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Agricultural machinery, tractors, and earth-moving machinery — Safety of electrical and electronic components and systems operating at 32 V to 75 V DC and 21 V to 50 V AC

Matériel agricole, tracteurs et engins de terrassement — Sécurité des composants et systèmes électriques et électroniques fonctionnant sous 32 V à 75 V DC et 21 V à 50 V AC

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Contents

Page

Foreword

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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 document 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).

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This document was prepared by Technical Committee ISO/TC 23, *Tractors and machinery for agriculture and forestry*, Subcommittee SC 19, *Agricultural electronics*, in collaboration with ISO/TC 127, *Earth-moving machinery*, Subcommittee SC 3, *Machine characteristics, electrical and electronic systems, operation and maintenance*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Electrification technology can provide increased flexibility in mobile machinery configuration. It offers efficiency gains and enhanced power delivery options, which are not possible with current mechanical and hydraulic systems.

Traditional agricultural and earth-moving machinery electrical systems operate in VC-A1, 0 V DC to 32 V DC and 0 V AC to 21 V AC. VC-B2 mobile machinery operate in the 75 V DC to 1 500 V DC and 50 V AC to 1 000 V AC and are covered by ISO 16230-1 for agricultural machines and ISO 14990 series for earth-moving machines. This document covers mobile machinery with systems operating in VC-A2 and VC-B1 (see Table 1). Some of the content of this document is based on IEC 60204-1 and IEC 62477-1, adapted to the specific application of agricultural and earth-moving machinery. Non-electrical hazards are addressed by ISO 4254 series for agricultural machinery, ISO 26322 series for tractors used in agriculture and forestry, and ISO 20474 series for earth-moving machinery.

Even though this document addresses most hazards associated with the use of electrical systems within the voltage ranges in the scope of this document, 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.

Having a background in the IEC approach to electrical system safety helps the user make better decisions about the application of this document.

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

This document is of relevance, in particular, for the following stakeholder groups representing the market players with regard to machinery safety:

— machine manufacturers (small, medium and large enterprises); and

— health and safety bodies (regulators, accident prevention organisations, market surveillance, etc.)

Others can be affected by the level of machinery safety achieved with the means of the document by the above-mentioned stakeholder groups:

— machine users/employers (small, medium and large enterprises);

— machine users/employees (e.g. trade unions, organizations for people with special needs);

— service providers, (e.g. for maintenance, small, medium and large enterprises);

— consumers (in case of machinery intended for use by consumers).

The above-mentioned stakeholder groups have been given the possibility to participate at the drafting process of this document. The machinery concerned and the extent to which hazards, hazardous situations or hazardous events are covered are indicated in the Scope of this document.

When requirements of this type-C standard are different from those which are 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.

Agricultural machinery, tractors, and earth-moving machinery — Safety of electrical and electronic components and systems operating at 32 V to 75 V DC and 21 V to 50 V AC

1 Scope

This document primarily specifies both general design requirements and guidelines for protection of operators and bystanders against electric shock and electrically induced fire, for voltage classes A2 (32 V DC to 60 V DC and 21 V AC to 30 V AC) and B1 (60 V DC to 75 V DC and 30 V AC to 50 V AC), including waveforms synthesized by power electronic converters. This document is limited to addressing hazards that are not as commonly found in 12 V DC and 24 V DC systems, including those related to higher power converters and drive motors.

NOTE 1 Although protection against electrically induced fire hazards is addressed sparingly, conformance to content of this document has the impact of reducing the occurrence and hazards associated with fire.

This document is applicable to electric systems used on:

— tractors, self-propelled ride-on machines, interchangeable towed machinery, semi-mounted implements, and mounted implements used in or with agriculture and forestry; and

— earth-moving machinery (EMM) as defined in ISO 6165 and attachments.

For mobile machinery with multiple rated voltages, with at least one system rated greater than VC-B1, this document addresses the risks associated with the interactions between VC-A2 and VC-B1 systems and those systems which are nearby and rated greater than VC-B1.

NOTE 2 Electrical safety requirements for greater than VC-B1 are described in ISO 16230-1 for agricultural machines and ISO 14990 series for earth-moving machines.

NOTE 3 Although 12 V DC and 24 V DC systems are generally below the limits of this document, meeting appropriate requirements of this document ensures that proper protection exists between the covered systems and lower voltage systems.

This document is applicable to mobile machinery that are either externally powered or self-powered or both.

Alternative safety requirements can be necessary for special equipment or components such as underground mining equipment. This document does not address the additional risks for mobile machinery operating in potentially explosive atmospheres.

This document deals with all significant hazards, hazardous situations, or hazardous events relevant within its scope (see Annex A), when the mobile machinery is used as intended and under conditions of misuse which are 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.

This document is not applicable to mobile machinery manufactured before the date of its publication.

2 Normative references

The following documents are referred to in the text in such a way that some or all 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 6405-1:2017, *Earth-moving machinery — Symbols for operator controls and other displays — Part 1: Common symbols*

ISO 7010[1)], *Graphical symbols — Safety colours and safety signs — Registered safety signs*

ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction*

ISO 13857:2019, *Safety of machinery — Safety distances to prevent hazard zones being reached by upper and lower limbs*

ISO 14990-1:2016, *Earth-moving machinery — Electrical safety of machines utilizing electric drives and related components and systems — Part 1: General requirements*

ISO 14990-2, *Earth-moving machinery — Electrical safety of machines utilizing 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 utilizing electric drives and related components and systems — Part 3: Particular requirements for self-powered machines*

ISO 15003, *Agricultural engineering — Electrical and electronic equipment — Testing resistance to environmental conditions*

ISO 16230-1:2015, *Agricultural machinery and tractors — Safety of higher voltage electrical and electronic components and systems — Part 1: General requirements*

ISO 19014-3, *Earth-moving machinery — Functional safety — Part 3: Environmental performance and test requirements of electronic and electrical components used in safety-related parts of the control system*

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

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

IEC 60309-1, *Plugs, socket-outlets, and couplers for industrial purposes — Part 1: General requirements*

IEC 60364-5-54:2011/AMD1:2021, *Low-voltage electrical installations — Part 5-54: Selection and erection of electrical equipment — Earthing arrangements and protective conductors*

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

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

IEC 60664 (all parts), *Insulation coordination for equipment within low-voltage systems*

IEC 60990:2016, *Methods of measurement of touch current and protective conductor current*

IEC 61140:2016, *Protection against electric shock — Common aspects for installations and equipment*

IEC 61984, *Connectors — Safety requirements and tests*

IEC 62477-1:2022, *Safety requirements for power electronic converter systems and equipment — Part 1: General*

SAE J1614, *Wiring Distribution Systems for Off-Road, Self-Propelled Work Machines*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12100 and the following apply.

1) The graphical symbol collections of ISO 7010 and IEC 60417 can be previewed and purchased on the Online Browsing Platform (OBP), www.iso.org/obp.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
access system
(machine) access system
system provided on a machine for ascending from the ground or descending to the ground or for moving from one area on the machine to another area

[SOURCE: ISO 2867:2011, 3.2.1]

3.1.2
accessible conductive part
accessible part having a conductive surface that is bare or covered by an insulating layer that does not comply with the requirements of basic insulation

Note 1 to entry: An accessible conductive part is considered to be a hazardous live part if not separated from live parts by at least basic insulation.

3.1.3
accessible part
part which, as installed, can be touched by means of the jointed test finger in IEC 60529

[SOURCE: IEC 60050-442:1998, 442-01-15, modified — definition has been changed to be more specific about finger accessibility]

3.1.4
basic insulation
insulation of live parts providing protection against direct contact

Note 1 to entry: Basic insulation does not include insulation used exclusively for a functional purpose.

Note 2 to entry: The use of winding wire coatings as basic, supplementary, or reinforced insulation is restricted in some VC-B2 (and higher) standards. However, VC-A and VC-B1 are not subject to such restrictions.

[SOURCE: IEC 60050-195:2021, 195-06-06, modified — definition has been clarified and better reflect the voltage range covered by this document.]

3.1.5
basic protection
Protection against electrical shock under fault-free conditions

[SOURCE: IEC 60050-195:1998, 195-06-01]

3.1.6
conductive part
part of the machine that is capable of conducting electric current

[SOURCE: IEC 60050-195:2021, 195-01-06, modified — definition has been made clearer]

3.1.7
converter
electric energy converter
device for changing one or more characteristics associated with electric energy

Note 1 to entry: In informal usage, it is common to use the term "inverter" to mean converter, rectifier, or AC/DC or AC/AC converter. The informal meanings of "inverter" are not used in this document.

[SOURCE: IEC 60050-151:2001, 151-13-36, modified — Note has been removed and replaced by a new Note.]

3.1.8
double insulation
insulation comprised of both basic and supplementary insulation types

[SOURCE: IEC 60050-195:2021, 195-06-08, modified — definition has been made clearer]

3.1.9
earth
local earth
ground, US
local ground, US
part of the Earth which is in electric contact with an earth electrode and whose electric potential is not necessarily equal to zero

[SOURCE: IEC 60050-195:2021, 195-01-03]

3.1.10
electric chassis
chassis
conductive parts of a machine that are electrically connected and whose potential is taken as reference

[SOURCE: ISO 6469-4:2015, 3.5, modified — replaced "vehicle" with "machine" and added option of just using chassis]

3.1.11
enclosure
part providing protection of equipment against certain external influences and protection against direct contact in any direction

Note 1 to entry: Enclosures provide protection of persons against access to hazardous parts, and also protect enclosed devices from the environment.

3.1.12
enhanced protection
protective provision having a reliability of protection not less than that provided by two independent protective provisions

[SOURCE: IEC 60050-195:2021, 195-06-27, modified — original term was enhanced protection provision]

3.1.13
equipotential bonding
EPB
set of electric connections intended to achieve equipotentiality between conductive parts

Note 1 to entry: In standards referenced by this document and elsewhere, earth, earthed and earthing are often used to designate the equivalent of EPB. However, for mobile equipment it is often impractical and unnecessary to create an EPB connection to the actual earth, rather the frame of the machinery or other metallic components are often used for protection against shock.

[SOURCE: IEC 60050-195:2021, 195-01-10, modified — note to entry has been added]

3.1.14
functional-equipotential-bonding
FEPB
equipotential bonding for the reasons other than electrical shock, fire, and arc flash safety

Note 1 to entry: In this definition 'other than electrical shock, fire, and arc flash safety' is most typically the use of EPB to reduce electromagnetic interference and transient impact on control system functionality.

[SOURCE: IEC 60050-195:2021, 195-01-16, modified — to clarify electrical safety meaning within the definition]

3.1.15
protective-equipotential-bonding
PEPB
equipotential bonding for the purposes of electrical shock, fire, and arc flash safety

Note 1 to entry: In this definition 'electrical shock, fire and arc flash safety' most typically is the prevention of shock or fires by use of EPB to maintain low touch currents during a fault condition or to provide a low resistance current path facilitating effective OCP operation.

[SOURCE: IEC 60050-195:2021, 195-01-15, modified — to clarify electrical safety meaning within the definition]

3.1.16
fault
system, device, or component unable to perform a required function, excluding both human error and the inability to perform a required function during preventive maintenance or other planned action

Note 1 to entry: A fault is often the result of a failure but can exist without prior failure.

Note 2 to entry: A fault is not the operator ignoring a warning sign. 'Ignoring' is equivalent to human error for the purposes of this definition.

3.1.17
I^2t
current squared multiplied times the time
electrical quantity used to determine energy through a protective device, such as a circuit breaker or fuse, where I = current and t = time

Note 1 to entry: The excess heat generated in the protected conductors, is approximately proportional to the current squared times the duration of the overload.

3.1.18
interchangeable towed machinery
machine which is designed to be towed by a tractor and changes or adds to its functions

Note 1 to entry: It may include a load platform designed and constructed to receive any tools and appliances needed for those purposes, and to store temporarily any materials produced or needed during work.

Note 2 to entry: Any vehicle intended to be towed by a tractor and permanently incorporating an implement or designed to process materials shall be considered interchangeable towed machinery if the ratio of the technically permissible gross mass to the unladen mass of that vehicle is less than 3,0.

[SOURCE: ISO 12934:2021, 3.1.3]

3.1.19
IP code
degree of protection
extent of protection provided by an enclosure against access to hazardous parts, against egress of solid foreign objects and/or against ingress of water and verified by standardized test methods, related to preventing contact with live parts of a back-of-hand test (IPXXA), test finger (IPXXB), a test rod (IPXXC), or a test wire (IPXXD), which is also an indication of protection degrees related to the ingress of water and dust through enclosures (e.g. IPX3 by water spray, IPX5 by a water jet, IPX7 by short term immersion, IPX8 by continuous immersion, or IP6X for dust)

Note 1 to entry: IP degrees of protection are defined in IEC 60529.

