(i) Physical environment (e.g., lighting, vibration, noise levels, atmospheric contaminants)

(6) A description (including interconnection diagrams) of the safeguards, interacting functions, and interlocking of guards with potentially hazardous motions
(7) A description of the safeguarding means and methods provided where the primary safeguards are overridden (e.g., manual programming, program verification)
(8) Means provided for the control of hazardous energies
(9) Explanation of unique terms
(10) Parts list and recommended spare parts list
(11) Maintenance instructions and adjustment procedures
(12) Reference information (where appropriate) on the following:

(a) Lubrication diagram
(b) Pneumatic diagram
(c) Hydraulic diagram
(d) Miscellaneous system diagrams (e.g., coolant, refrigerant)

17.3 Requirements Applicable to All Documentation.

17.3.1 The documents shall be prepared in accordance with the requirements of Section 17.4 through Section 17.10.

17.3.2 For referencing of the different documents, the supplier shall select one of the following methods:

(1) Each of the documents shall carry as a cross-reference the document numbers of all other documents belonging to the electrical equipment. This method shall be used only where the documentation consists of four or fewer documents.
(2) All documents shall be listed with document numbers and titles in a drawing or document list.

17.3.3 Where appropriate, a table of contents shall appear prominently on the first sheet and shall refer to all major sections of the electrical drawings.

17.4* Basic Information. The technical documentation shall be permitted to be presented as a separate document or as part of the installation or operation documentation. The technical documentation shall contain, as a minimum, information on the following:

(1) Normal operating conditions of the electrical equipment, including the expected conditions of the electrical supply and, where appropriate, the physical environment
(2) Handling, transportation, and storage
(3) Inappropriate use(s) of the equipment

17.5 Installation Diagram.

17.5.1* The installation diagram shall provide all information necessary for the preliminary work of setting up the machine.

17.5.2 The specified position of the electrical supply to be installed on site shall be clearly indicated.

17.5.3* The data necessary for choosing the type, characteristics, rated currents, and setting of the overcurrent protective device(s) for the supply circuit conductors to the electrical equipment of the machine shall be stated.

17.5.4* Where necessary, the size, purpose, and location of any raceways in the foundation that are to be provided by the user shall be detailed.

17.5.5* The size, type, and purpose of raceways, cable trays, or cable supports between the machine and the associated equipment that are to be provided by the user shall be detailed.

17.5.6* Where necessary, the diagram shall indicate where space is required for the removal or servicing of the electrical equipment.

17.5.7* Where it is appropriate, an interconnection diagram or table shall be provided. That diagram or table shall give full information about all external connections. Where the electrical equipment is intended to be operated from more than one source of electrical supply, the interconnection diagram or table shall indicate the modifications or interconnections required for the use of each supply.

17.6* Block (System) Diagrams and Function Diagrams. Where it is necessary to facilitate the understanding of the principles of operation, a system diagram shall be provided. For the purposes of this chapter, a block diagram shall symbolically represent the electrical equipment together with its functional interrelationships without necessarily showing all of the interconnections.

17.7 Circuit Diagrams.

17.7.1* Diagrams, including machine schematics, of the electrical system shall be provided and shall show the electrical circuits on the machine and its associated electrical equipment. Electrical symbols shall be in accordance with IEEE 315 where included therein. Any electrical symbols not included in IEEE 315 shall be separately shown and described on the diagrams. The symbols and identification of components and devices shall be consistent throughout all documents and on the machine.

Exception: Wiring schematics shall not be required for commercially available or field replaceable components.

17.7.2* Pertinent information such as motor horsepower, frame size, and speed shall be listed adjacent to its symbol.

17.7.3* Where appropriate, a diagram showing the terminals for interface connections shall be provided. Switch symbols shall be shown on the electromechanical diagrams with all supplies turned off (e.g., electricity, air, water, lubricant) and with the machine and its electrical equipment in the normal starting condition and at 20°C (68°F) ambient temperature. Control settings shall be shown on the diagram.

17.7.4 Conductors shall be identified in logical order in accordance with Section 13.2.

17.7.5* Circuit Characteristics.

17.7.5.1 Circuits shall be shown in such a way as to facilitate the understanding of their function as well as maintenance and fault location.

17.7.5.2 A cross-referencing scheme shall be used in conjunction with each relay, output device, limit switch, and pressure switch so that any contact associated with the device can be readily located on the diagrams.

17.7.6 Control circuit devices shall be shown between vertical lines that represent control power wiring. The left vertical line shall be the control circuit's common and the right line shall be the operating coil's common, except where permitted by Chapter 9 design requirements. Control devices shall be shown on horizontal lines (rungs) between the vertical lines. Parallel circuits shall be shown on separate horizontal lines directly adjacent to (above or below) the original circuit.

Exception: Upon agreement between the machine manufacturer and the user, an alternative convention shall be permitted (e.g., one of the IEC standard presentation methods).

17.7.7 An interconnection diagram shall be provided on large systems having a number of separate enclosures or control stations. It shall provide full information about the external connections of all of the electrical equipment on the machine.

17.7.8 Interlock wiring diagrams shall include devices, functions, and conductors in the circuit where used.

17.7.9 Plug/receptacle pin identification shall be shown on the diagram(s).

17.8 Operating Manual.

17.8.1* The technical documentation shall contain an operating manual detailing proper procedures for setup and equipment use.

17.8.2 Where the operation of the equipment is programmable, detailed information on methods of programming, equipment required, program verification, and additional safety procedures (where required) shall be provided.

17.9 Maintenance Manual.

17.9.1* The technical documentation shall contain a maintenance manual detailing proper procedures for adjustment, servicing and preventive inspection, and repair.

17.9.2 Where methods for the verification of proper operation are provided (e.g., software testing programs), the use of those methods shall be detailed.

17.9.3 Where service procedures requiring electrical work while equipment is energized, the technical documentation shall make reference to appropriate safe work practices, such as the requirements of *NFPA 70E* or OSHA regulations in 29 CFR 1910.331–335.

17.10* Parts List.

17.10.1 The parts list shall comprise, as a minimum, information necessary for ordering spare or replacement parts (e.g., components, devices, software, test equipment, technical documentation) required for preventive or corrective maintenance, including those that are recommended to be carried in stock by the equipment user.

