NEMA Standards Publication ICS 7.1-2000

Safety Standards for Construction and
Guide for Selection, Installation, and Operation of
Adjustable-Speed Drive Systems

Published by

National Electrical Manufacturers Association
1300 North 17th Street, Suite 1847
Rosslyn, Virginia 22209

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Foreword

In the preparation of this Standards Publication, input of users and other interested parties has been sought and evaluated.

It is general knowledge that the misuse of electricity is potentially hazardous and may create risks to personnel and property. In addition to shocks or burns from direct contact with live parts, the risks may also include: (1) fire resulting from over loads, faulty wiring, or faulty equipment and (2) injuries resulting from erratic machine operation. The degree of hazard can be greatly reduced by proper design, construction, selection, installation and use, but hazards cannot be completely eliminated. The reduction of hazard should be the joint responsibility of the user and the manufacturers of: (1) the driven equipment, (2) the motor or motors, and (3) the electrical equipment for supplying and controlling the power for the motor or motors.

Since any electrical equipment can be installed or operated in such a manner that hazardous condition can occur, compliance with this publication does not by itself assure a safe installation. However, when equipment complying with this publication is properly selected with respect to the driven load and environment and is installed in accordance with the *National Electric Code*, the potential hazards to persons and property will be reduced.

The importance of communication between manufacturer and user cannot be overemphasized. The chances for preventing hazardous incidents and limiting their consequences are greatly improved when both user and manufacturer are correctly and fully informed with respect to the intended use and all environmental and operating conditions.

The purpose and scope of this Standards Publication are given on page 1. The book consists of the following clauses:

Clause 1—Defines the scope of the standard, lists the referenced standards and defines terms.

Clause 2—Defines construction details which contribute to safety. It is intended to assist the electrical manufacturer to design and build equipment with features which will reduce hazards and also to assist the user and the manufacturer of the driven equipment in the selection of electrical equipment which has been designed and built to include features that contribute to safety.

Clause 3—Sets forth test requirements.

Clause 4—Is intended to guide the user and the manufacturer of the driven equipment in the proper selection, installation, and operation of adjustable-speed drive systems. Since the reduction of hazards depends greatly on how equipment is selected, installed and used, this section points out possible hazards and suggests ways and means to reduce them.

ICS 7.1-2000 supplements NEMA Standards Publication No. ICS 7-2000 *Industrial Control and Systems: Adjustable Speed Drives*.

The purpose of this Standards Publication is to define the construction and test requirements for adjustable-speed drive systems and to provide recommendations for their selection, installation and operation in such a manner as to provide for the practical safeguarding of persons.

NEMA Standards Publications are subject to periodic review. They are revised frequently to reflect user input and to meet changing conditions and technical progress. Users should secure the latest editions.

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Comments will be welcomed. Proposed revisions to this Standards Publication should be submitted to:

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This standards publication was approved by the NEMA Industrial Automation Control Products and Systems Section. Section approval of this standard, however, does not necessarily imply that all section members voted for its approval or participated in its development. At the time this standard was approved, the Industrial Automation Control Products and Systems Section consisted of the following members:

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Alstom Drives and Controls, Inc. – Pittsburgh, PA
Automatic Switch Company – Florham Park, NJ
Balluff, Inc. – Florence, KY
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Section 1
GENERAL

1.1 SCOPE

These standards apply to all industrial equipment electrical components and wiring which are part of the electrical drive system, commencing at the point of connection of input power to these components. They apply to open or enclosed electrical equipment for use on circuits which operate from an alternating-current supply voltage of 600 volts or less.

These standards are intended for industrial equipment which will be installed in accordance with the *National Electrical Code* and the manufacturers, instructions. They are not considered adequate for industrial equipment intended for use in locations which are designated as hazardous in the *National Electrical Code*.

These standards are generally applicable, but there may be situations where a conflict with other safety measures or operational requirements will necessitate that these standards be modified.

Excluded from this publication are:

a. Portions, subassemblies, or parts of motors or controllers to be used in the manufacture of more complete controllers or drive systems

b. Main propulsion equipment for railroad and transit locomotive cars

c. Automotive equipment

d. Equipment for airborne or aerospace craft

e. Equipment for household use

f. Equipment built to military specifications which conflict with or override the provisions of this publication

g. Additional specific features required for use under unusual service conditions, in locations involving hazardous atmospheres and hazardous projects

h. Systems for processes using electricity for purposes other than supplying and controlling electric motors

i. Drive systems rated less than 1/4 horsepower

j. Drive systems for portable tools

k. Industrial electric trucks

l. Passenger elevators or moveable walkways or lifts

m. Marine equipment

1.2 DEFINITIONS

Refer to ICS 7, Part 1 for equipment definitions.