[SOURCE: IEC 60529:1989+AMD 1:1999+AMD 2:2023, modified — added extra context found in IEC 60529]

3.1.20
live part
conductor or conductive component intended to be electrically energized in normal use, but not a combined EPB-neutral conductor

Note 1 to entry: Unless meeting all requirements of an EPB conductor, negative and neutral conductors are considered live on a system even though they can be connected galvanically to the chassis. EPB conductors have additional requirements for fault conditions and durability, which extend beyond a simple neutral or negative conductor.

3.1.21
lockout
lockout device
placement of an energy-isolating device, in accordance with an established procedure, ensuring that the energy-isolating device and the equipment being controlled cannot be operated until the device is removed

Note 1 to entry: A lockout device is any device that uses positive means, such as a lock, to hold an energy-isolating device in a safe position, thereby preventing the energizing of machinery or equipment.

3.1.22
maximum working voltage
highest value of AC voltage (rms) or of DC voltage that can occur under any normal operating conditions according to the manufacturer's specifications, disregarding transients, and ripple

[SOURCE: ISO 6469-3:2021, 3.26]

3.1.23
mobile machinery
tractors, self-propelled ride-on machines, *interchangeable towed machinery* (3.1.18), semi-mounted implements, and mounted implements used in agriculture and forestry which also applies to earth-moving machinery (EMM), as defined in ISO 6165

3.1.24
neutral conductor
conductor electrically connected to the neutral point and capable of contributing to the distribution of electrical energy

[SOURCE: IEC 60050-195:2021, 195-02-06]

3.1.25
pollution degree
numeral characterizing expected pollution of the micro-environment

[SOURCE: IEC 60050-581:2008, 581-21-07, modified — to eliminate irrelevant note]

3.1.26
power supply
provision of electrical energy from a source

[SOURCE: IEC 60050 151-13-75:2001]

3.1.27
protective barrier
part providing protection against direct contact from any usual direction of access

[SOURCE: IEC 60050-195:2021, 195-06-15, modified — directionality has been clarified.]

3.1.28
protective impedance
impedance connected between hazardous live parts and accessible conductive parts, of such value that the touch current, in normal use and under likely fault conditions, is limited to a safe value, and which is so constructed that its ability is maintained throughout the life of the equipment

[SOURCE: IEC 60050-442:1998, 442-40-24, modified — definition has been clarified to better reflect needs of this document]

3.1.29
rated voltage
value of the voltage assigned by the manufacturer to a component, device, or equipment and to which operation and performance characteristics are referred

Note 1 to entry: It is possible for equipment to have more than one rated voltage value or to have a rated voltage range.

Note 2 to entry: For three-phase power supply, the line-to-line voltage applies.

[SOURCE: IEC 60050-442:2014, 442-09-10, modified — to clarify and better reflect needs of this document]

3.1.30
rated voltage range
voltage range as declared by the manufacturer expressed by its lower and upper rated voltages

[SOURCE: IEC 60050-151:2001, 151-16-49]

3.1.31
residual current device
RCD
switching device designed to make, carry, and break currents under normal service conditions and to cause the opening of the circuit when the residual current attains a given value under specified conditions

Note 1 to entry: A residual current device can be a combination of various separate elements designed to detect and evaluate the residual current and to make and break current. A current sensing circuit combined with a control system utilizing software can be used to meet the requirements of an RCD.

[SOURCE: IEC 60050-442:2014, 442-05-02, modified — added a note and removed mechanical and contact from definition]

3.1.32
reinforced insulation
insulation system applied to live parts which provides protection against direct contact equivalent to double insulation

Note 1 to entry: Reinforced insulation can be comprised of one, two or more layers which in some cases can be difficult to test individually as basic insulation or supplementary insulation.

[SOURCE: IEC 60050-195:2021, 195-06-09, modified — to clarify and better reflect needs of this document]

3.1.33
single fault condition
condition in which there is a fault of a single protection (but not a reinforced protection) or of a single component or a device

Note 1 to entry: If a single fault condition results in one or more other fault conditions, all are considered as one single fault condition.

Note 2 to entry: A single fault definition does not include operator error. Operator error for example includes intentionally removing a barrier with tools, ignoring safety signs, or intentionally contacting two separate exposed terminals.

[SOURCE: IEC 60050-903:2013, 903-01-15, modified — to clarify and better reflect needs of this document]

3.1.34
supplementary insulation
independent insulation applied in addition to basic insulation, in order to provide protection against electric shock in the event of a failure of the basic insulation

[SOURCE: IEC 60050-195:2021, 195-06-07, modified — to clarify and better reflect needs of this document]

3.1.35
touch current
electric current passing through a human body or through livestock when it touches one or more accessible parts of an electrical installation or equipment

Note 1 to entry: Methods of measurement of touch current are specified in IEC 60990.

[SOURCE: IEC 60050-195:2021, 195-05-21, modified — Note to entry has been added]

3.1.36
voltage class
VC
classification of an electric component or circuit according to its *maximum working voltage* (3.1.22)

Note 1 to entry: See Table 1 for the alphanumeric code indicating a range of maximum working voltages.

Note 2 to entry: Requirements in this document are based upon VC, however those requirements can be shifted to lesser requirements based on analysis of the actual wave form and corresponding risk of injury, according to 5.2.2.

[SOURCE: ISO 6469-3:2021, 3.36]

3.1.37
wet environment
environment where equipment is likely to be exposed to rain, cleaning or splashing water

Note 1 to entry: Agricultural sites and construction sites are typically considered wet environments.

Note 2 to entry: A non-wet environment can be created if provisions are specifically made to place electrical systems or components in a location shielded from rain, cleaning or splashing water (e.g. portions of the operator's station or a walk-in electrical vault).

Note 3 to entry: Submerged components and systems are addressed separately in 5.11.

3.2 Abbreviated terms

AC	alternating current
DC	direct current
EMC	electromagnetic compatibility
EMM	earth-moving machinery
IP	The meaning of IP is found in IEC 60529, but IP is not a proper acronym in that standard. IP is related to preventing contact with live parts of a back-of-hand test (IPXXA), test finger (IPXXB), a test rod (IPXXC), or a test wire (IPXXD); also, an indication of protection degrees related to the ingress of water and dust through enclosures (e.g. IPX3 by water spray, IPX5 by a water jet, IPX7 by short term immersion, IPX8 by continuous immersion, or IP6X for dust)
OCP	overcurrent protection (e.g. a fuse, circuit breaker, or solid-state device including its control system)
PPE	personal protective equipment
PTO	power take-off

PWM pulse width modulation

RMS root-mean-square

4 General requirements

4.1 V-model

The design methodology and layout of this document have been created in accordance with the V-model depicted in Figure B.1.

4.2 Voltages

The manufacturer shall characterize the voltages of the electrical systems. The VC are given in Table 1.

Table 1 — Voltage classes

Voltage class	Maximum working voltage	
	V DC	V AC_{rms}
VC-A	0 < U ≤ 60	0 < U ≤ 30
VC-A1	0 < U ≤ 32	0 < U ≤ 21
VC-A2	32 < U ≤ 60	21 < U ≤ 30
VC-B	60 < U ≤ 1 500	30 < U ≤ 1 000
VC-B1	60 < U ≤ 75	30 < U ≤ 50
VC-B2	75 < U ≤ 1 500	50 < U ≤ 1 000
VC-C	1 500 < U ≤ 36 kV	1 000 < U ≤ 36 kV
U = maximum working voltage		

NOTE 1 ISO 6469-3 voltage class A extends to 0 V, which is outside the scope of this document. This document splits VC-A into VC-A1 and VC-A2. VC-A1 includes 12 V DC and 24 V DC systems.

A characterization of all voltage parameters including transients shall be made to verify the proper correlated functioning of the components selected for design and field replacement.

NOTE 2 For automotive, ISO 21780 addresses 48 V DC rated components and ISO 21498-1 addresses VC-B rated components.

NOTE 3 VC-A2 and VC-B1 have no requirements to utilize isolated power systems in this document.

Voltages completely internal to an enclosure may exceed the rated voltage ranges of the circuits or components (as rated at the terminals).

4.3 Environmental and operational requirements

The requirements given in this document shall be met across the range of environmental and operational conditions for which the electrical system is rated to operate, as specified by the mobile machinery manufacturer. Unless specified elsewhere in this document, the electrical system or its components shall conform with to the environmental effects requirements of ISO 15003 for agricultural tractors and machinery and ISO 19014-3 for EMM.

Adequate protection shall be provided from penetration by moisture, dust, and debris consistent with IEC 60529 according to environment where the product is intended to be used, the pollution degrees selected and chemical compatibility of the design.

4.4 Components and devices

Manufacturers shall ensure the components and devices of the electrical system are:

— suitable for their intended use; and

— applied within their ratings (including derating as applicable), and in accordance with the supplier's instructions.

When relevant IEC standards exist, suitability for intended use includes either conformity with the safety-related content of those standards or demonstration of a comparable level of safety (e.g. applicable parts of the IEC 60034 series for rotating electrical machinery may be applied to various types of motors.)

For chargers and other devices that are to be connected, the manufacturer shall provide instructions to only use chargers and other devices that are properly rated, compatible with the system, and compliant with relevant standards (e.g. IEC 61851 for electric charging stations). These devices shall be evaluated as part of the electrical system to ensure compatibility.

5 Protection against electric shock hazards

5.1 Overview

The approaches to protection against electric shock hazards provided by this document are based upon those of IEC 62477-1 for power converters, which are in turn based on those of IEC 61140, which provides principles of shock prevention. Adjustments to requirements are permitted for shock prevention at electrical frequencies beyond the scopes of IEC 62477-1 and IEC 61140.

NOTE Annex C provides a summary of methods in this Clause.

5.2 General

5.2.1 Fundamental requirements

Electric shock protection shall be provided against both direct contact and against indirect contact occurring under single-fault conditions.

Table C.2 summarizes the paths for the prevention of shock directly described in this document. IEC 61140:2016, Annex A provides further details and additional approaches for providing two protections against electric shock which are available to the user of the document.

5.2.2 Determination of shock protection requirements

5.2.2.1 Overview

The shock protection requirements given by this document are based on IEC 62477-1, and in some cases, consideration of ISO 6469-3.

NOTE Table C.3 summarizes the requirement differences between VC-A2 and VC-B1 using the methods in 5.2.2.2 and 5.2.2.3.

One or more of the methods in 5.2.2.2 through 5.2.2.5 shall be used to determine the shock protection requirements, based on electrical characteristics, e.g. voltage, frequency, waveform shape, as well as the environmental conditions, e.g. wet or non-wet. Since equipment in the scope of this standard is typically used in wet environments, all protection requirements starting from 5.3 through the end of this document assume a wet environment. The user shall assume a wet environment unless the design has appropriate provisions or a specific use case determination for it to be considered as a non-wet environment. See Table C.1 in Annex C for a summary of the optional methods.

5.2.2.2 Simple method

For DC systems and zero-centred sinusoidal 50 Hz to 60 Hz wave systems, Table 1 is used for determining the VC. The requirements that follow starting in 5.3 until the end of this document shall apply as applicable to the VC from Table 1.

5.2.2.3 V_{rms} method

For systems utilizing other waveforms such as multiphase AC square waves and pulsating DC waves, often operating at frequencies other than 50 Hz to 60 Hz, the VC and requirements that follow are determined from the row in Table 1 corresponding to the V_{rms} of the waveform involved. The requirements that follow starting in 5.3 until the end of this document shall apply as applicable to the VC from Table 1.

NOTE 1 The V_{rms} method will typically lead to greater requirements than those derived fundamentally in IEC 62477-1 and references.

NOTE 2 Table C.3 summarizes the requirement differences between VC-A2 and VC-B1 using the simplified methods in 5.2.2.2 and 5.2.2.3.

5.2.2.4 VC sub-ranges method

When a voltage is used that is less than the maximum allowed in the VC, reduced requirements are derived from IEC 62477-1. Considerations for non-wet environments are also included in the determination of requirements. The requirements that follow starting in 5.3 until the end of this document shall apply as applicable from Table 1, unless specifically reduced by analysis performed in this subclause 5.2.2.4.

5.2.2.5 Fundamentally derived method

More advanced methods to determine VC definitions and associated requirements found in IEC 60479-1, IEC 60479-2, IEC 60990 and IEC 62477-1 are used to analyse complex waveforms, such as those from motor drives. Considerations for non-wet environments are also included in the analysis. If this type of analysis approach is used, the risk assessment for each application shall include a review of the possible electrical hazards of ventricular fibrillation (VF), exposed contact area, let go/immobilization, and electrical burns. The risk assessment shall determine which of these hazards apply in service, maintenance, normal operation, and single-fault conditions. For example, a scenario with no grip-able access of live parts could eliminate consideration of the let-go/immobilization hazard. The requirements that follow starting at 5.3 until the end of this document shall apply as applicable to the VC from Table 1, unless specifically modified by analysis performed in this subclause 5.2.2.5.

