IEC 61936-1

Edition 2.0 2010-08

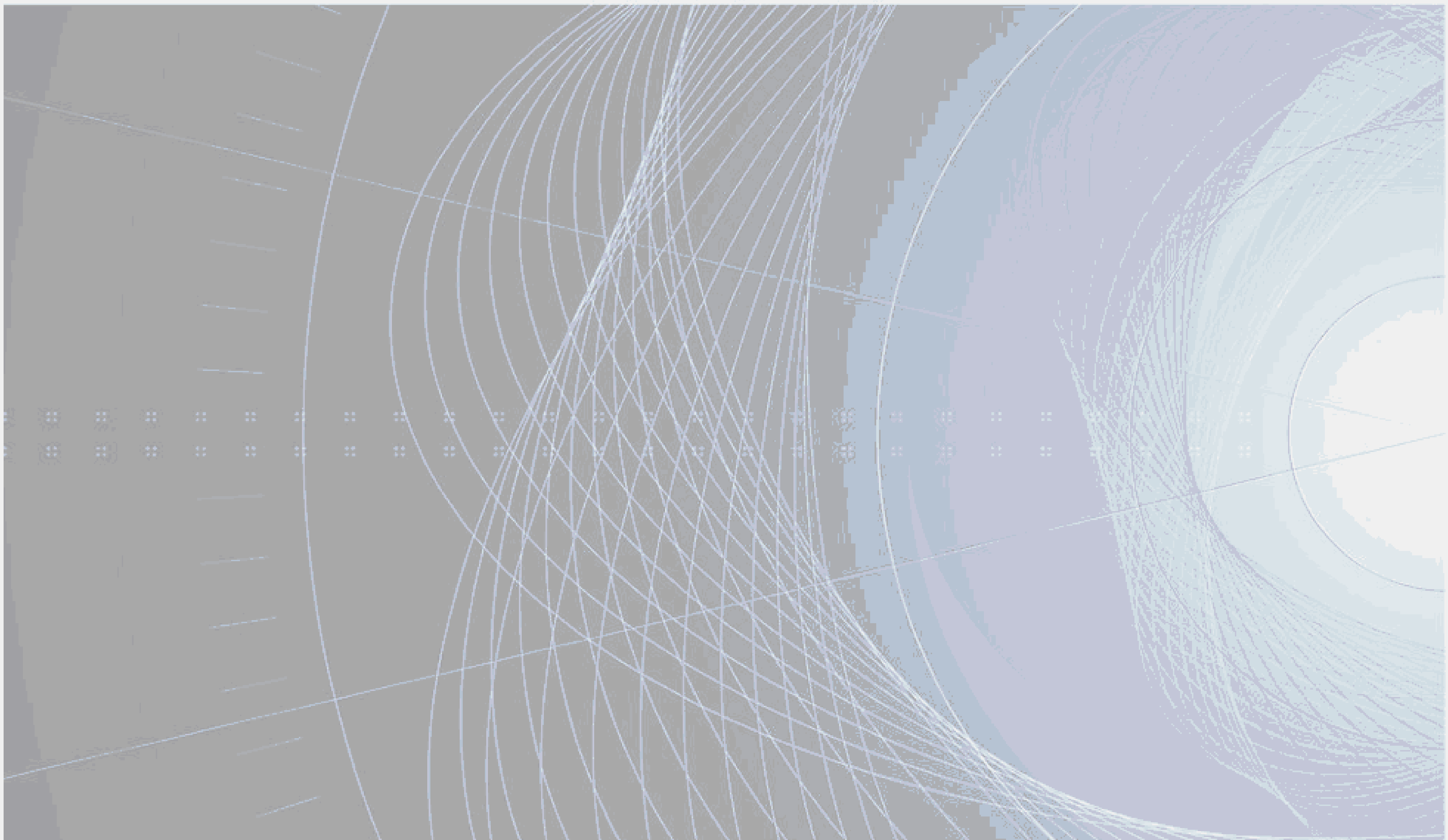
INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Power installations exceeding 1 kV a.c. –
Part 1: Common rules

Installations électriques en courant alternatif de puissance supérieure à 1 kV –
Partie 1: Règles communes



IEC 61936-1:2010

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

POWER INSTALLATIONS EXCEEDING 1 kV AC –

Part 1: Common rules

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 61936-1 has been prepared by IEC 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.

This second edition cancels and replaces the first edition, published in 2002. It constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

- new table of references for additional agreements between manufacturer/contractor/planer and user/orderer/owner (4.1.2)
- addition of minimum clearances in air not standardized by IEC but based on current practice in some countries (Annex A)
- deletion of nominal voltages (Table 1, Table 2, Clause 5)
- addition of regulations for fuses (6.2.15)
- simplification of regulations for escape routes (7.5.4)

- deletion of special regulations for operating aisles (7.5.4)
- modification of clearances for fire protection (Table 3)
- modification of safety criteria for earthing systems (10.2.1)
- modified curves of permissibly touch voltages (Figure 12, Annex B)
- deletion of numbering of subclauses without headlines
- change of "should" to "shall" in many cases or change of subclauses with "should" to a note

The text of this standard is based on the following documents:

FDIS	Report on voting
99/95/FDIS	99/96/RVD

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

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

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

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

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

The following differences exist in the countries indicated below.

- 4.3.2: The combinations are for example: –40 °C without ice and without wind; –0 °C with ice and without wind; –20 °C with wind. For special projects even value –50 °C without ice and without wind could be needed (Finland)
- 4.4.2.2a: Even class –50 °C could be needed (Finland)
- 6.2.4.1: It shall not be fuses in conductors from current transformers (Norway)
- 7.2.1: Barriers for outdoor installations shall have a minimum height of 2,0 m. They shall fulfil the same requirements as the external fence. The minimum height of live parts behind a barrier shall be N + 300 mm with a minimum of 800 mm (Finland)
- 7.2.2: The use of protective method obstacles is not allowed in electrical installations outside of buildings (Finland)
- 7.2.2: Rails, chains and ropes are not allowed as obstacles (Sweden)
- 7.2.2: The height H for outdoor installations shall be at least $H = N$ + 2 500 mm, with a minimum of 3 000 mm (Sweden)
- 7.2.4: The height H for outdoor installations shall be at least $H = N$ + 2 500 mm, with a minimum of 3 000 mm (Sweden)
- 7.2.4: The height H for outdoor installations shall be at least $H = N$ + 2 600 mm, with a minimum of 2 800 mm (Finland)
- 7.2.6: The height of the external fence shall be at least 2 000 mm. The local conditions of snow shall be taken into account (Finland)
- 7.2.6: The height of the external fence shall be at least 2 500 mm (Australia)
- 7.3: The use of indoor installations of open design is not allowed (Finland)
- 7.3: A rail shall be of not conductive material in the colours yellow/black behind (cell) doors and openings wider than 0,5 m (Norway)

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1 At the time of writing, future parts are still under consideration.

- 7.3: Rails, chains and ropes are not allowed as obstacle (Sweden)
- 7.4.1: Outside closed electrical operation areas equipment and cables shall either be constructed with an earthed intermediate shield or be protected against unintentional contact by placing out of reach. With an earthed intermediate shield, a metal enclosure for equipment or a screen for cables are understood (Sweden)
- 7.5.4: Gangways longer than 10 m shall be accessible from both ends. Indoor closed restricted access areas with length exceeding 20 m shall be accessible by doors from both ends (See IEC 60364-7-729) (Sweden)
- 7.5.8: Installations that are difficult to evacuate like Installations in underground, in mountains, wind-power stations e.g. special conditions shall be imposed to secure safe evacuation in case of fire or accident (Norway)
- 7.7: The minimum height H' of live parts above surfaces accessible to the general public shall be:

  - H' = 5 500 mm for rated voltages U_m up to 24 kV

  - $H' = N$ + 5 300 mm for rated voltages U_m above 24 kV (Finland)
- 8.2: Exposed conductive parts shall be earthed. Also extraneous conductive parts which by faults, induction, or influence could become live and be a hazard to persons or damage to property shall be earthed (Sweden)
- 8.2.1.2: The minimum height of protective barriers is 2 300 mm (Finland)
- 8.2.1.2: Rails, chains and ropes are not allowed as obstacles (Sweden)
- 8.2.2.1: Outside closed electrical operation areas equipment and cables shall either be constructed with an earthed intermediate shield or be protected against unintentional contact by placing out of reach. With an earthed intermediate shield, a metal enclosure for equipment or a screen for cables are understood (Sweden)
- 8.2.2.2: Rails, chains and ropes are not allowed as obstacles (Sweden)
- 8.2.2.2: The use of protective method obstacles is not allowed in electrical installations of buildings. The use of protective method placing out of reach is restricted only to situations where the use of insulation or enclosures or barriers is not practicable (Finland)
- 8.7.2.1: For transformers with below 1000 l special conditions are listed in FEF 2006 §4-9 (Norway)
- 8.9.1: Warning signs, markings and identifications shall be in Norwegian and special cases additional marking in other language (Norway)
- 10.2.1 and Annex B: Health & Safety Executive (HSE) has advised that 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 IEC60479-1:2005 (UK)
- 10.2.1: Permissible touch and step voltages in power installations shall be in accordance with the Federal law concerning electrical installations (High and low voltage) (SR 734.0) and the Regulations for electrical power installations (SR 743.2 StV) (Switzerland)
- Figure 1: Rails, chains and ropes are not allowed as obstacles (Sweden)

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 many national laws, standards and internal rules dealing with the matter coming within the scope of this standard 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.

The publication of this standard 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 standard.

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

POWER INSTALLATIONS EXCEEDING 1 kV AC –

Part 1: Common rules

1 Scope

This part of IEC 61936 provides common rules for the design and the erection of electrical power installations in systems with nominal voltages 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 standard 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;
- 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 standard does not apply to the design of factory-built, type-tested switchgear for which separate IEC standards exist.

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

If not otherwise required in this standard, for low-voltage electrical installations the standard series IEC 60364 applies.

2 Normative references

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

IEC 60034-1, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-3, *Rotating electrical machines – Part 3: Specific requirements for synchronous generators driven by steam turbines or combustion gas turbines*

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 60076-2:1993, *Power transformers – Part 2: Temperature rise*

IEC 60076-11, *Power transformers – Part 11: Dry-type transformers*

IEC 60079-0, *Explosive atmospheres – Part 0: Equipment – General requirements*

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

IEC 60255 (all parts), *Measuring relays and protection equipment*

IEC 60331-21, *Tests for electric cables under fire conditions – Circuit integrity – Part 21: Procedures and requirements – Cables of rated voltage up to and including 0,6/1,0 kV*

IEC 60331-1, *Tests for electric cables under fire conditions – Circuit integrity – Part 1: Test method for fire with shock at a temperature of at least 830 °C for cables of rated voltage up to and including 0,6/1,0 kV and with an overall diameter exceeding 20 mm*

IEC 60332 (all parts), *Tests on electric and optical fibre cables under fire conditions*

IEC 60364 (all parts), *Low-voltage electrical installations*

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 60617, *Graphical symbols for diagrams*

IEC 60721-2-6, *Classification of environmental conditions – Part 2-6: Environmental conditions appearing in nature – Earthquake vibration and shock*

IEC 60721-2-7, *Classification of environmental conditions – Part 2-7: Environmental conditions appearing in nature. Fauna and flora*

IEC 60754-1, *Test on gases evolved during combustion of materials from cables – Part 1: Determination of the amount of halogen acid gas*

IEC 60754-2, *Test on gases evolved during combustion of electric cables – Part 2: Determination of degree of acidity of gases evolved during the combustion of materials taken from electric cables by measuring pH and conductivity*

IEC/TS 60815-1, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 1: Definitions, information and general principles*

IEC 60826, *Design criteria of overhead transmission lines*

IEC 60865-1, *Short-circuit currents – Calculation of effects – Part 1: Definitions and calculation methods*

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

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

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

IEC 61034-1, *Measurement of smoke density of cables burning under defined conditions – Part 1: Test apparatus*

IEC 61082-1, *Preparation of documents used in electrotechnology – Part 1: Rules*

IEC 61100, *Classification of insulating liquids according of fire-point and net calorific value*

IEC 61140, *Protection against electric shock – Common aspects for installation and equipment*

IEC 61219, *Live working – Earthing or earthing and short-circuiting equipment using lances as a short-circuiting device – Lance earthing*

IEC 61230, *Live working – Portable equipment for earthing or earthing and short-circuiting*

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

IEC 61243 (all parts), *Live working – Voltage detectors*

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

IEC 62271-200, *High-voltage switchgear and controlgear – Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV*

IEC 62271-201, *High-voltage switchgear and controlgear – Part 201: AC insulation-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV*

IEC 62271-202, *High-voltage switchgear and controlgear – Part 202: High-voltage/low-voltage prefabricated substation*

IEC 62271-203, *High-voltage switchgear and controlgear – Part 203: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV*

IEC/TR 62271-303, *High-voltage switchgear and controlgear – Part 303: Use and handling of sulphur hexafluoride (SF_6)*

IEC 62305 (all parts), *Protection against lightning*

IEC 62305-4, *Protection against lightning – Part 4: Electrical and electronic systems within structures*

IEC Guide 107, *Electromagnetic compatibility – Guide to the drafting of electromagnetic compatibility publications*

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

ISO 1996-1, *Acoustics – Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment-procedures*

IEEE 80, *Guide for safety in AC substation grounding*

IEEE 980, *Guide for containment and control of oil spills in substations*

Official Journal of the European Communities, No. C 62/23 dated 28.2.1994: *Interpretative document, Essential requirements No. 2, "safety in case of fire"*

3 Terms and definitions

For the purposes of this document, the following 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

[IEC 60050-826:2004, 826-16-01]

3.1.2
nominal value
value of a quantity used to designate and identify a component, device, equipment or system

[IEC 60050-151:2001, 151-16-09]

3.1.3
nominal voltage of a system
suitable approximate value of voltage used to designate or identify a system

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

3.1.4
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

[IEC 60050-151:2001, 151-16-08]

3.1.5
highest voltage for installation
highest r.m.s value of phase-to-phase voltage for which the installation is designed in respect of its insulation

3.1.6
tested connection zone
zone in the vicinity of equipment terminals which has passed a dielectric type test with the appropriate withstand value(s), the applicable conductors being connected to the terminals in a manner specified by the manufacturer of the equipment

3.1.7
isolating distance
clearance between open contacts meeting the safety requirements specified for disconnectors

[IEC 60050-441:1984, 441-17-35]

3.1.8
isolation
switching off or disconnection of an installation, a part of an installation or an equipment from all non-earthed conductors by creating isolating gaps or distances

3.1.9
live part
conductor or conductive part intended to be energized in normal operation, including a neutral conductor, but by convention not a PEN conductor or PEM conductor or PEL conductor

[IEC 60050-195:1998, 195-02-19]

NOTE 1 This concept does not necessarily imply a risk of electric shock.

NOTE 2 For definitions of PEM and PEL see IEC 60050-195:1998, 195-02-13 and IEC 60050-195:1998, 195-02-14.

3.1.10
feeder
electric line originating at a main substation and supplying one or more secondary substations, or one or more branch lines, or any combination of these two types of installations

[IEC 60050-601:1985, 601-02-08, modified]

3.1.11
ferro-resonance
resonance of the capacitance of an apparatus with the inductance of the saturable magnetic circuit of an adjacent apparatus

[IEC 60050-604:1987, 604-01-14]

3.1.12
transient overvoltage
short duration overvoltage of a few milliseconds, or less, oscillatory or non-oscillatory, usually highly damped

[IEC 60050-604, Amendment 1:1998, 604-03-13]

3.1.13
high voltage
voltage exceeding 1 000 V a.c.

3.1.14
low voltage
voltage not exceeding 1 000 V a.c.

3.1.15
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.

3.1.16
normal conditions of operation
all operating conditions frequently encountered

NOTE These include rated operating conditions, maximum and minimum operating conditions, partial load, normal transients (start-up, shut-down, load changes) standby situations.

3.1.17
abnormal conditions of operation
operating conditions of low occurrence (typical only a few times during equipment lifetime)

NOTE These include human errors, loss of power supply, overvoltages, earthquake, etc. After such a condition has occurred, equipment inspection may be required.

3.1.18
electrical work
work on, with or near an power installation such as testing and measurement, repairing, replacing, modifying, extending, erection and inspection

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
operating areas subject to fire hazard
rooms, areas or locations, indoors or outdoors, where there is a danger, due to local or operating conditions, that hazardous quantities of easily flammable materials may come so close to the electrical equipment as to cause a fire hazard resulting from the high temperature of the equipment or due to arcing

3.2.3
sump
receptacle which is intended to receive the insulating liquid of a transformer or other equipment in case of leakage

[IEC 60050-605:1983, 605-02-30, modified]

3.2.4
catchment tank
collecting tank for the leakage liquids, rain water, etc. for one or more transformers or other equipment

3.2.5
busbar
conductor with associated connections, joints and insulated supports forming a common electrical connection between a number of circuits or individual pieces of apparatus

3.3 Definitions concerning types of installations

3.3.1
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.

EXAMPLE Transmission substation (of a transmission system), distribution substation, 400 kV substation, 20 kV substation.

[IEC 60050-605:1983, 605-01-01]

3.3.2
power station
installation whose purpose is to generate electricity and which includes civil engineering works, energy conversion equipment and all the necessary ancillary equipment.

[IEC 60050-602:1983, 602-01-01]

3.3.3
installations of open design
installations where the equipment does not have protection against direct contact

3.3.4
installations of enclosed design
installations where the equipment has protection against direct contact

NOTE For degrees of enclosure protection see IEC 60529.

3.3.5
switchgear 'bay' or 'cubicle'
each branch of a busbar in an installation

3.4 Definitions concerning safety measures against electric shock

3.4.1
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)

3.4.2
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

3.4.3
enclosure
part providing protection of equipment against certain external influences and, in any direction, protection against direct contact

3.4.4
protective barrier
part providing protection against direct contact from any usual direction of access

[IEC 60050-195:1998, 195-06-15]

3.4.5
protective obstacle
part preventing unintentional direct contact, but not preventing direct contact by deliberate action

[IEC 60050-195:1998, 195-06-16]

3.5 Definitions concerning clearances

3.5.1
clearance
distance between two conductive parts along a string stretched the shortest way between these conductive parts

[IEC 60050-441:1984, 441-17-31]

3.5.2
minimum clearance
smallest permissible clearance in air between live parts or between live parts and earth

3.5.3
protective barrier clearance
smallest permissible clearance between a protective barrier and live parts or those parts which may become subject to a hazardous voltage

3.5.4
protective obstacle clearance
smallest permissible clearance between a protective obstacle and live parts or those parts which may become subject to a hazardous voltage

3.5.5
danger zone
area limited by the minimum clearance (D_L) around live parts without complete protection against direct contact (see Figure 3)

NOTE Infringing the danger zone is considered the same as touching live parts.

3.5.6
vicinity zone
zone surrounding a danger zone, the outer boundary of which is limited by the distance D_V (see Figure 3)

NOTE 1 The outer boundary of the vicinity zone depends upon the voltage of the live part.

NOTE 2 Work in the vicinity zone is considered to be all work where a worker is either inside the zone or reaches into the zone with parts of the body or tools, equipment and devices being handled but does not reach into the danger zone.

3.5.7
working clearance
minimum safe distance (D_w) to be observed between normally exposed live parts and any person working in a substation or any conductive tool directly handled (see Figure 3)

[IEC 60050-605:1983, 605-02-25, modified]

NOTE 1 Values for electrically skilled or instructed persons are given in Figure 3. This refers only to non-live working. Specific definitions related to live working practices are found in IEC 60050-651.

NOTE 2 In Europe the term "minimum working distance" is used instead of "working clearance".

3.5.8
boundary clearance
smallest permissible clearance between an external fence and live parts or those parts which may become subject to a hazardous voltage

3.5.9
minimum height
smallest permissible vertical clearance between accessible surfaces and live parts without protection against direct contact or those parts which may become subject to a hazardous voltage (see Figure 3)

3.6 Definitions concerning control and protection

3.6.1
interlocking device
device which makes the operation of a switching device dependent upon the position or operation of one or more other pieces of equipment

[IEC 60050-441:1984, 441-16-49]

3.6.2
local control
control of operation from a point on or adjacent to the controlled switching device.

[IEC 60050-441:1984, 441-16-06]

3.6.3
remote control
control of operation at a point distant from the controlled switching device

[IEC 60050-441:1984, 441-16-07]

3.6.4
automatic reclosing
automatic reclosing of a circuit-breaker associated with a faulted section of a network after an interval of time which permits that section to recover from a transient fault

[IEC 60050-604:1987, 604-02-32]

3.7 Definitions concerning earthing

3.7.1
(local) earth
(local) ground
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.

[IEC 60050-195:1998, 195-01-03, modified]

3.7.2
reference earth
reference ground (remote earth/ground)
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.

[IEC 60050-195:1998, 195-01-01, modified]

3.7.3
earth electrode
ground electrode
conductive part, which may be embedded in a specific conductive medium, e.g. in concrete or coke, in electric contact with the Earth

[IEC 60050-195:1998, 195-02-01]

3.7.4
earthing conductor
grounding 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

[IEC 60050-195:1998, 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.

3.7.5
protective bonding conductor
protective conductor for ensuring equipotential bonding

3.7.6
earthing system
grounding system
arrangement of connections and devices necessary to earth equipment or a system separately or jointly

[IEC 60050-604:1987, 604-04-02]

3.7.7
earth rod
ground rod
earth electrode consisting of a metal rod driven into the ground

[IEC 60050-604:1987, 604-04-09]

3.7.8
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.

3.7.9
electric resistivity of soil
ρ_E
resistivity of a typical sample of soil

3.7.10
resistance to earth
R_E
real part of the impedance to earth

3.7.11
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.

3.7.12
earth potential rise
EPR
U_E
voltage between an earthing system and reference earth

3.7.13
potential
voltage between an observation point and reference earth

3.7.14
(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.

[IEC 60050-195:1998, 195-05-11, modified]

3.7.15
prospective touch voltage
U_{vT}
voltage between simultaneously accessible conductive parts when those conductive parts are not being touched

[IEC 60050-195:1998, 195-05-09, modified]

3.7.16
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

[IEC 60050-195:1998, 195-05-12]

3.7.17
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

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

3.7.18
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

3.7.19
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.

3.7.20
multi-earthed (multi-grounded) HV neutral conductor
neutral conductor of a distribution line connected to the earthing system of the source transformer and regularly earthed

3.7.21
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

[IEC 60050-826:2004, 826-12-10]

3.7.22
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

[IEC 60050-826:2004, 826-12-11, modified]

3.7.23
PEN conductor
conductor combining the functions of both protective earthing conductor and neutral conductor

[IEC 60050-826:2004, 826-13-25]

3.7.24
earth/ground fault
fault caused by a conductor being connected to earth or by the insulation resistance to earth becoming less than a specified value

[IEC 60050-151:1978[2], 151-03-40]

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

3.7.25
earth fault current
I_F
current which flows from the main circuit to earth or earthed parts at the fault location (earth fault location)

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

3.7.26
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

4 Fundamental requirements

4.1 General

4.1.1 General requirements

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.

The user shall define preferences for specific maintenance features and identify the safety requirements to be met for levels of segregation of the switchgear and controlgear to ensure minimal plant shutdown. Where necessary, the levels of segregation of switchgear shall be such as to minimize the spread of a fault, including a fire, occurring in any defined module into adjacent modules.

There are operating conditions of low occurrence or low cumulative duration which can occur and for which specific design criteria may be agreed between the user and the manufacturer. In such cases, measures required to prevent unsafe conditions and to avoid damage to electrical or plant equipment shall be taken.

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[2] IEC 60050-151:1978 has been replaced in 2001, but for this definition (151-03-40) the 1978 publication is applicable.

The generators shall be capable of meeting the requirements for connection to the power system grid or local grid, e.g. for voltage regulation, frequency response, etc.

4.1.2 Agreements between supplier (manufacturer) and user

The working procedures of the user shall be taken into account in the design of the installation.

For design and erection of power installations, additional agreements between manufacturer/contractor/planner and user/orderer/owner shall be followed, which also may have effects to necessary operational requirements. References can be found in the following subclauses:

Subclause	Item
4.1.1	General requirements (specific design criteria)
4.2.2	Voltage classification
4.4.2.1	Climatic and environmental conditions (for auxiliary equipment: indoor)
4.4.2.2	Climatic and environmental conditions (for auxiliary equipment: outdoor)
4.4.3.1	Conditions different from the normal environmental conditions
6.1.2	Compliance with operational and safety procedures
6.2.1	Method of indication (contact position of interrupting or isolating equipment)
6.2.1	Interlocks and/or locking facilities
6.2.1	Switching devices (reduced rating)
6.2.1	Rating of switchgear (specific requirements)
6.2.8	Level of pollution
6.2.8	Outdoor insulators in polluted or heavy wetting conditions
6.2.9.1	Insulated cables (temperature rise)
7.1	Higher values for distances, clearances and dimensions
7.1	Installations (operating procedures)
7.1.2	Documentation (extent of the documentation)
7.1.3	Transport routes (load capacity, height and width)
7.1.5	Lighting (presence and extent of the lighting)
7.5.4	Maintenance and operating areas (distances of the escape route)
8.4	Means to protect persons working on electrical installations (working procedures)
8.4.3	Devices for determining the de-energized state (extent of provisions)
8.4.4	Devices for earthing and short-circuiting (Extent of provision or supply)
8.4.5.1	Equipment acting as protective barriers against adjacent live parts (extent of Insertable insulated partitions)
8.4.5.2	Equipment acting as protective barriers against adjacent live parts (extent of insertable partition walls)
8.5	Protection from danger resulting from arc fault (degree of importance of measures)
8.6	Protections against direct lightning strokes (method of analysis)
8.7.1	Requirements for fire extinguishing equipment
9.1	Monitoring and control systems (agreement of fault level and protection grading studies)
9.3	Compressed air system (sectionalization for maintenance)
9.4	SF_6 gas handling plants (design and capacity of the plant)
11	Inspection and testing (extent of the inspection and testing / specification / documentation)
11.3	Tests during installation and commissioning (requirements / test equipment / schedule of tests)
11.4	Trial running (performance)

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. Furthermore 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 Voltage classification

The users shall define the nominal voltage and the maximum operating voltage of their system. Based on the maximum operating voltage, the highest voltage for installation (U_m) shall be selected either from Table 1, Table 2 or Annex A.

