

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Safety of machinery – Electrical equipment of machines –
Part 33: Requirements for semiconductor fabrication equipment**

**Sécurité des machines – Equipement électrique des machines –
Partie 33: Exigences pour les équipements de fabrication des semi-conducteurs**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SAFETY OF MACHINERY – ELECTRICAL EQUIPMENT OF MACHINES –

Part 33: Requirements for semiconductor fabrication equipment

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International Standard IEC 60204-33 has been prepared by technical committee 44: Safety of machinery – Electrotechnical aspects.

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

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

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

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- replaced by a revised edition, or
- amended.

The following differences exist in some countries:

- 4.3.1: The voltage characteristics of electricity supplied by public distribution systems in Europe are given in EN 50160:1999, Voltage characteristics of electricity supplied by public distribution systems.
- 5.1.3: Exception is not allowed (USA).
- 5.1.3: TN-C systems are not permitted in low-voltage installations in buildings (Norway).
- 5.2: Terminals for the connection of the protective earthing conductors may be identified by the colour green, the letters "G" or "GR" or "GRD" or "GND", or the word "ground" or "grounding", or with the graphical symbol IEC 60417-5019 (2006-08) or any combination (USA).
- 6.3.3: TT systems are preferred over TN systems (Japan).
- 6.3.3 b), 13.4.5 b), 18.2.1: TT power systems are not allowed (USA).
- 7.2.3: Disconnection of the neutral conductor is mandatory in a TN-S system (France and Norway).
- 7.2.3: Third paragraph: distribution of a neutral conductor with an IT system is not allowed (USA and Norway).
- 13.4.2: For the protective conductor, the colour identification GREEN (with or without YELLOW stripes) is used as equivalent to the bicolour combination GREEN-AND-YELLOW (USA and Canada).
- 13.4.3: The colour identification WHITE or GREY is used for earthed neutral conductors instead of the colour identification BLUE (USA and Canada).
- 15.2.2: First paragraph: Maximum value between conductors 150 V (USA).
- 15.2.2: 2nd paragraph, 5th bullet: The full load current rating of lighting circuits does not exceed 15 A (USA).

INTRODUCTION

IEC 60204-33 has been created to reflect the unique needs of electrical safety within the semiconductor manufacturing environment. This includes the specialized clean room environment in which semiconductors are fabricated as well as the specialized nature of the semiconductor fabrication equipment itself. IEC 60204-33 ensures a level of safety consistent with IEC 60204-1 while still permitting the flexibility needed in the design and operation of semiconductor fabrication equipment. It has been drafted to satisfy the electrical safety needs of the semiconductor industry.

This standard is not intended to address those functional aspects of semiconductor fabrication equipment that do not relate directly to safety.

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SAFETY OF MACHINERY – ELECTRICAL EQUIPMENT OF MACHINES –

Part 33: Requirements for semiconductor fabrication equipment

1 Scope

This part of IEC 60204 applies to electrical and electronic equipment associated with semiconductor fabrication equipment for the manufacture, measurement, assembly, and test of semiconductors.

NOTE 1 In this standard, the term electrical includes electrical, electronic, and programmable electronic matters (i.e. electrical equipment means electrical, electronic, and programmable electronic equipment).

NOTE 2 In the context of this standard, the term person refers to any individual and includes those persons who are assigned and instructed by the user or his agent(s) in the installation, use, and care of the fabrication equipment in question.

The electrical equipment covered by this standard commences at the point of connection of the supply to the electrical equipment (see 5.1), and includes proper instruction for its safe installation.

NOTE 3 For the requirements for the electrical supply installation in buildings, see IEC 60364 series.

This part is applicable to the electrical equipment or parts of the electrical equipment that operate with nominal supply voltages not exceeding 1 000 V for alternating current (a.c.) and not exceeding 1 500 V for direct current (d.c.), and with nominal supply frequencies not exceeding 200 Hz. For higher voltages or frequencies, special requirements may be needed.

NOTE 4 Electrical equipment within which derived voltages exceed these supply voltage limits is within the scope of this standard.

Included are requirements for protective measures against electrical safety hazards as well as electrical interlock circuits that protect against non-electrical hazards. However, it does not cover all the requirements that are needed or required by other standards or regulations in order to safeguard persons from hazards other than electrical hazards (e.g. chemical hazards, mechanical hazards, radiation hazards). Each type of machine has unique requirements to be accommodated to provide adequate safety.

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

- use, process, or produce potentially explosive material;
- are used in potentially explosive and/or flammable atmospheres;
- have special risks when producing or using certain materials;
- are hoisting machines (which are covered by IEC 60204-32).

This standard does not include specifications for performance or functional characteristics of the fabrication equipment.

This standard does not deal with the possible effects on human health that can result from emissions (for example EMFs, noise) from the fabrication equipment.

This standard does not specify requirements for electromagnetic compatibility (EMC).

2 Normative references

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

IEC 60034-11:2004, *Rotating electrical machines – Part 11: Thermal protection*

IEC 60038: *IEC standard voltages*

IEC 60073:2002, *Basic and safety principles for man-machine interface, marking and identification – Coding principles for indication devices and actuators*

IEC 60364-4-41:2005, *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock*

IEC 60364-4-43:2008, *Low-voltage electrical installations – Part 4-43: Protection for safety – Protection against overcurrent*

IEC 60364-6:2006, *Low-voltage electrical installations – Part 6: Verification*

IEC 60417, *Graphical symbols for use on equipment*

IEC 60445:2006, *Basic and safety principles for man-machine interface, marking and identification – Identification of equipment terminals and conductor terminations*

IEC 60446:2007, *Basic and safety principles for man-machine interface, marking and identification – Identification of conductors by colours or alphanumerics*

IEC 60447:2004, *Basic and safety principles for man-machine interface, marking and identification – Actuating principles*

IEC 60529:1989, *Degrees of protection provided by enclosures (IP Code)*

IEC 60617, *Graphical symbols for diagrams*

IEC 60695-11-10:1999, *Fire hazard testing – Part 11-10: Test flames – 50 W horizontal and vertical flame test methods*

IEC 60950-1:2005, *Information technology equipment – Safety – Part 1: General requirements*

IEC 61010-1:2001, *Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 1: General requirements*

IEC 61032:1997, *Protection of persons and equipment by enclosures – Probes for verification*

61310 (all parts): *Safety of machinery – Indication, marking and actuation*

IEC 61310-1:2007, *Safety of machinery – Indication, marking and actuation – Part 1: Requirements for visual, acoustic and tactile signals*

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety related systems*

IEC 61557-3:2007, *Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. – Equipment for testing, measuring or monitoring of protective measures – Part 3: Loop impedance*

IEC 61558-1:2005, *Safety of power transformers, power supplies, reactors and similar products – Part 1: General requirements and tests*

IEC 61558-2-6:2009, *Safety of transformers, reactors, power supply units and similar products for supply voltages up to 1 100 V – Part 2-6: Particular requirements and tests for safety isolating transformers and power supply units incorporating safety isolating transformers*

IEC 61800-5-1:2007, *Adjustable speed electrical power drive systems – Part 5-1: Safety requirements – Electrical, thermal and energy*

IEC 62061:2005, *Safety of machinery – Functional safety of safety-related electrical, electronic and programmable electronic control systems*

ISO 12100-2:2003, *Safety of machinery – Basic concepts, general principles for design – Part 2: Technical principles*

ISO 13849 (all parts): *Safety of machinery – Safety-related parts of control systems*

ISO 13849-1:1999, *Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design*

ISO 13851:2002, *Safety of machinery – Two-hand control devices – Functional aspects and design principles*

3 Terms and definitions

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

3.1

actuator

part of a device to which an external manual action is to be applied

NOTE 1 The actuator may take the form of a handle, knob, push-button, roller, plunger, etc.

NOTE 2 There are some actuating means that do not require an external actuating force but only an action.

NOTE 3 See also 3.40.

3.2

ambient temperature

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

[IEV 826-01-04]

3.3

appliance coupler

means enabling the connection and disconnection at will, of a cord to an appliance or other equipment and consisting of a connector and an appliance inlet

NOTE 1 An appliance inlet integrated in an appliance or equipment is an appliance inlet the shroud and base of which is formed by the housing of the appliance or equipment.

NOTE 2 An appliance inlet incorporated in an appliance or an equipment is a separate appliance inlet built-in or fixed to an appliance or equipment.

3.4

automatic disconnection

interruption of one or more of the line conductors by the automatic operation of a protective device in case of a fault

3.5

barrier

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

[IEV 826-03-13]

3.6

basic insulation

insulation of hazardous-live-parts which provides basic protection

[IEV 195-06-06]

3.7

cable tray

cable support consisting of a continuous base and raised edges and no covering

NOTE A cable tray may be perforated or non-perforated.

[IEV 826-06-08]

3.8

cable trunking system

system of closed enclosures comprising a base with a removable cover intended for the complete surrounding of insulated conductors, cables, cords and for the accommodation of other electrical equipment

[IEV 826-06-04]

3.9

concurrent

acting in conjunction; used to describe a situation wherein two or more control devices exist in an actuated condition at the same time (but not necessarily synchronously)

3.10

conduit

part of a closed wiring system of circular or non-circular cross-section for insulated conductors and/or cables in electrical installations, allowing them to be drawn in and/or replaced

NOTE Conduits should be sufficiently close-jointed so that the insulated conductors and/or cables can only be drawn in and not inserted laterally.

