

NFPA®

79

Electrical Standard for
Industrial Machinery

2021



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NFPA® 79

Electrical Standard for Industrial Machinery

2021 Edition

This edition of NFPA 79, *Electrical Standard for Industrial Machinery*, was prepared by the Technical Committee on Electrical Equipment of Industrial Machinery and released by the Correlating Committee on National Electrical Code®. It was issued by the Standards Council on October 5, 2020, with an effective date of October 25, 2020, and supersedes all previous editions.

This edition of NFPA 79 was approved as an American National Standard on October 25, 2020.

Origin and Development of NFPA 79

This standard was first submitted at the 1961 NFPA Annual Meeting under the title *Electrical Standard for Machine Tools* and was tentatively adopted subject to comments. It was extensively revised and resubmitted at the 1962 NFPA Annual Meeting, where it was officially adopted. In 1965 a revised edition was adopted, reconfirmed in 1969, and in 1970, 1971, 1973, 1974, 1977, 1980, 1985, 1987, 1991, 1994, 1997, 2002 and 2007, revised editions were adopted.

In September 1941, the metalworking machine tool industry wrote its first electrical standard to make machine tools safer to operate, more productive, and less costly to maintain, and to improve the quality and performance of their electrical components. That particular standard served as an American "War Standard."

To study the special electrical problems involved with machine tools, in 1941 the Electrical Section of the National Fire Protection Association sanctioned a Special Subcommittee on Wiring, Overcurrent Protection, and Control of Motor-Operated Machine Tools. This subcommittee, cooperating with machine tool builders, manufacturers of control equipment, and Underwriters Laboratories Inc., conducted tests and investigated the peculiar conditions involved with machine tools that might warrant exception to certain specific *National Electrical Code* requirements. This investigation resulted, on August 4, 1942, in a Tentative Interim Amendment and first appeared in a 1943 supplement to the 1940 edition of *NFPA 70®*, *National Electrical Code (NEC)*, as Article 670, "Machine Tools." It remained essentially unchanged through the 1959 edition.

Meanwhile, manufacturers of other types of industrial equipment erroneously began to follow the specialized practices permitted by Article 670. Late in 1952, a Technical Subcommittee on Fundamentals of Electrically Operated Production Machinery and Material Handling and Processing Equipment for Fixed Locations was organized to attempt to group the special requirements of this broad field into one article. The extremely broad scope introduced so many problems that, in December 1956, this technical subcommittee was reorganized into an NFPA committee whose scope was limited to machine tools and whose objective was the preparation of this NFPA standard with corresponding revisions in Article 670 in the *National Electrical Code*.

Modern machine tool electrical equipment may vary from that of single-motor machines, such as drill presses, that perform simple, repetitive operations, to that of very large, multimotored automatic machines that involve highly complex electrical control systems, including electronic and solid-state devices and equipment. Generally these machines are specially designed, factory wired, and tested by the builder and then erected in the plant in which they will be used. Because of their importance to plant production and their usually high cost, they are customarily provided with many safeguards and other devices not often incorporated in the usual motor and control application as contemplated by the *National Electrical Code*.

Although these machines may be completely automatic, they are constantly attended, when operating, by highly skilled operators. The machine usually incorporates many special devices to protect the operator, protect the machine and building against fires of electrical origin, protect the machine and work in process against damage due to electrical failures, and protect against loss of

production due to failure of a machine component. To provide these safeguards, it may be preferable to deliberately sacrifice a motor or some other component, rather than to chance injury to the operator, the work, or the machine. It is because of such considerations that this standard varies from the basic concepts of motor protection as contained in the *National Electrical Code*.

As NFPA 79 evolved, it became apparent that certain classes of light industrial machinery (e.g., small drill presses, bench grinders, sanders) were not appropriately covered. The 1977 edition of the standard recognized this problem and purposely excluded tools powered by 2 hp or less.

Subsequent to publication of the 1977 standard, a light industrial machinery standard development activity was initiated by the Power Tool Institute. The 1985 edition of NFPA 79 reflects this activity, and appropriate requirements are now included in the standard.

In 1975, the Society of the Plastics Industry requested that this standard be enlarged in scope to include plastics machinery. A formal request was received by NFPA in September 1978, and, through the combined efforts of the NFPA 79 committee and representatives of the Society of the Plastics Industry, the scope was broadened to include such machinery in the 1980 edition.

In June 1981, the Joint Industrial Council (JIC) Board of Directors acknowledged the dated state of the electrical and electronic standards and requested that NFPA 79 incorporate into its standard the material and topics covered by the JIC electrical (EMP-1-67, EGP-1-67) and electronic (EL-1-71) standards with the intention that the JIC standards eventually would be declared superseded. The NFPA Standards Council approved the request with the stipulation that the material and topics incorporated from the JIC standards be limited to areas related to electrical shock and fire hazards. The 1985 edition reflected the incorporation of the appropriate material from the JIC electrical (EMP-1-67, EGP-1-67) standards not previously covered. The 1991, 1994, and 1997 editions included additional references to international standards and reflected the committee's efforts in harmonization.

The 2002 edition was a major rewrite and represented a significant and historic effort in harmonizing an existing NFPA standard with an existing IEC standard. Major changes for this edition included renumbering section and chapter numbers to align with IEC 60204-1. A new chapter was added to address testing.

The 2007 edition continued to be aligned with IEC 60204-1. Because so much electrical equipment today contains both electrical and electronic equipment, Chapter 11, Electronic Equipment, was deleted, and any sections that remained applicable were dispersed to the appropriate chapters. The deletion of Chapter 11 caused all chapters after Chapter 11 to be renumbered to one less than in previous editions. A new Chapter 19, entitled "Servo Drives and Motors," was added to the end of the standard. This new chapter addressed some of the user concerns that are arising as servo drives and servo motors are integrated into industrial machinery. Other changes include further defining of cables and cords, clarifying emergency stop functions, permitting system isolation equipment, clarifying short-circuit current markings, and refining requirements associated with software- and firmware-based control systems performing safety-related functions.

Changes to the 2012 edition continued to align the standard with IEC 60204-1. Due to the continued advancement and expansion of wireless and cableless technology, major changes for this edition included a revised definition for the term cableless control and a new definition for the term *cableless operator control station*, along with revisions to Chapter 9, which aligned with IEC 60204-1. The title of Chapter 6 was changed, to recognize that there are other hazards (such as arc flash and stored energy) besides electrical shock. New sections were added to Chapters 6 and 16 to recognize these hazards and correlate with *NFPA 70E*. Furthermore, the sections on the hazards from stored energy in Chapter 7 were moved to Chapter 6 for clarity and proper location of those rules in the document. To align with the *NEC*, the requirements in 7.2.10 were changed for selecting overcurrent devices for motors. Chapter 12 received a new section to address user concerns permitting the use of appliance wiring material (AWM) as special cables, with clarifications on determining suitability for use under specific conditions. An important addition of a 90°C (194°F) temperature column to the conductor ampacity table in Chapter 12 was included to correlate with the *NEC*.

Other changes included adding the definition for short-circuit current rating (SCCR), extracted from the *NEC*; revising the definition for equipment grounding conductor; and adding a new definition for safety-related function specific to industrial machines to harmonize with IEC and ISO standards. Further changes to Chapter 19 addressed some of the user concerns arising from servo drives and servo motors being more commonly used in industrial machinery. Finally, adding an American Wire Gauge (AWG) to the metric conductor cross-reference table in Annex I provided the user and enforcement officials a means to judge AWG versus metric wire sizes required by the standard.

As in previous editions, the 2015 edition aligned with IEC 60204-1, and the alignment was made more intuitive and informative. Parenthetical terms that aligned with IEC terms throughout the main body of the document without explanation reside in Annex J with further explanation for their use. Global changes of the editorial type were accepted to comply with the *Manual of Style for NFPA Technical Committee Documents*. Two definitions were added — *industrial control panel* and *overcurrent protective device, branch circuit*. Seven definitions were deleted — *cable trunking systems* (3.3.16), *duct* (3.3.33), *earth* (3.3.34), *positive opening operation* (of a contact element) (3.3.74), *protective bonding circuit* (3.3.77), *protective conductor* (3.3.78), and *subassembly* (3.3.98). The title of Section 6.6 was revised to Arc Flash Hazard Warning to clarify that the requirement is to warn qualified individuals of, not to protect them from, a potential arc flash hazard. This change aligned with the 2014 *NEC* revision

to 110.16, which added “or factory” to allow the required arc-flash warning label to be applied at the factory as well as in the field — a change that was more conducive to industrial machinery and industrial control panels.

The conditions for emergency stop on Category 1 and Category 0 were revised, as well as those for emergency switching off. Working space rules for enclosures that contain supply conductors were revised to clarify that 110.26 of the *NEC* applies, and an exhibit was added to Annex A to illustrate the requirement. The requirement for width of the working space was also revised to specify the opening into the control cabinet and to consider situations where there were devices involved with industrial machine control cabinets. Table 12.5.5(a) was revised to add 60 degree and 90 degree columns to correlate with the addition of a 90 degree column to 12.5.1 in the 2012 edition and in the *NEC*. Finally, language was revised to clarify the rules for separate supply sources; the standard to use for warning signs; how to calculate SCCR marking where there are multiple control panels; that overcurrent protection is required for servo drives; and that conveyors, conveying machines, and material handling machines are within the scope of NFPA 79.

In the 2018 edition, “600 volts” was replaced with “1000 volts” to align with the *NEC*. Three definitions were revised — *adjustable speed drive*, *liquidtight flexible metal conduit*, and *wet location*. Four definitions were added — *basic protection*, *effective ground-fault current path*, *fault protection*, and *machine supply circuit*. Four definitions were deleted — *attachment plug (plug cap) (plug)*, *receptacle*, *socket*, and *visible*. The title of Chapter 5 was revised to Disconnecting Means to clarify that Chapter 5 covers all the supply circuit conductor terminations on the machine.

The 2018 edition also revised Section 5.1 to remove “incoming” and add “machine” to align with the newly added definition. The main disconnecting means must be marked “main disconnecting means” if it supplies multiple disconnecting means on the machine. The machine supply circuit disconnecting means, by Exception No. 2 to 5.3.1.3, is permitted to be externally mounted up to 20 ft (6 m) away. Finally, language was revised to allow adjustable speed drives marked “suitable for output conductor protection” to have the rating of the short-circuit protective device (SCPD) determined by the drive’s rated input current.

A requirement was added to 7.8.1 to require a surge-protection device (SPD) to correlate with 670.6 of the *NEC*; the title of Chapter 8 for grounding added “bonding”; clarification was added on connection of the grounded conductor to the equipment grounding conductor; and clarification that all parts of effective ground-fault current path is capable of withstanding the highest thermal and mechanical stress that can be caused by fault currents. Further enhancements to Chapter 11 were added to clarify the peculiar working space condition of industrial machines and machine tools.

In the 2021 edition, the inconsistent use of text involving voltages has been resolved and the use of the term *safety related control systems* has been updated. In Chapter 3, terms extracted from *NFPA 70* have been updated and the definition of *safety circuit* has been revised. In Chapter 4, references to voltage dips have been revised, cable types for power conversion equipment have been removed, and electromagnetic compatibility (EMC) involving transients has been revised. Requirements involving supply circuit disconnecting means, access, operations, and markings in Chapter 5 have been enhanced; in 5.2.4, the term *isolation devices* has been replaced with *disconnecting means*.

Chapter 6 requirements on enclosure access and interlocking have been changed, and voltage limitations and rejection capabilities for attachment plugs in protective extra low voltage (PELV) systems have been revised. In Chapter 7, language requiring surge-protection devices (SPDs) has been updated. Control system grounding requirements in Chapter 8 have been updated, and the exception to 8.3.2 involving insulation monitoring for Class 2 circuits has been changed.

In Chapter 9, an exception has been added to 9.4.2.1. In Chapter 10, 10.7.1.3 has been revised, requiring emergency stop devices to be listed. Revisions to Chapter 15 deleted “in the machine area” in 15.2.2.1. In Chapter 19, Section 19.1 has been determined as redundant to 19.1.1 and 19.1.2 and was deleted. Duplicate material in the annexes has also been deleted, and A.9.2.5.4 added a reference to ISO 12100.

The technical committee for this standard reports to NFPA through the Correlating Committee of the National Electrical Code. The primary reason is to correlate this standard and *NFPA 70*, especially with respect to Article 670.

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This list represents the membership at the time the Committee was balloted on the final text of this edition. Since that time, changes in the membership may have occurred. A key to classifications is found at the back of the document.

NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

Committee Scope: This Committee shall have primary responsibility for documents on minimizing the risk of electricity as a source of electric shock and as a potential ignition source of fires and explosions. It shall also be responsible for text to minimize the propagation of fire and explosions due to electrical installations.

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NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

Committee Scope: This Committee shall have primary responsibility for documents intended to minimize the potential hazard of electric shock and electrical fire hazards of industrial metalworking machine tools, woodworking machinery, plastics machinery and mass production equipment, not portable by hand. This Committee shall report to Correlating Committee of the National Electrical Code.

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Annex A.

A reference in brackets [] following a section or paragraph indicates material that has been extracted from another NFPA document. Extracted text may be edited for consistency and style and may include the revision of internal paragraph references and other references as appropriate. Requests for interpretations or revisions of extracted text should be sent to the technical committee responsible for the source document.

Information on referenced and extracted publications can be found in Chapter 2 and Annex K.

Chapter 1 Administration

1.1* Scope.

1.1.1 The provisions of this standard shall apply to the electrical/electronic equipment, apparatus, or systems of industrial machines supplied from a nominal voltage of 1000 volts or less, and commencing at the point of connection of the supply circuit conductors to the electrical equipment of the machine.

1.1.2* This standard does not include the additional requirements for machines intended for use in hazardous (classified) locations.

1.2 Purpose. This standard shall provide detailed information for the application of electrical/electronic equipment, apparatus, or systems supplied as part of industrial machines that will promote safety to life and property.

1.3 Application.

1.3.1 This standard is not intended to be applied retroactively.

1.3.2 When changes other than repairs are made to machines that do not comply with the provisions of this standard, the changes shall conform to the provisions of this standard.

1.3.3 This standard shall not apply to the following:

- (1) Fixed or portable tools judged under the requirements of a testing laboratory acceptable to the authority having jurisdiction
- (2) Machines used in dwelling units

1.4 Specific Provisions Other Than NFPA 79. The size and overcurrent protection of the supply conductors to a machine shall be covered by Article 670 of NFPA 70. The wiring between component machines of an industrial manufacturing system shall be covered by NFPA 70.

Exception: Wiring of component machines of an industrial manufacturing system that is supplied by the manufacturer and is an integral part of the system, is adequately protected and supported, and meets the requirements of this standard.

1.5* Specific Provisions Not Made in Relation to NFPA 70. On any point for which specific provisions are not made in this standard the provisions of NFPA 70 shall be observed.

1.6 State of the Art. This standard shall not limit or inhibit the advancement of the state of the art. Each type of machine has unique requirements that shall be accommodated to provide adequate safety.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this standard and shall be considered part of the requirements of this document.