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1.3 REFERENCED STANDARDS

In this publication, reference is made, in part or in full, to the following standards listed below. Copies are available from the indicated sources.

National Electrical Manufacturers Association
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ICS 1-2000	*Industrial Control and Systems General Requirements*
ICS 1.1-1984 (R1998)	*Safety Guidelines for the Application, Installation and Maintenance of Solid-State Control*
ICS 1.3-1986 (R2001)	*Preventive Maintenance of Industrial Control and Systems Equipment*
ICS 2-2000	*Industrial Control and Systems Controllers Contactors and Overload Relays*
ICS 7-2000	*Industrial Control and Systems Adjustable Speed Drives*
ICS 4-2000	*Industrial Control and Systems Terminal Blocks*
ICS 6-1993 (R2001)	*Industrial Controls and Systems Enclosures*
MG 1-1998	*Motors and Generators*
MG 2-1989 (R1999)	*Safety Standards for Construction and Guide for Selection, Installation and Use of Electric Motors and Generators*

National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

NFPA 70-1999	*National Electrical Code*
NFPA 70E-2000	*Standard for Electrical Safety Requirements for Employee Workplaces*
NFPA 79-1997	*Electrical Standard for Industrial Machinery*

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Section 2
CONSTRUCTION REQUIREMENTS

2.1 ADJUSTABLE SPEED DRIVE SYSTEM RATING AND IDENTIFICATION PLATES

2.1.1 Power Converter (Controller) Nameplate

A legible, durable nameplate shall be attached to the power converter (controller) and shall include the following data:

a. Manufacturer's name or identification number

b. Equipment identification

c. Supply voltage, phase (if polyphase) and frequency (if alternating current) for each source of supply

d. Maximum continuous input current or kVA. When multiple alternating-current inputs are employed for a given control cabinet, the full-load current for each input shall be indicated or referenced. (This does not apply to auxiliary control circuits requiring less than 15 amperes.)

e. Maximum permissible available symmetrical rms short-circuit current of each incoming power source

f. Nameplate data shall also include any nameplate information requirements for control equipment covered by ICS 7

2.1.2 Motor Nameplates

2.1.2.1 AC Motors

Alternating-current motors shall be identified in accordance with clause 1-10.40 of MG 1.

2.1.2.2 DC Motors

Direct-current motors shall be identified in accordance with clause 1-10.66 of MG 1.

2.1.3 Device Identification

2.1.3.1 Control and Power Devices

Control and power devices shall be plainly identified, using the same identification as shown on the elementary diagram.

2.1.3.2 Fuses

All fuses shall be identified by their rating and by class or type on the panel immediately adjacent to the fuse.

EXCEPTION—Where space does not permit, the fuse may be indicated by a device symbol provided that it is clearly referenced as to its rating and class or type on the appropriate documentation.

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2.2 OPERATING AND MAINTENANCE DATA

Warning labels and instruction documents should be furnished and should include at least the following:

a. Information necessary for calibrating components, devices and subassemblies which are intended to be adjusted by the user

b. Information to allow for the proper selection of the input circuit equipment and protection when an electronic power converter is designed for use in different applications with a range of load horsepower ratings

c. Operating instructions, including all information necessary to operate the complete drive system

d. Maintenance instructions, including information for locating and replacing faulty components or subassemblies

e. Appropriate warning notices where safety considerations exist

f. Description of stop circuit, emergency stop circuit, and terminal connections for these circuits

Documents should be of such a size and quality as to be clearly legible. The format and symbols for diagrams should be in accordance with clause 9 of ICS 1.

2.3 SUPPLY CIRCUIT DISCONNECTING DEVICES

2.3.1 General

The requirements of clause 2.3 apply to the disconnecting means required by the *National Electrical Code*, Section 430, Part J, if the devices used are supplied as a part of the control equipment.

If a device used for or as part of the disconnecting means is also used for any other function(s), such as overcurrent protection, the requirements of the other function(s) shall also be met.