For connectors containing signal pins with very small contact area (less than 1 mm^2), the next higher voltage level of IEC 62477-1:2022, Table 2, is permitted, which is an additional means of modifying requirements with ISO 62477-1.

5.3 Protective measures

To provide protection from exposure to live parts, one or both of the following shall be used:

— basic protection per 5.4 and fault protection per 5.5; or

— enhanced protection per 5.6.

See Table C.2 for a summary of shock protection requirements.

5.4 Basic protection

5.4.1 General

When basic protection is used to prevent persons from contacting hazardous live parts, it shall be accomplished by one or more of these measures:

— basic insulation per 5.4.2; or

— use of enclosures or barriers per 5.4.3; or

— limitation of touch current or capacitive discharge energy per 5.4.4; or

— limitation of voltage per 5.4.5.

5.4.2 Basic insulation

To provide basic protection by use of insulation, the insulation may be solid, liquid or gaseous (air).

VC-A2 and VC-B1 parts shall be completely surrounded by insulation, see Clause 12 for insulation coordination requirements. Circuits operating in the voltage range of this document and adjacent to higher voltages shall be protected in accordance with ISO 16230-1 for agricultural tractors and machinery or ISO 14990-1 for EMM.

An accessible conductive part shall be considered a hazardous live part if not separated from VC-A2 or higher live parts by at least basic insulation.

5.4.3 Enclosures or barriers

5.4.3.1 VC-A2

To provide basic protection by use of enclosures or barriers, VC-A2 live parts shall be placed in enclosures or behind barriers of at least protective type IPXXA.

5.4.3.2 VC-B1

To provide basic protection by use of enclosures or barriers, VC-B1 live parts shall conform with all the following as applicable when in the final assembly:

— be placed in enclosures or behind barriers of at least protective type IPXXB;

— be possible to open enclosures or remove barriers only with the use of a tool or key or after de-energization of live parts at least to the level specified in 5.9.2; and

— if accessible from top surfaces of enclosures or barriers which are accessible when the equipment is energized, meet at least protective type IPXXC with regard to vertical access only. For movable equipment with no defined top and bottom, IPXXC applies to all sides, but if an enclosure is installed in a location, that is not serviceable from a standing position on the ground or on the mobile machinery access system, then IPXXB applies instead of IPXXC. ISO 13857:2019, Tables 1, 3, 4, 6 and 7 shall be used to determine what is accessible.

NOTE This requirement is intended to reduce the likelihood of small objects such as tools from accidently falling into the enclosure and contacting live parts.

It is permissible to use open-type subassemblies and equipment (i.e. without basic protective measures), provided they are protected in accordance with these methods in the final assembly.

If during installation or maintenance an enclosure needs to be opened while the conductors within are energized to VC-B1, the following additionally apply to the VC-B1 conductors:

— live parts shall be protected to at least IPXXA; and

— live parts likely to be touched when making adjustments shall be protected to at least IPXXB.

The symbol W012 in accordance with ISO 7010 shall be visible on protective barriers and protective enclosures, which, when removed, exposes hazardous live parts of VC-B1 electric circuits if a risk assessment indicates the need. Accessibility and removability of protective barriers/protective enclosures should be considered when evaluating the risks and determining the need for the symbol. Alternatively, if a component is not intended to be repaired in the field and is protected to at least IPXXA during replacement with respect to live parts exposure, then no marking is required.

5.4.4 Limitation of touch current or capacitive discharge energy

To provide basic protection by use of touch current limitation or capacitive discharge energy, the touch current shall not exceed 3,5 mA AC or 10 mA DC, or the stored energy shall not exceed 0,5 mJ. The touch current limit shall be measured using the network of IEC 60990:2016, Figure 3.

NOTE The touch current limit is independent of voltage. The touch current limit is from IEC 62477-1.

5.4.5 Limitation of voltage

5.4.5.1 General

To provide protection by limitation by voltage, equipment shall conform with this subclause 5.4.5.1.

The steady state voltage between simultaneously accessible conductive surfaces shall not be greater than VC-A1. ISO 3457 shall be used for determining the accessibility to conductive surfaces.

5.4.5.2 Summing voltages basic protection

Where there is a possibility of adding series voltages to the accessible conductive surfaces under consideration from 5.4.5.1 to a sum greater than VC-A, those surfaces shall have basic protection according to 5.4.1. The following conditions shall be considered to assess this possibility of shock hazard:

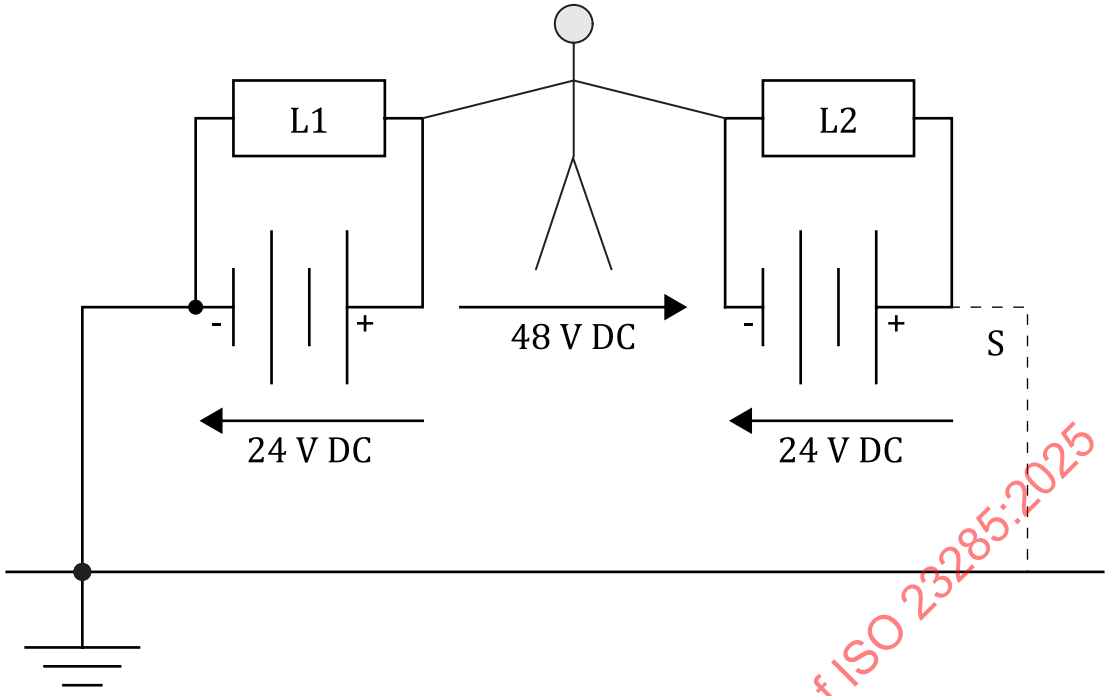
— whether the circuits involved are EPB or not;

— whether or not direct contact with live parts is possible;

— manufacturer approved changes in either equipment or the interconnections; and

— Single faults in either equipment of the interconnections.

See Figure 1 as an example in how 48 V DC power supply could be created via a single connection between the normally VC-A1 conductors. The right-side system in this example is intended to be a floating system (i.e. not connected to EPB), but it becomes connected after a short occurs between the EPB on the positive terminal. This elevates the potential between the two systems.



Key

S short to PEPB

L load

Figure 1 — Summing voltage example

5.4.5.3 Connector pins

For connectors containing signal pins with a contact area less than 1 mm^2, less stringent requirements may be derived using IEC 62477-1:2022, Table 2.

5.5 Fault protection

5.5.1 General

Fault protection is required to prevent fault currents due to an insulation failure that can result in hazardous voltages between accessible conductive parts.

One or more of the following fault protection measures shall be provided for each circuit:

— PEPB per 5.5.2; or

— automatic disconnection of power supply per 5.5.3; or

— supplementary insulation per 5.5.4; or

— basic protection between circuits per 5.5.5; or

— other applicable measures given in IEC 61140.

NOTE Fault protection can cover multiple circuits.

Circuits, components, and component finishes (e.g. winding varnishes) within VC-A2 and VC-B1 systems may apply a combination of the above protections within different portions of the system or circuits, provided that in the event of a basic insulation failure, exposure to VC-A2 and VC-B1 is protected according to 5.4.3.

5.5.2 PEPB

5.5.2.1 Fault protection by PEPB

To provide fault protection by PEPB, the PEPB shall be provided between accessible non-live conductive parts which could become live in the event of an insulation fault of the equipment (except for conductive parts separated from live parts by double or reinforced insulation) and have the means of connection to the conductive components (e.g. dedicated PEPB cable). PEPB shall be effective in both mains-connected and mains-disconnected conditions, as applicable.

5.5.2.2 Distinguishable

PEPB cables shall be easily distinguished. Acceptable means are colour of the protective cable insulation or marking, shape, or location. It is not required to adhere to the convention of using PEPB cable insulation that is coloured green or green with a yellow stripe.

NOTE There is no requirement to insulate PEPB.

5.5.2.3 Connections

Electrical contact through means of connection (conductor, cable, bar, etc.) to the PEPB circuit shall be achieved by direct metallic contact using one or more of the following means:

— through hardware fastener clamping force or welding of a dedicated PEPB conductor, see example in Figure 2, where the subsystems are connected to a common bus;

— through welding (e.g. without a cable or other additional conductor), see example in Figure 3, where the subsystems are directly connected to a metal subplate; or

— through direct contact with other accessible conductive parts or other metallic components which are not removed when the mobile machinery is used as intended, see example in Figure 3, where the subsystems are mounted to a metal subplate, and the subplate is connected to a bus.

PEBP conductor connections shall have adequate cross-sectional area according to Table 2.

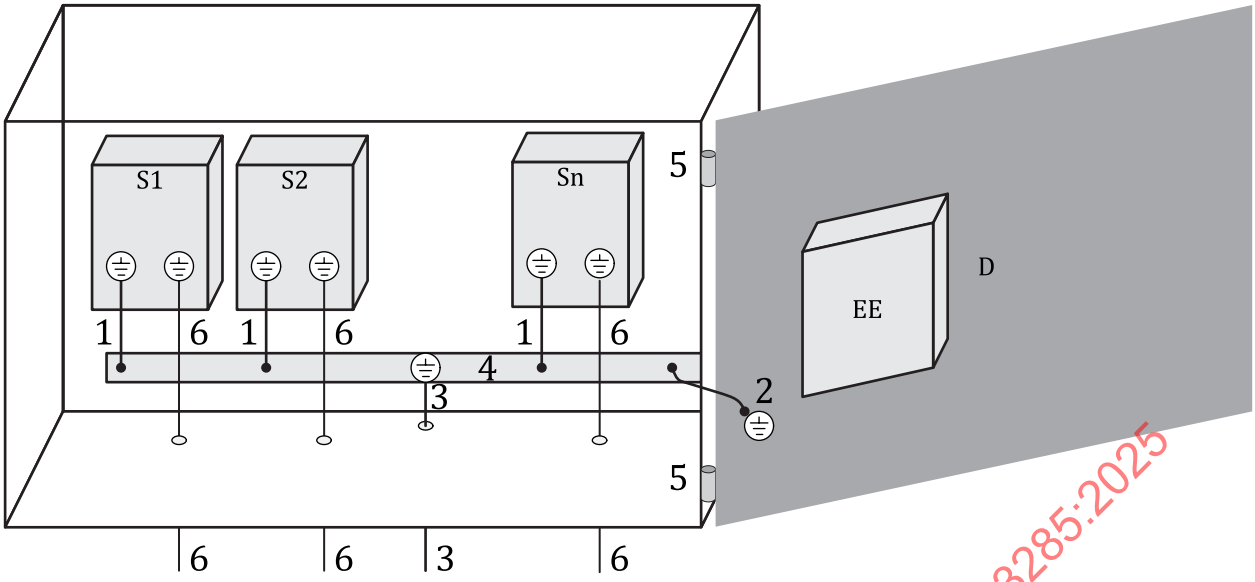
Direct metal contact assembly and service procedures should consider the possibility of corrosion (e.g. electrolytic, environmental, etc.) and contamination (e.g. oils, grease, mud, etc.) which can degrade the electrical contact over the life of the mobile machinery.

When painted surfaces (in particular, powder-coated surfaces) are joined together, masking from paint, paint piercing methods or a separate connection shall be made to ensure reliable contact. When a dedicated conductor is used, a bonding mark shall be provided.

Where electrical equipment is mounted on lids, doors, or cover plates, continuity of the PEPB circuit shall be ensured by a dedicated conductor or equivalent means complying with the requirements of 5.5.2.7 for PEPB. That is, fasteners, hinges or sliding contacts do not assure low enough impedance, so sufficient parallel bonding is required.

Electrical contact points of a PEPB circuit shall be designed so that contact pressure is only applied through materials rated for the temperature and forces anticipated for the life of the product, unless the metallic contact is independent of the presence of the materials (e.g. soft plastic washers can deform over time and then not apply adequate force to bolted joints, which can lead to increased resistance and overheating).