[IEV 826-06-03]

3.11

control device

device connected into the control circuit and used for controlling the operation of the machine (for example position sensor, manual control switch, relay, contactor, magnetically operated valve)

3.12**controlgear**

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

[IEV 441-11-03, modified]

3.13**controlled stop**

stopping of machine motion with electrical power to the machine actuators maintained during the stopping process

3.14**class II equipment**

equipment with

- basic insulation as provision for basic protection, and
- supplementary insulation as provision for fault protection

or in which

- basic and fault protection are provided by reinforced insulation

[IEC 61140, 7.3]

3.15**danger zone**

in the case of high voltage installations, systems, and equipment, area limited by the minimum clearance around hazardous-live-parts without complete protection against direct contact

NOTE Entering the danger zone is considered to be the same as touching hazardous-live-parts.

[IEC 61140, 3.35, modified]

3.16**direct contact**

contact of persons with live parts

NOTE For high-voltage installations, systems, and equipment, entering the danger zone is considered to be the same as touching hazardous live parts.

3.17**direct opening action (of a contact element)**

achievement of contact separation as the direct result of a specified movement of the switch actuator through non-resilient members (for example not dependent upon springs)

[IEC 60947-5-1, K.2.2]

3.18**double insulation**

insulation comprising both basic insulation and supplementary insulation

3.19**duct**

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

NOTE Conduits (see 3.9), cable trunking systems (see 3.7) and underfloor channels are types of duct.

3.20

electrical equipment

material, fittings, devices, components, appliances, fixtures, apparatus, and the like used as part of, or in connection with the use of electricity by semiconductor fabrication equipment

NOTE See also 3.27.

3.21

emergency stop device

manually actuated control device used to initiate an emergency stop function

[ISO 13850, 3.2]

3.22

emergency off

EMO

function which, when activated, will place the fabrication equipment into a safe shutdown condition, without generating any additional hazards

3.23

enclosed electrical equipment area

room or location for electrical equipment to which access is intended to be restricted to skilled or instructed persons by the opening of a door or the removal of a barrier by the use of a key or tool and which is clearly marked by appropriate warning signs

3.24

enclosure

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

[IEV 826-03-12]

NOTE The definition taken from the existing IEV needs the following explanations within the scope of this standard:

- a) Enclosures provide protection of persons against access to hazardous parts.
- b) Barriers, shaped openings, or any other means suitable to prevent or limit the penetration of the specified test probes, whether attached to the enclosure or formed by the enclosed equipment, are considered as part of the enclosure, except where they can be removed without the use of a key or tool.
- c) An enclosure may be:
 - a cabinet or box, either mounted on the machine or separate from the machine;
 - a compartment consisting of an enclosed space within the machine structure.

3.25

equipotential bonding

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

[IEV 195-01-10]

3.26

exposed conductive part

conductive part of electrical equipment, which can be touched and which is not live under normal operating conditions, but which can become live under fault conditions

[IEV 826-03-02, modified]

3.27**extraneous conductive part**

conductive part, for example of the fabrication equipment, not forming part of the electrical equipment

3.28**fabrication equipment**

machinery, associated electrical equipment, apparatus, process modules or devices used to manufacture, measure, assemble and test semiconductor products but not including any product (e.g., substrates, semiconductors)

NOTE See also 3.20.

3.29**failure**

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

NOTE 1 After failure the item has a fault.

NOTE 2 "Failure" is an event, as distinguished from "fault", which is a state.

[IEV 191-04-01, modified]

NOTE 3 In practice, the terms fault and failure are often incorrectly used synonymously.

3.30**fault**

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

NOTE 1 A fault is often the result of a failure of the item itself, but may exist without prior failure.

NOTE 2 In English the term "fault" and its definition are identical with those given in IEV 191-05-01. In the field of machinery, the French term "défaut" and the German term "Fehler" are used rather than the terms "panne" and "Fehlzustand" that appear with this definition.

3.31**functional bonding**

equipotential bonding necessary for proper functioning of electrical equipment

3.32**harm**

physical injury or damage to health

[ISO 12100-1, 3.5]

3.33**hazard**

potential source of physical injury or damage to health

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

NOTE 2 The hazard envisaged in this definition:

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

[ISO 12100-1, 3.6, modified]

3.34

hazardous electrical power

power levels equal to or greater than 240 VA

3.35

hazardous-live-part

live part which under certain conditions, can give a harmful electric shock

[IEV 195-06-05]

NOTE For the purposes of this standard voltages greater than 30 V r.m.s., 42,4 V peak, or 60 V d.c. are considered to have the possibility of a harmful electric shock.

3.36

hazardous situation

circumstance in which a person is exposed to at least one hazard. The exposure can immediately or over a period of time result in harm

[ISO 12100-1, 3.9]

3.37

hazardous voltage

voltage greater than 30 V r.m.s., 42,4 V peak, or 60 V d.c.

3.38

indirect contact

contact of persons with exposed conductive parts which have become live under fault conditions

[IEV 826-03-06, modified]

3.39

inductive power supply system

system of inductive power transfer, consisting of a track converter and a track conductor, along which one or more pick-up(s) and associated pick-up converter(s) can move, without any galvanic or mechanical contact, in order to transfer electrical power for example to a mobile machine

NOTE The track conductor and the pick-up are analogous to the primary and secondary of a transformer respectively.

3.40

(electrically) instructed person

person adequately advised or supervised by an electrically skilled person to enable him or her to perceive risks and to avoid hazards which electricity can create

[IEV 826-09-02, modified]

3.41

interlock

arrangement of devices operating together to:

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

3.42**live part**

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

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

[IEV 826-03-01]

3.43**machine actuator**

power mechanism used to effect motion within the fabrication equipment

NOTE See also 3.1.

3.44**machinery****machine**

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

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

[ISO 12100-1, 3.1, modified]

NOTE The term "component" is used here in a general sense and it does not refer only to electrical components.

3.45**maintenance**

activities intended to keep fabrication equipment in proper working order

NOTE See also 3.60.

3.46**marking**

signs or inscriptions for the purpose of identifying equipment, components and/or devices, which can include certain features thereof

3.47**neutral conductor****N**

in a star-connected three-phase system, conductor connected to the common point and capable of contributing to the transmission of electrical energy and in a single-phase system, a conductor connected to the side that is commonly at the same potential as the protective earth

[IEV 826-01-03, modified]

NOTE The neutral point is only defined for a.c. systems.

3.48**obstacle**

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

[IEV 826-03-14]

3.49

operator

person who interacts with the fabrication equipment in order for it to perform its intended function

NOTE 1 Operator functions are distinct from maintenance and repair functions.

NOTE 2 Performance of operator functions does not require the knowledge or ability of a skilled or instructed person.

3.50

overcurrent

current exceeding the rated value

NOTE For conductors, the rated value is the current-carrying capacity.

[IEV 826-05-06, modified]

3.51

overload (of a circuit)

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

NOTE *Overload* should not be used as a synonym for *overcurrent*.

3.52

plug/socket combination

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

NOTE Examples of plug/socket combination include:

- connectors which fulfil the requirements of IEC 61984;
- a plug and socket-outlet, a cable coupler, or an appliance coupler in accordance with IEC 60309-1;
- a plug and socket-outlet in accordance with IEC 60884-1 or an appliance coupler in accordance with IEC 60320-1.

3.53

protective bonding

equipotential bonding for protection against electric shock

NOTE Measures for protection against electric shock can also reduce the risk of burns or fire.

3.54

protective bonding circuit

protective conductors and conductive parts connected together to provide protection against electric shock in the event of an insulation failure

3.55

protective conductor

conductor required for protective bonding by some measures for protection against electric shock for electrically connecting any of the following parts:

- exposed conductive parts;
- extraneous conductive parts;
- main earthing terminal (PE)

[IEV 826-04-05, modified]

NOTE "some measures" includes for example protection by automatic disconnection of supply.

3.56**protective interlock circuit**

type of safety circuit, the purpose of which is to prevent the operation of hazardous functions under specified conditions, and which starts at the point where the safety-related signals are generated and ends at the components used to eliminate the hazard or reduce the risk

3.57**readily accessible**

capable of being reached without requiring the use of tools, keys, portable ladders or platforms, climbing over or removing obstacles or barriers

3.58**reference designation**

distinctive code which serves to identify unambiguously an item in the documentation and on the electrical equipment

3.59**reinforced insulation**

insulation of hazardous-live-parts which provides a degree of protection against electric shock equivalent to double insulation

NOTE Reinforced insulation may comprise several layers which cannot be tested singly as basic insulation or supplementary insulation.

[IEV 195-06-09]

3.60**repair**

activities intended to return to proper working order fabrication equipment that has failed (see also 3.45)

3.61**residual current device****RCD**

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

NOTE 1 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.

NOTE 2 A GFCI (ground-fault circuit interrupter) is a specific kind of RCD.