2.3.2 Type

The disconnecting device shall be a switch or circuit breaker which clearly indicates whether it is open or closed. Switches and circuit breakers which are normally power operated shall include means for manual opening and shall indicate when they have been opened manually. The devices need not indicate that they are in the tripped position when this position differs from the manually opened position.

If the main power disconnecting device is mounted in a control equipment enclosure, the indication shall be visible outside of the enclosure.

Provisions for locking the disconnecting device may be necessary in order to comply with the *National Electrical Code*.

2.3.3 Rating

The ampacity of the disconnecting means shall be not less than 115 percent of the maximum continuous current required for all equipment which may be in operation at the same time under normal conditions.

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The load interrupting capacity of the disconnecting device shall be not less than the maximum operating overload current of the drive system.

2.3.4 Supply Conductors to be Disconnected

All ungrounded conductors on the load side of the disconnect device shall be disconnected when the disconnecting device is open. Disconnection is not required for remotely energized control and signal conductors in industrial establishments where access is limited to qualified persons.

Additional precautions such as yellow wire or guarding should be considered for these remotely energized control and signal conductor circuits if they are rated above 50 volts.

2.3.5 Mounting

When the main power disconnecting means is mounted within the control equipment enclosure, its operating handle shall be externally operable.

When more than one disconnecting device is supplied, a warning label shall be provided adjacent to each operating handle to advise that multiple disconnecting devices serve the drive system.

Where two or more sources of main power (e.g., alternating and direct current) are required for a control equipment, separate disconnecting means shall be permitted to be employed for each type of power, provided:

a. The disconnecting means are grouped adjacent to each other.

b. An external handle is provided for each disconnecting means which is enclosed.

2.3.6 Operating Handle

When the external operating handle of the disconnecting device is in its highest position, the center of the grip shall be not more than 6-1/2 feet above the floor.

If locking means are provided, the operating handle shall be so arranged that it can be locked only in the OFF position.

EXCEPTION—When specified for applications for which opening may create a hazard, locking means shall also be arranged for locking in the ON position.

2.3.7 Isolation

The following requirements apply to any power isolating switch or circuit breaker that is furnished to isolate a portion of the electrical equipment of a drive system and that is not any part of the supply circuit disconnecting means required by the *National Electrical Code*, Article 430, Part J.

a. Where the isolating means is not intended to interrupt load current, a warning label shall state DO NOT OPEN UNDER LOAD

b. If the isolating means is mounted in an equipment enclosure with the operating handle externally operable, a warning label shall be provided adjacent to the operating handle stating that it does not disconnect all power from the equipment

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Where a control circuit disconnect may be confused with power circuit disconnects due to size or location, a warning label should be provided adjacent to the operating handle of the control circuit disconnect stating that it does not disconnect all power from the equipment.

2.4 PROTECTION

2.4.1 Interrupting Capacity

Devices which are intended to break short-circuit current shall have an interrupting capacity sufficient for the voltage used and for the current that must be interrupted when the control equipment or drive systems connected to a power supply having the capacity to apply maximum voltage and maximum available short-circuit current within the limits specified for the equipment.

2.4.2 Control Circuit

Control circuit overcurrent protection shall be in accordance with clause 7 of ICS 1.

EXCEPTION—Fusing of direct-current motor field circuit conductors is not required. However, if overcurrent protection of these conductors is used, provisions shall be made to prevent overspeed of the motor in the event of loss of field excitation.

2.4.3 Undervoltage (Low-Voltage) Protection

Undervoltage protection shall be required unless undervoltage release is specified. See clause 4.1.5.2.1.

2.4.4 Motor Overload

Each motor and its motor branch circuit shall be protected against running overload as required by the National Electrical Code, Article 430, Part C.

Running overload protection means include, but are not necessarily limited to, the following:

a. An individual overload device or electronic circuit responsive to motor current

b. An overtemperature device mounted in the motor, and responsive to motor overtemperature

Motor overload protection for motors operating at speeds below base speed requires special consideration. Since most motors are ventilated by fans integral to the motor shaft, a reduction in shaft speed also reduces the available motor ventilation. Therefore, best motor protection is achieved by a device responsive to motor temperature.

Manual resetting of an overload device shall not start the motor.

EXCEPTION—When undervoltage release is provided, manual resetting of an overload device may start the motor.

Ratings for fuses for DC circuits should be selected with consideration given to their DC performance since fuse ratings may be based on AC power.