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 purpose of this standard all types of short-circuit shall be considered, e.g.:

- three-phase;
- phase-to-phase;

– phase-to-earth;
– double phase-to-earth.

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.

Methods for the calculation of short-circuit currents in three-phase a.c. systems are given in the IEC 60909 series.

Methods for the calculation of the effects of short-circuit current are given in IEC 60865-1 and, for power cables, in IEC 60949.

4.2.5 Rated frequency

Installations shall be designed for the rated frequency of the system in which they shall operate.

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.

NOTE 1 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][3].

NOTE 2 Maximum permissible levels of radio interference may be given by national or local authorities.

NOTE 3 Guidance on acceptable levels of radio interference voltage for switchgear and controlgear can be found in IEC 62271-1:2007.

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.

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.

NOTE National and/or international regulations may specify acceptable levels.

4.2.8 Overvoltages

Equipment shall be protected against overvoltages resulting from switching operations or lightning that could exceed the withstand values according to IEC 60071-1 and 60071-2.

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3 Figures in square brackets refer to the bibliography.

4.2.9 Harmonics

Consideration should be given to the effect of harmonic currents and harmonic voltages on the installation, e.g. in industrial installations. Harmonic analyses may be required to determine what corrective measures are needed to meet local regulations and/or to ensure correct operation of the whole electrical system.

4.3 Mechanical requirements

4.3.1 Equipment and supporting structures

Equipment and supporting structures, including their foundations, shall withstand the anticipated mechanical stresses.

Two load cases shall be considered, normal and exceptional. In each of these load cases, several combinations shall be investigated, the most unfavourable of which shall be used to determine the mechanical strength of the structures.

In the normal load case, the following loads shall be considered:

– dead load;
– tension load;
– erection load;
– ice load;
– wind load.

NOTE 1 There may be a need to consider temporary stresses and loads that may be applied during construction or maintenance procedures. Specific equipment can be affected by cyclic loads (refer to specific equipment standards).

In the exceptional load case, dead load and tension load acting simultaneously with the largest of the following occasional loads shall be considered:

– switching forces;
– short-circuit forces;
– loss of conductor tension.

NOTE 2 The probability of earthquake loads should be considered in developing the exceptional load case. See also 4.4.3.5.

4.3.2 Tension load

The tension load shall be calculated from the maximum conductor tension under the most unfavourable local conditions.

Possible combinations include, for example:

- –20 °C without ice and without wind;
- –5 °C with ice and without wind;
- +5 °C with wind.

4.3.3 Erection load

The erection load is a load of at least 1,0 kN applied at the most critical position of a supporting structure, tensioning portal, etc.

4.3.4 Ice load

In regions where icing can occur, the resulting load on flexible conductors and on rigid busbars and conductors shall be taken into account.

If local experience or statistics are not available, ice coatings of 1 mm, 10 mm or 20 mm based on criteria given in IEC 62271-1:2007 may be assumed. The density of the ice is assumed to be 900 kg/m^3 in accordance with IEC 60826.

4.3.5 Wind load

Wind loads, which can be very different depending on the local topographic influences and the height of the structures above the surrounding ground, shall be taken into account. The most unfavourable wind direction shall be considered.

IEC 62271-1:2007 contains requirements for wind loading on switchgear and controlgear.

4.3.6 Switching forces

Switching forces shall be considered when designing supports. The forces shall be determined by the designer of the equipment.

4.3.7 Short-circuit forces

The mechanical effects of a short-circuit can be estimated by the methods detailed in IEC 60865-1.

NOTE The CIGRÉ technical brochure "Mechanical effects of short-circuit currents in open air substations" gives additional advice.

4.3.8 Loss of conductor tension

A structure with tension insulator strings shall be designed to withstand the loss of conductor tension resulting from breakage of the insulator or conductor which gives the most unfavourable load case.

NOTE 1 General practice is to base the calculation on 0 °C, no ice and no wind load.

NOTE 2 For bundle conductors, only one subconductor is assumed to fail.

4.3.9 Vibration

Vibration caused by wind, electromagnetic stresses and traffic (e. g. temporary road and railway traffic) shall be considered. The withstand capability of equipment against vibrations shall be given by the manufacturer.

4.3.10 Dimensioning of supporting structures

The dimensioning of supporting structures shall be in accordance with applicable codes and standards. Security factors are given in national rules.

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. Equipment can be selected according to IEC 60721 series.

4.4.2 Normal conditions

4.4.2.1 Indoor

a) The ambient air temperature does not exceed 40 °C and its average value, measured over a period of 24 h, does not exceed 35 °C.

   The minimum ambient air temperatures are:

   - –5 °C for class "–5 indoor",
   - –15 °C for class "–15 indoor" and
   - –25 °C for class "–25 indoor".

   On auxiliary equipment, such as relays and control switches, intended to be used in ambient air temperature below –5 °C, an agreement between supplier and user is necessary.

b) The influence of solar radiation may be neglected.

c) The altitude does not exceed 1 000 m above sea level.

d) The ambient air is not significantly polluted by dust, smoke, corrosive and/or flammable gases, vapours or salt.

e) The average value of the relative humidity, measured over a period of 24 h, does not exceed 95 %.

   For these conditions condensation may occasionally occur.

   NOTE 1 Condensation can be expected where sudden temperature changes occur in periods of high humidity.

   NOTE 2 To avoid breakdown of insulation and/or corrosion of metallic parts due to high humidity and condensation, equipment designed for such conditions and tested accordingly should be used.

   NOTE 3 Condensation may be prevented by special design of the building or housing, by suitable ventilation and heating of the station or by the use of dehumidifying equipment.

f) Vibration due to causes external to the equipment or to earth tremors is negligible.

g) Electromagnetic disturbances shall be considered as described in IEC Guide 107.

4.4.2.2 Outdoor

a) The ambient air temperature does not exceed 40 °C and its average value, measured over a period of 24 h, does not exceed 35 °C.

   The minimum ambient air temperatures are:

   - –10 °C for class "–10 outdoor",
   - –25 °C for class"–25 outdoor",
   - –30 °C for class "–30 outdoor" and
   - –40 °C for class "–40 outdoor".

   Rapid temperature changes shall be taken into account.

   Auxiliary equipment, such as relays and control switches, intended to be used in ambient air temperatures below –5 °C, shall be the subject of an agreement between supplier and user.

b) Solar radiation up to a level of 1 000 W/m^2 (on a clear day at noon) shall be considered.

NOTE 1 Under certain conditions of solar radiation, appropriate measures, for example roofing, forced ventilation, etc., may be necessary, or derating should be used in order not to exceed the specified temperature rises.

NOTE 2 Details of global solar radiation are given in IEC 60721-2-4.

NOTE 3 UV radiation can damage some synthetic materials. For more information, consult the IEC 60068 series.

c) The altitude does not exceed 1 000 m above sea level.

d) The ambient air is not significantly polluted by dust, smoke, corrosive gases, vapours or salt. Pollution does not exceed pollution class c – Medium, according to IEC/TS 60815-1.

e) The ice coating does not exceed 1 mm for class 1, 10 mm for class 10 and 20 mm for class 20. Additional information is given in 4.3.4.

f) The wind speed does not exceed 34 m/s (corresponding to 700 Pa on cylindrical surfaces).

NOTE 4 Characteristics of wind are described in IEC 60721-2-2.

g) Account should be taken of the presence of condensation or precipitation. Precipitation in the form of dew, condensation, fog, rain, snow, ice or hoar frost shall be taken into account.

NOTE 5 Precipitation characteristics for insulation are described in IEC 60060-1 and IEC 60071-1. For other properties, precipitation characteristics are described in IEC 60721-2-2.

h) Vibration due to causes external to the equipment or to earth tremors is negligible.

i) Electromagnetic disturbances shall be considered as described in IEC Guide 107.

4.4.3 Special conditions

4.4.3.1 General

When high-voltage equipment is used under conditions different from the normal environmental conditions given in 4.4.2, the user's requirements shall refer, for example, to the standardized steps given in the following subclauses.

4.4.3.2 Altitude

For installations situated at an altitude higher than 1 000 m above sea level, the insulation level of external insulation under the standardized reference atmospheric conditions shall be determined by multiplying the insulation withstand voltages required at the service location by a factor K_a in accordance with IEC 62271-1:2007.

NOTE 1 For internal pressurized insulation, the dielectric characteristics are identical at any altitude and no special precautions need be taken.

NOTE 2 For low-voltage auxiliary and control equipment, no special precautions need be taken if the altitude is lower than 2 000 m above sea level. For higher altitudes, see IEC 60664-1.

NOTE 3 The pressure variation due to altitude is given in IEC 60721-2-3. Regarding this phenomenon, particular attention should be devoted to the following points:

– thermal exchanges by convection, conduction or radiation;
– efficiency of heating or air-conditioning;
– operating level of pressure devices;
– efficiency of diesel generating set or compressed air station;
– increase of corona effect.

NOTE 4 The correction factor K_a of IEC 62271-1:2007 reflects the fact that modification is not required for altitudes below 1 000 m.

4.4.3.3 Pollution

For equipment in polluted ambient air, a pollution class d (heavy), or class e (very heavy), as defined in IEC/TS 60815-1, should be specified.

4.4.3.4 Temperature and humidity

For equipment in a place where the ambient temperature can be significantly outside the normal service condition range stated in 4.4.2, the preferred ranges of minimum and maximum temperature to be specified should be as follows:

–50 °C and +40 °C for very cold climates;

–5 °C and +50 °C for very hot climates.

In certain regions with frequent occurrence of warm, humid winds, sudden changes of temperature may occur, resulting in condensation, even indoors.

In tropical indoor conditions, the average value of relative humidity measured during a period of 24 h can be 98 %.

In some underground installations, equipment might be located under water. Such equipment shall be designed accordingly and proper operating procedures defined.

4.4.3.5 Vibration

Vibration due to external causes shall be dealt with in accordance with IEC 60721-2-6.

Installations situated in a seismic environment shall be designed to take this into account. This shall be achieved by applying the following measures.

a) Any individual equipment shall be designed to withstand the dynamic forces resulting from the vertical and horizontal motions of the soil. These effects may be modified by the response of the foundation and/or the supporting frame and/or the floor in which this equipment is installed. The spectrum of the impulse earthquake shall be considered for the design of the equipment.
b) The layout shall be chosen in order to limit the following loads to acceptable values:
   – loads due to interconnections between adjoining devices needing to accommodate large relatively axial, lateral, torsional or other movements, bearing in mind that other stresses may develop during an earthquake;
   – the service stresses of equipment, which may be transmitted through a common monolithic foundation or floor (for example opening/reclosing of circuit-breakers).

Where load specifications apply to the installation of civil work or equipment to meet seismic conditions, then these specifications shall be observed.

4.5 Special requirements

4.5.1 Effects of small animals and micro-organisms

If biological activity (through birds, other small animals or micro-organisms) is a hazard, measures against such damage shall be taken. These may include appropriate choice of materials, measure to prevent access and adequate heating and ventilating (for more details see IEC 60721-2-7).

4.5.2 Noise level

If noise level limits are given (usually by administrative authorities), they shall be achieved by appropriate measures such as

– using sound insulation techniques against sound transmitted through air or solids;
– using low noise equipment.

Criteria for noise evaluation for different places and different periods of day are given in ISO 1996-1.

4.5.3 Transport

The transport to site, e.g. large transformers and storage constraints may have consequences on the design of the high-voltage electrical installation.

5 Insulation

5.1 General

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

Insulation coordination shall be in accordance with IEC 60071-1.

5.2 Selection of insulation level

The insulation level shall be chosen according to the established highest voltage for installation U_m 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 neutral 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 neutral earthing or the protection by surge arresters make it inappropriate to lower the level of insulation, one of the higher alternative values of Table 1, Table 2 and Annex A shall be chosen.

In installations in which the configuration of the system, the adopted method of neutral earthing or the protection by surge arresters makes it appropriate to lower the level of insulation, the lower alternative values of Table 1, Table 2 and Annex A are sufficient.

5.2.2 Consideration of rated withstand voltages

In the voltage range I (1 kV < U_m ≤ 245 kV), the choice shall be based on the rated lightning impulse withstand voltages and the rated short-duration power-frequency withstand voltages of Table 1; in the voltage range II (U_m > 245 kV) the choice shall be based on the rated switching impulse withstand voltages and the rated lightning impulse withstand voltages given in Table 2. Values of rated insulation levels not standardized by IEC but based on current practice in some countries are listed in Annex A (Tables A.1, A.2 and A.3).

5.3 Verification of withstand values

If the minimum clearances in air given in Table 1, Table 2 and Annex A are maintained, it is not necessary to apply dielectric tests.

If the minimum clearances in air 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 withstand voltage values given in Table 1, Table 2 and Annex A.

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

NOTE In accordance with IEC 60071-2:1996, Annex A, 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 General

The minimum clearances in air given in Table 1, Table 2 and Annex A apply for altitudes up to 1 000 m above sea level. For higher altitudes, see 4.4.3.2.

NOTE Some values of minimum clearances are designated as "*N*". This is a symbol for those minimum clearances on which safety distances as given in 7 are based.

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 (see Tables 1a and 1b as well as Tables 2a and 2b of IEC 62271-1:2007). If between such parts of an installation the minimum clearances of Table 1 for range I, respectively the minimum phase-to-phase clearances of Table 2 for range II are increased by 25 % or more, it is not necessary to apply dielectric tests.

5.4.2 Minimum clearances in voltage range I

In the voltage range I (see Table 1) the minimum clearances in air are based on unfavourable electrode configurations with small radii of curvature (i.e. rod-plate). As the rated lightning impulse withstand voltage (LIWV) in these voltage ranges is the same as for the phase-phase insulation and phase-earth insulation, the clearances apply for both insulation distances.

5.4.3 Minimum clearances in voltage range II

In voltage range II (see Table 2) the 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).

Table 1 – Minimum clearances in air – Voltage range I
(1 kV < U_m ≤ 245 kV)

Voltage range	Highest voltage for installation	Rated short-duration power-frequency withstand voltage	Rated lightning impulse withstand voltage [a]	Minimum phase-to-earth and phase-to-phase clearance N	
	U_m r.m.s.	U_d r.m.s.	U_p 1,2/50 µs (peak value)	Indoor installations	Outdoor installations
	kV	kV	kV	mm	mm
I	3,6	10	20	60	120
			40	60	120
	7,2	20	40	60	120
			60	90	120
	12	28	60	90	150
			75	120	150
			95	160	160
	17,5	38	75	120	160
			95	160	160
	24	50	95	160	
			125	220	
			145	270	
	36	70	145	270	
			170	320	
	52	95	250	480	
	72,5	140	325	630	
	123	185 [b]	450 [b]	900	
		230	550	1 100	
	145	185 [b]	450 [b]	900	
		230	550	1 100	
		275	650	1 300	
	170	230 [b]	550 [b]	1 100	
		275	650	1 300	
		325	750	1 500	
	245	275 [b]	650 [b]	1 300	
		325 [b]	750 [b]	1 500	
		360	850	1 700	
		395	950	1 900	
		460	1 050	2 100	

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

[b] If values are considered insufficient to prove that the required phase-to-phase withstand voltages are met, additional phase-to-phase withstand tests are needed.

Table 2 – Minimum clearances in air – Voltage range II
(U_m > 245 kV)

Voltage	Highest	Rated	Rated	Minimum	Rated	Minimum

range	voltage for installation [c]	lightning impulse withstand voltage [a]	switching impulse withstand voltage	phase-to-earth clearance		switching impulse withstand voltage	phase-to-phase clearance	
	U_m r.m.s.	U_p 1,2/50 µs (peak value)	U_s Phase-to-earth 250/2 500 µs (peak value)	Conductor – structure	Rod – structure N	U_s Phase-to-phase 250/2 500 µs (peak value)	Conductor – conductor parallel	Rod – conductor
	kV	kV	kV	mm		kV	mm	
II	300	850/950	750	1 600 1 700 [b]	1 900	1 125	2 300	2 600
		950/1 050	850	1 800 1 900 [b]	2 400	1 275	2 600	3 100
	362	950/1 050	850	1 800 1 900 [b]	2 400	1 275	2 600	3 100
		1 050/1 175	950	2 200	2 900	1 425	3 100	3 600
	420	1 050/1 175	850	1 900 2 200 [b]	2 400	1 360	2 900	3 400
		1 175/1 300	950	2 200 2 400 [b]	2 900	1 425	3 100	3 600
		1 300/1 425	1 050	2 600	3 400	1 575	3 600	4 200
	550	1 175/1 300	950	2 200 2 400 [b]	2 900	1 615	3 700	4 300
		1 300/1 425	1 050	2 600	3 400	1 680	3 900	4 600
		1 425/1 550	1 175	3 100	4 100	1 763	4 200	5 000
	800	1 675/1 800	1 300	3 600	4 800	2 210	6 100	7 400
		1 800/1 950	1 425	4 200	5 600	2 423	7 200	9 000
		1 950/2 100	1 550	4 900	6 400	2 480	7 600	9 400

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

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

NOTE The introduction of U_m above 800 kV is under consideration. In IEC 60038, 1 050 kV, 1 100 kV and 1 200 kV are listed.

5.5 Minimum clearances between parts under special conditions

The minimum clearances between parts of an installation which may be subject to phase opposition shall be 20 % higher than the values given in Table 1, Table 2 and Annex A.

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.

If conductors swing under the influence of short-circuit forces, 50 % of the minimum clearances of Table 1, Table 2 and Annex A shall be maintained as a minimum.

If conductors swing under the influence of wind, 75 % of the minimum clearances of Table 1, Table 2 and Annex A shall be maintained as a minimum.

In case of rupture of one sub-chain in a multiple insulator chain, 75 % of the minimum clearances of Table 1, Table 2 and Annex A shall be maintained as a minimum.

If neither the neutral point nor a phase conductor is effectively earthed in an installation that is fed via auto transformers, the insulation of the lower voltage side shall be rated according to the highest voltage for equipment on the higher voltage side. Attention should be paid to neutral point insulation according to the method of neutral earthing.

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 Table 1, Table 2 and Annex A need not be maintained because the ability to withstand the test voltage is established by a dielectric type test.

6 Equipment

6.1 General requirements

6.1.1 Selection

Equipment shall be selected and installed to satisfy the following requirements:

a) safe construction when properly assembled, installed and connected to supply;
b) safe and proper performance taking into account the external influences that can be expected at the intended location;
c) safe and proper performance during normal operation and in the event of reasonably expected conditions of overload, abnormal operation and fault, without resulting in damage that would render the equipment unsafe;
d) protection of personnel during use and maintenance of the equipment.

6.1.2 Compliance

Equipment shall comply with the relevant IEC standards with particular attention to IEC Guide 107 and ISO/IEC Guide 51.

If compliance with operational and safety procedures specific to a certain installation is required, additional requirements shall be specified by the user.

6.1.3 Personnel safety

Particular attention shall be given to the safety of personnel during the installation, operation and maintenance of equipment.

This may include

a) manuals and instructions for transport, storage, installation, operation and maintenance,
b) special tools required for operation, maintenance and testing,
c) safe working procedures developed for specific locations,
d) safe earthing measures.

6.2 Specific requirements

6.2.1 Switching devices

A facility shall be provided to indicate the contact position of the interrupting or isolating equipment (including earthing switches). The method of indication in accordance with the equipment standard shall be specified by the user.

The position indicator shall provide an unambiguous indication of the actual position of the equipment primary contacts.

The device indicating the open/close position shall be easily visible to the operator.

Disconnectors and earthing switches shall be installed in such a way that they cannot be inadvertently operated by tension or pressure exerted manually on operating linkages.

Where specified by the user, interlocks and/or locking facilities shall be provided to prevent maloperation.

If an interlocking system is provided which prevents the earthing switch from carrying the full short-circuit current, it is permissible, by agreement with the user, to specify a reduced rating for the switch which reflects its possible short-circuit-current stress.

Equipment shall be installed in such a way that ionized gas released during switching does not result in damage to the equipment or in danger to operating personnel.

NOTE The word "damage" is considered to signify any failure of the equipment which impairs its function.

Ratings of switchgear shall be based on the appropriate IEC high-voltage standards. The switching of certain circuits may however require the use of more severe constraints than defined in those standards. Examples of such circuits are filter banks and loads having very high X/R ratios such as large transformers and generators. The specific requirements of switchgear for such circuits shall be agreed upon between the user and supplier.

6.2.2 Power transformers and reactors

Unless otherwise stated, this subclause applies to both transformers and reactors even when only transformers are referred to in the text.

The main selection criteria for transformers are given in Clause 4 and Clause 8.

The transformers are classified taking into account the dielectric in contact with the winding and the type of internal or external cooling, as described in Clause 3 of IEC 60076-2:1993.

When designing the transformer 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).

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

Water (ground water, surface water and waste water) shall not be polluted by transformer installations. This shall be achieved by the choice of the design of transformer 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 transformer whilst the transformer 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 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. Adjacent metal parts such as foundation reinforcements, fences and earthing grids shall not be subject to excessive temperature rise under normal load conditions.

The risk of damage to transformers from overstresses resulting from ferroresonance, harmonics and other causes should be minimized by appropriate system studies and measures.

Transformer pressure relief devices, if used, shall be arranged to direct the oil discharge downwards and away from the operational controls where personnel are likely to be standing.

6.2.3 Prefabricated type-tested switchgear

The requirements for gas insulated metal-enclosed switchgear (GIS), metal-enclosed switchgear, insulation-enclosed switchgear and other prefabricated type-tested switchgear assemblies are given in 7.4. For safety of personnel and gas handling, refer to 8.8.3 and 9.4.

6.2.4 Instrument transformers

The secondary circuits of instrument transformers shall be bonded to earth, or the secondary circuits shall be segregated by earthed metallic screening, in accordance with the recommendations of Clause 10.

The earthable point of the secondary circuit shall be determined in such a way that electrical interference is avoided.

Instrument transformers shall be installed in such a way that their secondary terminals are easily accessible when the switchgear assembly has been de-energized.

6.2.4.1 Current transformers

The rated overcurrent factor and the rated burden shall be selected so as to ensure correct functioning of the protective equipment and prevent damage to measuring equipment in the event of a short-circuit.

In high-voltage networks where the primary time constant is long and where reclosing is practiced, it is recommended that the transient stress due to the aperiodic portion of the short-circuit current be taken into account. The recommendations of IEC 60044-6 should be considered.

If measuring devices are also connected to protective current transformer cores, the measuring devices shall, if necessary, be protected against the damage resulting from large short-circuit currents by means of suitable auxiliary transformers.

If necessary, an effective screen between the primary and secondary circuit shall be provided for the reduction of the transient overvoltages on secondary circuits arising from the switching operation.

To protect against dangerous overvoltages, provisions shall be made to facilitate shorting the secondary windings of current transformers.

6.2.4.2 Voltage transformers

Voltage transformers shall be selected in such a way that the nominal output and accuracy are adequate for the connected equipment and wiring. The effects of ferroresonance shall be considered.

The secondary side of voltage transformers shall be protected against the effects of short-circuits, and it is recommended that protective devices be monitored.

6.2.5 Surge arresters

Surge arresters shall be designed or positioned in such a way as to provide personnel safety in case of breaking of the housing or operating of any pressure relief device.

The volt-time characteristics of surge arresters installed in the same circuit as current-limiting fuses shall take into account the overvoltages produced by the fuses.

If monitors are provided in the earth conductor of non-linear resistor type arresters, then the conductor between an arrester and the monitor, and the monitor itself, shall be protected in such a way as to prevent it being touched. It shall be possible to read the monitors and any counters with the equipment energized.

6.2.6 Capacitors

The risk of resonance and overvoltages due to harmonics shall be taken into consideration, and appropriate means for limitation of this risk shall be provided.

For the selection of the rated voltage and the current capacity of capacitors, the voltage increase caused by inductive reactances connected in series such as damping reactors and sound frequency or filter circuits shall be considered.

Capacitors for coupling, voltage measuring and over-voltage protection shall be selected according to the rated voltage of the switchgear, even if the operating voltage is lower.

Safe discharge of power capacitors shall be guaranteed. Discharge units shall be thermally and mechanically capable of carrying out their task.

The short-circuiting and earthing facilities provided for a capacitor bank shall take into account the interconnection of units within the bank, the discharge resistors and the type of fusing.

6.2.7 Line traps

The bandwidth shall be determined in accordance with the network frequency allocation.

6.2.8 Insulators

Unless otherwise specified, the minimum specific creepage distance of insulators shall comply with the recommendations of IEC/TS 60815-1, IEC/TS 60815-2 and IEC/TS 60815-3 for the level of pollution specified by the user.

The requirements of the wet test procedure of IEC 62271-1:2007 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.

6.2.9 Insulated cables

6.2.9.1 Temperature

Insulated cables shall be selected and laid in such a way that the maximum permitted temperature is not exceeded for conductors, their insulation, the connections, the equipment terminals or the surroundings under the following conditions:

a) normal operation;
b) special operating conditions, subject to previous agreement between the supplier and the user;

c) short-circuit.

The connection of a cable to equipment (for example motors, circuit-breakers) shall not result in the cable being subjected to temperatures higher than those admissible for the cable in the foreseeable operating conditions.

6.2.9.2 Stress due to temperature changes

The stress on equipment due to temperature-dependent changes in the length of conductors shall be taken into account. If necessary, the stress shall be relieved by suitable measures (for example flexible connections, expansion terminations or snaking). If these measures are not taken, the additional forces due to temperature changes shall be taken into account during verification of the mechanical strength of the equipment.

6.2.9.3 Flexible reeling and trailing cables

Flexible reeling and trailing cables shall be selected in accordance with the following requirements and conditions:

a) trailing cables, or cables having at least equivalent mechanical and electrical characteristics as trailing cables, shall be used for supplying power to hoisting mobile or moveable equipment;
b) in the case of more severe mechanical stress, for example where the cables are subject to abrasion, tension, deflection or winding during operation, double-sheathed trailing cables or cables with at least equivalent mechanical and electrical characteristics as trailing cables shall be used;
c) insulated cables for the power supply of hoisting mobile or moveable equipment shall contain a protective earth conductor;
d) the design of any connection, be it a joint, termination or other connection arrangement shall be such that in the event of a strain being placed upon the cable, the protective conductor shall be the last to part or separate;
e) insulated cables which are to be wound on a drum shall be dimensioned so that when the conductor is fully wound and subject to the normal service loading, the maximum permitted temperature is not exceeded.

The terminal ends of flexible and trailing cables shall be free from tension and compression; cable sleeves shall be protected against stripping and cable ends against twisting. The terminals shall also be designed so that the cables will not kink.