17.10.2 The parts list shall show the following for each item:

(1) Reference designation used in the documentation
(2) Its type designation
(3) Supplier (and supplier's part number)
(4) Its general characteristics where appropriate
(5) Quantity of items with the same reference designation

Chapter 18 Testing and Verification

18.1* General. The verification of the continuity of the effective ground-fault current path shall be conducted and documented. When the electrical equipment is modified, the requirements in Section 18.7 shall apply. Applicable tests shall be performed where deemed necessary in accordance with the references in the following list:

(1) Verification that the electrical equipment is in compliance with the technical documentation *(see Chapter 17)*
(2) Insulation resistance test *(see Section 18.3)*
(3) Voltage test *(see Section 18.4)*
(4) Protection against residual voltages test *(see Section 18.5)*
(5) Functional test *(see Section 18.6)*

18.2* Continuity of the Effective Ground-Fault Current Path. One of the following methods shall be used to verify the continuity of the effective ground-fault current path:

(1) Using an impedance measuring device, take into account any impedance in the measuring circuit. The measured impedance shall be 0.1 ohm or less.
(2) Apply a current of at least 10 amperes, 50 Hz or 60 Hz, derived from an SELV source. The tests are to be made between the equipment grounding terminal and relevant points that are part of the effective ground-fault current path; the measured voltage between the equipment grounding terminal and the points of test is not to exceed the values given in Table 18.2.

18.3 Insulation Resistance Tests. The insulation resistance measured at 500 volts dc between the power circuit conductors and the effective ground-fault current path shall not be less than 1 megohm. The test shall be permitted to be made on individual sections of the machine.

18.4* Voltage Tests. The machine shall withstand without breakdown a test voltage gradually applied from 0 volts to 1500 volts ac or 2121 volts dc and held at the maximum value for a period of at least 1 second between the conductors of all primary circuits and the effective ground-fault current path. The test voltage shall be supplied from an isolated power supply with a minimum rating of 500 volt amperes. Components that are not rated to withstand the test voltage shall be disconnected during testing.

18.5 Protection Against Residual Voltages. Residual voltage tests shall be performed to ensure compliance with Section 6.5.

18.6 Functional Tests. The functions of electrical equipment, particularly those related to safety and safeguarding, shall be tested and documented.

18.7 Retesting. Where a portion of the machine and its associated equipment is changed or modified, that portion shall be reverified and retested as appropriate.

Table 18.2 Verification of Continuity of the Effective Ground-Fault Current Path

Minimum Equipment Grounding Conductor Cross-Sectional Area of the Branch Under Test (AWG)	Maximum Measured Voltage Drop* (V)
18	3.3
16	2.6
14	1.9
12	1.7
10	1.4
>8	1.0

*Values are given for a test current of 10 amperes.

Chapter 19 Servo Drives and Motors

Δ 19.1 Overcurrent Protection for Drives and Servo Motors.

19.1.1 Branch-Circuit Overcurrent Protection. Branch-circuit overcurrent protection shall be provided for servo drives and motors in accordance with manufacturer's markings and instructions.

19.1.2 Overload Protection. Overload protection shall be provided for each motor.

19.1.3 Motor Amplifier/Drive. Where the amplifier/drive is marked to indicate that motor overload protection is included, additional overload protection shall not be required.

19.1.4 Multiple Motor Applications. For multiple motor applications, individual motor overload protection shall be provided.

19.2* Motor Overtemperature Protection.

19.2.1 General. Servo drive systems shall provide protection against motor overtemperature conditions. Protection shall be provided by one of the following means:

(1) Integral motor thermal protector(s)
(2) Servo drive controller(s) with load- and speed-sensitive overload protection and thermal memory detection upon shutdown or power loss
(3) Overtemperature protection relay(s) utilizing thermal sensors embedded in the motor
(4) Motors with cooling systems

19.2.2 Additional Conductor Protection. Overtemperature protection shall be in addition to any conductor protection.

19.2.3 Failure of Cooling System. Systems that utilize motor cooling such as forced air or water shall provide protection against a failed or inoperable cooling system.

19.2.4 Multiple Motor Applications. For multiple motor application, individual motor overtemperature protection shall be provided.

19.2.5 Other Sections. The provisions of 430.43 and 430.44 of *NFPA 70* shall apply to the motor overtemperature protection means.

19.3 Servo Drive System Conductors.

19.3.1 Servo Drive System Supply Conductors. Circuit conductors supplying servo drive systems shall be sized to have an ampacity not less than 115 percent of the rated input of the equipment.

19.3.2 Motor Circuit Conductors. Motor circuit conductors shall have an ampacity of at least 115 percent of the motor full-load current when operated in a continuous mode of operation or as specified by the servo drive system manufacturer. Motor circuit conductors for motors operating in other than continuous mode shall be permitted to have reduced ampacity based upon the design load and duty cycle.

19.3.3 Unshielded servo motor power conductors shall be run in a separate ferrous raceway from other control and instrumentation conductors, from the servo drive enclosure to the servo motor.

Exception: Where either the servo motor power, or control/instrumentation conductors, or both, are installed in raceway system(s) or by separation that shall provide the equivalent level of EMI protection as ferrous raceway utilizing Table 19.3.3

Table 19.3.3 Minimum Conductor Separation (Center to Center)

	Separation	
Ampacity	mm	in.
20 A or less	100	4
Over 20 A and not greater than 40 A	150	6
Over 40 A and not greater than 80 A	200	8
Over 80 A	*	

*Each doubling of current adds 50 mm (2 in.) more to the separation distance.

19.3.4 Where unshielded servo motor power conductors and unshielded control/instrumentation conductors are not contained in ferrous raceways and cross each other, they shall be installed perpendicular to each other.

19.3.5 Where unshielded servo motor power conductors and unshielded control/instrumentation conductors are not isolated by ferrous raceways, separation by distance shall be used per Table 19.3.3 unless otherwise specified by the manufacturer.

19.4 Contactor. Where a contactor is installed ahead of the supply conductors to the servo drive, the contactor current rating shall not be less than 115 percent of the maximum servo drive nameplate rating or shall be sized in accordance with the manufacturer's specifications.

19.5 Cable Shield. Use of a grounded servo motor conductor/cable shield shall not be permitted to satisfy the equipment grounding conductor requirements.

Annex A Explanatory Material

Annex A is not a part of the requirements of this NFPA document but is included for informational purposes only. This annex contains explanatory material, numbered to correspond with the applicable text paragraphs.

A.1.1 In this standard, the term *electrical* includes both electrical and electronic equipment. Requirements that apply only to electronic equipment are so identified.

The general terms *machine* and *machinery* as used throughout this standard mean industrial machinery. See Annex C for examples of industrial machines covered by this standard.

The publications referenced throughout Annex A are listed in Annex K with their appropriate dates of issue.

A.1.1.2 For additional requirements for machines intended to be used in hazardous (classified) areas, see Article 500 of *NFPA 70*.

A.1.5 Motor design letter designations are found in NEMA MG-1 and IEEE 100.

