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Earth-moving machinery — Electrical safety of machines utilizing electric drives and related components and systems

Part 1: General requirements

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National foreword

This British Standard is the UK implementation of ISO 14990-1:2016.

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

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

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Earth-moving machinery — Electrical safety of machines utilizing electric drives and related components and systems —

Part 1: **General requirements**

Engins de terrassement — Sécurité électrique des machines utilisant des moteurs électriques et composants et systèmes connexes —

Partie 1: Exigences générales

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html

The committee responsible for this document is ISO/TC 127, *Earth-moving machinery*, Subcommittee SC 3, *Machine characteristics, electrical and electronic systems, operation and maintenance*.

This document is intended to be used in conjunction with ISO 14990-2 and ISO 14990-3.

Introduction

This document is a type-C standard as defined in ISO 12100.

The machinery concerned and the extent to which hazards, hazardous situations, or hazardous events are covered are indicated in Annex A of this document.

When requirements of this type-C standard are different from those stated in type-A or type-B standards, the requirements of this type-C standard take precedence over the requirements of the other standards for machines that have been designed and built according to the requirements of this type-C standard.

Electrification is an enabling technology providing increased flexibility in machine form packaging. Because in the past earth-moving machinery (EMM) electrical systems have predominately been in the 12–24 V DC range, two safety aspects require particular attention:

— significantly higher voltages, such as are utilized in industrial or structural applications and in other transportation sectors;

— greater available electrical energy.

Portions of this document appear to govern electrical design practices (e.g. Clauses 9, 11, 12, and 17). Their requirements are necessary because certain aspects of design cannot be separated from electrical safety.

Some of the content of this document is based on IEC 60204-1 and IEC 60204-11, adapted to the needs of earth-moving machinery. Non-electrical hazards are addressed in the ISO 20474 series.

Earth-moving machinery — Electrical safety of machines utilizing electric drives and related components and systems —

Part 1: General requirements

1 Scope

This document specifies general safety requirements for the electrical equipment and its components incorporated into earth-moving machines (EMMs) as defined in ISO 6165, and addresses the safety of operators, technicians, service/maintenance personnel and bystanders.

It is applicable to those machines using on-board voltages in the ranges of 50 V–36 kV AC r.m.s. at any frequency and 75 V–36 kV DC — including any repetition rate of pulsating DC — intended for outdoor use. It is applicable to both low and high voltages, except where its applicability to high- or low-voltage equipment only is indicated. Voltages occurring within devices are not considered to be on-board voltages and are thus not within its scope.

NOTE 1 Special considerations typically apply at frequencies greater than 30 kHz. Where reference standards are limited to frequencies below those used on the EMM, it is the responsibility of the user to assess the risks and address them appropriately.

This document covers all significant hazards, hazardous situations, and hazardous events relevant to the voltage range for earth-moving machinery within its scope when the machinery is used as intended or under conditions of misuse reasonably foreseeable by the manufacturer. It specifies appropriate technical measures for eliminating or reducing risks arising from significant hazards, hazardous situations, or hazardous events during commissioning, operation, and maintenance. It is not applicable to machines manufactured before the date of its publication.

It is intended to be used in conjunction with ISO 14990-2 and ISO 14990-3, which give provisions specific to the machine's power source that take precedence over the requirements of this document for the machines covered. For multipurpose machinery, all those parts of ISO 14990 are applicable whose requirements cover the functions and applications of the machine.

Even though this document addresses most hazards associated with the use of low- or high-voltage electrical systems in earth-moving machines, owing to the possible presence of additional electrical hazards, conformance with it cannot be taken as an absolute guarantee of electrical safety. Areas of concern are included in the list of significant hazards found in Annex A.

This document specifies requirements for on-board generators, electrically isolated from other low-voltage systems and provided as power sources for general-purpose socket outlets installed on EMMs, and transformer or inverter power sources for general-purpose socket outlets.

NOTE 2 Local or regional requirements may also apply to general-purpose socket outlet arrangements.

Although nominal 12 V and 24 V (alternator/battery) systems are not addressed, the meeting of some of the requirements, including those of PELV, will ensure that the low-voltage system is sufficiently isolated from 12 V and 24 V systems.

This document does not address risks associated with explosive atmospheres, which are sometimes found in mining and other EMM applications.

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.

ISO 2860, *Earth-moving machinery — Minimum access dimensions*

ISO 2867:2011, *Earth-moving machinery — Access systems*

ISO 3457:2003, *Earth-moving machinery — Guards — Definitions and requirements*

ISO 9244:2008, *Earth-moving machinery — Machine safety labels — General principles*. Amended by ISO ISO 9244:2008/Amd. 1:2016

ISO 14990-2:2016, *Earth-moving machinery — Electrical safety of machines utilising electric drives and related components and systems — Part 2: Particular requirements for externally-powered machines*

ISO 14990-3, *Earth-moving machinery — Electrical safety of machines utilising electric drives and related components and systems — Part 3: Particular requirements for self-powered machines*

ISO 15817, *Earth-moving machinery — Safety requirements for remote operator control systems*

IEC 60071-1:2006, *Insulation Coordination — Part 1: Definitions, principles and rules.* Amended by IEC 60071-1:2006/Amd. 1:2010

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

IEC 60204-1:2005, *Safety of machinery — Electrical equipment of machines — Part 1: General requirements*. Amended by IEC 60204-1:2005/Amd. 1:2008

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

IEC 60364-4-41:2005, *Electrical installations of buildings Part 4-41: Protection for safety Protection against electric shock*

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

IEC 60417-DB, *Graphical symbols for use on equipment*[1)]

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

IEC 60617-DB, *Graphical symbols for diagrams*[2)]

IEC 60664-1, *Insulation coordination for equipment within low-voltage systems Part 1: Principles, requirements and tests*

IEC 60871-1: 2014, *Shunt capacitors for AC power systems having a rated voltage above 1 000 V — Part 1: General*

IEC 60947-1, *Low-voltage switchgear and controlgear — Part 1: General rules*

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

IEC 61439-1, *Low-voltage switchgear and controlgear assemblies — Part 1: General rules*

IEC 61557 (all parts), *Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. — Equipment for testing, measuring or monitoring of protective measures*

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1) Online database: available at http://www.graphical-symbols.info/

2) Online database: available at http://std.iec.ch/iec60617

IEC 61558-1, *Safety of power transformers, power supply units and similar — Part 1: General requirements and tests*

IEC 61558-2-6, *Safety of power transformers, power supply units and similar — Part 2-6: Particular requirements for safety isolating transformers for general use*

IEC 61984, *Connectors — Safety requirements and tests*

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

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms, definitions and abbreviated terms given in ISO 12100 and the following 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 Electric shock protection-related terms and definitions

3.1.1
electrically protective barrier
barrier
part providing protection against direct contact from any usual direction of access

[SOURCE: IEV 826-12-23]

3.1.2
direct contact
electric contact of persons with live parts

[SOURCE: IEV 826-12-03, modified]

3.1.3
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* (3.1.1) without the use of a key or tool, and which is clearly marked by appropriate warning signs

[SOURCE: IEC 60204-1: 2005, 3.15]

3.1.4
electrically protective enclosure
protective enclosure
enclosure
electrical enclosure (3.1.5) surrounding internal parts of equipment to prevent access to hazardous-live-parts from any direction

[SOURCE: IEV 826-12-22]

3.1.5
electrical enclosure
enclosure (3.1.4) providing protection against the foreseen dangers created by electricity

[SOURCE: IEV 826-12-21, modified]

Note 1 to entry: Some electrical enclosures also provide protection for equipment. It can be either of discrete construction or an enclosed space within the *machine* (3.5.2).

3.1.6
equipotential bonding
provision of electric connections between conductive parts, intended to achieve equipotentiality

[SOURCE: IEV 195-1-10]

3.1.7
protective equipotential bonding
equipotential bonding (3.1.6) for the purposes of safety

[SOURCE: IEV 195-01-15]

3.1.8
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: IEV 826-12-10]

3.1.9
extra-low voltage
ELV
voltage supplied from a source within the device that does not exceed 50 V between conductors and between conductors and earth (or chassis in the case of self-powered machines) when the device is supplied at rated voltage

[SOURCE: IEC 60335-1, 3.4.1, modified]

3.1.10
extraneous conductive part
conductive part not forming part of the electrical equipment and liable to introduce a potential, generally the ground (or chassis in the case of self-powered machines) potential

[SOURCE: IEV 826-12-11, modified]

3.1.11
indirect contact
contact of persons with *exposed conductive parts* (3.1.8) which have become live due to fault conditions

[SOURCE: IEV 826-12-04, modified]

3.1.12
live part
conductor or conductive part intended to be energized in normal use, including a neutral conductor, but, by convention, not a PEN conductor

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

[SOURCE: IEC 60204-1: 2005, 3.33]

3.1.13
obstacle
part preventing unintentional direct contact, but not preventing direct contact by deliberate action

[SOURCE: IEC 60204-1: 2005, 3.38]

3.1.14
protective conductor
conductor provided for purposes of safety, e.g. protection against electric shock

[SOURCE: IEV 826-13-22, modified]

Note 1 to entry: A protective conductor is typically used to connect any of the following:

— exposed conductive parts;

— extraneous conductive parts;

— PE (or chassis ground in the case of self-powered machines) terminal.

3.1.15
protective extra-low voltage
PELV
earthed (or chassis-bonded in the case of self-powered machines) circuit operating at safety extra-low voltage which is separated from other circuits by basic insulation and protective screening, double insulation or reinforced insulation

[SOURCE: IEC 60335-1, 3.4.4, modified]

Note 1 to entry: Protective screening is the separation of circuits from live parts by means of an earthed (or chassis-bonded in the case of self-powered machines) screen.

3.1.16
safety extra-low voltage
SELV
voltage not exceeding 42 V between conductors and between conductors and earth (or chassis in the case of self-powered machines), the no-load voltage not exceeding 50 V

[SOURCE: IEC 60335-1, 3.4.2, modified]

Note 1 to entry: When safety extra-low voltage is obtained from the source mains, it is through a safety isolating transformer or a convertor with separate windings, the insulation of which complies with double insulation or reinforced insulation requirements.

3.1.17
touch voltage
voltage between conductive parts when touched simultaneously by a person or animal

[SOURCE: IEV 195-05-11]

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

3.2 Control-related terms and definitions

3.2.1
actuator
part of the actuating system to which an external actuating force is applied

Note 1 to entry: An actuator typically takes the form of a handle, knob, push-button, roller, plunger, etc.

Note 2 to entry: Cf. 3.2.5.

[SOURCE: IEC 60204-1: 2005, 3.1, modified]

3.2.2
controlgear
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* (3.1.4) and supporting structures, intended in principle for the control of electric energy consuming equipment

[SOURCE: IEV 441-11-03]

3.2.3
emergency switching-off device
manually actuated control device used to switch off the source of electrical energy to all or a part of the electrical equipment of a *machine* (3.5.2) where a risk of electric shock or another risk of electrical origin is involved

[SOURCE: IEC 60204-1: 2005, 3.18, modified]

3.2.4
emergency stop device
manually actuated control device used to initiate an emergency stop function

[SOURCE: ISO 13850, 3.2]

3.2.5
machine actuator
electromechanical or electronic power mechanism used to effect a function of the *machine* (3.5.2)

[SOURCE: IEC 60204-1: 2005, 3.34, modified]

3.3 Electrical infrastructure-related terms and definitions

3.3.1
ampacity
maximum current, in amperes, that a conductor can carry continuously under the conditions of use without exceeding its temperature rating

3.3.2
cable trunking system
system of enclosures, each consisting of a base with a removable cover, intended to completely enclose insulated conductors, cables, cords and for the accommodation of other electrical devices

[SOURCE: IEV 442-02-34, modified]

3.3.3
direct opening action
<of a contact element> achievement of contact separation as the direct result of a specified movement of the switch *actuator* (3.2.1) through non-resilient members (e.g. not dependent upon springs)

[SOURCE: IEC 60947-5-1: 2009, K.2.2]

3.3.4
duct
enclosed channel designed specifically to hold and protect electrical conductors, cables, and busbars

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

[SOURCE: IEC 60204-1: 2005, 3.14, modified]

3.3.5
functional equipotential bonding
equipotential bonding for operational reasons other than safety

[SOURCE: IEV 195-01-16]

3.3.6
high voltage
HV
voltage greater than 1 000 V AC and not exceeding 36 kV AC r.m.s or greater than 1500 V DC and not exceeding 36 kV DC

3.3.7
low voltage
voltage greater than 50 V AC and not greater than 1000 V AC r.m.s or greater than 75 V DC and not greater than 1500 V DC

3.4 Risk-related terms and definitions

3.4.1
failure
termination of the ability of a device to perform a required function

Note 1 to entry: After failure, the item has a *fault* (3.4.2).

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.

[SOURCE: IEV 191-04-01, modified]

3.4.2
fault
state of a device characterized by its inability to perform a required function

Note 1 to entry: A fault is often the result of a *failure* (3.4.1) of the item itself, but in some instances exists without prior failure.

[SOURCE: IEC 60204-1: 2005, 3.26, modified]

3.4.3
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 (e.g. mechanical hazard, electrical hazard) or the nature of the potential harm (e.g. electric shock hazard, cutting hazard, toxic hazard, and fire hazard).

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

— permanently present during the intended use of the *machine* (3.5.2) (e.g. motion of hazardous moving elements, electric arc during a welding phase, unhealthy posture, noise emission, high temperature), or

— can appear unexpectedly (e.g.: 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]

3.4.4
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]

3.4.5
safeguard
guard or protective device or protective function provided as a means to protect persons from a *hazard* (3.4.3)

[SOURCE: IEC 60204-1:2005, 3.49, modified]

3.4.6
safeguarding
protective measure using safeguards to protect persons from the *hazards* (3.4.3) which cannot reasonably be eliminated or from the *risks* (3.4.4) which cannot be sufficiently reduced by inherently safe design measures

[SOURCE: ISO 12100:2010, 3.21]

3.5 Miscellaneous terms and definitions

3.5.1
electrically instructed person
instructed person
person adequately advised or supervised by an electrically skilled person to enable him or her to perceive *risks* (3.4.4) and to avoid *hazards* (3.4.3) which electricity can create

[SOURCE: IEV 826-18-02, modified]

3.5.2
machinery
machine
assembly of linked parts or components, at least one of which moves, with the appropriate *machine actuators* (3.2.5), control and power circuits, joined together for a specific application

Note 1 to entry: The term machinery also covers an assembly of machines which, in order to achieve the same end, are arranged and controlled so that they function as an integral whole.

[SOURCE: ISO 12100:2010, 3.1, modified]

3.5.3
overload
<of a circuit> non-fault time-current event in a circuit, in which the electrical ratings of the circuit are exceeded

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

[SOURCE: IEC 60204-1: 2005, 3.40, modified]

3.5.4
electrically skilled person
skilled person
person with relevant training, education, and experience to enable him or her to perceive risks and to avoid hazards associated with electricity

[SOURCE: IEV 826-18-01, modified]

3.6 Abbreviated terms

EMM	earth-moving machinery
ELV	extra-low voltage
PE	protective earthing (or protective equipotential bonding to chassis in the case of self-powered machines)
PELV	protective extra-low voltage
SELV	safety extra-low voltage
PPE	personal protective equipment
TN	*terra* neutral (IEC 60364-1-defined earthing system)
TT	*terra terra* (IEC 60364-1-defined earthing system)
IT	isolation *terra* (IEC 60364-1-defined earthing system)
OCP	overcurrent protection (e.g. a fuse, a circuit breaker, or a solid-state device including its control system)
AC	alternating current
DC	direct current

4 General requirements

4.1 General

The overall risk assessment for the machine shall include risks associated with electrical hazards. Appropriate risk assessment methods are given in ISO 12100. Annex A provides a list of significant hazards and hazardous situations associated with the use (or misuse), maintenance, and servicing of electrical equipment of earth-moving machines.

