

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Safety of machinery – Electrical equipment of machines –
Part 11: Requirements for equipment for voltages above 1 000 V AC or 1 500 V
DC and not exceeding 36 kV**

**Sécurité des machines – Équipement électrique des machines –
Partie 11: Exigences pour les équipements fonctionnant à des tensions
supérieures à 1 000 V en courant alternatif ou 1 500 V en courant continu et ne
dépassant pas 36 kV**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**SAFETY OF MACHINERY –
ELECTRICAL EQUIPMENT OF MACHINES –****Part 11: Requirements for equipment for voltages
above 1 000 V AC or 1 500 V DC and not exceeding 36 kV****FOREWORD**

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International Standard IEC 60204-11 has been prepared by IEC technical committee 44: Safety of machinery – Electrotechnical aspects.

This second edition cancels and replaces the first edition, published in 2000. This edition constitutes a technical revision.

This edition contains significant technical changes with respect to the previous edition regarding the following:

- aspects of risk assessment, which are mirrored from ISO 12100;
- equipotential bonding and earthing;
- EMC and power quality;
- HV switchgear and controlgear;

- creepage distances for conductors and slip-ring assemblies;
- a list of machinery using HV equipment, in Annex A.

This second edition of IEC 60204-11 has been updated and improved to reflect the experience gained with the first edition and the evolution of high-voltage equipment reflected in the relevant standards.

Regarding formal requirements, IEC 60204-11 has been aligned with

- IEC 60204-1:2016,
- IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014,
- IEC 62271 (all parts).

This document is intended to be used in conjunction with IEC 60204-1.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
44/819/FDIS	44/828/RVD

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

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

A list of all parts in the IEC 60204 series, published under the general title *Safety of machinery – Electrical equipment of machines*, can be found on the IEC website.

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

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

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INTRODUCTION

This part of IEC 60204 provides requirements and recommendations relating to the high-voltage electrical equipment (HV equipment) of machines together with its associated low-voltage electrical equipment (LV equipment) so as to promote

- safety of persons and property,
- consistency of control response,
- maintainability.

Figure 1 is a block diagram of a machine and associated equipment showing the various elements of the electrical equipment addressed in this document. Numbers in parentheses (...) refer to clauses and subclauses in this document. It is understood that all of the elements taken together including the safeguards, software and the documentation constitute the machine or group of machines working together with usually at least one level of supervisory control.

This document should be used in conjunction with IEC 60204-1. HV equipment can include LV control parts in the same general enclosure or in separate compartments.

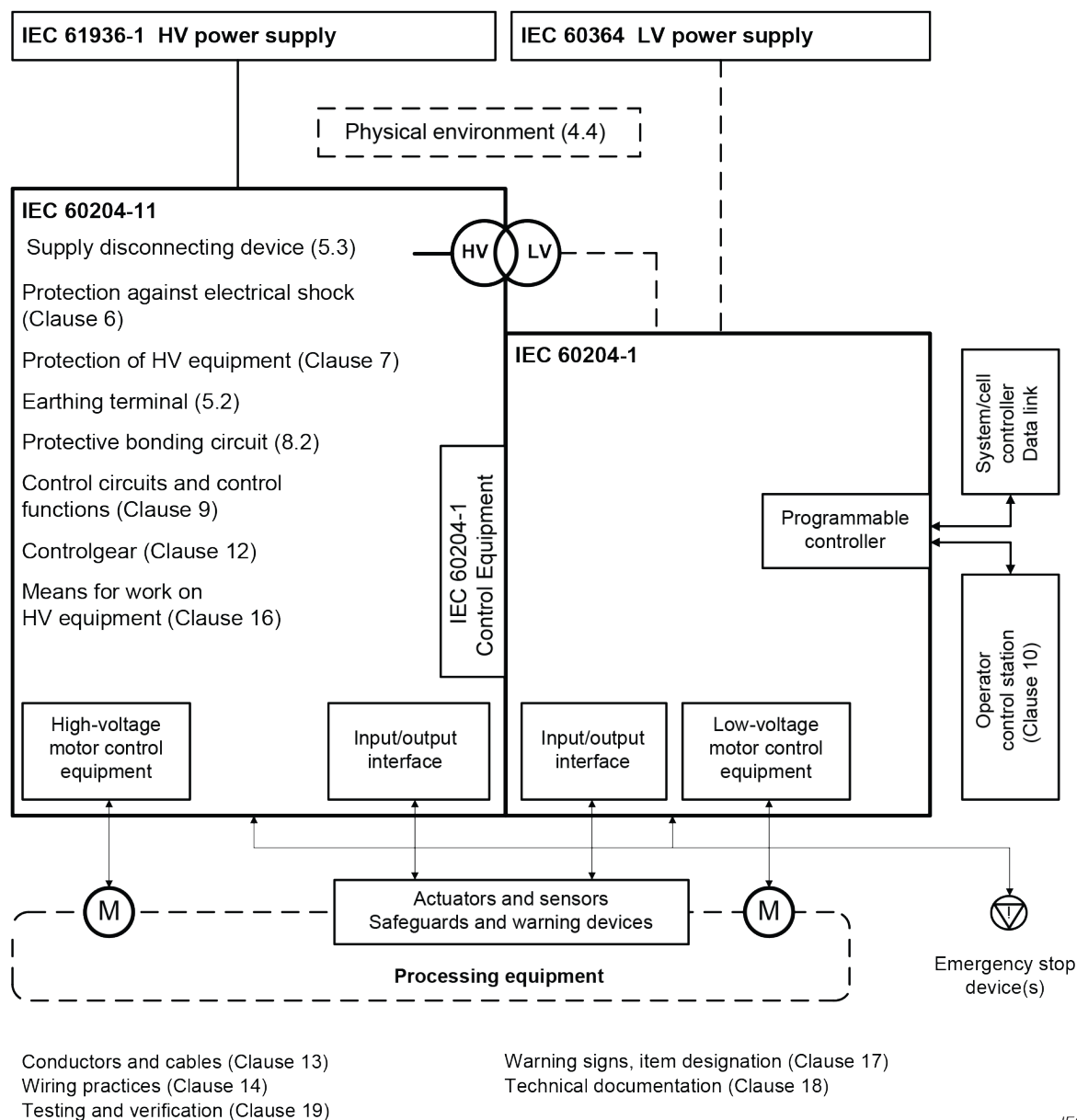


Figure 1 – Block diagram of a machine containing HV equipment

SAFETY OF MACHINERY – ELECTRICAL EQUIPMENT OF MACHINES –

Part 11: Requirements for equipment for voltages above 1 000 V AC or 1 500 V DC and not exceeding 36 kV

1 Scope

This part of IEC 60204 applies to electrical and electronic equipment and systems to machines, including a group of machines working together in a co-ordinated manner, which operate at nominal voltages above 1 000 V AC or 1 500 V DC and not exceeding 36 kV AC or DC with nominal frequencies not exceeding 60 Hz.

In this document, the term HV equipment also covers the LV equipment forming an integral part of the equipment operating at high voltage. The requirements in this document primarily cover the parts operating at high-voltage except where explicitly stated otherwise.

NOTE 1 LV equipment not forming part of the HV equipment is covered by IEC 60204-1:2016.