[IEV 442-05-02, modified]

3.62**risk**

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

[ISO 12100-1, 3.11, modified]

3.63**safeguard**

guard or protective device provided as a means to protect persons from a hazard

3.64

safeguarding

protective measure using safeguards to protect persons from the hazards which cannot reasonably be eliminated or from the risks which cannot be sufficiently reduced by inherently safe design measures

[ISO 12100-1, 3.20]

NOTE Protective interlocks are examples of safeguarding.

3.65

safety circuit

circuit that carries out a safety function that is intended to maintain the safe condition of the fabrication equipment or prevent an increase of the risks under single fault conditions

NOTE Safety circuits include protective interlock circuits and emergency off (EMO) circuits.

3.66

servicing level

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

3.67

short-circuit current

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

[IEV 441-11-07]

3.68

short-circuit rating of the electrical equipment

maximum input current from the supply, resulting from a short-circuit fault, that the equipment can withstand under defined conditions

NOTE 1 This necessitates adequate co-ordination of protective devices within the equipment such that the short-circuit ratings of all the overcurrent protective devices in the equipment are at least equal to the prospective fault current at their points of connection within the equipment and adequate protection is provided by those devices.

NOTE 2 Where multiple input supplies are used for the electrical equipment (fabrication equipment) short-circuit current ratings are determined for each respective supply.

3.69

(electrically) skilled person

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

[IEV 826-09-01, modified]

3.70

supplementary insulation

independent insulation applied in addition to basic insulation, for fault protection

[IEV 195-06-08]

3.71

supplier

entity (for example manufacturer, contractor, installer, integrator) who provides the fabrication equipment or its associated equipment or services

NOTE The user organization may also act in the capacity of a supplier to itself.

3.72**switching device**

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

[IEV 441-14-01, modified]

NOTE A switching device may perform one or both of these actions.

3.73**touch voltage**

voltage between conductive parts when touched simultaneously by a person

[IEV 195-05-11, modified]

3.74**uncontrolled stop**

stopping of machine motion by removing electrical power to the machine actuators

NOTE This definition does not imply any particular state of other stopping devices, for example mechanical or hydraulic brakes.

3.75**uninterruptible power supply****UPS**

power source that is capable of supplying power to the electrical equipment after power from the facilities has been discontinued

3.76**user**

entity who utilizes the fabrication equipment and its associated electrical equipment

4 General requirements

4.1 General considerations

The risks associated with the hazards relevant to the electrical equipment shall be assessed as part of the overall requirements for risk assessment of the fabrication equipment. This will enable the determination of adequate risk reduction, and the necessary protective measures for persons who can be exposed to those hazards, while still maintaining an acceptable level of performance of the fabrication equipment.

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

- failures or faults in the electrical equipment resulting in the possibility of electric shock or electrical fire;
- failures or faults in control circuits (or components and devices associated with those circuits) resulting in the malfunctioning of the fabrication equipment that can increase risk;
- disturbances or disruptions in power sources as well as failures or faults in the electrical equipment resulting in the malfunctioning of the fabrication equipment that can increase risk;
- loss of continuity of circuits that depend upon sliding or rolling contacts, resulting in a failure of a safety function;
- electrical disturbances (for example electromagnetic, electrostatic either from outside the electrical equipment or internally generated, resulting in the malfunctioning of the fabrication equipment that can increase risk);
- release of stored energy (either electrical or mechanical) resulting in, for example, electric shock, unexpected movement that can cause injury;

- surface temperatures that can cause injury.

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

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

4.2 Selection of electrical equipment

Electrical components and devices that are used as part of a safety related system and those that handle hazardous voltage or hazardous electrical power shall be suitable for their intended use, be applied in accordance with their supplier's instructions; and

- conform to relevant IEC standards where such exist;
- as an alternative, conform to a relevant standard that is developed by a national standards organization and/or meet construction and test requirements of this document as is appropriate to the application.

4.3 Electrical supply

4.3.1 General

The electrical equipment shall operate correctly when connected to its specified electrical supply. The specifications for the supply shall include the following where appropriate:

- a.c. supply voltage with plus and minus tolerances;
- d.c. supply voltage with plus and minus tolerances.

The term "correct operation" in this context does not consider the quality of the fabricated product.

Interruptions in the facilities electrical supply shall not result in hazardous conditions.

4.4 Physical environment and operating conditions

4.4.1 General

The electrical equipment shall be suitable for use in the physical environment and operating conditions specified by the manufacturer of the fabrication equipment including the following environmental parameters:

- ambient air temperature range;
- limitations on altitude of installation;
- humidity of operating installation;
- electromagnetic environment.

NOTE 1 The generic EMC standards IEC 61000-6-1 or IEC 61000-6-2 and IEC 61000-6-3 or IEC 61000-6-4 give general EMC emission and immunity limits.

NOTE 2 IEC/TR 61000-5-2 gives guidelines for earthing and cabling of electrical and electronic systems aimed at ensuring EMC. If specific product standards or product family EMC standards exist (for example, IEC 61496-1, IEC 61800-3, IEC 60947-5-2, IEC 61326 series) they take precedence over generic standards.

4.4.2 Contaminants

Electrical equipment shall be adequately protected against the ingress of solid bodies and liquids likely to be present in the environment in which the electrical equipment is intended to be used. Electrical equipment shall be adequately protected against or resistant to degradation resulting from foreseeable chemical exposures.

4.4.3 Ionizing and non-ionizing radiation

When electrical equipment can be subject to radiation (e.g. microwave, ultraviolet, lasers, X-rays), additional measures shall be taken to avoid failures of the electrical equipment that can result in a hazardous situation.

4.4.4 Vibration, shock, and bump

Effects of vibration, shock and bump (including those generated by the fabrication equipment and those created by the physical environment) that can result in a hazardous situation shall be avoided by the selection of suitable electrical equipment, by mounting it away from the source of disturbance, or by provision of anti-vibration mountings.

4.5 Transportation and storage

Unless the manufacturer specifies different temperature and humidity ranges, the equipment shall withstand temperatures from -25°C to $+55^{\circ}\text{C}$ and for short periods not exceeding 24 h, $+70^{\circ}\text{C}$, and relative humidity from 10 % to 90 %.

NOTE Electrical equipment susceptible to damage at low temperatures includes PVC insulated cables.

Suitable means should be provided to prevent damage from humidity, vibration, and shock.

4.6 Provisions for handling

Heavy and bulky electrical equipment shall be provided with suitable means for handling, for example by mechanical handling equipment.

4.7 Installation

Electrical equipment shall be installed in accordance with the electrical equipment supplier's instructions.

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

5.1 Incoming supply conductor terminations

5.1.1 General

It is recommended that, where practicable, there should be a single point of connection for the incoming electrical supply. Where another supply is necessary for certain parts of the electrical equipment (for example, electronic equipment that operates at a different voltage), that supply should be derived, as far as is practicable, from devices (for example, transformers, converters) forming part of the electrical equipment. For large complex fabrication equipment comprising a number of widely-spaced subsystems working together in a co-ordinated manner, there can be a need for more than one incoming supply depending upon the site supply arrangements (see 5.3.1).

5.1.2 Termination of the supply conductors

Unless the electrical equipment is cord and plug connected (see 5.3.2 d)), it is recommended that the supply conductors be terminated at the supply disconnecting device.

5.1.3 Neutral conductor

Where a neutral conductor is used it shall be clearly indicated in the technical documentation of the fabrication equipment, such as in the installation diagram and in the circuit diagram, and a separate insulated terminal, labelled N or "Neutral" in accordance with 16.1, shall be provided for the neutral conductor.

There shall be no connection between the neutral conductor and the protective bonding circuit nor shall a combined PEN terminal be provided.

EXCEPTION: A connection may be made between the neutral terminal and the PE terminal at the point of the connection of the power supply for TN-C systems.

5.1.4 Terminal identification

All terminals for the incoming supply connection shall be clearly identified with one of the following:

- "U", "V", and "W"
- "L1", "L2", and "L3"

For the identification of the external protective conductor terminal, see 5.2.

5.2 Terminal for connection to the external protective earthing system

For each incoming supply, a terminal shall be provided in the vicinity of the associated phase conductor terminals for connection to the external protective earthing system or to the external protective conductor, depending upon the supply distribution system.

NOTE This is intended to facilitate the provision of an external protective earthing system or external protective conductor in association with the incoming supply conductors.

The terminal shall be of such a size as to enable the connection of an external protective copper conductor with a cross-sectional area in accordance with Tables C.1 to C.5. At each incoming supply point, the terminal for connection of the external protective earthing system or the external protective conductor shall be marked or labelled with the letters PE and/or the symbol IEC 60417-5019 (2006-08) (see IEC 60445):



5.3 Supply disconnecting (isolating) device

5.3.1 General

A supply disconnecting device shall be provided:

- for each incoming source of supply to the fabrication equipment;

NOTE The incoming supply can be connected directly to the machine or via a feeder system. Feeder systems can include conductor wires, conductor bars, slip-ring assemblies, flexible cable systems (reeled, festooned) or inductive power supply systems.

- for the output of each UPS, in accordance with 5.3.7.