2.2 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA 70®, *National Electrical Code*®, 2020 edition.

NFPA 70E®, *Standard for Electrical Safety in the Workplace*®, 2021 edition.

2.3 Other Publications.

2.3.1 ANSI Publications. American National Standards Institute, Inc., 25 West 43rd Street, 4th Floor, New York, NY 10036.

ANSI Z535.4, *Product Safety Signs and Labels*, 2011, reaffirmed 2017.

2.3.2 ASTM Publications. ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM B8, *Standard Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft*, 2011, reapproved 2017.

ASTM B174, *Standard Specification for Bunch-Stranded Copper Conductors for Electrical Conductors*, 2017.

ASTM B286, *Standard Specification for Copper Conductors for Use in Hookup Wire for Electronic Equipment*, 2007, reapproved 2017.

2.3.3 IEC Publications. International Electrotechnical Commission, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland.

IEC 60072-1, *Dimensions and output series for rotating electrical machines — Part 1: Frame numbers 56 to 400 and flange numbers 55 to 1080*, 1991.

IEC 60072-2, *Dimensions and output series for rotating electrical machines — Part 2: Frame numbers 355 to 1000 and flange numbers 1180 to 2360*, 1990.

2.3.4 IEEE Publications. IEEE, 3 Park Avenue, 17th Floor, New York, NY 10016-5997.

IEEE 315, *Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters)*, 1993.

2.3.5 NEMA Publications. National Electrical Manufacturers Association, 1300 North 17th Street, Suite 900, Arlington, VA 22209.

NEMA ICS 2, *Industrial Control and Systems: Controllers, Contactors, and Overload Relays Rated 600 Volts*, 2000, errata 2008.

NEMA MG-1, *Motors and Generators*, 2016.

NEMA 250, *Enclosures for Electrical Equipment (1000 Volts Maximum)*, 2014.

2.3.6 UL Publications. Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096.

UL 50, *Enclosures for Electrical Equipment, Non-Environmental Considerations*, 2015.

UL 50E, *Enclosures for Electrical Equipment, Environmental Considerations*, 2015.

UL 508, *Industrial Control Equipment*, 2018.

UL 508A, *Industrial Control Panels*, 2018.

UL 870, *Wireways, Auxiliary Gutters, and Associated Fittings*, 2016.

UL 1063, *Machine-Tool Wires and Cables*, 2017, revised 2018.

UL 1581, *Electrical Wires, Cables, and Flexible Cords*, 2001, revised 2017.

2.3.7 US Government Publications. US Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20401-0001.

Title 29, Code of Federal Regulations, Part 1910.331-335, "Safety-Related Work Practices."

2.3.8 Other Publications.

Merriam-Webster's Collegiate Dictionary, 11th edition, Merriam-Webster, Inc., Springfield, MA, 2003.

2.4 References for Extracts in Mandatory Sections.

NFPA 70®, *National Electrical Code*®, 2020 edition.

NFPA 70E®, *Standard for Electrical Safety in the Workplace*®, 2018 edition.

defined in this chapter or within another chapter, they shall be defined using their ordinarily accepted meanings within the context in which they are used. *Merriam-Webster's Collegiate Dictionary*, 11th edition, shall be the source for the ordinarily accepted meaning.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction (AHJ). An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

3.2.3 Labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

3.2.4* Listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

3.2.5 Shall. Indicates a mandatory requirement.

3.2.6 Should. Indicates a recommendation or that which is advised but not required.

3.2.7 Standard. An NFPA Standard, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and that is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions are not to be considered a part of the requirements of a standard and shall be located in an appendix, annex, footnote, informational note, or other means as permitted in the NFPA Manuals of Style. When used in a generic sense, such as in the phrase "standards development process" or "standards development activities," the term "standards" includes all NFPA Standards, including Codes, Standards, Recommended Practices, and Guides.

3.3 General Definitions.

3.3.1 Accessible (as applied to equipment). Admitting close approach; not guarded by locked doors, elevation, or other effective means. [70:100]

3.3.2 Accessible, Readily (Readily Accessible). Capable of being reached quickly for operation, renewal, or inspections, without requiring those to whom ready access is requisite to climb over or remove obstacles or to resort to portable ladders, and so forth.

3.3.3* Actuator. The part of the actuating system to which an external actuating force is applied.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter shall apply to the terms used in this standard. Where terms are not

3.3.4* Actuator, Machine. A power mechanism used to effect motion of the machine.

3.3.5* Adjustable Speed Drive. Power conversion equipment that provides a means of adjusting the speed of an electric motor. [70:100]

3.3.6 Adjustable Speed Drive System. A combination of an adjustable speed drive, its associated motor(s), and auxiliary equipment. [70:100]

3.3.7* Ambient Temperature. The temperature of the air or other medium where the equipment is to be used.

3.3.8 Ampacity. The maximum current, in amperes, that a conductor can carry continuously under the conditions of use without exceeding its temperature rating. [70:100]

3.3.9 Attachment Plug (Plug Cap) (Plug). A device that, by insertion in a receptacle, establishes a connection between the conductors of the attached flexible cord and the conductors connected permanently to the receptacle. [70:100]

3.3.10 Barrier. A physical obstruction that is intended to prevent contact with equipment or energized electrical conductors and circuit parts or to prevent unauthorized access to a work area. [70E:100]

3.3.11* Basic Protection. Protection against electric shock under fault-free conditions.

3.3.12 Bonding (Bonded). Connected to establish electrical continuity and conductivity. [70:100]

3.3.13 Branch Circuit. The circuit conductors between the final overcurrent device protecting the circuit and the outlet(s). [70:100]

3.3.14* Cable. A combination of conductors insulated from one another with a common covering that is not a cord.

3.3.14.1* Cable with Flexible Properties. A cable or special cable that is malleable but without flexing or constant flexing properties.

3.3.14.2* Flexible Cable. A cable or special cable manufactured with flexing or constant flexing properties.

3.3.14.3* Special Cable. A cable intended for specific limited purposes.

3.3.15 Cable Tray System. A unit or assembly of units or sections and associated fittings forming a structural system used to securely fasten or support cables and raceways. [70:392.2]

3.3.16 Cableless Control. Control devices employing wireless (e.g., radio, infrared) techniques for transmitting commands and signals between a machine control system and operator control station(s).

3.3.17* Cableless Operator Control Station. An operator control station that is capable of using wireless (e.g., radio, infrared) techniques to communicate with one or more machines and that incorporates a self-contained power source, such as a battery.

3.3.18* Circuit Breaker. A device designed to open and close a circuit by nonautomatic means and to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within its rating. [70:100]

3.3.19* Color Graphic Interface Device. An interface between the operator and the machine, where a color video display and either a touch screen or touch pad or keyboard or mouse are used to initiate machine action by the selection of on-screen icons.

3.3.20 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 simultaneously).

3.3.21 Conduit.

3.3.21.1 Flexible Metal Conduit (FMC). A raceway of circular cross section made of helically wound, formed, interlocked metal strip. [70:348.2]

3.3.21.2 Intermediate Metal Conduit (IMC). A steel threadable raceway of circular cross section designed for the physical protection and routing of conductors and cables when installed with its integral or associated coupling and appropriate fittings.

3.3.21.3 Liquidtight Flexible Metal Conduit (LFMC). A raceway of circular cross section having an outer liquidtight, nonmetallic, sunlight-resistant jacket over an inner flexible metal core with associated couplings, connectors, and fittings for the installation of electric conductors. [70:350.2]

3.3.21.4* Liquidtight Flexible Nonmetallic Conduit (LFNC). A raceway of circular cross section of various types as follows: (1) A smooth seamless inner core and cover bonded together and having one or more reinforcement layers between the core and covers, designated as Type LFNC-A; (2) A smooth inner surface with integral reinforcement within the raceway wall, designated as Type LFNC-B; (3) A corrugated internal and external surface without integral reinforcement within the raceway wall, designated as LFNC-C. [70:356.2]

3.3.21.5 Rigid Metal Conduit (RMC). A threadable raceway of circular cross section designed for the physical protection and routing of conductors and cables when installed with its integral or associated coupling and appropriate fittings. RMC is generally made of steel (ferrous) with protective coatings or aluminum (nonferrous). Special use types are silicon bronze and stainless steel.

3.3.21.6 Rigid Nonmetallic Conduit (RNC). A nonmetallic raceway of circular cross section, with integral or associated couplings, connectors, and fittings for the installation of electrical conductors and cables.

3.3.22 Contact.

3.3.22.1 Direct Contact. Contact of persons with live parts.

3.3.22.2 Indirect Contact. Contact of persons with exposed conductive parts that have become live under fault conditions.

3.3.23* Control Circuit (of a machine). The circuit of a control apparatus or system that carries the electric signals directing the performance of the controller but does not carry the main power current.

3.3.24 Control Circuit Transformer. A voltage transformer utilized to supply a voltage suitable for the operation of control devices.

3.3.25 Control Circuit Voltage. The voltage utilized for the operation of control devices.

3.3.26 Control Device. A device connected into the control circuit and used for controlling the operation of the machine (e.g., position sensor, manual control switch, relay, magnetically operated valve).

3.3.27 Control Equipment. Operating elements, such as relays, contactors, circuit breakers, switches, solenoids, brakes, and similar types of components, intended to govern or perform a given function in the operation, including measuring, sensing, monitoring, protecting, and regulating of machinery.

3.3.28 Controller. A device or group of devices that serves to govern, in some predetermined manner, the electric power delivered to the apparatus to which it is connected. [70:100]

3.3.29 Cord. Two or more flexible insulated conductors enclosed in a flexible covering that provides mechanical protection.

3.3.30 Device. A unit of an electrical system, other than a conductor, that carries or controls electric energy as its principal function. [70:100]

3.3.31 Digital. Operated by the use of discrete signals to represent data in the form of numbers or other characters.

3.3.32 Direct Opening Operation. Achievement of contact separation as the direct result of a specified movement of the switch actuator through nonresilient members (e.g., not dependent upon springs).

3.3.33 Disconnecting Means. A device, or group of devices, or other means by which the conductors of a circuit can be disconnected from their source of supply. [70:100]

3.3.34 Dwelling Unit. A single unit, providing complete and independent living facilities for one or more persons, including permanent provisions for living, sleeping, cooking, and sanitation. [70:100]

3.3.35 Effective Ground-Fault Current Path. An intentionally constructed, low-impedance electrically conductive path designed and intended to carry current under ground-fault conditions from the point of a ground fault on a wiring system to the electrical supply source and that facilitates the operation of the overcurrent protective device or ground-fault detectors. [70:100]

3.3.36 Electromechanical. Any device in which electrical energy is used to magnetically cause mechanical movement.

3.3.37 Electronic Equipment. That part of electrical equipment containing circuitry mainly based on electronic devices and components.

3.3.38 Emergency Switching Off. An emergency operation intended to switch off the supply of the electrical energy to all or part of an installation.

3.3.39 Enabling Device. Manually operated control device used in conjunction with a start control, that when continuously actuated, will allow a machine to function.

3.3.40 Enclosure. The case or housing of apparatus, or the fence or walls surrounding an installation to prevent personnel from accidentally contacting energized parts or to protect the equipment from physical damage. [70:100]

3.3.41 Energized. Electrically connected to, or is, a source of voltage. [70:100]

3.3.42 Equipment. A general term including material, fittings, devices, appliances, luminaires, apparatus, and the like.

3.3.43 Exposed (as applied to live parts). Capable of being inadvertently touched or approached nearer than a safe distance by a person. It is applied to parts not suitably guarded, isolated, or insulated.

3.3.44* Failure (of equipment). The termination of the ability of an item to perform a required function.

3.3.45* Fault. The 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.

3.3.46 Fault Current. The current delivered at a point on the system during a short-circuit condition. [70:100]

3.3.47* Fault Current, Available (Available Fault Current). The largest amount of current capable of being delivered at a point on the system during a short-circuit condition. [70:100]

3.3.48* Fault Protection. Protect against electric shock under single-fault conditions.

3.3.49 Feeder. All circuit conductors between the service equipment, the source of a separately derived system, or other power supply source and the final branch-circuit overcurrent device. [70:100]

3.3.50 Flame Retardant. So constructed or treated that it will not support flame.

3.3.51 Ground. The earth. [70:100]

3.3.52 Ground Fault. An unintentional, electrically conductive connection between an ungrounded conductor of an electrical circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth. [70:100]

3.3.53 Grounded (Grounding). Connected (connecting) to ground or to a conductive body that extends the ground connection. [70:100]

3.3.54 Grounded Conductor. A system or circuit conductor that is intentionally grounded. [70:100]

3.3.55 Grounding Conductor, Equipment (EGC). The conductive path(s) that provides a ground-fault current path and connects normally non-current-carrying metal parts of equipment together and to the system grounded conductor or to the grounding electrode conductor, or both. [70:100]

3.3.56* Guard. Part of a machine specifically used to provide protection by means of a physical barrier.

3.3.57 Hazard. A source of possible injury or damage to health.

3.3.58 Hazardous Condition. A circumstance in which a person is exposed to a hazard(s) that has the potential to result in harm immediately or over a long period of time.

3.3.59* Identified (as applied to equipment). Recognizable as suitable for the specific purpose, function, use, environment, application, and so forth, where described in a particular code or standard requirement. [70:100]

3.3.60 Industrial Control Panel. An assembly of two or more components consisting of one of the following: (1) power circuit components only, such as motor controllers, overload relays, fused disconnect switches, and circuit breakers; (2) control circuit components only, such as pushbuttons, pilot lights, selector switches, timers, switches, and control relays; (3) a combination of power and control circuit components. These components, with associated wiring and terminals, are mounted on, or contained within, an enclosure or mounted on a subpanel. The industrial control panel does not include the controlled equipment. [70:100]

3.3.61 Industrial Machinery (Machine). A power-driven machine (or a group of machines working together in a coordinated manner), not portable by hand while working, that is used to process material by cutting; forming; pressure; electrical, thermal, or optical techniques; lamination; or a combination of these processes. It can include associated equipment used to transfer material or tooling, including fixtures, to assemble/disassemble, to inspect or test, or to package. [The associated electrical equipment, including the logic controller(s) and associated software or logic together with the machine actuators and sensors, are considered as part of the industrial machine.] [70:670.2]

3.3.62 Industrial Manufacturing System. A systematic array of one or more industrial machines that is not portable by hand and includes any associated material handling, manipulating, gauging, measuring, or inspection equipment.

3.3.63 Input. The terminals where current, voltage, power, or driving force may be applied to a circuit or device; the state or sequence of states occurring on a specific input channel; or the device or collective set of devices used for bringing data into another device.

3.3.64 Inrush Current (Solenoid). The inrush current of a solenoid is the steady-state current taken from the line at rated voltage and frequency with the plunger blocked in the rated maximum open position.

3.3.65 Inrush Locked Rotor Current (Motor). See 3.3.72, Locked Rotor Current.

3.3.66 In Sight From (Within Sight From, Within Sight). Where this standard specifies that one equipment shall be "in sight from," "within sight from," or "within sight of," and so forth, of another equipment, the specified equipment is to be visible and not more than 15 m (50 ft) distant from the other. [70:100]

3.3.67 Interlock (for safeguarding). An arrangement that interconnects guard(s) or device(s) with the control system or all or part of the electrical energy distributed to the machine.