A.3.2.1 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluate testing laboratories. In determining the acceptability of installations, procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A.3.2.2 Authority Having Jurisdiction (AHJ). The phrase "authority having jurisdiction," or its acronym AHJ, is used in NFPA documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A.3.2.4 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A.3.3.3 Actuator. The actuator can take the form of a handle, knob, pushbutton, roller, plunger, touchscreen, and so forth. There are some actuating means that do not require an external actuating force but only an action. See also 3.3.4, Actuator, Machine.

N **A.3.3.4 Actuator, Machine.** Some examples of a machine actuator are a motor, solenoid, and pneumatic or hydraulic cylinder.

A.3.3.5 Adjustable Speed Drive. This term includes ac and dc voltage modes and frequency mode controls. Belt, chain, or roller shifting controllers are not included.

A variable frequency drive is one type of electronic adjustable speed drive that controls the rotational speed of an ac electric motor by controlling the frequency and voltage of the electrical power supplied to the motor. [**70:**100]

A.3.3.7 Ambient Temperature. Ambient air temperature as applied to an enclosure or housing is the average temperature of the surrounding air that comes in contact with the enclosure or housing. Ambient air temperature as applied to a component or device within the enclosure is the average temperature of the surrounding air that comes in contact with the component.

A.3.3.11 Basic Protection (Protection From Direct Contact). In previous editions of this standard, the term "protection against direct contact" was used in place of "basic protection."

A.3.3.14 Cable. For additional information on types of cable, refer to Chapter 3 of *NFPA 70.*

A.3.3.14.1 Cable with Flexible Properties. See 12.2.2.

A.3.3.14.2 Flexible Cable. See 12.2.2.

A.3.3.14.3 Special Cable. For additional information on types of special cables, see Section 12.9 or refer to Chapters 4, 6, 7, and 8 of *NFPA 70.*

A.3.3.17 Cableless Operator Control Station. These stations are not physically connected to the machine by either communications or power conductors. While all cableless devices utilize wireless technology, not all wireless devices are cableless. Examples of cableless devices include cableless teach pendants, cableless crane pendants, and cableless jog pendants.

A.3.3.18 Circuit Breaker. The automatic opening means can be integral, direct acting with the circuit breaker, or remote from the circuit breaker.

A.3.3.19 Color Graphic Interface Device. This does not include monochrome or black and white displays.

A.3.3.21.4 Liquidtight Flexible Nonmetallic Conduit (LFNC). FNMC is an alternative designation for LFNC. [**70:**356.2 Informational Note]

A.3.3.23 Control Circuit (of a machine). Power circuit protection can be provided by control shunt-tripping.

A.3.3.44 Failure (of equipment). After failure, the item has a fault. "Failure" is an event, as distinguished from "fault," which is a state. This concept as defined does not apply to items consisting of software only.

A.3.3.45 Fault. A fault is often the result of a failure of the item itself, but can exist without prior failure.

N **A.3.3.47 Fault Current, Available (Available Fault Current).** A short circuit can occur during abnormal conditions such as a fault between circuit conductors or a ground fault.

A.3.3.48 Fault Protection (Protection from Indirect Contact). In previous editions of this standard, the term "protection against indirect contact" was used in place of "fault protection."

A.3.3.56 Guard. Depending on its construction, a guard can be called a casing, a cover, a screen, a door, or an enclosing guard.

A.3.3.59 Identified (as applied to equipment). Some examples of ways to determine suitability of equipment for a specific purpose, environment, or application include investigations by a qualified testing laboratory (listing and labeling), an inspection agency, or other organizations concerned with product evaluation. [**70:**100 Informational Note]

A.3.3.68 Interrupting Rating. Equipment intended to interrupt current at other than fault levels may have its interrupting rating implied in other ratings, such as horsepower or locked rotor current. [**70:**100 Informational Note]

A.3.3.77 Overcurrent. A current in excess of rating may be accommodated by certain equipment and conductors for a given set of conditions. Therefore, the rules for overcurrent protection are specific for particular situations. [**70:**100 Informational Note]

A.3.3.79 Overcurrent Protective Device, Supplementary. Supplementary overcurrent protective devices are not general use devices, as are branch circuit devices, and must be evaluated for appropriate application in every instance where they are used. Supplementary overcurrent protective devices are extremely application oriented, and prior to applying the devices, the differences and limitations for these devices must be investigated. Such a device is allowed to be incomplete in construction or restricted in performance. Such a device is not suitable for branch circuit protection and is not used where branch circuit protection is required.

One example of differences and limitations is that a supplementary overcurrent protective device could have spacing, creepage, and clearance that are considerably less than those of a branch circuit overcurrent protective device.

Example: A supplemental protector, listed to UL 1077, has spacings that are 9.5 mm (0.375 in.) through air and 12.7 mm (0.5 in.) over surface. A branch circuit–rated UL 489 molded-case circuit breaker has spacings that are 19.1 mm (0.75 in.) through air and 31.8 mm (1.25 in.) over surface.

Another example of differences and limitations is that branch circuit overcurrent protective devices have standard overload characteristics to protect branch circuits and feeder conductors. Supplementary overcurrent protective devices do not have standard overload characteristics and could differ from the standard branch circuit overload characteristics. Also, supplementary overcurrent protective devices have interrupting ratings that can range from 32 amperes to 100,000 amperes. When supplementary overcurrent protective devices are considered for proper use, it is important to be sure that the device's interrupting rating equals or exceeds the available fault current and that the device has the proper voltage rating for the installation (including compliance with slash voltage rating requirements, if applicable).

Examples of supplemental overcurrent protective devices include, but are not limited to, those listed to the following:

(1) UL 248-14
(2) UL 1077

A.3.3.80 Overload. Overload should not be used as a synonym for overcurrent.

A.3.3.83 Programmable Electronic System (PES). This term includes all elements in the system extending from sensors to other input devices via field bus or other communication paths to the machine actuators or other output devices.

A.3.3.84 Qualified Person. Refer to *NFPA 70E* for electrical safety training requirements. [**70:**100 Informational Note]

A.3.3.90 Risk. Examples of references to risk assessment include ANSI B11.0 and ISO 12100.

N **A.3.3.95 Safety Circuit.** "Safety-related control system" and "safety interlock circuit" are common terms used to refer to the safety circuit in other standards. The safety circuit can include hardwired, communication, and software-related components.

A.3.3.98 Servo Drive System. See Figure A.3.3.98, Servo System.

A.3.3.99 Short-Circuit Current Rating (SCCR). The short-circuit current rating of an apparatus or system can be determined either by testing or by evaluation using an approved method such as Supplement SB of UL 508A.