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2.4.5 Supply-Circuit Overcurrent (Short-Circuit) Protection

Supply circuits shall include overcurrent (short-circuit) protection per National Electrical Code, Article 430.

Supply-circuit overcurrent protection may be provided with the equipment or at the time of installation.

2.4.6 Overspeed Protection for Motors

Unless the inherent characteristics of the motor or power converter (controller) or both are such as to adequately limit the speed, power converters (controllers) for motors shall include protection from overspeed.

Overspeed protection means include, but are not limited to, the following:

a. A mechanical overspeed device interlocked in the drive to remove power on motor overspeed

b. An electrical overspeed detector which will remove power on motor overspeed

c. Field loss detection for DC motors with shunt field to remove power upon the loss of field current

On drives operating overhauling loads, additional means (e.g., mechanical brakes) may be required to prevent overspeed.

The safe operating speed of the driven equipment may be less than that of the motor. In this case, the user should coordinate with the drive manufacturer to obtain the most suitable means of limiting operation to safe operating speed. Reference should also be made to clause 4.1.5.2.7.

2.4.7 Power Transformer

A transformer used exclusively for one or more drive systems shall be protected against overload by at least one of the following:

a. Primary or secondary overcurrent device(s) rated or set for not more than 125 percent of the transformer rated current.

b. Protection responsive to transformer temperature.

c. Device(s) used for motor running overload protection, providing the device(s) will protect the transformer from sustained load in excess of 125 percent of the transformer rated current.

2.4.8 Draining of Stored Charge

Capacitors shall be provided with a means of draining the stored charge.

2.4.8.1 Time of Discharge

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

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EXCEPTION—Drives are not required to comply with this discharge requirement when they are provided with instructions that read, "CAUTION - Risk of Electric Shock," followed by instructions to discharge the specific capacitor or indicating the time required for the capacitor to discharge to a level below 50 V DC.

2.4.8.2 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 upon the removal of voltage from the line. Manual means of switching or connecting the discharge circuit shall not be used.

2.4.9 Short-Circuit Withstandability of Equipment

Under normal operating conditions a power converter (controller) shall not create a hazard in the event of a short-circuit at any point within the power converter (controller) when it is connected to a power source as specified on the nameplate and protected as specified in the installation manual.

2.5 CONTROL CIRCUITS

2.5.1 Source of Control-Circuit Power

The control circuit shall be connected to a power source on the load side of the main disconnect device, or a separate disconnect device shall be provided for the control power.

2.5.2 Manually Operated Control Device

Control circuits connected to manually operated devices shall be isolated from AC voltages greater than 150 volts and from DC voltages greater than 300 volts.

2.5.3 Grounding of Control Circuits

Provision for grounding of control circuits shall be provided. Ground faults on any control circuit shall not cause unintentional starting or unpredictable movements, or prevent stopping of the motor.

2.5.4 Interlocking

2.5.4.1 Opposing Motions Interlocked

All reversing starters, contactors controlling mechanically connected solenoids, and contactors controlling opposing motions shall be protected from simultaneous energization.

2.5.4.2 Plugging Circuits

All plugging switches or zero speed switches that are used to control the application or removal of power in order that moving parts may be slowed down, stopped, or reversed shall be provided with features incorporated in the control circuit to prevent the reapplication of power after the completion of the plugging operation and to prevent the application of power through any manual movement of the plugging switch shaft, or of the motor or equipment.

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2.5.4.3 Bypass and Isolation Interlocked

All bypass and isolation circuits shall be protected from simultaneous energization unless specifically designed by the manufacturer for simultaneous energization.

2.6 CONTROL DEVICES

2.6.1 AC Motor Starters

When operated, AC motor starters shall open all of the power conductor leading to their associated motors.

2.6.2 Contactors

Where a definite-purpose contactor is used in conjunction with gate interlocking, the contactor shall be capable of interrupting current up to the maximum current limit setting at maximum voltage at least once, independent of the gate interlocking. Where gate interlocking is not provided, contactors shall meet the requirements of ICS 2.

2.7 CONTROL ENCLOSURES

2.7.1 Materials

All enclosures shall be made of materials that will not support combustion in air.

2.7.2 Doors

Doors shall swing a minimum of 90 degrees. All parts of door fasteners shall remain captive when the door is opened.

The outer door assembly shall accommodate locking means or shall require the use of a tool to open except when it is specified for use where access is limited to qualified persons.

2.7.3 Wall Thickness

The walls of enclosures shall be not less than the thicknesses specified in ICS 6.