Each supply disconnecting device shall remove electrical power from the load side of the disconnecting device when it is opened (for example for work on the fabrication equipment, including the electrical equipment).

Where two or more supply disconnecting devices are provided, interlocks shall be provided as necessary to prevent a hazardous situation.

When two or more supply disconnecting devices are present each shall be provided with marking such as “WARNING: Risk of Electric Shock or Burn. Disconnect all [number of feed locations] sources of electrical supply prior to maintenance or repair”

5.3.2 Type

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

- a) a switch-disconnector, with or without fuses, utilization category AC-23B or DC-23B;
- b) a disconnector, with or without fuses, that has an auxiliary contact that in all cases causes switching devices to break the load circuit before the opening of the main contacts of the disconnector;
- c) a circuit-breaker suitable for isolation;
- d) a plug/socket combination under the following conditions:
 - the plug/socket combination shall be connected so that the part connected to the incoming supply is protected to at least IP2X or IPXXB, and either
 - the rated current does not exceed 16 A and total power rating does not exceed 3 kW; or
 - where the rated current exceeds 16 A or the total power rating does not exceed 3 kW,
 - it shall not be possible to connect or disconnect a plug/socket combination without adequate breaking capacity, during load conditions;
 - where a plug/socket combination with breaking capacity is used, it shall have a breaking capacity of at least the rated current of the machine at rated voltage. Where a plug/socket combination is used for disconnection under overload (e.g. locked rotor), the rating should be at least locked rotor current. In addition, the electrical equipment shall have a device for switching the machine on and off.

NOTE For switch-disconnectors and disconnectors, see IEC 60947-3. For circuit-breakers suitable for isolation, see IEC 60947-2.

5.3.3 Requirements

When the supply disconnecting device is one of the first three types specified in 5.3.2 (i.e. a switch-disconnector, a disconnector used in combination with switching devices, or a circuit-breaker), it shall fulfil all of the following requirements:

- a) isolate the electrical equipment from the supply and have one OFF (isolated) and one ON position marked with "O" and "I" (symbols IEC 60417-5008 (2002-10) and IEC 60417-5007 (2002-10), see 10.2.2); a 'tripped' position is also permitted in the case of circuit-breakers;
- b) have a visible contact gap or a position indicator which cannot indicate OFF (isolated) until all contacts are actually open and the requirements for the isolating function have been satisfied;
- c) have an external operating means (for example handle);
- d) be provided with a means (integral or external) permitting it to be locked only in the OFF (isolated) position (for example by padlocks). When so locked, remote as well as local closing shall be prevented;
- e) disconnect all live conductors of its power supply circuit. However, for TN supply systems, the neutral conductor may or may not be disconnected except in countries where disconnection of the neutral conductor is compulsory. Where the neutral conductor can be disconnected it shall be disconnected simultaneously with the phase conductors;

NOTE A TN system is one in which one point is directly earthed, with a protective conductor (PE) directly connected to that point. See Annex E and IEC 60364-1.

- f) have a breaking capacity sufficient to interrupt the current of the largest motor when stalled together with the sum of the normal running currents of all other motors and/or loads that can be operated at any time.

5.3.4 Operating means

The operating means (for example, a handle) of the supply disconnecting device shall be readily accessible and located not more than 2 m above the servicing level. A height of between 0,6 m and 1,7 m is recommended.

NOTE The direction of operation is given in IEC 61310-3.

5.3.5 Supply disconnecting device mounting

The supply disconnecting device shall be installed in accordance with one or more of the following:

- a) in its own electrical enclosure on or adjacent to the equipment for which it provides a disconnecting means;
- b) near the top of the electrical enclosure for which it provides a disconnecting means;
- c) anywhere below the top of the electrical enclosure for which it provides a disconnecting means provided that its incoming terminations are guarded to prevent accidental contact by personnel or by a tool dropped from above. Compliance can be demonstrated by verifying that a probe 3 mm in diameter and 15 mm long cannot contact live parts (see test probe 13 of IEC 61032).

EXCEPTION: Machines with a nominal power consumption of 1 500 W or less may be connected to a remotely mounted supply disconnecting device, provided that device is readily accessible and no more than 6 m from the machine.

5.3.6 Supply disconnecting device door interlock

Doors that provide access to live parts of the supply disconnecting device, shall be interlocked so that the door can only be opened when the supply disconnecting device is open and so that the supply disconnecting device can only be closed when the door is closed.

A tool or special device as prescribed by the supplier may be provided to permit skilled and instructed persons to defeat the interlock, provided that protection is provided against inadvertent contact with hazardous-live-parts inside the enclosure by the measures defined in 6.5.

EXCEPTION: Supply disconnecting device door interlocking need not be provided where protection is provided against inadvertent contact with hazardous-live-parts inside the enclosure by the measures defined in 6.5 for loads that:

- are rated less than 5 KVA, or
- consist of lighting circuits, or
- are cord and plug connected electrical equipment.

5.3.7 UPS disconnection

The output of each UPS that can supply greater than 30 V r.m.s., 42.4 V peak, 60 V d.c. or 240 VA, shall be disconnected when the main disconnecting device is opened or shall be provided with a disconnecting means that satisfies all the requirements for the supply disconnecting device in 5.3.1 to 5.3.5, or both. The UPS output wiring and terminals shall be labelled as “UPS Output”, or equivalent, at each connection point where the UPS wiring can be disconnected.

All power supplied from the UPS shall be disconnected when the emergency off-actuator is activated.

EXCEPTION: power supplied from the UPS to safety related devices (including EMO circuits) and computer systems that perform functions such as data/alarm logging and error recovery is excepted from this requirement.

5.4 Additional disconnecting devices

Where it can be necessary to perform work on parts of the fabrication equipment (e.g. motors) when they are de-energized and isolated while leaving other parts of the electrical equipment energized, then a separate disconnecting device shall be provided for each part requiring separate isolation.

Such disconnecting devices should be:

- appropriate and convenient for the intended use;
- suitably located;
- readily identifiable as to which part or circuit(s) of the electrical equipment is served (e.g. by durable marking where necessary).

Means shall be provided to prevent unauthorized, inadvertent, and/or mistaken closure of these devices (e.g. provisions for locking).

Motors installed in a location from which the supply disconnecting device is not visible (for example in a chase or sub-fab) shall be provided with an additional means of disconnecting all unearthed conductors within sight of, and not more than 3 m distance from, the motor. These means of disconnecting shall meet the requirements of 5.3.1 to 5.3.5.

5.5 Protection against unauthorized, inadvertent and/or mistaken connection of plug/socket combination

When a plug/socket combination is used as a supply disconnecting means during maintenance or repair, in addition to meeting the requirements of 5.3.2 d), it shall either be capable of being kept under the exclusive supervision of the person carrying out the maintenance or repair, or it shall be provided with a lockable means to ensure it remains in a disconnected state.

6 Protection against electric shock

6.1 General

The electrical equipment shall provide protection of persons against electric shock from:

- direct contact;
- indirect contact.

NOTE It is considered that some of the protection of skilled persons is provided by their training and experience.

Skilled and instructed persons are those having appropriate technical training and experience to be aware of hazards to which they are exposed. Skilled and instructed persons shall be protected against inadvertent and unexpected hazards in accordance with 6.5.

The recommended measures for this protection are given in 6.2, 6.3, 6.4, and 6.5.

6.2 Protection against direct contact

6.2.1 General

For each circuit or part of the electrical equipment, the measures of either 6.2.2 or 6.2.3 and, where applicable, 6.2.4 shall be applied.

When the electrical equipment is located in places open to persons other than skilled and instructed persons, measures of either 6.2.2 with a minimum degree of protection against direct contact corresponding to IP2X/IPXXB (see IEC 60529), or 6.2.3 shall be applied.

6.2.2 Protection by enclosures

Opening an enclosure other than that of the supply disconnecting device (see 5.3.6) that contains hazardous-live-parts (i.e. opening doors, lids, covers, and the like) shall be possible only under one of the following conditions:

- a) The use of a key or tool is necessary for access.

NOTE The necessity to use a key or tool is intended to restrict access to skilled or instructed persons.

Skilled and instructed persons shall be protected against inadvertent contact with hazardous-live-parts inside the enclosure by the measures defined in 6.5.

- b) The disconnection of hazardous-live-parts inside the enclosure before the enclosure may be opened. This shall either be accomplished by a mechanical and/or electrical interlock so that the door can only be opened when the hazardous supply is disconnected and so that the hazardous supply can only be connected when the door is closed. If an electrical interlock is used it shall meet all the requirements of Clause 9 for a protective interlock circuit.

EXCEPTION: a special device or tool as prescribed by the supplier may be provided to permit skilled and instructed persons to defeat the interlock, provided that protection is provided against inadvertent contact with hazardous-live-parts inside the enclosure by the measures defined in 6.5.

Any hazardous-live-parts that are not disconnected shall be marked with a warning sign in accordance with 17.2, except for the supply terminals of the supply disconnecting device when it is mounted alone in a separate enclosure.

- c) Opening without the use of a key or a tool and without disconnection of hazardous-live-parts shall be possible only when all hazardous-live-parts are protected against direct contact to at least IP2X or IPXXB (see IEC 60529). Where protection is removable, either it shall require a tool for its removal or all live parts protected by it shall be automatically disconnected when the protection is removed.