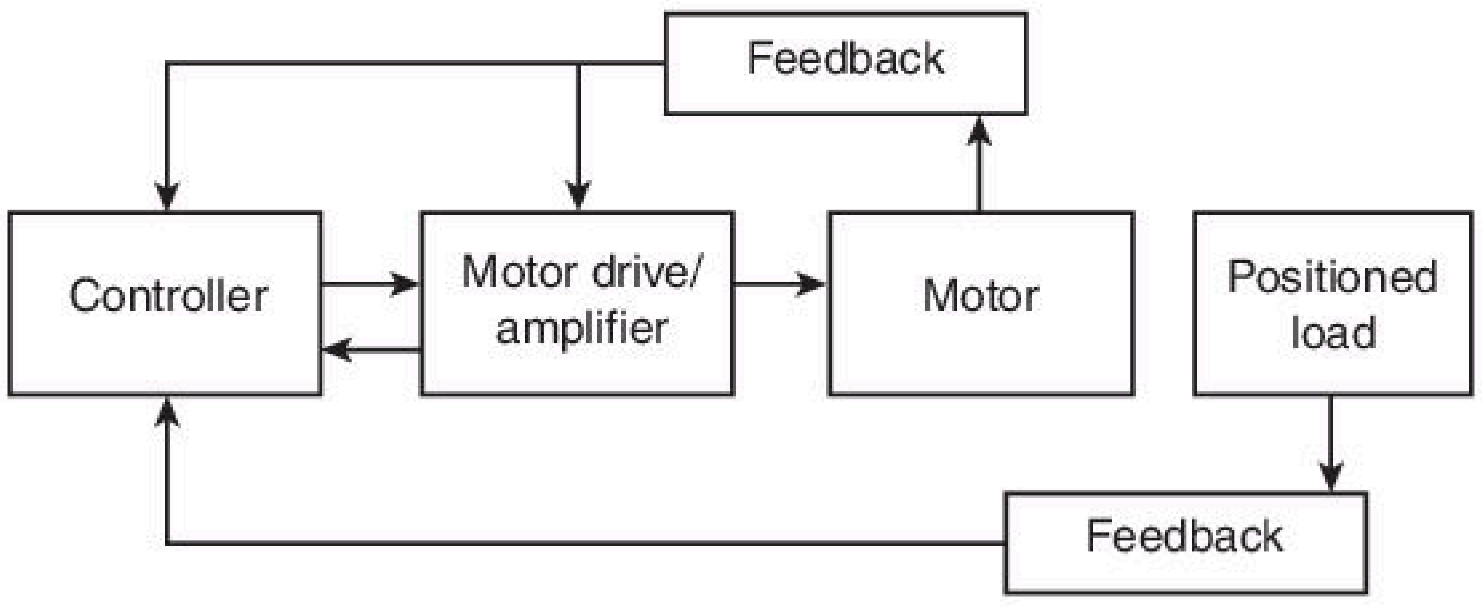

FIGURE A.3.3.98 Servo System.

A.3.3.103 Supplier. The user can also act in the capacity of a supplier to him- or herself.

A.3.3.110 Undervoltage Protection. The principal objective of this device is to prevent automatic restarting of the equipment. Standard undervoltage or low-voltage protection devices are not designed to become effective at any specific degree of voltage reduction.

A.4.1 A sample inquiry form is provided in Annex B for use in facilitating an agreement between the supplier and the user.

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

(1) Failures or faults in the electrical equipment resulting in the possibility of electrical shock, flash hazard, or electrical fire
(2) Failures or faults in control circuits (or components and devices associated with these circuits) resulting in malfunctioning of the machine
(3) Disturbances or disruptions in power sources as well as failures or faults in the power circuits, resulting in the malfunctioning of the machine
(4) Loss of continuity of circuits that depend upon sliding or rolling contacts, resulting in a failure of a safety-related function
(5) Electrical disturbances (e.g., electromagnetic, electrostatic, or radio interference) either from outside the electrical equipment or internally generated, resulting in the malfunctioning of the machine
(6) Release of electrical or mechanical stored energy, resulting in, for example, electric shock or unexpected movement that can cause injury
(7) Audible noise at levels that cause health problems to persons
(8) Surface temperatures that can cause injury

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

Design and development should be the first consideration in the reduction of risks. Where this is not possible, safeguarding should be considered. Safeguarding includes the use of safeguards, awareness means, and safe working procedures.

Examples of references to risk assessment include ANSI B11.0 and ISO 12100.

Flash hazard analysis, calculation methods, and ways to address the hazard are found in *NFPA 70E*.

One reference to recommended practices on static electricity is NFPA 77.

Δ **A.4.2** Semiconductor manufacturing equipment for use in semiconductor fabrication facilities could be accepted by one of the following judged under the requirements of a testing laboratory to an international (e.g., IEC 60204-1 or IEC 61010-1), regional (e.g., EN 60204-1 or EN 61010-1), national (e.g., UL 508, UL 508A, UL 61010-1, this document), or industry standard [e.g., SEMI S2 or SEMI S22 electrical standard(s)] deemed appropriate by the testing laboratory, field evaluation to this document, or another approach, such as "acceptable to the local authority having jurisdiction."

A.4.4.1 Annex B provides an inquiry form to ensure all parties have reviewed supplier-specific requirements concerning equipment operation.

A.4.4.2 The short-time value for the frequency can be specified by the user *(see Annex B)*.

N **A.4.4.2.8** Electrical equipment connected to the output of power conversion equipment can exhibit different behavior due to the characteristics of the output waveform. Manufacturers of such equipment provide guidance on suitability and proper use. See Chapter 12 and A.12.1.1 for information on conductor selection.

A.4.5.1 Annex B provides an inquiry form to ensure all parties have reviewed supplier-specific requirements concerning the physical environment or operating conditions that are outside those specified in this document.

A.4.5.2 The electrical interferences generated by the equipment itself should not exceed levels specified in the relevant equipment standards and others dealing with electromagnetic compatibility (EMC) levels. The levels allowed should be determined for the specific application.

Generated interference signals can be kept to a minimum by the following:

(1) Suppression at the source by using capacitors, inductors, diodes, Zener diodes, varistors, or active devices, or a combination of these
(2) Equipment screening in a bonded electrically conductive enclosure to provide segregation from other equipment

Undesirable effects of electrostatic discharge, radiated electromagnetic energy, and supply conductor (mains borne) interference should be avoided (e.g., use of appropriate filters and time delays, choice of certain power levels, suitable wiring types and practices).