Hazards and the risks arising from them shall be identified during the design and development process.

Hazards and risks shall be addressed in the following order of priority or hierarchy:

a) design measures shall provide inherent safety to eliminate hazards or sufficiently reduce risks; if such measures are not practicable;

b) protective measures such as safeguarding shall provide further reduction of risk; if such measures are not practicable, or if still further risk reduction is necessary;

c) additional measures, such as awareness means, shall be employed;

d) working procedures that reduce risk during EMM operation and maintenance shall be implemented in the operator's and service manuals.

Safety measures may be incorporated at the design stage (preferred), or the user may be instructed to implement some measures.

4.2 Provisions for handling

If the user or service personnel are instructed to, or are likely to need, to remove heavy or bulky electrical equipment from the EMM for transport or service, provisions shall be made for handling, such as lifting eyes, fork pockets or the like.

4.3 Provisions for transportation and storage

The electrical equipment of the EMM shall be designed to withstand, or shall be protected from, the effects of transportation and storage. Provision shall be made to protect against damage from humidity, vibration, and shock, as well as temperatures more severe than those specified in 4.5.1.

4.4 Components and devices

The components of the electrical system shall be

— suitable for their intended use, and

— applied within applicable ratings and in accordance with the supplier's instructions.

NOTE 1 Suitability for intended use includes conformity with relevant International Standards where these exist.

It is recommended that when an IEC component standard does not exist, relevant requirements of suitable International Standards or of other comparable standards be applied (e.g. applicable parts of the IEC 60034 series of motor standards may be applied to switched reluctance motors.).

NOTE 2 ELV components derived from sources of voltages lower than low voltage and without the possibility of "bleed through" are outside the scope of this document.

High-voltage equipment

If factory-built, type-tested HV switchgear is employed it shall comply with applicable standards (e.g. IEC 62271-1, IEC 62271-200, and IEC 62271-201).

4.5 Intended operating environment

4.5.1 General

Electrical equipment shall be suitable for the environment and operating conditions of its intended application. The criteria for environmental and operating conditions given in ISO 15998:2008, 4.6, are recommended. ISO 19014[3)] may be used as an alternative to ISO 15998. An agreement between user and supplier, based upon the enquiry forms provided in ISO 14990-2 and ISO 14990-3, might also be necessary.

NOTE ISO 15998:2008, 4.6, covers the following:

— ambient air temperature range;

— humidity;

— degree of protection (IP Code) (see 4.5.4);

— electromagnetic compatibility (EMC);

— vibration and shock.

An external charging system shall be verified as being compatible with the EMM by the manufacturer, or as specified in ISO 14990-2:2016, 4.2.2.

4.5.2 Exposure

All EMM covered by this document shall be suitable for outdoor use. EMM may also be designed for use indoors. The requirement for suitability for outdoor use includes suitability for outdoor storage during periods of non-use.

3) Under preparation.

The possibility of harmful internal condensation shall be addressed where necessary by measures such as prevention of condensation or provision for drainage.

4.5.3 Altitude

The electrical equipment of the EMM shall operate properly at altitudes up to 1 000 m above mean sea level. The operator's manual shall instruct the operator as to whether the EMM can be operated at altitudes greater than 1000 m, and if so it shall clearly identify and explain EMM limitations at altitudes greater than 1000 m.

4.5.4 Ingress protection

The electrical equipment of the EMM shall be protected against or be tolerant of the ingress of harmful solids and liquids, including dust, acids, corrosive gases, and salts, that might be present in the operating environment.

For air-cooled resistor grids, a special procedure might be necessary to dry the resistor grid when wet.

4.6 Electrical source

The electrical equipment shall operate correctly with variations of the source

— as specified in ISO 14990-2, for externally-powered machines (e.g. one or more EMMs supplied by one or more dedicated external generator sets),

— as specified in ISO 14990-3, for self-powered machines,

— as otherwise specified by the user.

5 Protection against electric shock hazards

5.1 General

The electrical equipment of the EMM shall provide protection of persons against electric shock. Such protection shall consist of the measures given in 5.2 to 5.11, as appropriate. If an assembly containing live parts is accessible by all persons, the provisions of 5.2 or 5.3, and, if applicable, 5.4, shall be applied.

Exception: If these protective measures are not practicable, other protective measures given in IEC 60364-4-41 or IEC 61140 may be used.

Each circuit or part shall provide protection against indirect contact according to 5.8 or 5.9 or both.

NOTE Classes of equipment and protective provisions are given in IEC 61140.

5.2 Protection by enclosures

Live parts shall be contained within enclosures that comply with the relevant requirements of Clause 4, Clause 12 and Clause 14, and which provide protection against direct contact of at least IP2X or IPXXB.

Exception 1: If the top surfaces of an enclosure are readily accessible, the minimum degree of protection against direct contact provided by those surfaces shall be IP4X or IPXXD.

Exception 2: If an assembly containing live parts is accessible to all persons, the minimum degree of protection against direct contact shall be IP4X or IPXXD.

Exception 3: Air-cooled resistor grids shall only be required to meet a minimum of IP2X or IPXXB, provided they do not create hazardous conditions in the installed position when exposed to rain or dust. If IP2X or IPXXB is not practical, it is also acceptable to use the crushing requirement dimensions specified in ISO 3457:2003, 10.7. Normal maintenance procedures shall be specified in the operator's manual, if necessary, to prevent debris build-up.

It shall not be possible to open an enclosure (e.g. via a door, lid, or cover) unless one of the following conditions, a) to c), is satisfied.

a) **Access requires the use of a key or tool**

   Live parts likely to be touched when performing adjustments while the equipment is connected shall be protected against direct contact to at least IP2X or IPXXB.

   Door-mounted live parts within the enclosure shall be protected against direct contact to at least IP1X or IPXXA.

b) **Live parts inside the enclosure are automatically disconnected if the enclosure is opened**

   An example of this measure is an interlock which operates a disconnecting device, arranged such that if the door is open, the disconnecting device is open and cannot be closed if the door is open.

   Accessibility of live parts behind doors and not directly interlocked with the disconnecting device shall be limited to skilled persons.

   Parts that remain live after switching off the disconnecting device(s) shall be protected against direct contact to at least IP2X or IPXXB. Such parts shall be marked with a warning in accordance with 16.2.1 (see 11.8 for identification of conductors by colour).

   Exception 1: this marking requirement does not apply to

   — parts that might be live only because they are part of an interlock circuit and that are colour-identified in accordance with 11.8 as potentially live,

   — the source terminals of a source disconnecting device if it is mounted alone in an enclosure.

   Exception 2: a special device or tool furnished or specified by the supplier may be used to bypass the interlock if the following conditions are met:

   — the disconnecting device can be opened and locked in the OFF (open) position, or unauthorized closure of the disconnect is prevented if the interlock is bypassed;

   — the interlock function is automatically returned to service upon closing the door;

   — live parts likely to be touched when performing adjustments while the equipment is connected shall be protected against direct contact to at least IP2X or IPXXB, and door-mounted live parts within the enclosure shall be protected against direct contact to at least IP1X or IPXXA.

   Appropriate information is provided with the electrical equipment in accordance with Clause 15.

c) **All live parts are protected against direct contact to at least IP2X or IPXXB if the enclosure can be opened without the use of a key or a tool or without automatic disconnection of live parts**

   If protection is provided by a barrier, a tool shall be required for removal of the barrier or else all live parts protected by it shall be automatically disconnected when it is removed.

   If a hazard can be caused by manual actuation of devices such as contactors or relays, manual actuation should be prevented by barriers or obstacles that require a tool for removal.

5.3 Protection by insulation

Live parts protected by insulation shall be completely enclosed by insulation which can be removed only by destruction.

NOTE Paints, varnishes, lacquers, and similar products alone are not generally considered adequate for protection against electric shock.

5.4 Protection against residual voltages

When a source voltage of electrical equipment is removed (e.g. by disconnection or by stopping a generator), residual voltages within the equipment shall conform to the values in Table 1. If the rate of discharge required to comply with the time limit specified would prevent the equipment from functioning as intended, a warning marking shall be placed at a prominent location on or adjacent to the capacitance enclosure. The warning marking shall state a minimum time interval required before the capacitor enclosure may be opened. This requirement does not apply to components containing stored charge of 60 µC or less. For high-voltage equipment, IEC 60871-1:2014, Clause 21 shall apply.

Table 1 — Residual voltage discharge requirements

Equipment type	Maximum discharge time	Maximum voltage at time limit
Low voltage	10 s	60 V
High voltage	10 min	75 V

In any case, in order to ensure discharge before opening the enclosure, it is recommended that a prominent marking in accordance with 16.2.1 be provided, warning the service person to wait a specified amount of time. The amount of time specified should be greater than that required for discharge to either a voltage ≤60 V, or a stored charge ≤60 µC. The recommended maximum time is 5 min.

Service literature shall provide a method for verification of discharge of residual voltages prior to servicing, and shall stress the necessity of doing so. Service literature shall instruct the service person as to wearing of proper personal protective equipment (PPE) and verification that the residual voltage measuring device is functioning correctly.

Service literature shall provide a procedure for manual discharge of residual voltages in the event of failure of the automatic discharge means. If a device is required for manual discharge of residual voltages, the device shall be provided or specified by the EMM manufacturer.

For low voltage systems, If disconnection by means of a plug or connector results in accessible live parts, voltages of the accessible live parts greater than 60 V shall decrease to 60 V or less within 1 s after disconnection. Alternatively, protection against direct contact to a level of at least IP2X or IPXXB shall be provided. Energy storage devices (e.g. batteries or double-layer energy storage capacitors) are excluded if a warning marking is provided.

5.5 Protection by barriers

Requirements for protection by barriers are given by IEC 60364-4-41:2005, A.2.

NOTE Unless they can be removed without the use of a key or tool, barriers 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 to be part of the enclosure.

5.6 Protection by inaccessibility

Requirements for protection by placing out of reach or by obstacles are given by IEC 60364-4-41:2005, B.3 and B.2, respectively.

5.7 Special considerations for low voltage energy storage devices and related buses

Low-voltage energy storage devices and bus systems that remain energized during servicing shall provide protection from inadvertent contact. Energy storage devices shall be contained in electrical enclosures meeting all the other requirements of Clause 6, except that it shall be allowed to service these devices with low voltage and hazardous amperages exposed. The means of protection shall be one or more of methods given in a) to d), below, in addition to e), or methods that offer equivalent levels of hazard reduction:

a) bus systems connecting multiple energy devices: coated or covered by insulating materials in all locations, except in the areas where the electrical connections are made;

b) recessed, separated, or recessed and separated connections to reduce inadvertent contact between exposed live components of differing voltages;

c) bus systems mounted in ways that deflect dropped tools away from making direct contact, such as vertically mounted busbars;

d) bus systems that are interconnected by contact relays, knife switches, or similar devices that allow the energy storage device to be broken in to smaller, less hazardous storage sub-units;

e) warning labels, servicing instructions, or both indicating

   — the hazards of electrical shorting,

   — methods to be used to prevent shorting, such as using insulated tools and insulated gloves,

   — appropriate personal protection equipment.

Energy storage device terminals shall

— be fully shrouded, or

— have insulating barriers installed between them,

or both.

5.8 Prevention of touch voltage

5.8.1 General

Measures to prevent the occurrence of a touch voltage include use of class II or equivalent insulation, and electrical separation.

5.8.2 Protection by class II construction or equivalent

This measure is intended to prevent the occurrence of touch voltages on accessible parts due to a fault in basic insulation.

Protection is accomplished by one or more of the following:

— class II electrical devices or apparatus (double insulation, reinforced insulation or equivalent insulation according to IEC 61140);

— switchgear and controlgear assemblies having total insulation according to IEC 61439-1;

— supplementary or reinforced insulation according to IEC 60364-4-41.

5.8.3 Protection by electrical separation

This measure is intended to prevent a touch voltage on exposed conductive parts that become energized due to a fault in basic insulation of live parts of that circuit. The requirements of IEC 60364-4-41:2005, C.3, apply.

5.9 Protection by automatic disconnection of source

This measure is intended to interrupt one or more of the line conductors by the automatic operation of a protective device in the event of a fault. Interruption shall occur within a time sufficiently short enough to limit the duration of a touch voltage to a time within which the touch voltage is not hazardous. Interruption times are given in Annex B.

Coordination is required between the following:

— the type of source and earthing (or chassis equipotential bonding in the case of self-powered machines) system;

— the impedances of the relevant parts of the protective equipotential bonding system;

— the characteristics of the protective devices.

This measure includes both protective equipotential bonding of exposed conductive parts and one of the following:

a) in TN systems, OCP for automatic disconnection of the source on detection of an insulation fault, or

b) in TT systems, residual current protective devices to initiate automatic disconnection of the source upon detection of an insulation fault from a live part to exposed conductive parts or to earth (or chassis in the case of self-powered machines), or

c) in IT systems, either

   1) insulation monitoring for the first fault from a live part to exposed conductive parts or to earth (or chassis in the case of self-powered machines), or

2) residual current protective devices that initiate automatic disconnection.

   In respect of 1), above, the insulation monitoring device shall initiate an audible signal, a visual signal, or both, and this signal shall continue as long as the fault persists. Machine operators and service personnel shall be warned about a “first fault” according to 15.7.2.

   NOTE The provision of an earth (or chassis in the case of self-powered machines) fault location system facilitates troubleshooting.

TN, TT, and IT systems are defined by IEC 60364-1, which covers voltages up to 1 000 V AC and 1 500V DC.

This document extends the range of application for TN, TT, and IT systems to 36 kV AC or DC.

Foreseeable misuse, e.g. disabling of the audible or visual signal while continuing operating the machine, shall be also considered.

If automatic disconnection is provided in accordance with a), above, and disconnection time is greater than specified in B.1, supplementary equipotential bonding shall be provided as necessary to comply with B.3 (see Annex B).

5.10 Protection by equipotential bonding

5.10.1 General

Protective equipotential bonding (see 5.10.2) protects persons against electric shock from indirect contact in the event of a fault.

Functional equipotential bonding (see 5.10.3) serves a different purpose, which is to minimize the consequences of insulation failures or electrical disturbances which could affect the operation of the EMM. Functional equipotential bonding is usually achieved by connection to the protective equipotential bonding circuit, but if the level of electrical disturbances on the protective equipotential bonding circuit could interfere with proper functioning of sensitive electrical equipment, the functional equipotential bonding circuit may be connected to a separate functional earthing or chassis equipotential bonding conductor.

5.10.2 Protective equipotential bonding circuit

5.10.2.1 General

The protective equipotential bonding circuit consists of

— PE terminals (or chassis protective equipotential bonding terminal(s) in the case of self-powered machines),

— protective conductors in the equipment of the EMM including sliding contacts where they are part of the circuit,

— exposed conductive parts and conductive structural parts of the electrical equipment, and

— miscellaneous conductive parts which form the structure of the EMM.

Each part of the protective equipotential bonding circuit shall be capable of withstanding the highest thermal and mechanical stresses that can result from earth-fault or chassis-fault currents that could flow in that part of the protective equipotential bonding circuit.

Where the resistance of structural parts of the electrical equipment or of the EMM is greater than that of the smallest protective conductor connected to the exposed conductive parts, a supplementary protective equipotential bonding conductor shall be provided. The supplementary protective equipotential bonding conductor shall have a cross-sectional area not less than half that of the corresponding protective equipotential bonding conductor.