NOTE 2 In this document, the term "electrical" includes both electrical and electronic matters (i.e. electrical equipment means both the electrical and the electronic equipment).

NOTE 3 This document does not apply to independent high-voltage power supply installations for which separate IEC standards exist.

The electrical equipment covered by this document commences at the point of connection of the supply to the electrical equipment of the machine (see 5.1).

NOTE 4 For the requirements for high-voltage power supply installations, see IEC 61936-1.

This document is a generic safety standard. It does not cover all the requirements (e.g. guarding, interlocking or control) which are needed or required by other standards or regulations in order to safeguard personnel from hazards other than electrical hazards. Each type of machine has unique requirements to be accommodated to provide adequate safety.

NOTE 5 In some machines the high-voltage power supply can be produced by a step-up transformer (autotransformer), supplied by a low-voltage system (e.g. by a LV generator).

NOTE 6 In the context of this document, the term "person" refers to any individual; "personnel" are those persons who are assigned and instructed by the user or his agent(s) in the use and care of the machine in question.

This part of IEC 60204 specifically includes, but is not limited to, machines as defined in 3.29 (Annex A lists examples of machines whose electrical equipment can be covered by this document).

For protection against electric shock from high-voltage equipment, this document refers to IEC 61936-1. When it comes to low-voltage equipment, this document refers to IEC 60204-1:2016.

NOTE 7 High- and low-voltage standards use different terms regarding protection against electric shock. Whereas high-voltage standards use the terms "direct contact" and "indirect contact", low-voltage standards correspondingly use "basic protection" and "fault protection".

Additional and special requirements can apply to the electrical equipment of machines that

- are used in the open air (i.e. outside buildings or other protective structures);
- use, process or produce potentially explosive material (e.g. paint or sawdust);
- are used in potentially explosive and/or flammable atmospheres;

- have special risks when producing or using certain materials;
- are used in mines.

Hazards as a result of noise and vibration are excluded from the scope of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

IEC 60076-5, *Power transformers – Part 5: Ability to withstand short-circuit*

IEC 60204-1:2016, *Safety of machinery – Electrical equipment of machines – Part 1: General requirements*

IEC 60364-5-54:2011, *Low-voltage electrical installations – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors*

IEC 60417, *Graphical symbols for use on equipment* (available at <http://www.graphical-symbols.info/equipment>)

IEC 60445, *Basic and safety principles for man-machine interface, marking and identification – Identification of equipment terminals, conductor terminations and conductors.*

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

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

IEC 61800 (all parts), *Adjustable speed electrical power drive systems*

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

IEC 62061, *Safety of machinery – Functional safety of safety-related electrical, electronic and programmable electronic control systems*

IEC 62271-102, *High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches*

IEC 62271-103, *High-voltage switchgear and controlgear – Part 103: Switches for rated voltages above 1 kV up to and including 52 kV*

IEC 62271-105, *High-voltage switchgear and controlgear – Part 105: Alternating current switch-fuse combinations for rated voltages above 1 kV up to and including 52 kV*

IEC 62271-107, *High-voltage switchgear and controlgear – Part 107: Alternating current fused circuit-switchers for rated voltages above 1 kV up to and including 52 kV*

IEC 62271-200:2011, *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 solid-insulation enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV*

IEC 62745, *Safety of machinery – Requirements for cableless control systems of machinery*

ISO 13849-1, *Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design*

ISO 3864-1:2011, *Graphical symbols – Safety colours and safety signs – Part 1: Design principles for safety signs and safety markings*

ISO 3864-2:2016, *Graphical symbols – Safety colours and safety signs – Part 2: Design principles for product safety labels*

ISO 7010:2011, *Graphical symbols – Safety colours and safety signs – Registered safety signs*

ISO 12100, *Safety of machinery – General principles for design – Risk assessment and risk reduction*

3 Terms and definitions

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

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

ambient temperature

temperature of the air or other medium where the equipment is to be used

3.2

barrier

part providing protection against contact with live parts from any usual direction of access

3.3

basic protection

protection against electric shock under fault-free conditions

Note 1 to entry: Previously referred to as “protection against direct contact”.

[SOURCE: IEC 60050-195:1998, 195-06-01, modified – The note has been added.]

3.4

cable tray

cable support consisting of a continuous base with raised edges but no covering

Note 1 to entry: A cable tray may be perforated or mesh.

[SOURCE: IEC 60050-826:2004, 826-15-08]

3.5**conductor wire
conductor bar
conductor rail**

conductive wire, bar or rail of a feeder system with a sliding current collector

3.6**control circuit**

<of a machine> circuit used for the control, including monitoring, of a machine and the electrical equipment

3.7**control device**

device connected into the control circuit and used for controlling the operation of the machine

EXAMPLE Position sensor, manual control switch, relay, magnetically operated valve.

3.8**controlgear**

general term covering switching devices and their combination with associated control, measuring, protective, and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures, and supporting structures, intended in principle for the control of electrical energy consuming equipment

[SOURCE: IEC 60050-441:2000, 441-11-03]

3.9**duct**

enclosed channel designed expressly for holding and protecting electrical conductors, cables, and busbars

Note 1 to entry: Conduits, cable trunking systems and underfloor channels are types of duct.

3.10**earthing system**

all the electric connections and devices involved in the earthing of a system, an installation and equipment

[SOURCE: IEC 60050-826:2004, 826-13-04, modified – The preferred terms have been deleted and the deprecated term is used as a preferred term.]

3.11**electrical operating area**

room or location for electrical equipment to which access is intended to be restricted to skilled or instructed persons, by the opening of a door or the removal of a barrier without the use of a key or tool, and which is clearly marked by appropriate warning signs

Note 1 to entry: An (electrically) instructed person is a person adequately advised or supervised by an electrically skilled person to enable him or her to perceive risks and to avoid hazards which electricity can create (see IEC 60050-826:2004, 826-18-02).

Note 2 to entry: An (electrically) skilled person is a person with relevant education and experience to enable him or her to perceive risks and to avoid hazards which electricity can create (see IEC 60050-826:2004, 826-18-01)

3.12**electronic equipment**

part of the electrical equipment containing circuitry mainly based on electronic devices and components

3.13

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 a protective barrier only by the use of a key or tool, and which is clearly marked by appropriate warning signs

Note 1 to entry: See also Notes to entry 1 and 2 of definition 3.11.

3.14

enclosure

part providing a specified degree of protection of equipment against external influences and, in any direction, a specified degree of protection against approach to or contact with live parts and against contact with moving parts

Note 1 to entry: The definition needs the following explanations within the scope of this document:

Enclosures provide protection of persons or livestock against access to hazardous parts.

Barriers, shaped openings, or any other means suitable to prevent or limit the penetration of the specified test probes, whether attached to the enclosure or formed by the enclosed equipment, are considered as part of the enclosure, except where they can be removed without the use of a key or tool.

An enclosure may be

- a cabinet or box, either mounted on the machine or separate from the machine;
- a compartment consisting of an enclosed space within the machine structure.

[SOURCE: IEC 60050-441:2000, 441-13-01, modified – "of an assembly" has been deleted and "in any direction" and the note have been added.]