2.7.4 Size of Opening

The size of enclosure opening shall conform to ICS 6.

2.7.5 Minimum Wire Size

The minimum wire size for openings which are screened shall conform to ICS 6.

2.7.6 Screen Enclosures

Screen enclosures shall conform to ICS 6.

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2.8 INTERNAL CONDUCTORS

2.8.1 General

The internal wiring shall consist of material which is suitable for the particular application with respect to temperature, voltage and condition of service.

Conductors for control circuits shall be of annealed copper.

2.8.2 Size

Conductors for panel wiring shall be no smaller than No. 18 AWG and those for electronic and solid state control subassemblies no smaller than No. 30 AWG.

2.8.3 Ampacity

The maximum continuous current of panel wiring conductors in control equipment shall not exceed the ampacity given in Table 1.

EXCEPTION—Where the operating conditions of the conductor are known and controlled so as to limit the conductor temperature to the rated temperature of the insulation, the ampacities in Table 1 need not apply.

For single-motor drives, the motor power circuit conductors shall have an ampacity not less than the maximum continuous rms current rating of the motor. For multimotor drives, the motor power circuit conductors shall have an ampacity not less than the maximum continuous rms current rating of the highest rated motor, plus the sum of the maximum continuous rms current ratings of all other connected motors and apparatus that may be in operation at the same time.

For direct-current motor drives, the rms current may be estimated from the average current rating appearing on the motor nameplate and the rated form factor, if stated, or the characteristics of the identified power supply.

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Table 1
AMPACITIES OF INTERNAL COPPER CONDUCTORS WITH AN INSULATION RATING OF 90°C AT AN AMBIENT TEMPERATURE OF 55°C

Conductor Size AWG	Ampacity	Conductor Size MCM	Ampacity
30	0.5	250	340
28	0.8	300	375
26	1	350	420
24	2	400	455
22	3	500	515
20	5	600	575
18	7	700	630
16	10	750	655
14	20	800	680
12	25	900	730
10	40	1000	780
8	55		
6	80		
4	105		
3	120		
2	140		
1	165		
1/0	195		
2/0	225		
3/0	260		
4/0	300		

NOTE 1—The ampacities of insulated copper conductors with insulation ratings of 110°, 125°, and 200°C can be considered as being 125, 140 and 170 percent, respectively, of the ampacities given in the above table for the same conductor size.

NOTE 2—The ampacities of aluminum conductors with an insulation rating of 90°C can be obtained by multiplying the ampacity given in the table for the same size of copper conductor by 0.78. The ampacities of insulated aluminum conductor with insulation ratings of 110°, 125° and 200°C can be considered as being 116, 124 and 134 percent, respectively, of the ampacities calculated for the same size of aluminum conductor with an insulation rating of 90°C.

NOTE 3—The ampacities listed in the table and determined in accordance with Notes I and II apply to wireways or bundles greater than 5 feet in length. They include an allowance: (1) for wireways for conductor sizes 12 AWG and smaller, and (2) for bundles of one through six conductors larger than 12 AWG.

NOTE 4—The values in this table are derived from NFPA 79, Table 11. Ampacities for conditions other than those covered in the table will differ and can be determined by interpolation or extrapolation, as shown in Table 310-16 and Table 310-17 in NFPA 70. For example, for conductors having an insulation rating of 90°C, the ampacities at an ambient temperature of 40°C will be 120 percent of those at 55°C.

NOTE 5—The ampacities given in the table can be exceeded if the routing and operating conditions of the conductor are known and controlled so as to limit the conductor temperature to the rated temperature of the insulation.

2.9 WIRING METHODS AND PRACTICES

2.9.1 Identification

Terminals on terminal blocks for connection to wires outside of the control equipment shall be marked to correspond with the markings on the diagrams.

Where white is used to identify wire at any incoming or outgoing terminal of a control equipment, it shall be used only for terminals which can be connected to a grounded conductor. Where green (or green with one or more yellow stripes) is used to identify wire at any incoming or outgoing terminal of a control equipment, it shall be used only for an equipment grounding or bonding conductor.

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Where color coding is used, only the terminations of the conductor need be identified.

2.9.2 Terminals

A label shall be provided adjacent to the field wired powered terminals marked with tightening torque values and with the insulation temperature ratings for the conductors, or listed in provided instructions.

Terminals for power circuits shall be grouped separately from control circuits.