If an IT distribution system is used, the EMM structure shall be part of the protective equipotential bonding circuit and insulation monitoring shall be provided [see 5.9 c)].

Conductive structural parts of equipment considered to be class II or equivalent (see 5.8.2) need not be connected to the protective equipotential bonding circuit. Miscellaneous conductive parts which form the structure of the EMM need not be connected to the protective equipotential bonding circuit if all equipment provided is class II or equivalent.

5.10.2.2 Protective conductors

Protective conductors shall be identified in accordance with 11.8.2.

Copper conductors are preferred. The electrical resistance per unit length of a conductor material other than copper shall not exceed that of the allowable copper conductor.

For low-voltage equipment, the cross-sectional area of protective conductors shall be determined in accordance with the requirements of

— IEC 60364-5-54:2011, 543, or

— IEC 61439-1,

as appropriate.

For high-voltage equipment, the minimum cross-sectional area, S, of protective conductors shall be determined by available fault current.

a) For earth fault current $I_E \leq 100A$, $S = S_{min}$:

— for copper, $S_{min} = 16\ mm^2$,

— for aluminium, $S_{min} = 35\ mm^2$, and

— for steel, S_{min} = 50 mm^2.

b) For earth fault current I_E > 100 A, $S = S_{min}(I_E/100)^2$.

5.10.2.3 High leakage currents

Earth leakage current is defined as "current flowing from the live parts of an installation to earth, in the absence of an insulation fault" (IEV 442-01-24). This current might have a capacitive component, including that resulting from the deliberate use of capacitors.

NOTE Most adjustable speed electrical power drive systems that comply with relevant parts of IEC 61800 have an earth (or chassis in the case of self-powered machines) leakage current greater than 3,5 mA AC. A touch current measurement method is specified as a type test in IEC 61800-5-1 to determine the earth (or chassis) leakage current of an adjustable speed electrical power drive system.

If electrical equipment has an earth leakage current (e.g. adjustable speed electrical power drive systems and information technology equipment) that is greater than 10 mA AC or DC referenced to the supply source, one or more of the following conditions shall be satisfied for the associated protective equipotential bonding circuit:

a) the protective conductor shall have a cross-sectional area of at least 10 mm^2 Cu or 16 mm^2 Al;

b) if a protective conductor has a cross-sectional area of less than 10 mm^2 Cu or 16 mm^2 Al, a second protective conductor with a separate terminal and of at least the cross-sectional area necessary for the combined pair of conductors to meet this requirement shall be provided up to a point where the protective conductor has a cross-sectional area not less than 10 mm^2 Cu or 16 mm^2 Al;

c) automatic disconnection of the supply in the event of loss of protective conductor continuity.

High leakage currents can be restricted to the device or equipment having high leakage current by connection of that equipment to a dedicated supply transformer having separate windings. The protective equipotential bonding circuit shall be connected to exposed conductive parts of the equipment and, in addition, to the secondary winding of the transformer. The protective conductors between the equipment and the secondary winding of the transformer shall comply with one or more of the arrangements described in 5.10.2.3.

5.10.2.4 Continuity of the protective equipotential bonding circuit

All exposed conductive parts except those specified in 5.10.2.6 shall be connected to the protective equipotential bonding circuit in accordance with 5.10.2.1.

The arrangement of the protective equipotential bonding circuit shall be such that if a part is removed for any reason (e.g. routine maintenance), the protective equipotential bonding circuit for the remaining parts shall not be interrupted.

NOTE In the preceding requirement, the structure or part containing the main equipotential bonding connecting point on an EMM, such as the frame or main electrical enclosure, is not considered an electrical part for removal, provided that its removal effectively disables the EMM.

Connection and protective equipotential 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 possibility of electrolytic corrosion.

Metal ducts of flexible or rigid construction and metallic cable sheaths shall not be used as protective equipotential bonding 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 equipotential bonding circuit.

Continuity of the protective equipotential bonding circuit for electrical equipment mounted on lids, doors or cover plates shall be ensured; a protective conductor is recommended. Otherwise, fastenings, hinges or sliding contacts designed to have a low resistance shall be used.

The continuity of the protective equipotential bonding conductor in cables that are exposed to damage (e.g. flexible trailing cables) shall be ensured by appropriate measures (e.g. monitoring).

Requirements for the continuity of the protective conductor using conductor wires, conductor bars and slip-ring assemblies are given by 11.6.2.

5.10.2.5 Exclusion of switching devices

No means of interruption of the protective equipotential bonding conductor shall be provided.

This means that a protective equipotential bonding circuit shall not include a switching device or OCP.

Exception: links for test or measurement purposes that cannot be opened without the use of a tool and that are located in an enclosed electrical operating area.

If the continuity of the protective equipotential bonding circuit can be interrupted by means of removable current collectors or plug/socket combinations, the protective equipotential bonding circuit shall be interrupted by a first-make, last-break contact. This also applies to removable or withdrawable plug-in units.

5.10.2.6 Parts that need not be bonded

Exposed conductive parts need not be connected to the protective equipotential bonding circuit if those parts are constructed or installed so that they are not a source of hazards. Such parts:

— cannot be touched on large surfaces or grasped with the hand and are small in size (less than approximately 50 mm × 50 mm); or

— are located so that contact with live parts or an insulation failure is unlikely.

This applies to small parts such as screws, rivets, and nameplates and to parts inside an enclosure, irrespective of their size (e.g. electromagnets of contactors or relays and mechanical parts of devices), (see also IEC 60364-4-41:2005, 410.3).

5.10.2.7 Protective conductor connecting points

Connecting points for protective conductors shall have no other function. They shall not be used to attach or secure other devices or parts, including cable retention hardware. Protective conductor terminations shall be identified in accordance with 11.8.2.

Marking requirements are given in ISO 14990-2 and ISO 14990-3.

To prevent difficulties associated with electromagnetic disturbances, the EMC requirements of ISO 13766 should be applied to the installation of duplicate protective conductors.

5.10.3 Functional equipotential bonding

Protection against malfunction as a result of insulation failures can be achieved by connecting to a common conductor.

NOTE 1 For externally powered machines, see ISO 14990-2.

NOTE 2 For self-powered machines (see ISO 14990-3); chassis can be considered as a common conductor.

5.10.4 Devices for earthing and short-circuiting live parts

For high-voltage equipment, devices for earthing and short-circuiting all live parts of high-voltage equipment to the earthing system shall

— comply with IEC 61230, and

— be provided in adequate quantity to enable work on live parts to be carried out safely.

See 5.10.1 regarding functional equipotential bonding to protect against electromagnetic disturbances.

5.11 Protection by use of PELV

5.11.1 General

PELV protects persons against electric shock from indirect contact and limited area direct contact. A PELV circuit needs to satisfy all of the following conditions.

a) For 12 V DC and 24 V DC (nominal) battery/alternator-supplied circuits

  — The batteries shall be protected by an enclosure from inadvertent contact during normal EMM use.

  — Terminals of the batteries shall be protected from tools contacting them during routine maintenance.

  — Other unfused terminals such as the alternator, starter and starter solenoid are protected from tools contacting them during routine maintenance.

  — Other exposed live surfaces are protected by fuses, and shall have exposed area less than 50 mm × 50 mm.

b) For circuits other than those of a), the nominal voltage shall not exceed

  — 25 V AC r.m.s. or 60 V ripple-free DC when the equipment is normally used in dry locations and when large area contact of live parts with the human body is not expected, or

  — 6 V AC r.m.s. or 15 V ripple-free DC in all other cases.

  NOTE *Ripple-free* is defined for a sinusoidal ripple voltage as a ripple content of not more than 10 % r.m.s.

c) One side of the PELV circuit or one point of the source of the source of that circuit shall be connected to the protective equipotential bonding circuit.

d) Live parts of PELV circuits shall be electrically separated from other live circuits. Electrical separation shall be at least that required between the primary and secondary circuits of a safety isolating transformer (see IEC 61558-1 and IEC 61558-2-6).

e) Conductors of each PELV circuit shall be physically separated from those of any other circuit. If this requirement is impracticable, the insulation provisions of 5.3 shall apply.

f) Plugs for PELV circuits shall not be able to enter socket-outlets of other voltage systems, and PELV socket-outlets shall not admit plugs of other voltage systems.

5.11.2 Sources for PELV

A PELV source shall be one of the following:

— a safety isolating transformer in accordance with IEC 61558-1 and IEC 61558-2-6;

— a source of current providing a degree of safety equivalent to that of the safety isolating transformer (e.g. a motor-generator with winding providing equivalent isolation);

— an electrochemical source (e.g. a battery) or another source independent of a higher voltage circuit (e.g. an engine-driven generator);

— an electronic power supply conforming to appropriate standards specifying measures to be taken to ensure that, even in the case of an internal fault, the voltage at the outgoing terminals cannot exceed the values specified in 5.11.1.

6 Protection against electrical fire hazards

6.1 General

6.2 Fire hazard assessment

The risk assessment for electrical hazards shall include fire-related risks. Information regarding fire hazards and electrical equipment is given in IEC 60695 series. The risk assessment need not take into consideration combustible materials compliant with ISO 20474-1:2008, 4.20.1.

The electrical equipment should be examined as both a cause of and a contributor to fire.

6.3 Prevention of ignition

IEC 60695-1-20, IEC 60695-1-21, and IEC 60695-1-30 provide guidance regarding flammability and ignitability of nonmetallic parts and materials. Component standards usually address these concerns, and they generally take precedence over the generic IEC 60695 standards.

6.4 Minimizing the spread of fire

Minimizing the spread of fire is a second protective measure in addition to prevention of ignition. If ignition occurs, spread of the resulting fire should be minimized by suitably enclosing the ignition area or by controlling the flammability of surrounding parts, or by both measures. Component standards usually address these concerns, and they generally take precedence over the generic IEC 60695 standards.

7 Protection against thermal hazards

Protection against thermal hazards should be according to ISO 20474-1.

NOTE Attention is directed to ISO 13732-1 and ISO 13732-2.

8 Protection against mechanical hazards

Protection against mechanical hazards should be according to ISO 3457 and ISO 20474-1.

9 Protection against abnormal operation hazards

9.1 General

This clause provides requirements for protection against abnormal operation hazards such as those listed in item 3 of Table A.1.

9.2 Overcurrent protection (OCP)

9.2.1 General

If the current in an EMM circuit can exceed the rating of any component or the ampacity of conductors, overcurrent protection shall be provided. See 9.2.4 regarding ratings and settings.

Overcurrent protection need not be provided for a neutral conductor if the cross-sectional area of the neutral conductor is at least equal to that of the phase conductors.

NOTE In IT systems, it is recommended that the neutral conductor not be used. For other considerations regarding neutral conductors, see IEC 60364-5–52:2011, 524, and IEC 60364-4–43:2008, 431.2.2.

The neutral conductor of AC power circuits and the earthed (or chassis-bonded in the case of self-powered machines) conductor of DC power circuits shall not be disconnected without disconnecting all associated live conductors.

9.2.2 Transformers

Transformers shall be protected against overcurrent in accordance with the manufacturer's instructions. Additionally, such protection shall avoid nuisance tripping due to transformer magnetizing inrush currents and prevent a winding temperature rise in excess of the permitted value for the insulation class of transformer when the transformer secondary is short-circuited.

9.2.3 Overcurrent protection (OCP) implementation

The rated interrupting capacity of the OCP shall not be less than the available fault current at the point of installation. Additional short-circuit currents other than from the source (e.g. from motors or power factor correction capacitors) shall be taken into consideration in design or selection of the OCP.

A lower breaking capacity is permitted if another protective arrangement (e.g. the OCP for the source conductors) having the necessary breaking capacity is installed on the supply side. The characteristics of the two overcurrent protective systems shall be coordinated so that the let-through energy (I^2t) of the two systems in series does not exceed that which can be withstood without damage to the OCP on the load side and to the conductors protected by that system (see IEC 60947-2: 2013, Annex A).

NOTE A coordinated arrangement of the OCPs can result in the operation of both.

Where fuses are provided as the OCP, a type readily available in the country of use shall be selected, or arrangements shall be made for the supply of spare parts.

9.2.4 Rating and setting of overcurrent protective systems

Current ratings of fuses or the settings of other OCPs shall be selected so as to be as low as possible, yet adequate for anticipated overcurrents (e.g. during motor starting or transformer energizing). Consideration shall be given to the protection of switching devices against damage due to overcurrents (e.g. welding of contacts).

The necessary rated current or setting of an OCP is determined in accordance with 11.4 by the ampacity of the conductors to be protected and the maximum allowable interrupting time *t*, taking into account coordination with other electrical devices in the circuit.

9.2.5 Placement of overcurrent protective devices

An OCP shall be placed at each point where a reduction in the cross-sectional area of conductors or some other change reduces the down-stream current-carrying capacity of the conductors, unless the following are satisfied:

— the current carrying capacity of the conductors is at least equal to that of the load;

— the conductor is installed in such a manner as to reduce the possibility of a short-circuit, such as protection by an enclosure or duct.

9.3 Abnormal temperature protection

Resistance heating or other circuits capable of attaining or causing abnormal temperatures (e.g. due to short-time rating or loss of cooling medium) and that therefore can cause a hazardous situation, shall be provided with suitable detection to initiate an appropriate control response.

9.4 Earth (or chassis in the case of self-powered machines) fault/residual current protection

Earth (or chassis in the case of self-powered machines) fault/residual current protection can be provided to reduce damage to equipment due to earth (or chassis) fault currents less than the detection level of the OCP. The setting of the fault/residual current devices shall be as low as possible consistent with proper operation of the equipment.

9.5 Protection against overvoltages due to lightning and to switching surges

Protective devices can be provided to protect against the effects of overvoltages due to lightning or switching surges.

Where provided:

— devices for the suppression of overvoltages due to lightning shall be connected to the incoming terminals of the supply disconnecting device;

— devices for the suppression of overvoltages due to switching surges shall be connected across the terminals of all equipment requiring such protection.

9.6 Protection against other abnormal operation hazards

Appropriate protection shall be provided on liquid-filled electrical equipment (e.g. transformers, reactors, and switchgear) to account for the effects of abnormal temperature, overpressure or leakage.

10 Electric power source

10.1 Disconnection of source

10.1.1 General

Operation of a lockable disconnecting device shall disconnect (isolate) the electrical equipment of the EMM from the electrical source powering the equipment.

A disconnecting device shall be provided

— for each incoming source powering an externally-powered EMM, and

— for each on-board power source of a self-powered EMM.

Exception 1: A disconnecting device is not required for an engine-driven power source if an equivalent engine-stop provision is made.

Exception 2: Circuits intended to be used during servicing such as lighting, convenience socket outlets, control circuits, and the like are not required to be disconnected. It is recommended that such circuits be provided with dedicated disconnecting devices.

Protective interlocks shall be provided if two or more disconnecting devices are employed.

If a circuit is not disconnected by the source disconnecting device:

— a warning marking (see 16.1) shall be placed near the disconnecting device;

— an appropriate warning and relevant information shall be included in the service literature;

— the equipment shall comply with one or more of the following:

  1) a warning marking (see 16.1) shall be placed near each excepted circuit;

  2) the excepted circuit shall be electrically isolated from other circuits;

  3) the circuit conductors shall be identified by colour (see 11.8.4).

For cables which remain live after a disconnection is made, additional warnings and instructions shall be provided to address potential hazards.

For high-voltage equipment, means shall be provided to connect all live conductors of each incoming supply to the earthing system.

