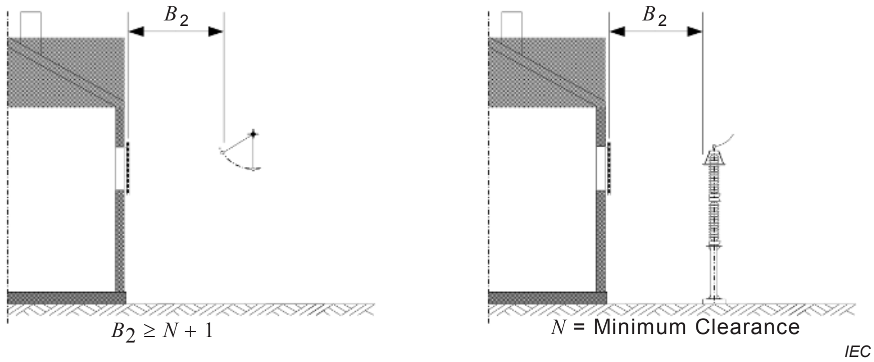
Dimensions in millimetres



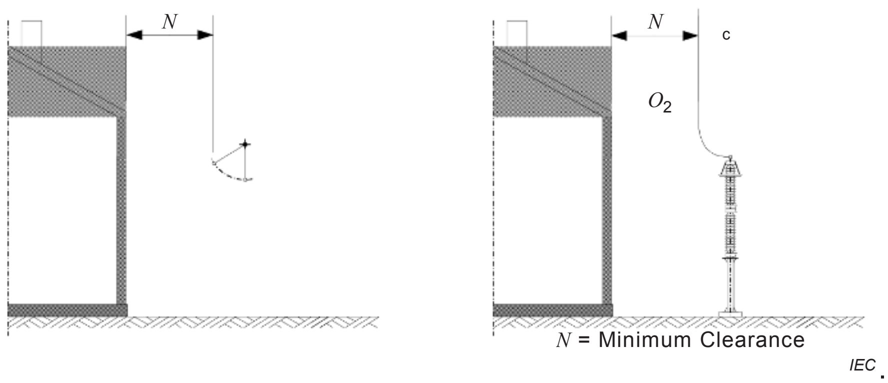
a The roof cannot be accessed when the conductors are live — $D_V = N + 1\,000$ for $U_n \leq 110$ kV

b The roof can be accessed when the conductors are live — $D_V = N + 2\,000$ for $U_n > 110$ kV

a) Outer wall with unscreened windows



b) Outer wall with screened windows



c $O_2 \geq N + 300$ (600 min.) if the roof is accessible when the conductors are live

c) Outer wall without windows

When work is performed on the roof when the conductors are live, clearances from Figure 3 of IEC 61936-1:2010 shall be used.

Figure 1 – Approaches with buildings (within closed electrical operating areas)

7.2.6 External fences or walls and access doors

See 7.2.6 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

7.3 Indoor installations of open design

The layout of open-type indoor installations shall take into account the minimum pole-to-pole and pole-to-earth clearances specified in 5.4.

The design of the installation shall be such as to prevent access to danger zones taking into account the need of access for operational and maintenance purposes. Therefore, safety distances or permanent protective facilities within the installation shall be provided.

For protective barrier clearances, safety distances and minimum height, see 7.2.

For buildings, corridors, escape routes, doors and windows, see 7.5.

For solid walls or screens less than 1 800 mm high, and for rails, chains or ropes, the protective obstacle clearances are at least

$O_1 = N +$ 200 mm (minimum 500 mm, see Figure 1 of IEC 61936-1:2010/AMD1:2014)

For chains or ropes, the values shall be increased taking into account the sag. They shall be fitted at a minimum height of 1 200 mm to a maximum of 1 400 mm, where appropriate.

7.4 Installation of prefabricated type-tested switchgear

See 7.4 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

7.5 Requirements for buildings

7.5.1 General

See 7.5.1 of IEC 61936-1:2010.