6.2.9.4 Crossings and proximities

Where insulated cables cross or are near to gas, water or other pipes, an appropriate clearance shall be maintained between cables and the pipelines. Where this clearance cannot be maintained, contact between the cables and the pipelines shall be prevented, for example, by the insertion of insulating shells or plates. These measures shall be coordinated with the operator of the pipeline. In the case of a long parallel routing, a calculation of the overvoltage induced on the pipeline during a short-circuit shall be effected. It may be necessary to determine appropriate measures (for example, an alternative routing for the cables or pipelines, or a greater clearance between cables and pipelines).

Where insulated cables cross or are near to telecommunication installations, an appropriate clearance shall be maintained between cables and telecommunication installations.

In the case of a long parallel routing, the overvoltage induced on the telecommunication installation during a short-circuit shall be calculated (for guidance refer to ITU directives). It may be necessary to take appropriate measures to reduce this overvoltage (alternative routing for the cables or the telecommunication installations, greater clearance between cables and telecommunication installations).

Where insulated cables cross or are near to other insulated cables, the mutual thermal effects shall be calculated in order to determine the minimum clearance between cables or to determine other appropriate measures (e.g. derating). Cables shall be installed at a sufficient distance from heat sources or shall be separated from such heat sources by means of thermal insulating shields.

NOTE Crossing and proximity of insulated cables, gas and water pipes or other pipes and appropriate clearance should be in compliance with national regulations and standards.

6.2.9.5 Installation of cables

Provision of suitable access shall be made for the maintenance and testing of cables (see Clause 11).

Care shall be taken to protect the cable from mechanical damage during and after installation as follows:

a) to avoid any damage to the cable, the laying operations shall be performed at the ambient temperature specified by the equipment standards or by the manufacturer;
b) single-core insulated cables shall be laid in such a way as to ensure that the forces resulting from short-circuit currents do not cause damage;
c) the method of laying shall be chosen to ensure that the external effects are limited to acceptable safe values. In addition, when buried in troughs, the cables shall be installed at a specific depth and covered by slabs or a warning grid to prevent any damage being caused by third parties. Underground and submarine cables shall be mechanically protected where they emerge from the water or the soil;
d) laying of cables in earth shall be carried out on the bottom of a cable trench free of stones. The bedding shall be in sand or soil, free of stones. Special constructions of cables can be chosen, if necessary, to protect against chemical effects;
e) measures shall be taken to prevent cables in troughs from being damaged by vehicles running over them;
f) ground movements and vibrations shall be taken into account;
g) for vertical installations, the cable suitable for that installation shall be supported by suitable cleats, at intervals determined by the cable construction, and information provided by the manufacturer.

Cables installed in metallic pipes shall be grouped in such a way that the conductors of all phases (and the neutral, if any) of the same circuit are laid in the same pipe to minimize eddy currents. Consideration should be given to the location of the earthing conductor.

Insulated cables shall be installed so that touch voltages are within the permissible values, or so that accessible parts with impermissible touch voltages are protected against contact by adequate measures.

NOTE There may be a risk of high circulating currents in screens of sheathed single-core cables, especially when laid flat.

Metallic sheaths shall be earthed in accordance with Clause 10.

The length of cable connecting transformers and reactors to a circuit shall be selected so as to minimize the occurrence of ferroresonance.

Care shall be taken to limit the mechanical stress on equipment when connecting power cables.

6.2.9.6 Bending radius

The minimum values of bend radius during and after installation are dependent on the type of cable. These are given in the relevant standards or shall be specified by the manufacturer.

6.2.9.7 Tensile stress

The maximum permissible tensile stress during laying depends on the nature of the conductor and on the type of cable. These are given in the relevant standards or shall be specified by the manufacturer.

The continuous static and peak tensile stress applied to the conductors of flexible and trailing cables shall be as small as possible, and shall not exceed the values given by the manufacturer.

6.2.10 Conductors and accessories

This subclause deals with conductors (rigid or flexible) and accessories, which are part of outgoing feeders or busbars in installations.

Provision shall be made to allow for the expansion and contraction of conductors caused by temperature variations. This shall not apply where the stress caused by temperature variations has been allowed for in the conductor system design.

Joints between conductors and connections between conductors and equipment shall be without defects and shall not deteriorate while in service. They shall be chemically and mechanically stable. The joint faces shall be suitably prepared and connected as specified for the type of connection. The temperature rise of a connection between conductors and switchgear in service shall not exceed the values specified in IEC 62271-1:2007.

NOTE The open ends of tubular busbars should be plugged to prevent corrosion and birds nesting.

6.2.11 Rotating electrical machines

The risk of personal injury from faults within the terminal boxes of machines shall be minimized. The terminal boxes of motors shall withstand the local short-circuit conditions. Current-limiting devices may be necessary.

The degree of protection against the ingress of objects, dust and water shall be chosen in accordance with the special climatic and environmental conditions at the site of installation. Hazardous parts of the machine shall be protected against accidental contact by persons.

The insulation level of the machine shall be selected in accordance with IEC 60034-1.

Sufficient cooling shall be provided.

NOTE Machines should be protected against exceeding the maximum permitted temperature rise by use of suitable electric protective devices. Particularly for large machines or those critical for a production process, protection devices should be installed which indicate an internal fault of the machine or, if necessary, automatically shut it down.

The overall design of the installation shall identify requirements for the type of motor enclosure, particularly if the motor is to be installed in a hazardous area. In addition, safety issues such as noise levels, maximum temperature of surfaces accessible to personnel, control of spillage and guarding, shall meet the particular requirements of the installation.

Starting large motors results in voltage drops in the electrical distribution system. Different techniques are available for reducing the impact on the electrical network when starting large motors. The protection equipment shall be designed to provide adequate protection of the motor during the complete starting sequence.

The contribution of large motors to the short-circuit current shall be considered.

6.2.12 Generating units

The type of power rating for the generating unit shall be stated (e.g. continuous, prime, or standby power). Operation of the generator in parallel with the utility or in parallel with other generators should be stated. The switching devices to be used for synchronizing shall be defined.

The overall design of the installation shall identify the general safety requirements specific to the equipment, particularly for fire protection and use of hydrogen. See IEC 60034-3.

6.2.13 Generating unit main connections

For small generating units, selection and specification of generator main connections (busbars) may be based upon appropriate clauses of IEC 62271-200.

However, particular care shall be taken in the selection of rated peak making currents. It may also be necessary to specify additional testing or calculations for connections that are not factory-built and type-tested.

Where necessary, fault studies shall be conducted to establish peak making and short-time withstand currents, particularly for branch connections of reduced cross-section (e.g. to auxiliary transformers).

For larger generating units, and where higher system security is required, it is recommended to use phase isolated or phase segregated busbar systems.

The impact of the magnetic field due to the use of generating unit main connections without metallic enclosures shall be considered in the design of the installation.

The design shall take into account the fact that when a generating unit is off line but rotating at low speed to prevent deformation of the generator shaft:

a) there is a possibility of induced voltages presenting a safety hazard; and
b) means shall be provided to change the off-circuit tap position on transformers connected directly to generator terminals.

NOTE When connections between the generator and the transformer are short, provision should be made to add capacitors in the connection gear to limit overvoltages which can occur during switching.

6.2.14 Static converters

Accessible parts of converter units that can carry dangerous voltage during normal operation or under fault conditions shall be adequately marked and shall be adequately protected against accidental contact by persons. This may be achieved by providing suitable protective barriers.

The cooling and heat transfer mediums shall not contain mechanical pollution or chemically aggressive components which might cause malfunction of the equipment.

When water is used as coolant, the possibility of corrosion caused by leakage currents (currents due to the conductivity of water) shall be considered.

When oil is used as coolant, similar protection against fire and pollution of ground water shall be provided as for oil-filled transformers and reactors.

When planning the layout of converter units, the possibility of magnetic interference, caused by high a.c. currents, on other equipment or parts of the installation, especially steel components, shall be considered.

6.2.15 Fuses

6.2.15.1 Clearances

Minimum electrical clearances for fuse assembly installations shall take into consideration all possible positions of the live parts before, during and after operation.

Vented fuses shall be provided with adequate clearances or appropriate protective barriers in the direction or directions in which they are vented. Discharges from vented fuses may contain hot gases, arc plasma and molten metal. They may also be conductive.

Facilities shall be provided to ensure that personnel are not exposed to discharges of vented fuses either during replacement or when working in the area. When this is not possible, the circuit feeding the fuse shall be de-energized prior to possible exposures, or the personnel shall use protective shielding and clothing.

6.2.15.2 Fuse replacement

Fuses shall be installed in such a way that their replacement can be carried out safely according to manufacturer's instructions.

NOTE All necessary information should be available to the operating and maintenance personnel for the proper selection of replacement fuses.

6.2.16 Electrical and mechanical Interlocking

Interlocking may be necessary to ensure the correct sequence of operation of equipment, to prevent danger to personnel and to prevent damage to the equipment.

Interlocking may be achieved by electrical or mechanical methods. In the event of the loss of power supplies, electrical interlocking schemes shall be designed to fail safely.

7 Installations

7.1 General requirements

This clause 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.

NOTE For minimum clearances (*N*) of live parts, refer to 5.4 and to Table 1, Table 2 and Annex A.

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 defined by the user (see 7.1.1).

7.1.1 Circuit arrangement

The circuit arrangement shall be chosen to meet operating requirements and to enable implementation of the safety requirements in accordance with 8.3. The continuity of service under fault and maintenance conditions, taking into account the network configuration, shall also be considered. The circuits shall be arranged so that switching operations can be carried out safely and quickly.

Each electrically separated system shall be provided with an earth fault indicating device which permits detection or disconnection of an earth fault.

It shall be ensured that isolated sections of an installation cannot be inadvertently energized by voltage from parallel connected secondary sources (for example instrument transformers).

Isolating equipment accessible to the general public shall be capable of being locked.

Installations shall be capable of withstanding the thermal and dynamic stresses resulting from short-circuit current in accordance with Clause 4.

The circuit arrangement may, however, be configured in such a way that sections of the installation which are normally operated separately are interconnected for short periods during switching operations, even when, as a result of such connection, the short-circuit current exceeds the design rating for the installation. In such cases, suitable protective measures shall be taken to prevent danger to personnel. Defined operating procedures may be required for this purpose.

NOTE 1 This situation may be unavoidable in operation if, for example, feeders are switched from one busbar to another.

In circuits that have current-limiting protective devices, equipment and short connections may have ratings that correspond to the cut-off (let through) current of the current-limiting device.

NOTE 2 Equipment located between the busbar and the current-limiting devices will have sufficient through-fault current duty only in case of faults on the load side of the current-limiting devices.

7.1.2 Documentation

Where applicable, the documentation shall be provided with each installation to allow erection, commissioning, operation, maintenance and environmental protection.

The extent and the language of the documentation shall be agreed upon between the supplier and the user.

Diagrams, charts and tables, if any, shall be prepared in accordance with IEC 60617 and IEC 61082-1.

7.1.3 Transport routes

Transport routes, their load capacity, height and width shall be adequate for movements of anticipated transport units and shall be agreed upon between the supplier and the user.

Within closed electrical operating areas, the passage of vehicles or other mobile equipment beneath or in proximity to live parts (without protective measures) is permitted, provided the following conditions are met (see Figure 5):

– the vehicle, with open doors, and its load does not infringe the danger zone: minimum protective clearance for vehicles $T = N + 100$ (minimum 500 mm);
– the minimum height, H, of live parts above accessible areas is maintained (see 7.2.4).

Under these circumstances, personnel may remain in vehicles or mobile equipment only if there are adequate protective measures on the vehicle or mobile equipment, for example the cab roof, to ensure that the danger zone defined above cannot be infringed.

For the lateral clearances between transport units and live parts, similar principles apply.

7.1.4 Aisles and access areas

The width of aisles and access areas shall be adequate for work, operational access, emergency access, emergency evacuation and for transport of equipment.

NOTE Maintenance and operating areas in buildings see 7.5.4

7.1.5 Lighting

Accessible indoor and outdoor installations shall be provided with suitable lighting for routine operations.

Emergency/auxiliary lighting shall be provided if necessary; this may be a fixed installation or portable equipment.

In some cases, in small distribution substations, a lighting installation may not be required. In such cases, the presence and extent of the lighting shall be agreed upon between the supplier and the user.

Any part of the lighting installation which needs maintenance or replacement, for example lamps, shall be installed so that when the work is carried out correctly, the working clearance to live parts can be maintained.

NOTE Lighting levels should be in accordance with current applicable international and/or national standards and regulations.

7.1.6 Operational safety

Operational safety installations shall be designed so that the escape and rescue paths and the emergency exit can be safely used in the event of a fire, and that protection and environmental compatibility are ensured.

Where necessary, installations themselves shall be protected against fire hazard, flooding and contamination. If required, additional measures shall be taken to protect important installations against the effects of road traffic (salt spray, vehicle accident).

7.1.7 Labelling

Identification and labelling are required to avoid operating errors and accidents.

All important parts of the installation, for example busbar systems, switchgear, bays, conductors, shall be clearly, legibly and durably labelled.

Safety warnings, for example warning notices, safety instruction notices and informative notices shall be provided at suitable points in the installation (see 8.9).

NOTE 1 Local and national regulations should be taken into account.

NOTE 2 Informative notices should be provided for the operation of key-interlocking schemes.

NOTE 3 Safety warnings may be provided wherever multiple sources of high-voltage power are required to be disconnected for the complete deenergization of equipment or where equipment may be inadvertently back-fed.

7.2 Outdoor installations of open design

The layout of open type outdoor installations shall take into account the minimum phase-to-phase and phase-to-earth clearances given in Clause 5.

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 (see Figure 1):

– for solid walls, without openings, with a minimum height of 1 800 mm, the minimum protective barrier clearance is $B_1 = N$;
– for wire meshes, screens or solid walls, with openings, with a minimum height of 1 800 mm and a degree of protection of IP1XB (see IEC 60529), the minimum protective barrier clearance is $B_2 = N + 100$ mm for equipment, where U_m is greater than 52 kV;
– for wire meshes, screens or solid walls, with openings, with a minimum height of 1 800 mm and a degree of protection of IP2X (see IEC 60529), the minimum protective barrier clearance is $B_3 = N + 80$ mm for equipment, where U_m is up to 52 kV.

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):

– 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:

– 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.

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). 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 4):

- 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 7.2.1): protective barrier clearances B_2 in accordance with 7.2.1;
- outer wall without windows: N.

7.2.6 External fences or walls and access doors

Unauthorized access to outdoor installations shall be prevented. Where this is by means of external fences or walls, the height and construction of the fence/wall shall be adequate to deter climbing.

Additional precautions may be required in some installations to prevent access by excavation beneath the fence.

The external fence/wall shall be at least 1 800 mm high. The lower edge of a fence shall not be more than 50 mm from the ground (for clearances see Figure 2).

Access doors to outdoor installations shall be equipped with security locks.

External fences/walls and access doors shall be marked with safety signs in accordance with 8.8.

In some cases, for public security reasons, additional measures may be necessary.

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

7.3 Indoor installations of open design

The layout of open-type indoor installations shall take into account the minimum phase-to-phase and phase-to-earth clearances specified in Clause 5.

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

$$O_1 = N + 200 \text{ mm (minimum 500 mm, see Figure 1)}$$

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

7.4.1 General

This subclause specifies additional requirements for equipment which apply to external connections, erection and operation at the place of installation. The installation shall be dimensioned and designed to avoid danger to persons and damage to property, taking into account the type of installation and local conditions.

Factory-built, type-tested high voltage switchgear shall be manufactured and tested in accordance with relevant IEC standards such as IEC 62271-1:2007, IEC 62271-200, IEC 62271-201 and IEC 62271-203.

NOTE In some countries, switchgear complying with IEC 62271-201 may be considered as an open type indoor installation.

The switchgear shall be well adapted to its purpose, clearly arranged and so designed that essential parts are accessible for erection, operation and maintenance. Arrangements and access shall be provided to permit assembly at site. Future possible extensions should be considered.

Appropriate arrangements shall be made for external connections. Conductors and cables shall be selected and arranged in such a way as to ensure safe insulation level between conductors and between each conductor and surrounding earthed metallic structures.

Safety devices that are intended to reduce the internal switchgear pressure resulting from a fault shall be designed and arranged with consideration for their potential hazard to personnel. The accumulation of dangerous concentrations of gas decomposition products in switch rooms shall be prevented.

7.4.2 Additional requirements for gas-insulated metal-enclosed switchgear

7.4.2.1 Design

If platforms and ladders are necessary for operation and maintenance, they shall be designed and arranged to provide safe access for personnel. These elements may be fixed or removable.

Where necessary, arrangements shall be made to protect the switchgear from dangerous vibrations from transformers/reactors with gas-insulated connections. Bellows shall be provided, where necessary, to allow for heat expansion, erection tolerances and settlement of foundations.

For gas-insulated installations with several pressure chambers, clear labels shall be provided indicating the construction of the installation and the position of partitions. Monitoring devices shall be clearly marked and located to permit easy supervision.

Gas pipelines and fittings in areas where mechanical damage is expected shall be protected.

SF_6 gas pipelines shall be marked where there is a possibility of confusion with other pipelines.

7.4.2.2 Erection on site

Erection of GIS shall be carried out in a clean environment.

For outdoor installations, it may be necessary to provide a suitable temporary enclosure over the work area to protect the equipment from the environmental conditions whilst installation and/or maintenance is taking place.

For SF_6 gas handling, see 9.4.

For SF_6 leakage, see 8.8.2 and 8.8.3.

7.4.2.3 Protection against overvoltages

Protection of the GIS against overvoltages should normally be provided by the surge arresters installed on the feeders. In some cases, the protection given by this equipment may be inadequate. This situation arises mainly in the following configurations:

- large distance between the GIS and transformers;
- transformers connected to the GIS by means of cables;
- long busbars open at their ends;
- connection to overhead lines by means of insulated cables;
- locations with high probability of lightning strikes.

For these configurations, the installation of additional surge arresters may be required. Their location should be based on experience with similar situations or on calculations.

7.4.2.4 Earthing

The enclosure of a GIS should be connected to the earthing system at least at the following points:

a) inside the bays:
   - close to the circuit-breaker;
   - close to the cable sealing end;
   - close to the SF_6/air bushing;
   - close to the instrument transformer.
b) on the busbars:
   - at both ends and at intermediate points, depending on the length of the busbars.

The three enclosures of a single-phase type GIS shall be bonded together before earthing. The bonding conductor shall either be rated to carry the nominal current of the bays and busbars, or if a lower rated bonding conductor is used, then it shall be proved by tests that no danger will arise during operation.

Additional bonding straps are not required at flange joints if it can be ensured that the contact pressure of the flange provides adequate contact connection for high frequencies.

Earthing conductors of surge arresters for the protection of gas-insulated installations shall be connected by as short a connection as possible to the enclosure.

Metallic sheaths (for example metal enclosures, armoured coverings, screens) of cables with nominal voltages above 1 kV should be connected directly to the GIS enclosure.

In some special cases, e.g. cathodic protection of cables, it may be necessary to separate the earth connection of the cables from the GIS enclosure. In this case, the installation of a voltage surge protection device is recommended between the sealing end and enclosure.

7.5 Requirements for buildings

7.5.1 Introduction

Buildings shall comply with national building codes and fire regulations. Where such national standards do not exist, the following may be used as a guide.

This subclause indicates the requirements that have to be satisfied in areas or locations where electrical equipment for high-voltage installations is installed. For the purpose of this standard, prefabricated substations covered by IEC 62271-202 are not considered as buildings.

7.5.2 Structural provisions

7.5.2.1 General

Load-carrying structural members, partition walls, claddings, enclosures, etc. shall be selected to withstand the expected combustible load.

Electrical operating areas shall be designed to prevent ingress of water and to minimize condensation.

Materials used for walls, ceilings and floors on the ground shall, where possible, not be damaged by water penetration or leakage. If this requirement cannot be met, precautions shall be taken to prevent the consequences of a leak or of condensation affecting the operating safety.

The building design shall take into account the expected mechanical loading and internal pressure caused by an arc fault.

Pipelines and other equipment, if allowed in substations, shall be designed so that the electrical installation is not affected, even in the event of damage.

7.5.2.2 Specifications for walls

The external walls of the building shall have sufficient mechanical strength for the environmental conditions.

The mechanical strength of the buildings shall be sufficient to withstand all static and dynamic loads due to normal operation of the installation.

The passage of pipes or wiring systems shall not affect the structural integrity of the walls.

Metal parts that pass through walls shall meet the requirements of Clause 10.

Panels of the exterior surface of buildings that are accessible to the general public shall not be removable from the outside. The constituent materials of the external enclosures shall be capable of withstanding the attacks of atmospheric elements (rain, sun, aggressive wind, etc.).

7.5.2.3 Windows

Windows shall be designed so that entry is difficult. This requirement is considered fulfilled if one or more of the following measures are applied:

– the window is made of unbreakable material;

– the window is screened;
– the lower edge of the window is at least 1,8 m above the access level;
– the building is surrounded by an external fence at least 1,8 m high.

7.5.2.4 Roofs

The roof of the building shall have sufficient mechanical strength to withstand the environmental conditions.

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

The floors shall be flat and stable and shall be able to support the static and dynamic loads.

7.5.3 Rooms for switchgear

The dimensions of the room and of the required pressure relief openings depend on the type of switchgear and the short-circuit current.

If pressure relief openings are necessary, they shall be arranged and situated in such a way that when they operate (blow out due to an arc fault) the danger to persons and damage to property is minimized.

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.

NOTE The doors of switchgear cubicles or bays should 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_m greater than 52 kV, and 20 m for installation of rated voltages up to U_m = 52 kV. 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

Access doors shall be equipped with security locks to prevent unauthorised entry.

Access doors shall open outwards and be provided with safety signs in accordance with 8.9.

Doors which lead to the outside shall be of low flammability material, except where the building is surrounded by an external fence at least 1,8 m high.

Doors between various rooms within a closed electrical operating area are not required to have locks.

It shall be possible to open emergency doors from the inside without a key by using a latch or other simple means, even when they are locked from the outside. This requirement need not be complied with for small installations where the door has to be kept open during operating or servicing.

The minimum height of an emergency door shall be 2 m and the minimum clear opening 750 mm.

7.5.6 Draining of insulating liquids

Protective measures shall be taken when insulating liquids are used (see also 8.8).

7.5.7 Air conditioning and ventilation

Indoor climate conditions shall be established e.g. by adequate cooling, heating, dehumidifying, ventilation or by adequate design of the building.

It is preferable to use natural ventilation for transformer rooms.

Forced ventilation systems (permanent or mobile) shall be designed to take into consideration smoke removal from the building.

Monitoring of the operation of a permanent fan is recommended.

Ventilation openings shall be designed so as to prevent any dangerous proximity to live parts and any dangerous ingress of foreign bodies.

Coolants and heat transfer media shall not contain mechanical impurities or chemically aggressive substances in quantities or qualities which may be hazardous to the correct function of the equipment in the installation.

Filters or heat exchangers shall be provided, if necessary.

Mechanical ventilation systems shall be so arranged and placed that inspection and maintenance can be carried out even when the switchgear is in operation.

7.5.7.1 Ventilation of battery rooms

Rooms containing batteries shall take into account the ventilation requirements, if necessary, depending on battery types, to prevent the explosive build-up of combustible gas during battery charging.

7.5.7.2 Rooms for emergency generating units

Consideration should be given to installing emergency generating units in separate rooms.

Ventilation equipment shall be provided. Containment shall be provided to capture and control fuel or lubricating oil spills.

Engine exhaust systems shall be installed and located such that exhaust fumes shall not return to the ventilating air intake of the switchgear and control rooms, nor enter the air intake for the emergency generating unit.

7.5.8 Buildings which require special consideration

For high-voltage installations located in public or residential buildings, special conditions shall be imposed, in accordance with existing standards or national regulations.

7.6 High voltage/low voltage prefabricated substations

For the rules governing manufacture and testing, see IEC 62271-202.

Compact substations shall be situated so that they are unlikely to be damaged by road vehicles. Adequate space for operating and maintenance purposes shall also be provided.