10.1.2 Source disconnecting devices

A disconnecting device shall comply with an existent IEC International Standard for that device, and qualify for the appropriate service category defined in that International Standard (such as under-load switching of motors or other inductive loads).

A disconnecting device shall meet the isolation requirements of IEC 60947-1.

Alternatively, a suitably rated plug/socket combination complying with IEC 60309-1 is permitted, provided that it also satisfies a) to e) of 11.10.5.

A source disconnecting device other than a plug/socket combination shall satisfy all of the following:

— have one OFF (isolated) and one ON (connected) position marked with the symbols IEC 60417-5008 (for OFF) and IEC 60417-5007 (for ON);

— be provided with a means of locking in the OFF position such that neither remote nor local closing is possible;

— disconnect all live conductors;

— have a breaking capacity sufficient to interrupt the current of the largest total load, including stalled or running motors, which breaking capacity may be reduced by use of a proven diversity factor.

  NOTE The diversity factor is the reciprocal of the coincidence factor. The coincidence factor is the ratio, expressed as a numerical value or as a percentage, of the simultaneous maximum demand of a group of electrical appliances or consumers within a specified period, to the sum of their individual maximum demands within the same period. In using this term, it is necessary to specify to which level of the system it relates.

A source disconnecting device shall be mounted so that the operating means (e.g. a handle) is easily accessible.

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

The supply disconnecting device and associated earthing switch should preferably be combined in a functional unit.

Interlocks shall exist to ensure that earthing of the live conductors is only possible when the disconnecting device is in the open position, and closing the disconnecting device is only possible when the live conductors are not earthed.

10.1.3 Equipment disconnecting devices

Where appropriate, disconnecting devices shall be provided for individual items of electrical equipment so as to allow work to be carried out with the equipment item de-energised and isolated. The source disconnecting device may fulfil that function.

Disconnectors, withdrawable fuse links, and withdrawable links are permitted in addition to the source disconnecting devices described in 10.1.1 and 10.1.2, but only if they are located in an electrical operating area and relevant information is provided with the electrical equipment.

10.2 Prevention of unintended start-up

Provision shall be made to prevent unintended start-up (e.g. if, during servicing, a start-up of the EMM or part of the EMM might result in a hazard).

Such devices shall be easily usable for the intended purpose, appropriately placed, and readily identifiable (e.g. by a marking in accordance with 16.1).

NOTE 1 This document does not address all provisions for prevention of unintended start up. See ISO 14118.

Inadvertent closure of these devices from any location shall not be possible.

Devices permitted for this purpose are those described in 10.1.2; also disconnectors, withdrawable fuse links, and withdrawable links, if they are located in an enclosed electrical operating area.

Devices that do not comply with the requirements for isolation may only be used for circuits involved in inspections; adjustments; or work on the electrical equipment where there is no shock or burn hazard, the switching off remains effective throughout the work, and the work is of a minor nature (e.g. replacement of plug-in devices without disturbing wiring), and for high-voltage equipment, provided that no work is being carried out on or near the high voltage electrical equipment.

NOTE 2 The risk assessment, taking into account the intended users of the device, guides the device selection.

10.3 External electrical charging

The risk assessment for electrical hazards shall consider external electrical charging in case the electrical charging option is available.

The risk assessment for external electrical charging should include machine hazards, electrical hazards, burn hazards and thermal hazards.

Often no guarantee can be provided for adequacy of external electrical charging source. Hence, in case of external electrical charging of EMM, appropriate measures shall be undertaken on the EMM side to ensure that dangerous situations can be avoided.

NOTE 1 Attention is directed to IEC 61851-1 and IEC 62196-1.

NOTE 2 Appropriate measures can include implementation of a dedicated machine charging safe state, charging instructions for machine operators, proper marking of the charging outlet/plug, protection against misuse (the outlet/plug available only with help of a special tool or keys), the charging outlet/plug formed in a special shape, consideration of charging in the machine earthing system, installation of OCP devices, phase sequence protection, etc.

11 Wiring

11.1 General

Conductors and cables shall be suitable for operating conditions, including

— voltage,

— current,

— grouping of cables,

— protection against electric shock,

— ambient temperature,

— moisture, water, or insulation-degrading substances,

— mechanical stresses, including installation stresses, and

— risk of fire.

CAUTION — Usage of polyvinyl chloride (PVC) insulation is not recommended for EMM due to risk of burning and chemical hazards.

IMPORTANT — The requirements of this clause do not apply to the internal wiring of equipment and devices that comply with the relevant IEC International Standards.

11.2 Conductors

Copper conductors are preferred. If aluminium conductors are used, their cross-sectional area shall not be less than 16 mm^2.

In order to provide sufficient mechanical strength, the cross-sectional area of conductors should not be less than 1 mm^2 for power circuit cables or single-core control circuit cables, 0,5 mm^2 for two-core unshielded control cables, 0,2 mm^2 for two-core shielded or multi-core unshielded control circuit cables, or 0.08 mm^2 for data communication cables. Conductors with smaller cross-sectional areas or other constructions are acceptable if sufficient mechanical strength is achieved by supplemental means without impairment of proper functioning.

Conductors subject to movement shall comply with 11.5.

11.3 Insulation

The mechanical properties and thickness of cable insulation, especially for cables pulled into place, shall be such that the insulation is unlikely to be damaged during installation or in operation.

It is recommended that power cables comply with IEC 60502-1 or, if shielded or multi-core, the combination of ISO 6722-1 and ISO 14572.

The insulation of cables and conductors used shall be suitable for a test voltage

— of not less than 2 000 V AC for a duration of 5 min for operation at voltages higher than 50 V AC or 120 V DC, or

— of not less than 500 V AC for a duration of 5 min for PELV circuits (see IEC 60364-4-41, class III equipment).

Consideration should be given to whether the insulation of conductors and cables can be a source of hazards due to propagation of fire or emission of toxic or corrosive fumes (see IEC 60332).

11.4 Conductor and cable ampacity

Designated conductor ampacity shall take into account relevant factors such as insulation material, number of conductors in a cable, presence of a sheath, methods of installation, grouping, and ambient temperature. See IEC 60364-5-52 for detailed information.

The cable manufacturer should be consulted for applications where the cable design parameters are affected by the period of the duty cycle and the thermal time constant of the cable.

Unless other requirements apply, where a general-purpose socket outlet or lighting outlet is used, the voltage drop from the point of supply to the load shall not exceed 5 % of the nominal voltage under normal operating conditions.

11.5 Flexible cables

11.5.1 General

Flexible cables shall be constructed from conductors at least as fine as Class 5 (see IEC 60228).

Cables that in the intended application experience stresses such as from the following should be appropriately constructed to avoid reduced operating life:

— abrasion;

— kinking;

— stress resulting from guide rollers and forced guiding;

— being wound on cable reels;

— high tensile stress;

— small radius bending;

— bending into another plane;

— high duty cycles.

11.5.2 Mechanical rating

A cable-handling system (e.g. reels, festooned or suspended cable, flexible cable trays) shall be such that the tensile stress of the conductors is kept as low as practicable during operation.

The tensile stress applied to copper conductors shall not exceed 15 N/mm^2 of the copper cross-sectional area.

If the tensile stress in operation exceeds 15 N/mm^2, specially constructed cables should be used, with agreement from the cable manufacturer as to the maximum tensile stress.

NOTE Tensile stress on the conductors is affected by acceleration forces, rate of motion, hanging weight of the cables, method of guiding, and design of a cable reel system.

11.5.3 Ampacity of cables wound on reels

Ampacity of cables wound on reels is addressed by of IEC 60204-1:2005, 12.6.3.

11.6 Assemblies having sliding contacts

This subclause applies to assemblies having sliding contacts, including conductor wires, conductor bars, and slip-ring assemblies.

11.6.1 Accessibility of live parts

Accessibility of conductor wires, conductor bars and slip-ring assemblies shall be limited by partial insulation of live parts or by enclosures or barriers of at least IP2X (see IEC 60364-4-41:2005, 412.2).

Readily accessible horizontal top surfaces of barriers or enclosures shall provide a degree of protection of at least IP4X.

Exception: Protection may be achieved by placing live parts out of reach in combination with emergency switching off in accordance with 14.5.8.

Conductor wires and conductor bars, especially if unprotected, shall be so arranged as to prevent contact with conductive items such as the cords of pull-cord switches, strain-relief devices and drive chains.

11.6.2 Protective conductor circuit

Conductor wires, conductor bars and slip-ring assemblies that are part of the protective equipotential bonding circuit shall not carry current during normal operation. However, they may conduct small transients and currents caused by capacitive coupling.

The protective conductor and the neutral conductor shall be separate conductors. The continuity of a protective conductor circuit using sliding contacts shall be ensured by measures such as duplication of the current collector or continuity monitoring.

11.6.3 Protective conductor current collectors

Protective conductor current collectors shall have a physical configuration such that they cannot interfere with other current collectors during operation.

11.6.4 Removable current collectors used for disconnection

If a removable current collector has a disconnecting function, its protective conductor circuit shall be interrupted only after the live conductors have been disconnected. The protective conductor circuit shall be reconnected before any live conductor is reconnected.

11.6.5 Clearances

Clearances between conductors and between adjacent systems of conductor wires, conductor bars, slip-ring assemblies and current collectors shall be as follows:

— **for low-voltage equipment**, as specified by IEC 60664-1;

— **for high-voltage equipment**, suitable for the rated short-duration power frequency withstand voltage and the lower level of the rated lightning impulse withstand voltage shown in IEC 60071-1:2006, Table 2.

11.6.6 Creepage distances

For low-voltage equipment, creepage distances between adjacent conductors or systems of conductor wires, conductor bars and slip-ring assemblies, and their current collectors, shall be as specified by IEC 60664-1. Creepage distances shall be suitable for the intended environment. In environments that may result in unusually heavy deposits of dust, moisture, or corrosive or conductive substances, the following creepage distance requirements apply:

— 60 mm minimum for unprotected conductor wires, conductor bars, and slip-ring assemblies;

— 30 mm minimum for enclosed conductor wires, insulated multi-pole conductor bars and insulated individual conductor bars.

For high-voltage equipment, creepage distances between adjacent conductors or systems of conductor wires, conductor bars and slip-ring assemblies, and their current collectors, shall be such that the equipment is suitable for operation at pollution level II, III or IV according to of IEC 60071-2:1996, Table 2.

For all equipment, if the intended application involves a high pollution degree, component manufacturers' recommendations for measures to prevent gradual degradation of insulation values shall be followed.

11.6.7 Conductor system sectioning

If conductor wires or conductor bars are arranged so that they can be divided into isolated sections, energizing of adjacent sections by the current collectors themselves shall be prevented.

11.6.8 Construction and installation

Conductor wires, conductor bars and slip-ring assemblies of power circuits shall be grouped separately from those of control circuits and shall be capable of withstanding the electromechanical and thermal effects of short-circuit currents without damage.

If conductor bars are installed in a metal enclosure, the individual parts of the enclosure shall be bonded together and connected to a protective equipotential bonding conductor at several points determined by the lengths of the sections.

NOTE Metal hinges are considered sufficient to ensure continuity for protective equipotential bonding of covers or cover plates of metal enclosures and ducts.

11.7 Connections and routing

11.7.1 General

Connections, especially those of the protective equipotential bonding circuit, shall be secured against accidental loosening.

Connecting devices shall be suitable for the sizes and types of conductors being terminated.

Connection of more than one conductor to one terminal is permitted only if the terminal has been evaluated for that purpose.

Exception: Not more than one protective conductor shall be connected to one terminal connecting point.

Soldered connections shall be permitted only if the connecting devices are intended for soldering.

Terminal blocks shall be plainly marked or labelled to correspond with the diagrams.

If there is a risk of incorrect electrical connection and it is not practicable to reduce the likelihood of incorrect connection by design measures, the conductors and terminations shall be identified in accordance with 11.8.1.

The installation of flexible conduits and cables shall be such that liquids from rain, cleaning, etc. shall drain away from the fittings at entry points to enclosures.

Exception: Fittings that prevent liquid penetration into enclosures may accommodate any orientation.

Conductor strands shall be confined when terminating conductors at devices or terminals that do not provide for retention of copper strands. Solder shall not be used for strand retention.

Shielded conductors that may be disconnected in the field, such as for repairs, shall be terminated so as to prevent fraying of strands and to allow easy disconnection.

Internal and external wiring shall not cross over the terminals of terminal blocks (see IEC 60947-7-1).

11.7.2 Conductor and cable runs

The following rules apply to conductor and cable runs.

a) Runs shall be from terminal-to-terminal without splices or joints.

   Exception: Where it is impracticable to provide terminals in a junction box (e.g. repair of cable due to mechanical stresses during installation or operation), splices or joints may be used.

NOTE Plug/socket combinations with suitable protection against accidental disconnection are not considered to be joints.

b) If cables or cable assemblies need to be connected or disconnected in the field, sufficient length shall be provided for that purpose.

c) Cable terminations shall be adequately supported to minimize mechanical stresses on the conductors.

d) The loop impedance shall be minimised by installing the protective conductor close to the associated live conductors to the extent practicable.

e) High voltage cables should be physically separated from low-voltage cables.

11.7.3 Conductors of different circuits

Conductors of different circuits may be installed together, may occupy the same duct, or may be in the same multi-conductor cable if the arrangement does not impair the proper functioning of the respective circuits.

Conductors of circuits operating at different voltages shall be separated by barriers or shall be insulated for the highest voltage to which any conductor insulation within the same duct is subjected.

11.8 Identification of conductors

11.8.1 General

Every conductor shall be identified at its terminations in a manner consistent with the technical documentation.

It is recommended that conductors be identified by number, alphanumeric, colour (either solid or with one or more stripes), or a combination of colour and numbers or alphanumeric.

11.8.2 Protective conductor identification

The protective conductor shall be easily distinguished. Acceptable means are colour of the protective conductor insulation or marking, shape, or location.

If identification is by colour alone, the bicolour combination GREEN-AND-YELLOW shall be used throughout the length of the protective conductor. This colour identification is strictly reserved for the protective conductor. The bicolour combination GREEN-AND-YELLOW shall be such that on any 15 mm length, one of the colours covers at least 30 percent and not more than 70 percent of the surface of the protective conductor (or its insulation if insulated), the other colour covering the remainder of the surface.

If protective conductor identification is by shape, position, or construction (e.g. a braided protective conductor or other uninsulated stranded protective conductor such as a woven strap), or where an insulated protective conductor is not readily accessible, colour coding throughout its length is not required, but the ends and any other accessible locations shall be clearly identified by the graphical symbol IEC 60417-5019 or by the bicolour combination GREEN-AND-YELLOW.

11.8.3 Neutral conductor identification

If a neutral conductor is identified by colour alone, that colour shall be BLUE. In order to avoid confusion, it is recommended that a “light blue” colour be used.

If a colour is the sole identification of the neutral conductor:

— that colour shall not be used for identifying any other conductor unless there is no chance of confusion;

— uninsulated conductors used as neutral conductors in each enclosure shall bear a coloured stripe, 15 mm to 100 mm wide, or colouring throughout their length.

11.8.4 Identification by colour

If colour-coding is used for identification of conductors other than protective and neutral conductors, the following colours may be used:

— BLACK

— BROWN

— RED

— YELLOW

— GREEN

— BLUE (including LIGHT BLUE)

— VIOLET

— GREY

— WHITE

— PINK

— TURQUOISE.

NOTE This list of colours is derived from IEC 60757.