7.5.2 Structural provisions

7.5.2.1 General

See 7.5.2.1 of IEC 61936-1:2010.

7.5.2.2 Specifications for walls

See 7.5.2.2 of IEC 61936-1:2010.

7.5.2.3 Windows

See 7.5.2.3 of IEC 61936-1:2010.

7.5.2.4 Roofs

The roof of the building shall have sufficient mechanical strength to withstand the environmental conditions. In case of valves intended to be suspended by anchoring to the roof, the roof of the valves building shall have sufficient mechanical strength to withstand both the environmental conditions and the valves weight.

If the ceiling of the switchgear room is also the roof of the building for pressure relief, the anchoring of the roof to the walls shall be adequate.

7.5.2.5 Floors

See 7.5.2.5 of IEC 61936-1:2010.

7.5.3 Rooms for switchgear

See 7.5.3 of IEC 61936-1:2010.

7.5.4 Maintenance and operating areas

Maintenance and operating areas comprise aisles, access areas, handling passages and escape routes.

Aisles and access areas shall be adequately dimensioned for carrying out work, operating switchgear and transporting equipment.

Aisles shall be at least 800 mm wide.

The width of the aisles shall not be reduced even where equipment projects into the aisles, for example permanently installed operating mechanisms or switchgear trucks in isolated positions.

Space for evacuation shall always be at least 500 mm, even when removable parts or open doors, which are blocked in the direction of escape, intrude into the escape routes.

For erection or service access ways behind closed installations (solid walls), a minimum width of 500 mm is required.

Clear and safe access for personnel shall be provided at all times.

The doors of switchgear cubicles or bays shall close in the direction of escape.

Below ceilings, covers or enclosures, except cable accesses, a minimum height of 2 000 mm is required.

Exits shall be arranged so that the length of the escape route within the room does not exceed 40 m for installation of rated voltages U_{dm} greater than 45 kV d.c., and 20 m for installation of rated voltages up to U_{dm} = 45 kV d.c.. This does not apply to accessible bus ducts or cable ducts. If the above distances of the escape route cannot be met, an agreement shall be made with the user.

Permanently installed ladders or similar are permissible as emergency exits in escape routes.

7.5.5 Doors

See 7.5.5 of IEC 61936-1:2010.

7.5.6 Draining of insulating liquids

See 7.5.6 of IEC 61936-1:2010.

7.5.7 Air conditioning and ventilation

See 7.5.7 of IEC 61936-1:2010.

7.5.7.1 Ventilation of battery rooms

See 7.5.7 1 of IEC 61936-1:2010.

7.5.7.2 Rooms for emergency generating units

See 7.5.7.2 of IEC 61936-1:2010.

7.5.8 Buildings which require special consideration

See 7.5.8 of IEC 61936-1:2010.

7.6 High voltage/low voltage prefabricated substations

See 7.6 of IEC 61936-1:2010.

7.7 Electrical installations on mast, pole and tower

The minimum height H' of live parts above surfaces accessible to the general public shall be

– H' = 4 300 mm for rated voltages U_{dm} up to 45 kV;
– $H' = N +$ 4 500 mm (minimum 6 000 mm) for rated voltages U_{dm} above 45 kV;

where N is the minimum clearance.

Where the reduction of safety distances due to the effect of snow on accessible surfaces needs to be considered, the values given above shall be increased.

Isolating equipment and fuses shall be arranged so that they can be operated without danger. Isolating equipment accessible to the general public shall be capable of being locked. The operating rods shall be compliant with the relevant standard.

Safe pole-to-pole connection and earthing of the overhead line shall be possible.

8 Safety measures

8.1 General

See 8.1 of IEC 61936-1:2010.

8.2 Protection against direct contact

See 8.2 of IEC 61936-1:2010.