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

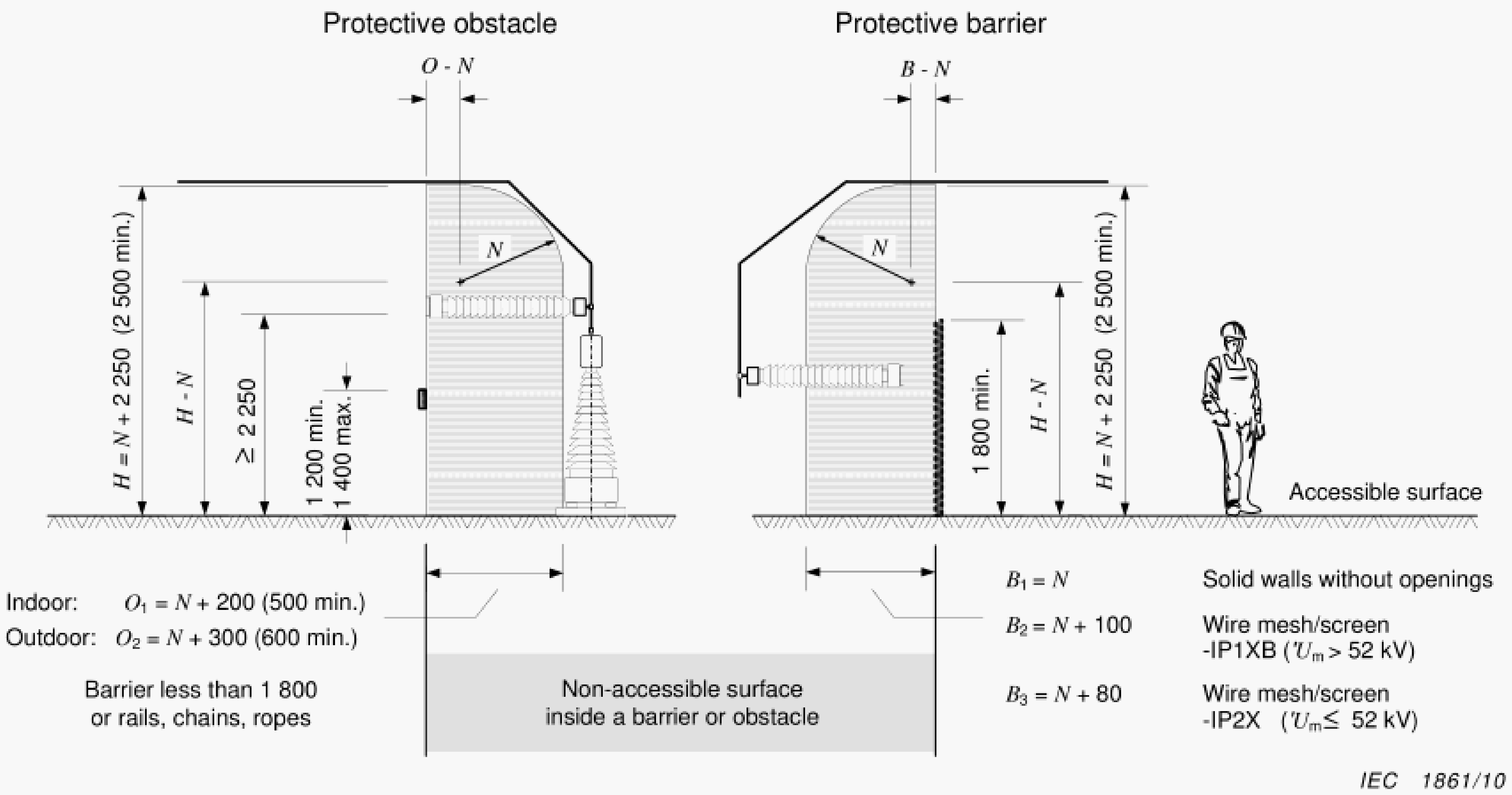
- H' = 4 300 mm for rated voltages U_m up to 52 kV;
- $H' = N$ + 4 500 mm (minimum 6 000 mm) for rated voltages U_m above 52 kV;

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



Dimensions in millimetres

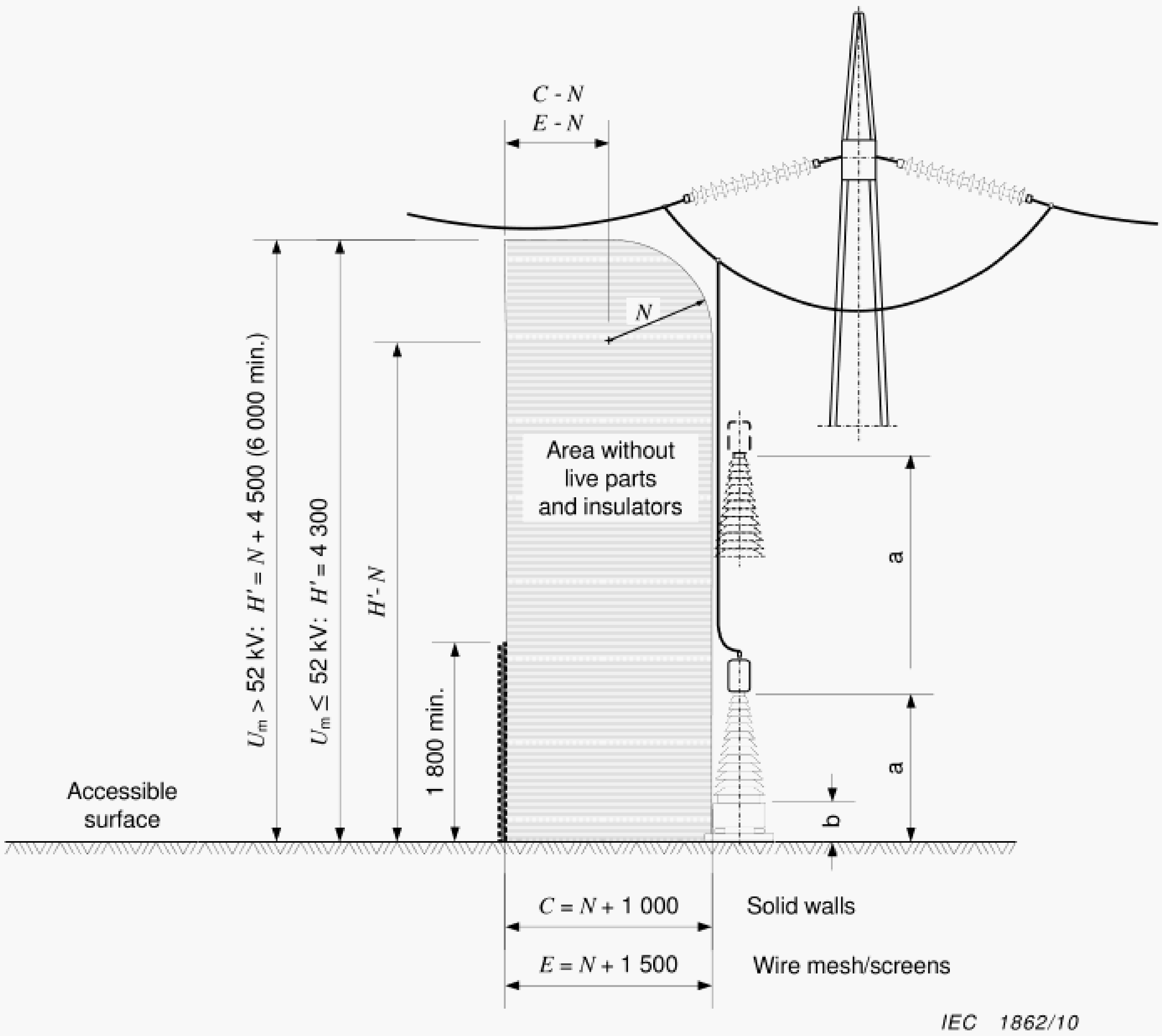
Key

N Minimum clearance

O Obstacle clearance

B Barrier clearance

Figure 1 – Protection against direct contact by protective barriers/protective obstacles within closed electrical operating areas



Dimensions in millimetres

Key

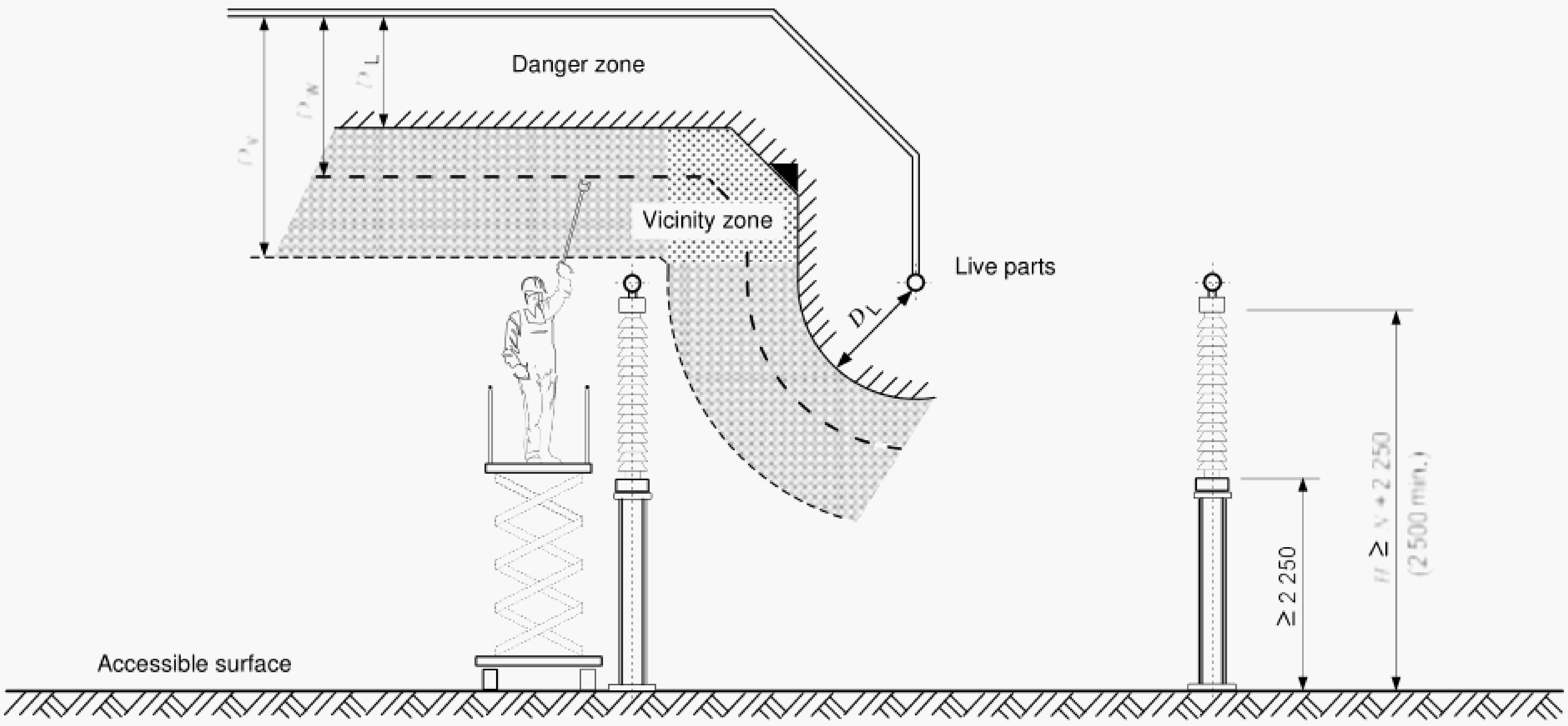
N Minimum clearance

H' Minimum clearance of live parts above accessible surface at the external fence

a If this distance to live parts is less than *H*, protection by barriers or obstacles shall be provided

b If this distance is smaller than 2 250 mm, protection by barriers or obstacles shall be provided

Figure 2 – Boundary distances and minimum height at the external fence/wall



IEC 1863/10

Dimensions in millimetres

Key

D_L N

D_V N + 1 000 for $U_n \leq$ 110 kV

D_V N + 2 000 for $U_n >$ 110 kV

D_W Working clearance according to national standards or regulations

N Minimum clearance

H Minimum height

Figure 3 – Minimum heights and working clearances within closed electrical operating areas

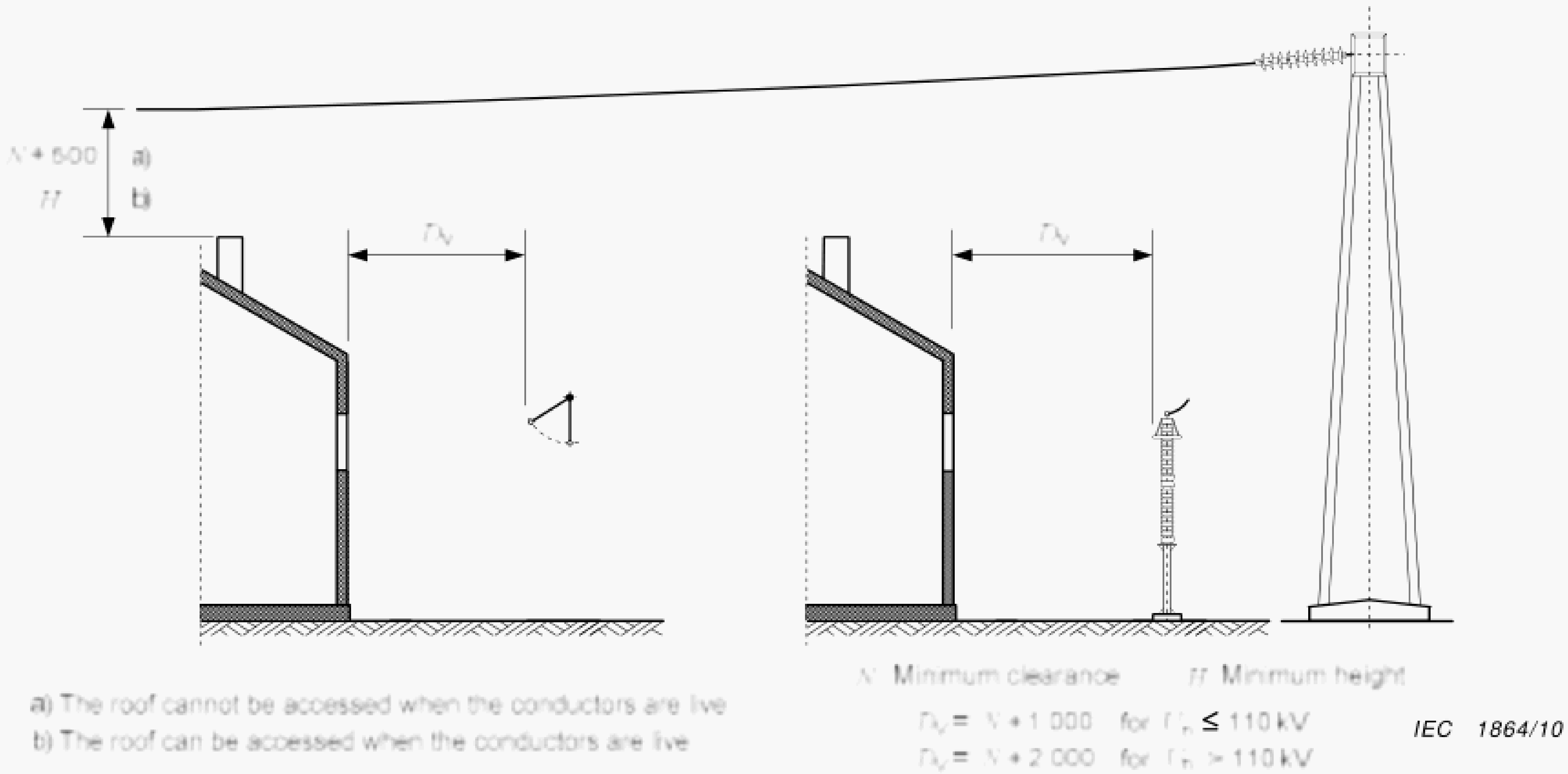


Figure 4a – Outer wall with unscreened windows

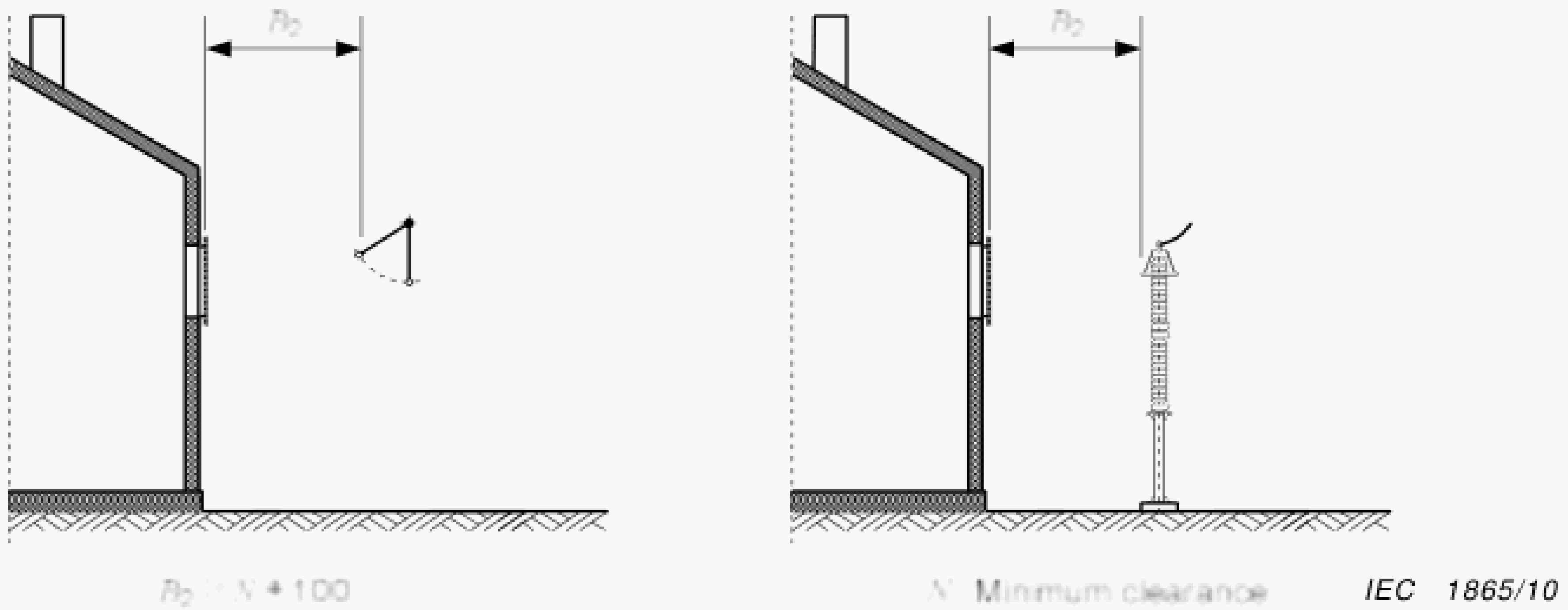


Figure 4b – Outer wall with screened windows

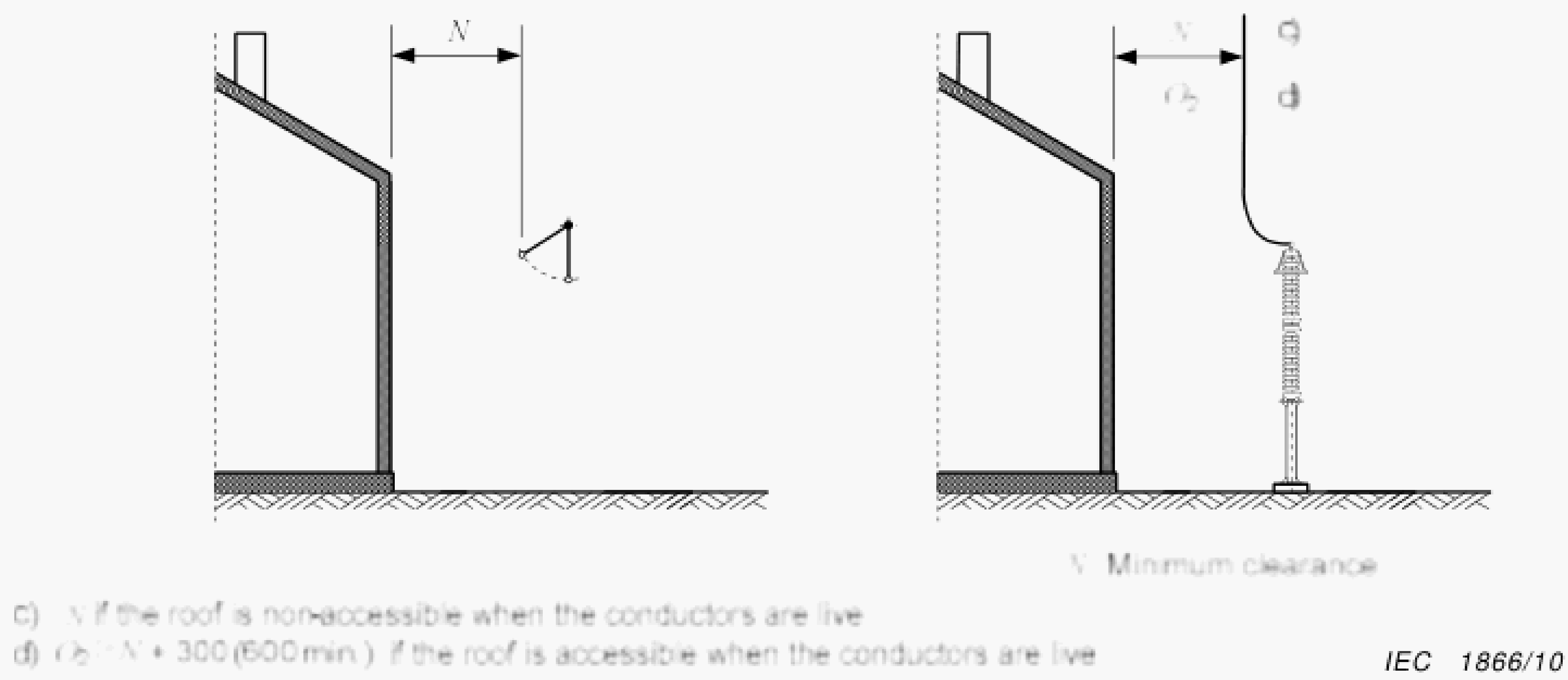
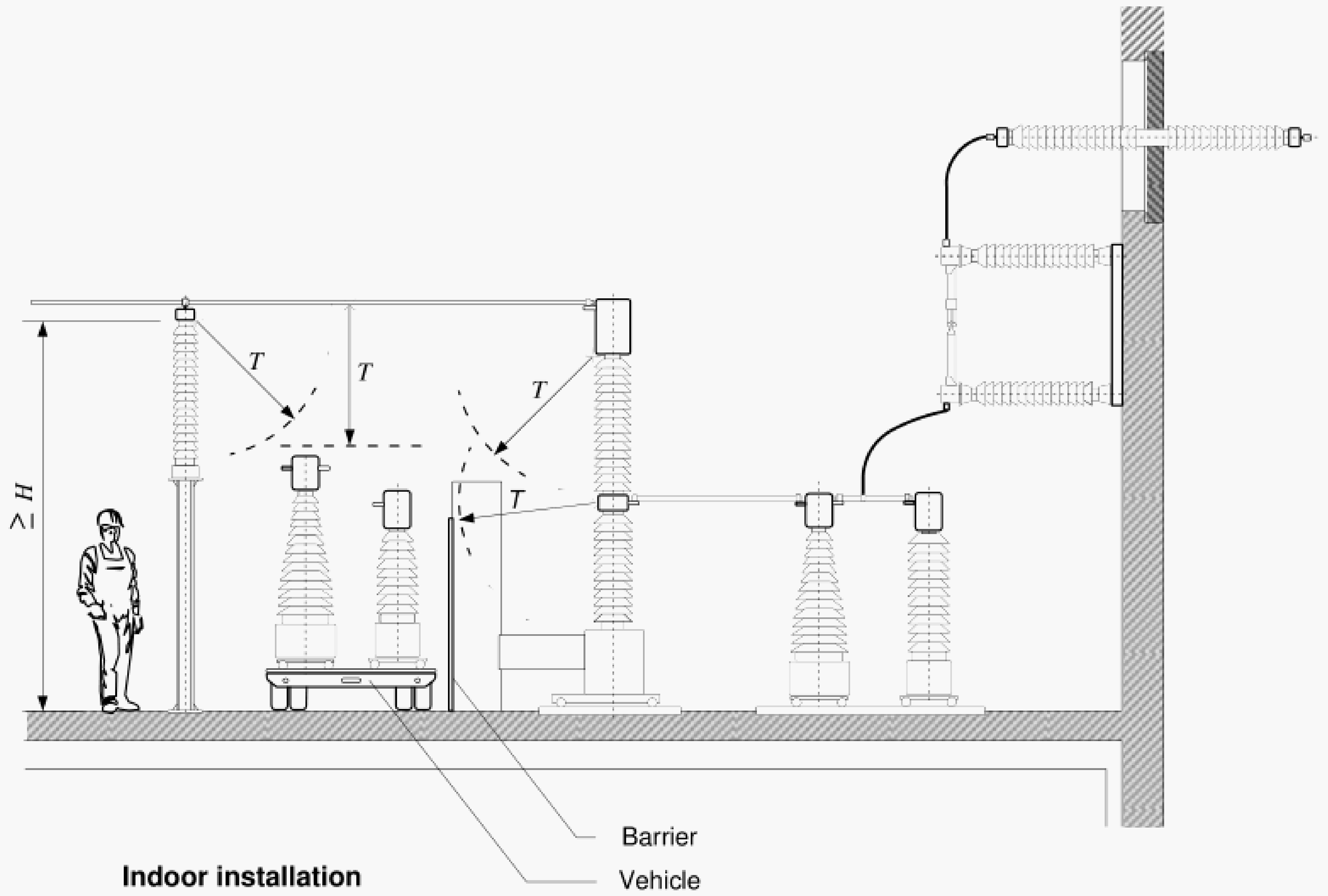


Figure 4c – Outer wall without windows

Dimensions in millimetres

NOTE When work is performed on the roof when the conductors are live, clearances from Figure 3 should be used.

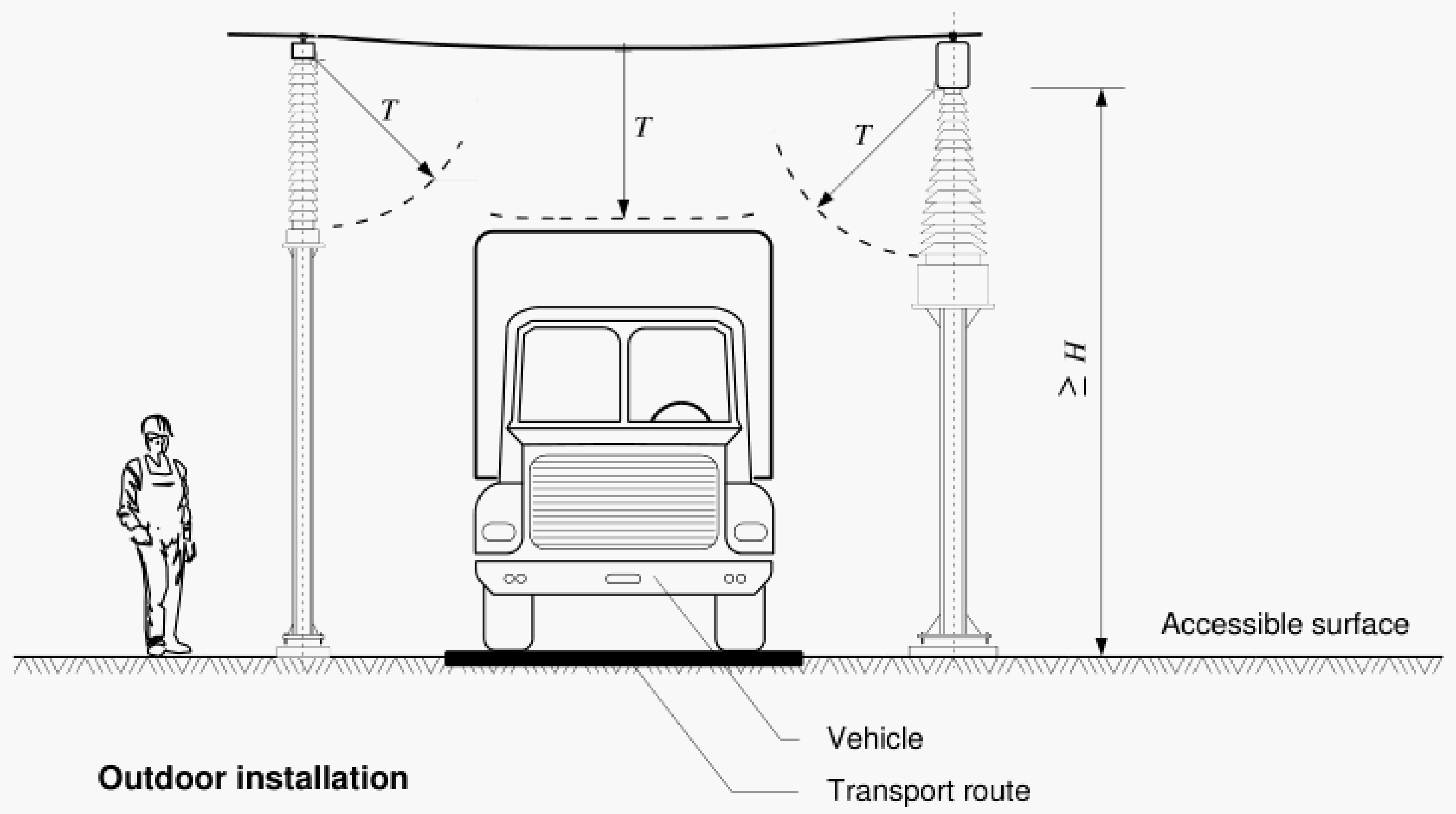
Figure 4 – Approaches with buildings (within closed electrical operating areas)



$T = N + 100$ (500 min.)