3.3.68* Interrupting Rating. The highest current at rated voltage that a device is identified to interrupt under standard test conditions. [70:100]

3.3.69 Jogging (Inching). The quickly repeated closure of the circuit to start a motor from rest for the purpose of accomplishing small movements of the driven machine.

3.3.70 Live Parts. Energized conductive components. [70:100]

3.3.71 Location.

3.3.71.1 Dry Location. A location not normally subject to dampness or wetness. A location classified as dry may be temporarily subject to dampness or wetness, as in the case of a building under construction. [70:100]

3.3.71.2 Wet Location. Installations underground or in concrete slabs or masonry in direct contact with the earth; in locations subject to saturation with water or other liquids, such as vehicle washing areas; and in unprotected locations exposed to weather. [70:100]

3.3.72 Locked Rotor Current. The steady-state current taken from the line with the rotor locked and with rated voltage (and rated frequency in the case of alternating-current motors) applied to the motor.

3.3.73 Machine Supply Circuit. The conductors between the premises wiring and the machine supply circuit disconnecting means or terminals.

3.3.74 Marking. Signs or inscriptions attached by the manufacturer, for the identification of the type of a component or device.

3.3.75 Obstacle. A part preventing unintentional direct contact, but not preventing direct contact by deliberate action.

3.3.76 Output. The terminals where current, voltage, power, or driving force may be delivered by a circuit or device; the state or sequence of states occurring on a specific output channel; or the device or collective set of devices used for taking data out of another device.

3.3.77* Overcurrent. Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit, or ground fault. [70:100]

3.3.78 Overcurrent Protective Device, Branch-Circuit. A device capable of providing protection for service, feeder, and branch circuits and equipment over the full range of overcurrents between its rated current and its interrupting rating. Such devices are provided with interrupting ratings appropriate for the intended use but no less than 5000 amperes. [70:100]

3.3.79* Overcurrent Protective Device, Supplementary. A device intended to provide limited overcurrent protection for specific applications and utilization equipment such as found within industrial machines. This limited protection is in addition to the protection provided in the required branch circuit by the branch circuit overcurrent protective device.

3.3.80* Overload. Operation of equipment in excess of normal, full-load rating, or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or a ground fault, is not an overload. [70:100]

3.3.81 Point of Operation. The location in the (machine) where the material or workpiece is positioned and work is performed.

3.3.82 Power Circuit. A circuit used for supplying power from the supply network to units of equipment used for productive operation and to transformers supplying control circuits.

3.3.83* Programmable Electronic System (PES). A system based on one or more central processing units (CPUs),

connected to sensors or actuators, or both, for the purpose of control or monitoring.

3.3.84* Qualified Person. One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved. [70:100]

3.3.85 Raceway. An enclosed channel of metal or nonmetallic materials designed expressly for holding wires, cables, or busbars, with additional functions as permitted in this standard. Raceways include, but are not limited to, rigid metal conduit, rigid nonmetallic conduit, intermediate metal conduit, liquidtight flexible conduit, flexible metallic tubing, flexible metal conduit, electrical nonmetallic tubing, electrical metallic tubing, underfloor raceways, cellular concrete floor raceways, cellular metal floor raceways, surface raceways, wireways, and busways.

3.3.86 Receptacle. A contact device installed at the outlet for the connection of an attachment plug, or for the direct connection of electrical utilization equipment designed to mate with the corresponding contact device. A single receptacle is a single contact device with no other contact device on the same yoke. A multiple receptacle is two or more contact devices on the same yoke or strap. [70:100]

3.3.87 Redundancy. The application of more than one device or system, or part of a device or system, with the objective of ensuring that in the event of one failing to perform its function another is available to perform that function.

3.3.88 Reference Designation. A distinctive code that serves to identify an item in a diagram, list, or chart, and on the equipment.

3.3.89 Relative Humidity. The ratio between the amount of water vapor in the gas at the time of measurement and the amount of water vapor that could be in the gas when condensation begins, at a given temperature.

3.3.90* Risk. A combination of the probability and the degree of possible injury or damage to health in a hazardous situation.

3.3.91 Risk Assessment. The process by which the intended use of the machine, the tasks and hazards, and the level of risk are determined.

3.3.92 Safe Working Procedure. A method of working that reduces risk.

3.3.93 Safeguard. A guard or protective device used as a safety measure to protect persons from a present or impending hazard.

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

3.3.95* Safety Circuit. The part of a control system containing one or more devices that perform a safety-related function.

3.3.96 Safety-Related Function. A function which is intended to maintain the safe condition of the machine, or prevent or reduce hazardous situations.

3.3.97 Servicing Level. Location on which persons normally stand when operating or maintaining the electrical equipment.

3.3.98* Servo Drive System. A system consisting of a controller, servo amplifier, motor, and feedback device(s) providing for the positioning control of a motion axis through the use of velocity, acceleration, and deceleration.

3.3.99* Short-Circuit Current Rating. The prospective symmetrical fault current at a nominal voltage to which an apparatus or system is able to be connected without sustaining damage exceeding defined acceptance criteria. [70:100]

3.3.100 Special Permission. The written consent of the authority having jurisdiction. [70:100]

3.3.101 Stop.

3.3.101.1 Controlled Stop. The stopping of machine motion, while retaining power to the machine actuators during the stopping process.

3.3.101.2 Uncontrolled Stop. The stopping of machine motion by removing power to the machine actuators, all brakes and/or other mechanical stopping devices being activated.

3.3.102 Subplate (Subpanel). An internal metal surface separate from the walls of an enclosure or controller on which various component parts of the controller are mounted and wired.

3.3.103* Supplier. An entity (e.g., manufacturer, contractor, installer, integrator) that provides equipment or services associated with the machine.

3.3.104 Surge-Protective Device (SPD). A protective device for limiting transient voltages by diverting or limiting surge current; it also prevents continued flow of follow current while remaining capable of repeating these functions and is designated as follows: Type 1: Permanently connected SPDs intended for installation between the secondary of the service transformer and the line side of the service disconnect overcurrent device. Type 2: Permanently connected SPDs intended for installation on the load side of the service disconnect overcurrent device, including SPDs located at the branch panel. Type 3: Point of utilization SPDs. Type 4: Component SPDs, including discrete components, as well as assemblies. [70:100]

3.3.105 Switching Device. A device designed to make or break the current in one or more electric circuits.

3.3.106 System Isolation Equipment. A redundantly monitored, remotely operated contactor-isolating system, packaged to provide the disconnecting/isolation function, capable of verifiable operation from multiple remote locations by means of lockout switches, each having the capability of being padlocked in the "off" (open) position. [70:430.2]

3.3.107 Tap Conductors. As used in this standard, a tap conductor is defined as a conductor, other than a service conductor, that has overcurrent protection ahead of its point of supply that exceeds the value permitted for similar conductors that are protected as described elsewhere in this standard. [70:240.2]

3.3.108 Terminal. A conductive part of a device provided for electrical connection to circuits external to the device.

3.3.109 Tight (suffix). So constructed that the specified material is excluded under specified conditions.

3.3.110* Undervoltage Protection. The effect of a device that operates on the reduction or failure of voltage to cause and maintain the interruption of power.

3.3.111 User. An entity that utilizes the machine and its associated electrical equipment.

3.3.112 Ventilated. Provided with a means to permit circulation of air sufficient to remove excess heat, fumes, or vapors. [70:100]

3.3.113 Voltage, Nominal. A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class (e.g., 120/240 volts, 480Y/277 volts, 600 volts). The actual voltage at which a circuit operates can vary from the nominal within a range that permits satisfactory operation of equipment.

3.3.114 Wireway. A sheet-metal or flame-retardant nonmetallic trough with hinged or removable covers for housing and protecting electric wires and cable and in which conductors are laid in place after the wireway has been installed as a complete system.

Chapter 4 General Requirements and Operating Conditions

4.1* General Considerations. This chapter describes the general requirements and conditions for the operation of the electrical equipment of the machine. 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 machine. The risks associated with the hazards identified by the risk assessment shall be reduced such that the safety performance determined by the risk assessment is met.

4.2* Electrical Components and Devices. Electrical components and devices shall be installed and used assuming the operating conditions of ambient temperature, altitude, humidity, and supply voltage outlined in this chapter, and within their design ratings, taking into account any derating stipulated by the component or device manufacturer. Listed or labeled equipment shall be permitted to be used without modifications, on or with industrial machines, where approved for the location and use.

4.3 Installation and Use of Listed or Labeled Equipment. Listed or labeled equipment shall be installed and used in accordance with any instructions included in the listing or labeling.

4.4 Electrical Supply.

4.4.1* General. The electrical equipment shall be designed to operate correctly with the conditions of the supply as specified according to one of the following:

- (1) The requirements in 4.4.2, 4.4.3, and 4.4.4
- (2) The requirements specified by the user
- (3) The requirements specified by the supplier

4.4.2* Alternating Current (ac) Supplies.

4.4.2.1 Voltage. The electrical equipment shall be designed to operate correctly where the steady-state supply voltage is from 90 percent to 110 percent of the nominal voltage.

4.4.2.2 Frequency. The electrical equipment shall be designed to operate correctly where the supply frequency is from 99 percent to 101 percent of the nominal frequency

continuously. For short periods of time, the supply frequency shall be permitted to be from 98 percent to 102 percent of the nominal frequency.

4.4.2.3 Harmonics. The electrical equipment shall be designed to operate correctly where the harmonic distortion from the electric supply does not exceed 10 percent of the total voltage (rms value) between ungrounded conductors for the sum of the second through fifth harmonic. An additional 2 percent of the total voltage (rms value) between ungrounded conductors for the sum of the sixth through thirtieth harmonic shall be permitted.

4.4.2.4 Voltage Unbalance (in 3-Phase Supplies). The electrical equipment shall be designed to operate correctly where neither the voltage of the negative sequence component nor the voltage of the zero sequence component in 3-phase supplies exceeds 2 percent of the voltage of the positive sequence component.

4.4.2.5 Voltage Impulses. The electrical equipment shall be designed to operate correctly where the supply voltage impulses do not exceed 1.5 milliseconds in duration with a rise/fall time between 500 nanoseconds and 500 microseconds. A peak supply voltage impulse shall not exceed more than 200 percent of the rated supply voltage (rms value).

4.4.2.6 Voltage Interruption. The electrical equipment shall be designed to operate correctly where the supply voltage is interrupted at zero voltage for not more than 3 milliseconds at any random time in the supply cycle. The time interval between successive voltage interruptions shall be more than 1 second.

4.4.2.7 Voltage Dips. The electrical equipment shall be designed to operate correctly where the supply voltage dips do not exceed 20 percent of the peak voltage of the supply for more than one cycle. The time interval between successive dips shall be more than 1 second.

4.4.2.8* Circuits Supplied from Power Conversion Equipment. Electrical conductors and equipment supplied by power conversion equipment as part of adjustable speed drive systems and servo drive systems shall be identified as suitable for the electrical power characteristics and in accordance with any instructions provided by the manufacturer(s).

4.4.3 Direct Current (dc) Supplies from Batteries.

4.4.3.1 Voltage. The electrical equipment shall be designed to operate correctly where the dc supply voltage of batteries is from 85 percent to 115 percent of the nominal voltage. A supply voltage from 70 percent to 120 percent of the nominal voltage shall be permitted for dc supplies to battery-operated vehicles.

4.4.3.2 Voltage Interruption. The electrical equipment shall be designed to operate correctly where the dc supply voltage of batteries is interrupted for a time interval not exceeding 5 milliseconds.

4.4.4 Direct Current (dc) Supplies from Converting Equipment.

4.4.4.1 Voltage. The electrical equipment shall be designed to operate correctly where the dc supply voltage of converting equipment is from 90 percent to 110 percent of the nominal voltage.

4.4.4.2 Voltage Interruption. The electrical equipment shall be designed to operate correctly where the dc supply voltage of converting equipment is interrupted for a time interval not exceeding 20 milliseconds. The time interval between successive voltage interruptions shall be more than 1 second.

4.4.4.3 Ripple (Peak-to-Peak). The electrical equipment shall be designed to operate correctly where the dc supply voltage ripple (peak-to-peak value) of converting equipment does not exceed 0.05 of the nominal voltage.

4.5 Physical Environment and Operating Conditions.

4.5.1* General. The electrical equipment shall be suitable for use in the physical environment and operating conditions specified in 4.5.3 through 4.5.6 and 4.5.8. When the physical environment or the operating conditions are outside those specified, an agreement between the supplier and the user shall be considered.

4.5.2* Electromagnetic Compatibility (EMC). Transient suppression, isolation, or other appropriate means shall be provided where necessary to ensure that the expected level of electromagnetic interference or electrical transients in the machine supply circuit(s) or generated by the electrical equipment of the machine does not lead to the loss of the safety-related control function(s) of the industrial machine.

4.5.3* Ambient Operating Temperature. Electrical equipment shall be capable of operating correctly in the intended ambient air temperature. The ambient operating temperatures for correct operation of the electrical equipment shall be between air temperatures of 5°C and 40°C (41°F and 104°F).

4.5.4* Relative Humidity. The electrical equipment shall be capable of operating correctly within a relative humidity range of 20 to 95 percent (noncondensing). Harmful effects of relative humidity outside the permitted range shall be avoided by design of the equipment or, where necessary, by additional measures (e.g., built-in heaters, air conditioners, humidifiers).

4.5.5* Altitude. Electrical equipment shall be capable of correct operation at altitudes up to 1000 m (3300 ft) above mean sea level.

4.5.6* Contaminants. Electrical equipment shall be adequately protected against the ingress of solid bodies and liquids (*see Section 11.3*). Equipment shall be suitable for the environment where contaminants (e.g., dust, acids, corrosive gases, salt) are present.

4.5.7* Nonionizing Radiation.

4.5.8 Vibration, Shock, and Bump. Undesirable effects of vibration, shock, and bump, including those generated by the machine and its associated equipment and those created by the physical environment, shall be avoided by the selection of suitable equipment, by mounting it away from the machine, or by the use of antivibration mountings.

4.6 Transportation and Storage. The electrical equipment shall be designed to withstand storage and transportation temperatures within the range of -25°C to 55°C (-13°F to 131°F) and up to 70°C (158°F) for short periods not exceeding 24 hours. Suitable means shall be provided to prevent damage from excessive moisture, vibration, stress, and mechanical shock during shipment.

4.7 Provisions for Handling. Heavy and bulky electrical equipment that has to be removed from the machine for transport or that is independent of the machine shall be provided with suitable means for handling by cranes or similar equipment.

4.8 Installation and Operating Conditions. The electrical equipment shall be installed and operated in accordance with the conditions outlined in the manufacturer's instructions. Any conditions that are outside the operating conditions specified in Chapter 4 shall be permitted where acceptable to both the manufacturer and the user.