3.15

equipment

items used in connection with the utilisation of electricity by machines or parts of machines, for example material, fittings, devices, components, appliances, fixtures, apparatus, and similar

3.15.1

high-voltage electrical equipment

items as defined in IEC 60204-11:2018, 3.15 which are designed to operate at voltages above 1 000 V AC or 1 500 V DC

Note 1 to entry: For easier reading in this document "HV equipment" is used where the context is obvious.

3.16

equipotential bonding

provision of electric connections between conductive parts, intended to reduce the potential differences and achieve equipotentiality between these parts

[SOURCE: IEC 60050-195:1998, 195-01-10, modified – "reduce the potential differences" and "between these parts" have been added.]

3.17

protective bonding conductor

protective conductor provided for protective equipotential bonding

[SOURCE: IEC 60050-195:1998, 195-02-10]

3.18**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

[SOURCE: IEC 60050-195:1998, 195-06-10]

3.19**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

[SOURCE: IEC 60050-195:1998, 195-06-11]

3.20**failure**

termination of the ability of an item to perform a required function

Note 1 to entry: After failure the item has a fault.

Note 2 to entry: "Failure" is an event, as distinguished from "fault", which is a state.

Note 3 to entry: This concept, as defined, does not apply to items consisting of software only.

Note 4 to entry: In practice the terms "fault" and "failure" are often used synonymously.

[SOURCE: IEC 60050-603:1986, 603-05-06, modified – The notes have been added.]

3.21**fault**

state of an item characterized by the inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources

Note 1 to entry: A fault is often the result of a failure of the item itself, but may exist without prior failure.

Note 2 to entry: In English the term "fault" and its definition are identical with those given in IEC 60050-192:2015, 192-04-01. In the field of machinery, the French term "défaut" and the German term "Fehler" are used rather than the terms "Panne" and "Fehlzustand" that appear with this definition.

3.22**fault protection**

protection against electric shock under single-fault conditions

Note 1 to entry: Previously referred to as "protection against indirect contact".

[SOURCE: IEC 60050-195:1998, 195-06-02]

3.23**hazard**

potential source of physical injury or damage to health

Note 1 to entry: The term hazard can be qualified in order to define its origin (for example, mechanical hazard, electrical hazard) or the nature of the potential harm (for example, electric shock hazard, cutting hazard, toxic hazard, and fire hazard).

Note 2 to entry: The hazard envisaged in this definition:

- either is permanently present during the intended use of the machine (for example motion of hazardous moving elements, electric arc during a welding phase, unhealthy posture, noise emission, high temperature);
- or can appear unexpectedly (for example: explosion, crushing hazard as a consequence of an unintended/unexpected start-up, ejection as a consequence of a breakage, fall as a consequence of acceleration/deceleration).

[SOURCE: ISO 12100:2010, 3.6, modified – "harm" has been replaced with "physical injury or damage to health" and Note 3 has been deleted.]

3.24

interlock

interlock for safeguarding

arrangement of devices operating together to:

- prevent hazardous situations, or
- prevent damage to equipment or material, or
- prevent specified operations, or
- ensure correct operations

3.25

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

Note 1 to entry: This concept does not necessarily imply a risk of electric shock.

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

3.26

machine bonding conductor

conductor connecting the machine equipotential bonding to the earthing system

Note 1 to entry: This is an earthing conductor as defined in IEC 60050-826:2004, 826-13-12 and used in IEC 61936-1.

Note 2 to entry: This corresponds to the term "earthing conductor" in IEC 61936-1.

3.27

machine actuator

power mechanism of the machine used to effect motion

EXAMPLE Motor, solenoid, pneumatic or hydraulic cylinder.

3.28

neutral conductor

conductor electrically connected to the neutral point and capable of contributing to the distribution of electric energy

[SOURCE: IEC 60050-195:1998, 195-02-06]

3.29

machinery

machine

assembly of linked parts or components, at least one of which moves, with the appropriate machine actuators, control and power circuits, etc., joined together for a specific application, in particular for the processing, treatment, moving or packaging of a material

Note 1 to entry: The terms "machinery" and "machine" also cover:

- an assembly of machines which, in order to achieve one and the same end, are arranged and controlled so that they function as an integral whole;
- interchangeable equipment modifying the function of a machine, which is placed on the market (supplied) for the purpose of being assembled with a machine or a series of different machines or with a tractor by the operator himself insofar as this equipment is not a spare part or tool.

3.30**obstacle**

part preventing unintentional direct contact, but not preventing direct contact by deliberate action

[SOURCE: IEC 60050-826:2004, 826-12-24, modified – "electrically protective" has been deleted from the term.]

3.31**overcurrent**

electric current exceeding the rated electric current

Note 1 to entry: For conductors, the rated value is considered as equal to the current-carrying capacity

[SOURCE: IEC 60050-826:2004, 826-11-14]

3.32**overload**

<of a circuit> time/current relationship in a circuit which is in excess of the rated full load of the circuit when the circuit is not under a fault condition

Note 1 to entry: "Overload" should not be used as a synonym for overcurrent.

3.33**plug-socket combination**

component and suitable mating component, appropriate to terminate conductors, intended for connection or disconnection of two or more conductors

3.34**power circuit**

circuit used for supplying power from the supply network to units of electrical equipment used for productive operation and to transformers supplying control circuits

3.35**protective bonding circuit**

the whole of the protective conductors and conductive parts used for protection against electric shock in the event of an insulation failure

3.36**protective conductor**

conductor providing a primary fault current path from the exposed conductive parts of the electrical equipment to a protective earthing (PE) terminal

Note 1 to entry: The equivalent term in IEC 61936-1 is "protective bonding conductor".

3.37**reference designation**

distinctive code which serves to identify an item in a diagram, list or chart, and on the equipment

3.38**risk**

combination of the probability of occurrence of harm (i.e. physical injury or damage to health) and the severity of that harm

[SOURCE: ISO 12100:2010, 3.12, modified – The text in parentheses has been added.]

3.39

safe working procedure

method of working that reduces risk

3.40

safeguard

guard or protective device used as a means to protect persons from a present or impending hazard

3.41

safeguarding

safety measures consisting of the use of specific means called safeguards to protect persons from hazards that cannot reasonably be removed or are not sufficiently limited by design

3.42

servicing level

level on which persons normally stand when operating or maintaining the electrical equipment

3.43

short-circuit current

overcurrent resulting from a short circuit due to a fault or an incorrect connection in an electric circuit

[SOURCE: IEC 60050-441:2000, 441-11-07]

3.44

supplier

entity that provides equipment or services associated with the machine

EXAMPLE Manufacturer, contractor, installer, integrator.

Note 1 to entry: The user may also act in the capacity of a supplier to himself.

3.45

switching device

device designed to make or break the current in one or more electric circuits

Note 1 to entry: A switching device may perform one or both of these actions.

[SOURCE: IEC 60050-441:2000, 441-14-01, modified – The note has been added.]

3.46

terminal

conductive part of a device provided for electrical connection to external circuits

3.47

user

entity who utilizes the machine and its associated electrical equipment

4 General requirements

4.1 General

This document focuses on high-voltage electrical equipment of machines.