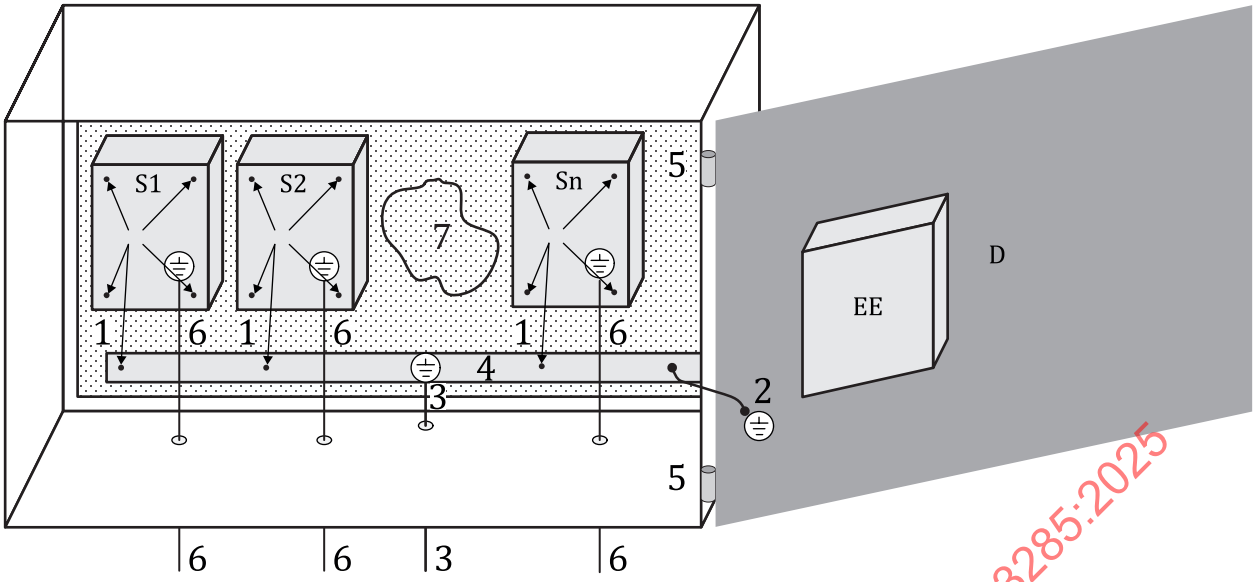
Unless verified to operational loading, fault condition loading, and environmental conditions in 4.3, and by the manufacturer and in conformance with 5.4.3, metal ducts of flexible or rigid construction and metallic cable sheaths shall not be used as PEPB means. Nevertheless, such metal ducts and the metal sheathing of all connecting cables shall be connected to the PEPB circuit.



Key

1 PEPB of subsystems
2 PEPB of the door
3 PEPB to a common PEPB point on the mobile machinery
4 PEPB bar (bus)
5 hinge
6 PEPB of the load
D door
EE other electrical equipment (bonded as relevant for that equipment)
S subsystem

Figure 2 — Example of an assembly and its associated PEPB utilizing a common bus



Key

1 PEPB of subsystems through direct metallic contact (paint removed)
2 PEPB of the door
3 PEPB to a common PEPB point on the mobile machinery
4 PEPB bar (bus)
5 hinge
6 PEPB of the load
7 metal subplate
D door
EE other electrical equipment (bonded as relevant for that equipment)
S subsystem

Figure 3 — Example of an assembly and its associated PEPB utilizing a subplate

5.5.2.4 Prevention of open PEPB circuits

The PEPB system shall not incorporate a component such as a switch or overcurrent protective device which can open the circuit.

5.5.2.5 Sizing

PEPB shall either be:

— sized in accordance with the requirements for the PEPB 5.5.2.6 and the means of connection for the PEPB in order to ensure voltage drop does not exceed VC-A1 across the accessible conductive parts in or connected to the PEPB during a fault; or

— sized:

  — to withstand the highest stresses that can occur to the item(s) concerned when they are subjected to a fault connecting to accessible non-live conductive parts;

  — to remain effective for as long as a fault to the accessible non-live conductive parts persists or until an upstream protective device removes power from the part; and

  — to ensure no voltage drop across the accessible conductive parts in or connected to the PEPB exceeding VC-A during normal operation and during a fault

5.5.2.6 Loss of EPB or loss of neutral conductor

Analysis of circuits shall be performed to ensure that a single point loss of EPB or loss of neutral conductor will not create an exposed hazardous voltage if there are multiple connections between the negative conductors and the chassis. The analysis shall include consideration for connections to optional devices (e.g. field implements).

5.5.2.7 PEPB, negative, neutral, and common conductors

5.5.2.7.1 General

To provide fault protection by PEPB, the PEPB system shall be connected at all times when power is supplied to the equipment, unless the equipment complies with the requirements of 5.4.5. For non-IT systems, PEPB cross-sectional area of conductors (including terminals) shall be determined from Table 2 when the same material is used for PEPB as the power supply conductors; or for different material by calculation in accordance with IEC 60364-5-54:2011/AMD1:2021, 543.1.

For IT systems, the same method may be used from Table 2, or the cross-sectional area of protective conductors (including terminals) shall be at a minimum according 5.5.2.8.

If a PEPB cable is routed through a plug and socket or similar means of disconnection, it shall not be possible to disconnect it unless power is simultaneously removed from the part to be protected.

Table 2 — PEPB cross-section[a]

Cross-sectional area of conductors S mm²	**Minimum cross-sectional area of the corresponding PEPB conductor** S_p mm²
$S \leq 16$	S
$16 < S \leq 35$	16
$35 < S$	$S/2$

[a] These values are valid only if the PEPB is made of the same material as the power supply conductors.

In addition to the requirements in Table 2, the cross-sectional area of every PEPB that does not form part of a power supply cable or cable enclosure shall not be less than:

— 2,5 mm² if mechanical protection is provided, or

— 4 mm² if mechanical protection is not provided.

5.5.2.7.2 Multi-voltage class power supplied components

Component EPB and power supply conductors shall conform with either 1) or 2), when there are components simultaneously connected to more than one of the voltage classes VC-A1, VC-A2, VC-B1, VC-B2 or higher:

1) Power supply connections, including negative and neutral conductors, for each different voltage class of power supplied shall be physically separated from one another; and if EPB is necessary, separate EPB connections shall be provided for each different voltage class of power supplied.

2) Combined EPB with negative or neutral conductors and other combined conductor methods may be used, provided that if any component loses its EPB, or its negative, neutral, or other power supply conductor, then testing or analysis shall be performed to demonstrate the open conductor results in no disruption of communication (beyond those losing a power supply). An open conductor shall also result in no damage to electrical circuits and result in no hazardous voltages on exposed conductive surfaces.

If common conductors are used with multiple or complex power supplies, testing or analyses shall be performed to demonstrate the prevention of excess currents from creating a hazardous loss of connection of any power supply conductor due to high current flow on the chassis or PEPB.

NOTE 1 When exposed to direct contact, power supply conductors, including negative and neutral conductors, require insulation as stated elsewhere in this document.

NOTE 2 In addition to the stated requirements, separate FEPB conductors can be necessary for EMC purposes or for control of transients. Additionally, some components are not designed for combined conductor methods.

5.5.2.7.3 Multiple and complex power supplies

Multiple and complex power supplies may rely on common conductors. A connection between a common negative or neutral conductor and the chassis is also then normally only made to the bonding path at one location near the power supply. If negative or neutral connections are made in another manner, single point failure analysis shall be performed to mitigate the risks of shock and mobile machinery damage. EMC and transient concerns can be raised by this configuration.

If a common negative or neutral conductor is used with multiple or complex power supplies, testing or analysis shall be performed to demonstrate that an open circuit causes no disruption of communication beyond that of losing a power supply. An open common negative or neutral conductor shall result in no damage to electrical circuits and result in no hazardous voltages on exposed conductive surfaces.

5.5.2.8 Touch current and the PEPB

The requirements of this subclause 5.5.2.8 are intended to reduce the likelihood of accessible conductive parts from becoming energized by the loss of a protective conductor.

For plug-connected equipment, touch current shall not exceed those found in IEC 62477-1:2022, Table 5.

A pluggable connection with a PEPB cable shall be provided with a cross-section according to Table 2, but not less than 2,5 mm^2, as part of a multi-conductor power cable. Adequate strain relief shall be provided.

NOTE Lug connectors are generally more susceptible to failures, necessitating additional requirements.

For all other equipment, if the touch current is 10 mA_{rms} or greater, it is required to use a fixed connection and one or more of these:

— a PEPB cross-section of at least 10 mm^2 for copper, 16 mm^2 for aluminium, or for different material by calculation according to IEC 60364-5-54:2011/AMD1:2021, 543.1; or

— continuity monitoring of the PEPB with automatic disconnection of the power supply in case of discontinuity of the PEPB; or

— provision of an additional terminal for a second PEPB of meeting the same cross-sectional area requirements as the original PEPB.

5.5.2.9 Touch current, multiple power supplies and assemblies

For equipment which can be energized from multiple power supplies of power supply, the touch current limits in 5.4.4 apply in all possible intended installation configurations and combinations of power supplies that can be energized at the same time, unless at least one of the three fixed connection measures in accordance with 5.5.2.8 is applied.

When it is intended and allowed to interconnect two or more assemblies using one common PEPB path, the touch current requirements of 5.4.4 apply to the maximum number of assemblies to be interconnected, unless one of the fixed connection measures in accordance with 5.5.2.8 is applied.

5.5.3 Automatic disconnection of power supply

To provide fault protection by an automatic disconnect, the following shall be provided:

— a PEPB system; and

— a protective device operated by fault current or loss of PEPB to disconnect one or more of the line conductors supplying power to the equipment, system, or installation in case of a failure of basic insulation. The disconnection may be initiated by overcurrent in the conductors, or by abnormal current flow in the PEPB path, or by detection of an open bonding connection.

  The protective device shall interrupt the fault current within a time of 1 s.

5.5.4 Supplementary insulation

To provide protection by supplementary insulation, independent insulation (e.g. a second layer of insulation) in addition to basic insulation shall be provided, in order to protect against electric shock in the event of a failure of the basic insulation. The supplementary insulation shall fulfil the same requirements as basic insulation.

5.5.5 Basic protection between circuits

To provide protection by basic protection between circuits, all the following shall be met:

— basic insulation rated for the highest voltage that can occur shall be provided between circuits, including the EPB;

— if any component is connected between separated circuits, that component shall withstand the electric stresses specified for the insulation which it bridges;

— if any component (e.g. a resistor) is connected between a circuit and a circuit connected to EPB, its impedance shall limit the maximum current flow through the component to a steady-state touch current of 3,5 mA AC or 10 mA DC; and

— if one or more components are connected between circuits and a circuit connected to earth, their impendence shall limit the total current flow through the component(s) to the steady-state touch current of 3,5 mA AC or 10 mA DC.

5.6 Enhanced protection

5.6.1 General

Enhanced protection shall provide both basic and fault protection and can be achieved by means of:

— reinforced insulation, per 5.6.2; or

— protective separation between circuits per 5.6.2; or

— protection by means of protective impedance per 5.6.3; or

— other applicable measures as given in IEC 61140:2016, 5.4.6.

See Table C.2 for a summary of shock protection requirements.

5.6.2 Reinforced insulation and protective separation between circuit

5.6.2.1 General

To demonstrate conformance to this subclause 5.6.2, equipment shall:

— meet requirements for enhanced protection, per 5.6.2.2 or 5.6.2.3, and the enclosure(s) shall meet the requirement for basic protection per 5.4.3 with respect to accessibility of hazardous live parts; and

— not have means of connection for a PEPB cable. PEPB cables are permitted to pass through the equipment, to equipment series connected beyond it.

When PEPB cables pass through equipment, the PEPB cables and the means for connection shall be separated from:

— conductive accessible surfaces of the equipment (i.e., conductive surfaces that are non-enclosed per 5.4.3 and that are accessible per ISO 13857:2019, Tables 1, 3, 4, 6 and 7); and

— circuits which employ protective separation with at least basic protection between circuits per 5.5.5.

If basic protection between circuits is used per 5.5.5, it shall be designed according to the rated voltage of the series-connected equipment.

Equipment may have provision for the connection of a FEPB conductor for functional reasons or for the damping of overvoltage transients. In this case, the FEPB conductor shall be separated from circuits which employ protective separation with at least protective separation.

Consider IEC 62477-1:2022, 6.3.9.2 for appropriate markings.

5.6.2.2 Reinforced insulation

Reinforced insulation shall be designed to withstand electric, thermal, mechanical, and environmental stresses with the same reliability of protection as provided by double insulation (basic insulation with supplementary insulation).

5.6.2.3 Protective separation between circuits

Protective separation between EPB and conductors of VC-A1 circuits and other higher voltage class circuits shall be achieved by one of the following means:

— double insulation (basic insulation and supplementary insulation);

— reinforced insulation; or

— a combination of these provisions.