2.9.3 Panel Wiring

The surface of wiring channels, if used, shall be of a flame-retardant material.

Wiring routings shall avoid sharp edges, burrs, moving parts, etc., which may cause abrasion of the insulation and conductors. Holes in walls or barriers through which insulated wires pass and on the edges of which they may bear shall be provided with smoothly rounded bushings or grommets or shall have smooth, well-rounded surfaces upon which the wires may bear, to prevent abrasion of the insulation.

Wireways shall be smooth and entirely free from burrs.

Wire insulation shall be identified and adequate for the voltage on that conductor. Where the conductors are run with or adjacent to other conductors, all conductors shall have insulation rated for the maximum voltage involved.

2.9.4 Spacings

The clearance and creepage distance between nonarcing uninsulated live parts, and:

a. Nonarcing uninsulated parts of different potential

b. Metal parts (other than enclosure walls) which may be grounded when the equipment is installed

c. Exposed ungrounded metal parts

d. The walls of a metal enclosure (including fittings for conduit or armored cable) shall be not less than those shown in ICS 1

2.10 GROUNDED CIRCUITS AND EQUIPMENT GROUNDING

2.10.1 Enclosure Lighting Circuits and Convenience Outlets

When the equipment includes lights or convenience outlets supplied by a transformer that is part of the equipment, one side of the circuit shall be grounded at the transformer by bonding it to the equipment enclosure or framework.

The grounded conductors shall be identified by a white or natural gray colored insulation. The grounded conductor, when run to a screw-shell lampholder, shall be connected to the screw-shell.

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2.10.1.1 Convenience Plugs and Receptacles

Convenience plugs and receptacles shall be provided with a grounding pole and shall be so constructed that the grounding pole is made before any current-carrying poles are made and is not broken until all current-carrying poles of the plug have been disconnected.

The grounding pole of both plugs and receptacles shall be used for grounding purposes only and not as a formal current-carrying pole.

2.10.1.2 Work Lights

The lighting circuit voltage shall not exceed 150 volts between conductors.

The work light circuit shall be arranged so as to be energized by one of the following methods when the equipment is otherwise totally de-energized.

a. Light circuits shall be wired so that they may be supplied from a separately protected branch circuit.

b. Where the equipment includes the disconnecting means, the light circuit shall be tapped off the line side of the disconnecting means, provided a disconnecting means for the light circuit is mounted adjacent to the main disconnecting means. There shall be no exposed live parts in the light circuit.

EXCEPTION—When specified and when separate over-current protection for the light circuit is provided, the light circuit shall be tapped off the load side of the disconnecting means or shall be tapped off the control circuit.

c. The conductors to stationary or built-in lights shall meet the requirements of clause 2.8. The conductors within fixtures shall not be smaller than 18 AWG.

2.10.2 Methods of Grounding

Exposed non-current-carrying metal parts shall be electrically bonded to the enclosure or to a ground bus or ground terminal. Moving enclosure parts which have metal-to-metal bearing surfaces shall be considered as being adequately bonded. Sliding parts separated by oil or air under pressure shall not be considered to be bonded together.

Portable, pendent, and resilient mounted equipment shall be bonded or provided with grounding screws to allow bonding.

2.10.3 Equipment Grounding Conductors

Grounding conductors shall be in accordance with the *National Electrical Code*, Article 250.

2.11 SET-UP AND SERVICE REQUIREMENTS FOR ENERGIZED EQUIPMENT

2.11.1 Movable Assemblies

If a portion of the equipment carries more than 50 volts and can be moved into a position outside of the volume occupied by the closed enclosure or into an aisle, the assembly shall include guarding for circuits above 50 volts except where the short-circuit current for these voltages is limited to less than 5 milliamperes.

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2.11.2 Adjustments, Monitoring Points, and Manual Operators

Adjustments, monitoring points and manual operators which are normally used with the equipment energized shall be accessible from the front of the equipment.

Except where the short-circuit current is limited to less than 5 milliamperes, adjustments, monitoring points, and manual operators shall not require personnel or tools to come closer to adjacent exposed parts (energized at more than 50 volts) than the surface of a hemisphere 6 inches in diameter plus a truncated 45-degree cone whose diameter is 6 inches at the point of adjustment and whose axis is parallel to the direction of access. See Figure 1.