The risks associated with the hazards relevant to the HV equipment shall be assessed as part of the risk assessment, for example in accordance with ISO 12100. This will:

- identify the need for risk reduction;
- determine adequate risk reductions; and
- determine the necessary protective measures for persons who can be exposed to those hazards, while still maintaining an appropriate performance of the machine and its equipment.

Hazardous situations can result from, but are not limited to, the following causes:

- failures or faults in the electrical equipment resulting in the possibility of electric shock, arc or fire;
- failures or faults in control circuits (or components and devices associated with those circuits) resulting in the malfunctioning of the machine;
- disturbances or disruptions in power sources as well as failures or faults in the power circuits resulting in the malfunctioning of the machine;
- loss of continuity of circuits that can result in a failure of a safety function, for example those that depend on sliding or rolling contacts;
- electrical disturbances, for example electromagnetic, electrostatic either from outside the electrical equipment or internally generated, resulting in the malfunctioning of the machine;
- release of stored energy (either electrical or mechanical) resulting in, for example, electric shock, unexpected movement that can cause injury;
- acoustic noise and mechanical vibration at levels that cause health problems to persons;
- surface temperatures that can cause injury.

Safety measures are a combination of the measures incorporated at the design stage and those measures required to be implemented by the user.

The design and development process shall identify hazards and the risks arising from them. Where the hazards cannot be removed and/or the risks cannot be sufficiently reduced by inherently safe design measures, protective measures (for example safeguarding) shall be provided to reduce the risk. Additional means (for example, awareness means) shall be provided where further risk reduction is necessary. In addition, working procedures that reduce risk can be necessary.

It is recommended that, where the user is known, Annex B be used to facilitate an exchange of information between the user and the supplier(s) on basic conditions and additional user specifications related to the electrical equipment.

NOTE Those additional specifications can

- provide additional features that are dependent on the type of machine (or group of machines) and the application;
- facilitate maintenance and repair, and
- improve the reliability and ease of operation.

4.2 Selection of electrical equipment

Electrical components and devices shall

- be suitable for their intended use;
- conform to their relevant IEC standards; and
- be applied in accordance with the supplier's instructions.

Type-tested HV switchgear should be selected from those manufactured and tested in accordance with IEC 62271 (all parts).

HV Adjustable speed electrical power drive systems and their elements should be selected from those manufactured and tested in accordance with IEC 61800 (all parts).

4.3 Electrical power supply

4.3.1 General

The electrical equipment shall be designed to operate correctly with the conditions of the supply as

- specified in 4.3.2, or
- otherwise specified by the user (see Annex B), or
- specified by the supplier in the case of a special source of supply (see 4.3.3).

4.3.2 Voltage characteristics

High-voltage equipment of machinery should be able to operate at supply conditions described by the requirements given by IEC TS 62749.

Voltage	Steady-state voltage 0,9 to 1,1 of nominal voltage. NOTE 1 In case of reduction of voltage below the nominal value, the performance of machine actuators can be affected.
Frequency	± 1 % of nominal frequency continuously; ± 2 % short time.
Harmonics	The total harmonic distortion (THD) of the voltage should not exceed 8 % of the total RMS voltage between live conductors for the sum of the 2 nd through 50 th harmonic.
Voltage unbalance	Neither the voltage of the negative sequence component nor the voltage of the zero sequence component in three-phase supplies shall exceed 2 % of the positive sequence component.

NOTE 2 DC voltage characteristics of electrical power supply are under consideration.

4.3.3 On-board power supply

For special supply systems such as on-board generators, the limits given in 4.3.2 may be exceeded provided that the electrical equipment is designed to operate correctly with those conditions.

4.4 Physical environment and operating conditions

4.4.1 General

The HV equipment shall be suitable for use in the physical environment and operating conditions specified in 4.4.2 to 4.4.8 of IEC 60204-1:2016. There may be additional influences and environmental conditions which are to be taken into account. When the physical environment or the operating conditions are outside those specified, an agreement may be needed between the supplier and the user (see Annex B to specify the minimum requirements).

4.4.2 Electromagnetic compatibility (EMC)

High-voltage equipment of machinery shall not generate electromagnetic disturbances above levels that are appropriate for its intended operating environment. In addition, the HV equipment shall have a sufficient level of immunity to electromagnetic disturbances so that it can function in its intended environment.

Immunity and/or emission tests are required on the electrical equipment unless the following conditions are fulfilled:

- the incorporated devices and components comply with the EMC requirements for the intended EMC environment specified in the relevant product standard (or generic standard where no product standard exists), and;
- the electrical installation and wiring are consistent with the instructions provided by the supplier of the devices and components with regard to mutual influences, (cabling, screening, earthing, etc.) or with informative Annex H of IEC 60204-1:2016 if such instructions are not available.

For control systems of HV equipment the basic EMC rules of 9.6 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014 apply. For electronic HV equipment (e.g. power converters, power drive systems) the EMC provisions of the relevant product standard apply.

4.5 Transportation and storage

Subclause 4.5 of IEC 60204-1:2016 is applicable.

4.6 Provisions for handling

Heavy and bulky electrical equipment that has to be removed from the machine for transport, or that is independent of the machine, shall be provided with suitable means for handling by cranes or similar equipment (see also 14.5). Where appropriate, equipment shall be labelled to show the correct method of lifting and the maximum weight when fully equipped shall be indicated.

4.7 Installation

4.7.1 General

High-voltage electrical equipment shall be installed in accordance with the requirements of Clause 8 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014 and the supplier's instructions in order to:

- enable the safe access of personnel for operation and maintenance;
- facilitate fault clearing under safe working conditions.

Where lighting is installed for HV equipment, the relevant provisions of 7.2.6 and 15.2 of IEC 60204-1:2016 are applicable; refer to 18.2.

4.7.2 Assembly and mounting

When the equipment is not fully assembled for transport, all transport units should be clearly marked. Detailed drawings showing assembly of these separated parts should be provided with the equipment included related wiring and provisions to maintain the integrity of the equipment in terms of safety.

5 Incoming supply conductor terminations and devices for disconnecting and switching off

5.1 Incoming high-voltage conductor terminations

All terminations for the incoming supply connection shall be clearly identified in accordance with IEC 60445.

5.2 Earthing terminal of high-voltage equipment

High-voltage equipment shall be provided with an earthing terminal for connection of an earthing conductor suitable for specified fault conditions.

The connecting point shall be marked with the "protective earth" symbol IEC 60417-5019:2006-08.

5.3 Supply disconnecting devices and means for earthing

5.3.1 General

A supply disconnecting device shall be provided for

- each incoming source of supply to a machine;
Exception: In the case of on-board generation (for example diesel generator) as the only source of supply, the disconnecter is not necessary if the voltage can be reduced to, and maintained at, zero by other means;
- the source of supply to a feeder system using conductor wires, conductor bars, slip-ring assemblies, flexible cable systems (reeled, festooned), to a machine or a number of machines;
- each on-board power supply if there are more than one generator for the same supply (for example common busbar).

The supply disconnecting device shall isolate the high-voltage equipment of the machine from the supply when required (e.g. for work on the machine or its electrical equipment).