N Minimum clearance

IEC 1867/10



IEC 1868/10

Dimensions in millimetres

Figure 5 – Minimum approach distance for transport

8 Safety measures

8.1 General

Installations shall be constructed in such a way as to enable the operating and maintenance personnel to circulate and intervene within the framework of their duties and authorizations, according to circumstances, at any point of the installation.

Specific maintenance work, preparation and repair work, which involve working in the vicinity of live parts or actual work on live parts, are carried out observing the rules, procedures and work distances as defined in national standards and regulations.

8.2 Protection against direct contact

Installations shall be constructed so that unintentional touching of live parts or unintentional reaching into a dangerous zone near live parts is prevented.

Protection shall be provided for live parts, parts with functional insulation only and parts which can be considered to carry a dangerous potential.

Examples of such parts are as follows:

- exposed live parts;
- parts of installations where earthed metallic sheaths or conducting screens of cables have been removed;
- cables and accessories without earthed metallic sheaths or earthed conducting elastomeric screens, as well as flexible cables without conducting elastomeric screens;
- terminations and conducting sheathing of cables, if they can carry a dangerous voltage;
- insulating bodies of insulators and other such parts, for example electrical equipment insulated by cast resin, if a dangerous touch voltage can occur;
- frames or cases of capacitors, converters and converter transformers, which can carry a dangerous voltage during normal operation;
- windings of electrical machines, transformers and air-cored reactors.

Protection may be achieved by different means, depending on whether the installation is located in a closed electrical operating area or not.

Information on protection against electric shock is given in IEC 61140.

8.2.1 Measures for protection against direct contact

8.2.1.1 Recognized protection measures

The following types of protection are recognized:

- protection by enclosure;
- protection by barrier;
- protection by obstacle;
- protection by placing out of reach.

8.2.1.2 Design of protective measures

Protective barriers can be solid walls, doors or screens (wire mesh) with a minimum height of 1 800 mm to ensure that no part of the body of a person can reach the dangerous zone near live parts.

Protective obstacles can, for example, be covers, rails, chains and ropes as well as walls, doors and screens which are less than 1 800 mm high and therefore cannot be considered as protective barriers.

Protection by placing out of reach is achieved by placing live parts outside a zone extending from any surface where persons can usually stand or move about, to the limits which a person can reach with a hand in any direction (see Clause 7).

Protective facilities used as a protective measure against direct contact, such as walls, covers, protective obstacles, etc., shall be mechanically robust and securely mounted.

Doors of switchgear rooms or bays used as a part of an enclosure shall be designed so that they can be opened only by using a tool or a key. In areas outside closed electrical operating areas, these doors shall be provided with safety locks.

Movable, conductive protective facilities shall be secured so that when correctly used the relevant protective barrier or protective obstacle clearance is maintained; otherwise they shall be made of insulating material or dry wood. It is permitted that a rail may be removed without the use of a tool. Protective rails shall be rigid.

In areas or rooms accessible to the public, protective facilities shall not be easily removable from outside with normal tools.

8.2.2 Protection requirements

8.2.2.1 Protection outside of closed electrical operating areas

Outside the closed electrical operating areas, only protection by enclosure or protection by placing out of reach is allowed.

When protection by enclosure is used, the minimum degree of protection shall be IP2XC.

NOTE As an exception, ventilation openings may be such that a straight wire cannot intrude into the equipment in such a way that it causes danger by approaching parts needing to be protected from direct contact.

When protection by placing out of reach is used, the vertical clearances between accessible surfaces and the parts to be protected from direct contact shall be in accordance with 7.2.6 or Figure 2.

8.2.2.2 Protection inside closed electrical operating areas

Inside closed electrical operating areas, protection by enclosure, protective barrier, protective obstacle or placing out of reach is allowed.

When protection by enclosure is used, the degree of protection shall meet the requirements of IP2X in minimum. However, special protection measures to meet danger resulting from arc faults may be necessary.

When protection by protective barrier is used, see 7.2.1.

When protection by protective obstacle is used, see 7.2.2 and 7.3.

When protection by placing out of reach is used, see 7.2.4 and 7.2.5.

NOTE For more detailed requirements on external fences, transport routes, crossings and access to buildings, etc., see Clause 7.

8.2.2.3 Protection during normal operation

NOTE 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 transformer.

In installations with $U_m \leq 52$ kV, 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

Measures to be taken in order to protect persons in case of indirect contact are given in Clause 10.

Information on protection against electric shock is given in IEC 61140.

8.4 Means to protect persons working on electrical installations

Electrical installations shall be constructed and installed to ensure that the measures necessary for the protection of persons working in or on electrical installations can be employed. The relevant standards for operation and maintenance of electrical power installations shall also be taken into account. The working procedures shall be agreed upon between the manufacturer and the user.

NOTE Whilst individual functions are considered in separate subclauses, these functions may be combined in a single item of equipment.

8.4.1 Equipment for isolating installations or apparatus

Equipment shall be provided by means of which the complete installation or sections thereof can be isolated, depending on operating requirements.

This may be achieved by disconnectors or switch disconnectors (see 6.2.1) or by disconnecting part of the installation, for example by removing links or cable loops. In the latter case, see 5.4.1.

Installations or parts of installations which can be energized from several sources shall be arranged so that all sources can be isolated from points of supply from which each section or part thereof can be made live.

If the neutral points of several pieces of equipment are connected to a common neutral bus, it shall be possible to isolate each neutral point individually. This also applies to associated earth fault coils and resistors. The overvoltage protection shall be maintained in operational condition.

Where equipment may be charged at some voltage following disconnection from the installation, for example capacitors, devices shall be provided to discharge the system/equipment.

Isolating gaps may only be bridged by insulators if leakage currents from the terminal on one side to the terminal on the other side are prevented.

8.4.2 Devices to prevent reclosing of isolating devices

Suitable devices shall be provided to render inoperative the actuating force (i.e. spring force, air pressure, electrical energy) or the control of power mechanisms used for the operation of switchgear employed for isolating purposes.

NOTE It may be statutory in certain countries that these devices shall be rendered inoperative by suitable locking facilities.

Where removable parts such as fuses or screw-in circuit breakers are used for complete disconnection and are replaced by screw caps or blank inserts, these caps or inserts shall be such that they can only be removed using an approved tool.

Manually operated switches shall permit the use of mechanical locking devices in order to prevent reconnection to the system following isolation.

8.4.3 Devices for determining the de-energized state

Devices for determining that the equipment is no longer energized, shall be provided, where required, considering operational requirements. The extent of such provisions - wherever practicable - shall be agreed between the supplier and the user.

All devices supplied shall permit the de-energized state to be checked at all points where the work is to be done that have previously been live, without danger for the operational personnel.

Either fixed equipment or portable devices (see the IEC 61243 series) can be used to meet this requirement.

8.4.4 Devices for earthing and short-circuiting

Each part of an installation that can be isolated from the system shall be arranged to enable it to be earthed and short-circuited.

Equipment (for example transformers or capacitors) shall be provided with a means of earthing and short-circuiting adjacent to the equipment. This requirement shall not apply to parts of a system where this is not practicable or is unsuitable (for example transformers or electrical machines with flange-mounted cable sealing ends or with cable connection boxes). In these cases, earthing and short-circuiting shall be effected by the application of circuit main earths at the associated switchgear cubicles or bays on the primary and secondary sides. Normally, it should be possible to earth and short-circuit all sides of a transformer, including neutrals.

The following shall be provided for or supplied as earthing and short-circuiting devices, with the scope being agreed between the supplier and the user:

- earthing switches (preferably fault-making and/or interlocked);
- earthing switch trucks;
- earthing equipment integrated with other switching devices e.g. circuit-breakers;
- free earthing rods and short-circuiting equipment (see IEC 61230);
- guided earthing rods and short-circuiting equipment (see IEC 61219).

For each part of an installation, suitably dimensioned and easily accessible connection points shall be provided on the earthing system and on the live parts for connection of earthing and short-circuiting equipment. Switchgear cubicles or bays shall be designed so that connection of the earthing and short-circuiting equipment by hand to the earth terminal point can be carried out in accordance with the rules for carrying out work in the vicinity of live parts.

When earthing and short-circuiting is achieved by remotely controlled earthing switches, the switch position shall be reliably transmitted to the remote control point.

When earthing is achieved through a load-breaking device having control circuits, all control circuits of the load-breaking device shall be made inoperative following the application of the circuit main earth. Inadvertent re-energization of the control circuits shall be prevented.

8.4.5 Equipment acting as protective barriers against adjacent live parts

All boundary elements such as walls, floors, etc. shall be constructed according to 7.2 or 7.3.

If walls or protective facilities do not exist, the separation to neighbouring bays or sections shall respect the appropriate distances.

If working clearances cannot be maintained, live parts in the vicinity of the working area shall be capable of being covered by insertable insulated partitions or walls in such a way that accidental proximity to these parts by body parts, tools, equipment and materials is prevented.

8.4.5.1 Insertable insulated partitions

Movable screens and insertable insulated partitions shall meet the following requirements:

a) the edges of insulating shutters shall not be located within the danger zone;
b) gaps are permissible outside the danger zone:
   - up to 10 mm wide without limitation,
   - up to 40 mm wide provided the distance from the edge of the shutter to the danger zone is at least 100 mm,
   - up to 100 mm wide in the vicinity of disconnector bases.

Insertable insulated partitions used as protective barriers against live parts shall be part of the equipment or provided separately in accordance with operational requirements by agreement between the supplier and the user.

Insertable insulated partitions shall be capable of being secured so that their position cannot be accidentally altered where this would lead to a hazardous condition.

Insertable insulated partitions used as protective barriers against live parts shall not touch or be in contact with live parts.

It shall be possible to install and remove insertable insulated partitions without persons being required to enter the danger zone.

NOTE This can be achieved by the type of insulating shutters (for example angled plate, associated insulating rods, suitable operating rods) or by the installation (for example guide rails).

8.4.5.2 Insertable partition walls

For installations without permanently installed partition walls, suitable insertable partition walls should be provided to isolate adjacent live cubicles or bays in accordance with the operational requirements. When required, the extent shall be agreed upon between the supplier and the user.

Insertable partition walls which enter the danger zone during installation or removal, or which lie within the danger zone when fitted, shall meet the requirement for mobile insulating plates.

Insertable insulated partition walls used as protective barriers against live parts shall not touch or be in contact with live parts.

8.4.6 Storage of personal protection equipment

If personal protection equipment is to be stored in the installation, a place shall be provided for this purpose where the equipment is protected from humidity, dirt and damage whilst remaining readily accessible to operational personnel.

8.5 Protection from danger resulting from arc fault

Electrical installations shall be designed and installed so that personnel are protected as far as practical from arc faults during operation.

The following list of measures to protect against dangers resulting from arc fault shall serve as a guide in the design and construction of electrical installations. The degree of importance of these measures shall be agreed upon between the supplier and user.

a) Protection against operating error, established, for example, by means of the following:
   - load break switches instead of disconnectors,
   - short-circuit rated fault-making switches,
   - interlocks,
   - non-interchangeable key locks.
b) Operating aisles as short, high and wide as possible (see 7.5).
c) Solid covers as an enclosure or protective barrier instead of perforated covers or wire mesh.
d) Equipment tested to withstand internal arc fault instead of open-type equipment (e.g. IEC 62271-200, IEC 62271-203).
e) Arc products to be directed away from operating personnel, and vented outside the building, if necessary.
f) Use of current-limiting devices.
g) Very short tripping time; achievable by instantaneous relays or by devices sensitive to pressure, light or heat.
h) Operation of the plant from a safe distance.
i) Prevent of re-energization by use of non-resetable devices which detect internal equipment faults, incorporate pressure relief and provide an external indication.

8.6 Protection against direct lightning strokes

Different methods of analysis are available. The method to be used shall be agreed upon between the supplier and user.

The user shall select the level of protection to be achieved, depending on the reliability level required, and the protection method to be used.

NOTE 1 For calculation methods, see for example either Annex E or IEEE Guide 998 [28].

Lightning rods and shield wires shall be earthed.

It is not necessary to equip a steel structure with a separate earthing conductor where it provides a suitable path for the lightning current itself.

Shield wires shall be connected to the steel structure or earthing conductor to ensure that the lightning current flows to earth. For buildings and similar structures, see IEC 62305 series.

For associated standards, IEC 62305-4 shall be referred to.

NOTE 2 For technical and economic reasons, damage resulting from lightning strokes cannot be fully prevented.

8.7 Protection against fire

8.7.1 General

Relevant national, provincial and local fire protection regulations shall be taken into account in the design of the installation.

NOTE Fire hazard and fire risk of electrical equipment is separated into two categories: fire victim and fire origin. Precautions for each category should be taken into account in the installation requirements.

a) Precautions to fire victim:
   - i) space separation from origin of fire;
   - ii) flame propagation prevention:
     - – physical layout of the substation,
     - – liquid containment,
     - – fire barriers (e.g. REI fire-resistant materials 60/90),
     - – extinguishing system;

b) Precautions to fire origin:
   - i) electrical protection;
   - ii) thermal protection;
   - iii) pressure protection;
   - iv) fire resistant materials.

Care shall be taken that, in the event of fire, the escape and rescue paths and the emergency exits can be used (see 7.1.6).

The user or owner of the installation shall specify any requirement for fire extinguishing equipment.

Automatic devices to protect against equipment burning due to severe overheating, overloading and faults (internal/external) shall be provided, depending on the size and significance of the installation.

Equipment in which there is a potential for sparks, arcing, explosion or high temperature, for example electrical machines, transformers, resistors, switches and fuses, shall not be used in operating areas subject to fire hazard unless the construction of this equipment is such that flammable materials cannot be ignited by them.

If this cannot be ensured, special precautions, for example fire walls, fire-resistant separations, vaults, enclosures and containment, are necessary.

Consideration should be given to separating different sections of switchgear by fire walls. This can be achieved by means of bus ducts which penetrate the fire wall and which connect the sections of the switchgear together.

8.7.2 Transformers, reactors

In the following subclauses, the word 'transformer' represents 'transformers and reactors'.

For the identification of coolant types, see 6.2.2.

IEC 61100 classifies insulating liquids according to fire point and net caloric value (heat of combustion). IEC 60076-11 classifies dry-type transformers in terms of their behaviour when exposed to fire.

The fire hazard associated with transformers of outdoor and indoor installations is dependent on the rating of the equipment, the volume and type of insulating mediums, the type and proximity and exposure of nearby equipment and structures. The use of one or more recognized safeguard measures shall be used in accordance with the evaluation of the risk.

NOTE For definition of risk, see ISO/IEC Guide 51.

Common sumps or catchment tanks, if required, for several transformers shall be arranged so that a fire in one transformer cannot spread to another.

The same applies to individual sumps which are connected to the catchment tanks of other transformers; gravel layers or pipes filled with fluid can, for example, be used for this purpose. Arrangements which tend to minimize the fire hazard of the escaped fluid are preferred.

8.7.2.1 Outdoor installations

The layout of an outdoor installation shall be such that burning of a transformer with a liquid volume of more than 1 000 l will not cause a fire hazard to other transformers or objects, with the exception of those directly associated with the transformer. For this purpose, adequate clearances, G, shall be necessary. Guide values are given in Table 3. Where transformers with a liquid volume below 1 000 l are installed near combustible walls, special fire precautions may be necessary, depending on the nature and the use of the building.

If automatically activated fire extinguishing equipment is installed, the clearance G can be reduced.

If it is not possible to allow for adequate clearance as indicated in Table 3, fire-resistant separating walls with the following dimensions shall be provided:

a) between transformers (see Figure 6) separating walls. For example EI 60 in accordance with the *Official Journal of the European Community*, No. C 62/23:
   - height: top of the expansion chamber (if any), otherwise the top of the transformer tank;
   - length: width or length of the sump (in the case of a dry-type transformer, the width or length of the transformer, depending upon the direction of the transformer);
b) between transformers and buildings separating walls. For example EI 60; if additional fire separating wall is not provided, fire rating of the building wall should be increased, for example REI 90 (see Figure 7) in accordance with the *Official Journal of the European Community* C 62/23.

Table 3 – Guide values for outdoor transformer clearances

Transformer type	**Liquid volume** l	**Clearance *G* to** **other transformers or non-combustible building surface** m	**Clearance *G* to** **combustible building surface** m
Oil insulated transformers (O)	1 000 <….< 2 000	3	7,5
	2 000 ≤….< 20 000	5	10
	20 000 ≤….< 45 000	10	20
	≥ 45 000	15	30
Less flammable liquid insulated transformers (K) without enhanced protection	1 000 <…< 3 800	1,5	7,5
	≥ 3 800	4,5	15
Less flammable liquid insulated transformers (K) with enhanced protection	**Clearance *G* to building surface or adjacent transformers**		
	Horizontal m		**Vertical** m
	0,9		1,5
Dry-type transformers (A)	**Fire behaviour class**	**Clearance *G* to building surface or adjacent transformers** **Horizontal** m	**Clearance *G* to building surface or adjacent transformers** **Vertical** m
	F0	1,5	3,0
	F1	None	None

NOTE 1 Enhanced protection means

– tank rupture strength,

– tank pressure relief,

– low-current fault protection,

– high-current fault protection.

For an example of enhanced protection, see Factory Mutual Global standard 3990 [33], or equivalent.

NOTE 2 Sufficient space should be allowed for periodic cleaning of resin-encapsulated transformer windings, in order to prevent possible electrical faults and fire hazard caused by deposited atmospheric pollution.

8.7.2.2 Indoor installation in closed electrical operating areas

Minimum requirements for the installation of indoor transformers are given in Table 4.

Table 4 – Minimum requirements for the installation of indoor transformers

Transformer type	Class	Safeguards
Oil insulated transformers (O)	Liquid volume	
	≤ 1 000 l	EI 60 respectively REI 60
	> 1 000 l	EI 90 respectively REI 90 **or** EI 60 respectively REI 60 and automatic sprinkler protection
Less flammable liquid insulated transformers (K)	Nominal power/max. voltage	
Without enhanced protection	(no restriction)	EI 60 respectively REI 60 **or** automatic sprinkler protection
With enhanced protection	≤ 10 MVA and U_m ≤ 38 kV	EI 60 respectively REI 60 **or** separation distances 1,5 m horizontally and 3,0 m vertically
Dry-type transformer (A)	Fire behaviour class	
	F0	EI 60 respectively REI 60 **or** separation distances 0,9 m horizontally and 1,5 m vertically
	F1	Non combustible walls

NOTE 1 REI represents the bearing system (wall) whereas EI represents the non-load bearing system (wall) where R is the load bearing capacity, E is the fire integrity, I is the thermal insulation and 60/90 refers to time in minutes.

NOTE 2 Enhanced protection means

– tank rupture strength,

– tank pressure relief,

– low-current fault protection,

– high-current fault protection.

For an example of enhanced protection, see Factory Mutual Global standard 3990 [33], or equivalent.

NOTE 3 Sufficient space should be allowed for periodic cleaning of resin-encapsulated transformer windings, in order to prevent possible electrical faults and fire hazard caused by deposited atmospheric pollution.

Doors shall have a fire resistance of at least 60 min. Doors which open to the outside are adequate if they are of low flammability material. Ventilation openings necessary for the operation of the transformers are permitted in the doors or in adjacent walls. When designing the openings, the possible escape of hot gases shall be considered.

8.7.2.3 Indoor installations in industrial buildings

For all transformers in industrial buildings, fast-acting protective devices which provide immediate automatic interruption in the event of failure are necessary.

Transformers with coolant type O require the same provisions as in 8.7.2.2.

For all other liquid-immersed transformers, no special arrangements in respect of fire protection are required, except for the provisions for liquid retention in case of leakage and the provision of portable fire extinguishing apparatus suitable for electrical equipment.

Dry-type transformers (A) require the selection of the correct fire behaviour class depending on the activity of the industry and on the material present in the surroundings. Fire extinguishing provisions are advisable, particularly for class F0.

NOTE For all transformers in industrial buildings, additional fire precautions may be necessary, depending on the nature and use of the building.

8.7.2.4 Indoor installations in buildings which are permanently occupied by persons

In high-voltage installations, located in public or residential buildings, special conditions shall be observed in accordance with existing standards or national regulations.

8.7.2.5 Fire in the vicinity of transformers

If there is an exceptional risk of the transformer being exposed to external fire, consideration shall be given to

- fire-resistant separating walls;
- gas-tight vessels capable of withstanding the internal pressure generated;
- controlled release of the hot liquid;
- fire extinguishing systems.

8.7.3 Cables

The danger of the spread of fire and its consequences shall be reduced, as far as possible, by selecting suitable cables and by the method of installation.

The cables may be assessed by reference to the following categories:

- cables without particular fire performance characteristics;
- cables (single) with resistance to flame propagation (IEC 60332 series);
- cables (bunched) with resistance to flame propagation (IEC 60332 series);
- cables with low emission of smoke (IEC 61034-1);
- cables with low emission of acidic and corrosive gases (IEC 60754-1 and IEC 60754-2);
- cables with fire-resisting characteristics (IEC 60331-21 or IEC 60331-1).

Cables in trenches and buildings shall be laid in such a way that the regulations regarding fire safety of the building are not adversely affected. For example, to avoid fire propagation, holes through which the cables go from one room to another shall be sealed with suitable material.

A physical separation or different routing of power circuits from the control circuits for high-voltage equipment is recommended if it is necessary to preserve the integrity of the latter as long as possible following damage to the power circuits.

Where necessary, a fire alarm and fire extinguishing systems shall be installed in cable tunnels and in cable racks in the basement of control buildings.

8.7.4 Other equipment with flammable liquid

For all equipment, such as switchgear which contains more than 100 l of flammable liquid in each separate compartment, special fire precautions as specified for transformers may be necessary, depending on the nature and use of the installation and its location.

8.8 Protection against leakage of insulating liquid and SF_6

8.8.1 Insulating liquid leakage and subsoil water protection

8.8.1.1 General

Measures shall be taken to contain any leakage from liquid-immersed equipment so as to prevent environmental damage. National and/or local regulations may specify the minimum quantity of liquid contained in an equipment for which containment is required. As a guideline, where no national and/or local regulations exist, containment should be provided around liquid-immersed equipment containing more than 1 000 l (according to IEEE 980: 2 500 l).

NOTE In all cases, local regulations should be taken into account and approvals obtained when required.

8.8.1.2 Containment for indoor equipment

In indoor installations, spills of insulating liquid may be contained by providing impermeable floors with thresholds around the area where the equipment is located or by collecting the spilled liquid in a designated holding area in the building (see Figure 11).

The volume of the insulating liquid in the equipment as well as any volume of water discharging from a fire protection system shall be considered when selecting height of threshold or volume of the holding area.

8.8.1.3 Containment for outdoor equipment

The quantity of insulating liquid in equipment, the volume of water from rain and fire protection systems, the proximity to water courses and soil conditions shall be considered in the selection of a containment system.

NOTE 1 Containments (sumps) around liquid immersed equipment and/or holding tanks (catchment tanks) are extensively used to prevent escape into the environment of insulating liquid from equipment.

Containments and holding tanks, where provided, may be designed and arranged as follows:

- tanks;
- sump with integrated catchment tank for the entire quantity of fluid (Figure 8);
- sump with separate catchment tank. Where there are several sumps, the drain pipes may lead to a common catchment tank; this common catchment tank shall then be capable of holding the fluids of the largest transformer (Figure 9);
- sump with integrated common catchment tank for several transformers, capable of holding the fluids of the largest transformer (Figure 10).

The walls and the associated pipings of sumps and catchment tanks shall be impermeable to liquid.

The capacity of the sumps/catchment tanks for insulating and cooling fluids shall not be unduly reduced by water flowing in. It shall be possible to drain or to draw off the water.

A simple device indicating the level of liquid is recommended.

Attention shall be paid to the danger of frost.

The following additional measures shall be taken for protection of waterways and of ground water:

- the egress of insulating and cooling fluid from the sump/tank/floor arrangement shall be prevented (for exceptions, see 8.8.1.1);
- drained water should pass through devices for separating the fluids; for this purpose, their specific weights shall be taken into account.

NOTE 2 For outdoor installations, CIGRE Report 23-07 [30] recommends that the length and width of the sump is equal to the length and the width of the transformers plus 20 % of the transformer's height (including the conservator) on each side. IEEE 980 recommends that spill containment extends a minimum 1 500 mm beyond any liquid-filled part of the equipment.

NOTE 3 Examples for the automatic draining of water and separating of liquids is given in CIGRE Report 23-07 and IEEE 980.

State and regional laws and regulations shall be taken into account.

8.8.2 SF_6 leakage

Recommendations for use and handling of SF_6 gas are given in IEC/TR 62271-303.

To cover the unlikely event of an abnormal leakage, ventilation shall be provided in the switchgear room and in other accessible locations where the accumulation of gas may present a hazard. In case of outdoor installation, no special precautions are needed.

In rooms with SF_6 installations, which are above ground, natural venting is sufficient, if the gas volume of the largest compartment at atmospheric pressure does not exceed 10 % of the volume of the accessible switchgear room. If this demand cannot be fulfilled, mechanical ventilation shall be installed.