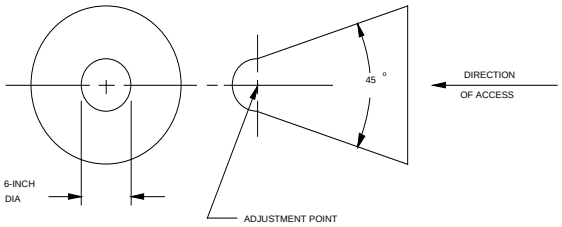


Figure 1
CONE OF ACCESS

2.11.3 Nonelectrical Apparatus

Nonelectrical apparatus shall not be located in the same compartment with electrical control equipment unless the devices and their air, water, or hydraulic fluid supply lines are essential to the operation of the electrical components. Nonelectrical apparatus shall not require servicing while the electrical apparatus is energized.

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Section 3
TESTS

3.1 MOTORS AND GENERATORS

Motors and generators shall be capable of withstanding the high-potential tests described in clause 2-2.10 of MG 2.

3.2 CONTROL EQUIPMENT AND SYSTEMS

Industrial control equipment and systems shall be capable of withstanding the high-potential tests described in clause 8 of ICS 1.

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Section 4
GUIDE FOR SAFETY IN SELECTION, INSTALLATION, AND OPERATION OF ADJUSTABLE-SPEED DRIVE SYSTEMS

4.1 SAFETY IN APPLICATION

4.1.1 Factors to be Considered

The applications for adjustable-speed drive systems are so numerous that exceptions can be cited to almost every recommendation for safe application. Among the many factors that should be considered in application are the following:

a. Service conditions

b. Degree of enclosure

c. Use of "back-up" equipment where the application requires exceptional reliability for the protection of life and health, property or perishable products.

Many adjustable speed drive systems make use of solid state devices in the power and control circuits. ICS 1.1 should also be considered in the application and installation of adjustable speed drives when solid state devices are involved.

4.1.2 Service Conditions

Industrial power converters (controllers) and drive systems should be properly selected with respect to their service conditions, usual or unusual, both of which involve the environmental conditions to which the machine is subjected and the operating conditions.

Service conditions, other than those specified as usual, may involve some degree of hazard. The additional hazard depends upon the degree of departure from usual operating conditions and the severity of the environment to which the equipment is exposed. The additional hazard results from such things as overheating, mechanical failure, abnormal deterioration of the insulation system, corrosion, fire, and explosion.

Usual and unusual service conditions for motors are defined in clauses 3.8 and 3.8 of MG 2.

Usual and unusual service conditions for industrial control and systems equipment are defined in ICS 1.

4.1.3 Degree of Enclosure

4.1.3.1 General

Recommendations for motor enclosures are given in clause 3.4 of MG 2. The required degree of enclosure for motor controllers and drive systems should be established by the user or the manufacturer of the driven equipment, considering the following:

a. Will the equipment be installed in:

   1. places regularly open to the public

   2. places frequented only by persons employed on the premises

   3. places accessible only to qualified personnel

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b. Will the equipment be attended by an operator when it is in use

c. Does the enclosure discourage inappropriate use or approaches to the equipment

d. Is it possible to encounter hazard in the installed equipment if it is approached or serviced in a manner other than the manner for which it was designed? If so, are the hazards of such actions visibly obvious to the personnel operating, servicing, and generally having access to the equipment

The following recommendations for the selection of enclosures are given as a guide. In addition, it may be appropriate to make the equipment inaccessible by fencing, by isolation in a room, by additional enclosures, or by other means, so that access to the isolated areas is limited only to qualified personnel. Qualified personnel are those who are familiar with the construction and operation and maintenance of the equipment and the hazards involved.

4.1.3.2 Application in Places Regularly Open to the Public

For those applications in places which are regularly open to the public and which cannot be isolated from the public, only the following equipment should be used:

a. Motors as described in clause 3.4.2 of MG 2

b. Enclosed control and power conversion equipment with provision for locking or padlocking doors

4.1.3.3 Application in Places Restricted to Persons Employed on the Premises

Many years of experience in industrial plants, light commercial installations, and other areas where access to the equipment is normally restricted to persons employed on the premises have established that the following equipment has a successful and satisfactory safety record:

a. Motors as described in clause 3.4.3 of MG 2

b. Enclosed control and power conversion equipment

4.1.3.4 Application in Places Accessible Only to Qualified Personnel

Any of the enclosures mentioned in 4.1.3.3 may be used in these places. In addition, many years of experience in power plants and in other applications where equipment is so located or installed that it is accessible only to qualified personnel have established that open equipment has a successful and satisfactory safety record.