All conductors used for low or high voltage that are not contained within electrical enclosures or ducts shall be covered with orange insulation, orange conduit, orange braiding or sleeving, or be otherwise marked orange, to make clear they are low or high voltage conductors and not, for example, fluid hoses. The required orange marking may be placed periodically along the length of the conductor, provided those markings are closely enough spaced to ensure that wherever the cable is visible, an orange marking is also visible. Orange marking of enclosed conductors is optional.

It is recommended that, where colour is used for identification, the colour be used throughout the length of the conductor either by the colour of the insulation or by colour markers at regular intervals and at the ends and accessible locations.

The colour GREEN or the colour YELLOW should not be used unless there is no possibility of confusion with the bicolour combination GREEN-AND-YELLOW.

Colour identification using combinations of the colours listed above may be used provided there is no possibility of confusion and that GREEN or YELLOW is not used except in the bicolour combination GREEN-AND-YELLOW.

If colour-coding is used for identification of conductors, it is recommended that the listed colours be applied as follows:

— BLACK: AC and DC power circuits;

Exception: low voltage conductors not enclosed: ORANGE, as required in this subclause 11.8.4.

— RED: AC control circuits;

— BLUE: DC control circuits;

Exceptions: The following are permitted:

— insulation that is not available in the recommended colours; or

— multi-conductor cable, but not the bicolour combination GREEN-AND-YELLOW.

11.9 Wiring inside enclosures

Conductors inside enclosures shall be supported where necessary.

Electrical equipment mounted inside enclosures should be arranged in such a way as to permit modification of the wiring from the front of the enclosure. If that is not practicable and equipment is connected from the rear of the enclosure, access doors or swing-out panels should be provided to facilitate wiring service.

Connections to equipment mounted on doors or other movable parts shall be made using flexible conductors in accordance with 11.2 and 11.5. Such conductors shall be secured to both the stationary and movable parts.

NOTE The electrical connections or terminations are not considered to be means of securement.

Terminal blocks or plug/socket combinations shall be used to terminate control wiring that extends beyond an enclosure.

Measuring equipment may be directly connected to the terminals of the devices, provided that the equipment meets the respective IEC International Standards.

11.10 Wiring outside enclosures

11.10.1 General

The degree of protection of an enclosure shall not be reduced by penetrations such as installation of cables or ducts and their associated glands, bushings, and the like.

11.10.2 External ducts

Appropriate ducts as described in 11.11 shall enclose conductors outside of electrical equipment except for suitably protected cables intended for installation unenclosed and with or without the use of continuous support.

Dedicated cables of devices such as sensing devices are not required to be enclosed in ducts if the cables are suitable for the purpose, as short as practicable, and located or protected so as to reduce the possibility of damage.

Flexible connections to pendant pushbutton stations shall employ flexible conduit or flexible multi-conductor cable. In general, means other than flexible conduit or flexible multi-conductor cable shall be used to support the weight of pendant stations. Only flexible conduit or flexible multi-conductor cable designed to support the necessary weight shall be used without additional support.

11.10.3 Connection to moving elements of the EMM

Connections to frequently moving parts shall be made using conductors complying with 11.2 and 11.5. Flexible cable and flexible conduit shall be installed so as to avoid excessive flexing and straining, particularly at fittings.

Support shall be provided for cables subject to movement so that there is neither mechanical strain on the connection points nor sharp flexing. If a cable loop is employed, it shall permit a cable bending radius not less than 10 times the cable diameter.

Flexible cables shall be installed or protected so as to minimize the likelihood of damage due to situations such as the following:

— contact with the EMM structure during movements;

— feeding in and out of cable baskets or reels;

— acceleration forces and wind forces on festooned or suspended cables;

— excessive rubbing by cable collector;

— exposure to excessive heat.

The cable sheath shall be resistant to normal wear and environmental contaminants such as oil, water, coolants, and abrasive dust.

A space of at least 25 mm shall be maintained between cables subject to movement and other moving parts. If that distance is not practicable, fixed barriers between the cables and the moving parts shall be provided.

Flexible conduit located adjacent to moving parts shall not be damaged under all conditions of operation. Flexible conduit shall not be used where rapid or frequent movements occur unless specifically intended for that purpose.

The cable handling system shall not induce lateral cable angles exceeding five degrees. Torsion in the cable when being wound on and off cable reels and approaching and leaving cable guidance devices shall be minimised.

At least two turns of a flexible cable shall always remain on a reel.

Flexible cable handling devices shall not cause excessive cable bending. The inner bending radius at all points shall not be less than the following:

— 6 times a cable diameter (or thickness) up to 20 mm;

— 8 times a cable diameter (or thickness) greater than 20 mm.

Exception: cables of diameter or thickness greater than 8 mm and up to 20 mm being fed through guide rollers shall be subject to a bending radius not less than 8 times the cable diameter or thickness.

Exception: the cable manufacturer rates the cable to the application taking into account relevant factors, such as the number times/hour the cable is flexed.

The length of a straight section between two bends shall be at least 20 times the cable diameter or thickness.

11.10.4 Interconnection of devices on the EMM

Where provided, terminals providing test points for EMM-mounted switching devices (e.g. position sensors and pushbuttons) connected in series or in parallel shall be:

— mounted so as to provide unobstructed access;

— clearly identified to correspond with the documentation;

— adequately insulated;

— sufficiently spaced.

It is recommended that such intermediate test points be provided.

11.10.5 Plug/socket combinations

Plug/socket combinations shall satisfy one or more of the following, as applicable:

Exception: The requirements of a) – j) are not applicable to a component or device inside an enclosure which is terminated by fixed plug/socket combination involving no flexible cable or to a component connected by a plug/socket combination to a bus system. In accordance with 5.2, plug/socket combinations inside of enclosures need not meet touch requirements of this subclause. In accordance with 5.6, plug/socket combinations which are out of reach need not meet IP requirements of this subclause.

a) Plug/socket combinations correctly installed in accordance with e) shall prevent unintentional contact with live parts, including during insertion or removal of the plug. The degree of protection shall be at least IPXXB.

NOTE This requirement does not apply to PELV circuits per Clause 1.

b) Have a first-make/last-break protective equipotential bonding contact (earthing contact [or chassis protective equipotential bonding contact in the case of self-powered machines]) if used in TN- or TT-systems.

c) Plug/socket combinations intended to be connected or disconnected under load shall have sufficient load-breaking capacity. A plug/socket combination rated 30 A or greater shall be interlocked with a switching device such that the plug/socket combination cannot be connected or disconnected unless the switching device is in the OFF position.

d) If an unintended disconnection of a plug/socket combination can cause a hazardous situation, the plug/socket combination shall be provided with a retaining means. A plug/socket combination rated more than 16 A shall have a retaining means to prevent unintended disconnection.

Installations of plug/socket combinations shall satisfy the following, as applicable:

e) The component which remains live after disconnection shall have a degree of protection of at least IP2X or IPXXB.

NOTE This requirement does not apply to PELV circuits per Clause 1.

f) Metallic housings of plug/socket combinations shall be bonded to the protective equipotential bonding circuit.

NOTE This requirement does not apply to PELV circuits per Clause 1.

g) Plug/socket combinations intended to carry power loads and not to be disconnected under load shall be provided with a retaining means to prevent unintended disconnection and shall be clearly marked that to indicate that they are not to be disconnected under load.

h) If more than one plug/socket combination is provided in the same electrical equipment, the associated combinations shall be clearly identified.

It is recommended that mechanical coding be used to prevent incorrect insertion.

i) Plug/socket combinations used in control circuits shall satisfy the applicable requirements of IEC 61984.

Exception: See item j).

j) Plug/socket combinations intended for household and similar general-purposes shall not be used for control circuits. For plug/socket combinations in accordance with IEC 60309-1, only those contacts intended for control circuits shall be used for that purpose.

Exception: The requirements of item j) do not apply to control functions communicated via high frequency signals on the power supply lines.

11.10.6 Dismantling for shipment

If it is necessary to disconnect wiring for shipment, terminals or plug/socket combinations shall be provided for connections between sections of the EMM or its equipment. Such terminals shall be enclosed, and plug/socket combinations shall be protected from the environment during transportation and storage.

If other than plug-and-socket electrical connections need to be made in the field, or if field assembly can result in damage to the low voltage electrical system, the verification tests of Clause17 shall be performed.

11.10.7 Spare conductors

If spare conductors are provided, they shall be connected to spare terminals or isolated in such a manner as to prevent contact with live parts.

Consideration should be given to providing additional conductors for purposes of maintenance, repair, or modification.

11.11 Ducts and boxes

11.11.1 General

Ducts shall serve no purpose other than mechanical protection of conductors and shall provide a degree of protection appropriate for the application. Nonmetallic ducts shall be permitted only if they are made from a flame-retardant insulating material.

Ducts and cable trays shall be rigidly supported and positioned away from moving parts and in such a manner so as to minimize the possibility of damage or wear. In areas where human presence is likely, ducts and cable trays shall be mounted at least 2 m above the standing surface. However if ducts and cable trays are located below 2 m in height, then they shall be suitable in strength for guarding per ISO 3457.

Sharp edges, burrs, rough surfaces, or threads which can be contacted by conductor insulation shall be removed from ducts and enclosure metal which has been worked. Conductor insulation shall additionally be protected where necessary by flame-retardant and, if appropriate, oil-resistant, sleeving material.

Cable trunking systems, connection boxes, and other boxes used for wiring purposes subject to accumulation of oil or moisture are permitted to have drain holes of up to 6 mm diameter. Other means of drainage, such as tubes or labyrinths are acceptable, provided that the required IP rating is maintained.

To minimize the chance of confusion of conduits with piping, it is recommended that the conduits be either physically separated or suitably identified.

Cables laid in partially covered cable trays shall be of a type suitable for installation with or without the use of open cable trays or cable support means.

Partially covered cable trays should not be considered to be ducts or cable trunking systems.

The percentage fill of a duct should be based on the number and degree of bends of the duct, flexibility of the conductors, and the number and size of current-carrying conductors relative to the duct size.

It is recommended that the dimensions and arrangement of the ducts be such as to facilitate the insertion of the conductors and cables. Consideration should be given to limiting the number of bends in a duct run to a total of 360 degrees.

11.11.2 Rigid metal conduit and fittings

Rigid metal conduit and fittings shall be of galvanized steel or of a corrosion-resistant material suitable for the conditions.

Contact of dissimilar metals which can result in galvanic action should be avoided.

Conduits shall be securely held in place, including at each end regardless of whether coupled or entering a box or panel.

Fittings shall be compatible with the conduit, appropriate for the application, and threaded, unless designed to be threadless.

Conduit bends shall not result in damage to the conduit or significant reduction of internal diameter.

A maximum of 360 degrees of bends should be placed between any two pull-points or insertion points.

11.11.3 Flexible metal conduit and fittings

Flexible metal conduit shall be formed from flexible metal tubing or woven wire and shall be suitable for the application. Fittings shall be compatible with the conduit and appropriate for the application.

11.11.4 Flexible nonmetallic conduit and fittings

Flexible non-metallic conduit shall resist kinking and shall be suitable for use in the application. Fittings shall be compatible with the conduit and appropriate for the application.

11.11.5 Cable trunking systems

Cable trunking systems outside of enclosures shall be rigidly supported and located away from moving or contaminating areas of the EMM.

If a cable trunking system is furnished in sections, the sections shall fit together tightly. Gaskets are not required.

Covers shall overlap the sides; gaskets are permitted. Covers shall be securely attached to cable trunking systems. Horizontal cable trunking systems shall not be installed with the cover on the bottom unless specifically designed for such orientation.

NOTE Requirements for cable trunking and ducting systems are given in the IEC 61084-1.

A cable trunking system shall contain no openings except those required for wiring or drainage. Cable trunking systems shall not have unused (open) knockouts.

11.11.6 EMM compartments and cable trunking systems

Compartments or cable trunking systems within the chassis of an EMM are permitted to enclose conductors, provided the compartments or cable trunking systems are separated from liquid reservoirs and are completely enclosed.

11.11.7 Boxes

Boxes for connection or wiring shall be accessible for service. The boxes shall provide ingress protection, taking into account the external influences under which the EMM is intended to operate. Boxes shall not have unused (open) knockouts nor any other openings.

11.11.8 Motor wiring boxes

Motor wiring boxes shall provide proper non-conductive barriers or sufficient spacing and insulation of terminals between the motor terminals and any other connections or devices within the box.

12 Electric motors and generators

12.1 General

As many controllers do not fully disconnect the power source from a motor when it is at rest, care shall be taken to ensure conformance with the requirements of 10.1.2, 10.1.3, 10.2, 12.4, and recommendations of 14.4.

Electric motors and generators should conform as much as practicable to the relevant parts of the IEC 60034 series.

12.2 Enclosures

The degree of protection for all motors and generators shall be at least IP23. More stringent measures shall be considered based upon applications where, for example, dust or moisture is present.

NOTE The uninstalled motor need not comply with any IP rating.

Electric motor and generator enclosures should conform as much as practicable to the relevant parts of IEC 60034-5.

12.3 Dimensions

Electric motor and generator dimensions should conform as much as practicable to the relevant parts of the IEC 60072 series.

12.4 Mounting and compartments

A motor or generator shall be so mounted that proper cooling is ensured and the temperature rise remains within the limits of the insulation class.

NOTE Short excursions above the insulation class rating are allowed by the IEC 60034 motor standards.

The mounting arrangement for a motor or generator shall be such that all hold-down means and all wiring boxes are accessible.

A motor or generator and its associated power transmission components should be installed so that they are adequately protected and are reasonably accessible for inspection, maintenance, lubrication, and replacement.

Motor or generator cooling vents shall be such that ingress of dirt, dust, or water spray is at an acceptable level.

Where practicable, compartments in which motors or generators are installed should be clean and dry.

An opening is allowed between a compartment in which a motor or generator is installed and another compartment only if the adjoined compartment meets the motor or generator compartment requirements.

12.5 Criteria for motor selection or design

Motors and associated equipment shall be selected or designed taking into account the anticipated service and environmental conditions. Concerns that shall be considered include the following:

— type of motor;

— duty cycle;

— fixed speed or variable speed operation, (and for air-cooled motors the consequent variable ventilation);

— mechanical vibration;

— type of motor control;

— influence of the waveform of the voltage or current feeding the motor on the temperature rise, particularly when it is supplied from an electronic adjustable speed drive;

— variation of counter-torque load with time and speed, including overhauling loads;

— effects of loads with large inertia;

— effects of constant torque or constant power operation;

— possible need of inductive reactors between a motor and an electronic adjustable speed drive.

12.6 Overheating protection

Overheating protection shall be provided for motors or generators rated more than 0,5 kW.

Exception: If automatic shutdown of a motor or generator is unacceptable, the means of overheating detection shall warn the operator, e.g. to prevent a hazard. An overheating motor may continue to operate, to ensure a machine braking system stays active.

Protection of motors against overheating can be achieved by methods such as overload protection, impedance protection, over-temperature protection, or current-limiting protection. It is recommended that protection against overheating comply with IEC 60034-11.

12.7 Overspeed protection

Protection shall be provided against excessive motor or generator speed if it can cause a hazardous situation.

13 Non-motor loads

13.1 Accessories

If an EMM is provided with socket-outlets intended to be used for accessory equipment (e.g. hand-held power tools or test equipment), the following apply:

— unless the source is PELV, continuity of the protective equipotential bonding circuit to the socket-outlet shall be ensured;

— all unearthed (or non-chassis-referenced in the case of self-powered machines) conductors connected to the socket-outlet shall be protected against overcurrent in accordance with 9.2. The overcurrent protection shall be separate from that of other circuits.

Socket-outlets should conform to IEC 60309-1. If that is not practicable, they should be clearly marked with voltage and current ratings.