The effects of interference on equipment can be reduced by the following:

(1) *Use of surge protective devices and filters.* The installation of surge protection devices and/or filters for equipment sensitive to electromagnetic influences is recommended to improve electromagnetic compatibility with regard to conducted electromagnetic phenomena.
(2) *Reference potential circuit or common connections.* Each common connection treated as a single circuit and connected to one of several central reference points that are connected to ground (wired to earth) by insulated conductors of large cross-sectional area.
(3) *Frame connections.* In each piece of equipment all frame connections are to be taken to a common point with a conductor of large cross-sectional area (e.g., braided conductors, foil strips having a width much greater than the thickness) used between slides and enclosures. The connections to the frame are to be as short as possible.
(4) *Transmission of signals.* Electrostatic screens, electromagnetic shields, twisted conductors, and orientation (i.e., crossing cable runs at as near to 90 degrees as practicable) as necessary to ensure that the low level signal wiring is not affected by interference from control or power cables, or running the connections parallel to the ground plane as necessary.
(5) *Separation of equipment.* Separating and/or shielding sensitive equipment (e.g., units working with pulses and/or at low signal levels) from switching equipment (e.g., electromagnetic relays, thyristors); separation of low level signal wiring from control and power cables.
(6) *Electromagnetic disturbances.* Measures to limit the generation of electromagnetic disturbances — that is, conducted and radiated emissions — include the following:
    (a) Power supply filtering
    (b) Cable shielding
    (c) Enclosures designed to minimize RF radiation
    (d) RF suppression techniques.
(7) *Enhance immunity.* Measures to enhance the immunity of the equipment against conducted and radiated RF disturbance using the designs of a functional bonding system include the following:
    (a) Connection of sensitive electrical circuits to the chassis. Such terminations should be marked or labeled with the IEC Symbol 5020 from IEC 60417-1. *[See Figure A.4.5.2(a).]*
    (b) Connection of the chassis to earth (PE) using a conductor with low RF impedance and as short as practicable.
    (c) Connection of sensitive electrical equipment or circuits directly to the PE circuit or to a functional earthing conductor (FE), to minimize common mode disturbance. This latter terminal should be marked or labeled with the IEC Symbol 5018 from IEC 60417. *[See Figure A.4.5.2(b).]*
    (d) Separation of sensitive circuits from disturbance sources.
    (e) Enclosures designed to minimize RF transmission.
    (f) EMC wiring practices as follows:
        i. Using twisted conductors to reduce the effect of differential mode disturbances
        ii. Keeping distance between conductors emitting disturbances and sensitive conductors
        iii. Using cable orientation as close to 90° as possible when cables cross
        iv. Running the conductors as close as possible to the ground plane
        v. Using electrostatic screens and/or electromagnetic shields with a low RF impedance termination

A.4.5.3 For very hot environments (e.g., hot climates, steel mills, paper mills) and for cold environments, extra requirements could be necessary. *(See Annex B.)*

A.4.5.4 For extremely dry or moist environments, extra requirements might be necessary to prevent static discharge.

A.4.5.5 Annex B provides an inquiry form to ensure all parties have reviewed requirements for electrical equipment operating at altitudes 1000 m (3300 ft) or more above sea level.

A.4.5.6 Annex B provides an inquiry form to ensure all parties have reviewed requirements for electrical equipment operating where contaminants are of a special concern.

A.4.5.7 Where equipment is subject to radiation (e.g., microwave, ultraviolet, lasers, x-rays), additional measures should be taken to avoid malfunctioning and accelerated deterioration of the insulation.

A.5.1.1 For large complex machinery comprising a number of widely spaced machines working together in a coordinated manner, more than one machine supply circuit might be needed, depending upon the site supply circuit arrangements *(see 5.1.9.7)*.

A.5.1.7 See Question 14 in Annex B, Figure B.1.

A.5.1.8 For additional information on the equipment grounding conductor terminal, see 8.2.1.3.

A.5.1.9.2 When a single disconnecting means is provided, a marking such as "main machine disconnect" is sufficient to convey the purpose. Where multiple supplies are present, a descriptive marking is necessary to clearly indicate the controlled supply voltage or equipment that is disconnected, such as "main disconnect — 480V, 3ph," or "main disconnect — drive motors."

A.5.1.11.1 For additional information, see IEC 61310-3 or 404.7 of *NFPA 70* for direction of operation of the disconnecting actuator.

A.5.1.11.2 A suitably rated attachment plug and receptacle listed to UL 498 or UL 1682 is a method of meeting the requirements of 5.1.11.2(2) and 5.1.11.2(3).

A.5.3.3 The selection of other means is dependent on many factors, taking into account those persons for whom its use is intended. *(See ANSI B11.0 and ISO 12100.)*

A.6.1 The requirements of Chapter 6 reduce the likelihood that an arc flash event will occur. Only enclosures listed as arc resistant are evaluated for providing protection from arc flash events.

A.6.2.3.1 The use of a key or tool or enclosure interlocking is intended to restrict access to qualified persons. It is the responsibility of the employer to determine the relevant safe work practices and the qualifications necessary to perform a specific task(s). See *NFPA 70E* for additional information on work practices.

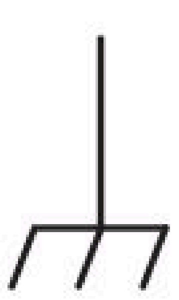

FIGURE A.4.5.2(a) Symbol that Represents Functional Equipotential Bonding — IEC Symbol Number 5020.

FIGURE A.4.5.2(b) Symbol that Represents Functional Earthing — IEC Symbol Number 5018.

A.6.3.1 Ripple-free is conventionally defined for a sinusoidal ripple voltage as a ripple content of not more than 10 percent rms. For additional information on isolating transformers, refer to IEC 60742 and IEC 61558-1. In addition, the following measures need to be considered:

(1) The type of supply and grounding system
(2) The impedance values of the different elements of the equipment grounding system
(3) The characteristics of the protective devices used to detect insulation failure

A.7.2.1 Figure A.7.2.1(a) and Figure A.7.2.1(b) show typical circuits acceptable for the protection of current-carrying and current-consuming electrical machine components. Protective interlocks are not shown.

A.7.2.2 See 7.2.10 and Section 17.5. The size and overcurrent protection of the supply conductors to a machine are covered by Article 670 of *NFPA 70*.

A.7.2.9 Proper application of molded case circuit breakers on 3-phase systems, other than solidly grounded wye, particularly on corner grounded delta systems, considers the circuit breakers' individual pole interrupting capability.

A.7.2.10.1 In Note 6 of Table 1 of IEC 60947-4-1, the terms Type 1 and Type 2 coordinated protection are defined as follows:

(1) *Type 1 protection.* Under short-circuit conditions the contactor or starter might not be suitable for further use without repair or replacement.

(2) *Type 2 protection.* Under short-circuit conditions the contactor or starter shall be suitable for further use.

The maximum allowable values in Table 7.2.10.1 do not guarantee Type 2 protection. Type 2 protection is recommended for use in applications where enhanced performance and reliability are required.

A.7.4 An example could be a resistance heating circuit that is short-time–rated or that loses its cooling medium.