4.9 Available Fault Current. The available fault current at each machine supply circuit disconnecting means shall not be greater than the corresponding short-circuit current rating marked on the machine industrial control panel nameplate.

Chapter 5 Disconnecting Means

5.1 Machine Supply Circuit and Disconnecting Means.

5.1.1* Machine Supply Circuit. Where practicable, the electrical equipment of a machine shall be connected to a single power supply circuit. Where it is necessary to use another supply circuit for certain parts of the equipment (e.g., electronic circuits, electromagnetic clutches), that supply circuit shall, as far as is practicable, be derived from devices (e.g., transformers, converters) forming part of the electrical equipment of the machine.

5.1.2 Machine Supply Circuit Conductor Separation. Each set of machine supply circuit conductors on the line side of the machine supply circuit disconnecting means shall be separated from all other internal conductors, including conductors of other circuits, by either of the following:

- (1) Mounting the machine supply circuit disconnect as near as practicable to the top of the enclosure with dedicated wire bending space as required in 5.1.5
- (2) Mounting the machine supply circuit disconnect other than at the top of the enclosure and by separating the machine supply circuit conductors from other internal conductors with a barrier

5.1.3 Machine Supply Circuit Conductor Terminations. The machine supply circuit conductors shall be terminated at the machine supply circuit disconnecting means, where practicable. Connections to terminal blocks ahead of the machine supply circuit disconnecting means shall be permitted for excepted circuits according to 5.1.13 or where the machine supply circuit conductors are other than those identified for the disconnecting means. Terminals for more than one conductor shall be so identified.

5.1.3.1 Marking. All terminals for each machine supply circuit shall be legibly marked (e.g., L1, L2, L3) and shall correspond with markings on the technical documentation.

5.1.4 Back-Fed Terminations.

5.1.4.1 The connections to the machine supply circuit disconnecting means shall not be back-fed or reversed with the load side if it is marked line and load.

5.1.4.2 A machine supply circuit disconnecting means that is not marked line and load shall be permitted to be back-fed

provided there is a marking on or adjacent to the disconnecting means identifying the line and load terminations.

5.1.5 Wire-Bending Space. The wire-bending space provided between the terminals of a supply circuit disconnecting means or terminals described in 5.1.3 and the wall of the enclosure shall not be less than what is required by 430.10(B) of *NFPA 70*. The wire-bending space shall either be determined by the maximum wire size of the supply circuit conductors or be equal to or larger than the conductors required by 670.4(A) of *NFPA 70*. When the wire-bending space is based on more than one conductor per phase, the intended conductor size and number shall be so identified on interconnection diagrams as required in 17.5.7.

5.1.6 Protection of Line Side Live Parts. All live parts on the line side of the machine supply circuit disconnecting means shall be protected from unintentional direct contact by use of insulation or obstacle(s) when the machine supply circuit disconnecting means is in the open (off) position and the enclosure door is open.

5.1.7* Grounded Conductor. Where a grounded conductor is used, it shall be indicated in the technical documentation of the machine, such as in the installation diagram and in the circuit diagram. A separate insulated terminal shall be provided for the grounded conductor.

5.1.8* Equipment Grounding Conductor Terminal. A grounding terminal shall be provided for each machine supply circuit equipment grounding conductor.

5.1.9 Machine Supply Circuit Disconnecting Means. The requirements in 5.1.9.1 through 5.1.9.8 apply to 5.1.10 through 5.1.13.

5.1.9.1 A machine supply circuit disconnecting means shall be provided for the following:

- (1) Each machine supply circuit
- (2) Each machine supply circuit to a machine or a number of machines connecting to a feeder system using collector wires, collector bars, slip-ring assemblies, or flexible cable systems (reeled, festooned)
- (3) Each on-board power source (e.g., generators, uninterruptible power supplies)

Exception: Communication, remote control, and signaling circuits of less than 50 volts rms ac or 60 volts dc shall not be required to be provided with a machine supply circuit disconnecting means.

5.1.9.2* Each machine supply circuit disconnecting means shall be legibly marked to indicate the equipment it disconnects.

5.1.9.3 A machine supply circuit disconnecting means shall be marked as "Machine Supply Circuit Disconnect" if additional disconnecting means are supplied from the supply circuit disconnecting means.

5.1.9.4 Where a machine is supplied by more than one supply circuit, a marking shall be installed at each machine supply circuit disconnect location denoting the location of all other machine supply circuit disconnects.

5.1.9.5 The machine supply circuit disconnecting means shall disconnect the electrical equipment of the machine, including all control circuits, from the machine supply circuit when required (e.g., for work on the machine, including the electrical equipment). Circuits that are not required to be disconnected

by the machine supply circuit disconnecting means shall comply with 5.1.13.

5.1.9.6 Each machine supply circuit disconnecting means other than attachment plugs and receptacles shall be mounted within the control enclosure it supplies or immediately adjacent thereto.

Exception: Externally mounted machine supply circuit disconnecting means shall be permitted to be mounted up to 6 m (20 ft) away from the control enclosure, provided the control enclosure is marked to indicate the location of the machine supply circuit disconnecting means and the machine supply circuit disconnecting means complies with all the following:

- (1) *Is in sight of the control enclosure it supplies*
- (2) *Is readily accessible*
- (3) *Is marked in accordance with 5.1.9.2*

5.1.9.7 Access to enclosures containing the machine supply circuit disconnecting means shall be in accordance with 6.2.3.1.

5.1.9.8 Where two or more machine supply circuit disconnecting means are provided within the same control enclosure for multiple machine supply circuits, they shall be grouped in one location where practicable. Protective interlocks for their correct operation shall be provided where a hazardous condition or damage to the machine or to the work in progress can occur.

5.1.10 Type. The machine supply circuit disconnecting means shall be one of the following types:

- (1) A listed motor circuit switch rated in horsepower
- (2) A listed molded case circuit breaker
- (3) A listed molded case switch
- (4) An instantaneous trip circuit breaker that is part of a listed combination motor controller limited to single motor applications
- (5) A listed self-protected combination controller limited to single motor applications
- (6) An attachment plug and receptacle for cord connection

5.1.11 Requirements.

5.1.11.1* Where the machine supply circuit disconnecting means is one of the types in 5.1.10(1) through 5.1.10(5), it shall fulfill all of the following requirements:

- (1) Disconnect the electrical equipment from the machine supply circuit and have one off (open) and one on (closed) position only. Circuit breakers, instantaneous trip circuit breakers, molded-case switches, and self-protected combination motor controllers are permitted to have a reset (tripped) position between off (open) and on (closed).
 - (2) Have an external operating means (e.g., handle) that complies with 5.1.12.
- Exception: Power-operated switchgear need not be operable from outside the enclosure where there are other means to open it.*
- (3) Be provided with a permanent means permitting it to be locked in the off (open) position only (e.g., by padlocks), independent of the enclosure door or enclosure cover position. When so locked, remote as well as local closing into the on position shall be prevented.
 - (4) Simultaneously disconnect all ungrounded conductors of the supply circuit.

- (5) Be operable by qualified persons independent of the enclosure door or enclosure cover position without the use of accessory tools or devices.
- (6) Be rated for the application as follows:
 - (a) With an ampere rating at least 115 percent of the sum of the full-load currents required for all equipment that is in operation at the same time under normal conditions of use
 - (b) Where rated in horsepower, with a horsepower rating at least equal to that which is defined by Table 430.251(B) of *NFPA 70* for a locked rotor current equal to the largest sum resulting from the locked rotor currents of any combination of motors that can be started simultaneously and the full-load currents of the remaining motor and non-motor loads that can be operated at that time
 - (c) With a voltage rating at least equal to the nominal supply circuit voltage
- (7) Be of a type that indicates whether it is in the off (open) or on (closed) position.

5.1.11.2* When the machine supply circuit disconnecting means is an attachment plug and receptacle, it shall fulfill all of the following requirements:

- (1) Have a load-break rating or be interlocked with a switching device that is load-break rated and complies with 5.1.11.1(6)
- (2) Be listed as a switch-rated plug and receptacle rated greater than 20 amperes or 2 hp
- (3) Be of such a type and be so installed to prevent unintended contact with live parts at any time, even during insertion or removal of the connectors
- (4) Have a first-make, last-break electrical grounding contact
- (5) Have a retaining means to prevent unintended or accidental disconnection where rated at more than 20 amperes
- (6) Be located within sight from the operator station and be readily accessible

5.1.11.3 In addition to the requirements in 5.1.11.2, an additional switching device on the machine shall be provided for routine power switching operations of the machine on and off.

5.1.12 Operating Handle.

5.1.12.1 The center of the grip of the operating handle of a supply circuit disconnecting means, when in its highest position, shall be not more than 2.0 m (6 ft 7 in.) above the servicing level. A permanent operating platform, readily accessible by means of a permanent stair(s) or ladder, shall be considered the servicing level.

5.1.12.2 An operating handle of a machine supply circuit disconnecting means shall meet the following criteria:

- (1) Be readily accessible with the enclosure door(s) in the open or closed position
- (2) Maintain the environmental rating of the enclosure to the degree necessary for the application when installed through the control enclosure
- (3) Not be restricted by the enclosure door(s) when the door is in the open or closed position

5.1.13 Excepted Circuits.

5.1.13.1 The following circuits shall not be required to be disconnected by the machine supply circuit disconnecting means:

- (1) Lighting circuits for lighting needed during maintenance or repair
- (2) Attachment plugs and receptacles for the exclusive connection of repair or maintenance tools and equipment (e.g., hand drills, test equipment)
- (3) Undervoltage protection circuits that are only used for automatic tripping in the event of supply circuit failure
- (4) Circuits supplying equipment that need to remain energized for satisfactory operation [e.g., temperature-controlled measuring devices, product (work in progress) heaters, program storage devices, inputs, non-motion outputs, displays, and safety interlocks]

5.1.13.2 Excepted circuits shall be provided with all of the following:

- (1) A disconnecting means, isolating transformer, and over-current protection mounted in an enclosure adjacent to or within the control enclosure containing the machine supply circuit disconnecting means
- (2) Line side (of the machine supply circuit disconnecting means) supply circuit conductors, when internal to the control enclosure, that are separate from and do not share a raceway with other conductors and that are encased in rigid or flexible conduit if longer than 460 mm (18 in.)

5.1.13.3 The control interlocking circuits shall be capable of being disconnected at the control panel from which they are sourced.

5.1.13.4 Where the excepted circuits are not disconnected by the machine supply circuit disconnecting means, all of the following requirements shall be met:

- (1) A permanent safety sign(s) shall be placed adjacent to the machine supply circuit disconnecting operating handle(s), indicating that it does not de-energize all exposed live parts when it is in the open (off) position as in 16.2.4.
- (2) A statement containing the information from 16.2.4 shall be included in the machine documentation.
- (3) A permanent safety sign shall be placed on a nonremovable part inside the control enclosure in proximity to each excepted circuit, or shall be identified by color as defined in 13.2.4.

5.2 Additional Disconnecting Means.

5.2.1 In addition to the machine supply circuit disconnecting means, devices shall be permitted to be provided for disconnecting electrical equipment to enable work to be performed on individual portions of the machine.

5.2.2 The following devices shall be permitted to fulfill the function of 5.2.1:

- (1) Devices described in 5.1.10
- (2) A manual motor controller marked "suitable as motor disconnect" and in compliance with UL 508 where located on the load side of the last short-circuit protective device in the branch

- (3) System isolation equipment that incorporates control lockout stations and is listed for disconnection purposes where located on the load side of the machine supply circuit disconnecting means and overcurrent protection

5.2.3 An operating means of the additional disconnecting means in 5.2.2 shall be as follows:

- (1) Readily accessible and complies with 5.1.12

Exception: Switches and circuit breakers installed adjacent to motors, appliances, or other equipment that they supply shall be permitted to be accessible by portable means.

- (2) Within sight of the part of the machine requiring disconnection
- (3) Readily identifiable as a disconnecting means and marked to identify the equipment that is disconnected
- (4) For other than attachment plugs, provided with permanent means for locking in the off position only

5.2.4 Enclosure Access. Access to enclosures containing disconnecting means shall be in accordance with 6.2.3.1.

5.3 Means for Removal of Power for Prevention of Unexpected Start-Up.

5.3.1 Means for removal of power shall be provided when prevention of unexpected start-up is required (e.g., during maintenance where the unexpected start-up of a machine or part of the machine results in a hazardous situation) and shall be as follows:

- (1) Appropriate for the intended use
- (2) Conveniently located
- (3) Readily identifiable as to their function and purpose
- (4) Provided with permanent means for locking in the off position only

5.3.2 Removal of power shall be accomplished by one of the following:

- (1) The machine supply circuit disconnecting means
- (2) Additional devices conforming to 5.1.10 or 5.2.2
- (3) Other means (e.g., a contactor switched off by a control circuit) that meet the requirements of 5.3.3 and 5.3.4

5.3.3* Where other means of removal of power are used, a single failure of any of its components shall not result in an inadvertent or unexpected start-up.

5.3.4 Other means of removal of power shall be employed only for situations that include the following:

- (1) Routine exchange of work pieces, fixtures, and tools requiring no significant dismantling of the machine
- (2) Work on the electrical equipment where all of the following conditions exist:
 - (a) There is no hazard arising from electric shock and burn.
 - (b) The switching off means cannot be negated by the work.
 - (c) The work is of a minor nature (e.g., replacement of plug-in devices without disturbing existing wiring).
 - (d) There is no hazard arising from the unexpected energizing or de-energizing of circuits.

Chapter 6 Protection from Electrical Hazards

6.1* General. Electrical equipment shall provide basic protection (see Sections 6.2 and 6.4) and fault protection (see Sections 6.3 and 6.4) to persons from electric shock.

6.2 Basic Protection. Live parts operating at or above 50 volts rms ac or 60 volts dc shall be guarded against contact.

6.2.1 General. The basic protection (see 3.3.11) requirements of 6.2.2 or 6.2.3 shall be applied to live parts operating at or above 50 volts rms ac or 60 volts dc.

6.2.2 Protection by Insulation of Live Parts.

6.2.2.1 Live parts protected by insulation shall be completely covered with insulation that is removable only by destruction.

6.2.2.2 Such insulation as described in 6.2.2.1 shall be capable of withstanding the mechanical, chemical, electrical, and thermal stresses to which the insulation is subjected under normal operating conditions.

6.2.2.3 Paints, varnishes, lacquers, and similar products shall not be considered protection against electric shock under normal operating conditions.

6.2.3 Protection by Enclosures. Equipment enclosures, enclosure openings, and observation windows shall meet the requirements of UL 508, UL 508A, UL 50, or NEMA 250.

Exception: If an enclosure is not rated, its suitability shall be permitted to be determined by using a test finger as described in Figure 6.2.3. The test finger shall not be able to contact live parts in any direction by applying minimal force in every opening in the enclosure, including openings created by removal of parts mounted through the enclosure walls, doors, or covers.