NOTE 1 Disconnectors are capable of opening and closing a circuit only at either negligible current (a current not exceeding 0,5 A) or if no significant change in the voltage across the terminals occurs. Therefore disconnecting devices always require associated switches or circuit-breakers for switching normal operating and fault currents; refer to Clause 7.

NOTE 2 HV disconnection implies physical separation (isolation).

When two or more supply disconnectors are provided, protective interlocks for their correct operation shall be used so that no hazardous condition or damage to personnel or the machine can occur.

For each incoming HV supply, means shall be provided to earth and short-circuit all live parts by connecting them to the earthing system (e.g. for work on the HV equipment).

5.3.2 Type

The supply disconnecting device shall be one of the following types:

- a) a switch-disconnector;

NOTE 1 A switch-disconnector often is combined with HRC fuses.

- b) a disconnector with interlocking to ensure that it can only be operated if an associated switch or circuit-breaker interrupted the load circuit;
- c) a plug and socket combination (see 3.33) for a flexible cable supply (e.g. reeled, festooned) to a mobile machine under the following conditions:
 - It shall not be possible to connect or disconnect a plug-socket combination during load conditions or when voltage is present. The effects of charging currents shall be taken into account.
 - The plug-socket combination shall be so connected that the part connected to the incoming power supply is that which is protected to at least IP 2XH or IP XXBH, when located inside an enclosed electrical operating area, or to at least IP 4XH or IP XXDH when located outside an enclosed electrical operating area.

NOTE 2 High-voltage plug-socket combinations are designed according to EN 50181.

When used, disconnectors shall be designed and selected in accordance with IEC 62271-102.

5.3.3 Requirements for disconnectors

When the supply disconnector is one of the types specified in 5.3.2 a) or 5.3.2 b) it shall comply with IEC 62271-102.

For instance, the disconnector shall

- have an external handle for the disconnecting function (this can be the handle also used for operating the earthing device);
- have a reliable position indicator;
- disconnect all live conductors from the power supply circuit.

The OFF (disconnected) and one ON positions shall be clearly marked with "O" and "I" (see symbols IEC 60417-5008:2002-10 and IEC 60417-5007:2002-10).

If a switch-disconnector (specified in 5.3.2 a)) is used, it shall comply with IEC 62271-102 and IEC 62271-103 and its breaking capacity shall be sufficient to interrupt the current of the largest motor under blocked rotor condition together with the sum of the normal operating currents of all other motors and/or loads. The calculated breaking capacity may be reduced by the use of a proven diversity (simultaneity) factor.

NOTE For motors supplied by converter(s) or similar devices the maximum operating current of the converter is relevant.

Unintended opening of disconnectors shall be prevented. Depending on the risk assessment, remote controlled locking systems shall have appropriate safety integrity level (SIL) or performance level (PL); according to IEC 62061 or ISO 13849-1.

Where a switch-disconnector is combined with HV fuses, the combination shall comply with IEC 62271-105.

Where fused circuit-switchers are used, the combination shall comply with IEC 62271-107.

Where an external operating means (e.g. handle) is provided it should be BLACK or GREY. Exception: If a switch-disconnector may be locally operated to serve the function of emergency stop, its actuator shall meet the colour requirements of 10.2.1 of IEC 60204-1:2016.

5.3.4 Requirements for earthing and short-circuiting

The means for earthing shall be capable of withstanding the prospective short-circuit current of the supply.

When used, an earthing switch shall comply with IEC 62271-102.

For instance, the earthing switch shall

- have a reliable position indicator;
- have an external handle for the earthing function (this can be the handle also used for operating the disconnecting device);
- earth and short-circuit all live conductors to the earthing system.

Mechanical locking in the ON position and the OFF position should be possible preferably by padlocks.

When an associated circuit-breaker is used for short-circuiting and for earthing and is locked in the closed (and earthed) position, unintended manual and/or opening by the short-circuit current itself shall be prevented. Depending on the risk assessment, remote controlled locking

systems shall have appropriate safety integrity level (SIL) or performance level (PL) according to IEC 62061 or ISO 13849-1.

5.3.5 Arrangement of disconnecting and earthing devices

It is recommended that the supply disconnecting device and the associated earthing switch are combined in a functional unit of prefabricated metal-enclosed switchgear complying with IEC 62271-200 or IEC 62271-201. If the earthing switch and disconnecter are not assembled in a functional unit, interlocks shall ensure that

- the earthing switch can only be operated if the disconnecting device is in the open position, and
- the disconnecting device can only be operated if the earthing switch is in the open position.

The operating means of the supply disconnecting and earthing devices shall be easily accessible and located between 0,6 m and 1,9 m above the servicing level. An upper limit of 1,7 m is recommended.

5.4 Devices for switching off for prevention of unexpected start-up

Devices for switching off for the prevention of unexpected start-up shall be provided (e.g. where, during maintenance, a start-up of the machine can create a hazard). Devices described in 5.3.2 may fulfil that function. Disconnectors, withdrawable fuse links or withdrawable links may also be used for that purpose, but only when located in a closed electrical operating area (see 3.13).

Such devices shall be appropriate and convenient for the intended use, shall be suitably placed, and readily identifiable (e.g. by a durable marking where necessary).

Means shall be provided to prevent inadvertent, and/or mistaken closing of the disconnector (see also 5.6).

Devices that do not fulfil the isolation function (for example a contactor switched off by a control circuit, or power drive system (PDS) with a safe torque off (STO) function in accordance with IEC 61800-5-2) may only be used for prevention of unexpected start-up during tasks such as:

- inspections;
- adjustments;
- work on the electrical equipment where:
 - there is no hazard arising from electric shock (see Clause 6) and burn;
 - the switching off means remains effective throughout the work;
 - the work is of a minor nature (for example, replacement of plug-in devices without disturbing existing wiring).

The selection of a device will be dependent on the risk assessment, taking into account the intended use of the device, and the persons who are intended to operate them.

5.5 Devices for disconnecting and means for earthing HV equipment

Devices for disconnecting (isolating) and means for earthing HV equipment or part of it shall be provided to enable work to be carried out without a risk from electric shock or burn.

The supply disconnecting device together with a means for earthing the relevant circuit (see 5.3) may fulfil these functions. However, where it is necessary to work on individual HV part(s) of the electrical equipment of a machine, or on one of a number of machines fed by a common conductor bar or conductor wire system, a disconnecting device together with a means for

earthing shall be provided for each part, or for each machine, requiring separate isolation and earthing. Where HV capacitors are part of the electrical equipment, discharging means shall be provided.

Devices described in 5.3 may fulfil these functions. Other means of isolation such as disconnectors, withdrawable fuse links or withdrawable links, together with a means for earthing, may also be used for that purpose, but only when located in an enclosed electrical operating area.

Exception: If these means, for example a removable collector for crane-disconnection, are not located in an enclosed electrical operating area, they shall fulfil the following conditions:

- it shall not be possible to remove the disconnecting device during load conditions;
- it shall be so designed that the protective conductor circuit (earthing circuit) is interrupted only after the live conductors have been disconnected, and the continuity of the protective conductor circuit is re-established before any live conductor is reconnected;
- in open and in closed condition of the removable collector, the conductor bar has to be protected according to 13.8.1.