A.7.6.1 Overspeed protection means include, but are not necessarily limited to, the following:

(1) A mechanical overspeed device incorporated in the drive to remove armature voltage upon motor overspeed.
(2) An electrical overspeed detector that will remove armature voltage upon motor overspeed.
(3) Field loss detection to remove armature voltage upon the loss of field current.
(4) Voltage-limiting speed-regulated drives that operate with constant full field. In this case, protection is obtained individually for the loss of field or tachometer feedback; however, protection against simultaneous loss of field and tachometer is not provided.

A.7.7 Conditions of use that can lead to an incorrect phase sequence include the following:

(1) A machine transferred from one supply to another
(2) A mobile machine with a facility for connection to an external power supply

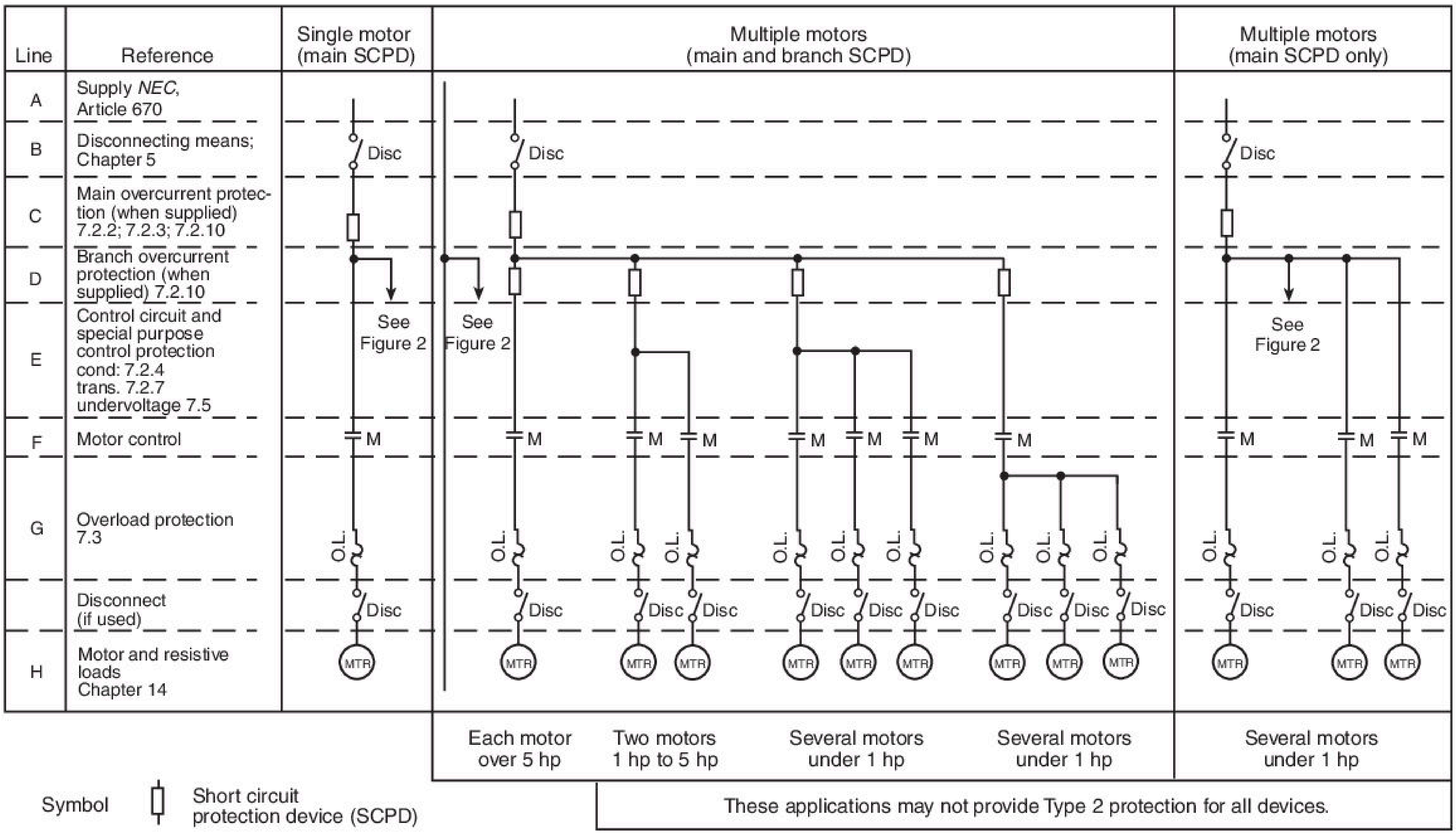

FIGURE A.7.2.1(a) One Line Representation of Electrical System Power Distribution.