8.2.1 Measures for protection against direct contact

8.2.1.1 Recognized protection measures

See 8.2.1.1 of IEC 61936-1:2010.

8.2.1.2 Design of protective measures

See 8.2.1.2 of IEC 61936-1:2010.

8.2.2 Protection requirements

8.2.2.1 Protection outside of closed electrical operating areas

See 8.2.2.1 of IEC 61936-1:2010.

8.2.2.2 Protection inside closed electrical operating areas

See 8.2.2.2 of IEC 61936-1:2010.

8.2.2.3 Protection during normal operation

The relevant standards for operation of electrical installations should be taken into account.

Protection measures in an installation shall take into account the need for access for purposes of operation and control and maintenance, e.g.:

– control of a circuit-breaker or a disconnector;
– changing a fuse or a lamp;
– adjusting a setting value of a device;
– resetting a relay or an indicator;
– earthing for work;
– erection of a temporary insulating shutter;
– reading the temperature or oil level of a reactor.

In installations with $U_{dm} \leq 45$ kV d.c., where doors or covers have to be opened in order to carry out normal operation or maintenance, it may be necessary to provide fixed non-conductive rails as a warning.

8.3 Means to protect persons in case of indirect contact

See 8.3 of IEC 61936-1:2010.

8.4 Means to protect persons working on electrical installations

See 8.4 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

8.5 Protection from danger resulting from arc fault

See 8.5 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

8.6 Protection against direct lightning strokes

See 8.6 of IEC 61936-1:2010.

8.7 Protection against fire

See 8.7.of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014 as far as applicable.

8.8 Protection against leakage of insulating liquid

See 8.8 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014 as far as applicable.

8.9 Identification and marking

See 8.9 of IEC 61936-1:2010.

9 Protection, control and auxiliary systems

See Clause 9 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014 as far as applicable.

10 Earthing systems

10.1 General

This Clause 10 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.

D.C. earth electrodes shall be located far enough away from the installation or other immersed metal structures so that electrolytic corrosion is negligible in comparison with other causes of corrosion, and to avoid transformer saturation.

NOTE IEC TS 62344 provides general guidelines on the design of earth electrode stations for high-voltage direct current (HVDC) links.

As the electrolytic corrosion due to the d.c. earth electrode depends on the ampere-hours of use, the distance of the d.c. earth electrode from the installation could be reduced in case of temporary use of the electrode.

10.2 Fundamental requirements

10.2.1 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 d.c. 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 ground including shoes or gravel;
– fault duration.

For installation design, the curve shown in Figure 2 is calculated according to the method defined in Annex B.

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

– body impedance from Table 10 of IEC TS 60479-1:2005 (not exceeded by 50 % of the population),
– permissible body current corresponding to the c_2 curve in Figure 22 and Table 13 of IEC TS 60479-1:2005 (probability of ventricular fibrillation is less than 5 %),
– heart current factor according to Table 12 of IEC TS 60479-1:2005.

The curve in the following Figure 2, which gives the allowable 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 exceeding the voltage limits given in IEC 60364-4-41 [8].