6.2.3.1* Enclosure Access. Opening an enclosure (e.g., door, lid, cover) that contains live parts operating at or above 50 volts rms ac or 60 volts dc shall be permitted only under one or more of the following conditions:

- (1) The use of a key or tool is necessary for access to live parts operating at or above 50 volts rms ac or 60 volts dc. All live parts mounted on the inside of doors or covers that are operating at or above 50 volts rms ac or 60 volts dc shall be protected from unintentional direct contact by the inherent design of components or the application of barriers or obstacles such that a 50 mm (2 in.) sphere cannot contact any live parts. A safety sign shall be provided in accordance with 16.2.4.
- (2) The disconnecting means supplying the enclosure is interlocked with the enclosure door(s) in accordance with 6.2.3.2.
- (3) Opening without the use of a key or a tool and without disconnection of live parts shall be permitted only when all live parts inside that are operating at or above 50 volts rms ac or 60 volts dc are separately enclosed or guarded such that there cannot be any contact with live parts. A safety sign shall be provided in accordance with 16.2.4.

- (4) Relevant information about the procedures for the defeat of the interlock is provided with the instructions for use of the electrical equipment.

6.2.3.3 Excepted Circuits. All parts operating at or above 50 volts rms ac or 60 volts dc that are still energized after switching off the machine supply circuit disconnecting means (*see 5.1.13*) shall be protected from unintentional contact by the inherent design of components or the application of barriers or obstacles such that a 50 mm (2 in.) sphere cannot contact any live parts.

6.3 Fault Protection.

6.3.1* General. Fault protection (*see 3.3.48*) preventing hazardous conditions to continue in the event of an insulation fault between live and exposed conductive parts shall be provided.

6.3.1.1 For each circuit part or part of the electrical equipment, at least one of the following measures shall be applied:

- (1) Measures to prevent the occurrence of a hazardous touch voltage by means of double insulation (*see 6.3.2*)
- (2) Automatic disconnection of the supply (interruption of one or more of the ungrounded conductors affected by the automatic operation of a protective device in case of a fault) (*see 6.3.2.3*)

6.3.2 Protection by Double Insulation.

6.3.2.1 Measures to prevent the occurrence of a hazardous touch voltage shall be by use of double insulation to prevent the occurrence of hazardous touch voltages on the accessible parts through a failure in the basic insulation.

6.3.2.2 When the means described in 6.3.2.1 is used to prevent a hazardous touch voltage, the equipment shall be distinctively marked and shall be listed to be protected by a system of double insulation or its equivalent.

6.3.2.3 Protection by Automatic Disconnection of Supply. Automatic disconnection of the supply of any circuit affected by the particular circuit overcurrent protective device in the event of a fault shall prevent an exposure to a continuous hazardous touch voltage with the following protective measures:

- (1) Protective bonding of exposed conductive parts (*see 8.2.3*)
- (2) The use of overcurrent protection devices for the automatic disconnection of the supply in the event of a fault

6.4 Protection by the Use of Protective Extra Low Voltage (PELV) or Class 2 Circuits.

6.4.1 General Requirements.

6.4.1.1 The use of PELV, as described in Section 6.4, shall protect persons against electric shock from indirect contact and limited area direct contact.

6.4.1.2 Class 2 circuits, as covered in 13.1.1 and Article 725 of *NFPA 70* (NEC), shall be permitted to be used to provide protection from electric shock and other hazards.

6.4.2 PELV circuits shall satisfy all of the following conditions:

- (1) The nominal voltage shall not exceed the following:
 - (a) 30 volts ac (rms value) or 60 volts dc (ripple-free) when the equipment is used in normally dry loca-

tions and when large area contact of live parts with the human body is not expected

- (b) 6 volts ac (rms value) or 15 volts dc (ripple-free) in all other cases
- (2) One side of the circuit or one point of the source of the supply of that circuit shall be connected to the equipment grounding circuit.
- (3) 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.
- (4) 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.
- (5) Attachment plugs and receptacles for a PELV circuit shall conform to the following:
 - (a) Attachment plugs shall not be able to enter receptacles of other voltage systems.
 - (b) Receptacles shall not admit plugs of other voltage systems.

6.4.3 Sources for PELV. The source for PELV shall be one of the following:

- (1) A safety isolating transformer
- (2) A source of current providing a degree of safety equivalent to that of the safety isolating transformer (e.g., a motor generator with winding providing equivalent isolation)
- (3) An electrochemical source (e.g., a battery) or another source independent of a higher voltage circuit (e.g., a diesel-driven generator)
- (4) An identified electronic power supply conforming to standards specifying measures to be taken to ensure that, even in the case of an internal fault, the voltage at the outgoing terminals does not exceed the values specified in 6.4.2(1)

6.5 Protection Against Residual Voltages.

6.5.1 Live parts having a residual voltage greater than 60 volts after the supply has been disconnected shall be reduced to 60 volts or less within 5 seconds of disconnecting the supply voltage.

Exception No. 1: Components having a stored charge of 60 microcoulombs or less shall be exempt from this requirement.

Exception No. 2: Where such a provision would interfere with the functioning of the equipment, a durable safety sign that draws attention to the hazard and states the delay required before entry to the enclosure is allowed shall be displayed at a visible location on or immediately adjacent to the enclosure containing the capacitance.

6.5.2 The withdrawal of plugs or similar devices, which results in the exposure of conductors (e.g., pins), shall have a discharge time that does not exceed 1 second.

Exception No. 1: Exempted from this requirement are components having a stored charge of 60 microcoulombs or less.

Exception No. 2: Exempted from this requirement are conductors that are protected against direct contact.

6.5.3 Discharge of Stored Energy. Capacitors shall be provided with a means of discharging stored energy.

6.5.3.1 Time of Discharge. The residual voltage of a capacitor shall be reduced to 50 volts, nominal, or less, within 1 minute after the capacitor is disconnected from the source of supply.

Exception: Where the requirement would interfere with the functioning of the equipment, a safety sign that draws attention to the hazard and states the delay required before entry to the enclosure shall be permitted to be displayed at a visible location on or immediately adjacent to the enclosure containing the capacitor(s).

6.5.3.2 Means of Discharge. The discharge circuit shall be either permanently connected to the terminals of the capacitor or capacitor bank, or provided with automatic means of connecting it to the terminals of the capacitor bank on removal of voltage from the line. Manual means of switching or connecting the discharge circuit shall not be used.

Exception: Where conductors in the main power circuit are protected against direct contact and where the capacitor is being used as an energy storage device in accordance with the manufacturer's instructions, a manual means of switching or connecting the discharge circuit shall be permitted.

6.6 Arc Flash Hazard Warning. A safety sign shall be provided in accordance with 16.2.3.

Chapter 7 Protection of Equipment

7.1 General. Chapter 7 shall detail the measures to be taken to protect equipment against the effects of the following:

- (1) Overcurrent arising from a short circuit
- (2) Overload or loss of cooling of motors
- (3) Ground faults
- (4) Overvoltages due to lightning and switching surges
- (5) Abnormal temperatures
- (6) Loss of or reduction in the supply voltage
- (7) Overspeed of machines/machine elements
- (8) Incorrect phase sequence

7.2 Overcurrent Protection.

7.2.1* General.

7.2.1.1 Overcurrent protection shall be provided where the current in a machine circuit can exceed either the rating of any component in the circuit or the current-carrying capacity of the conductors in the circuit, whichever is the lesser value.

7.2.1.2 All overcurrent protective devices shall be selected and applied with proper consideration being given to, but not limited to, the following:

- (1) System maximum available fault current at the point of application
- (2) Interrupting rating of the overcurrent protective device
- (3) Voltage rating of the system
- (4) Load and circuit characteristics
 - (a) Normal operating current
 - (b) Inrush characteristics
 - (c) Thermal withstand capability (I^2t)
 - (d) Magnetic withstand capability (I_p)
- (5) Current-limiting ability of the overcurrent protective device
- (6) Coordination of the overcurrent protective devices to each other

7.2.1.3 Supplementary overcurrent protective devices shall not be used as a substitute for branch-circuit overcurrent protective devices.

7.2.1.4 A circuit breaker, self-protected combination motor controller, or a manual motor controller suitable as tap conductor protection in group installations marked with a slash rating, such as 120/240V or 480Y/277V, shall be applied in a solidly grounded circuit where the nominal voltage of any conductor to ground does not exceed the lower voltage rating and the nominal voltage between any two conductors does not exceed the higher voltage rating. When slash-rated devices are connected to the supply circuit of the machine, the nameplate voltage rating in 16.4.1(3) shall not exceed the lower voltage rating or shall include the complete slash rating. When slash rated devices are connected to the secondary of a transformer forming part the electrical equipment of the machine, the transformer secondary shall be grounded such that the line-to-line voltage for each phase and voltage to ground for any pole do not exceed the respective slash ratings.

7.2.2* Supply Conductors. Unless otherwise specified by the user, the supplier of the electrical equipment shall not be 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 diagram the data necessary for selecting this overcurrent protective device.

7.2.3 Power Circuits. Feeder and branch-circuit conductors shall be protected against overcurrent in accordance with their ampacities as specified in Section 12.5. In power circuits for motors, devices for detection and interruption of overcurrent, selected in accordance with 7.2.10, shall be applied to each ungrounded phase conductor. The grounded conductor shall not be disconnected unless (1) all ungrounded and grounded conductors open with no pole operating independently, or (2) the overcurrent protection is additionally relied upon for motor overload protection in accordance with 430.36 and 430.37 of NFPA 70.

7.2.4 Control Circuit Protection.

7.2.4.1 General. A control circuit tapped from the load side of the branch-circuit short-circuit and ground-fault protective device(s) and functioning to control the load(s) connected to that branch circuit shall be protected against overcurrent in accordance with 7.2.4.2. Such a tapped control circuit shall not be considered to be a branch circuit and shall be permitted to be protected by either a supplementary or branch-circuit overcurrent protective device(s).

7.2.4.2 Control Circuit Conductor Protection.

7.2.4.2.1 Control circuit conductors, other than flexible cords and fixture wires, shall be protected against overcurrent in accordance with their ampacities as specified in Section 12.5, unless otherwise permitted in 7.2.4.2.2 through 7.2.4.2.6.

7.2.4.2.2 Control circuit conductors sizes of 18, 16, and 14 AWG shall be considered as protected by an overcurrent device(s) of not more than a 20-ampere rating.

7.2.4.2.3 Control circuit conductors that do not extend beyond the control cabinet enclosure shall be considered protected by the load branch-circuit short-circuit and ground-fault protective device(s) where the rating of the protective device(s) is not more than 400 percent of the ampacity of the

control circuit conductor for conductors 14 AWG and larger, or not more than 25 amperes for 18 AWG and 40 amperes for 16 AWG.

7.2.4.2.4 Control circuit conductors of 14 AWG and larger that extend beyond the enclosure shall be considered protected by the load branch-circuit short-circuit and ground-fault protective device(s) where the rating of the protective device(s) is not more than 300 percent of the ampacity of the control circuit conductors.

7.2.4.2.5 Control circuit conductors supplied by the secondary side of a single-phase transformer having a 2-wire (single-voltage) secondary shall be considered protected by overcurrent protection provided on the primary (supply) side of the transformer, if this protection is in accordance with 7.2.7 and does not exceed the value determined by multiplying the secondary conductor ampacity by the secondary-to-primary voltage ratio. Transformer secondary conductors (other than 2-wire) shall not be considered to be protected by the primary overcurrent protective device.

7.2.4.2.6 Control circuits conductors shall be considered protected by the motor branch-circuit short-circuit and ground-fault protective device(s) where the opening of the control circuit would create a hazard (e.g., the control circuit of a magnetic chuck).

7.2.5 Receptacle Outlets and Their Associated Conductors for Accessory Circuits.

7.2.5.1 Overcurrent protection shall be provided for the circuits feeding general purpose receptacle outlets intended primarily for supplying power to maintenance equipment.

7.2.5.2 Overcurrent protective devices shall be provided in the ungrounded phase conductors of each circuit feeding receptacle outlets. Overcurrent protection for these receptacle outlets shall not exceed 15 amperes.

7.2.6 Lighting Circuits. Overcurrent protection for lighting branch circuits shall not exceed 15 amperes.

7.2.7 Transformers. Transformers for motor control circuits shall be protected in accordance with Article 430, Part VI, of *NFPA 70*. Transformers for other than motor control circuits shall be protected in accordance with Article 450, Part I, of *NFPA 70*.

7.2.8 Location of Overcurrent Protective Devices. An overcurrent protective device shall be located at the point where the conductor to be protected is connected to the supply except as follows:

- (1) Overcurrent protection at the supply shall not be required if all of the following conditions are met:
 - (a) The current-carrying capacity of each of the conductors is at least equal to that required for their respective load, in accordance with Section 12.5.
 - (b) Each connecting conductor to the overcurrent protective devices is no longer than 3 m (10 ft).
 - (c) The conductor is suitably protected from physical damage.
 - (d) The conductor does not extend beyond the control panel enclosure.
 - (e) The conductor terminates in a single branch circuit overcurrent protective device.

- (2) Overcurrent protection at the supply shall not be required if all of the following conditions are met:

- (a) The conductor has an ampacity of at least one-third that of the conductor from which it is supplied.
- (b) The conductor is suitably protected from physical damage.
- (c) The conductor is not over 7.5 m (25 ft) long, and the conductor terminates in a single branch circuit overcurrent protective device.

7.2.9* Short-Circuit Current Rating or Interrupting Rating.

The short-circuit current rating or interrupting rating shall be at least equal to the available fault current at the point of application. Where the fault current to an overcurrent protective device includes additional currents other than from the supply (e.g., from motors, from power factor correction capacitors), these shall be taken into consideration.

7.2.10 Rating and Setting of Overcurrent Protective Devices.

7.2.10.1* Each motor controller and its associated wiring shall be protected as an individual branch circuit by a short-circuit protective device (SCPD) as specified by the controller manufacturer. The maximum rating of the designated SCPD shall be as shown in Table 7.2.10.1.

Exception No. 1: Table 7.2.10.1 shall not apply to Design B energy efficient motor circuits. The provisions of NFPA 70 shall be observed for Design B energy efficient motor circuits.

Exception No. 2: Where the controller is an adjustable speed drive that is listed and marked "Suitable for Output Motor Conductor Protection," the maximum rating of the designated SCPD shall be permitted to be determined by replacing the full-load current in Table 7.2.10.1 with the drive's rated input current. The SCPD shall not exceed the rating marked on the adjustable speed drive or in the manufacturer's instructions.

7.2.10.1.1 A listed self-protected combination controller shall be permitted in lieu of the devices specified in Table 7.2.10.1 for branch circuit and overload protection of a single motor circuit.

7.2.10.1.2 Where a listed self-protected combination controller has an adjustable, instantaneous trip setting, the setting shall not exceed 1300 percent of full-load motor current for other than Design B energy efficient motors and not more than 1700 percent of full-load motor current for Design B energy efficient motors.

7.2.10.2 Several motors, each not exceeding 1 hp in rating, shall be permitted on a nominal 120-volt branch circuit protected at not over 20 amperes or a 1000-volt nominal or less branch circuit, protected at not over 15 amperes, where all of the following conditions are met:

- (1) The full-load rating of each motor does not exceed 6 amperes.
- (2) The rating of the branch-circuit short-circuit and ground-fault protective device marked on any of the controllers is not exceeded. The short-circuit and ground-fault protection is provided by a single inverse time circuit breaker or single set of fuses.
- (3) Individual overload protection conforms to Section 7.3.