Circuits for socket-outlets may be provided with residual current protective devices (RCDs). RCDs are required in some countries.

It is recommended that socket-outlet circuits not disconnected by the source disconnecting device for the EMM or the section of the EMM be provided with dedicated disconnecting devices.

13.2 Local lighting

13.2.1 General

These requirements do not apply to lighting operating at extra-low voltage (generally not more than 50 V AC nominal line-to-line or line-to-earth/chassis).

See 5.10.2.2 for requirements for connection to the protective equipotential bonding circuit.

An ON/OFF switch shall not be incorporated in a lampholder or in a connecting cord.

Lighting shall be of a type that does not produce stroboscopic effects.

If fixed lighting is provided within an enclosure, electromagnetic compatibility should be taken into account.

13.2.2 Source

The nominal line-to-line voltage of the local lighting circuit shall not exceed 480 V.

Lighting circuits shall be supplied from one of the following sources:

— a dedicated isolating transformer connected to the load side of the source disconnecting device, with overcurrent protection provided in the secondary circuit;

— a dedicated isolating transformer connected to the line side of the source disconnecting device, with overcurrent protection provided in the secondary circuit. That source is permitted only for maintenance lighting circuits in control enclosures;

— an EMM circuit with dedicated overcurrent protection;

— an isolating transformer connected to the line side of the source disconnecting device, provided with a dedicated primary disconnecting means and secondary overcurrent protection, and mounted within a control enclosure adjacent to the source disconnecting device.

Exception: This Subclause does not apply if fixed lighting is out of reach of operators during normal operation.

13.2.3 Protection

Unearthed (or non-chassis-bonded in the case of self-powered machines) conductors of circuits supplying lighting shall be protected by OCP separate from that protecting other circuits.

13.2.4 Fittings

Lampholders shall comply with the relevant IEC International Standard and shall be constructed with an insulating material protecting the lamp cap so as to prevent unintentional contact.

A reflector shall be supported by a bracket and not by a lampholder.

Adjustable lighting fittings shall be suitable for the application environment.

Exception: This subclause does not apply if fixed lighting is out of reach of operators during normal operation.

14 Controls

14.1 Control circuits

Per the scope, these requirements do not apply to control circuits operating at extra-low voltage (generally not more than 50 V AC nominal line-to-line or line-to-earth/chassis), e.g. 12/24 V DC alternator/battery systems.

14.1.1 Control circuit voltages

For high-voltage equipment, a control circuit connected directly to high voltage circuits shall be electrically isolated from low voltage circuits by means such as optical or isolation transformer coupling.

14.1.2 Protection

OCP as specified in 9.2.1 shall be provided for control circuit conductors connected directly to the source and those supplying control circuit transformers.

OCP shall be provided for conductors of control circuits supplied by a control circuit transformer or DC source as follows:

— for the switched conductor in control circuits connected to the protective equipotential bonding circuit;

— in control circuits not connected to the protective equipotential bonding circuit,

1) for the switched conductor if the same cross sectional area conductors are used in all control circuits, and

2) for both switched and common conductors of each sub-circuit if different cross sectional areas conductors are used in different sub-circuits.

14.2 Control functions

Control functions should be according to ISO 20474-1, except as specifically modified in this Clause 14.

14.3 Protective interlocks

14.3.1 Reclosing or resetting of an interlocking safeguard

Reclosing or resetting of an interlocking safeguard shall not initiate hazardous EMM operation.

NOTE Requirements for interlocking guards with a start function (control guards) are given in ISO 12100.

14.3.2 Operating limits, auxiliary functions, interlocks, and reverse current braking

Provisions concerning exceeding of operating limits, operation of auxiliary functions, interlocks between different operations and for contrary motions, and reverse current braking should be according to ISO 20474-1.

14.4 Control functions in the event of failure

These provisions (e.g. prevention of EMM movement due to control system failure) should be according to ISO 20474-1. Consideration should also be given to the provisions of ISO 13849.

14.4.1 General

Appropriate measures shall be taken to minimize the probability of occurrence of failures or disturbances in the electrical equipment that can cause a hazardous situation or damage to the EMM. The level of risk associated with the respective application shall determine the required measures and the extent to which they are implemented, either individually or in combination.

Exception: Provisions related to functional safety with respect to EMM movement after a control system failure should be according to ISO 20474-1.

Electrical control circuits shall have an appropriate level of safety performance that has been determined from the risk assessment of the EMM. The provisions of ISO 20474-1 should be applied.

Measures to reduce control failure risks include the following:

— protective devices fitted on the EMM;

— protective interlocking of the electrical circuit;

— use of proven circuit techniques and components;

— provision of partial or complete redundancy or diversity;

— provision for functional tests.

If memory retention requires external power, such as battery power, measures shall be taken to prevent hazardous situations arising from failure of the battery or its removal. Means such as the use of a key, access code, or tool shall be provided to prevent unauthorized or inadvertent memory alteration.

14.4.2 Measures to minimize risk in the event of failure

14.4.2.1 Use of proven circuit techniques and components

Risk in the event of failure shall be minimized by the use of proven techniques and components, such as the following:

— functional equipotential bonding of control circuits to the protective equipotential bonding circuit;

— for externally-powered machines, connection of control devices in accordance with ISO 14990-2;

— stopping by de-energizing (for emergency switching-off functionality see 14.5.8);

— switching all control circuit conductors to the device being controlled;

— use of switching devices with direct opening action (see IEC 60947-5-1);

— circuit design to reduce the likelihood of failures causing undesirable operations.

14.4.2.2 Provisions of partial or complete redundancy

If off-line redundancy which is not active during normal operation is provided, acceptable provisions to ensure availability of those control circuits when required shall be made.

By providing partial or complete redundancy, it is possible to minimize the probability that a single failure in the electrical circuit results in a hazardous situation. Redundancy may be designed to be effective in normal operation (online redundancy) or designed as special circuits that take over the protective function only if the operating function fails (off-line redundancy).

14.4.2.3 Provision of diversity

Diversity can be achieved through use of control circuits having different principles of operation, or use of different types of components or devices (e.g. a combination of normally open and normally closed contacts associated with interlocking guards) to reduce the likelihood of hazards resulting from faults or failures.

A combination of electrical and non-electrical systems (e.g. mechanical, hydraulic, pneumatic) may be used to provide redundancy and diversity.

14.4.2.4 Provision for functional tests

Functional tests may be carried out by any combination of

— automatic tests by the control system, and

— manual inspection or tests at start-up and at predetermined intervals.

14.4.3 Protection against malfunction due to earth (or chassis in the case of self-powered machines) faults, voltage interruptions and loss of continuity

14.4.3.1 Earth (or chassis in the case of self-powered machines) faults

Earth (or chassis in the case of self-powered machines) faults on any control circuit shall not cause unintentional starting, potentially hazardous motions, or prevent stopping of the machine.

Methods to meet these requirements include but are not limited to the following:

Method a) — Control circuits fed by control transformers

1) For earthed (or chassis-referenced in the case of self-powered machines) control circuit supplies, the common conductor is connected to the protective bonding circuit at the point of supply. ("Supply" means the control transformer secondary.) All contacts, including solid state, which are intended to operate an electromagnetic or other device (for example, a relay or indicator light) are inserted between one side of the control circuit supply (the switched conductor) and one terminal of device. The other terminal of the device (preferably always having the same marking) is connected directly to the common conductor of the control circuit supply without any switching elements.

   Exception: Contacts of protective devices may be connected between the common conductor and the devices, provided that

   — the circuit is interrupted automatically in the event of an earth fault, or

   — the connection is very short (for example in the same enclosure) so that an earth (or chassis in the case of self-powered machines) fault is unlikely (e.g. overload relays).

2) Control circuits fed from a control transformer and not connected to the protective bonding circuit having the same arrangement as in 1), but provided with a device that interrupts the circuit automatically in the event of an earth (or chassis in the case of self-powered machines) fault.

Method b) — Control circuit fed from a control transformer with a centre-tapped winding, the centre tap being connected to the protective bonding circuit, with the overcurrent protective device having switching elements in all control circuit supply conductors. ("Supply" means the control transformer secondary.)

NOTE On a centre-tapped earthed control circuit, the presence of one earth (or chassis in the case of self-powered machines) fault can leave 50 % voltage on a relay coil. In this condition, a relay can hold on, resulting in inability to stop a machine.

Devices may be switched on either or both sides.

Method c) — Control circuit not fed from a control transformer but either directly connected

1) between the phase conductors of an earthed (or chassis-referenced in the case of self-powered machines) supply, or

2) between the phase conductors or between a phase conductor and a neutral conductor of a supply that is not earthed or is earthed (or chassis-referenced in the case of self-powered machines) through a high impedance.

Multi-pole control switches that switch all live conductors are used for START or STOP of those machine functions that can cause a hazardous situation or damage to the machine in the event of unintentional starting or failure to stop, or in the case of c) 2), a device shall be provided that interrupts the circuit automatically in the event of an earth (or chassis in the case of self-powered machines) fault.

14.4.3.2 Voltage interruptions

If a control system uses memory, provision shall be made to prevent loss of memory in the event of power failure. Examples of such provision are use of non-volatile memory and battery backup.

14.4.3.3 Loss of circuit continuity

If a safety-related control circuit depends upon sliding contacts, and loss of continuity can result in a hazardous situation, provision shall be made to address the possibility of loss of continuity, such as by duplication of sliding contacts.

14.5 Operator interface and machine-mounted control devices

14.5.1 General

14.5.1.1 General

Operator interface and machine-mounted control devices should be according to ISO 20474-1, ISO 6011, and ISO 6682.

14.5.1.2 Location and mounting

Location and mounting requirements should be according to ISO 20474-1 and IEC 60204-1:2005, 10.2.

14.5.1.3 Protection

The degree of protection of an enclosure, together with other appropriate measures, shall provide protection against the ingress of aggressive liquids, vapours, gases or contaminants found in the operating environment or used on the EMM.

Operator interface control devices shall have a minimum degree of protection against direct contact of IPXXD.

14.5.1.4 Portable and pendant control stations

Portable and pendant control station requirements are given in ISO 15817.

14.5.2 Push-buttons

14.5.2.1 Colours

Colours of push-buttons shall be according to IEC 60204-1:2005, 10.2.1.

14.5.2.2 Markings

Marking requirements should be according to ISO 6405-1 and ISO 6405-2.

14.5.3 Indicator lights and displays

Indicator light and display requirements should be according to ISO 20474-1 and IEC 60204-1:2005, 10.3

14.5.4 Illuminated push-buttons

Illuminated push-button requirements should be according to IEC 60204-1:2005, 10.4.

14.5.5 Rotary control devices

Devices having a rotational member, such as potentiometers and selector switches, shall not rely on friction alone to prevent rotation of the stationary member.

14.5.6 Start devices

Start device requirements should be according to ISO 20474-1 and ISO 10968.

14.5.7 Emergency stop devices

Emergency stop device requirements should be according to ISO 20474-1, ISO 13850, and IEC 60204-1:2005, 10.7

Emergency stop devices shall be located at each operator control station and at other locations where the initiation of an emergency stop is required.

14.5.8 Emergency switching off devices

Emergency switching off device requirements should be according to IEC 60204-1:2005, 10.8.

14.5.9 Enabling control devices

Enabling control device requirements should be according to ISO 20474-1 and IEC 60204-1:2005, 10.9.

14.6 Controlgear: location, mounting, and enclosures

14.6.1 General

Controlgear shall be located and mounted so as to facilitate accessibility, protection against external influences or conditions, and operation and maintenance.

Exception: This and the following requirements apply unless the location relative to accessibility and maintenance is not achievable due to the geometry or size of the EMM.

14.6.2 Location and mounting

14.6.2.1 Accessibility and maintenance

Controlgear shall be identifiable without moving devices or wiring.

If controlgear items require checking for correct operation or might need replacement, those actions should be possible without disassembling other equipment or parts of the EMM (except opening doors or removing covers, barriers or obstacles).

Controlgear shall be mounted so as to permit its operation and maintenance from the front. If a special tool is necessary to adjust, maintain, or remove a device, such a tool shall be supplied.

Only devices for operating, indicating, measuring, and cooling shall be mounted on doors or on normally removable access covers of enclosures. If control devices are connected through plug-in arrangements, their association shall be made clear by type (shape), marking, or reference designation, individually or in combination.

Plug-in devices that are handled during normal operation shall be provided with non-interchangeable features if the lack of such a feature can result in malfunction.

Plug/socket combinations that are handled during normal operation shall be located so as to provide unobstructed access.

14.6.2.2 Physical separation or grouping

14.6.2.2.1 Non-electrical parts and devices not directly associated with the electrical equipment shall not be located within enclosures containing controlgear.

14.6.2.2.2 Devices such as solenoid valves should be separated from the other electrical equipment (e.g. in a separate compartment).

14.6.2.2.3 Control devices mounted in the same location and supplied by either the source voltage or both source and control voltages, shall be grouped separately from those supplied only by the control voltage.

14.6.2.2.4 Terminals shall be separated into groups for power circuits, associated control circuits, and other control circuits fed from external sources (e.g. for interlocking).

14.6.2.2.5 The control groups may be mounted adjacently if each group is readily identifiable (e.g. by markings, by use of different sizes, or by use of barriers or by colours).

14.6.2.2.6 Clearances and creepage distances specified by the supplier for control devices shall be maintained in their location (including interconnections).

14.6.2.2.7 For high-voltage equipment, an enclosure containing high-voltage equipment shall not contain low-voltage equipment or non-electrical parts except where they form an integral part of the high-voltage equipment and are essential for its correct operation. High-voltage equipment shall be clearly marked and distinguishable from low-voltage equipment. High voltage switchgear adjacent to low-voltage equipment shall be metal-enclosed and capable of withstanding an internal arc-fault.

14.6.3 Degrees of protection

The protection of controlgear against ingress of solids and liquids shall be adequate taking into account the operating environment.

NOTE 1 Requirements for protection against electric shock are given in Clause 5.

The degrees of protection against ingress of water are covered by IEC 60529. Additional protective measures against other liquids can be necessary.

Enclosures of controlgear shall provide a degree of protection of at least IP22.

Exception 1: an electrical operating area used as a protective enclosure for an appropriate degree of protection against the ingress of solid bodies and liquids.

Exception 2: removable collectors on conductor wire or conductor bar systems where IP22 is not achieved, but the measures of 5.5 are applied.

Some examples of enclosures, along with the degree of protection typically provided, are

— ventilated enclosure, containing only motor starter resistor and other large-size equipment IP10,

— ventilated enclosure, containing other equipment IP32,

— enclosure used in general industry IP32, IP43 and IP54,

— enclosure used in locations that are cleaned with low-pressure water jets (hosing) IP55,

— enclosure providing protection against fine dust IP65,

— enclosure containing slip-ring assemblies IP2X.

The actual operating environment may require a different degree of protection.

Enclosures having provisions for resistor grid air-cooling shall be protected to IP XXB.

14.6.4 Enclosures, doors, and openings

Materials of enclosures shall be capable of withstanding the mechanical, electrical, and thermal stresses as well as the humidity and other environmental factors likely to be encountered in normal service.

Windows provided for viewing internally mounted indicating devices shall be of a material suitable to withstand mechanical stress and chemical attack (e.g. toughened glass or polycarbonate sheet of not less than 3 mm thickness).

The joints or gaskets of doors, lids, covers and enclosures shall withstand the chemical effects of the aggressive liquids, vapours, or gases used on the EMM. The means provided to maintain the degree of protection of an enclosure on doors, lids and covers that require opening or removal for operation or maintenance shall be securely attached to either the door/cover or the enclosure and shall not deteriorate due to removal or replacement of the door or the cover, and so impair the degree of protection.