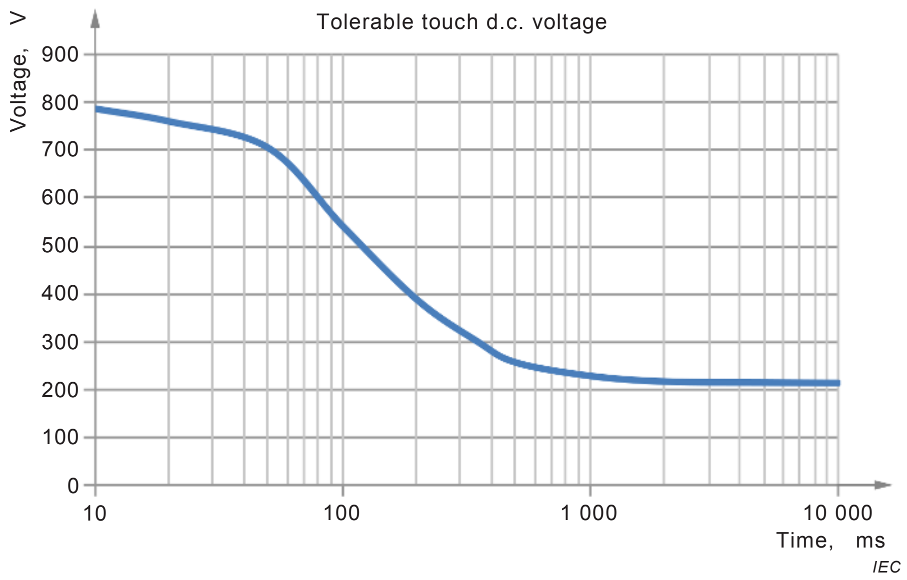


Figure 2 – Touch voltage limit d.c.

10.2.2 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 back-up protection operating time.

In general, a.c. and d.c. earthing systems shall be interconnected except for the d.c. earth electrode which will be separated from the a.c. and d.c. earthing systems.

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.

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 TR 61000-5-2.

10.2.3 High and low voltage earthing systems

See 10.2.3 of IEC 61936-1:2010.

10.3 Design of earthing systems

10.3.1 General

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 whether it is part of a global earthing system;

d) if not, determine soil characteristics e.g. specific soil resistivity of layers;
e) determine the current flowing into earth from the earthing system, based on earth fault current;
f) determine the overall impedance to earth, based on layout, soil characteristics, and parallel earthing systems;
g) determine earth potential rise;
h) determine tolerable touch voltage;
i) if the earth potential rise is below the permissible touch voltages, the design is completed;
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;

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.

A flowchart of this design process is given in Annex D of IEC 61936-1:2010/AMD1:2014.

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.

10.3.2 Power system faults

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) pole to earth;
b) two poles to earth;
c) metallic return to earth.

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

10.3.3 Lightning and transients

See 10.3.3 of IEC 61936-1:2010.

10.4 Construction of earthing systems

See 10.4 of IEC 61936-1:2010.

10.5 Measurements

See 10.5 of IEC 61936-1:2010.

10.6 Maintainability

10.6.1 Inspections

See 10.6.1 of IEC 61936-1:2010.

10.6.2 Measurements

See 10.6.2 of IEC 61936-1:2010.

11 Inspection and testing

11.1 General

See 11.1 of IEC 61936-1:2010.

11.2 Verification of specified performances

See 11.2 of IEC 61936-1:2010.

11.3 Tests during installation and commissioning

See 11.3 of IEC 61936-1:2010.

11.4 Trial running

See 11.4 of IEC 61936-1:2010.

12 Operation and maintenance manual

See Clause 12 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

Annex A
(informative)

Values of rated insulation levels and minimum clearances in air based on nominal voltage of some HVDC projects worldwide

Nominal voltage for installation	Highest voltage for installation	Rated 15 minutes d.c. withstand voltage	Rated lightning impulse withstand voltage[a]	Rated switching impulse withstand voltage	Minimum pole-to-earth clearance		Rated switching impulse withstand voltage	Minimum pole-to-pole clearance	
	U_{dm}		1,2/50 µs peak value	Pole-to-earth 250/2 500 µs peak value	Conductor – structure	Rod – structure	Pole-to-pole 250/2 500 µs peak value	Conductor – conductor parallel	Rod – conductor
kV	kV	kV	kV	kV	mm		kV	mm	
80	82.5	115	350 450	170	700 900		350	700 900	
100	103	145	450 550	250	900 1 100		450	900 1 100	
150	154,5	215	550 650 750	350	1 100 1 300 1 500		650	1 200 1 300 1 500	1 300 1 300 1 500
200	206	290	750 850 950	450	1 500 1 700 1 900		850	1 700 1 700 1 900	1 900 1 900 1 900
250	257,5	360	850 950 1 050	550	1 700 1 900 2 100		1 050	2 200	2 500
270	278	390	950 1 050 1 175	650	1 900 2 100 2 400		1 125	2 300	2 600
300	309	435	950 1 050 1 175	650	1 900 2 100 2 400		1 275	2 600	3 100
320	329,5	460	1 050 1 175 1 300	750	2 100 2 400 2 600		1 360	2 900	3 400
350	360,5	505	1 175 1 300 1 425	750	2 400 2 600 2 900		1 425	3 100	3 600
400	412	580	1 300 1 425 1 550	850	2 600 2 900 3 100		1 680	3 900	4 600
450	463,5	650	1 425 1 550 1 675	950	2 900 3 100 3 400		1 850	5 200	6 000