Such disconnecting devices and means for earthing shall be

- appropriate and convenient for the intended use;
- suitably located;
- readily identifiable as to which HV part or HV circuit(s) of the electrical equipment is served (e.g. by durable marking where necessary);
- provided with adequate means to prevent unauthorized, inadvertent, and/or mistaken closure of the disconnecting devices and opening of the means for earthing. Exception: see 5.6.

Electrical equipment such as HV transformers or HV capacitors shall be provided with additional means of earthing and short-circuiting, except where it is located in the immediate vicinity of the associated switchgear.

NOTE Where the HV equipment (for example the main circuit-breaker) is part of the distribution switchgear, 8.3 of IEC 61936-1:2010 can apply.

5.6 Protection against unauthorized, inadvertent and/or mistaken operation

The devices for disconnecting (isolating) and means for earthing described in 5.4 and 5.5 that are capable of being equipped with means to lock them in the OFF position or disconnected state or earthed condition (e.g. by padlocks) in order to achieve protection against unauthorized, inadvertent, and/or mistaken operation shall be equipped with such means. Other means of protection against such operation (e.g. warning labels) may be used where the non-lockable means are located in an enclosed electrical operating area.

However, when a device according to 5.3.2 c) (e.g. plug-socket combination) and/or a means for earthing is so positioned that it can be under the immediate supervision of the person carrying out the work, means for locking need not be provided.

6 Protection against electric shock

6.1 General

The HV electrical equipment shall provide protection of persons against electric shock by

- basic protection against direct contact (6.2);
- fault protection against indirect contact (6.3).

The measures for this protection given in 6.2 and 6.3, are a recommended selection from IEC 61936-1 (regarding high-voltage) and from IEC 60364-4-41 (regarding low-voltage).

6.2 Protection against direct contact

Basic protection against direct contact with live parts, parts with insulation for functional purposes only and with parts which can be considered to have a hazardous potential (for examples of such parts see 8.2 of IEC 61936-1:2010) shall be provided as follows:

a) installations outside enclosed electrical operating areas

Protection against direct contact shall be provided by enclosures with a minimum degree of protection of IP 4X or IP XXDH, according to IEC 60529.

b) installations inside enclosed electrical operating areas

Protection against direct contact shall be provided by enclosures or doors or mesh-grids or barriers to a minimum degree of protection of IP 1X or IP XXAH, according to IEC 60529. Dimensions of doors, mesh-grids and barriers and clearances to live parts shall be in accordance with 7.3 of IEC 61936-1:2010.

Access to HV parts of the electrical equipment shall only be possible by the use of a key or tool.

Where these measures are not practicable, other measures for protection against direct contact (e.g. by placing out of reach, using obstacles) as specified in 8.2 of IEC 61936-1:2010 may be applied.

NOTE For protective measures for conductor wires, conductor bars and slip-ring assemblies, see 13.8.1.

6.3 Protection against indirect contact

6.3.1 General

Fault protection against indirect contact is intended to prevent hazardous situations due to an insulation fault between live parts and exposed conductive parts.

For each HV circuit or HV part of the electrical equipment, protection against indirect contact can be achieved by automatic disconnection of the supply preventing the occurrence of a touch voltage which exceeds the tolerable limited time of fault duration.

NOTE The risk of harmful physiological effects from a touch voltage depends on the value of the touch voltage and the duration of possible exposure.

These measures necessitate coordination between

- the type of power system (e.g. neutral earthing) and exposed conductive parts to earth,
- the impedance values of the different elements of the protective bonding circuit, and
- the characteristics of the devices used to detect insulation failure.

6.3.2 Measures to prevent the occurrence of a hazardous touch voltage for an unlimited time of fault duration

Measures to prevent the occurrence of a hazardous touch voltage for an unlimited time of fault duration include the following:

- selection or design of the supply system and neutral earthing in accordance with 4.2 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014, and
- design of the earthing system in accordance with Clause 10 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

It is recommended that a supply system is used whose neutral point is isolated from earth or is high impedance earthed. An earth fault detection device should be provided to initiate an alarm when an earth fault is detected.

NOTE Supply systems isolated from earth include systems without a neutral point such as single-phase systems, delta connected systems and DC systems.

6.3.3 Protection by automatic disconnection of supply within a limited time of fault duration

Automatic disconnection of the supply of any circuit affected by the occurrence of an insulation failure within a limited time is intended to prevent a hazardous condition resulting from a touch voltage higher than the tolerable touch voltage for an unlimited time of fault duration.

This protective measure comprises both

- the connection of exposed-conductive-parts to the protective bonding circuit (see Clause 8), and
- either
 - a) the use of devices for the automatic disconnection of the supply in the event of an insulation failure in a supply system with low-impedance neutral earthing or direct neutral earthing, or
 - b) the use of earth fault detection to initiate automatic disconnection of a supply system isolated from earth or with high impedance earthed neutral point.

The selection/setting of the device(s) shall be such as to ensure that automatic disconnection of the supply takes place before the touch voltage, arising from an insulation failure, becomes hazardous.

NOTE For hazardous touch voltages, see Clause 10 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

6.3.4 Protection for mobile machines

The measures described in 6.3.2 and 6.3.3 shall be selected by taking the following into consideration:

- system voltage;
- length of supply cable;
- number of machines connected to the point of supply;

over which there may be little influence, and

- type of supply cable;
- type of neutral earthing;
- value of earth-fault current in a supply system with low impedance neutral earthing.

General limitations depending upon the type of supply system are given below:

- direct neutral earthing is generally only appropriate for system voltages less than 2 kV. Automatic disconnection is always required;
- low impedance neutral earthing may be appropriate for system voltages up to 36 kV and a cable length up to 4 km. Automatic disconnection is normally necessary;
- isolated neutral point or high impedance neutral point earthing is appropriate for system voltages up to 36 kV and a cable length up to 8 km (this length depends upon the capacitive reactance of all cables connected to the supply). Automatic disconnection is normally not necessary.

7 Protection of HV equipment

7.1 General

Clause 7 details the measures to be taken to protect HV parts of the electrical equipment against the effects of

- overcurrent;
- overheating of motors;
- abnormal temperature;
- overvoltage due to lightning and switching surges;
- other abnormal conditions;
- loss of or reduction in the supply voltage;
- overspeed of machines/machine elements;
- earth fault;
- incorrect phase sequence;
- overvoltage;
- arc faults.

7.2 Overcurrent protection

7.2.1 General

Overcurrent protection shall be provided where the current in a machine circuit can exceed either the rating of any component or the current-carrying capacity of the conductors, whichever is the lesser value. The ratings or settings to be used are detailed in 7.2.6.

7.2.2 Supply conductors

Unless otherwise specified by the user, the supplier of the HV equipment shall not be responsible for providing the overcurrent protective device for the supply conductors to the HV equipment.

The supplier of the HV equipment shall state on the installation diagram the data necessary for selecting the overcurrent protective device (see 7.2.6, and Annex B, question 15).

7.2.3 Power circuits

Devices for detection and interruption of overcurrent, selected in accordance with 7.2.6, shall be applied to each live conductor.