6.2.3 Protection by insulation of live parts

Live parts protected by insulation shall be completely covered with insulation that can only be removed by destruction. Such insulation shall be capable of withstanding the mechanical, chemical, electrical, and thermal stresses to which it can be subjected under normal operating conditions.

NOTE Paints, varnishes, lacquers, and similar products alone are generally considered to be inadequate for protection against electric shock under normal operating conditions.

6.2.4 Protection against residual voltages

Live parts having a residual voltage greater than 60 V after the supply has been disconnected shall be discharged to 60 V and 20 J or less within a time period of 10 s after disconnection of the supply voltage provided that this rate of discharge does not interfere with the proper functioning of the fabrication equipment.

Electrical equipment that cannot be discharged to this level in 10 s is exempted from this requirement if the following conditions are satisfied:

- the conductors supplied with stored energy cannot be accessed without the removal of a panel that requires a tool to remove; and
- the panel that is removed to access those conductors is marked specifying the discharge time required for the discharge conditions to be less than both 60 V and 20 J; and
- the discharge time does not exceed 5 min.

In the case of plugs or similar devices, the withdrawal of which results in the exposure of conductors (for example pins), the discharge time shall not exceed 1 s, otherwise such conductors shall be protected against direct contact to at least IP2X or IPXXB. If neither a discharge time of 1 s nor a protection of at least IP2X or IPXXB can be achieved, additional switching devices or an appropriate warning device (for example a warning notice in accordance with 16.1) shall be applied.

NOTE Voltage supplied by a UPS is considered to be a battery source and is not considered to be a residual voltage.

6.3 Protection against indirect contact

6.3.1 General

Protection against indirect contact (3.38) is intended to prevent hazardous situations due to an insulation fault between live parts and exposed conductive parts.

For each circuit or part of the electrical equipment, at least one of the following measures in accordance with 6.3.2 to 6.3.3 shall be applied:

- measures to prevent the occurrence of a touch voltage (6.3.2), or
- automatic disconnection of the supply before the time of contact with a touch voltage can become hazardous (6.3.3).

NOTE 1 The risk of harmful physiological effects from a touch voltage depends on the value of the touch voltage and the duration of possible exposure.

NOTE 2 For classes of electrical equipment and protective provisions, see IEC 61140.

6.3.2 Prevention of the occurrence of a touch voltage

6.3.2.1 General

Measures to prevent the occurrence of a touch voltage include the following:

- provision of class II equipment or by equivalent insulation;
- electrical separation.

6.3.2.2 Protection by provision of class II equipment or by equivalent insulation

This measure is intended to prevent the occurrence of touch voltages on the accessible parts through a fault in the basic insulation. See IEC 60364-4-41.

NOTE Examples of this measure include:

- class II electrical devices or apparatus (see 3.14);
- switchgear and controlgear assemblies having total insulation in accordance with IEC 61439-1.

6.3.2.3 Protection by electrical separation

6.3.2.3.1 General

Electrical separation of an individual circuit is intended to prevent a hazardous touch voltage through contact with exposed conductive parts that can be energized by a fault in the basic insulation of the live parts of that circuit. In order to provide this type of protection either the requirement of both sub-clauses 6.3.2.3.2 and 6.3.2.3.3 shall be satisfied or the requirements for electrical separation in IEC 60364-4-41 shall be satisfied.

6.3.2.3.2 Isolated power systems

The circuit to be protected by electrical separation shall have a high impedance between its conductors and the incoming supply connection to the equipment and a high impedance to earth. Impedance of one megohm or more is considered to be sufficiently high. This can be achieved by the use of isolation transformers or power supplies that have no direct electrical connection between their primary conductors and their secondary conductors.

NOTE 1 An isolation transformer with one conductor of the secondary connected to ground is not an isolated power system.

NOTE 2 Auto transformers do not provide electrical isolation.

NOTE 3 Isolated power systems are commonly used to reduce sources of electronic noise by not deliberately referencing the output circuit conductors to earth (ground).

6.3.2.3.3 Requirements for isolated circuits

Isolated circuits shall meet the following requirements:

- the transformer or power supply, and any components (devices) connected to their output, shall be clearly labeled adjacent to the isolated circuit(s) or on the enclosure to warn operators and service personnel of the unearthed condition, and
- earth fault detection lights, an insulation monitoring device, or a device that interrupts the circuit automatically in the event of an earth fault (for example, a ground-fault circuit-interrupter (GFCI)), shall be installed.

6.3.3 Protection by automatic disconnection of supply

This protective measure consists of the interruption of one or more of the line conductors by the automatic operation of a protective device in case of an insulation fault. It is intended to prevent a hazardous situation by interrupting the supply within a sufficiently short time to limit the duration of a touch voltage to a time within which that voltage is not hazardous. While the use of TN systems is preferred because of the lower touch voltage on exposed and extraneous conductive parts in the event of an earth fault, TT systems in accordance with the relevant parts of IEC 60364 may be used where the distribution system provides no PEN or PE conductor.

Requirements for TN supply systems are given in Annex A. A protective circuit impedance in accordance with 18.2.5 can be considered sufficiently low to meet the requirements of Annex A.

NOTE 1 A TT supply system is one in which one point is directly earthed but the protective conductor (PE) of the equipment is not directly connected to that earth point of the electrical supply system. See Annex E and IEC 60364-1.

Requirements for TT supply systems are given in Annex B.

NOTE 2 TN supply systems are commonly preferred over TT supply systems.

NOTE 3 In Japan TT supply systems are commonly used.

NOTE 4 This protective measure can necessitate co-ordination between:

- the type of supply and earthing system;
- the impedance values of the different elements of the protective bonding system;
- the characteristics of the protective devices that detect insulation fault(s).

This protective measure comprises both protective bonding of exposed conductive parts (see 8.2.3), and one of the following:

- a) overcurrent protective devices for automatic disconnection of the supply on detection of an insulation fault in TN systems, or

- b) residual current protective devices to initiate the automatic disconnection of the supply on detection of an insulation fault from a live part to exposed conductive parts or to earth in TT systems, or
- c) insulation monitoring or residual current protective devices to initiate automatic disconnection of IT systems. Except where a protective device is provided to interrupt the supply in the case of the first earth fault, an insulation monitoring device shall be provided to indicate the occurrence of a first fault from a live part to exposed conductive parts or to earth. This insulation monitoring device shall initiate an audible and/or visual signal which shall continue as long as the fault persists.

Where automatic disconnection is provided in accordance with a), and disconnection within the time specified in Clause A.1 cannot be assured, supplementary bonding shall be provided as necessary to meet the requirements of Clause A.3.

6.4 Protection by the use of PELV

6.4.1 General requirements

The use of PELV (protective extra-low voltage) is intended to protect persons against electric shock from indirect contact and limited area direct contact (see 8.2.5).

PELV circuits shall satisfy all of the following conditions:

- a) the nominal voltage shall not exceed:
 - 25 V a.c. r.m.s. or 60 V ripple-free d.c. when the fabrication equipment is normally used in dry locations and when large area contact of live parts with the human body is not expected; or
 - 6 V a.c. r.m.s. or 15 V ripple-free d.c. in all other cases;

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

- b) one side of the circuit or one point of the source of the supply of that circuit shall be connected to the protective bonding circuit;
- c) live parts of PELV circuits shall be electrically separated from other live circuits. Electrical separation shall be not less than that required between the primary and secondary circuits of a safety isolating transformer (see IEC 61558-1 and IEC 61558-2-6);
- d) conductors of each PELV circuit shall be physically separated from those of any other circuit. When this requirement is impracticable, the insulation provisions of 13.1.3 shall apply;
- e) plugs and socket-outlets for a PELV circuit shall conform to the following:
 - plugs shall not be able to enter socket-outlets of other voltage systems;
 - socket-outlets shall not admit plugs of other voltage systems.

6.4.2 Sources for PELV

The source for PELV shall be one of the following:

- a safety isolating transformer in accordance with IEC 61558-1 and IEC 61558-2-6;
- a source of current providing a degree of safety equivalent to that of the safety isolating transformer (for example a motor generator with winding providing equivalent isolation);
- an electrochemical source (for example a battery) or another source independent of a higher voltage circuit (for example a diesel-driven generator);
- an electronic power supply conforming to appropriate standards specifying measures to be taken to ensure that, even in the case of an internal fault, the voltage at the outgoing terminals cannot exceed the values specified in 6.4.1.

6.4.3 Design to minimise risks of live working

The electrical equipment shall be designed to minimize the need to calibrate, modify, repair, test, adjust, or maintain equipment while it is energized, and to minimize the need for work to be performed on components near exposed hazardous energized circuits.

Appropriate safety procedures (e.g., use of appropriate personal protective equipment and barriers) for troubleshooting, shall be described in the instructions for use. See 17.2.