7.2.10.3 Where the branch-circuit short-circuit and ground-fault protective device is selected not to exceed that allowed by 7.2.10.1 for the smallest rated motor, two or more motors or

Table 7.2.10.1 Maximum Rating or Setting of Fuse and Circuit Breakers: Motor, Motor Branch Circuit, and Motor Controller

Fuse Class with Non-Time Delay	Full-Load Current (%)		
	AC-2	AC-3	AC-4
R	300	300	300
CF or J	300	300	300
CC	300	300	300
T	300	300	300
Fuse Class with Time Delay ^b	Type of Application ^a		
	AC-2	AC-3	AC-4
RK-5 ^c	150	175	175
RK-1	150	175	175
CF or J	150	175	225
CC	150	300	300
Instantaneous trip circuit breaker ^d	800	800	800
Inverse trip circuit breaker ^e	150	250	250

Note: Where the values determined by this table do not correspond to the standard sizes or ratings, the next higher standard size, rating, or possible setting shall be permitted.

^a Types of starting duty are as follows:

- (1) AC-2: All light-starting duty motors, including slip-ring motors; starting, switching off
- (2) AC-3: All medium starting duty motors including squirrel-cage motors; starting, switching off while running, occasional inching, jogging, or plugging but not to exceed 5 operations per minute or 10 operations per 10 minutes and all wye-delta and two-step autotransformer starting motors
- (3) AC-4: All heavy starting duty motors including squirrel-cage motors; starting, plugging, inching, jogging

^b Where the rating of a time-delay fuse (other than CC type) specified by the table is not sufficient for the starting of the motor, it shall be permitted to be increased but shall in no case be permitted to exceed 225 percent. The rating of a time-delay Class CC fuse and non-time-delay Class CC, J, CF, or T fuse shall be permitted to be increased but shall in no case exceed 400 percent of the full-load current.

^c Unless a motor controller is listed for use with RK-5 fuses, Class RK-5 fuses shall be used only with NEMA-rated motor controllers.

^d Instantaneous trip circuit breakers shall be permitted to be used only if they comply with all of the following:

- (1) They are adjustable.
- (2) Part of the combination controller has motor-running protection, short-circuit protection, and ground-fault protection in each conductor.
- (3) The combination is especially identified for use.
- (4) It is installed per any instructions included in its listing or labeling.
- (5) They are limited to single motor applications; circuit breakers with adjustable trip settings are to be set at the controller manufacturer's recommendation, but not greater than 1300 percent of the motor full-load current.

^e Where the rating of an inverse time circuit breaker specified in this table is not sufficient for the starting current of the motor, it shall be permitted to be increased but in no case exceed 400 percent for full-load currents of 100 amperes or less or 300 percent for full-load currents greater than 100 amperes.

one or more motors and other loads, with each motor having individual overload protection, shall be permitted to be connected to a branch circuit where it can be determined that the branch-circuit short-circuit and ground-fault protective device will not open under severe normal conditions of service that might be encountered. The short-circuit and ground-fault protection shall be provided by a single inverse time circuit breaker or single set of fuses.

7.2.10.4 Two or more motors, or one or more motors and other loads, and their control equipment shall be permitted to be connected to a single branch circuit where short-circuit and ground-fault protection is provided by a single inverse time circuit breaker or a single set of fuses, provided the following conditions under 7.2.10.4(1) and either 7.2.10.4(2) or 7.2.10.4(3) are met:

- (1) Each motor controller and overload device is either listed for group installation with specified maximum branch-

circuit protection or selected such that the ampere rating of the motor branch short-circuit and ground-fault protective device does not exceed that permitted by 7.2.10.1 for that individual motor controller or overload device and corresponding motor load.

- (2) The rating or setting of the branch short-circuit and ground-fault protection device does not exceed the values in Table 7.2.10.4 for the smallest conductor in the circuit.

Exception: Where a controller is an adjustable speed drive that is listed and marked "Suitable for Output Motor Conductor Protection," the conductors from the drive to the motor shall not be required to be used when determining the smallest conductor in the circuit. The conductors from the drive to the motor shall have an ampacity in accordance with Sections 12.5 and 12.6.

- (3) The rating or setting of the branch short-circuit and ground-fault protection does not exceed the value specified in 7.2.10.1 for the highest rated motor connected to

the branch circuit plus an amount equal to the sum of the full-load current ratings of all other motors and the ratings of other loads connected to the circuit. Where this calculation results in a rating less than the ampacity of the branch circuit conductors, it shall be permitted to increase the maximum rating of the fuses or circuit breaker to a value not exceeding that permitted by Sections 12.5 and 12.6. Overcurrent protection for loads other than motor loads shall be in accordance with 7.2.3, 7.2.4, and 7.2.11. Where 16 AWG or 18 AWG conductors are used for branch circuit conductors or tap conductors under 7.2.10.5, the rating and type of the branch short-circuit and ground-fault protection shall be in accordance with 12.6.1.

7.2.10.5 For group installations described in 7.2.10.4(3), the conductors of any tap supplying a single motor shall not be required to have an individual branch-circuit short-circuit and ground-fault protective device, provided they comply with one of the following:

- (1) No conductor to the motor shall have an ampacity less than that of the branch-circuit conductors.
- (2) No conductor to the motor shall have an ampacity less than one-third that of the branch-circuit conductors, with a minimum in accordance with Sections 12.5 and 12.6, the conductors to the motor overload device being not more than 7.5 m (25 ft) long and being suitably protected from physical damage in accordance with Chapter 13.
- (3) Conductors from the point of the tap from the branch-circuit to a listed manual motor controller additionally marked "Suitable for Tap Conductor Protection in Group Installations" or to a branch circuit protective device shall be permitted to have an ampacity not less than 1/10 the rating or setting of the branch-circuit short-circuit and ground-fault protective device. The conductors from the

controller to the motor shall have an ampacity in accordance with Sections 12.5 and 12.6. The conductors from the point of the tap to the controller shall (1) be enclosed either by an enclosed controller or by a raceway and be not more than 3 m (10 ft) long or (2) have an ampacity not less than that of the branch-circuit conductors.

7.2.11 Resistance Heating Branch-Circuit Overcurrent Protection.

7.2.11.1 If the branch circuit supplies a single non-motor-operated load rated at 16.7 amperes or more, the overcurrent device rating shall not exceed 150 percent of the load rating.

7.2.11.2 Equipment employing resistance-type heating elements rated at more than 48 amperes shall have the heating elements subdivided. Each subdivided load shall not exceed 48 amperes and shall be protected at not more than 60 amperes.

Exception: A single sheath-type heating element requiring more than 48 amperes shall be protected at not more than 125 percent of the load where the element is integral with and enclosed within the machine housing.

7.2.11.3 The additional overcurrent protective devices shall be all of the following:

- (1) Installed within or on the machinery or provided as a separate assembly
- (2) Accessible (but need not be readily accessible)
- (3) A branch-circuit overcurrent protective device

7.2.11.4 The main conductors supplying these additional overcurrent protective devices shall be considered branch-circuit conductors.

7.2.12 Programmable Electronic System Power Supply Input Overcurrent Protection. Programmable electronic system power supply inputs shall be protected by overcurrent protective devices either externally or internally. The overcurrent protection size or rating shall be in accordance with the manufacturer's instructions.

7.2.13 Control Devices. Pushbuttons, selector switches, sensors, and limit switches shall in no case be connected to a circuit rated larger than 10 amperes.

7.2.14 Common Overcurrent Device. The use of the same overcurrent device to provide the protection called for in 7.2.4, 7.2.6, and 7.2.7 shall be permitted.

7.3 Overload Protection of Motors. Overload devices shall be provided to protect each motor, motor controller, and branch-circuit conductor against excessive heating due to motor overloads or failure to start.

7.3.1 Motors. Motor overload protection shall be provided in accordance with Article 430, Part III, of *NFPA 70*.

7.3.2 Resetting. Resetting of the overload device shall not restart the motor.

Exception: Where the machine has only a single motor of 2 hp or less, an overload reset operator mounted on the motor shall be permitted to restart the motor provided that the distance between the overload reset operator and the machine start pushbutton operator is 300 mm (12 in.) or less, and a suitable warning label is attached on or adjacent to the overload reset operator.

Table 7.2.10.4 Relationship Between Conductor Size and Maximum Rating or Setting of Short-Circuit Protective Device for Power Circuits Group Installations

Conductor Size (AWG)	Maximum Rating Fuse or Inverse Time* Circuit Breaker (amperes)
18	See footnote.
16	See footnote.
14	60
12	80
10	100
8	150
6	200
4	250
3	300
2	350
1	400
0	500
2/0	600
3/0	700
4/0	800

*Maximum ratings and type of branch short-circuit and ground-fault protective devices for 16 AWG and 18 AWG shall be determined in accordance with 12.6.1.

7.3.3 Number of Overloads. The minimum number and location of running overload units shall be determined from Table 7.3.3.

7.3.3.1 An overload unit in each phase shall not be required where overload protection is provided by other approved means.

7.3.3.2 Short-time-rated motors or high-reversing duty motors that are unable to be protected by external overload devices shall be protected by a thermal device mounted in the motor and sensitive to the temperature of the motor, or to both motor temperature and current.

7.3.3.3 Motors that are an integral part of a refrigeration compressor of the hermetic or semihermetic type shall be protected in accordance with the compressor manufacturer's recommendations.

7.4* Abnormal Temperature Protection. Resistance heating or other circuits that are capable of attaining or causing abnormal temperatures and, therefore, cause a hazardous condition shall be provided with suitable detection to initiate an appropriate control response.

7.5 Protection Against Supply Interruption or Voltage Reduction and Subsequent Restoration.

7.5.1 General. Where a supply interruption or a voltage reduction can cause a hazardous condition or damage to the machine or to the work in progress, undervoltage protection shall be provided (e.g., to switch off the machine) at a predetermined voltage level. Where only a part of the machine or of the group of machines working together in a coordinated manner is affected by the voltage reduction or supply interruption, the undervoltage protection shall initiate appropriate control responses to ensure coordination.

7.5.2 Undervoltage Protection. Where the operation of the machine allows for an interruption or a reduction of the voltage for a short time period, delayed undervoltage protection shall be permitted to be provided. The operation of the undervoltage device shall not impair the operation of any stopping control of the machine.

7.5.3 Restarting. Upon restoration of the voltage or upon switching on the machine supply circuit, automatic or unintentional restarting of the machine shall be prevented when such a restart causes a hazardous condition.

7.6 Overspeed Protection.

7.6.1* Motor Overspeed Protection. Unless the inherent characteristics of the motor or the controller, or both, are such

as to limit the speed adequately, drive systems motors shall include protection against motor overspeed where overspeed results in a hazardous condition.

7.6.2 Equipment Overspeed Protection. Where the safe operating speed of the equipment is less than that of the drive motor, means shall be provided to limit the speed of the equipment.

7.7* Phase Sequence Protection. Where a phase loss or an incorrect phase sequence of the supply voltage causes a hazardous condition or damage to the machine, protection shall be provided.

7.8 Protection Against Overvoltages Due to Lightning and Switching Surges.

7.8.1* Surge-Protective Devices (SPDs). Industrial machinery with safety circuits not effectively protected from the effects of overvoltages due to lightning or switching surges shall have surge protection installed.

Exception: SPDs shall not be required where the risks associated with the effects of overvoltages are mitigated such that the safety performance determined by a risk assessment is met.

7.8.2 Connections. Where provided, SPDs shall be connected in accordance with product markings and installation instructions.

7.8.3 SPD Type and Location. The type of SPD provided shall be suitable for the circuit location within the electrical equipment of the industrial machinery. Type 1, Type 2, and Type 3 SPDs shall be listed devices.

7.8.3.1 Type 1 SPD. Where the SPD is located on the line side of the service disconnect overcurrent protection, a Type 1 SPD shall be provided.

7.8.3.2 Type 2 SPD. Where the SPD is located on the load side of the service disconnect overcurrent protection, feeder circuit, or separately derived system, a Type 1 or Type 2 SPD shall be provided. Where Type 2 SPDs are provided, the SPD shall be on the load side of an overcurrent protective device.

7.8.3.3 Type 3 SPD. Where the SPD is located on the load side of the branch-circuit overcurrent protective device, a Type 1, Type 2, or Type 3 SPD shall be provided. Where Type 3 SPDs are provided and where included in the manufacturer's instructions, the Type 3 SPD connection shall be a minimum of 10 m (30 ft) of conductor distance from the service or separately derived system disconnect.

Table 7.3.3 Running Overload Units

Kind of Motor	Supply System	Number and Location of Overload Units (Such as Trip Coils, Relays, or Thermal Cutouts)
1-phase, ac or dc	2-wire, 1-phase ac or dc ungrounded	One in either conductor
1-phase, ac or dc	2-wire, 1-phase ac or dc, one conductor grounded	One in ungrounded conductor
1-phase, ac or dc	3-wire, 1-phase ac or dc, one conductor grounded	One in either ungrounded conductor
3-phase, ac	Any 3-phase	Three, one in each phase

Note: For 2-phase power supply systems, see 430.37 of *NFPA 70*.

7.8.3.4 Component Assembly and Other Type 4 SPD. Component assembly SPDs (Type 1, 2, or 3) shall be applied in accordance with 7.8.3.1 through 7.8.3.3 and any additional conditions of use specified by the device manufacturer. Where a Type 4 component assembly SPD or other component type is used, it shall be identified as suitable for the intended use. Component assembly SPDs or other component type SPDs shall only be installed by the industrial control panel manufacturer.

7.8.4 Short-Circuit Current Rating. The SPD shall be marked with a short-circuit current rating and shall not be installed at a point on the system where the available fault current is in excess of that rating.

7.9 Power Factor Correction Capacitor Overcurrent Protection. Where capacitors are installed for motor power factor correction on circuits of 1000 volts, nominal, and under, overcurrent protection for the conductors shall be provided. Each capacitor cell or capacitor bank shall be protected against rupture of the individual cells. Protection included as a part of the capacitor assembly shall be permitted.

Chapter 8 Grounding and Bonding

8.1* General.

8.1.1 Applicability. This chapter provides the requirements for grounding, bonding, and for the grounded conductor.

8.1.2 Separately Derived Systems. Separately derived systems shall be installed in accordance with 250.30 of *NFPA 70*.

8.1.3 Connections. Except at either the source or first disconnecting means of a separately derived system, grounded conductors shall not be connected to the equipment grounding conductor.

8.1.4 Mounting. Mounting hardware shall not be used for terminating conductors used for grounding or bonding.

8.2 Equipment Grounding Conductors and Bonding Jumpers.

8.2.1 Equipment Parts. The equipment frame and all non-current-carrying conductive parts, material, or other equipment likely to become energized shall be bonded together and connected to an equipment grounding conductor or bonding jumper.