In rooms with SF_6 installations which are below ground on all sides, mechanical ventilation shall be provided if gas quantities which pose an intolerable risk to the health and safety of personnel (see note below) are capable of collecting in terms of gas quantity versus size of the room.

Chambers, ducts, pits, shafts, etc., situated below SF_6 installation rooms and connected to them, shall have the possibility of being ventilated.

To guarantee that no thermal decomposition of SF_6 present in the atmosphere can occur the following provisions shall be made:

- no parts of any equipment installed in the switchgear room which are in contact with air shall exceed a temperature of 200 °C;
- when filling of equipment is carried out during erection on site (not sealed systems) measures should be taken to prevent smoking, open fire and welding in the working areas.

NOTE For maximum SF_6 concentration, national regulations should be considered.

8.8.3 Failure with loss of SF_6 and its decomposition products

Recommendations for use and handling of SF_6 gas are given in IEC/TR 62771-303.

NOTE Guidance has been issued by CIGRE 23-04 [29].

8.9 Identification and marking

8.9.1 General

Clear identification and unambiguous marking are required to avoid incorrect operation, human error, accidents, etc. while operation and maintenance are carried out (see also 7.1.7).

Signs, boards and notices shall be made of durable and non-corrosive material and printed with indelible characters.

The operational state of switchgear and controlgear shall be clearly shown by indicators except when the main contacts can clearly be viewed by the operator.

Cable terminations and components shall be identified. Relevant details making identification possible in accordance with a wiring list or diagram shall be provided.

8.9.2 Information plates and warning plates

In closed electrical operating areas and in industrial buildings, all electrical equipment rooms shall be provided, on the outside of the room and on each access door, with necessary information identifying the room and pointing out any hazards.

The colours and contrasting colours shall comply with IEC standards or national regulations.

8.9.3 Electrical hazard warning

All access doors to closed electrical operating areas, all sides of outer perimeter fences and masts, poles and towers with a transformer or switching device shall be provided with a warning sign.

The signs shall comply with IEC standards or national regulations.

8.9.4 Installations with incorporated capacitors

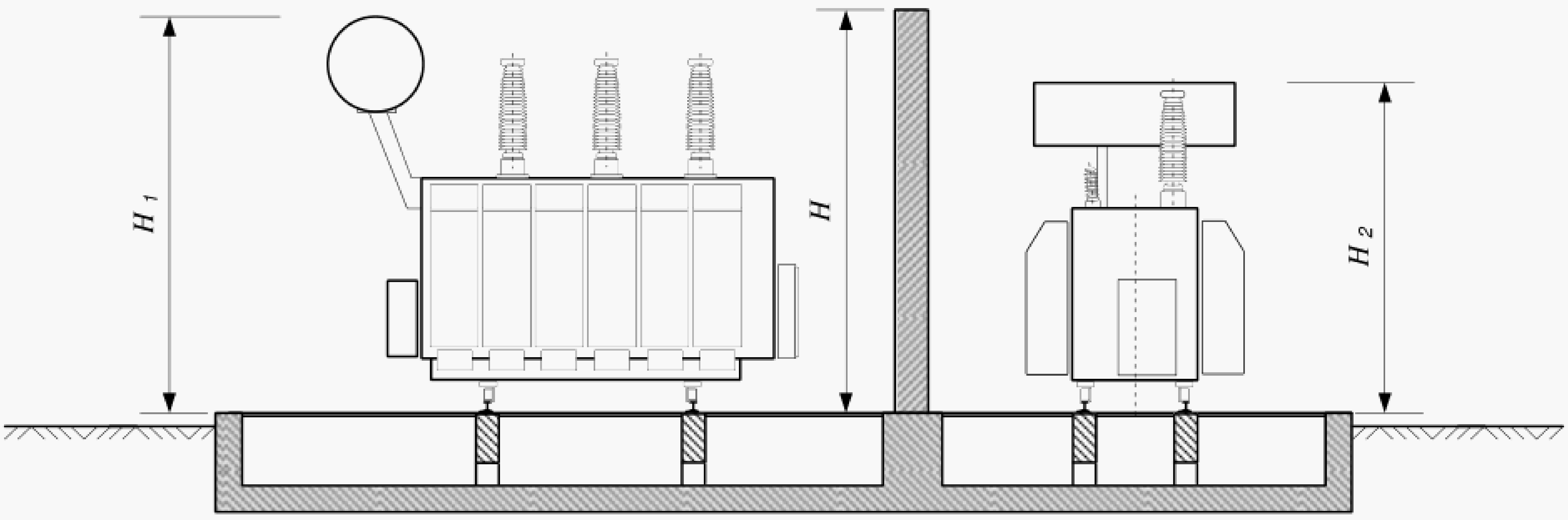
The capacitors shall be provided with a warning label indicating the discharge time.

8.9.5 Emergency signs for emergency exits

Emergency exits shall be indicated by the appropriate safety warning sign. The signs shall comply with IEC standards or national regulations.

8.9.6 Cable identification marks

The position where cables enter buildings should be identified. Identification marks shall not be placed on removable covers or doors that could be interchanged.



$H \geq H_1$ (with $H_1 > H_2$)

$L \geq B_2$ (with $B_2 > B_1$)

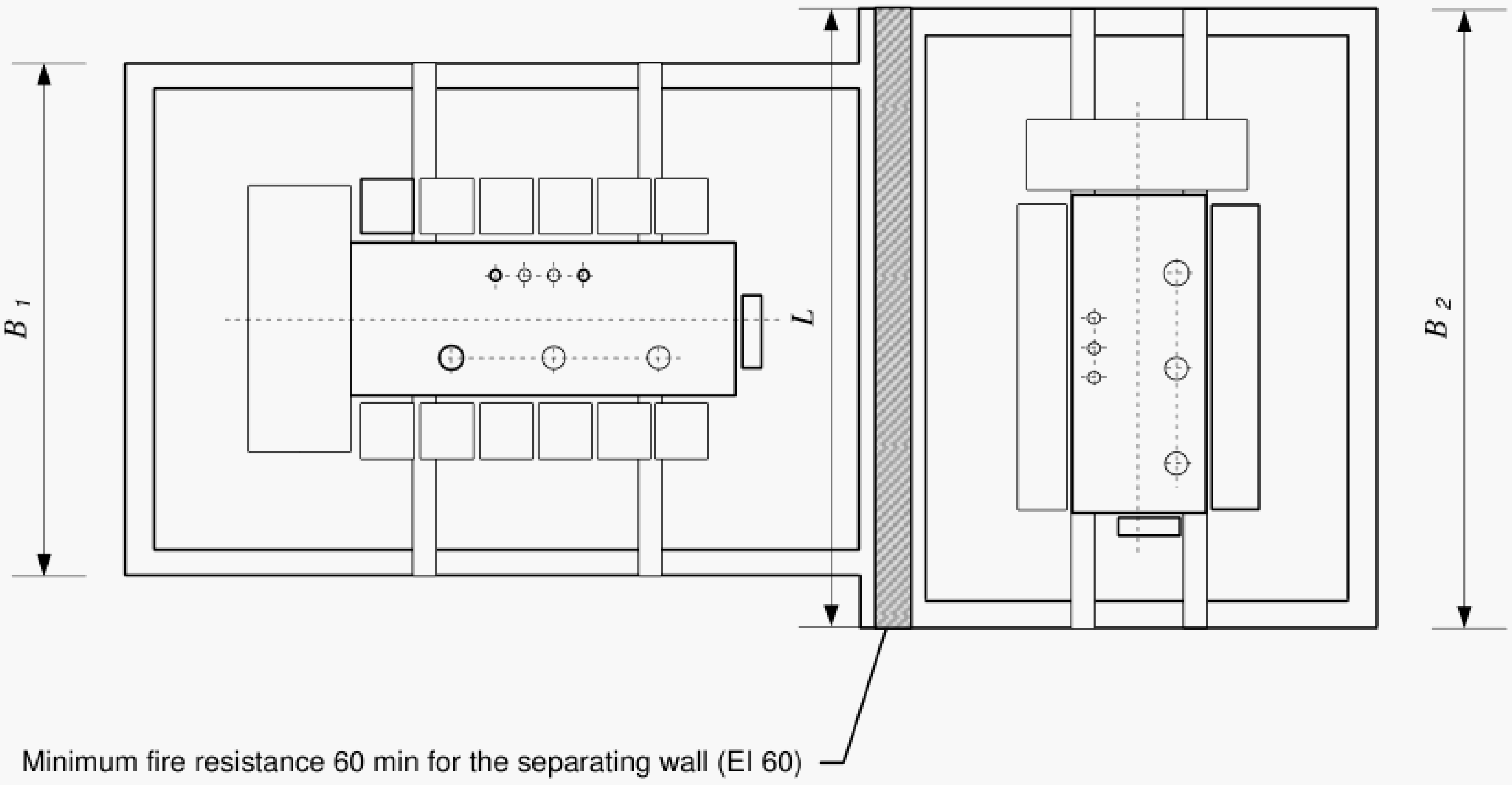
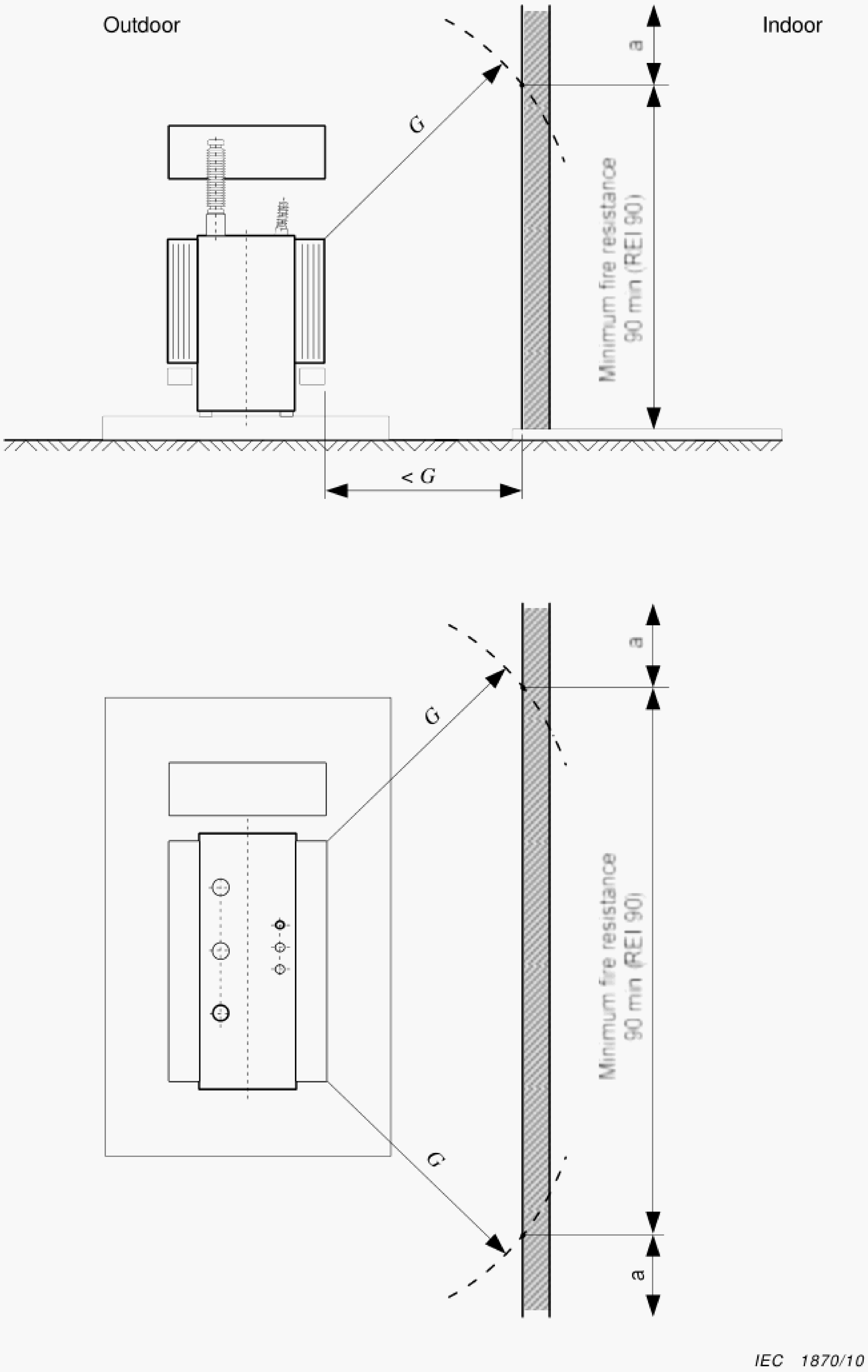


Figure 6 – Separating walls between transformers

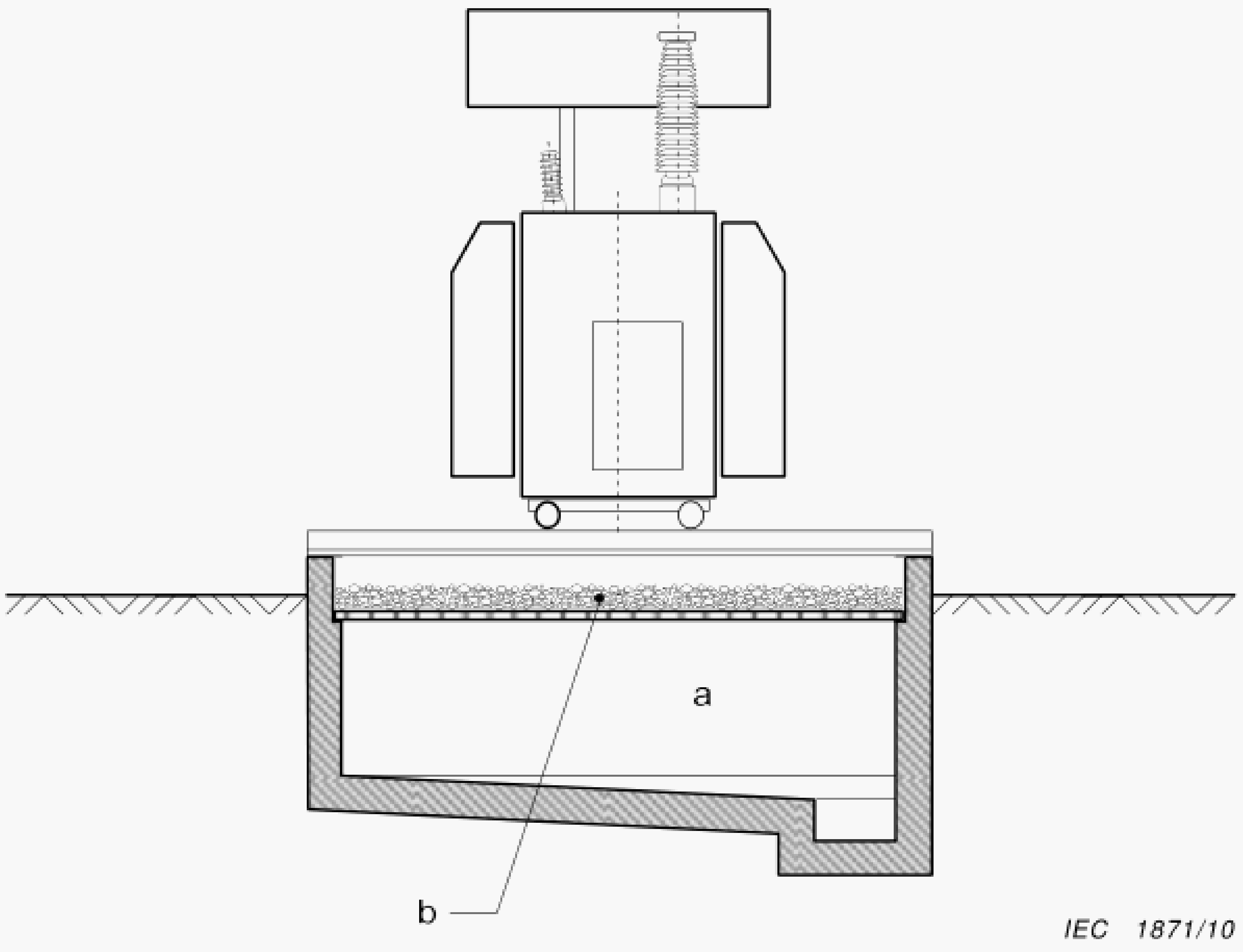


Key

For Clearance G, see Table 3

a The wall in this area shall be designed to avoid a spread of fire

Figure 7 – Fire protection between transformer and building



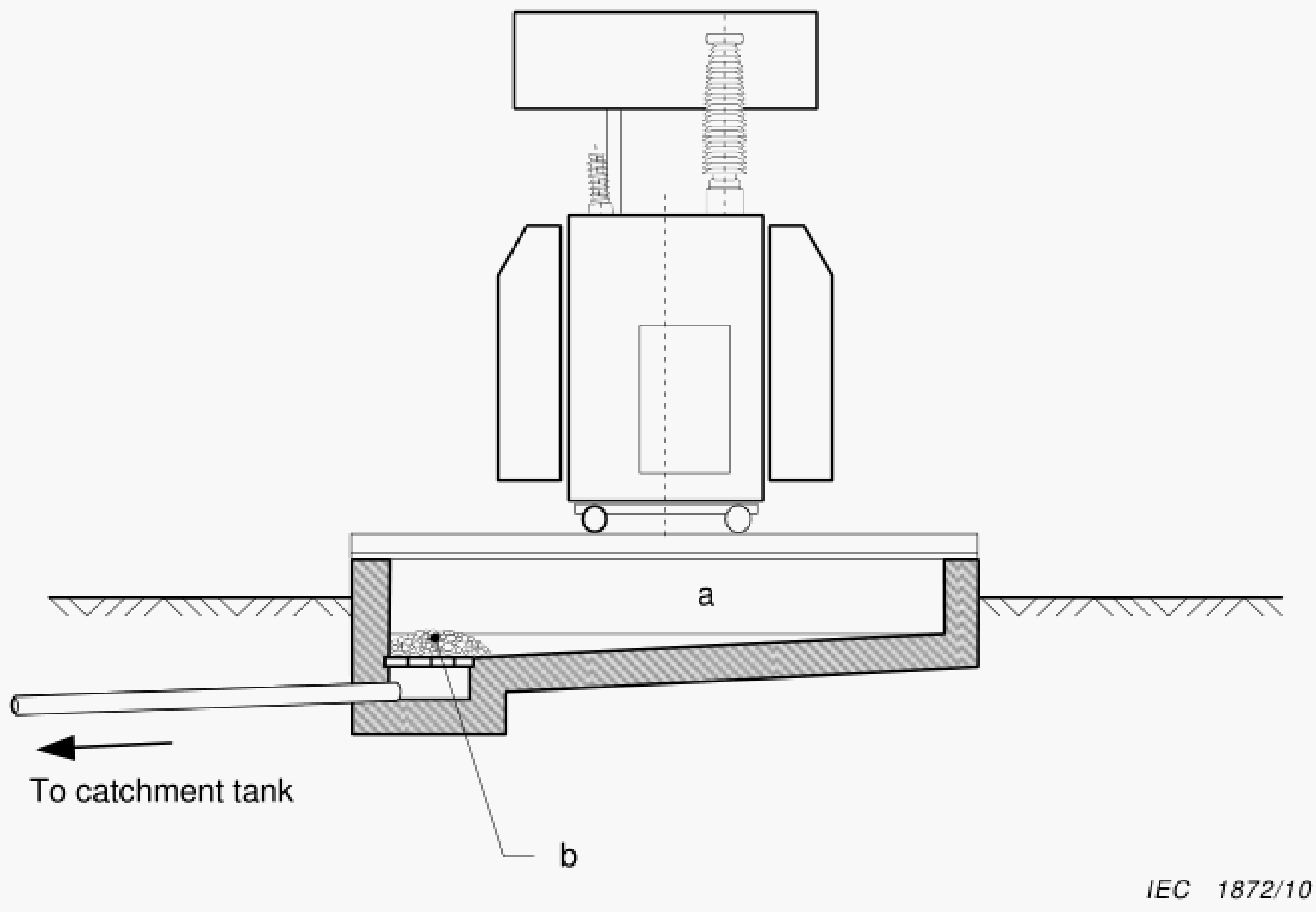
Key

a Containment: the entire quantity of fluid of the transformer plus rain water

b Gravel layer for fire protection see 8.7.2

NOTE In addition, the water from the fire-extinguishing installation (if any) should be considered.

Figure 8 – Sump with integrated catchment tank

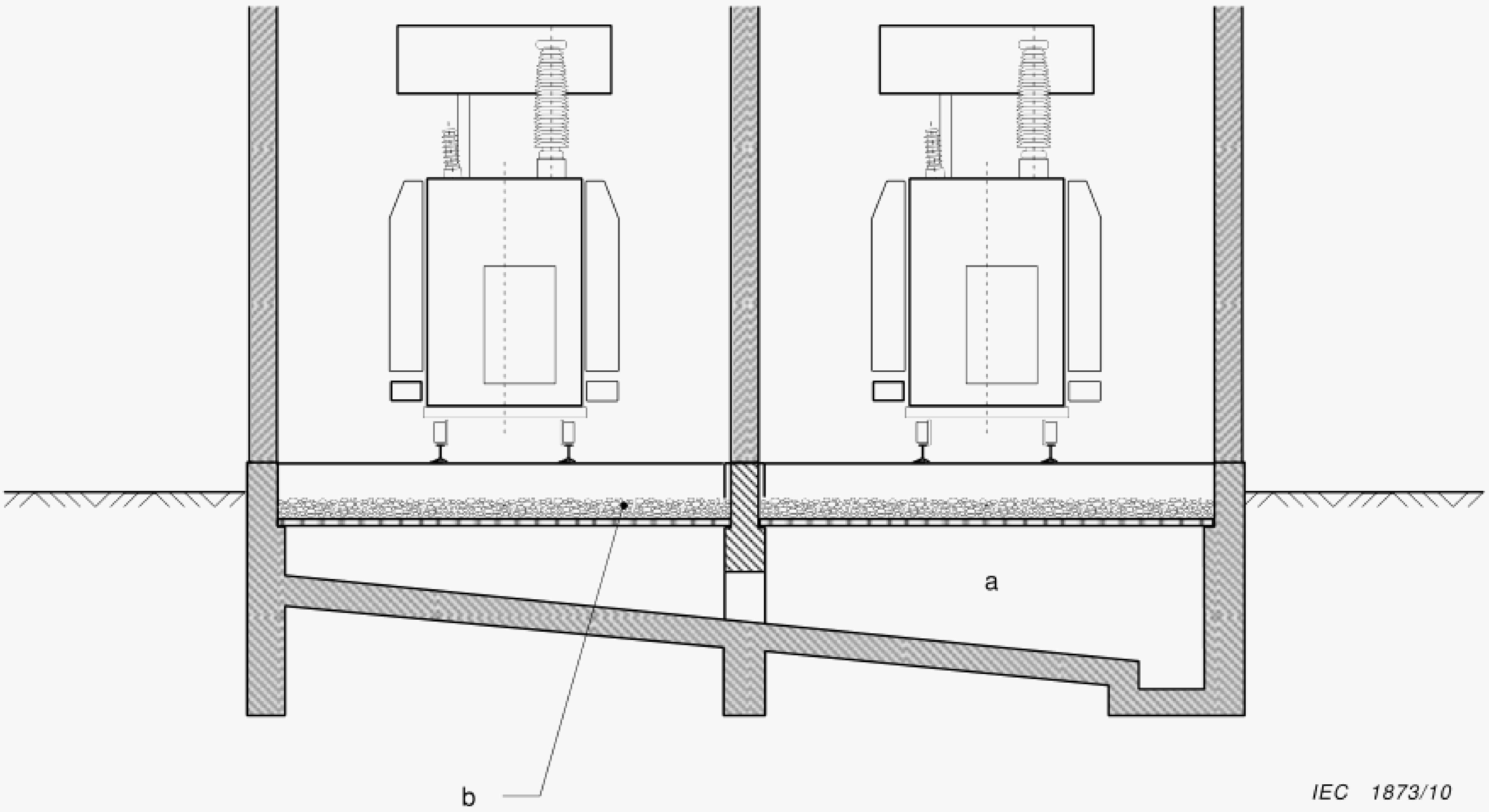


Key

a Containment: minimum 20 % of the fluid from the transformer

b Gravel layer for fire protection see 8.7.2

Figure 9 – Sump with separate catchment tank



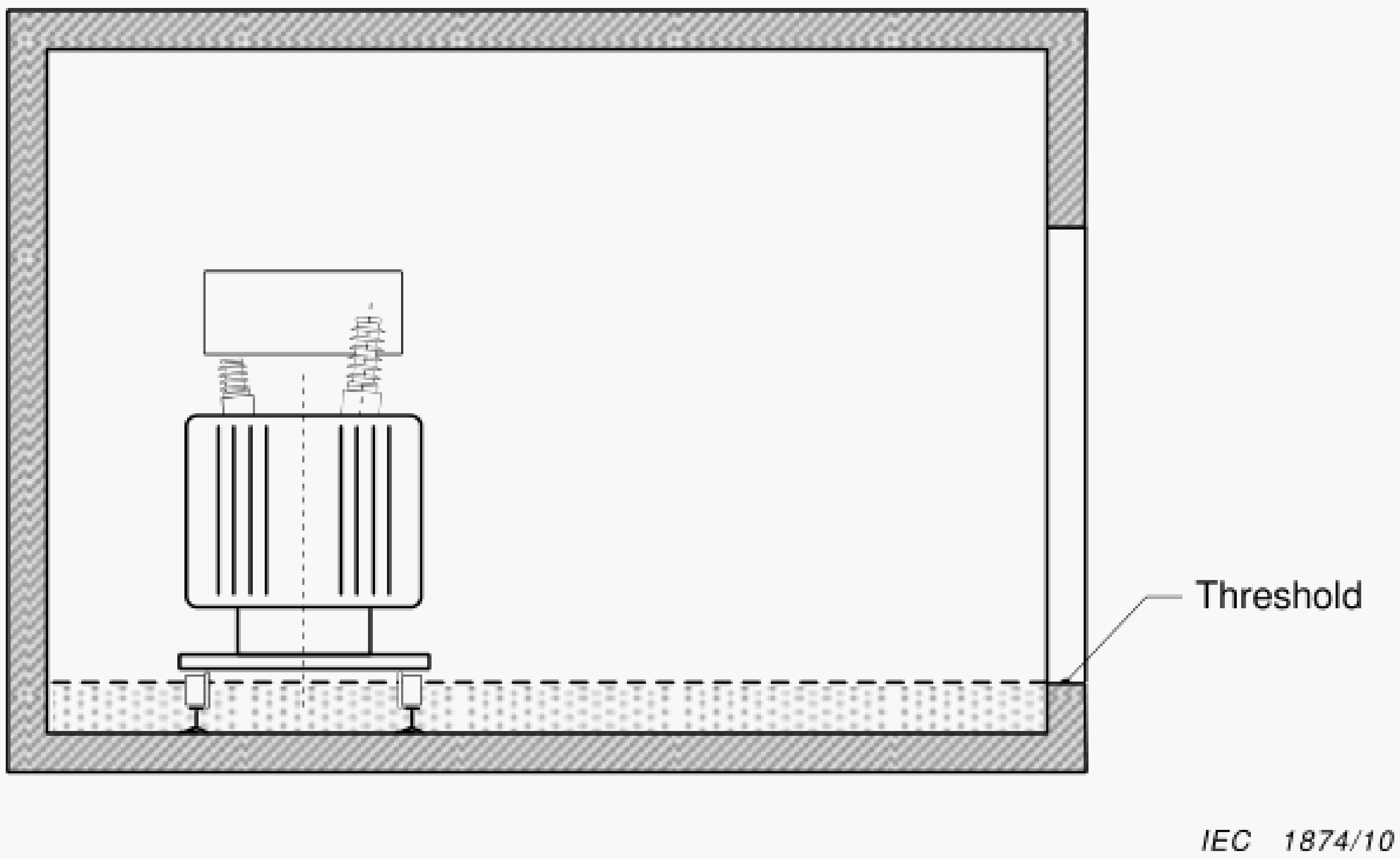
Key

a Containment outdoor: the entire quantity of fluid of the largest transformer plus rain water
Containment indoor: the entire quantity of fluid of the largest transformer

b Gravel layer for fire protection see 8.7.2

NOTE In addition, the water from the fire-extinguishing installation (if any) should be considered.