6.5 Protection of skilled persons and instructed persons against inadvertent contact with hazardous-live-parts

6.5.1 General

Inadvertent contact to circuits that are not PELV shall be prevented by design. Persons shall not be inadvertently exposed to electrical or mechanical hazards while performing manual adjustments. Adequate access shall be provided for maintenance and repair. Where maintenance and repair personnel need to access the electrical equipment while it is energized, live parts (other than PELV) shall be protected against inadvertent contact by the provision of obstacles. Obstacles shall be provided where it is necessary to reach over, under, around, or close to electrical hazards. They shall also be provided where dropped objects or failure of liquid fittings could result in short circuits or arcing.

6.5.2 Obstacles

Obstacles that are used to protect against inadvertent contact shall be made of non-conductive material or if made of conductive material they shall be earthed. They shall be of substantial construction sufficient to withstand foreseeable abuse.

6.5.3 Probe holes

When necessary for electrical testing, probe holes shall be provided in the obstacles. These probe holes shall be located over test points and designed to protect against inadvertent contact with live parts. They should also provide adequate access for a test probe where it is needed and they shall be identified in the information for use (see 17.2). Where obstacles are of conductive material the perimeter of the probe holes shall be insulated.

7 Protection of equipment

7.1 General

This Clause details the measures to be taken to protect equipment against the effects of:

- overcurrent including the effect of a short circuit;
- overload and/or loss of cooling of motors;
- abnormal temperature;
- loss of or reduction in the supply voltage;
- overspeed of machines/machine elements;
- earth fault/residual current;
- incorrect phase sequence;
- overvoltage due to lightning and switching surges.

7.2 Overcurrent protection

7.2.1 General

Overcurrent protection shall be provided in all circuits that can be supplied with hazardous electrical power under normal operations or single fault conditions where current can exceed either the rating of any component or the current carrying capacity of the conductors, whichever is the lesser value. The ratings or settings to be used are detailed in 7.2.9.

7.2.2 Supply conductors

The supplier of the electrical equipment is not responsible for providing the overcurrent protective device for the supply conductors to the electrical equipment.

The supplier of the electrical equipment shall state on the installation documentation the data necessary for selecting the overcurrent protective device (see 7.2.9 and 17.4).

7.2.3 Neutral conductor protection

In TN or TT systems, neutral conductors shall not be disconnected without disconnecting the associated live conductors. Where the cross-sectional area of the neutral conductor is at least equal to or equivalent to that of the phase conductors, it is not necessary to provide overcurrent detection for the neutral conductor nor automatic disconnection for that conductor. For a neutral conductor with a cross-sectional area smaller than that of the associated phase conductors, the measures detailed in 431.2.1 of IEC 60364-4-43 shall apply.

In IT systems, it is recommended that the neutral conductor is not used. However, where a neutral conductor is used, the recommendations detailed in 431.2.2 of IEC 60364-4-43 are applicable.

NOTE An IT system is a distribution system that is not directly earthed. See Annex F.

7.2.4 Socket outlets and their associated conductors

Where general purpose socket outlets are provided for supplying power to maintenance equipment, overcurrent protective devices shall be provided in the unearthed live conductors of each circuit feeding such socket outlets in accordance with 7.2.9.

7.2.5 Lighting circuits

All unearthed conductors of circuits supplying lighting shall be protected against the effects of short circuits by the provision of overcurrent devices independent of those protecting other circuits in accordance with 7.2.9.

7.2.6 Transformers

Transformers shall be protected against overcurrent in accordance with the transformer manufacturer's instructions and with 7.2.9. If the manufacturer's instructions differ from the requirements of 7.2.9, the more stringent requirements shall apply.

7.2.7 Location of overcurrent protective devices

An overcurrent protective device shall be located at the point where a reduction in the cross-sectional area of each conductor or another change reduces the current-carrying capacity of the conductor such that it is not protected by the upstream protective device, except where all the following conditions are satisfied:

- the current carrying capacity of the conductor is at least equal to that of the load;
- the part of the conductor between the point of reduction of current-carrying capacity and the position of the overcurrent protective device is no longer than 3 m;

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

7.2.8 Overcurrent protective devices

7.2.8.1 General

The short-circuit rating of overcurrent protective devices shall be at least equal to the prospective fault current at their point of connection when the equipment is connected to an incoming supply as specified by the equipment manufacturer. Where the short-circuit current to an overcurrent protective device can include additional currents other than from the supply (for example from motors, from power factor correction capacitors), those currents shall be taken into consideration.

The characteristics of two series connected OCPDs devices shall be coordinated so that the let-through energy (I^2t) of the two devices in series does not exceed that which can be withstood without damage to the overcurrent protective device on the load side and to the conductors protected by that device. This can be determined by tests and/or by calculation.

NOTE 1 See for example Annex A of IEC 60947-2. Other techniques for the evaluation can be found in, for example, SEMI S.22, UL 508A.

NOTE 2 The use of such a co-ordinated arrangement of overcurrent protective devices can result in the operation of both overcurrent protective devices.

NOTE 3 Circuit breakers are commonly preferred to fuses.

Overcurrent protective devices include fuses and circuit-breakers. Electronic devices designed to reduce or to limit the current in protected circuits may also be used.

7.2.8.2 Additional requirements for fuses

When fuses are provided they shall be in fixed fuse holders.

7.2.8.3 Additional requirements for circuit-breakers

All circuit breakers shall have the OFF (isolated) position and ON position clearly marked with "O" and "I" (symbols IEC 60417-5008 (2002-10) and IEC 60417-5007 (2002-10), see 10.2.2).

Actuating directions shall be in accordance with the following:

- a) Circuit breakers that are mounted on a vertical surface and vertically oriented shall be mounted with the handle up for the "ON" position.
- b) Circuit breakers that are mounted on a vertical surface and horizontally oriented shall be mounted with the handle to the right for the "ON" position.
- c) Circuit breakers that are mounted in two columns, horizontally oriented, shall be mounted with the handles toward the centre for the "ON" position; or clearly marked indicating the "ON" and "OFF" positions.
- d) Circuit breakers that are mounted on a horizontal surface shall be mounted with the handle to the right for the "ON" position.

7.2.9 Rating and setting of overcurrent protective devices

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

Overcurrent protection shall be limited as follows.

- a) Conductors and plug/socket combinations shall have overcurrent protection that does not exceed their rating.
- b) The overcurrent protection of other devices or components, with the exception of motors, shall not exceed 125 % of the current rating of the device or component or 125 % of maximum nominal load.
- c) Non-process lighting circuits shall have overcurrent protection at not greater than 15 A.
- d) Transformers that operate at 50/60 Hz shall be protected in accordance with Table 1 or Table 2 as appropriate.

Table 1 – Protection of transformers without thermal protection

Transformer primary rating	Transformer secondary rating	Maximum primary protection percentage of rating	Maximum secondary protection percentage of rating
Any rating	≥ 9 A	250	125
Any rating	< 9 A	250	167
≥ 9 A	Any rating	125	Not required
< 9 A and > 2 A	Any rating	167	Not required
≤ 2 A	Any rating	300	Not required

Table 2 – Protection of transformers with thermal protection

Transformer impedance	Maximum primary protection percent of rating (see Note)	Maximum secondary protection percent of rating (see Note)
≤ 6 %	600	125
> 6 % and < 10 %	400	125

NOTE Where the rating does not match a standard overcurrent device rating, the next standard size is permitted.

In all cases, the next larger standard size of overcurrent device from the calculated value may be used to satisfy this requirement.

7.3 Protection of motors against overheating

7.3.1 General

Protection of motors against overheating shall be provided for each motor consuming more than 240 VA.

Protection of motors against overheating can be achieved by:

- overload protection (7.3.2), or

NOTE 1 Overload protective devices detect the time and current relationships (I^2t) in a circuit that are in excess of the rated full load of the circuit and initiate appropriate control responses.

- over-temperature protection (7.3.3),

NOTE 2 Temperature detection devices sense over temperature and initiate appropriate control responses.

Automatic restarting of any motor after the operation of protection against overheating shall be prevented where this can cause a hazardous situation or damage to the machine.

Motor installation shall provide for proper cooling to maintain temperature within the motor rating.

7.3.2 Overload protection

Where overload protection is provided, detection of overload(s) shall be provided in each live conductor except for the neutral conductor. For motors having single-phase or d.c. power supplies, detection in only one unearthed live conductor is permitted.

Where overload protection is achieved by switching off, the switching device shall switch off all live conductors. The switching of the neutral conductor is not necessary for overload protection.

Unless suitable overload protection for the motor is provided by power conversion equipment, overload protection shall be provided external to the power conversion equipment.

Where motors with special duty ratings are required to start or to brake frequently (for example, motors for rapid traverse, locking, rapid reversal, sensitive drilling) it can be difficult to provide overload protection with a time constant comparable with that of the winding to be protected. Appropriate protective devices designed to accommodate special duty motors or over-temperature protection (see 7.3.3) can be necessary.

For motors that cannot be overloaded (for example torque motors, motion drives that either are protected by mechanical overload protection devices or are adequately dimensioned), overload protection is not required.

7.3.3 Over-temperature protection

The provision of motors with over-temperature protection in accordance with IEC 60034-11 is recommended in situations where the cooling can be impaired. Depending upon the kind of motor, protection under stalled rotor or loss of phase conditions is not always ensured by over-temperature protection, and additional protection should then be provided.