If conductors of a separated circuit are contained together with conductors of other circuits in a multi-conductor cable or in another grouping of conductors, they shall be insulated, individually or collectively, for the highest voltage present, so that double or reinforced insulation is achieved.

If any component is connected between separated circuits, that component shall comply with the requirements for protective impedance devices (see 5.6.3).

5.6.3 Protection by means of protective impedance and limited capacitive discharge energy

Protective impedance shall be provided so that under both normal and single fault conditions the touch current available shall be limited to 3,5 mA AC or 10 mA DC, as measured using IEC 60990:2016, Figure 5, or the available capacitive discharge energy shall not exceed 0,5 mJ.

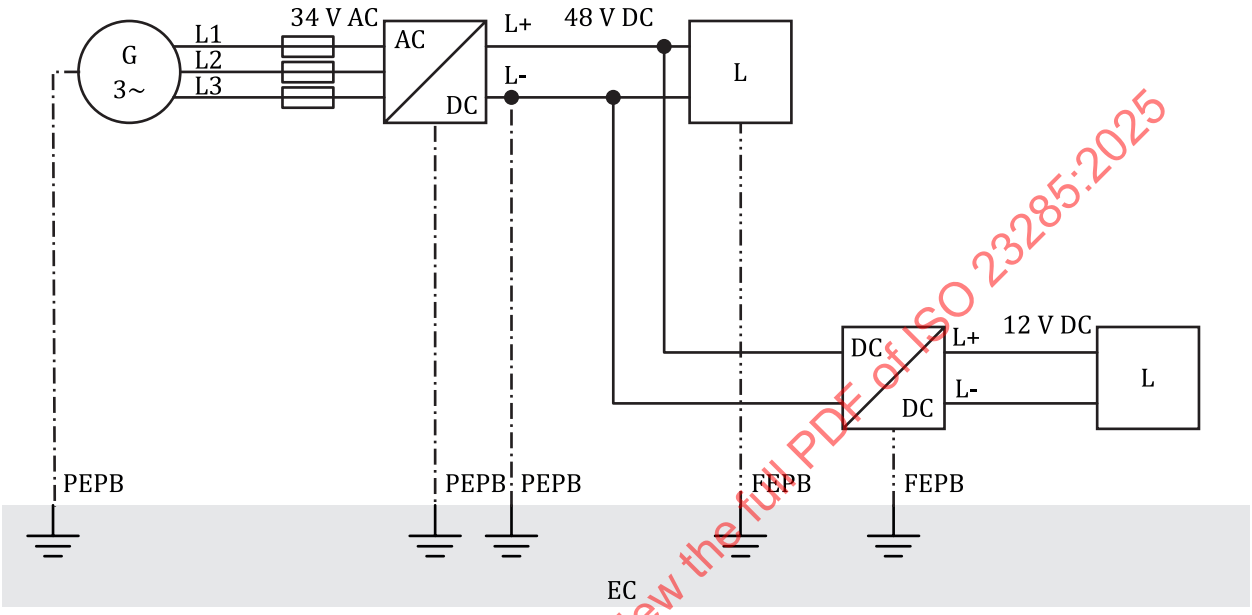
NOTE 1 The touch current limit is derived from IEC 62477-1:2022, 4.4.5.5, Table 5.

The protective impedances shall be designed and tested to withstand the impulse voltages and temporary over voltages for the circuits to which they are connected.

NOTE 2 A protection according to this subclause 5.6.3 is not considered to be a galvanic connection.

5.7 Equipment protective combinations

The methods of protection are provided in 5.1 through 5.6. Combinations of protection methods may be combined on the same mobile machinery (e.g. see Figure 4). See Figure 4 for examples of PEPB that can be provided depending on the protective methods selected.



Key

PEPB	protective bonding conductor
FEPB	bonding for functional purposes in this case
L	load
EC	electric chassis (as EPB)
G	generator
–·–·–	example PEPB locations
–··–	example FEPB locations

Figure 4 — Multiple protection example

NOTE 1 For VC-A2 and VC-B1 systems, L- is often connected to PEPB as shown on Figure 4 at the output of the AC/DC power converter, however other PEPB connections to other live parts are possible. See IEC 60364-5-54 for bonding schemes.

NOTE 2 It is common to have mobile machinery relying on multiple protection methods.

Information about the protective systems used may be provided in the operator's and service manuals to facilitate field modifications.

Annex D provides requirements for the optional use of protective classes and additional related information to provide in the operator's and service manuals to facilitate field modifications.

5.8 Separation of VC-A2- and VC-B1-systems from VC-B2 (and higher) systems

ISO 16230-1 agricultural tractors and machinery and the ISO 14990 series for EMM shall be applied to address VC-B2 systems and separation from VC-A and VC-B1.

VC-A2 and VC-B1 circuits supplied by power converters from VC-B2 (and higher), and exposed conductive parts of equipment may be connected to the EPB.

VC-A2 and VC-B1 circuits connected through power converters to VC-B2 (and higher), and exposed conductive parts of equipment may be connected to the EPB.

Exposed conductive parts are those either not enclosed per 5.4.3 or not accessible per ISO 13857:2019, Tables 1, 3, 4, 6 and 7.

NOTE See 5.5.2.7.2 for related multi-VC bonding requirements.

5.9 Protection against residual voltages

NOTE See 5.4.3 for related exposure related requirements.

5.9.1 Basic protection

When energy storage via battery or capacitor is present, accessible live parts shall be protected to IPXXA for VC-A2, and protected to IPXXB for VC-B1, to prevent contact with residual voltages. See 5.4.3 for general enclosure requirements. Circuits with less than 0,5 mJ of stored energy are considered non-hazardous and do not need to meet this requirement

If a battery of VC-A2 or VC-B1 is provided, operator's and service manual instructions and a warning marking indicating a shock hazard due to the presence of stored energy shall be provided.

If a capacitor stores VC-B1 energy, the following apply:

— A method shall be provided for the verification of discharge prior to servicing near live parts not protected by at least basic protection in 5.4 for systems that inherently discharge stored energy immediately upon loss of power; and

— An on-board residual voltage measuring device should be provided if access to measuring points is difficult. If a residual voltage measuring device is provided, a method for verification that the device is functioning correctly shall also be provided.

NOTE A message via CAN-Bus system indicating the residual voltage of the capacitor is considered to serve the need of a voltage measuring device.

5.9.2 Protection by power supply disruption

When protection from shock is provided by power supply disruption (e.g. by stopping the engine, or by disconnection of a connector) the possibility of direct contact of service personnel with live parts shall be limited as follows:

— conductors of VC-A2 shall be protected to IPXXA, unless:

  — the residual voltages within the system decays to less than VC-A2 eventually; or

  — a warning marking, the operator's manual, or service manual, provides instructions indicating a shock hazard due to the presence of stored energy.

— conductors of VC-B1 shall be protected to IPXXB unless:

  — the residual voltages within the system decays within 1 s to less than VC-B1 and less than VC-A2 eventually;

  — a warning marking, the operator's manual, or service manual, provides instructions indicating a shock hazard due to the presence of stored energy and the time required to dissipate to less than VC-B1 is provided; and

  — access shall require the use of a tool or key.

5.10 Connector human contact

5.10.1 General

Subclauses 5.10.2 and 5.10.3 provide requirements to prevent shock from contact with non-enclosed connectors.

NOTE 1 See Clause 9 for other connector requirements.

NOTE 2 See 5.4.3 for related shock prevention requirements.

5.10.2 Mated non-enclosed connectors

Mated non-enclosed VC-A2 connector conductors shall have IPXXA protection. If a protective barrier is used to meet this requirement, it may be removable without the use of tools (e.g. a soft rubber boot).

Mated non-enclosed VC-B1 connector conductors shall have IPXXB protection when connectors are external to the operator station, and IPXXD when connectors are internal to the operator station.

5.10.3 Non-mated, non-enclosed connectors

5.10.3.1 Separation by use of tools

When non-mated, conductors with less than IPXXB protection remain live at VC-A2 continuously after disconnection, they shall be provided with a warning marking to indicate the risk of shock and shall require a tool to disconnect.

When non-mated, conductors with less than IPXXB protection, or less than IPXXD if internal to the operator station, remain live at VC-B1 for more than 1 s after disconnection, they shall be provided with a warning marking, instructions in operator's manual or instructions in the service manual to indicate the risk of shock, the time necessary to be less than VC-B1 and the connectors shall require a tool to disconnect.

5.10.3.2 Separation without the use of tools

Components or devices inside an enclosure, terminated by fixed plug/socket combinations (with no flexible cable), or components connected to a bus system by a plug/socket combination, are not considered to be plug/socket combinations for the purposes of this subclause 5.10.3.2.

If a connector can be separated from its mating component without the use of a tool, it shall meet at least one of the following conditions:

— The connector shall comply with the applicable requirements of 5.3 when separated from its mating component (e.g. enclosed, insulated, finger contact protection);

— All conductors that remain live at greater than VC-A2 for longer than 1 s after disconnection shall be provided with a degree of protection of at least IPXXB when external to the operator station and IPXXD when located in an operator station.

  All conductors that remain live at greater than VC-A1 continuously after disconnection shall be provided with a degree of protection of at least IPXXB;

NOTE It is a common practice to have the load side of a plug/socket combination utilize exposed plug terminals. When disconnected, the plug terminal voltage usually dissipates very rapidly, depending on the design.

— Plug/socket combinations shall be placed out of reach by compliance to ISO 13857:2019, Tables 1, 3, 4, 6 and 7 for a significant hazard (e.g. this may be accomplished be placing more than 2 700 mm above a walking surface).

5.10.4 Enclosed connectors

Connectors which are protected by use of an enclosure per the requirements of 5.4.3.1 or 5.4.3.2, need no additional protection with respect to human contact.

5.10.5 Tractor implement plug/socket combinations (or similar mobile machinery implement and attachment combinations)

When plug/socket combinations are used to connect an implement to a tractor (or similar implement and attachment combinations), conductor voltages shall decrease to less than VC-B1 within 1 s and less than VC-A2 eventually, after disconnection unless a warning marking, instructions in the operator's manual or instructions in the service manual are provided to indicate the risk of shock and the time necessary to be less than VC-B1. In addition, such conductors shall be provided with a degree of protection of at least IPXXB when disconnected, regardless of discharge time.

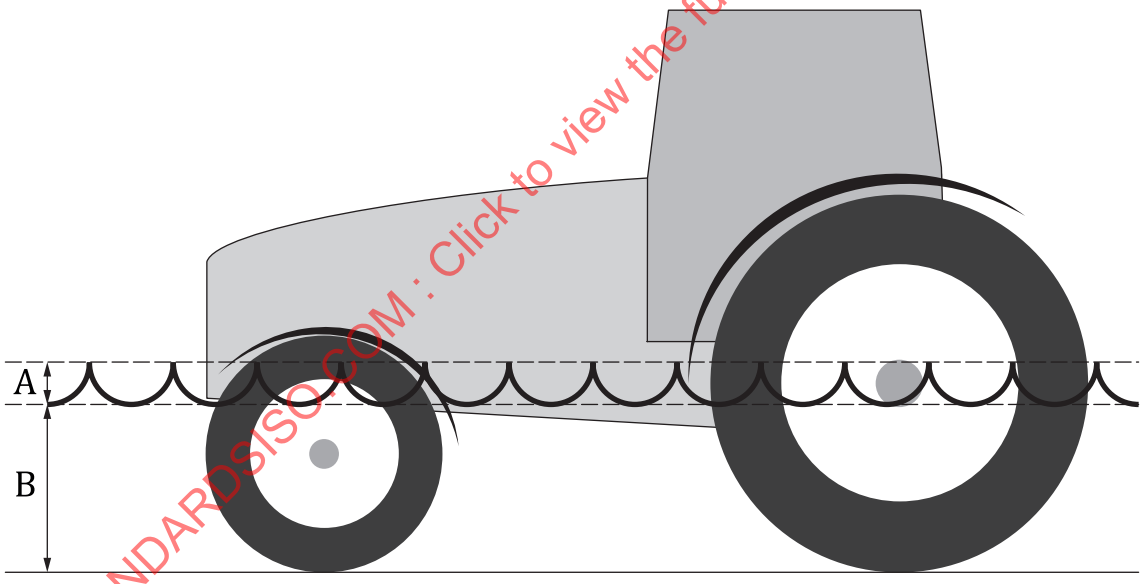
5.11 Water depth

Determination of the maximum permissible depth of the water that mobile machinery is approved by the manufacturer to operate in, is based on these two parameters.

— Wade depth, for which the continuously submerged parts of the electrical system shall be protected to IPX8.

— Wave depth (above wade depth) for which the intermittently submerged parts of the electrical system shall be protected according to IPX7.

See Figure 5.