Figure 10 – Sump with integrated common catchment tank



NOTE The dotted area denotes the volume of the entire quantity of insulating fluid of the transformer spilled on the floor.

Figure 11 – Example for small transformers without gravel layer and catchment tank

9 Protection, control and auxiliary systems

9.1 Monitoring and control systems

Monitoring, protection, regulating and control devices shall be provided, as necessary, for the correct and safe functioning of the equipment.

Automatic devices, designed to offer selectivity and quick operation, shall provide protection against the effects of unacceptable overload and internal and external faults appropriate to the size and significance of installation.

Consideration shall be given for protection against the following effects:

– overcurrent, short-circuit and earth fault;
– overload and thermal effect;
– overvoltage;
– undervoltage;
– underfrequency.

Protection coordination studies shall be conducted as agreed between the user and supplier in order to determine the setting of protective devices. Back-up protection shall be considered for short-circuit protection and also for earth fault protection when clearing of earth faults is required.

Low-frequency conditions generally indicate power system problems. For installations supplied by a power system, low-frequency disconnection devices may be required in accordance with local regulations or power system requirements. For installations having their own independent power supply, consideration should be given to implementing load shedding to prevent total loss of power during disturbances.

Investigations shall be performed to determine possible overvoltages during operating conditions. Protection shall be installed where overvoltages may exceed tolerance limits of the installed equipment.

The effects of undervoltages on the operation of electrical equipment shall be considered. Devices to detect undervoltages shall be provided where necessary in order to initiate automatic transfers to an alternative supply, or to disconnect the equipment to prevent incorrect operation or damage from occurring.

Equipment shall comply with the severity class (see IEC 60255 series) corresponding to the part of the installation in which it is located.

Facilities shall be provided for isolating the control circuit of each primary switching equipment or each switchgear bay in order to allow maintenance of high-voltage equipment to be performed safely.

Provision shall be made to allow for repair, maintenance, and/or testing to be carried out on protection and control devices without any danger to personnel or the equipment.

Control circuits and signalling circuits shall, preferably, be functionally separated. Tripping signals shall be displayed on the protection panel if it exists.

Alarm and fault-indicating equipment shall clearly indicate danger and fault conditions; several signals can be combined as a common signal to be transmitted to a remote control point.

The control equipment and system, including cables and cords, shall be designed and installed to minimize the possibility of damage to the connected equipment due to electromagnetic interference. Basic rules are given in 9.6.

The control equipment and system, including cables and cords, shall be designed and installed in such a way that they minimize the danger from operating failure, inadvertent operation or incorrect information. In meeting this requirement, influences such as voltage dips, supply failure, insulation faults and electromagnetic interference effects shall be taken into account.

The actuating elements for the control of a switchgear shall be designed and installed in such a way that accidental actuation is avoided.

Where a remote control is available, local/remote control selection shall be provided at the local operating position (i.e. at or in the close vicinity of the switches).

The control circuit of switching devices operated remotely or automatically shall be provided with suitable means near the device to prevent accidental operation during planned outages.

When required, the monitoring and control system shall implement load shedding, emergency shut down, automatic transfer and network reconfiguration, motor re-acceleration and re-starting, etc. in order to maintain safe operating conditions during electrical system disturbances.

For safety reasons, it is recommended that hard-wired interfaces to industrial process control equipment be designed such that maintenance of the process control circuits can be carried out without accessing high-voltage equipment, for example by using interposing relays installed in a separate cubicle.

9.2 DC and AC supply circuits

9.2.1 General

Auxiliary power supply systems shall be designed for the permitted voltage fluctuation range and suitable power capacity which is required by the equipment for control and auxiliary systems.

Low-voltage a.c. and d.c. systems shall be designed in accordance with the IEC 60364 series.

Auxiliary switchboards shall be provided to separate and protect the various auxiliary circuits.

A voltage loss or failure in the supply circuit should initiate a signal to a control location.

Power supply systems may be categorized into essential and non-essential groups. Essential supplies should be continuously available without any interruption, whereas non-essential ones may be allowed to be subject to interruptions.

9.2.2 AC supply

For supplies belonging to the essential group, such as the supplies to a computerized control system, or the supplies to any equipment whose interruption might cause a hazardous condition after a transient loss of power, the provision of a suitable UPS (uninterruptible power supply) is recommended.

Some equipment (e.g. SF_6-breaker heaters) may require the provision of changeover power supplies.

9.2.3 DC supply

DC supply units shall be capable of supplying power to all permanent d.c. loads and to the loads associated with essential operations. This may be achieved by choosing an appropriate number of independent units of sufficient capacities.

It is recommended that d.c. supply units such as batteries and chargers be provided with instruments for monitoring voltage and current.

DC batteries shall be sized to provide power for operation of an electrical installation during total loss of a.c. station services. The most probable duration of a.c. station services loss shall be evaluated to allow proper sizing and selection of d.c. batteries.

Sizing of batteries shall be based on worst case scenarios that might cause a total loss of a.c. station services (i.e. total blackout, fault on a major bus in the installation, etc.). As a minimum, the d.c. batteries shall have enough capacity to trip breakers and switches at the beginning of the discharge period, to supply power to the continuous d.c. load and to close the elements of the installation that will restore a.c. services.

Battery banks with exposed live parts shall be kept in a room or cubicle accessible only to authorized personnel.

Battery rooms or cubicles shall be dry and adequately ventilated to limit hydrogen accumulation. Allowable hydrogen levels and recommended number of air changes shall conform to national regulations.

An easy means of escape from battery rooms shall be provided. Eyewash stations or personal protective equipment shall be provided, preferably located outside the battery room and close to the battery room door.

Battery banks shall preferably be isolated from control rooms to prevent the spread of fumes and to prevent accidental contact.

Where the risk of explosion cannot be avoided, explosion-protected equipment shall be used (see IEC 60079-0).

The risk of explosion due to combustion of gas mixtures in the presence of an open flame or glowing parts shall be indicated by means of corrosion-resistant, legible signs of suitable size.

Notwithstanding the ventilation provided, rooms containing open type lead batteries shall be considered as locations with corrosive environments. Walls, ceilings and floors shall meet the requirements for protection against corrosion and gaseous products. Means shall be provided to prevent corrosive substances from entering any drainage systems.

9.3 Compressed air systems

Compressed air systems shall be designed to comply with the appropriate legislative rules regarding pressure vessels and pressurized systems.

Instruments and alarms shall be provided to ensure safe and reliable operation of the compressed air system.

The compressed air system shall be capable of providing air of relative humidity appropriate to the type and operating pressure of the equipment to be supplied under all environmental conditions. Where necessary drying equipment shall be provided.

Compressed air systems shall be designed so that water can be drained from all receivers or other points where it may collect during operation.

The compressed air system shall be designed to operate at its maximum and minimum capacity over the full range of environmental conditions to be expected for the associated switchgear and/or system. Adequate compressor cooling shall be provided as well as suitable protection to allow intermittent operation under freezing conditions.

Pressure vessels and pipelines shall be protected against corrosion internally and externally.

The function of various components of the compressed air system shall be clearly indicated on the equipment. Different pressures shall be identified on pipework, vessels and diagrams by a method acceptable to the purchaser.

The compressed air system shall be provided with sufficient points of isolation and drainage to allow sectionalization for maintenance in accordance with the operating and safety rules of the user.

Pipes which are permanently under pressure shall be protected against damage due to direct arcing.

All controls of the compressed air system which have to be used during operation shall be arranged so that they are safely accessible.

9.4 SF_6 gas handling plants

Where gas has to be handled and retrieved, a gas service unit shall be provided to transfer gas to and from gas-filled equipment in order to permit maintenance on the primary equipment. This gas service unit shall be capable of evacuating and storing the largest quantity of gas specified and of evacuating the largest volume specified to the vacuum level and refilling to the highest filling pressure specified by the manufacturer. The design and capacity of the gas service unit shall be determined in agreement between supplier and user.

The gas service unit shall also be capable of extracting air at atmospheric pressure from the largest volume specified to the vacuum level specified by the manufacturer. The gas service unit shall be capable of returning gas to the equipment and recycling used gas through filters.

NOTE Guidance on handling of plants containing SF_6 is given in IEC 60480 and IEC 62271-303.

9.5 Hydrogen handling plants

The hydrogen-cooled generator, or synchronous condenser and its hydrogen cooling system shall be installed in the following way.

- The structure of the generator or synchronous condenser and its hydrogen cooling system shall be leak-tight and capable of preventing the mixture of hydrogen and air.
- The generator, synchronous condenser, hydrogen pipes, valves and other fittings in the hydrogen system shall be capable of withstanding the explosion of hydrogen at atmospheric pressure.
- The generator plant shall be provided with a device through which hydrogen gas can be purged to the open air safely when hydrogen leaks out the generator shaft seal.
- A device capable of introducing hydrogen safely into the generator or synchronous condenser and also a device capable of expelling hydrogen safely out of the generator or synchronous condenser shall be installed.
- An instrument shall be provided which detects abnormal conditions of the equipment and gives a warning.

9.6 Basic rules for electromagnetic compatibility of control systems

9.6.1 General

This subclause deals with the protection of control circuits against electromagnetic interference.

9.6.2 Electrical noise sources in high voltage installations

Interferences may be transmitted into HV installations by means of conduction, capacitive coupling, induction or radiation.

a) High frequency interferences are produced by
   - switching in primary circuits,
   - lightning strokes on overhead lines or on grounded components of high voltage installations,
   - operation of surge arresters with gaps,
   - switching in secondary circuits,
   - high frequency radio transmitters,
   - electrostatic discharges.
b) Low frequency interferences are produced by
   - short-circuits,
   - earth faults,
   - electromagnetic fields generated by equipment (busbars, power cables, reactances, transformers, etc.)

Protection against interference is based on two general principles:

- reduction of the penetration of electromagnetic fields into the equipment;
- establishment of equal potential between every piece of equipment and the earthing system.

9.6.3 Measures to be taken to reduce the effects of high frequency interference

The recommendations listed below are the most important ones for reducing the effects of high frequency electromagnetic interference:

a) suitable construction of instrument transformers (voltage transformers, current transformers), effective shielding between primary and secondary winding, testing of high frequency transmission behaviour;
b) protection against lightning strokes;
c) improvement of the earthing system and earthing connections (see 10.3.3);
d) shielding of secondary circuit cables:
   - shields should be continuous;
   - shields should have a low resistance (a few ohms per kilometre);
   - shields should have a low coupling impedance within the interference frequency range;
   - earthing of the shields should be as short as possible;
   - the shields should be earthed at both ends and intermediate points where possible;
   - the shields should be earthed at their entry to the control cabinets so that the currents circulating in the shields do not affect the unshielded circuits. Connections should preferably be circular by using suitable cable glands or a welding procedure;

e) grouping of circuits: in order to reduce the differential mode overvoltages, the incoming and outgoing wires associated to a same function should be grouped within the same cable. As far as possible, control cables should be segregated from other cables.

9.6.4 Measures to be taken to reduce the effects of low frequency interference

The recommendations listed below are the most important ones for reducing the effects of low-frequency electromagnetic interference.

a) Measures concerning cable laying:
   - separation of control cables from power cables by using spacing or different routes;
   - power cables in trefoil formation should be preferred to a flat formation;
   - as far as possible, cable routes should not be parallel to bus bars or power cables;
   - control cables should be laid away from inductances and single-phase transformers.
b) Measures concerning the circuit arrangement:
   - loops should be avoided;
   - for d.c. auxiliary supply circuits, a radial configuration is preferable to a ring configuration;
   - the protection of two different d.c. circuits by the same miniature circuit-breaker should be avoided;
   - parallel connection of two coils located in separate cubicles should be avoided;
   - all wires of the same circuit should be located in the same cable. When different cables have to be used, they should be laid in the same route.
c) Twisted pairs cables are recommended for low level signals.

9.6.5 Measures related to the selection of equipment

The installation shall be divided into different zones, each of them corresponding to a specific class of environment (see 4.4).

In each zone, equipment shall be selected in accordance with the associated class of environment.

Where necessary the following measures shall be taken in the internal circuitry:

a) metallic isolation of the I/O signal circuits;
b) installation of filters on auxiliary power supply circuits;
c) installation of voltage-limiting devices such as
   - capacitor or RC circuits;
   - low voltage surge arresters;
   - zener diodes or varistors;
   - transzorb diodes.

These devices shall be installed inside the protection and control equipment.

Additional measures concerning gas-insulated switchgear.

d) Connection of concrete reinforcement grids to the earthing system at various points, especially in the floor (see Clause 10).
e) Good shielding at the GIS/air bushings by multiple connections between the enclosure and the building wall (to the reinforcement grid or metallic cladding) and multiple connections between the wall and earthing system.

f) Adequate design and testing of secondary equipment concerning their immunity against electrical transients.

9.6.6 Other possible measures to reduce the effects of interference

The recommendations listed below supplement, when applicable, the previous recommendations:

– installation of control cables in metallic cable ducts is recommended. Continuity and earthing of ducts should be ensured along their whole length;

– where possible, installation of cables along metallic surfaces;

– use of optical fibre cables with appropriate equipment.

10 Earthing systems

10.1 General

This clause 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.

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 power-frequency purposes is derived from the appropriate curve in IEC/TS 60479-1:2005. 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.

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 12 is calculated according to the method defined in Annex B.

NOTE The curve is based on data extracted from IEC/TS 60479-1:2005:

– body impedance from Table 1 of IEC/TS 60479-1:2005 (not exceeded by 50 % of the population),

– permissible body current corresponding to the c2 curve in Figure 20 and Table 11 of IEC/TS 60479-1:2005 (probability of ventricular fibrillation is less than 5 %),

– heart current factor according to Table 12 of IEC/TS 60479-1:2005.

The curve in Figure 12, which gives the permissible touch voltage, should be used. Annex C shows the IEEE 80 curve which can be used as an alternative to the curve in Figure 12.

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 limit given in IEC 60364-4-41 (e.g. 50 V) [17].

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 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.

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

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.

10.2.3.1 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.

10.2.3.2 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 5 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.

10.2.3.3 LV in the proximity of HV substations

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

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

[a] For definitions of the type of LV systems, see IEC 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 should be 1.

[e] U_{Tp} is derived from Figure 12

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.

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 if 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 discharged into soil from earthing system, based on earth fault current;

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

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 5 are met the design is complete;

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.

A flowchart of this design process is given in Annex D.

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.

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) three phases to earth;

b) two phases to earth;

c) single phase to earth;

d) if applicable: 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.

10.3.3 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.

10.4 Construction of earthing systems

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

10.5 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.

10.6 Maintainability

10.6.1 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.

10.6.2 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.

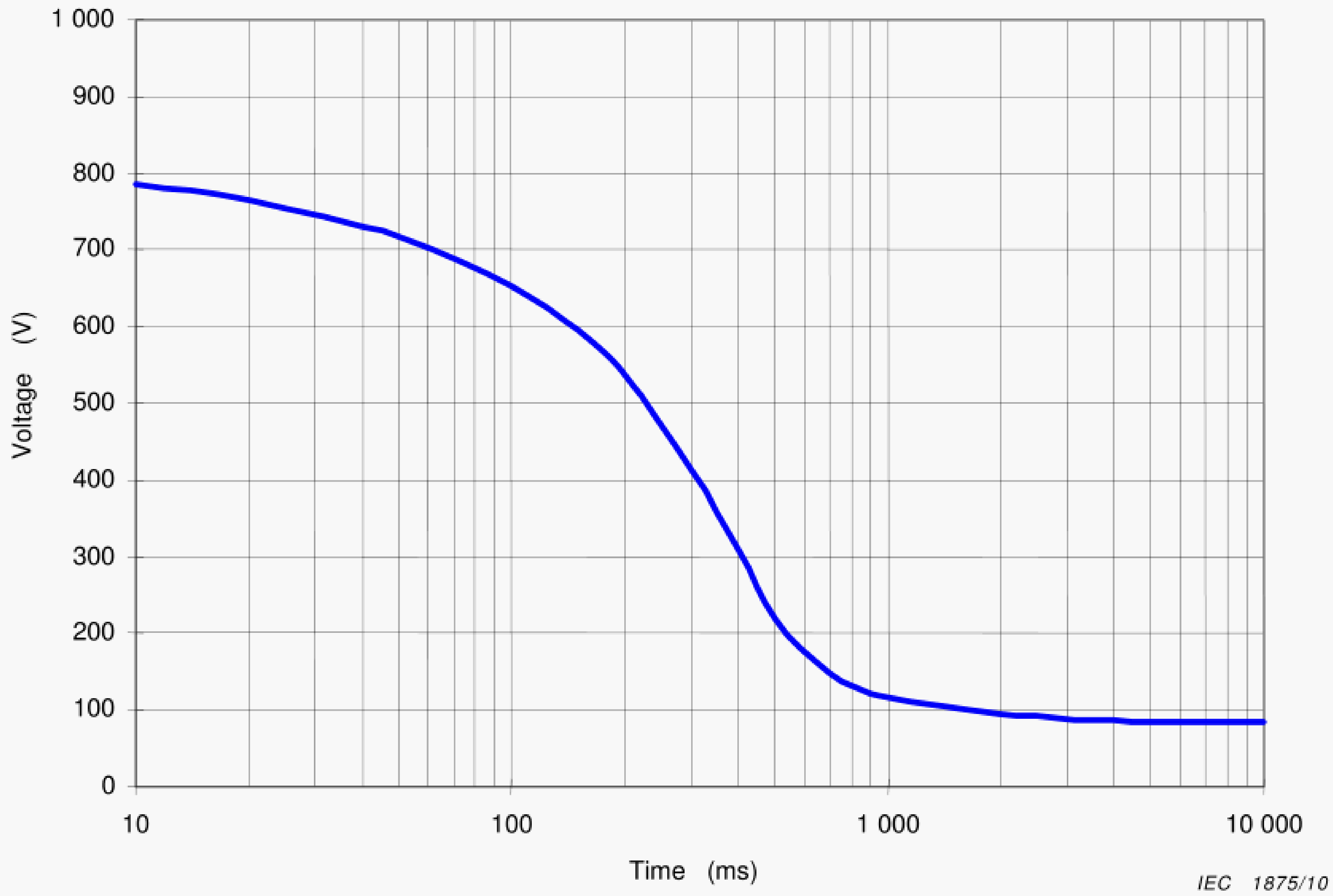


Figure 12 – Permissible touch voltage U_{Tp}

11 Inspection and testing

11.1 General

Inspections and tests shall be carried out to verify compliance of the installation with this standard and compliance of the equipment with the applicable technical specifications.

The following shall be subject to agreement between the supplier and the user:

– the extent of the inspection and testing;

– which specifications are applicable;

– the extent and type of documentation provided.

NOTE Specific tests on site for factory-built and type-tested equipment and for factory-built assemblies are indicated and are based on IEC standards.

Verification may be achieved by the following methods:

a) visual inspections;

b) functional tests;

c) measuring.

Inspections and tests on parts of power installations may be carried out after delivery as well as when the installation has been completed.

Typical activities that are usually carried out are, for example:

- verification of characteristics of the equipment (including rated values) for the given operating conditions;
- verification of minimum clearances between live parts and between live parts and earth;
- power frequency voltage test for switchgear;
- voltage test for cables;
- verification of minimum heights and of protective barrier clearances;
- visual inspections and/or functional tests of electrical equipment and parts of installation;
- functional tests and/or measuring of protective, monitoring, measuring and controlling devices;
- inspection of markings, safety signs and safety devices;
- verification of correct fire ratings for buildings/enclosures;
- verification that emergency exits are operational;
- verification of the earthing system.

11.2 Verification of specified performances

Tests will, in general, be carried out on the various items of equipment comprising an installation at appropriate stages of the contract to ultimately verify performance of the installation. The tests required, their conditions and organization are to be defined. This may include definition of the provision of site services, personnel, etc.

11.3 Tests during installation and commissioning

The user and supplier shall agree on the requirements (methods and acceptance criteria) for tests during installation and commissioning, together with a listing of the testing standards to be applied. This may include functional tests to demonstrate the ability of the equipment to satisfy the operational requirements, such as automatic start-up and shutdown.

The test equipment for demonstration of achievement of design requirements shall be agreed between the user and supplier.

The user and supplier shall agree on a schedule of tests for components and systems during the installation and commissioning period. The necessary services to allow the tests to be carried out shall be agreed between the parties.

NOTE The contractual consequences of the outcome of the tests during installation and commissioning should be stated in the enquiry, where appropriate.

11.4 Trial running

When agreed between the user and supplier, a trial run shall be performed. The purpose of the trial run is to prove the functional capability of the high-voltage installation. During the run, therefore, all significant components should be in operation.

The agreement should define under what circumstances a breakdown of a significant component constitutes an interruption of the trial. The user may also give exception criteria for breakdowns of a very short period, for example simply extending the period of the trial by the outage time.

The conditions that have to be met for the successful completion of the trial run should be defined in the enquiry.

NOTE The contractual consequences of the outcome of the trial run should be stated in the enquiry, where appropriate.

12 Operation and maintenance manual

Each installation shall have an operation manual describing the normal, emergency, and maintenance procedures as well as safety instructions for the operation of the high-voltage electrical installation.

Each installation shall have a set of up-to-date drawings and operating diagrams on the premises. These drawings and diagrams shall allow operation and maintenance personnel to provide safe and efficient interventions in the installation.

Manufacturers of major components of an installation shall provide operation and maintenance manuals and test and in-service reports. These documents shall be readily available for use when necessary.

Emergency routes to the nearest hospital and emergency phone numbers shall be displayed in a visible location in the installation.

Annex A
(normative)

Values of rated insulation levels and minimum clearances based on current practice in some countries

Table A.1 – Values of rated insulation levels and minimum clearances in air for 1 kV < U_m ≤ 245 kV for highest voltage for installation U_m not standardized by the IEC based on current practice in some countries

Voltage range	Highest voltage for installation	Rated short-duration power-frequency withstand voltage	Rated lightning impulse withstand voltage [a]	Minimum phase-to-earth and phase-to-phase clearance N	
	U_m r.m.s.	U_d r.m.s.	U_p 1,2/50 µs peak value	Indoor installations	Outdoor installations
	kV	kV	kV	mm	mm
I	2,75	15	30	60	120
			45	70	120
			60	90	120
	4,76	19	60	90	120
	5,5	19	45	70	120
			60	90	120
			75	120	120
	8,25	27	60	90	120
			75	120	150
			95	160	160
	8,25	26	75	120	150
		35	95	160	160
	15	35	95	160	160
		50	110	180	180
	15,5	35	75	120	150
			85	150	160
			110	180	180
	17,5	38	110	180	
			125	220	
	24	50	150	280	
	25	50	95	190	290
			125	210	
			150		
	25,8	50	125	220	
		70	150	280	
	27	50	95	160	
			125	220	
			150	280	

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

Table A.2 – Values of rated insulation levels and minimum clearances in air for 1 kV < U_m ≤ 245 kV for highest voltage for installation U_m not standardized by IEC based on current practice in some countries

<table>
<tr><th rowspan="2">Voltage range</th><th>Highest voltage for installation</th><th>Rated short-duration power-frequency withstand voltage</th><th>Rated lightning impulse withstand voltage [a]</th><th colspan="2">Minimum phase-to-earth and phase-to-phase clearance
N</th></tr>
<tr><th>U_m
r.m.s.</th><th>U_d
r.m.s.</th><th>U_p
1,2/50 µs
peak value</th><th>Indoor installations</th><th>Outdoor installations</th></tr>
<tr><td rowspan="15">I</td><td>kV</td><td>kV</td><td>kV</td><td>mm</td><td>mm</td></tr>
<tr><td>30</td><td>70</td><td>160</td><td colspan="2">290</td></tr>
<tr><td>36</td><td>70</td><td>200</td><td colspan="2">380</td></tr>
<tr><td>38</td><td>70</td><td>125
150
200</td><td colspan="2">220
280
360</td></tr>
<tr><td>38</td><td>70
95</td><td>150
200</td><td colspan="2">280
360</td></tr>
<tr><td>38,5</td><td>75</td><td>155
180
195</td><td>270
320</td><td>400</td></tr>
<tr><td>40,5</td><td>80</td><td>190</td><td colspan="2">350</td></tr>
<tr><td>41,5</td><td>80</td><td>170
200</td><td colspan="2">320
360</td></tr>
<tr><td>48,3</td><td>105</td><td>150
200
250</td><td colspan="2">280
360
480</td></tr>
<tr><td>48,3</td><td>120</td><td>250</td><td colspan="2">480</td></tr>
<tr><td>72,5</td><td>160</td><td>350</td><td colspan="2">690</td></tr>
<tr><td>82,5</td><td>150</td><td>380</td><td colspan="2">750</td></tr>
<tr><td>100</td><td>150
185</td><td>380
450</td><td colspan="2">750
900</td></tr>
<tr><td>204</td><td>275
325</td><td>650
750</td><td colspan="2">1 300
1 500</td></tr>
<tr><td colspan="6">[a] The rated lightning impulse is applicable to phase-to-phase and phase-to-earth.</td></tr>
</table>

Table A.3 – Values of rated insulation levels and minimum clearances in air for U_m > 245 kV for highest voltages for installation U_m not standardized by IEC based on current practice in some countries

Voltage range	Highest voltage for installation	Rated short-duration power-frequency withstand voltage	Rated lightning impulse withstand voltage[a]	Rated switching impulse withstand voltage	Minimum phase-to-earth clearance		Rated switching impulse withstand voltage	Minimum phase-to-phase clearance	
	U_m r.m.s.	U_d r.m.s.	U_p 1,2/50 µs peak value	U_p Phase-to-earth 250/2 500 µs peak value	Conductor – structure	Rod – structure *N*	U_p Phase-to-phase 250/2 500 µs peak value	Conductor – conductor parallel	Rod – conductor
	kV	kV	kV	kV	mm		kV	mm	
II	362	520	1 300	950	2 400	2 900	1 425	3 100	3 600
	550	680	1 800	1 175		4 000			6 500
	550	710	1 800	1 175	3 300	4 100	2 210	6 100	7 400
	550	775	1 800	1 175	3 350	3 650		4 600	5 200
	550	635	1 300 1 425 1 550 1 800			5 800			5 800

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

Annex B
(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 60479-1:2005, where probability of ventricular fibrillation is less than 5 %. I_{B} depends on fault duration
Heart current factor	HF	Table 12 of IEC/TS 60479-1:2005, 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 60479-1:2005 ZT not exceeded by 50 % of the population ZT depends on touch voltage. Therefore first calculation has to start with assumed level
Body factor	BF	Figure 3 of IEC/TS 60479-1:2005, 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 (as indicated in the Foreword).