Over-temperature protection is also recommended for motors that cannot be overloaded (for example torque motors, motion drives that either are protected by mechanical overload protection devices or are adequately dimensioned), where the possibility of over-temperature exists (for example due to reduced cooling).

7.4 Motor overspeed protection

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

The overspeed protection should operate in such a manner that the maximum permissible speed of the motor or its load is not exceeded.

NOTE This protection can consist, for example, of a centrifugal switch or speed limit monitor.

7.5 Abnormal temperature detection

Resistance heating or other circuits that are capable of attaining or causing abnormal temperatures (for example, due to short-time rating or loss of cooling medium) shall be provided with suitable detection to initiate an appropriate control response.

Where abnormal temperature can cause a hazardous situation, protective interlock functions shall be provided in accordance with 9.4.1.

7.6 Protection against supply interruption or voltage reduction and subsequent restoration

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

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

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

Where only a part of the fabrication equipment is affected by the voltage reduction or supply interruption, the undervoltage protection shall initiate appropriate control responses to ensure co-ordination with other parts of the equipment, to protect against any potentially hazardous situations resulting in the equipment.

7.7 Earth fault/residual current protection

In addition to providing overcurrent protection for automatic disconnection as described in 6.3, earth fault/residual current protection can be provided to reduce damage to electrical equipment due to earth fault currents less than the detection level of the overcurrent protection.

The setting of the devices should be as low as possible consistent with correct operation of the electrical equipment.

7.8 Phase sequence protection

Where an incorrect phase sequence of the supply voltage can cause a hazardous situation or damage to the fabrication equipment, suitable protection shall be provided, such as a hardware device or phase marking and appropriate warnings or cautions.

7.9 Protection against overvoltages due to lightning and to switching surges

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

Where provided:

- devices for the suppression of overvoltages due to lightning shall be connected to the incoming terminals of the supply disconnecting device.
- devices for the suppression of overvoltages due to switching surges shall be connected across the terminals of all electrical equipment requiring such protection.

7.10 Electrolytic capacitors

Where practicable capacitors that are greater than 25,4 mm (1,0 in) in diameter or are capable of storing more than 4 J should:

- a) be self-vented or protected from rupture by equivalent means. Capacitor vents should be unobstructed for a minimum of 5,1 mm (0,2 in);
- b) have containment provisions within the capacitor itself or be shielded such that vapours or debris will not become hazardous to personnel;
- c) have terminals that are insulated or protected from short circuits by tools. Lacquer and sealing compounds shall not be relied upon to provide protection.

EXCEPTION: These recommendations need not apply to capacitors that are components of a product conforming to an IEC product standard (e.g., capacitors that are included in an Adjustable Speed Drive conforming to IEC 61800-5-1).

8 Equipotential bonding

8.1 General

This Clause provides requirements for both protective bonding and functional bonding. Figure 1 illustrates those concepts.

Protective bonding is a basic provision for fault protection to enable protection of persons against electric shock from indirect contact (see 6.3.3 and 8.2).

The objective of functional bonding (see 8.3) is to minimize:

- the consequence of an insulation failure which could affect the operation of the machine ;
- the consequences of electrical disturbances to sensitive electrical equipment which could affect the operation of the machine.

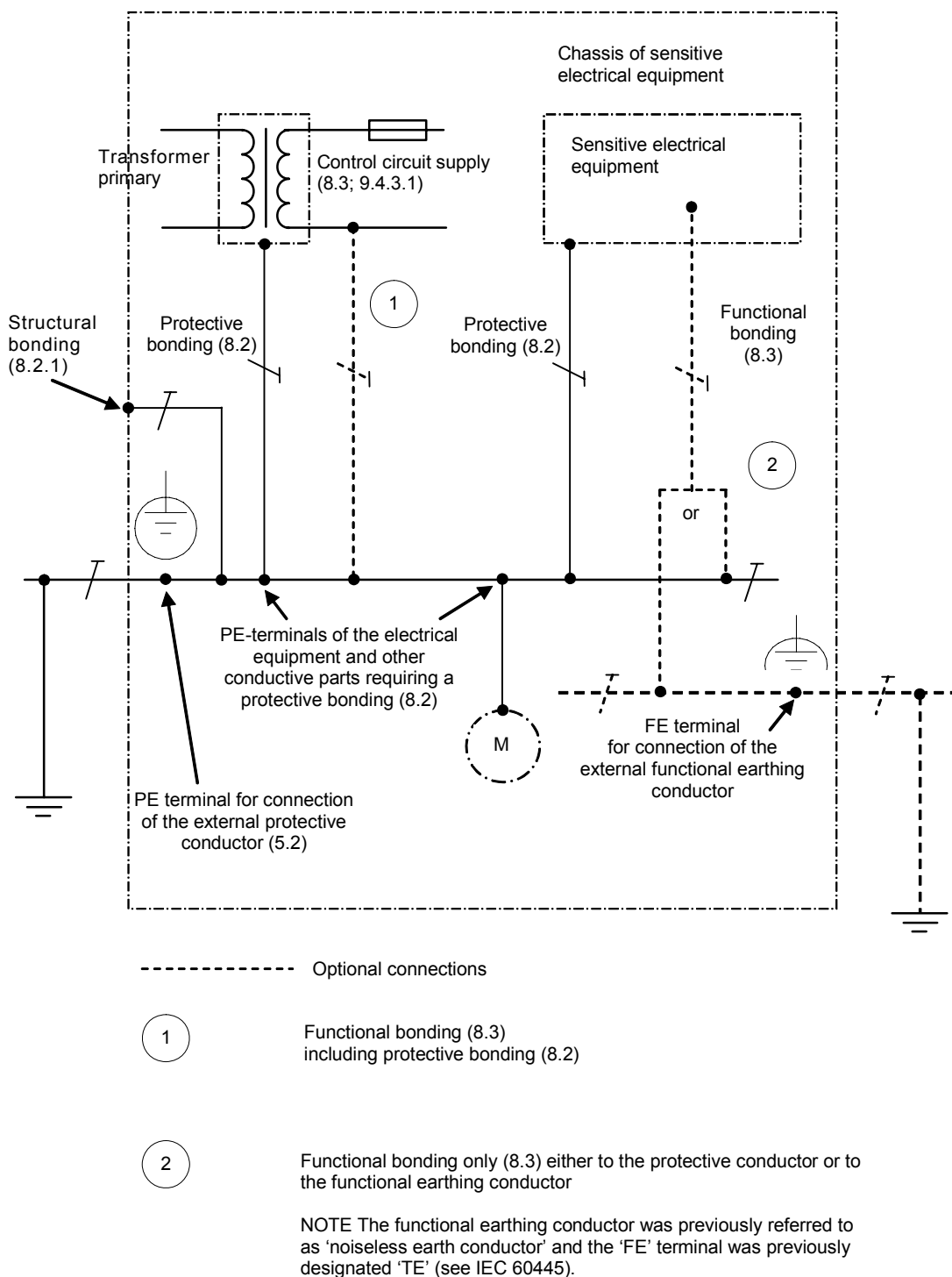
Normally functional bonding is achieved by connection to the protective bonding circuit, but where the level of electrical disturbances on the protective bonding circuit is not sufficiently low for proper functioning of electrical equipment, it can be necessary to connect the functional bonding circuit to a separate functional earthing conductor (see Figure 1). Functional bonding to enhance the immunity of the electrical equipment against conducted and radiated RF disturbance can include:

- a) connection of sensitive electrical circuits to the chassis:
 - such terminations should be marked or labelled with the symbol IEC 60417-5020 (2002-10):



- connection of the chassis to earth (PE) using a conductor with low RF impedance and as short as practicable;
- b) connection of sensitive electrical equipment or circuits directly to the PE circuit or to a functional earthing conductor (FE) (see Figure 1), to minimize common mode disturbance. The FE terminal should be marked or labelled by the symbol IEC 60417-5018 (2002-10):





IEC 2178/09

Figure 1 – Example of equipotential bonding for electrical equipment

8.2 Protective bonding circuit

8.2.1 General

8.2.1.1 Overview

The protective bonding circuit consists of:

- PE terminal(s) (see 5.2);
- the protective conductors in the electrical equipment including sliding contacts where they are part of the circuit;
- the exposed conductive parts and conductive structural parts of the electrical equipment;
- those extraneous conductive parts which form the structure of the semiconductor fabrication equipment.

8.2.1.2 Thermal and mechanical stresses

All parts of the protective bonding circuit shall be so designed that they are capable of withstanding the highest thermal and mechanical stresses that can be caused by earth-fault currents that could flow in that part of the protective bonding circuit.

NOTE 1 Particular attention is necessary to ensure sufficient mechanical integrity of the protective bonding circuit in the case of equipment having high earth leakage currents.

NOTE 2 Earth leakage current is defined as "current flowing from the live parts of an installation to earth, in the absence of an insulation fault" (IEV 442-01-24). This current may have a capacitive component including that resulting from the deliberate use of capacitors.

8.2.1.3 Current-carrying capacity

All parts of the protective bonding circuit shall have sufficient current-carrying capacity to withstand the fault current that can occur in that part of the protective bonding circuit.