Key

A wave depth

B wade depth

Figure 5 — Wade and wave depth

The operator's manual shall indicate a maximum wave depth and wade depth if there is potential for fire or a shock hazard associated with the electrical system when submerged during intended operation and reasonably foreseeable misuse. See Figure 5 for an example. A risk assessment shall determine the need for additional actions, instructions, or warning markings.

NOTE See 4.3 for environmental considerations, to reduce the likelihood of corrosion and shorting.

6 Wiring practices

6.1 Conductor and cable runs

If in-line cable splices or joints are used, they shall be provided with proper support on both sides of a splice or joint. In-line ultrasonic welding is recommended over compression joints.

When the chassis is used as a conductor, confirmation of the long-term adequacy of the chassis is essential. Painted surfaces and moving greased joints shall not be relied upon for electrical connections.

The power supply conductors and EPB (when the EPB is in common with a negative or neutral conductor per 5.5.2.7.2 bullet 2) shall be sized according to expected current levels to avoid excessive voltage offset. IEC 60204-1:2016, 4.3.3 or ISO 21780 may be used as guidance for testing and ensuring compatibility.

6.2 Colour

All conductors used for VC-B1 that are not contained within electrical enclosures or ducts shall be covered with orange or orange and purple insulation, conduit, braiding or sleeving, or be otherwise marked orange or orange and purple, to indicate they are VC-B1 conductors. The colours distinguish these VC-B1 conductors from other similar looking objects such as fluid hoses.

In case of the two-colour combination, each colour shall cover at least 30 % of the surface.

6.3 Cable protection inside an enclosure

Inside of electrical enclosures, cable routing shall utilize one or more of these methods:

— use clamps or similar retention devices to route cables away from uninsulated conductors of different potentials such as terminals and buses;

NOTE 1 This method is typically used to create an air gap between conductors.

— provide double or reinforced insulation along with clamps or similar retention devices providing routing to prevent wear due to vibration; or

NOTE 2 This method can allow conductors to be adjacent and only separated by insulation by preventing relative motion.

— provide overcurrent protection to prevent the failure of the cable insulation external to the enclosure.

Designated conductor current-carrying capacity 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 or the IEC 60287 series for further guidance.

The cable manufacturer's specification shall 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 to ensure cable integrity. Alternatively, direct measurement of insulation temperature under maximum load may be used to verify the insulation does not exceed its maximum temperature.

For bolted joints, terminal strips and other clamping type connections, routing and marking techniques shall be utilized to reduce the likelihood of incorrect connections.

6.4 Power supply voltage differences

For mobile machinery having multiple systems or subsystems, undesirable voltage differences can arise between individual power supply points.

Analysis, testing or a combination of both shall be performed to verify that differences arising during normal operation have no adverse effect on system functionality.

EXAMPLE OCP can malfunction when there is a large enough voltage difference condition and cause insulation damage or frequent activation of the OCP. Frequent activation can encourage unsafe customer modifications which can cause fires and shock risks. Increasing power supply conductor sizes can reduce voltage differences.

7 Overcurrent protection (OCP)

7.1 Overview

If the available current in a circuit can exceed the rating of any component or the ampacity of conductors, overcurrent protection shall be provided. See 7.2.4 regarding ratings and settings of OCP.

OCP 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.

Any conductor of an AC power circuit shall not be disconnectable by an OCP without disconnecting all other associated live non-neutral conductors as well. This does not apply to fused circuit protection.

The negative, neutral, or common conductor of DC power circuits shall not be disconnectable by an OCP without disconnecting all other associated live conductors. This does not apply to fused circuit protection.

7.2 General

7.2.1 Transformers

Transformers shall be protected against overcurrent in accordance with the supplier's instructions. This protection shall be designed to avoid nuisance tripping due to transformer magnetizing inrush currents. Nuisance tripping can encourage unsafe customer modifications which can cause fires and increase shock risks.

The protection shall also be designed to prevent winding temperature rise in excess of the permitted value for the insulation temperature class of transformer when the transformer secondary is short-circuited.

Winding varnish meeting the overvoltage and environmental requirements of this document may be used to achieve basic insulation.

7.2.2 Power converters

Power converters used for OCP shall conform with IEC 62477-1:2022, 4.3.

7.2.3 OCP implementation

The rated interrupting capacity of the OCP shall be equal to or greater than the available fault current at the point of installation. Additional short-circuit currents other than from the power supply (e.g. from motors) shall be taken into consideration in design or selection of the OCP.

Selective coordination may be used to ensure that there is protection from both high inrush failures and overload conditions. To achieve selective coordination, a lower interrupting capacity is permitted if another protective arrangement (e.g. the OCP for the power supply conductors) having the necessary interrupting capacity is installed on the power supply side. The characteristics of the two overcurrent protective systems shall be coordinated so that the energy through the two systems in series, i.e. I^2t, 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.

NOTE Selective coordination of the OCPs can result in the operation of both.

7.2.4 Rating and setting of OCP

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

The necessary rated current or setting of an OCP shall be determined in coordination with other electrical devices in the circuit, the current-carrying capacity of the conductors to be protected and the maximum allowable interrupting time.

7.2.5 Placement of OCP

OCP shall be provided 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 conductors are installed in such a manner as to reduce the possibility of a short-circuit, such as by physical protection; and

— insulation remains intact in the event of any single component failure.

7.2.6 Protection via engine shutoff

Overcurrent protection by means of automatic engine shutoff is permitted if the I^2t ratings of conductors and components are not exceeded while shutting down; and there are no other significant power supplies connected to the circuit (e.g. batteries).

7.3 Chassis faults/residual currents

Chassis fault/residual current protection may be provided to reduce damage to equipment due to chassis fault currents less than the activation 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.

8 Disconnection and connection

8.1 General disconnecting devices

An electrical disconnecting device is required for all VC-A2 or VC-B1 power supplies. An engine-stop provision such as key switch with a lockable battery disconnect fulfils this requirement for an engine driven power supply. A risk assessment shall be performed to determine the acceptable means of disconnecting batteries (e.g. plug and socket, quick coupling, or disconnecting switch).

The symbol for battery disconnect/battery shut-off, in accordance with ISO 6405-1:2017, 9.16 shall be used or the equivalent for identification if applicable.

8.2 Specifics of disconnecting

8.2.1 VC-B1

Disconnect means for VC-B1, shall include a visible contact gap or a position indicator which cannot indicate OFF (isolated) until all contacts of the non-PEPB conductors are actually open. Alternatively, an electronically controlled lockout relay is permitted (e.g. a menu item on the monitor, but it shall provide fault detection to be certain the contactors actually open or a means to directly probe the voltage).

The disconnection means shall be capable of being locked (e.g. padlock) if reconnection indicates it is needed per a risk assessment.

NOTE If the power for VC-A2 or VC-B1 is converted from VC-B2 power supplies, then the requirements for VC-B2 systems disconnect are found in ISO 16230-1 for agricultural tractors and machinery. See the ISO 14990 series for EMM.

8.2.2 Power converter disconnects

For DC-to-DC converters from VC-A1 to VC-A2 or VC-B1, a means shall be provided to prohibit both VC-A2 and VC-B1 output exposure during servicing and maintenance.

8.2.3 Manually actuated disconnecting devices

If a disconnection system is provided, the operation shall disconnect (isolate) the electrical equipment of the mobile machinery from the electrical power supply powering the equipment. A disconnection system shall be capable of being locked (e.g. padlock or keyed switch) if reconnection could create a hazard (e.g. the mobile machinery form inhibits direct visibility from the disconnect device to potentially hazardous locations).

NOTE 1 Lockout devices which rely on a control system are under the scope of the functional safety standards. See the ISO 25119 series for agricultural tractors and machinery and ISO 13849-1 or the ISO 19014 series for EMM.

NOTE 2 A disconnect without the ability to be locked is not considered a lockout device.

If there is a delayed shutdown circuit used during disconnecting (e.g. for diesel emissions fluid purging or access/egress lighting) a warning marking or other indication shall be provided to indicate when VC-A2 or VC-B1 are present after a disconnecting switch is in the off position.

Depending on the risk assessment:

— A suitably rated plug/socket combination conforming with performance requirements of IEC 60309-1 is permitted as a disconnecting device, provided it also satisfies 5.9.2.

— A withdrawable fuse links or withdrawable links are permitted as a power supply disconnecting device if they have the protections of Clause 5 in the open and closed condition. They shall also be placed in an enclosure if there is a risk of contacting live parts in the process of open or closing the circuit.

A power supply disconnecting device, other than a plug/socket, withdrawable fuse link or withdrawable link, combination shall satisfy all 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 power supply conductors (except the negative or neutral conductor may remain connected if it is galvanically connected to chassis.);

— have an interrupting capacity sufficient to interrupt the current of the largest total load, including stalled or running motors (or generator if power flow is reversed).

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

The operator's and service manuals shall identify when one or multiple lockout devices are required for servicing of components or areas of the mobile machinery where electrical connections are opened or disconnected to gain access.

8.2.4 Disconnecting multiple power supplies

If a risk assessment shows risk for short circuit or shock regarding contact with live parts, disconnecting devices shall be provided for individual items of electrical equipment so as to allow work to be carried out with the item(s) de-energized and isolated. The power supply disconnecting device may fulfil that function.

To allow efficient servicing of VC-A components on the mobile machinery, it is permissible to have a secondary device to prevent the engine from cranking, or that otherwise prevents exposure to live VC-B1 (and higher) live parts which may be adjacent to VC-A live parts (e.g. 12 V DC, 24 V DC and 48 V DC components). The secondary device may also be implemented via software in a monitor menu with a code or the equivalent.

If two or more power supplies are used, when there is a hazard caused by connecting only one power supply, one or both of the following shall be provided. (The hazards would include giving the service person the impression the mobile machinery has been brought to a 0 V state during a repair):

— A device which disconnects both power supplies simultaneously; or

— a warning marking with disconnection instructions provided to mitigate risks of multi-power supplied systems.

For mobile machinery with multiple electric systems, separate disconnects for the different systems may be provided. When separate disconnects are provided, they shall be clearly marked to indicate what power systems are being disconnected. A marking shall be provided if separate disconnects are required to completely disable the electrical systems.

Instructions shall be provided in the operator's and service manual for safe disconnection of energy source(s) in order to minimize the risk of shock from contacting live parts.

8.3 Prevention of unintended start-up

Unintentional starting can lead to shock hazards during servicing inside of service panels where live parts may have increased exposure.

If a risk assessment addressing start-up while servicing the mobile machinery indicates the need, provision shall be made to prevent unintended start-up.

Devices for prevention of unintended start-up shall be easily usable for the intended purpose, appropriately placed, and readily identifiable (e.g. by a marking).

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

Devices permitted for this purpose are those described in 8.1 and 8.2.

Devices that do not comply with the requirements for unintended start-up 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).

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

8.4 Charging power supplies and recuperation

8.4.1 Electrical power supplies

Risk assessments for electrical hazards shall consider all power supplies, including:

— recuperating external charging systems;

— spinning permanent magnet motors such as on traction drives: and

— implements that could provide charging.

Often, no full assurance can be provided for suitability of external electrical charging power supplies. Hence, in case of external electrical charging of mobile machinery, appropriate measures based on risk assessment shall be undertaken on the mobile machinery side to ensure that dangerous situations are mitigated (e.g. a custom connector to allow only appropriate power supplies to connect, a standardized charging system, or a battery management system on-board).

NOTE 1 Attention is drawn to IEC 61851-1, IEC 62196-1 and ISO 15118 for methods to address charging and connecting.

NOTE 2 Appropriate measures can, for example, include implementation of a dedicated mobile machinery charging safe state, charging instructions for mobile machinery operators, marking of the charging outlet/plug, protection against misuse (the outlet/plug available only by use of a tool or key), the charging outlet/plug formed in a special shape, consideration of charging in the mobile machinery grounding system, installation of OCP devices and phase sequence protection.

8.4.2 Powered interchangeable towed machinery and towed machines

If interchangeable towed machinery (agriculture) or a towed machine (EMM) is intended to receive power from mobile machines doing the towing:

— there shall be instructional markings on the interchangeable towed machinery (agriculture) or towed machines (EMM) to attach only to mobile machinery with a power supply provided with a lockout device capable of disabling the power supply, or

— the interchangeable towed machinery (agriculture) or towed machines (EMM) shall be provided with detailed instructions in the operator's and service manual for the prevention of electrical shock during servicing.

Interchangeable towed machinery (agriculture) or towed machine (EMM) shall have a location to store the connector or other means, such as a clutch, for preventing hazardous shocks due to charging.

See 10.6 for additional requirements for towing.

8.4.3 PTO

For electrical systems which are dependent on a PTO shaft or the equivalent to generate electricity and are easily removable, a lockout device is not required since the electrical system can be securely disabled by removing.

8.5 Pre-charge protective measures

Pre-charge protection is used to prevent high battery currents which can cause fires.