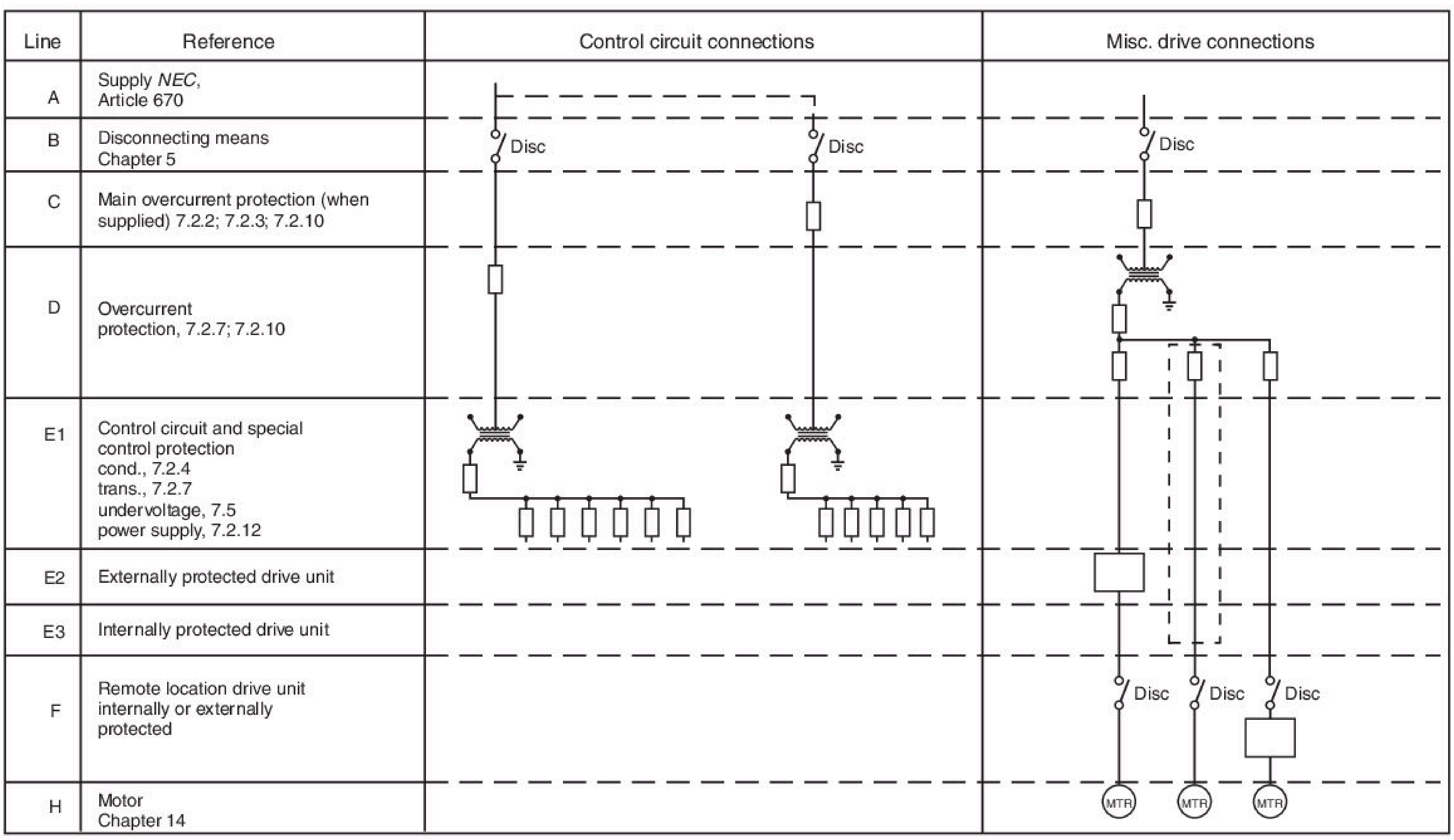

FIGURE A.7.2.1(b) One Line Representation of Electrical System Power Protection.

N **A.7.8.1** The manufacturer of the industrial machinery can determine what specific type of SPD, if any, and circuit location is to be used to provide the needed protection based on the installation and equipment design.

A risk assessment can be used to identify if the overvoltage protection for safety circuits is sufficient or if additional surge protection devices are needed.

A.8.1 See Annex J for descriptions of various grounding and bonding terminologies used in IEC and ANSI standards.

A.8.2.1.3 The minimum cross-sectional area of the external protective copper conductor can be required to be larger for IEC applications. See Table 1 in IEC 60204-1 for these requirements.

A.8.2.1.3.3 Some other standards require the letters PE for the connection to the external protective earthing system.

A.8.2.4 For additional information, see 13.4.5.3.

A.8.2.5.2 The letters PE or the bicolor combination GREEN-AND-YELLOW are used in some countries.

A.9.2 Some examples of safety-related functions are emergency stopping, interlocking, temperature or speed control, and so forth, IEC 62061, ISO 13849-1,ISO 13849-2, ANSI B11.0, ANSI B11-TR4, and ANSI B11-TR6 are examples of applicable functional safety standards. Compliance with other standards for particular applications and types of machinery can require additional or specific functional safety requirements.

A.9.2.2 For removal of power it can be sufficient to remove the power needed to generate a torque or force. This can be achieved by declutching, disconnecting, switching off, or by electronic means *(see 9.2.5.4.1.4)*. When stop functions are initiated it can be necessary to discontinue machine functions other than motion.

A.9.2.3.3 See 9.2.4 for overriding of safeguards under special conditions.

A.9.2.5.3.1 The supply circuit disconnecting means when opened achieves a Category 0 stop.

Δ **A.9.2.5.4** For other safety-related stop functions, see 9.4.3.4.

Emergency stop and emergency switching off are complementary protective measures that are not primary means of risk reduction for hazards (e.g., entrapment, entanglement, electric shock, or burn) at a machine *(see ISO 12100)*.

An emergency stop function might be required based on the risk assessment and when one or more of the following criteria exist:

(1) Hazards and hazardous situations could arise rapidly as in the case of fast-moving equipment.
(2) Hazard zones for a large machine extend beyond an area immediately accessible by one person [e.g., length exceeds 10 m (30 ft)].
(3) Machine hazard zones are not completely within view from a single vantage point.
(4) There are motions accessible that are deemed low risk but still have the potential for causing harm (e.g., product moving on a roller conveyor).
(5) Multiple workstations and/or multiple personnel are involved in the normal production operation.

Principles for the design of emergency stop equipment, including functional aspects, are given in ISO 13850.

See Annex E of IEC 60204-1.

A.9.2.5.4.1.4 IEC 61508 and IEC 61800-5-2 give guidance to the manufacturer of drives on how to design a drive for safety-related functions.

A.9.2.5.4.2 The functional aspects of emergency switching off are given in 536.4 of IEC 60364-5-53.

A.9.2.5.5.1 Hold-to-run controls can be accomplished by two-hand control devices.

A.9.2.5.6 Annex B provides an inquiry form to ensure all parties have reviewed this requirement where certain conditions could be a point of concern.

A.9.2.7.1 Some of these applications and system integrity considerations can also be applicable to control functions employing serial data communication techniques where the communications link uses a cable (e.g., coaxial, twisted pair, optical).

A.9.2.7.3.1(3) A valid signal also includes the signal that confirms communication is established and maintained. *(See Annex B.)*

A.9.2.7.4 One way to determine applicable error detection methods is to refer to IEC 60870-5-1.

A.9.3.2 On some manually controlled machines, operators provide monitoring.

A.9.4.1 More information on these risk reduction techniques can be found in Annex H. In general, only single failures need to be regarded. In the event of higher levels of risk, it can be necessary to ensure that more than one failure cannot result in a hazardous condition. Where memory retention is achieved, for example, by the use of battery power, measures should be taken to prevent hazardous situations arising from failure or removal of the battery. Means should be provided to prevent unauthorized or inadvertent memory alteration by, for example, a key, an access code, or a tool.

A.9.4.3 SEMI S2 permits software- and firmware-based controllers performing safety-related functions, and SEMI S2 Related Information #14 provides additional information on how to design and implement functional safety for use in semiconductor manufacturing equipment.

A.9.4.3.4 IEC 62061, ISO 13849-1, and ISO 13849-2 provide requirements for the design of control systems incorporating the use of software- and firmware-based controllers to perform safety-related functions (i.e., safety circuits). IEC 61508 provides requirements for the design of software- and firmware-based safety controllers. IEC 61800-5-2 and IEC 61508 give guidance to the drive manufacturer on the design of drives intended to provide safety functions.

A.10.1.1 For further information on device selection, mounting, identification, and coding, see IEC 61310-1 and IEC 61310-3. Particular consideration should be taken in the selection, arrangement, programming, and use of operator input devices such as touchscreens, keypads, and keyboards, for the control of hazardous machine operations.