Exception: Small parts such as screws, rivets, and nameplates that are not likely to become energized shall not be required to be grounded.

8.2.1.1 Effective Ground-Fault Current Path. The effective ground-fault current path shall be capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point where a ground fault could occur from the point of connection of the supply circuit conductors to the electrical equipment of the machine.

8.2.1.2 Equipment Grounding and Bonding.

8.2.1.2.1 The machine and all exposed, non-current-carrying conductive parts, material, and equipment likely to become energized shall be connected in a manner that provides an effective ground-fault current path.

8.2.1.2.2 Where electrical devices are mounted on metal mounting panels that are located within nonmetallic enclosures, the metal mounting panels shall be connected to an equipment grounding conductor or bonding jumper.

8.2.1.2.3 Where specified by the manufacturer, components and subassemblies shall be bonded in accordance with the manufacturer's instructions.

8.2.1.3* Equipment Grounding Conductor Terminal.

8.2.1.3.1 For each machine supply circuit, an equipment grounding conductor terminal shall be provided in the vicinity of the associated phase conductor terminals and shall be connected to the equipment grounding conductor.

8.2.1.3.2 The equipment grounding conductor terminal shall accommodate an equipment grounding conductor sized in accordance with Table 8.2.2.4.

8.2.1.3.3* The equipment grounding conductor terminal shall be identified with the word "GROUND," the letters "GND" or "GRD," the letter "G," the color GREEN, or the symbol shown in Figure 8.2.1.3.3; in addition, the letters "PE" shall also be permitted to identify this terminal.

8.2.1.3.4 Where an auxiliary grounding electrode is specified by the industrial machinery manufacturer or provider, a terminal shall accommodate this additional grounding electrode conductor.

8.2.2 Equipment Grounding Conductors and Bonding Jumpers.

8.2.2.1 Equipment grounding conductors and bonding jumpers shall be identified in accordance with 13.2.2.

8.2.2.2 Conductors used for grounding and bonding purposes shall be copper.

8.2.2.2.1 Stipulations on stranding and flexing as outlined in Chapter 12 shall apply.

8.2.2.3 Equipment grounding conductors and bonding jumpers shall be insulated, covered, or bare and shall be protected against physical damage.

8.2.2.4 Equipment grounding conductors and bonding jumpers of the wire type shall not be smaller than shown in Table 8.2.2.4, but shall not be required to be larger than the circuit conductors supplying the equipment.

8.2.3 Continuity.

8.2.3.1 Continuity of equipment grounding conductors and bonding jumpers shall be ensured by effective connections.

8.2.3.2 Equipment grounding conductors and bonding jumpers shall be installed in a manner such that removal of a wiring device, such as a receptacle or switch, does not interrupt the continuity of the equipment grounding conductor or bonding conductor.

8.2.3.3 Bonding of equipment with bolts or other identified means shall be permitted if paint and dirt are removed from the joint surfaces or the bonded members are effectively penetrated.



FIGURE 8.2.1.3.3 Grounding Symbol.

Table 8.2.2.4 Minimum Size of Equipment Grounding Conductors and Bonding Jumpers

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of the Equipment (Not Exceeding Amperes)	Copper Conductor Size (AWG or kcmil)
10	16
15	14
20	12
30	10
40	10
60	10
100	8
200	6
300	4
400	3
500	2
600	1
800	1/0
1000	2/0
1200	3/0
1600	4/0
2000	250
2500	350
3000	400
4000	500
5000	700
6000	800

8.2.3.4 Equipment containing energized conductors shall be provided with a separate wire-type equipment grounding conductor or bonding jumper.

8.2.3.5 Doors or Covers.

8.2.3.5.1 Where electrical devices are mounted on conductive doors or covers, an equipment bonding jumper shall be installed.

8.2.3.5.2 Where required, an equipment bonding jumper shall connect the conductive door or cover to the equipment enclosure or to an equipment grounding terminal within the enclosure.

8.2.3.6 Portable, pendant, and resilient-mounted equipment shall be bonded by separate conductors. Where multiconductor cable is used and an equipment grounding conductor is required to carry fault current, the equipment grounding conductor shall be used to provide the bonding.

8.2.4* Exclusion of Switching Devices.

8.2.4.1 The equipment grounding circuit shall not contain any switches or overcurrent protective devices.

8.2.4.2 Separable connections such as those provided in draw-out equipment or attachment plugs and mating connectors and receptacles shall provide for first-make, last-break of the equipment grounding conductor.

8.2.4.3 First-make, last-break shall not be required where interlocked equipment, plugs, receptacles, and connectors preclude energization without grounding continuity.

8.2.5 Equipment Grounding Conductor Connecting Points.

8.2.5.1 All equipment grounding conductors shall be terminated in accordance with 13.1.1, and the equipment grounding conductor connecting points shall have no other function.

8.2.5.2* The equipment grounding conductor connecting points, other than the equipment grounding terminal, shall be identified by the color GREEN, by the bicolor combination of GREEN-AND-YELLOW, or by use of the symbol shown in Figure 8.2.1.3.3.

8.3 Control Circuits. Control circuits shall be permitted to be grounded or ungrounded.

Exception: Exposed control circuits as permitted by Section 6.4 shall be grounded.

8.3.1 If the control system is grounded, the output shall be grounded as near as practicable to the control power source and before the first control device. Switching devices shall not be permitted in a grounded conductor(s) unless the control circuit conductor(s) is opened simultaneously.

Exception: Overload relay contacts shall be permitted in the grounded conductor(s) if the conductor(s) does not extend beyond the control enclosure.

8.3.2 Ungrounded control circuits shall be provided with an insulation-monitoring device that either indicates a ground fault or interrupts the circuit automatically after a ground fault.

Exception: Class 2 circuits as defined in Article 100 and as covered in Article 725 of NFPA 70 shall not require insulation monitoring unless required by 9.4.2.1.

8.4 Lighting Circuits.

8.4.1 One conductor of all machine lighting and maintenance lighting circuits shall be grounded. The grounded conductor(s) shall be identified in accordance with Section 13.2.

8.4.2 Where the lighting circuit is supplied by a separate isolation transformer, one terminal of the secondary of the transformer shall be directly connected to the equipment grounding circuit.

8.4.3 The grounded conductor, where run to a screw-shell lampholder, shall be connected to the screw-shell.

Chapter 9 Control Circuits and Control Functions

9.1 Control Circuits.

9.1.1 Control Circuit Supply.

9.1.1.1 Where control circuits are supplied from an ac source, control transformers shall be used for supplying the control circuits. Control circuits shall not be derived from autotransformers. Control circuits supplied from windings of multiwinding power transformers shall be permitted if the output voltage of the winding supplying the control circuit does not exceed 120 volts ac and the available fault current does not exceed 1000 amperes rms.

9.1.1.2 Where dc control circuits are connected to the equipment grounding circuit, they shall be supplied from a separate winding of the ac control circuit transformer or by another control circuit transformer or a listed dc power supply.

9.1.1.3 Transformers shall not be required if the supply voltage does not exceed 120 volts ac and the available fault current does not exceed 1000 amperes rms.

9.1.1.4 The source of supply for all control circuits shall be taken from the load side of the supply disconnecting means.

Exception: Control circuits meeting the requirements of excepted circuits in 5.1.13.1(4) shall be permitted to be taken from the line side of the supply disconnecting means or other power source. The marking requirements of 16.2.4 shall apply.

9.1.2 Control Circuit Voltages.

9.1.2.1 AC Control Circuit Voltages. The ac voltage for control circuits shall not exceed 120 volts, ac single phase.

Exception No. 1: Other voltages shall be permitted, where necessary, for the operation of electronic, precision, static, or similar devices used in the control circuit.

Exception No. 2: Any electromechanical magnetic device having an inrush current exceeding 20 amperes at 120 volts shall be permitted to be energized above control voltage through contactor or relay contacts. The contactor or relay contacts shall break both sides of the circuit powering the magnetic device. The relay coil shall be connected to the control circuit.

9.1.2.2 DC Control Circuit Voltages. DC control voltage shall be 250 volts or less.

9.1.3 Protection. Control circuits shall be provided with over-current protection in accordance with Chapter 7.

9.1.4 Connection of Control Circuit Devices.

9.1.4.1 All operating coils of electromechanical magnetic devices and indicator lamps (or transformer primary windings for indicator lamps) shall be directly connected to the same side of the control circuit. All control circuit contacts shall be connected between the coil and the other side of the control circuit.

Exception No. 1: Overload relay contacts where the wiring to these contacts does not extend beyond the control enclosure.

Exception No. 2: Contacts of multipole control circuit switching devices that simultaneously open both sides of the control circuit.

Exception No. 3: Ground test switching device contacts in ungrounded control circuits.

Exception No. 4: Solenoid test switching device contacts in ungrounded circuits.

Exception No. 5: Coils or contacts used in electronic control circuits where the wiring to these coils or contacts does not extend beyond the control enclosure.

Exception No. 6: "Run" pushbuttons for two-hand operation, such as for presses having ground detection circuits and overcurrent protection in each conductor.

9.1.4.2 Contacts shall not be connected in parallel where the purpose is to increase ampacity.

9.2* Control Functions. Safety circuits shall meet the safety performance requirements determined by the risk assessment of the machine and the applicable functional safety standards.

9.2.1 Start Functions. Start functions shall operate by energizing the relevant circuit.

9.2.2* Stop Functions. Stop functions shall override related start functions. The reset of the stop functions shall not initiate any hazardous conditions. The three categories of stop functions shall be as follows:

- (1) Category 0 is an uncontrolled stop by immediately removing power to the machine actuators.
- (2) Category 1 is a controlled stop with power to the machine actuators available to achieve the stop then power is removed when the stop is achieved.
- (3) Category 2 is a controlled stop with power left available to the machine actuators.

9.2.3 Operating Modes.

9.2.3.1 Each machine shall be permitted to have one or more operating modes (e.g., automatic, manual, normal, and bypass) determined by the type of machine and its application.

9.2.3.2 Where a hazardous condition results from mode selection, inadvertent selection shall be prevented from occurring (e.g., key-operated switch, access code). Mode selection by itself shall not initiate machine operation. A separate action by the operator shall be required.

9.2.3.3* Safeguarding means shall remain effective for all operating modes.

9.2.3.4 Indication of the selected operating mode shall be provided (e.g., position of mode selector, provision of indicating light, visual display indication).

9.2.4 Overriding Safeguards. Where it is necessary to temporarily override one or more safeguards, a mode selection device or means capable of being secured (e.g., locked) in the desired mode shall be provided to prevent automatic operation. The control circuit for the suspension of a safeguard shall have the same safety requirements as the suspended safeguard itself. In addition, one or more of the following measures shall be provided:

- (1) Initiation of motion by a hold-to-run or other control device.
- (2) A portable control station (e.g., pendant) with an emergency stop device, and where used, an enabling device. Where a portable station is used, motion shall only be initiated from that station.
- (3) Limiting the speed or the power of motion.
- (4) Limiting the range of motion.

9.2.5 Operation.

9.2.5.1 General.

9.2.5.1.1 The necessary interlocks shall be provided for safe operation.

9.2.5.1.2 Measures shall be taken to prevent movement of the machine in an unintended manner after any stopping of the machine (e.g., locked-off condition, power supply fault, battery replacement, lost signal condition with cableless control).

9.2.5.2 Start.

9.2.5.2.1 The start of an operation shall be possible only where all of the safeguards are in place and functional except for conditions as described in 9.2.4.

9.2.5.2.2 On those machines where safeguards cannot be applied for certain operations, manual control of such opera-

tions shall be by hold-to-run controls together with enabling control, where appropriate.

9.2.5.2.3 Interlocks shall be provided to ensure correct sequential starting.

9.2.5.2.4 On machines requiring the use of more than one control station to initiate a start, the following criteria shall be met:

- (1) Each control station shall have a separate manually actuated start control device.
- (2) All required conditions for machine operation shall be met.
- (3) All start control devices shall be in the released (off) position before a start operation is permitted.
- (4) All start control devices shall be actuated concurrently.

9.2.5.3 Stop.

9.2.5.3.1* Category 0, Category 1, and/or Category 2 stops shall be provided as required with the minimum of at least one stop function. The number of stop functions and the stop function category shall be determined by the risk assessment and the functional requirements of the machine. Category 0 and Category 1 stops shall be operational regardless of operating modes, and Category 0 shall take priority.

9.2.5.3.2 Where required, provisions to connect protective devices and interlocks shall be provided. Where applicable, the stop function shall signal the logic of the control system that such a condition exists.

9.2.5.4* Emergency Operations (Emergency Stop, Emergency Switching Off). Emergency operation requirements are as follows:

- (1) This section specifies the requirements for the emergency stop and the emergency switching-off functions of the emergency operations, both of which are initiated by a single human action.
- (2) Once active operation of an emergency stop (*see Section 10.7*) or emergency switching off (*see Section 10.8*) actuator has ceased following a command, the effect of this command shall be sustained until it is reset. This reset shall be possible only at that location where the command has been initiated. The reset of the command shall not restart the machinery but only permit restarting.
- (3) It shall not be possible to restart the machinery until all emergency stop commands have been reset. It shall not be possible to reenergize the machinery until all emergency switching off commands have been reset.

9.2.5.4.1 Emergency Stop. Emergency stop functions provided in accordance with 9.2.5.3 shall be designed to be initiated by a single human action.

9.2.5.4.1.1 In addition to the requirements for stop, the emergency stop shall have the following requirements:

- (1) It shall override all other functions and operations in all modes.
- (2) Power to the machine actuators, which causes a hazardous condition(s), shall be removed as quickly as possible without creating other hazards (e.g., by the provision of mechanical means of stopping requiring no external power, by reverse current braking for a Category 1 stop).
- (3) The reset of the command shall not restart the machinery but only permit restarting.

9.2.5.4.1.2 Where required, provisions to connect additional emergency stop devices shall be provided in accordance with Section 10.7.

9.2.5.4.1.3 The emergency stop shall function as either a Category 0 or a Category 1 stop (*see 9.2.2*). The choice of the category of the emergency stop shall be determined by the risk assessment of the machine.

Exception: In some cases, to avoid creating additional risks, it can be necessary to perform a controlled stop and maintain the power to machine actuators even after stopping is achieved. The stopped condition shall be monitored and upon detection of failure of the stopped condition, power shall be removed without creating a hazardous situation.

9.2.5.4.1.4* Where a Category 0 or Category 1 stop is used for the emergency stop function, it shall have a circuitry design (including sensors, logic, and actuators) according to the relevant risk as required by Section 4.1 and 9.4.1. Final removal of power to the machine actuators shall be ensured and shall be by means of electromechanical components. Where relays are used to accomplish a Category 0 emergency stop function, they shall be nonretentive relays.

Exception: Drives, or solid state output devices, designed for safety-related functions shall be allowed to be the final switching element, when designed according to relevant safety standards.

9.2.5.4.2* Emergency Switching Off. Where the emergency switching-off function is used, it shall be initiated by a single human action.