Fasteners used to secure doors and covers should be of the captive type.

It is recommended that enclosure doors be not wider than 0,9 m and have vertical hinges, with an angle of opening of at least 95°.

If openings are provided, including toward the floor or other parts of the EMM, means shall also be provided to ensure the degree of protection specified for the equipment. Openings for cable entries shall be easily able to be reopened on-site. A suitable opening may be provided in the base of an enclosure so that condensation can drain away.

An enclosure containing electrical equipment shall have no opening to compartments containing coolant, lubricating or hydraulic fluids, or those into which oil, other liquids or dust can penetrate. Excluded from this requirement are electrical devices specifically designed to operate in oil and liquid-cooled electrical equipment.

If mounting holes are provided in an enclosure, after mounting the holes shall not impair the required protection.

Taking into account both normal and abnormal operation, the equipment or devices shall

— be located within an enclosure capable of withstanding, without risk of fire or hazardous damage, such temperatures as might be generated, and

— be located at a sufficient distance from adjacent equipment or devices so as to allow safe dissipation of heat, or

— be otherwise shielded by material that can withstand, without risk of fire or hazardous damage, the heat produced by the equipment or device.

A warning label in accordance with 16.2.2 may be necessary.

14.6.5 Access to controlgear

14.6.5.1 Total access system

The total access system shall comply with ISO 2867.

14.6.5.2 Other access openings

Access openings other than other than those addressed in ISO 2867 shall comply with ISO 2860.

14.6.5.3 Doors for access

Doors in gangways and for access to electrical operating areas shall

— comply with the maintenance opening dimensions given in ISO 2867:2011, Table 1,

— open outwards, and

— have a means (e.g. panic bolts) to allow opening from the inside without the use of a key or tool.

Enclosures which readily allow a person to fully enter shall be provided with means to allow escape, e.g. panic bolts on the inside of doors. Enclosures intended for such access shall meet the dimensional requirements found in ISO 2867:2011, Clause 11 for a primary opening.

In cases where equipment is likely to be live during access and conducting parts are exposed, the clear width shall be at least 1,0 m. In cases where such parts are present on both sides of the access way, the clear width shall be at least 1,5 m.

NOTE These dimensions are derived from ISO 14122.

14.7 Access to low and high-voltage equipment

Provisions for access should be according to ISO 20474-1 and ISO 2867.

15 Manuals and technical documentation

15.1 General

Provisions concerning the information necessary for the installation, operation and maintenance of the electrical equipment of an EMM should be according to ISO 20474-1, unless specified in this Clause 15.

NOTE In some countries, the use of one or more specific languages is required.

15.2 Information to be provided

The information provided with the electrical equipment shall include the following:

1) a description (including interconnection diagrams) of the safeguards, interlocking functions and interlocking of guards against hazards;

2) a description of the safeguarding and of the means provided and procedures needed for disabling the safeguarding (e.g. for adjustments or maintenance);

3) information on residual risks associated with the protection measures, an indication of whether any particular training is required, and the specification of any necessary PPE.

15.3 Documentation

Requirements applicable to all documentation should be in accordance with IEC 60204-1:2005, 17.3.

Documentation on electrical system shall be sufficient for production of an EMM, including assembly, production testing and verification.

NOTE Attention is directed to IEC 60204-1: 2005, 17.4, for installation, including commissioning.

15.4 Overview diagrams and function diagrams

If it is necessary to explain the principles of operation, an overview diagram shall be provided.

NOTE 1 An overview diagram presents the electrical equipment symbolically together with its functional interrelationships without necessarily showing all of the details.

NOTE 2 Examples of overview diagrams can be found in IEC 61082-1.

Function diagrams may be provided either as part of, or in addition to, the overview diagram.

NOTE 3 Examples of function diagrams can be found in IEC 61082–1.

15.5 Circuit diagrams

Circuit diagrams showing the electrical circuits of the EMM and its electrical equipment shall be provided.

If a graphical symbol not shown in IEC 60617-DB is used, it shall be separately shown and described on the diagrams or supporting documents. The symbols and identification of components and devices shall be consistent throughout all documents and on the EMM.

Conductors shall be identified in accordance with 11.8.

If appropriate, a diagram or table showing the terminals for interface connections shall be provided.

That diagram may be combined with the circuit diagrams for simplification.

The diagram or table should contain a reference to the detailed circuit diagram of each unit shown.

Circuit diagrams shall be arranged so as to clearly indicate circuit functions and facilitate maintenance and fault diagnosis. Device information not evident from a symbolic representation shall be included adjacent to the symbol on a diagram or provided in a footnote.

Switch symbols on electromechanical diagrams shall indicate the switch positions for all electrical and mechanical supplies turned off and with the EMM and its electrical equipment ready for a normal start.

15.6 Operator's manual

General documentation requirements should be according to ISO 20474-1.

The operator's manual shall instruct the operator as to EMM limitations at altitudes greater than 1 000 m.

The operator's manual shall specify locations on the EMM which cannot be cleaned with jets of water.

The technical documentation of EMM shall include procedures for use of the electrical equipment with particular attention to the electricity-related safety measures. Appropriate education schemes for operators shall be suggested.

15.7 Maintenance manual and service literature

15.7.1 General

General requirements for literature for maintenance or service should be according to ISO 20474-1.

Maintenance manual and service literature shall account for education level of maintenance personnel with respect to electricity and electrical safety.

15.7.2 Reduction of electrical hazards while servicing

Literature for maintenance or service shall include the following:

— instructions addressing service personnel as to the wearing of proper electrical PPE to reduce the likelihood of accidental contact and to reduce the effects of arc flash and arc blast;

— a method for verification that the residual voltage measuring device is functioning correctly;

— a method for verification of discharge of residual voltages prior to servicing;

— a procedure for manual discharge of residual voltages in the event of failure of the primary and secondary automatic discharge means. If a device is required for manual discharge of residual voltages, the device shall be provided or specified by the EMM manufacturer;

— specification of the practices and procedures for "Lock-Out/Tag-Out", necessary to disable the specific equipment and to prevent the release of potentially hazardous energy while maintenance and servicing are performed;

— information to address the hazards of electric shock, arc flash, and arc blast in accordance with 15.7.2.1 to 15.7.2.3;

— specification of locations on the EMM which cannot be cleaned with jets of water;

— instructions addressing machine operators and service personnel in properly handling the IT system, considering that the "first fault" can be triggered during routine maintenance.

15.7.2.1 Description of effects of electricity on the human body

The literature for maintenance or service shall state the following warning or equivalent:

> **"Direct contact with electricity can cause injury or death. Observe all safety precautions provided in this manual while servicing this machine."**

15.7.2.2 Medical training recommendation

The literature for maintenance or service should state the following or equivalent:

> "The most severe physiological effect of current flowing through the body is the effect it can have on the heart. For this reason service personnel should be trained in first aid including cardiopulmonary resuscitation (CPR) and the use of an automatic external defibrillator (AED)."

15.7.2.3 Resource material

For hazards associated with servicing electrical equipment the manufacturer should consult, among others, References [46], [47], [49], [50], [66], [84], [85], [86] and[87], as well as IEC 60364-4-41.

15.8 Parts list

If a parts list is provided, it shall, as a minimum, contain information necessary for ordering spare or replacement parts, including components, devices, software, test equipment, and technical documentation required for maintenance or service.

16 Marking

16.1 General

Warning signs, nameplates, markings, and identification plates shall be of sufficient durability to withstand the operating environment.

For graphical symbols, see ISO 7000, for safety signs ISO 7010, and for safety labels ISO 9244.

Exception: Push-button marking shall be according to 14.5.2.2.

16.2 Warning signs

For general hazards associated with EMM, safety signs shall be in accordance with ISO 9244. For hazards directly associated with the low voltage used on the EMM, warning signs shall additionally comply with this Clause 16.

NOTE Conformance with ISO 9244 requires that a machine safety label include at least two panels. When only two panels are used, typically one panel warns of a specific hazard and the other panel indicates how to avoid the hazard. An example of a two-panel label is given in 16.2.2.

16.2.1 Electric shock hazard

Enclosures that do not clearly show that they contain electrical equipment that can give rise to a risk of electric shock shall be marked with the safety sign ISO 7010-W012[4)].

The warning sign shall be plainly visible on the enclosure door or cover.

The warning sign may be omitted for:

— an enclosure equipped with a source disconnecting device;

— an operator-EMM interface or control station;

— a single device with its own enclosure (e.g. a position sensor).

16.2.2 Hot surfaces hazard

If the risk assessment indicates a need to warn against the possibility of hazards due to hot surfaces, the appropriate graphical symbol of ISO 9244 shall be used.

NOTE ISO 9244:2008, Figure C.16 provides an example of a full safety label. This label includes two panels: one panel presents the hot surface warning, and the other panel presents an example of avoidance (maintaining a distance away from a hot surface).

16.2.3 Magnetic field hazard

If the risk assessment indicates a need to warn against the possibility of hazards due to magnetic fields, the warning sign ISO 7010-W006[5)] shall be used. If magnetic fields are likely to be of such a nature as to include the possibility of hazards to users of pacemakers, that hazard shall be warned against.

16.2.4 Arc flash hazard

If the risk assessment indicates a need to warn against the possibility of exposure to hazardous arc flash, the appropriate graphical symbol of ISO 9244 shall be used in warning markings on electrical equipment such as switchgear, panelboards, control panels, and motor control centers that are likely to require examination, adjustment, servicing, or maintenance while energized.

4) ISO Online browsing platform: available at http://www.iso.org/obp. Search using W012.

5) ISO Online browsing platform: available at http://www.iso.org/obp. Search using W006.

A marking shall be prominently displayed on the outside of the enclosure housing a possible arc source. The marking shall state the available incident energy or required level of PPE.

16.2.5 Residual voltage hazard

A prominent warning marking shall be provided to warn service persons to allow time for the discharge of residual voltages, in accordance with 15.7.2.

16.3 Functional identification

Functional identification requirements for control devices, visual indicators, and displays (particularly those related to safety) should be according to ISO 20474-1.

16.4 Marking of equipment

16.4.1 General

Marking should be according to the general requirements of ISO 20474-1.

16.4.2 Indication of hazardous voltages (all machines)

If there is a possibility of finger contact with live parts inside an enclosure during servicing, the enclosure shall be marked on the outside with the hazardous voltage levels within. Examples of such enclosures are electrical cabinets, controlgear enclosures, motor connection enclosures, and similar.

16.5 Reference designations

All enclosures, assemblies, control devices, and components shall be plainly marked or identifiable through the use of the technical documentation. Reference designation markings shall be consistent with those used in the technical documentation.

16.6 Protective equipotential bonding terminals

Protective equipotential bonding terminals shall be marked in accordance with 5.10.2.6.

17 Tests

17.1 General

This document gives general verification requirements for the electrical equipment of EMMs. These requirements shall be applied for both type testing and routine testing. For low volume machines, type testing and routine test can be one test. In the context of self-powered EMM, connection to "earth" is understood to mean connection to the EMM chassis.

The verifications shall always include the items a) through g).

If field assembly is performed, if it involves making low voltage connections, and if it can damage the low voltage electrical system, then field assembly instructions shall include the verification tests a) through f), except that simple plug-and-socket-type connections require no field verification:

a) conformance of the electrical equipment with its technical documentation;

b) protective equipotential bonding circuit continuity;

c) conditions for protection by automatic disconnection of source, if automatic disconnection is relied upon for protection against indirect contact;

d) insulation resistance test;

e) voltage test at the greater of rated voltage or 1000 V;

f) protection against residual voltage;

g) functional tests.

It is recommended that the tests be performed in the sequence listed above.

If the electrical equipment is modified, 17.8 shall apply.

The tests shall be carried out using measuring equipment that complies with relevant IEC International Standards. Measuring equipment compliant with the IEC 61557 series shall be used for the tests of 17.3 and 17.4.

The results of verification inspections and tests shall be documented.

17.2 Protective equipotential bonding circuit continuity

The test presented in this subclause shall be carried out on each protective equipotential bonding circuit of an EMM.

The resistance of each protective equipotential bonding circuit between the PE terminal and points that are part of each protective equipotential bonding circuit shall be measured with a current between 0,2 A and approximately 10 A.

The test current shall be derived from an isolated source (e.g. SELV, see IEC 60364-4-41:2005, 413.1) having a maximum no-load voltage of 24 V AC or DC.

Use of a PELV source is not recommended for this test because such supplies can produce misleading test results.

The measured resistance shall be within a range corresponding to the length, cross-sectional area, and material of the protective equipotential bonding conductor(s) tested.

NOTE Use of larger currents increases the accuracy of this test, in particular when measuring low resistance values.

17.3 Conditions for protection by automatic disconnection of source

If protection against indirect contact is provided by automatic disconnection, the conditions for automatic disconnection of supply shall be verified.

During verification, measures shall be undertaken to avoid machine hazards and machine-specific electricity-related hazards, such as burning and chemical hazards.

The verification shall be performed with safety precautions and shall not be destructive to the machine and its electrical equipment.

NOTE For verification of automatic disconnection of source in TT, TN and IT earthing systems, attention is directed to IEC 60364-6.

17.3.1 General

If protection against indirect contact is provided by automatic disconnection, the conditions for automatic disconnection of source shall be verified.

NOTE The verification for TN systems is specified in 17.3.2. For additional information and for TT and IT systems, see IEC 60364-6.

17.3.2 Fault loop impedance verification and suitability of the associated overcurrent protective device in TN systems

This test verifies the conditions for protection by automatic disconnection of the source. When this test is carried out by measurement, it shall always be preceded by the test of 17.2.

NOTE 1 A discontinuity of the protective equipotential bonding circuit can cause a hazardous situation for the tester or other persons, or damage to the electrical equipment during the loop impedance test.

Power source connections and connection of the incoming external protective conductor to the PE terminal of the EMM, shall be verified by inspection.

The conditions for the protection by automatic disconnection of source as specified in Annex B shall be verified by both of the following:

1) verification of the fault loop impedance by
   - calculation, or
   - measurement in accordance with B.3;
2) verification that the setting and characteristics of the associated overcurrent protective device comply with the requirements of Annex B.

NOTE 2 A fault loop impedance measurement can be carried out for circuits where the conditions of protection by automatic disconnection requires a current I_a up to about 1 kA (I_a is the current causing the automatic operation of the disconnecting device within the time specified in Annex B).

17.4 Insulation resistance tests

If the electrical equipment of the EMM contains surge protection devices which are likely to operate during the test, these devices may be disconnected or the test voltage reduced to a value lower than the voltage protection level of the surge protection devices, but not lower than the peak value of the upper limit of the source (phase-to-neutral) voltage.

17.4.1 Low-voltage insulation resistance test

The insulation resistance measured at 500 V DC between the power circuit conductors and the protective equipotential bonding circuit shall be not less than 1 MΩ. The test may be made on individual sections of the electrical equipment of the EMM.

Exception: a lower minimum value, which shall not be less than 50 kΩ, is permitted for parts of electrical equipment incorporating busbars, conductor wire, conductor bar systems, or slip-ring assemblies.

17.4.2 High-voltage insulation resistance test

The insulation resistance, between power circuit conductors and the protective bonding circuit shall be not less than 1 MΩ when measured at rated voltage of the high-voltage equipment or 5 kV, whichever is less. Individual sections of the complete high-voltage equipment may be tested separately.

Exception: By agreement with the equipment manufacturer, a lower minimum value is permitted for certain parts of high-voltage equipment incorporating busbars, conductor wire, conductor bar systems or slip-ring assemblies.