7.2.4 Transformers

Transformers shall be protected against overcurrent in accordance with IEC 60076-5. Such protection shall (see also 7.2.6)

- avoid nuisance tripping due to transformer magnetizing inrush currents;
- avoid a winding temperature rise in excess of the permitted value for the insulation class of transformer when it is subjected to the effects of a short circuit at its secondary terminals.

The type and setting of the overcurrent protective device should be in accordance with the recommendations of the transformer supplier.

For the provision of protection against other abnormal conditions, see 7.10.

7.2.5 Overcurrent protective devices

The rated short-circuit breaking capacity shall be at least equal to the prospective fault current at the point of installation. Where the short-circuit current to an overcurrent protective device can include additional currents other than from the supply (e.g. from motors, from power factor correction capacitors), those currents shall be taken into consideration.

Overcurrent protective devices for power circuits include fuses and circuit-breakers.

7.2.6 Rating and setting of overcurrent protective devices

The rated current of fuses or the setting current of other overcurrent protective devices shall be selected as low as possible but adequate for the anticipated overcurrents (e.g. during starting of motors or energizing of transformers). When selecting those protective devices, consideration should be given to the protection of switching devices against damage due to overcurrents (e.g. welding of the switching device contacts).

The rated current or setting of an overcurrent protective device is determined by the current carrying capacity of the conductors to be protected by that device in accordance with 13.4. That should take into account the needs of coordination with other electrical devices in the protected circuit. The recommendations of the supplier of those devices should be followed.

7.3 Protection of motors against overheating

Protection of motors against overheating shall be provided for each HV motor.

Exception: In applications where an automatic interruption of the motor operation is unacceptable, the means of detection shall give a warning signal to which the operator can respond.

7.4 Protection against abnormal temperature

Equipment shall be protected against abnormal temperatures that can result in a hazardous situation.

7.5 Protection against the effects of supply interruption or voltage reduction and subsequent restoration

Where a supply interruption or a voltage reduction can cause a hazardous situation, damage to the machine, or to the work in progress, undervoltage protection shall be provided by, for example, switching off the machine at a predetermined voltage level.

Where the operation of the machine can allow for an interruption or a reduction of the voltage for a short time period, delayed undervoltage protection may be provided. The operation of the undervoltage device shall not impair the operation of any stopping control of the machine.

Upon restoration of the voltage or upon switching on the incoming supply, automatic or unexpected restarting of the machine shall be prevented where such a restart can cause a hazardous situation.

Where only a part of the machine or of the group of machines working together in a coordinated manner is affected by the voltage reduction or supply interruption, the undervoltage protection shall initiate appropriate control commands to ensure co-ordination.

7.6 Motor overspeed protection

Overspeed protection shall be provided where overspeeding can occur and could possibly cause a hazardous situation. Overspeed protection shall initiate appropriate control responses and shall prevent automatic restarting.

7.7 Earth fault protection

Earth fault protection shall be provided as described below when the earth-fault current can be lower than the setting of the overcurrent protective devices and unacceptable damage to the electrical equipment can occur.

An earth fault monitoring system that is appropriate to the type of HV supply system in use (e.g. system isolated from earth, earthed system) shall be provided. The electrical equipment or the appropriate section of the electrical equipment shall be switched off if the earth fault exceeds a given current/time value.

The setting of the earth fault protective devices shall be as low as possible and consistent with proper operation of the electrical equipment.

Unless otherwise specified by the user, the supplier of the HV equipment is not responsible for providing the earth fault protective device for the HV supply conductors. The supplier of the HV equipment shall state on the installation diagram the data necessary for selecting the earth fault protective device (see 7.2.6 and, Annex B, question 15).

7.8 Protection against overvoltage due to lightning and switching surges

Equipment shall be protected against overvoltage resulting from switching operations or lightning that could exceed the withstand values. Since different protection methods are available, depending on the level of protection to be achieved and the reliability level required, the method to be used shall be agreed upon between the manufacturer and user; refer to Annex B.

For lightning protection refer to IEC 62305 (all parts).

7.9 Protection against hazards due to arc faults

The high-voltage part of the electrical installation shall be designed and installed so that persons are protected against arc faults during normal operation as described by 8.5 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014. The degree of importance of the measures indicated in IEC 61936-1 shall be agreed upon between the supplier and user (for example, the IAC classification, according to IEC 62271-200).

7.10 Protection against overpressure and leakage

Protection against overpressure and/or leakage of liquid-filled high-voltage equipment such as transformers, reactors and switchgear shall be provided as applicable in accordance with 8.8 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014.

Where liquid-immersed equipment is used (e.g. oil insulated transformers), measures shall be taken to prevent environmental damage in the event of leakage.

7.11 Protection against fire

Protection against fire shall be provided in accordance with 8.7 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014 to prevent the occurrence of a hazardous situation.

8 Equipotential bonding

8.1 General

Clause 8 gives requirements for the protective (equipotential) bonding of

- the exposed-conductive-parts of the electrical equipment,

- the extraneous-conductive-parts of the machine, and
- the earthing system,

and for supplementary protective bonding (see 8.2.6) as required, in order to ensure fault protection (against indirect contact). Figure 2 illustrates these concepts.



Key**Protective bonding circuit:**

- (1) Interconnection of protective conductor(s) and the PE terminal
- (2) Connection of exposed conductive parts
- (3) Protective conductor connected to an electrical equipment mounting plate used as a protective conductor
- (4) Connection of conductive structural parts of the electrical equipment
- (5) Conductive structural parts of the machine

Parts connected to the protective bonding circuit, which are not to be used as protective conductor:

- (6) Metal ducts of flexible or rigid construction
- (7) Metallic cable sheaths or armouring
- (8) Metallic pipes containing flammable materials
- (9) Extraneous conductive parts, if earthed independently from the power supply of the machine and liable to introduce a potential, generally the earth potential, e.g.: metallic pipes, fences, ladders, handrails
- (10) Flexible or pliable metal conduits
- (11) Protective bonding of support wires, cable tray and cable ladders

Connections to the protective bonding circuit for functional reasons:

- (12) Functional bonding

Reference designations:

- T1 Auxiliary transformer
U1 Mounting plate of electrical equipment

High-voltage equipment

- (a) Equipotential bonding of the high-voltage installation
- (b) Protective earthing of low-voltage control equipment
- (c) Earthing connection of high-voltage equipment
- (d) HV cable screen bonding
- (e) Connection to conductive structural parts of the machine
- (f) Interconnection to low-voltage earthing system
- (g) Machine bonding conductor
- (h) Earthing system of installation (building)

NOTE The out-of-reach distance of 2,5 m refers to IEC 60364-4-41.

Figure 2 – Example of equipotential bonding for electrical equipment of a machine**8.2 Protective bonding circuit****8.2.1 General**

The protective bonding circuit consists of (see Figure 2)

- the machine bonding conductor(s);
- the protective conductors of the electrical equipment of the machine, including sliding contacts where they are part of the circuit; and
- the protective bonding conductors connected to the structural parts of the electrical equipment and to the structural parts of the machine (equipotential bonding on the machine).

On mobile machines with on-board power supplies, the protective bonding circuits, the exposed-conductive-parts, and the extraneous-conductive-parts shall all be connected to a protective bonding terminal to provide protection against electric shock. When a mobile

machine is also capable of being connected to an external incoming supply, the protective bonding terminal shall be the connection point for the external protective conductor.