The system shall be designed to automatically apply a DC pre-charge of a VC-A2 or VC-B1 prior to connection of batteries on start-up, unless it can be determined based on the characteristics of the systems that it is not needed. If used, the system shall verify that the charge builds to an appropriate level in order to avoid damaging components such as fuses on the battery due to charging currents of capacitors.

NOTE I^2t current overload measurements are not easily made in such systems. Measurements of battery component temperatures might be needed.

9 Connectors

9.1 General

The cable connections at motors, generators, power converters, energy dissipating resistors, and other devices employing similar high current connections shall be designed, manufactured, and provided with maintenance and service instructions to reduce the likelihood of ignition.

NOTE Faults of connections at motors, generators, power converters, energy dissipating resistors, and other devices employing similar high current connections can become ignition sources.

9.2 Negative connectors and terminals

Negative connectors and terminals connecting to chassis need not be protected from contact if the analysis given in Clause 5 indicates no need based on a risk assessment and in addition that any necessary instructions are provided in the operator and service manual.

9.3 Connector mating

9.3.1 Incompletely mated connectors

Connections shall be analysed for the possibility of localized overheating of incompletely mated connectors, which can in certain circumstances lead to damage. Connections shall also be analysed for damage due to high inrush currents. If there are such risks, appropriate measures according to 9.3.2 shall be taken.

9.3.2 Connecting and disconnecting under load

Connectors can be prematurely degraded if disconnected during current flow. Repeated occurrences can lead to internal insulation break down and excessive heat. Connections intended to be connected or disconnected under load, shall be designed to withstand connecting and disconnecting under load for the life of the product. Examples of methods to achieve this requirement are:

— power through the connector is automatically reduced or disconnected prior to full separation of the connector; (e.g. IEC 61508-7:2010, A.8.2 or IEC 60204-1:2006+A1:2009, 6.4).

— low current, appropriately rated or de-rating current, e.g. according to IEC 61508-7:2010 A.2.8;

— low switched current, idle current principle (e.g. according to IEC 61508-7:2010 A.1.5);

— surge protection;

— arcing protection.

If a connector is likely to be prematurely degraded by connection or disconnection under load (e.g. easily accessible, on attachments which are frequently removed, or pulled apart by mobile machine oscillations), then one or more of the following measures shall be applied or by other means providing similar results:

— power automatically reduced or disconnected prior to full separation of the connector;

— bolted joints (less likely to be opened while energized);

— retention hardware requiring use of a tool to separate the connection; and

— an appropriate instructional marking if it is foreseeable that the user might separate a connection under load frequently enough to damage the connector.

NOTE 1 Connection or disconnection under load can be caused by reasonably foreseeable misuse by the operator.

NOTE 2 At voltage classes within this document, the potential for dangerous arc flash is reduced.

9.4 Power cable connections

Faults of cable connections at motors, generators, power converters, energy dissipating resistors and any other similar high current connections can lead to fire ignition external to electrical enclosures. Cable connections shall be designed, manufactured, and serviced, as necessary, to reduce the likelihood of failure.

Any instructions necessary to minimize the possibility of connection failures shall be provided in the service manual. If there is the possibility of sufficient heat escaping (caused by connection failure) the electrical enclosure to act as an ignition source as determined by testing or risk assessment, a marking referring to the service manual may be placed adjacent to connectors that necessitate any unusual procedures for making proper connections, fastener torques, cleaning, and similar.

If connections require periodic servicing to reduce the likelihood of failure, the operator's and service manuals shall provide appropriate instructions and advise to contact a service person to provide this servicing. The instructions shall be clear about proper disconnection and the need to keep connections clean and free of corrosion.

9.5 Terminals for the PEPB cables

If PEPB cables are connected individually and not via multi-cable connectors, all of the following apply.

— Devices shall have a means of connection for the PEPB cables, located near respective live conductor connection points.

— The means of connection shall be corrosion-resistant and shall be suitable for the connection of PEPB cable sized according to Table 2.

— The means of connection for the PEPB cable shall not be used as a part of the mechanical assembly of the equipment or for other connections.

— Connection and bonding points shall be designed so that their current-carrying capacity is not impaired by mechanical, chemical, or electrochemical influences.

— For VC-A2, each connection of a PEPB cable should each have a dedicated connection point; for example, it is not recommended to have more than one ring terminal on a single bonding stud.

— For VC-B1, each connection of a PEPB cable shall have a dedicated connection point; for example, it is not acceptable to have more than one ring terminal on a single bonding stud.

NOTE One purpose of dedicated PEPB terminals is to avoid inadvertent removal of PEPB of multiple components during the servicing of one component.

— Where enclosures and/or conductors of aluminium or aluminium alloys are used, the possibility and effect of electrolytic corrosion shall be considered.

9.6 Plug/socket combination

If plug/socket combinations are used, all of the following apply.

— Plug/socket combinations that rely on hardware to maintain electrical contact, shall be provided with self-retaining hardware, (e.g. a screw that is attached with a lanyard so that it cannot fall on the ground when the screw is loosened).

— Plug/socket combinations intended to be connected or disconnected under load shall have sufficient load-breaking capacity. It shall not be possible to connect/disconnect a plug/socket combination at greater than its rated disconnecting current while under load without the use of tools.

  To increase the allowed current, the connection system may reduce the current prior to the separation of the conducting terminals (e.g. the use of an electrical interlock circuit can be broken first, which de-energizes the connector prior to separation of the terminals).

This requirements of this second bullet do not apply to separation caused by extreme external forces when mobile machinery is pulling apart a connector, which is cause by operator error or misuse.

— If a PEPB contact is used in a VC-B1 plug/socket combination, the PEPB contact shall be first make/last break to provide PEPB when the plugged-in device is energised. This shall also be provided for VC-A2 and VC-B1 used on user-interchangeable towed machinery (agriculture) connections, or other similar towed connections, if the connections are live during disconnect normally or when disconnected caused by operator error.

NOTE Corroded and unprotected conductors can lead to shorting and overheating.

— Metallic housings of plug/socket combinations shall be bonded to the PEPB circuit, unless the voltage internal to the connector is less than VC-B1 or the connector has both basic and fault protection, or enhanced protection between the live conductors and the metallic housing, with a retaining means requiring the use of tools to discourage disconnection. Alternatively, for tractor and interchangeable towed machinery (agriculture) and for other similar connections, an intentional breakaway connector may be used to prevent harness damage.

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

— Plug/socket combinations used in control circuits shall satisfy the applicable requirements of IEC 61984. 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. Alternatively, control functions communicated via high frequency signals on the power supply cables may use other connectors.

10 Electric motors and generators

10.1 General

NOTE 1 Electric motors and generators are broadly referred to in the electrical industry and in the IEC 60034 series of standards (all parts referenced) as rotating electrical machines. In that context, “machine” is often used to refer to a motor or generator. In this document, machines and machinery generally refer to agricultural and forestry machines and earthmoving machinery.

Winding varnish meeting the overvoltage and environmental requirements of this document may be used to achieve basic insulation.

Rating markings on motors should be provided when there is the possibility of incorrect replacement.

Air cooled motors with appropriate insulation are generally acceptable, but consideration should be given to the likelihood of exposure to high pressure cleaning.

NOTE 2 A controller might not fully disconnect the power supply from a motor when it is at rest, which can impact conformance with the requirements of Clause 8.

10.2 Enclosures

The degree of protection for all motors and generators shall be at least IPXXB for VC-B1 and IPXXA for VC-A2.

More stringent measures shall be considered based upon applications where, for example, dust or moisture is present.

NOTE The uninstalled motors need not comply with any degree of protection.

10.3 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 temperature class.

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

The mounting arrangement for motors, generators, and wiring enclosures in general shall be positioned such that they are as accessible as is practicable to facilitate proper inspection, maintenance, and replacement.

10.4 Overheating protection

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

Protection of motors against overheating by automatic shutdown or derating can be achieved by methods such as overload protection, impedance protection, over-temperature protection, or current-limiting protection.

Alternatively, if automatic shutdown or derating of a motor or generator is unacceptable based on a risk assessment (e.g. to prevent possible mobile machinery damage), the means of overheating detection shall warn the operator to prevent potential shock hazards or possible fires. If applicable, an overheating motor may continue to operate to ensure mobile machinery braking and other safety critical systems stay active.

10.5 Overspeed protection

Protection shall be provided against excessive motor or generator speed (e.g. motors/generators coupled to engines, transmissions, or wheels) if insulation failure could occur, or overvoltage could lead to a safety related failure. The overspeed requirements of IEC 60034-1 shall apply.

10.6 Towing and coasting

Overvoltage/overcurrent caused by towing at speeds higher than normal operating speeds can damage insulation which can lead to increase shock risk. For example, double insulation on a cable can be burned off, leading to direct exposure to the live conductors after towing is completed and the mobile machinery is placed back into service.

Under the conditions 1 through 3, there shall be no fire or shock hazards caused by insulation damage or overvoltage. If a risk assessment indicates there is a possibility of electrical system damage that could result in a fire or shock hazard, then an appropriate warning to indicate the associated hazards shall be placed both near the towing area and in the operator's manual. A warning may also be provided on the system's monitor as appropriate.

1) When towing mobile machinery at a reasonably foreseeable overspeed (since there is a possibility of generation due to permanent magnet motors, as well as passive rectification causing charging of capacitors).

2) When mobile machinery can be placed in neutral and allowed to coast downhill at a reasonably foreseeable overspeed.

3) When a system is placed into a 3-phase short condition (e.g. at startup for braking, or by fault condition).

10.7 Bonding

10.7.1 Motors and generators

Motors and generators, unless meeting one of exemptions in this subclause 10.7.1, shall be equipped with a PEPB terminal to permit the connection of a PEPB cable or another similar terminated conductor. If any

type of EPB terminal is used, then an appropriate EPB marking symbol shall be applied on it or adjacent to it. Exempted from terminal requirement are motors and generator that:

— are fitted with (and rely upon) double or reinforced insulation for protection; or

— are intended to be assembled into apparatus having double or reinforced insulation; or

— rely on sheathing for bonding inside a cable connection; or

— rely on bonding provided via the mounting method, similar to the subsystems in Figure 3.

NOTE Mitigation of EMC issues can require EPB even on double or reinforced insulation components.

10.7.2 Exempted from marking requirement

Marking is not required when an EPB terminal is not used (e.g. when the shielding is used for bonding inside a cable connection or when bonding is provided via the mounting method). See Figure 3.

11 Non-motor loads (components)

11.1 General

If a socket-outlet is provided, further regulatory and standards requirements can apply. The brief content of this clause does not address all the issues associated with socket-outlets on products covered by this document.

11.2 Accessories

NOTE 1 Accessories themselves are not covered by this document.

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

— if PEPB is needed for protection of the plugged-in device, the continuity of the PEPB circuit to the socket-outlet shall be provided;

— all non-chassis-referenced conductors connected to the socket-outlet shall be protected against overcurrent in accordance with Clause 7. The overcurrent protection shall be separate from that of other circuits.

Socket-outlets shall be clearly marked with voltage and current ratings, unless following a recognized industry configuration standard.

Circuits for socket-outlets may be provided with residual current devices (RCD) If provided, the device shall interrupt the circuit at a non-hazardous level of touch current.

NOTE 2 A Ground Fault Circuit Interrupter (GFCI) is a North American term for a type of RCD.

12 Insulation coordination

12.1 General

Insulation coordination shall be according to the impulse voltage, temporary overvoltage or working voltage, whichever gives the most severe requirement for the circuits involved according to the principles of the IEC 60664 series. Transients from systems utilizing high speed PWM technology can be a significant cause of insulation and functional failure in control systems.

It shall not be possible to remove solid insulation except by destruction.

12.2 Cable insulation

12.2.1 Temperature and loading

12.2.1.1 General

Cable insulation shall remain intact under maximum temperature and loading conditions. It shall also remain intact in the event of a failed component causing overcurrent. One or both of the Methods 1 and 2 shall be utilized to ensure compliance.

12.2.1.2 Method 1

Comply with the methods of SAE J1614, IEC 62477-1 or other comparable methods, ensuring an adequate design. Particular attention shall be given to the number cables involved in the bundling, abnormal operating conditions for the components, and maximum ambient temperatures.

12.2.1.3 Method 2

Cable insulation shall not be degraded in application to the point of losing its effectiveness in preventing electric shock. Cable insulation shall be designed according to the design life of the mobile machinery and shall conform with ISO 16230-1:2015, Clause 7 for agricultural tractors and machinery, ISO 14990-1:2016, 11.4 for EMM.

12.2.2 Inspection

Instructions for when to perform periodic inspections and when to replace cables shall be provided in the operator's manual and the service manual. Cable replacement instructions can include inspections to determine if damage, cracking, wear, etc. has occurred.

12.2.3 Shielding

If cabling has a conductive shield, the current in the shield shall be analysed by measurement, calculation, or simulation under maximum operating loads to ensure it does not damage the insulation in normal use, and under all single point faults of the conductor or other single point system failures which can cause higher than normal currents to flow in the shield.