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

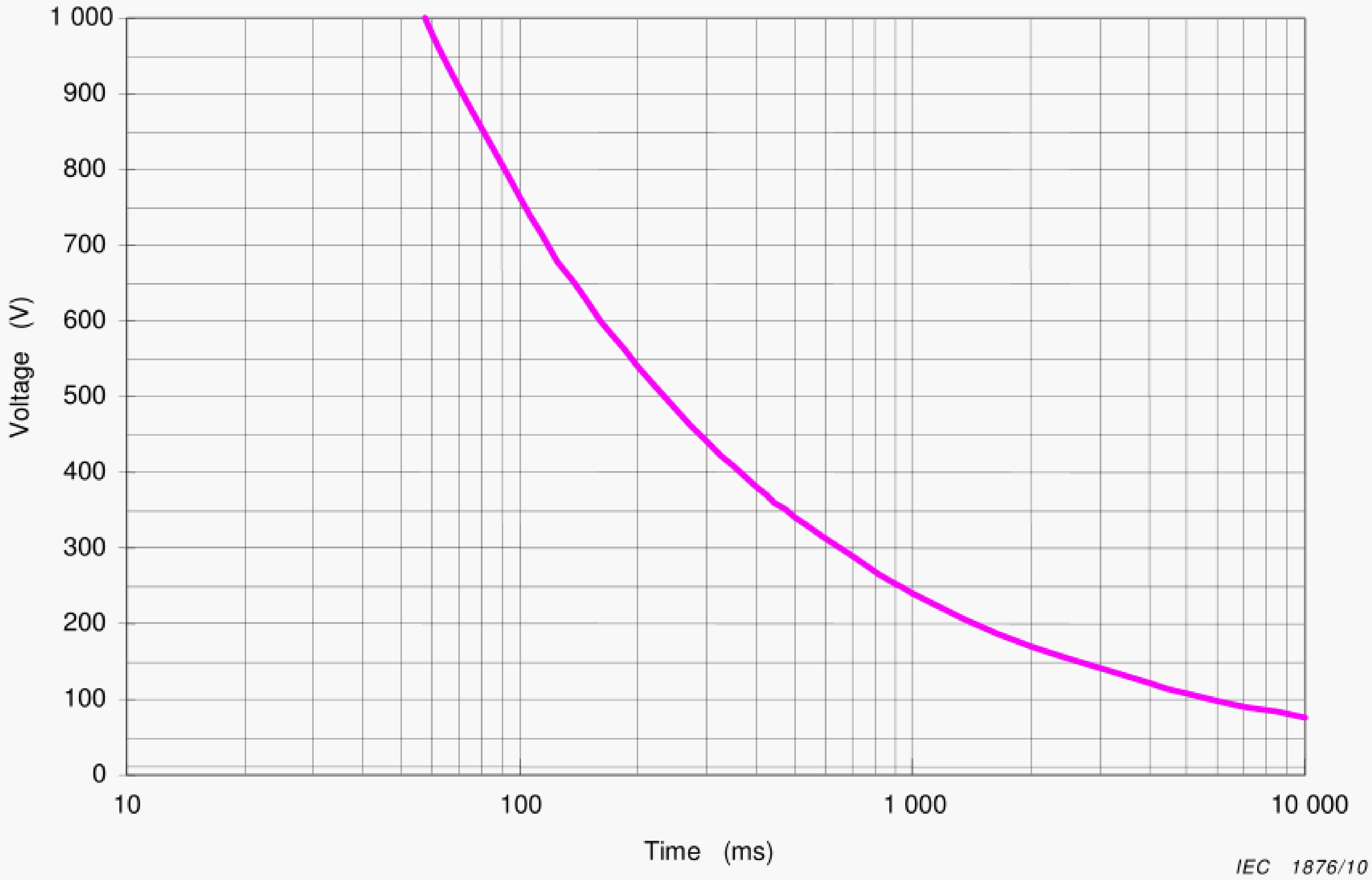
$$U_{\mathrm{vTp}} = I_{\mathrm{B}}(t_{\mathrm{f}}) \cdot \frac{1}{HF} \cdot \left(Z_{\mathrm{T}}(U_{\mathrm{T}}) \cdot BF + R_{\mathrm{H}} + R_{\mathrm{F}}\right)$$

Additional factors:

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

Annex C
(normative)

Permissible touch voltage according IEEE 80



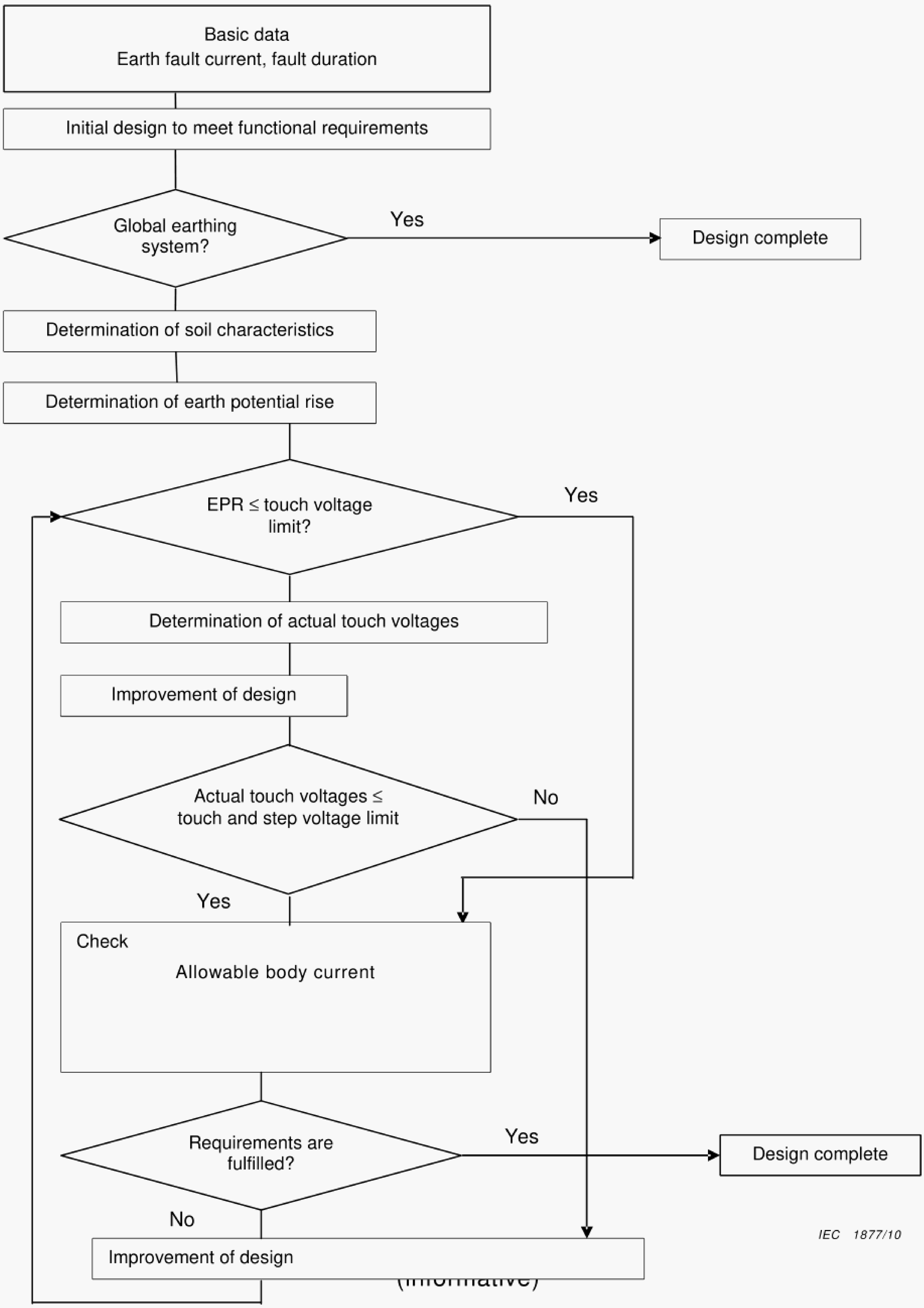
NOTE 1 The touch voltage curve is based on a specific soil resistivity of 100 Ωm and a surface layer of 0,1 m with a specific resistivity of 1 000 Ωm.

NOTE 2 Figure C.1 assumes a person weighing 50 kg and a gravel surface.

Figure C.1 – Permissible touch voltage U_{Tp} according IEEE 80

Annex D
(normative)

Earthing system design flow chart



Protection measures against direct lightning strokes

E.1 General

Model tests, measurements, observation and experience over many years have shown that direct lightning strokes can be avoided with a high degree of certainty by using the following arrangements of lightning conductors or rods. The protection zones shown in Figures E.1 through E.4 are valid for installations up to a height H of 25 m. For heights exceeding 25 m the protection zone is reduced.

NOTE The height of 25 m corresponds to a 420 kV network structure.

The following method supplies a sufficient protection level but without detailed studies of insulation coordination.

E.2 Shield wires

A single shield wire provides a tent-shaped protection zone, the limits of which are formed by arcs with a radius of 2 H beginning at the shield wire peak (see Figure E.1) and following the length of the wire.

Two shield wires at a distance of less than 2 H apart provide an extension of the protection zone which is limited by the two conductors, an arc of radius R and centre M_R at a height 2 H (see Figure E.2).

This zone is continuous all along the span of conductors.

E.3 Lightning rods

Upward streamer discharges develop earlier from lightning rods than from shield wires.

The protection zone of a lightning rod is generally larger than that of a shield wire at the same height.

A single lightning rod provides a cone-shaped protection zone with limits of an arc of radius 3 H passing through the tip of the lightning rod (refer to Figure E.3).

Two lightning rods at a spacing of less than 3 H provide an extension of the protection zone (see Figure E.4) which is limited by an arc of radius R with the centre M_R at a height of 3 H passing through the tips of the lightning rods.

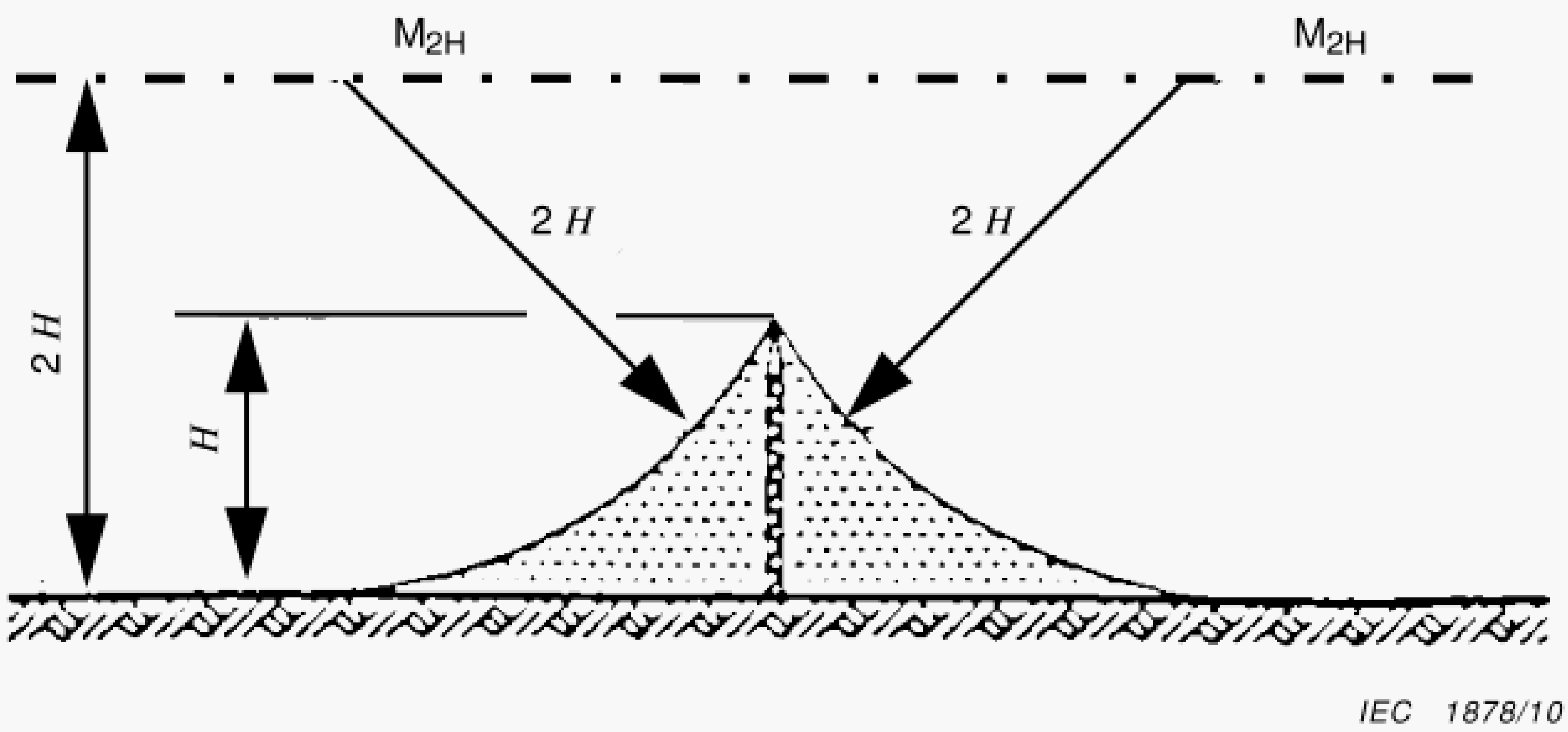


Figure E.1 – Single shield wire

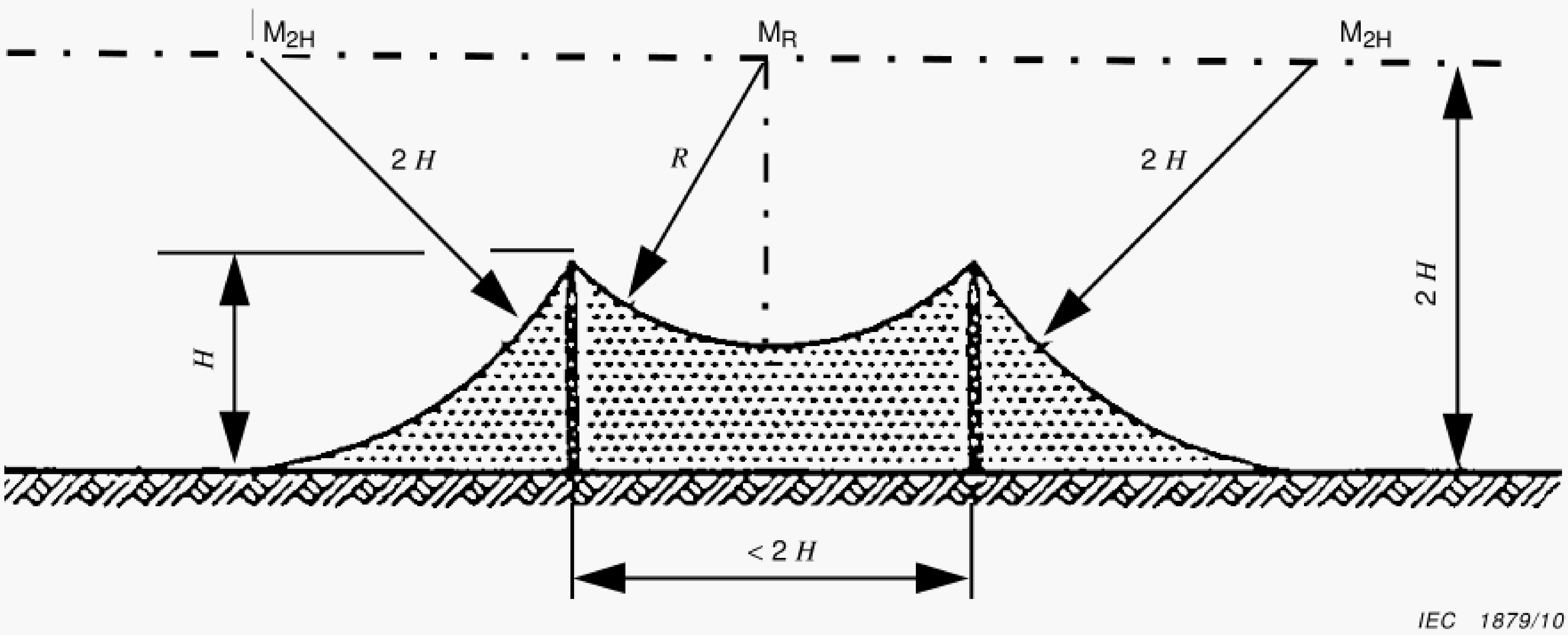


Figure E.2 – Two shield wires

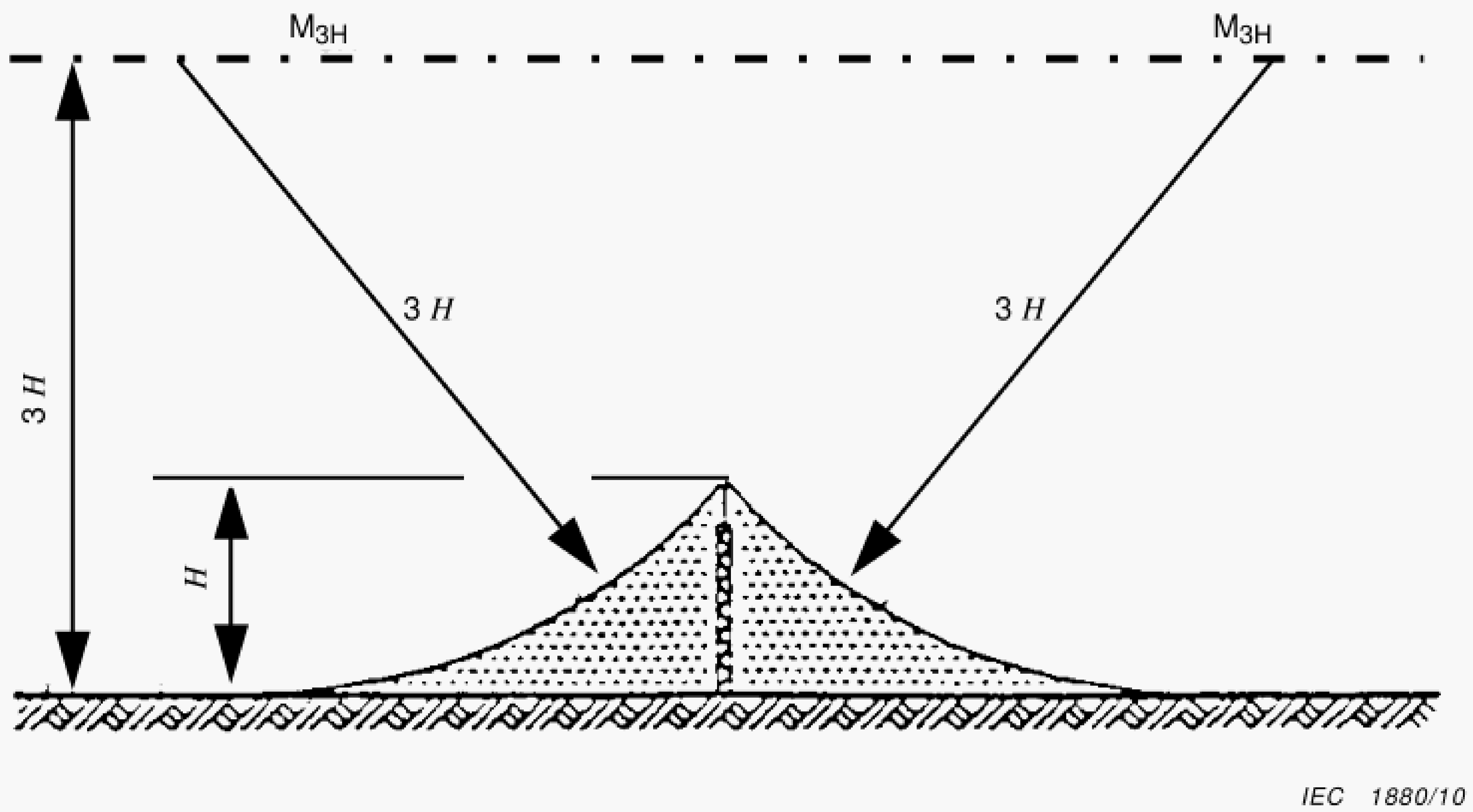


Figure E.3 – Single lightning rod

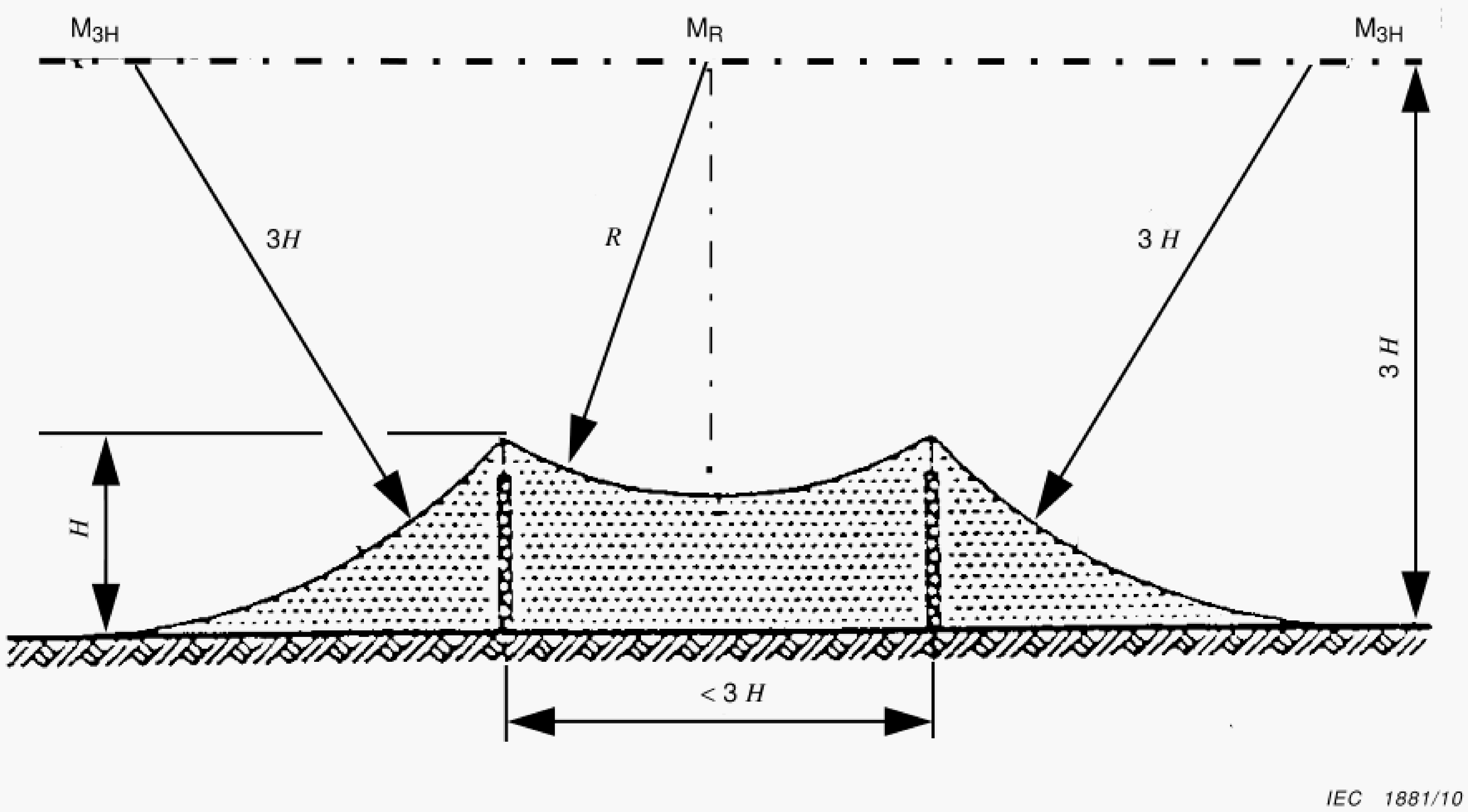


Figure E.4 – Two lightning rods

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