17.5 Voltage withstand tests

The test voltage shall be at a nominal frequency of 50 Hz or 60 Hz. Alternatively, the test may be performed with DC voltage having a value equal to the peak value of the specified AC voltage. Testing in both DC polarities is optional.

The test voltage shall be the greater of

— the rated source voltage or working voltage of the equipment, or

— 1 000 V.

The test voltage shall be applied between the power circuit conductors and the protective equipotential bonding circuit for a period of approximately 1 s. This PASS-FAIL test is passed if no electrical breakdown occurs.

Components and devices that are not rated to withstand the test voltage shall be disconnected during testing. Individual components and devices that are a part of the insulation being tested should not be disconnected for this test. Care shall be paid to avoid possible damage to the tested electric/electronic system.

Voltage tests should be conducted using test equipment compliant with IEC 61180-2.

Components and devices that have been voltage tested in accordance with their product standards may be disconnected during testing.

17.6 Protection against residual voltages

For all components containing stored charges greater than 60 μC, conformance with 5.4 shall be demonstrated. (Direct measurement is not necessary on, for example, a 24 V circuit.)

17.7 Functional tests

The functions of electrical equipment shall be tested.

Safety-related circuits (e.g. earth [or chassis in the case of self-powered machines] fault detection) shall be tested.

In particular, verification of appropriate installation of electrical motors and monitoring functions shall be included into the functional tests.

17.8 Retesting

If any portion of the electrical equipment of an EMM is modified, that portion shall be re-verified and retested, as appropriate and according to 17.1 to 17.7.

Consideration should be given to the possible adverse effects of retesting on the equipment, such as stressing of insulation and stresses of disconnections and reconnections.

17.9 IP test for high-voltage equipment

For high-voltage equipment, the equipment shall provide a minimum degree of protection against direct contact of IPXXDH when evaluated according to IEC 60529.

Annex A
(informative)

List of significant hazards

Annex A contains examples of hazards, hazardous situations, hazardous situation causes, and areas of design concern. See Table A.1.

Table A.1 — List of significant hazards

No.	Hazard	Relevant clauses/subclauses
1	Example hazards: safety hazards arising from the use of electricity involve the following, which is not an exhaustive list:	
1.1	Electric shock	Clause 5
1.2	Arc flash	Clause 15
1.3	Stored energy	Clause 15
1.4	Fire	Clause 6
1.5	Hot surfaces	Clause 7
1.6	Effects of EMC	Clause 4
2	Example hazardous situations: some situations where personnel encounter the example hazards include:	
2.1	In general, the operation, service, and maintenance of low voltage electrical systems	All
2.2	Use of personal protective equipment (PPE)	5.4, 15.2
2.3	Use of special test equipment and the instructions for its use	11.10.4, 15.8, 17.5
2.4	Unforeseen EMM actions due to EMC	4.5.1, 5.10.2.7
2.5	Presence of Extra-low voltages that are derived from the main low voltage sources and have the possibility of “bleed-through” to the ELV circuits	4.4
2.6	Presence of energy dissipating resistor grids, such as resistors used for EMM braking	14.6.3
2.7	Equipment failures or faults	Clause 9
2.8	Inadequately protected equipment, with resultant hazards, e.g. electrically-caused fire	Clauses 5, 6, 7, 8 and 9
3	Example hazardous situation causes: hazardous situations can result from causes such as the following:	

Table A.1 *(continued)*

No.	Hazard	Relevant clauses/subclauses
3.1	Disturbances or disruptions in power sources as well as failures or faults in the power circuits resulting in the malfunctioning of the EMM NOTE examples include the following: — short circuits; — motor or generator overload; — loss of cooling to motor, generator, or power electronics; — abnormal equipment temperature; — motor or generator overspeed; — earth (or chassis in the case of self-powered machines) fault/residual current; — surges or transients caused by lightning or switching.	Clause 9
3.2	Loss of continuity of circuits that depend upon sliding or rolling contacts, resulting in a failure of a safety function	11.6
3.3	Release of stored energy (either electrical or mechanical) resulting in, e.g. electric shock or arc flash or unexpected movement that can cause injury	Clauses5, 8, 9 and 10
3.4	Incorrect phase sequence	11.8
3.5	Audible noise at levels that cause health problems to persons	3.4.3
4	Example areas of design concern: aspects of an EMM in which special attention “shall” be given to safety hazards include:	
4.1	Selection of equipment	4.4
4.2	Wiring practices, including protective equipotential bonding	Clause 11
4.3	Safety labels and safety symbols	Clause 16
4.4	Operator manual	Clause 15

Annex B
(normative)

TN systems — Protection against indirect contact

B.1 General

Annex B applies to both self-powered and externally-powered machines (see also IEC 60364-4-41 and IEC 60364-6 for additional clarification).

Overcurrent protection (OCP) shall be provided such that, in the event of a fault between a live part and an equipotential protective bonded part or conductor, the OCP:

— automatically disconnects the supply to the circuit or equipment; and

— accomplishes the disconnection within a time not exceeding 5 s.

Exception: If a disconnecting time of 5 s or less cannot be ensured, the touch voltage (see B.3) between simultaneously accessible conductive parts during a fault shall not exceed

— 50 V AC, or

— 120 V ripple-free DC

Maximum disconnecting times for circuits supplying Class I hand-held equipment or portable equipment, either through socket-outlets (e.g. socket-outlets on an EMM for accessory or service equipment) or fixed connections, shall be as given by IEC 60364-4-41:2005, Table 41.1.

Exception: A maximum disconnecting time of 0,4 s is permitted for a voltage greater than 230 V but not greater than 277 V AC r.m.s to earth (or chassis in the case of self-powered machines).

B.2 Fault conditions for operation of overcurrent protection

B.2.1 Requirement

The relationship between fault loop impedance, overcurrent protection trip current, and nominal line-to-earth (or chassis in the case of self-powered machines) is given by

$$Z_s \leq U_0/I_a$$

where

Z_s is the fault loop impedance (including the source, the live conductor up to the fault point, and the return path from the fault point to the source);

U_0 is the nominal AC line-to-earth voltage (or line-to-chassis in the case of self-powered machines);

I_a is the trip current causing the overcurrent protection to operate within the specified time.

The resistance increase of the conductors with the increase of temperature due to the fault current shall be taken into account.

NOTE For information for calculating short circuit currents, see the IEC 60909 series or consult suppliers of overcurrent protection.

B.2.2 Verification

B.2.2.1 General

Conformance of overcurrent protection with B.2.1 is determined by verification of the characteristics of the associated overcurrent protection (by inspection of the current setting for circuit-breakers or the current rating for fuses or evaluation of the actions of software), and by measurement of the fault loop impedance, Z_S.

Exception: Measurement of the fault loop impedance may be replaced by verification of the continuity of the protective conductors, provided that calculations of fault loop impedance or of resistance of the protective conductors are available, and if the nature of the installations permits verification of the lengths and cross-sectional areas of the conductors.

B.2.2.2 Measurement of the fault loop impedance

Measurement of the fault loop impedance shall be performed using measuring equipment that complies with IEC 61557-3.

For externally-powered EMM, the measurement shall be performed with the EMM connected to a source having the same frequency as the nominal frequency of the source at the intended location of use.

The measured fault loop impedance shall comply with B.2.1.

B.2.2.3 Difference between measured resistance of conductors and resistance under fault conditions

NOTE The measurements are made with low currents and at ambient temperature. Therefore to verify the conformance of the measured value of the fault loop impedance with the requirements of B.2.1, it is necessary to take into account the increase of resistance of the conductors with the increased temperature under fault conditions.

The increased resistance of the conductors with increased temperature due to fault current shall meet the following limit:

$$Z_{s(m)} \le \frac{2}{3} \times \frac{U_0}{I_a}$$

where $Z_{S(m)}$ is the measured value of Z_S.

If the measurement according to B.2.2.2 results in a value of the fault loop impedance exceeding the stated limit, a more precise measurement may be made using the procedure described in IEC 60364-6:2006, C.61.3.6.2.

B.3 Fault loop impedance for touch voltage below 50 V

B.3.1 Requirement

If conformance with B.2 cannot be ensured and supplementary protective equipotential bonding is used to ensure touch voltages no greater than 50 V, the condition for this protection is met if the impedance of the protective circuit, Z_{PE}, does not exceed

$$Z_{PE} \le \frac{50}{U_0} \times Z_s$$

where Z_{PE} is the impedance of the protective equipotential bonding circuit between the equipment anywhere in the installation and the PE terminal of the EMM or between simultaneously accessible exposed conductive parts that are bonded and/or extraneous conductive parts that are bonded.

B.3.2 Verification

Conformance with B.3.1 can be verified by the test of 17.2 to measure the resistance R_{PE}. Acceptable protection is achieved when the measured value of R_{PE} meets the following requirement:

$$R_{PE} \leq 50/I_{a(5s)}$$

where

$I_{a(5s)}$ is the 5 s operating current of the protective device;

R_{PE} is the resistance of the protective equipotential bonding circuit between the PE terminal and the equipment anywhere on the EMM, or between simultaneously accessible exposed conductive parts that are bonded and/or extraneous conductive parts that are bonded.

NOTE Supplementary protective equipotential bonding is considered an addition to protection against indirect contact.

Supplementary protective equipotential bonding may involve the entire EMM, a part of the EMM, a device or apparatus, or a location.

Annex C
(informative)

Explanation of emergency operation functions

Annex C, based upon IEC 60204-1:2005, Annex E, applies to both self-powered and externally-powered EMM.

NOTE These concepts are included here to give the reader an understanding of these terms even though in this document only two of them are used.

Emergency operation

Emergency operation includes the following, separately or in combination:

— emergency stop;

— emergency start;

— emergency switching off;

— emergency switching on.

Emergency stop

An emergency operation intended to stop a process or a movement that has become hazardous.

Emergency start

An emergency operation intended to start a process or a movement to remove or to avoid a hazardous situation.

Emergency switching off

An emergency operation intended to switch off the source of electrical energy to all or a part of an installation where a risk of electric shock or another risk of electrical origin is involved.

Emergency switching on

An emergency operation intended to switch on the source of electrical energy to a part of an installation that is intended to be used for emergency situations.

Annex D
(informative)

Comparison of selected requirements of ISO 14990, UN ECE R100 and ISO 6469-3

NOTE The comparison given by Table D.1 does not include every requirement.

Table D.1 — Comparison of selected requirements of ISO 14990, UN ECE R100 and ISO 6469-3

Topic	ISO 14990-1:2016		UN ECE R100:2011[83]		ISO 6469-3:2011	
	Section	Requirement	Section	Requirement	Section	Requirement
Voltage scope	Clause 1	50 V–36 kV AC At any frequency 75 V– 36 kV DC Pulsating DC at any rate	2	30–1 000 V AC 60–1 500 V DC No frequency range specified	Clause 1	30–1 000 V AC 60–1500 V DC No frequency range specified
Power source	Clause 1	Mains or self-powered	1	Self-powered (mains only for charging)	Clause 1	Self-powered (mains only for charging)
Components	4.4	Conform to IEC International Standards	None	None	7.8	Conform to IEC 60664 or PASS hipot
EMC	4.5.1	ISO 13766 recommended Some component standards contain applicable EMC requirements.	None	None	none	None
Ambient temperature	4.5.1	–25 to +70 °C recommended	None	None	Clause 4	None (as specified by mfr)
Ambient humidity	4.5.1	30–95 % RH recommended	None	None	Clause 4	None (as specified by mfr)
Vibration	4.5.1	ISO 15998 recommended	None	None	none	None
Operating altitude	4.5.3	Up to 1 000 m	None	None	Clause 4	None (as specified by mfr)
Enclosure (not in cab) IP rating	4.5.4 14.6.3	– “Shall be protected…”	5.1.1.2	IPXXB	7.6.2	IPXXB
Disconnection of power	10.1	Required (engine stop acceptable) Required disconnect characteristics	None	None	7.3.4	Optional. (“May be de-energized as a protection measure”) No requirements as to how or when de-energization is to be accomplished.
Prevention of unexpected startup	10.2	Required	None	None	None	None

Table D.1 *(continued)*

Topic	ISO 14990-1:2016		UN ECE R100:2011[83]		ISO 6469-3:2011	
	Section	Requirement	Section	Requirement	Section	Requirement
Protection against shock	Clause 5	By enclosures or by insulation or by residual voltage protection or by barriers or by placing out of reach or by Class II design or by automatic disconnection or by PELV	5.1	By enclosures or by insulation or — by barriers or — by class II design or — —	Clause 7	By enclosures or by insulation or — by barriers or — by Class II design or — —
Overcurrent protection/equipment protection	9.2	– Where required – OCPDs – Motors – Over temperature – Overspeed – Earth or chassis fault – Overvoltage	None	None	None	None
Equipotential bonding	5.10	– Protective conductors – Bonding circuit – Connections – High leakage currents – Functional bonding	5.1.2.1	“Exposed conductive parts...shall be galvanically connected securely to the electrical chassis by connection with electrical wire or ground cable, or by welding, or by connection using bolts, etc.”	7.9	“All components forming the potential equalization current path (conductors, connections) shall withstand the maximum current in a single-failure situation.”

Table D.1 *(continued)*

Topic	ISO 14990-1:2016		UN ECE R100:2011[83]		ISO 6469-3:2011	
	Section	Requirement	Section	Requirement	Section	Requirement
Controls	Clause 14	– Control circuit supply/protection – Interlocks – Functions in event of a failure – Operator interface – Controlgear – Enclosures – Access	None	None	None	None
Conductors and cables	Clause 11	– Conductors – conductor/cable insulation – flexing, winding, tensioning	None	None	None	None
Wiring	Clause 11	– Connections – Runs/routing – Identification of wires (including orange identification) – Flexing – Concealed and exposed – Plug/socket combinations – Breakdown for shipping – Ducts, boxes, conduits	5.1.1.5.3	Orange identification	6.2	Orange identification
Electric motors and generators	Clause 12	– Conform to IEC 60034 – Overcurrent, overload, overspeed – General design/selection criteria	None	None	None	None
Non-motor loads	Clause 13	– Overcurrent protection required	None	None	None	None

Table D.1 *(continued)*

Topic	ISO 14990-1:2016		UN ECE R100:2011[83]		ISO 6469-3:2011	
	Section	Requirement	Section	Requirement	Section	Requirement
Marking	Clause 16	Symbols specified for – shock hazard – hot surface – magnetic field – arc flash/blast Residual voltage warning Nameplate requirements	5.1.1.5.1	Shock hazard symbol	Clause 6	Shock hazard symbol
Manuals and technical documentation	Clause 15	– List of information items to be provided – Required items in operator's and service manuals	None	None	None	None
Tests	Clause 17	– Automatic disconnection – Bonding continuity (PASS = meet calculated range) – Insulation resistance (PASS = ≥ 1mΩ) – Hipot (PASS = no breakdown for greater of 2 × supply or 1000 V) – Residual voltage (PASS = < 60 V within 10s)	— 5.1.2.2 5.1.3.2 — 5.1.1.3	— < 0,1Ω 100 Ω/ V DC, 500 Ω/ V AC — ≤ 60 V DC or 30 V AC within 1 s	— 7.9 7.7, 8.2 8.3.3.2 8.3.3.3 7.3.4	— ≤ 0,1 Ω 100 Ω/Vdc, 500 Ω/Vac For self-powered (PASS = no breakdown for highest expected voltage) For plug-in (PASS = no breakdown for 2*U* + 1 000 V for basic insulation, 2*U* + 3250 V for double insulation) No test is specified, but the requirement is stated that decay shall be < 30 V AC or 60 V DC (decay time to be specified by mfr).

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