Nominal voltage for installation	**Highest voltage for installation**	**Rated 15 minutes d.c. withstand voltage**	**Rated lightning impulse withstand voltage**[a]	**Rated switching impulse withstand voltage**	**Minimum pole-to-earth clearance**		**Rated switching impulse withstand voltage**	**Minimum pole-to-pole clearance**	
	U_{dm}		**1,2/50 µs** peak value	**Pole-to-earth 250/ 2 500 µs** peak value	**Conductor – structure**	**Rod – structure**	**Pole-to-pole 250/ 2 500 µs** peak value	**Conductor – conductor parallel**	**Rod – conductor**
kV	kV	kV	kV	kV	mm		kV	mm	
500	515	720	1 550 1 675 1 800	1 050	3 100 3 400 3 600	3 400 3 600[b]	2 050	6 200	7 300
600	618	865	1 800 1 950 2 100	1 300	3 600 3 900 4 200	4 800	2 500	9 000	10 100

NOTE The introduction of U_{dm} above = 600 kV is under consideration.

[a] The rated lightning impulse is applicable pole-to-pole and pole-to-earth.

[b] Minimum clearance required for upper value of rated lightning impulse withstand voltage.

Annex B
(normative)

Method of calculating the voltage limit

The following Formula (B.1) shall be used:

$$U_\mathrm{T} = I_\mathrm{B}\,(t_\mathrm{f}) \times \frac{1}{HF} \times R_\mathrm{T}\,(U_\mathrm{T}) \times BF \qquad \text{(B.1)}$$

where

U_T is the touch voltage;

t_f is the fault duration; $I_\mathrm{B}(t_\mathrm{f})$ is the body current limit. See c_2 in Figure 22 and Table 13 of IEC TS 60479-1:2005 , where probability of ventricular fibrillation is less than 5 %. I_B depends on fault duration.

HF is the heart current factor. See Table 12 of IEC TS 60479-1:2005, i.e. 1,0 for left hand, both feet; 0,8 for right hand to both feet; 0,4 for hand to hand.

$R_\mathrm{T}(U_\mathrm{T})$ is the body resistance. See Table 10 and Figure 3 of IEC TS 60479-1:2005. R_T is not exceeded by 50 % of the population. Therefore, the first calculation has to start with an assumed level.

BF is the body fact. See Figure 3 of IEC TS 60479-1:2005, i.e. 0,75 for hand to both feet, 0,5 for both hands to both feet.

NOTE Different touch voltage conditions, e.g. left hand to feet, hand to hand, lead to different tolerable touch voltages. Figure 2 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).

For specific consideration of additional resistances the formula becomes:

$$U_\mathrm{T} = I_\mathrm{B}\,(t_\mathrm{f}) \times \frac{1}{HF} \times (R_\mathrm{T}\,(U_\mathrm{T}) \times BF + R_\mathrm{H} + R_\mathrm{F}) \qquad \text{(B.2)}$$

where

R_H is the additional hand resistance;

R_F is the additional foot resistance.

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