NOTE Material external to metal shielding is not part of the insulation.

12.2.4 Different voltages

Cables of different voltages shall only be routed in the same conduit when the cables have insulation rated to the higher voltage between the conductors, or the higher potential cable has double or reinforced insulation between it and any lower potential conductor within the conduit (see IEC 60204-1:2016, 13.1.3 for agricultural tractors and machinery or ISO 14990-1:2016, 11.7.3 for EMM).

EXAMPLE 1 Two 75 V DC cables passing through the same conduit, with basic insulation on each cable, is acceptable. Shielded cables can count the layer of insulation between the conductor and the shield as one layer, and the same insulation on the other cable as a second layer. The cover external to the metal shield is not counted as insulation.

EXAMPLE 2 A 75 V DC cable and a 12 V DC cable passing through the same conduit with 75 V DC rated double insulation between the cables is acceptable. The double or reinforced insulation can occur by various means, including supplemental insulation rated for 75 V DC on the 12 V DC cable.

NOTE EMC is potentially a greater risk when routing control and monitoring circuits adjacent to power circuits, in part due to the high switching speed of the power converters.

13 Verification and validation

13.1 General

Table E.1 provides a list of clauses with requirements from all of the content in Clauses 4 to 12 requiring verification and validation. The table shall be used as an outline for verification and validation. Individual tests may be supplemented to show compliance to the requirements listed. The verification plan may be modified based on the iterative nature of design as shown in Figure B.1.

NOTE According to the V Model in Figure B.1, the order of final completion of line items is likely to mostly occur reverse numerical order.

14 Information for use

14.1 General

Information for use shall be provided in accordance with ISO 12100:2010, 6.4.

14.2 Markings

14.2.1 First responder information

If VC-B1 is utilized in the electrical system, the manufacturer shall make available information for first responders to safely interact with a damaged mobile machinery. For example, information according to ISO 17840-4 may be in the manual, on a marking, or on a website.

14.2.2 Shock hazard symbols

The symbol ISO 7010-W012 shall be provided according to 5.4.3.2 as applicable.

14.2.3 Operating voltage

For VC-A2 and VC-B1 systems, the maximum normal operating voltage of the system should be placed on the mobile machinery.

14.2.4 Live parts accessible during installation and maintenance

A warning marking shall be provided per 5.4.3.2 to ensure that persons are aware that live parts with VC-B1 are accessible during field installation and maintenance.

After installation, open-type subassemblies and equipment do not require markings if protection is provided by the final assembly.

14.2.5 Bonding

The bonding marking requirements of 5.5.2.2 and 10.7 shall be satisfied by use of the graphical symbol IEC 60417-5019 placed near the points where PEPB connections are made. For other EPB types, the most appropriate symbol from IEC 60417 shall be used. Other forms of EPB, which are not PEPB, such as FEPB, 12 V DC systems, and 24 V DC systems, are not required to be marked. To avoid confusion, it is also acceptable to mark all bonding points on mobile machinery having systems in the voltage range of this document.

Optional bonding markings per 5.6.2.1 shall be considered for FEPB.

14.2.6 Residual voltage

Warnings shall be provided per 5.9.1 and 5.9.2 for residual voltage. The warning marking shall state a minimum time interval required before the conductor can be contacted, as applicable. The warning label shall indicate either:

— the minimum time interval to safely contact the conductors, or

— to see the operator's manual or service manual, as appropriate, where the minimum time is stated.

If a battery of VC-A2 or VC-B1 is provided, a warning marking indicating the presence of shock hazards shall be provided, using symbol ISO 7010-W012.

14.2.7 Power supply disruption

Warning marking requirements related to power supply disruption shall be according to 5.9.2.

14.2.8 Disconnected plug/socket combinations

When a warning marking is required per 5.10.3.1 and 5.10.5, for residual voltage hazards on plug/socket combinations, it shall be placed at a prominent location on or adjacent to the hazardous location. The warning label shall indicate either:

— the minimum time interval to safely contact the conductors, or

— to see the operator's manual or service manual, as appropriate, where the minimum time is stated.

14.2.9 Maximum water depth

According to 5.11, a marking shall indicate the maximum permissible water wade and wave depth.

14.2.10 Connection markings

If there is a risk of miss-wiring a component during repairs, markings shall be clear and according to IEC 62477-1:2022, 6.3.7.

A marking referring to the service manual shall be placed adjacent to connectors containing any unusual procedures for making proper connections (e.g. fastener torques, cleaning and similar).

14.2.11 Conductor and cable colour markings

VC-B1 conductors and cables shall be marked according to 6.2.

14.2.12 Bolted joints

Markings for bolted-joint, terminal strips and other clamping type electrical connections shall be according to 6.3.

14.2.13 Disconnection of electrical power supplies

A power supply disconnecting device other than a plug/socket combination shall be marked according to 8.2.4.

If a circuit is not disconnected by a power supply disconnecting device:

— a marking shall be placed near the power supply disconnecting device according to 8.2.3 or 8.2.4;

— unless part of a galvanically isolated circuit, the equipment shall comply with one or more of the following:

  — a warning marking shall be placed near each excepted circuit to indicate power is energized after disconnecting the power supply from other parts of the system;

— the circuit conductors shall be identified by colour.

For conductors which remain live at greater than VC-A1 after a disconnection is made, markings shall be provided to address hazards.

14.2.14 Multiple disconnects

Instruction marking to prevent shock shall be provided to mitigate risks of multi-power supplied systems according to 8.2.4.

14.2.15 Unintended start-up

Markings for the prevention of unintended start-up shall be according to 8.3.

14.2.16 External charging

Markings for external charging shall be according to 8.4.

14.2.17 Towing

Requirements for instructional markings for a powered interchangeable towed machinery (agriculture) or a towed machine (EMM) that is provided without a lockout device shall be according to 8.4.2.

If there is a possibility of electrical system damage, then a warning marking shall indicate any associated potential hazards and be placed near the towing area as appropriate. (See 10.6.)

14.2.18 Connecting and disconnecting under load

Instructional marking requirements are given in 9.3.2.

14.2.19 Phase cable connections

If there is the possibility of sufficient heat escaping the electrical enclosure to function as an ignition source as determined by the methods in 9.4, then marking requirements are given by 9.4.

14.2.20 Bonding of motors and generators EPB

Motor and generator EPB marking requirements are given in 10.7.

14.2.21 Shipping, dealer setup and transport

Marking requirements related to shipping, dealer setup, and transport considerations shall be according to 14.3.3.3

14.2.22 Electrical ratings

14.2.22.1 Systems used on tractor/interchangeable towed mobile machinery combinations and similar

Unless following a recognized industry configuration standard, the following markings shall be provided at the power supply connections at the rear of a tractor and on the front of interchangeable towed mobile machinery, (and in a similar fashion for other similar towed combinations):

— rated input or output voltage; and

— rated input or output current.

Consider also adding the following supplementary information:

— indication of the nature of the voltage (AC, DC, or other); and

— frequency, if applicable.

14.2.22.2 Circuits within a serviceable enclosure, under a removable guard or similar

At fuse locations, the type and voltage and current ratings of replacement fuses shall be marked.

14.2.22.3 Components such as motors, generators and power converters

Unless components such as motors, generators, and power converters follow a recognized industry standard configuration or are identified with a manufacturer's name and a part number, the following markings shall be provided:

— rated input or output voltage; and

— rated input or output current;

Motor markings are addressed in 10.1.

The required information shall be provided either on the components or in the service information.

Consider also adding the following supplementary information:

— indication of the nature of the voltage (AC, DC, or other); and

— frequency, if applicable.

14.2.23 Protection systems

If the optional protection Class II is designated for a system, it should be marked according to D.1. Other optional protective classes may be marked according to D.1.

14.2.24 General purpose socket-outlets

Unless using an industry standard configuration, to ensure compatibility of devices connected to general purpose socket-outlets, each such socket-outlet shall be marked with the following:

— voltage;

— AC, DC, both or other;

— maximum current;

— frequency if not DC.

NOTE At the time of publication of this document, common configurations for plugs and socket-outlets do not exist.

14.2.25 Magnetic hazard symbols

When permanent magnet rotating machines are used, a magnetic field warning sign indicating incompatibility with medical devices shall be placed in a visible location near the magnets using the graphical symbol ISO 7010-W006, unless it can be shown that the magnetic field is insufficient to cause harm. When the symbol is used, the operator's manual shall further explain the hazard. Service parts containing these magnets shall have warning signs attached, since the hazard resides with the parts. Once installed, the warning sign on the rotating machines might not be visible; therefore, a second label could be required.

14.3 Manuals and technical documentation

14.3.1 General

In addition to requirements in 14.2, the information for use in 14.3.2 and 14.3.3 shall be provided.

14.3.2 Operator's manual

The operator's manual shall include:

— procedures for use of the electrical equipment;

— the following warning or equivalent: Direct contact with electricity can cause injury or death. Observe all safety precautions;

— a description (including interconnection diagrams) of safeguards, interlocking functions and interlocking of guards against hazards, if used;

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

— information about energy storage devices that cannot easily be discharged for maintenance;

NOTE Batteries are typically not discharged since discharging can damage the batteries.

— instruction for the operator shall be provided regarding the maximum allowable altitude, (e.g. due to changes in insulation properties of air at higher altitudes);

— specific locations on the mobile machinery which cannot be cleaned with jets of water;

— instructions for jump-starting so as to avoid cross voltage jumping, short-circuits, and battery damage. Clear instructions shall be provided about the voltage of the jump-starting power supply and other details, since lead-acid batteries can be incompatible with other types;

— advice to the operator to contact a qualified service representative to provide this servicing if connections require periodic maintenance to reduce the likelihood of failure due to corrosion, wear and similar degradation that can cause excessive heat;

— instructions about protective systems with respect to field modifications, 5.7;

— the minimum time interval required before servicing per 5.9.1 and 5.9.2 unless provided on a warning sign or in the service manual;

— instructions for hazards associated with connectors be remaining live after disconnecting per 5.10.3.1 and 5.10.5, as applicable;

— an indication the maximum permissible water wade and wave depth in which the mobile machinery is allowed to operate according to 5.11. If submerged beyond the maximum permissible depth, the operator's manual shall indicate that after submersion, the mobile machinery shall not be operated until it has been serviced;

— instructions regarding disconnecting as specified in 8.2.3 and 8.2.4;

— instructions for hazards according to 9.2;

— instructions necessary to prevent connector failures shall be according to 9.4;

— instructions regarding towing and coasting as specified in 8.4.2 and 10.6;

— instructions for periodic cable inspection as specified in 12.2.2;

— instructions about protective classes per Annex D; and

— for VC-A2 and VC-B1 systems, the maximum normal operating voltage of the systems.

14.3.3 Service manuals

14.3.3.1 General

Service manuals shall recommend the competence level of service personnel with respect to electricity and electrical safety.

Service manuals shall include the following (as applicable):

— the warning statement or equivalent: Direct contact with electricity can cause injury or death. Observe all safety precautions provided in this manual while servicing this mobile machinery;

— a description (including interconnection diagrams) of safeguards, interlocking functions and interlocking of guards against hazards, if used;

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

— information about energy storage devices that cannot easily be discharged for maintenance;

NOTE 1 Batteries are typically not discharged since discharging can damage the batteries.

— instructions about protective systems with respect to field modifications, see 5.7;

— instructions advising service personnel as to the wearing of proper electrical PPE to reduce the likelihood of accidental contact with hazardous live parts; if there is stored energy per 5.9, the following apply:

  — instructions for the verification of discharge prior to servicing. (Verification is not required for very simple systems that inherently discharge stored energy immediately upon loss of power;)

  — where there is a residual voltage measuring device, instructions for verification that the device is functioning correctly;

  — a procedure for manual discharge of residual voltages in the event of failure of the primary and secondary automatic discharge means; alternatively, this may be offered only to service personnel; and

  — the minimum time interval required before servicing per 5.9.2 unless provided on a warning sign or in the operator's manual;

NOTE 2 Batteries are typically not discharged, since discharging can damage the batteries.

— instructions for hazards associated with connectors be remaining live after disconnecting per 5.10.3.1 and 5.10.5, as applicable;

— instructions for when one or more lockout devices are required for servicing of components or areas of the mobile machinery where electrical connections are opened or disconnected to gain access. See 8.2.3, 8.2.4 and 14.2.7;

— instructions for safe servicing of towed devices per 8.4.2, if required;

— instructions for servicing of connectors shall be provided according to subclauses 9.1 and 9.2;

— instructions necessary to prevent connector failures shall be according to 9.4;

— instructions for periodic cable inspection shall be provided in the service manual as specified in 12.2.2;

— instructions for correct use of fusing of the proper ratings;

— if used, an explanation regarding Class II marking or the double insulation symbol and an explanation of the bonding on the product;

— if appropriate, an instruction to discourage inappropriate bonding. Manufacturer should also provide this information for aftermarket modifications, according to D.1 if optional protective class designations are used; and