9.2.5.4.2.1 Emergency switching off shall be permitted under any of the following conditions:

- (1) Where protection against direct contact (e.g., with collector wires, collector bars, slip-ring assemblies, control gear in electrical operating areas) is achieved only by placing out of reach or by obstacles
- (2) Where other hazards or damage caused by electricity are possible

9.2.5.4.2.2 Emergency switching off shall be accomplished by disconnecting the machine supply circuit of the machine effecting a Category 0 stop. Where the machine cannot tolerate the Category 0 stop, it shall be necessary to provide other protection (e.g., against direct contact), so that emergency switching off is not necessary.

9.2.5.5 Hold-to-Run Controls.

9.2.5.5.1* Hold-to-run controls (e.g., jog, inch functions) shall require continuous actuation of the control device(s) to achieve operation.

9.2.5.5.2 Jog or inch functions shall operate only in the manual mode. Manual reverse shall be considered a jog function. The prevention of run or automatic operation during jog or inch shall be accomplished by an operator interface and a separate jog or inch selection method.

9.2.5.6* Two-Hand Controls. All two-hand controls shall have the following features:

- (1) The provision of two control devices shall require the concurrent actuation by both hands.
- (2) It shall be necessary to actuate the control devices within a certain time limit of each other, not exceeding 0.5 second.

- (3) Where this time limit is exceeded, both control devices shall be released before operation is initiated.
- (4) The control devices shall require continuous actuation during the hazardous conditions.
- (5) Machine operation shall cease upon the release of either control device when hazardous conditions are still present.
- (6) Machine operation shall require the release of both control devices before the machine operation is re-initiated.

9.2.5.7 Enabling Control.

9.2.5.7.1 An enabling control function incorporating the use of an enabling device shall, when activated, allow machine operation to be initiated by a separate start control and, when deactivated, stop the machine and prevent initiation of machine operation. An enabling device provided as a part of the enabling control function shall be designed to allow motion when actuated in one position only. In any other position, motion shall be inhibited.

9.2.5.7.2 Enabling controls shall have the following features:

- (1) Connect to a Category 0 or a Category 1 stop (*see* 9.2.2)
- (2) Design follows ergonomic principles
- (3) For two-position types, the positions are as follows:
 - (a) Position 1 is the off function of the switch (actuator is not operated).
 - (b) Position 2 is the enabling function (actuator is operated).
- (4) For three-position types, the positions are as follows:
 - (a) Position 1 is the off function of the switch (actuator is not operated).
 - (b) Position 2 is the enabling function (actuator is operated in its mid position).
 - (c) Position 3 is the off function of the switch (actuator is operated past its mid position).
- (5) A three-position enabling control shall require manual operation to reach Position 3. When returning from Position 3 to Position 2, the function shall not be enabled.

9.2.5.7.3 An enabling control shall automatically return to its off function when its actuator is not manually held in the enabling position.

9.2.6 Combined Start and Stop Controls. A single pushbutton and other devices that alternately start and stop motion shall only be used for secondary functions where no hazardous condition arises when they are operated.

9.2.7 Cableless Control Functions.

9.2.7.1* General. Cableless control (e.g., radio, infrared) techniques for transmitting commands and signals between a machine control system and operator control station(s) shall meet the requirements of 9.2.7.1.1 through 9.2.7.1.4.

9.2.7.1.1 Means shall be provided to verify the memory elements of the operator control station with the machine.

9.2.7.1.2 Means (e.g., key-operated switch, access code) shall be provided, as necessary, to prevent unauthorized use of the operator control station.

9.2.7.1.3 Each operator control station shall carry an unambiguous indication of which machine(s) is intended to be controlled by that operator control station.

9.2.7.1.4 Means shall be provided for visual or audible indication of active and inactive status.

9.2.7.2 Cableless Control Limitation.

9.2.7.2.1 Measures shall be taken to prevent the machine from responding to signals other than those from the intended operator control station(s).

9.2.7.2.2 Where necessary to prevent a hazardous condition, means shall be provided so that the machine can be controlled only from operator control station(s) in one or more predetermined zones or locations.

9.2.7.3 Stop Function.

9.2.7.3.1 A machine that is equipped with cableless control shall have a means of automatically initiating the stopping of the machine and preventing a potentially hazardous operation in the following situations:

- (1) When a stop signal is received
- (2) When a fault is detected in the cableless control system
- (3)* When a valid signal has not been detected within a specified period of time
- (4) When the control panel is taken outside the range of the cableless control where no hazardous situation can occur

9.2.7.3.2 Where an emergency stop device is installed on a cableless control panel it shall meet the following requirements:

- (1) The device shall provide a level of integrity equivalent to that of hardware-based components installed in accordance with this standard for emergency stop functions.
- (2) A continuous and distinctive visual or audible alarm shall be annunciated by the cableless operator control station in the event that the emergency stop initiating device has been actuated.

9.2.7.4* Serial Data Communication. In a machine where the safety-circuit relies on serial data transfer, correct communications shall be ensured by using an error detection method that is able to cope with up to three error bits in any command sequence. The safety capability of the serial data communication system shall be listed to have the same degree of safety capability as hardware-based components installed in accordance with this standard.

9.2.7.5 Use of More Than One Operator Control Station.

Where a machine has more than one operator control station, measures shall be taken to ensure that only one control station shall be enabled at a given time. Indication of which operator control station is in control of the machine shall be provided at locations where necessary for the safety requirements of the machine.

Exception: A stop command from any one of the control stations shall be effective where necessary for the safety requirements of the machine.

9.2.7.6 Battery-Powered Operator Control Stations. A variation in the battery voltage shall not cause a hazardous condition. If one or more potentially hazardous motions are controlled using a battery-powered operator control station, a clear indication shall be given to warn the operator when a variation in battery voltage exceeds specified limits. Under those circumstances, the operator control station shall remain functional long enough to put the machine into a nonhazardous condition.

9.3 Protective Interlocks.

9.3.1 Reclosing or Resetting of an Interlocking Safeguard.

The reclosing or resetting of an interlocking safeguard shall not initiate machine motion or operation that results in a hazardous condition.

9.3.2* Exceeding Operating Limits. Movement or action of a machine or part of a machine that can result in a hazardous condition shall be monitored by providing, for example, over-travel limiters, motor overspeed detection, mechanical overload detection, or anti-collision devices. Where an operating limit (e.g., speed, pressure, position) can be exceeded, leading to a hazardous condition, means shall be provided to detect when a predetermined limit(s) is exceeded and initiate an appropriate control action.

9.3.3 Operation of Auxiliary Functions.

9.3.3.1 Appropriate devices (e.g., pressure sensors) shall check the correct operation of the auxiliary functions.

9.3.3.2 Where the nonoperation of a motor or device for an auxiliary function (e.g., lubrication, coolant, swarf removal) causes a hazardous condition or causes damage to the machine or to the work in progress, interlocking shall be provided.

9.3.4 Interlocks Between Different Operations and for Contrary Motions.

9.3.4.1 All contactors, relays, and other control devices that control elements of the machine that cause a hazardous condition when actuated at the same time (e.g., those that initiate contrary motion) shall be interlocked against incorrect operation.

9.3.4.2 Motor contactors and starters that initiate opposing motion shall be both mechanically and electrically interlocked to prevent simultaneous operation. Relays and solenoids that are mechanically interlocked shall be electrically interlocked.

9.3.4.3 Where certain functions on the machine are required to be interrelated for safeguarding or for continuous operation, their coordination shall be ensured by interlocks. For a group of machines working together in a coordinated manner and having more than one controller, provision shall be made to coordinate the operations of the controllers as necessary.

9.3.4.4 Where a failure of a mechanical brake actuator results in the brake being applied when the associated machine actuator is energized and a hazardous situation results, interlocks shall be provided to switch off the machine actuator.

9.3.5 Reverse Current Braking.

9.3.5.1 Where reverse current braking is used on a motor, effective measures shall be taken to prevent the motor starting in the opposite direction at the end of braking where this reversal will cause a hazardous condition or damage to the machine or to the work in progress. For this purpose, the use of a device operating exclusively as a function of time shall not be allowed.

9.3.5.2 Control circuits shall be arranged so that rotation of a motor shaft, manually or otherwise, shall not result in a hazardous condition.

9.3.6 Protective Interlock. Where doors or guards have interlocked switches used in safety circuits, the interlocking devices shall be listed, either have direct opening operation or provide

similar reliability, and prevent the operation of the equipment when the doors or guards are open (difficult to defeat or bypass).

9.4 Control Functions in the Event of Failure. Where failures or disturbances in the electrical equipment cause a hazardous condition or damage to the machine or the work in progress, measures shall be taken to minimize the probability of the occurrence of such failures or disturbances. The electrical control circuits shall have an appropriate level of performance that has been determined from the risk assessment of the machine.

9.4.1* Risk Reduction Measures. Measures to reduce these risks shall include, but are not limited to, one or more of the following:

- (1) Protective devices on the machine (e.g., interlock guards, trip devices)
- (2) Protective interlocking of the electrical circuit
- (3) Use of proven circuit techniques and components
- (4) Provisions of partial or complete redundancy or diversity
- (5) Provision for functional tests

9.4.2 Protection Against Unintended Operation Due to Ground Faults and Voltage Interruptions.

9.4.2.1 Ground Faults. Ground faults on any control circuit shall not cause unintentional starting or potentially hazardous motions or prevent stopping of the machine. Grounded control circuits shall be in accordance with Section 8.2 and Section 8.3. Ungrounded control circuits shall be provided with an insulation monitoring device that either indicates a ground fault or interrupts the circuit automatically after a ground fault. A restart of the machine with a detected ground fault shall be prevented.

Exception: Ungrounded Class 2 circuits as defined in Article 100 and as covered in Article 725 of NFPA 70 shall not require insulation monitoring so long as the ground fault(s) will not cause unintentional starting or potentially hazardous motions or prevent stopping of the machine.

9.4.2.2 Voltage Interruptions.

9.4.2.2.1 The requirements detailed in Section 7.5 shall apply.

9.4.2.2.2 Where a memory is used, its functioning in the event of power failure shall be ensured (e.g., by using a nonvolatile memory) where such loss of memory results in a hazardous condition.

9.4.3* Control Systems Incorporating Software- and Firmware-Based Controllers.

9.4.3.1 Software Modification. Programmable electronic systems shall be designed and constructed so that the ability to modify the application program shall be limited to authorized personnel and shall require special equipment or other means to access the program (e.g., access code, key-operated switch).

Exception: The manufacturer or supplier shall be permitted to retain the right not to allow the user to alter the program.

9.4.3.2 Memory Retention and Protection.

9.4.3.2.1 Means shall be provided to prevent memory alteration by unauthorized persons.

9.4.3.2.2 Loss of memory shall not result in a hazardous condition.

9.4.3.2.3 Power supplies for electronic equipment requiring memory retention shall have battery backup of sufficient capacity to prevent memory loss for a period of at least 72 hours.

9.4.3.3 Software Verification. Equipment using reprogrammable logic shall have means for verifying that the software is in accordance with the relevant program documentation.

9.4.3.4* Use in Safety Circuits.

9.4.3.4.1 Software- and firmware-based controllers used in safety-circuits shall be listed for such use.

9.4.3.4.2 Safety circuits incorporating software- and firmware-based controllers shall be self-monitoring and conform to all of the following:

- (1) In the event of any single failure, the failure shall be as follows:
 - (a) Not lead to the loss of the safety-related function(s)
 - (b) Lead to the shutdown of the system in a safe state
 - (c) Prevent subsequent operation until the component failure has been corrected
 - (d) Prevent unintended startup of equipment upon correction of the failure
- (2) The safety circuit shall provide protection equivalent to that of control systems incorporating hardwired/hard-ware components.
- (3) The safety circuit shall be designed in conformance with an approved standard that provides requirements for such systems.

Chapter 10 Operator Interface and Control Devices

10.1 General.

10.1.1* Applicability. This chapter shall contain the requirements for devices mounted outside or partially outside control enclosures.

10.1.2 Location and Mounting.

10.1.2.1 Control Devices. As far as is practicable, control devices shall be as follows:

- (1) Readily accessible for service and maintenance
- (2) Mounted in such a manner as to minimize the possibility of damage from activities such as material handling

10.1.2.2 Hand-Operated Control Devices. The actuators of hand-operated control devices shall be selected and installed as follows:

- (1) They are not less than 0.6 m (2 ft) above the servicing level and are accessible from the normal working position of the operator.
- (2) The operator is not placed in a hazardous situation when operating them.
- (3) The possibility of inadvertent operation is minimized.

10.1.2.3 Machine-Mounted Control Equipment.

10.1.2.3.1 Control equipment (e.g., limit switches, brakes, solenoids, position sensors) shall be mounted rigidly in a reasonably dry and clean location, unless designed for a specific environment, shall be protected from physical damage, and shall be free from the possibility of accidental operation by normal machine movements or by the operator.

Exception No. 1: A solenoid sealed in an individual oil-filled container shall be permitted.

Exception No. 2: Prewired devices (e.g., limit switches, proximity switches) provided with an identified cable need not be equipped with provisions for termination of conduit.

10.1.2.3.2 All limit switches or position sensors shall be installed so that accidental overtravel by the machine will not damage the limit switch or sensor.

10.1.2.3.3 Solenoids for operating devices shall be mounted so that liquids drain away from the electrical component enclosure.

10.1.3* Protection. Operator interface, control devices, and enclosures shall be suitable for the environment and shall withstand the stresses of expected use.

10.1.4 Position Sensors.

10.1.4.1 Position sensors (e.g., limit switches, position switches, proximity switches) shall be arranged so that they will not be damaged in the event of overtravel.

10.1.4.2* Position sensors used in safety circuits shall either have direct opening operation or provide similar reliability.

10.1.5 Portable and Pendant Control Stations.

10.1.5.1 Portable and pendant operator control stations and their control devices shall be selected and arranged to minimize the possibility of inadvertent machine operations.

10.1.5.2 Pendant control stations that are vertically suspended from overhead shall comply with 13.4.2.4 or 13.5.10.

10.1.6 Operator Interface Devices.

10.1.6.1 Location of Operator Interface Devices.

10.1.6.1.1 Operator interface devices shall be mounted in locations that will minimize exposure to oil, coolant, and other contaminants.

10.1.6.1.2 Operator interface devices shall be within normal reach of the machine operator and shall be placed so that the operator is not exposed to hazards.

10.1.6.1.3 Operator interface devices shall be located so that unintentional operation by normal movement of the machine, operator, or work will be unlikely.

10.1.6.2 Arrangement of Operator Interface Devices. All start pushbuttons shall be mounted above or to the left of their associated stop pushbuttons.

Exception No. 1: This requirement shall not apply to start pushbuttons in series, such as operating pushbuttons on punch presses.

Exception No. 2: This requirement shall not apply to emergency stop devices.

10.1.7 Foot-Operated Switches. Foot-operated switches used for applications where accidental actuation could create a hazardous situation shall be protected to prevent accidental actuation by falling or moving objects and from unintended operation by accidental stepping onto the switch.

Exception: Foot-operated switches used for emergency stop in accordance with 10.7.2.1 shall not be of the covered or hooded type.