A.10.1.3 For further information on degrees of protection, see Annex F. Also see NEMA 250, UL 50, UL 508, and IEC 60529.

A.10.1.4.2 For further information on direct opening operation, see Annex K of IEC 60947-5-1.

A.10.3.3 Indicating towers on machines should have the applicable colors in the following order from the top down; RED, YELLOW, BLUE, GREEN, and WHITE.

A.10.3.4 For additional information, see IEC 61310-1 for recommended flashing rates and pulse/pause ratios.

A.10.7.2.2 For further information on direct opening operation, see Annex K of IEC 60947-5-1.

A.10.8.2.1 For further information on direct opening operation, see Annex K of IEC 60947-5-1.

A.10.8.4.2 Where emergency switching off devices are on operator control stations that can be disconnected, to avoid the possibility of confusion between active and inactive emergency switching off devices, it is recommended that emergency switching off devices on operator control stations that can be disconnected do not have a yellow background.

A.10.9 Displays intended to be warning devices are recommended to be of the flashing or rotary type and be provided with an audible warning device.

A.11.2.1.4 Where access is required for regular maintenance or adjustment, the location of relevant devices is recommended to be between 0.4 m (15.75 in.) and 2.0 m (6½ ft) above the servicing level to facilitate maintenance. The location of the terminals is recommended to be at least 0.2 m (7.88 in.) above the servicing level and be so placed that conductors and cables can be easily connected to them.

A.11.2.1.7 For additional information on attachment plug and receptacle combinations, see 13.4.5.

A.11.3.1 The degrees of protection against ingress of water and other liquids are covered by NEMA 250. See also Annex F.

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A.11.5 Figure A.11.5 identifies the requirements for determining the working spaces for electrical equipment associated with industrial machinery.

The left side of Figure A.11.5 depicts a situation where the machine supply circuit disconnecting means, required by 5.1.9.1, is located in the industrial machine control panel or compartment.

The right side of Figure A.11.5 depicts a situation where the machine supply circuit disconnecting means, required by 5.1.9.1, is externally mounted to the industrial machine control cabinet or the compartment it supplies.

A.12.1.1 Typical operating conditions include the following:

(1) Voltage and frequency
(2) Current
(3) Protection against electric shock
(4) Grouping of cables
(5) Characteristics associated with power conversion equipment

Some insulated circuit conductors (e.g., thermoplastic) connected to the output of power conversion equipment can be susceptible to breakdown from arcing (i.e., corona discharge) occurring under certain conditions due to the characteristics of the output waveform of the drive. Factors affecting the conductors include, but are not limited to, the voltage, frequency, and current of the output; the length of the conduc-

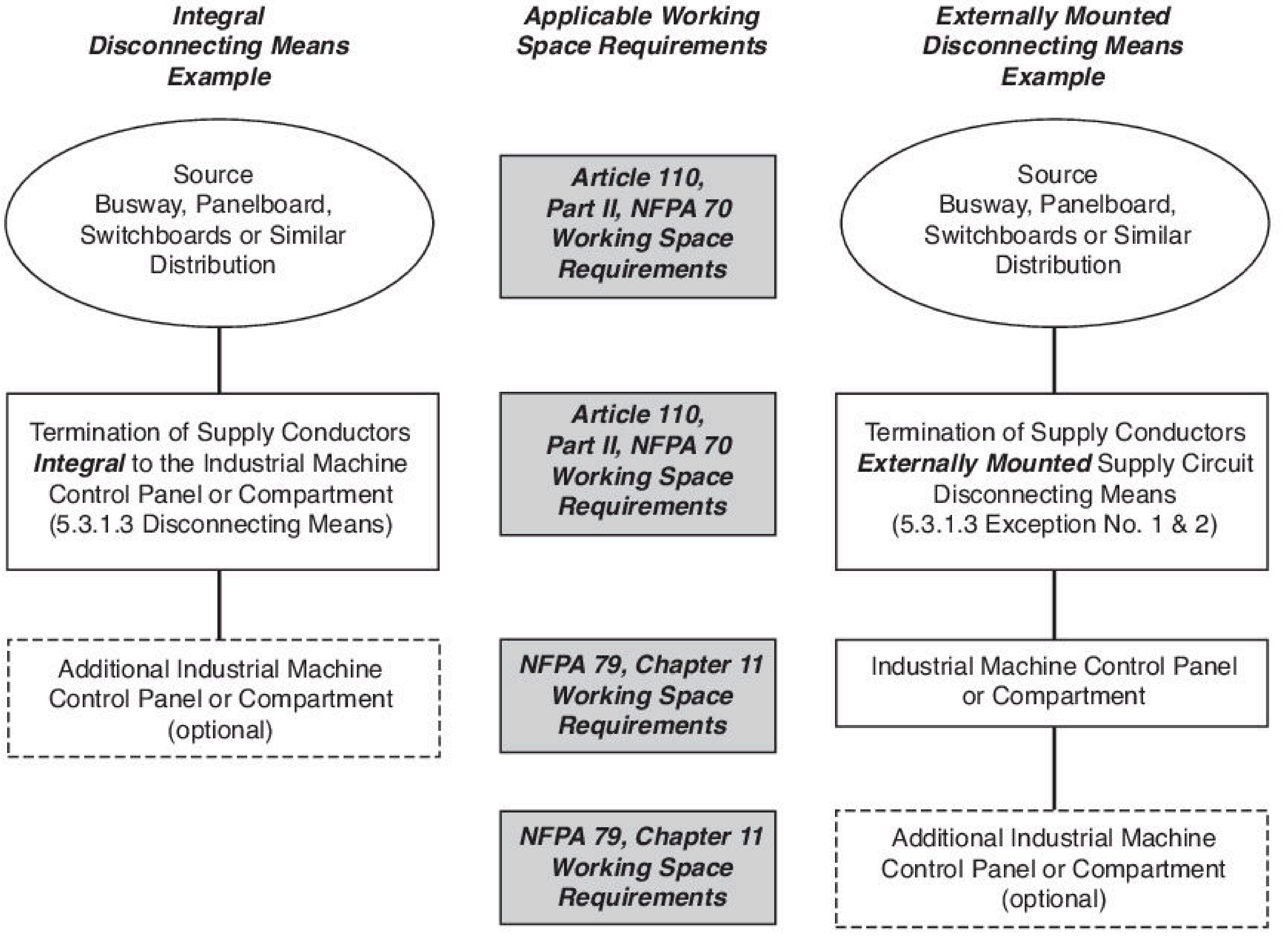

FIGURE A.11.5 Clarification of Working Space Requirements at the Termination Location of Machine Supply Circuit Conductors.