NOTE 1 When the supply of electrical energy is self-contained within stationary, mobile, or movable items of machinery, and when there is no external supply connected (e.g. when an on-board battery charger is not connected), there is no need to connect such electrical equipment to an external protective conductor.

All parts of the interconnected protective bonding circuits for the HV equipment and the LV equipment shall be so designed that they are capable of withstanding the highest thermal and mechanical stresses that can be caused by single or double earth-fault currents that could flow in any part of the protective bonding circuits.

NOTE 2 Details on how to fulfil this requirement are given in 10.2.3 of IEC 61936-1:2010 or in 6.1.1 of EN 50522:2010.

The structural parts of the machine shall be individually connected to the protective bonding circuit.

Any structural part of the electrical equipment or of the machine may be used as part of the protective bonding circuit provided that it satisfies the requirements of IEC 60364-5-54.

NOTE 3 As guidance for the design of earthing or bonding conductors, the current density in the conductor, if of copper, does not exceed 200 A/mm² for a rated duration of short circuit of 1 s, and 125 A/mm² for a rated duration of short circuit of 3 s. A method of calculating cross-sectional areas of conductors is given in IEC 60724.

8.2.2 Protective conductors

Protective conductors shall be identified in accordance with 14.2.

Copper conductors are preferred. Where a conductor material other than copper is used, its electrical resistance per unit length shall not exceed that of the allowable copper conductor and such conductors shall be not less than 16 mm² in cross-sectional area for reasons of mechanical durability.

Due to mechanical strength and stability against corrosion, minimum cross-sections of protective conductors are:

- copper: 16 mm²
- aluminium: 35 mm²
- steel: 50 mm²

NOTE Where the connection to an external installation earthing system using such a value is not sufficient to provide protection against indirect contact, the calculation of cross-sectional area of the bare conductor according to Annex D of EN 50522:2010 applies.

8.2.3 Continuity of the protective bonding circuit

All exposed-conductive-parts of the electrical equipment and the machine(s) shall be connected to the protective bonding circuit. Where a part is removed for any reason (e.g. routine maintenance), the protective bonding circuit for the remaining parts shall not be interrupted.

Connection and bonding points shall be so designed that their current-carrying capacity is not impaired by mechanical, chemical, or electrochemical influences. Where enclosures and conductors of aluminium or aluminium alloys are used, particular consideration should be given to the problems of electrolytic corrosion.

Metal ducts of flexible or rigid construction, metallic cable sheaths and busbar trunking systems shall not be used as protective conductors. Nevertheless, such metal ducts and the metal sheathing of all connecting cables (e.g. cable armouring, lead sheath) shall be connected to the protective bonding circuit.

Doors, lids or cover plates on which devices (e.g. operator interface devices) are mounted shall be connected to the protective bonding circuit by a protective conductor.

For machines, for example mobile machines, where the connection to the earthing system (machine bonding conductor) is provided solely by flexible cables, the continuity of the protective conductor shall be ensured by appropriate design of the cable (see 13.7). Where there is a possibility that the cable and hence the machine bonding conductor could become damaged (e.g. a trailing cable dragged on the ground), the continuity of the protective bonding circuit shall be monitored (see question 13 in Annex B). The HV supply to the electrical equipment of the machine or to the relevant part of the machine shall be switched off

- when loss of continuity of the protective bonding circuit is detected, or
- when failure of the monitoring means occurs.

For requirements for the continuity of the protective bonding circuit using conductor wires, conductor bars and slip-ring assemblies, see 13.8.2.

The protective bonding circuit shall not incorporate a switching device, an overcurrent protective device (e.g. switch, fuse) so that continuity of the earthing path is not interruptible and any metallic parts that may be touched during normal operation remain connected to the equipotential bonding and earthing system.

Exception: links that can only be opened with the use of tools (e.g. for measuring and testing purposes) and that are located in an enclosed electrical operating area may be provided for test or measurement purposes.

8.2.4 Mobile machines

Where the continuity of the protective bonding circuit can be interrupted by means of removable current collectors or plug-socket combinations, the protective bonding circuit shall not be interrupted before the live conductors have been disconnected, and shall be re-established before any live conductor is reconnected. This also applies to removable or withdrawable plug-in units (see also 14.4).

Metallic housings of plug-socket combinations shall be connected to the protective bonding circuit.

8.2.5 Protective bonding circuit connecting points

All protective conductors shall be terminated in accordance with 14.1.1. The protective conductor connecting points shall have no other function and shall not be used, for example, to mechanically attach or connect components or parts.

Each connecting point for

- protective conductors inside the electrical equipment of the machine,
- the protective bonding conductors on the machine (see Figure 2),
- the machine bonding conductor(s) (see Figure 2),

shall be identified as such using the symbol IEC 60417-5019:2006-08 (see Figure 3).



Figure 3 – Symbol for protective earth (protective ground)

8.2.6 Supplementary protective bonding conductors

Supplementary protective bonding conductors shall be used to connect the protective bonding circuit of the machine to the structural metalwork of the building when such metalwork is in close proximity (e.g. less than 2,5 m) to the machine. These conductors shall conform to Cause 544 of IEC 60364-5-54:2011 as appropriate. The cross-sectional area of a supplementary protective bonding conductor shall be not less than half the cross-sectional area of the associated machine bonding conductor and shall be not less than that specified in 8.2.2.

9 Control systems, control circuits and control functions

For control, protection and auxiliary systems of HV equipment the relevant subclauses of Clause 9 of IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014 apply. Control, protection and auxiliary devices shall ensure the correct and safe functioning of the HV equipment; and provide protection against the effects of unacceptable overload and any internal and external fault conditions.

Facilities shall be provided for isolating the control circuits in order to allow maintenance of high-voltage equipment to be performed safely. Provisions shall be made to allow for repair, maintenance, and/or testing to be carried out on control, protection and auxiliary devices without any danger to personnel or the equipment. Alarm and fault-indicating equipment shall clearly indicate danger and fault conditions.

For the control circuits the requirements of Clause 9 of IEC 60204-1:2016 apply except where the LV control circuits are covered by other standards. Control circuits directly connected to high-voltage circuits (e.g. thyristor gate circuits) shall be electrically separated from low-voltage circuits by the use of an interface technique such as optical coupling or transformer coupling.

Cableless control systems used in electrical equipment shall comply with IEC 62745.

10 Operator interface and machine-mounted control devices

The requirements of Clause 10 of IEC 60204-1:2016 apply, but the minimum degree of protection against direct contact shall be IP 4X or IP XXDH for operator interface and machine-mounted control devices (see also 6.2 for protection against direct contact).

11 Electronic equipment

HV electronic equipment, for example converters, power drive systems, shall comply with their relevant standards, for example, IEC 61800 (all parts) for power drive systems.

For static converters refer also to 6.2.14 of IEC 61936-1:2010. Where no specific standards for electronic power equipment exists, EN 50178 provides basic requirements.

12 Controlgear: location, mounting, and enclosures

12.1 General requirements

All controlgear shall be located and mounted so as to facilitate

- its accessibility and maintenance;
- its protection against the external influences or conditions under which it is intended to operate;