NOTE Bonding conductors in accordance with 8.2.2 are considered to meet this requirement.

8.2.1.4 Supplementary bonding conductor

Where a conductive structural part can become the path for fault currents, it shall have an impedance sufficiently low to ensure a fault clearing time to satisfy the requirements of Annex A or be provided with a supplementary protective bonding conductor. An impedance lower than 0,1 Ω is considered to be sufficiently low.

A supplementary protective bonding conductor connecting two exposed conductive parts shall have a conductance not less than that of the smaller protective conductor connected to the exposed conductive parts.

A supplementary protective bonding conductor connecting exposed conductive parts to extraneous conductive parts shall have a conductance not less than that of the cross-sectional area of the corresponding protective conductor.

NOTE 1 Derived from 544.2 of IEC 60364-5-54:2002.

NOTE 2 See 6.3.3.

8.2.1.5 IT distribution

If an IT distribution system is used, the structure shall be part of the protective bonding circuit in conjunction with insulation monitoring. In large fabrication equipment this can involve the provision of an earth fault supervision system.

NOTE See 6.3.3 c).

8.2.1.6 Parts that need not be bonded

It is not necessary to connect exposed conductive parts to the protective bonding circuit where those parts are mounted so that they do not constitute a hazard because:

- they cannot be touched on large surfaces or grasped with the hand and they are small in size (less than approximately 50 mm × 50 mm); or
- they are located so that either contact with live parts, or an insulation failure, is unlikely.

NOTE This exemption applies, for example, to bolts, rivets, nameplates and cable clips.

Conductive structural parts of electrical equipment in accordance with 6.3.2.2 need not be connected to the protective bonding circuit. Extraneous conductive parts which form the structure of the fabrication equipment need not be connected to the protective bonding circuit where all the electrical equipment provided is in accordance with 6.3.2.2.

8.2.1.7 Parts that shall not be bonded

Exposed conductive parts of equipment in accordance with 6.3.2.3 shall not be connected to the protective bonding circuit.

8.2.2 Protective conductors

Protective conductors shall be identified in accordance with 13.4.2.

Copper conductors are preferred.

The cross-sectional area of protective conductors shall comply with the requirements of Tables C.1 to C.5.

Where a conductor material other than copper is used, its electrical resistance per unit length shall not exceed that of the allowable copper conductor.

NOTE In Europe, there are no harmonised standards for non-copper cables with cross-sectional areas less than 16 mm².

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

8.2.3 Continuity of the protective bonding circuit

8.2.3.1 General

All exposed conductive parts shall be connected to the protective bonding circuit in accordance with 8.2.1.

EXCEPTION: see 8.2.1.6 and 8.2.1.7.

Where a part is removed for any reason (for example routine maintenance), the protective bonding circuit for the remaining parts shall not be interrupted.

8.2.3.2 Integrity of bonding points

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

NOTE Where enclosures and conductors of aluminium or aluminium alloys are used, particular consideration should be given to the possibility of electrolytic corrosion.

8.2.3.3 Door-mounted electrical equipment

Where the electrical equipment is mounted on lids, doors, or cover plates, continuity of the protective bonding circuit shall be ensured and a protective conductor (see 8.2.2) is recommended. Otherwise fastenings, hinges or sliding contacts designed to have a low resistance shall be used (see 18.3).

8.2.3.4 Continuity of the protective conductor

The continuity of the protective conductor in cables that are exposed to damage (for example flexible trailing cables) shall be ensured by appropriate measures. Where this cannot be achieved, the continuity shall be monitored.

8.2.4 Exclusion of switching devices from the protective bonding circuit

The protective bonding circuit shall not incorporate a switching device or an overcurrent protective device (for example switch, fuse).

No means of interruption of the protective bonding circuit shall be provided except under one of the following circumstances:

- a) Links for test or measurement purposes that cannot be opened without the use of a tool and that are located in an enclosed electrical equipment area.
- b) Chassis that need to be floating for normal operation are permitted where access within enclosures can be achieved only after the chassis are connected to the protective earth by automatic means. Such means shall be able to continue to perform its function in the presence of a single fault or failure.
- c) Where the continuity of the protective bonding circuit can be interrupted by means of plug/socket combinations, the protective bonding circuit shall be interrupted by a first make last break contact. This also applies to removable or withdrawable plug-in units (see also 13.4.5).

8.2.5 Protective conductor connecting points

All protective conductors shall be terminated in accordance with 13.1.1. The protective conductor connecting points shall have no other function and are not intended, for example, to attach or connect appliances or parts.

Each protective conductor connecting point shall be marked or labelled as such using the symbol IEC 60417-5019 (2002-10):



or with the letters PE, the graphical symbol being preferred, or by use of the bicolour combination GREEN-AND-YELLOW, or by any combination of these.

8.2.6 Mobile machines

On mobile machines with on-board power supplies, the protective conductors, the conductive structural parts of the electrical equipment, and those extraneous conductive parts which form the structure of the machine shall all be connected to a protective bonding terminal to provide protection against electric shock. Where a mobile machine is also capable of being connected to an external incoming power supply, this protective bonding terminal shall be the connection point for the external protective conductor.

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

8.2.7 Limitation of touch current on cord and plug connected equipment

The maximum current through a resistor of $1\,500\,\Omega$ connected between any exposed (accessible) part of cord and plug connected equipment and the protective earthing conductor of the supply shall not exceed 3,5 mA.

For the verification that this requirement is met 18.3 applies.

EXCEPTION: Equipment with touch current exceeding 3,5 mA is acceptable if the equipment is fully compliant with an applicable IEC product safety standard that explicitly permits a higher leakage current.

8.3 Functional bonding

Connection to a common conductor in accordance with 9.4.3.1 can contribute to protection against incorrect operation as a result of insulation failures.

For recommendations regarding functional bonding to avoid incorrect operation due to electromagnetic disturbances, see 4.4.2.

8.4 Measures to limit the effects of high leakage current

The effects of high leakage current can be restricted to the electrical equipment having high leakage current by connection of that electrical equipment to a dedicated supply transformer having separate windings. The protective bonding circuit shall be connected to exposed conductive parts of the fabrication equipment and, in addition, to the secondary winding of the transformer.

9 Control circuits, emergency off (EMO), and protective interlock circuits

9.1 Control circuits

9.1.1 Control circuit supply

It is recommended that, where practicable, circuits be supplied from power supplies or control transformers. Such transformers shall have separate windings.

NOTE This will limit currents under fault and surge conditions, and can provide enhanced EMC filtering.

Safety circuits should be designed using non-hazardous voltage and power levels consistent with the correct operation of the control circuit.

9.1.2 DC circuits derived from an a.c. supply

Where d.c. circuits derived from an a.c. supply are connected to the protective bonding circuit (see 8.2.1), it is recommended that they be supplied from a separate winding of a transformer.

NOTE Switch-mode units fitted with transformers having separate windings in accordance with IEC 61558-2-16 meet this recommendation.

9.1.3 Start functions

Start functions shall operate by energizing the relevant circuit (see 9.3.2).

9.1.4 Stop functions

There are three categories of stop functions that can be used for all or part of the fabrication equipment as follows:

- stop category 0: stopping of operation(s) by immediate removal of power to the machine actuators (i.e., an uncontrolled stop – see 3.74);
- stop category 1: a controlled stop of operation(s) (see 3.13) with power available to the machine actuators to achieve the stop and then removal of power when the stop is achieved;
- stop category 2: a controlled stop of operation(s) with power left available to the machine actuators.

9.1.5 Operating modes

Fabrication equipment can have one or more operating modes determined by the type of its application. When a hazardous situation can result from a mode selection, it shall be restricted by suitable means (for example key operated switch, access code).

NOTE The use of these means is intended to restrict access to skilled or instructed persons, and to prevent inadvertent selection.

Mode selection by itself shall not initiate operation of the fabrication equipment. A separate actuation of a start control shall be required.

For each specific operating mode, the relevant safety functions and/or protective measures shall be implemented.

Indication of the selected operating mode shall be provided (for example the position of a mode selector, the provision of an indicating light, a visual display indication on a user interface screen).

9.1.6 Multiple control stations

Where fabrication equipment has more than one control station, measures shall be provided to ensure that initiation of commands from different control stations does not lead to a hazardous situation.

Where this requires that only one of the control stations can be enabled at a given time, a hardware-based device or a circuit in accordance with 9.4 shall be used to ensure that only one of the control stations can be enabled at a given time. An indication of which operator control station is in control of the fabrication equipment shall be provided at suitable locations as determined from a risk assessment of the fabrication equipment.

Where more than one control station is provided, stop commands from any control station shall be effective unless otherwise indicated by the risk assessment of the fabrication equipment.

NOTE Multiple points of remote host control are under consideration for automated manufacturing.

9.2 Emergency Off (EMO)

9.2.1 General

Fabrication equipment shall have an emergency off circuit which when activated, will place the fabrication equipment into a safe shutdown condition, without generating any additional hazards.

EXCEPTION 1: for single phase fabrication equipment that is supplied at less than 250 V line to ground, with a total load not more than 2,4 KVA, and having only electrical hazards, an