4.1.4 Motor Application

Recommendations concerning the selection, operation, and loading of motors are provided in Section 3 of MG 2.

4.1.5 Control Application

4.1.5.1 Incoming Line Equipment

For drives supplied without the disconnecting devices described in clause 2.3, external disconnecting device(s) may be required in accordance with *National Electrical Code*, Article 430, Part J.

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Disconnection is not required for remotely energized control and signal conductors in locations where access is limited to qualified persons.

For the protection of maintenance personnel, provisions may be needed for locking the disconnecting or isolation means in the open position. Locking requirements, such as lock size or number of locks to be used, should be user specified. See also clause 4.4. Disconnects should be specified in accordance with the type, rating and specific application of requirements given in paragraphs 430-101 through 430-113 of the *National Electrical Code*.

Certain types of drives such as alternating-current adjustable-voltage drives and drives with high harmonic content can have a maximum continuous current at reduced speed higher than the full-load current at rated speeds. For such applications, the maximum continuous current should be used as a basis for selection of equipment rating.

The required interruption capacity of incoming line equipment, particularly with respect to the available fault current of the supply to which the power converter (controller) is to be connected, should be coordinated between manufacturer and user. Application information on ratings or protective settings of the protective devices is given in Table 430-152 and discussed in paragraphs 430-51 through 430-58 of the *National Electrical Code*.

4.1.5.2 Protective and Safety Functions

4.1.5.2.1 Undervoltage Protection

Undervoltage protection should be specified for all applications in which automatic or unexpected starting of a machine may be hazardous to persons or property.

Undervoltage protection requires that an operator initiate a reset or restart command each time the machine is to run following an unscheduled stop. If a power interruption occurs while the motor is running, the motor will stop and will not restart until the operator starts it after restoration of power.

Overload relays or other protective devices which can cause unscheduled stops should include provision for manual restarting in applications which require undervoltage protection. If the protective device resets automatically after a stop, it can be interlocked with the undervoltage protection to require a manual reset or restart command.

An intentional time delay is sometimes provided before the initiation of undervoltage protection. This allows the system to ride through a temporary loss of power without stopping. For applications which require an immediate stop, the sequence of protective functions should be so arranged that there is no intentional time delay.

4.1.5.2.2 Undervoltage Release

Undervoltage release causes the drive to stop when power is interrupted but permits automatic restarting when power is restored. This type of control is commonly used for pumps, compressors, fans, and similar applications controlled by float switches, thermostats, or time clocks.

Undervoltage release should not be used for applications in which automatic or unexpected starting of a machine may be hazardous to persons or property.

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4.1.5.2.3 Interlocking

Electrical or mechanical interlocking or both is frequently used to assure a desired sequence. The following are examples of types of interlocking which, when required, should be specified for adjustable-speed drive systems:

a. Limit switches to prevent overtravel of machine elements or interference with machine movements.

b. Nonrepeat control interlocking. The cycle does not repeat if the start button is held in the closed position. It is necessary for the operator to release the start button and to push it again to start a new cycle.

c. Door interlocks which prevent the opening of enclosure doors unless power is disconnected or which cause power to be disconnected if doors are opened.

d. Interlocks to prevent the application of one polarity until the other polarity has been disconnected, in cases where such simultaneous application would present a hazard.

e. Interlocks to cause brakes to be set following a stop command.

4.1.5.2.4 Stop Functions

A variety of stopping methods is available for every type of adjustable-speed drive. When experience has shown that a particular stopping method is satisfactory for use with a particular application, that method may be used. Otherwise, it is necessary to specify stopping performance in terms of time or distance and to provide information concerning inertia and speed-torque characteristics of the load.

The control requirements for initiating and maintaining certain stop modes is also important and can be application-specific. In addition to the following information, the user should consider the requirements found in NFPA 79 when specifying control requirements for stop.

The number and type of manual stop operator devices required should be specified. The types of devices commonly used for stopping are:

a. Red button with flat or concave head for normal stops

b. Red mushroom head button for emergency stops

c. ON-OFF selector switch (A RESET button is typically required when a selector switch is used with drives having undervoltage protection.)

Any specific requirements for stopping performance, such as may be required by a certain industry, should be specified. In the absence of a specific requirement and where necessary to avoid injury to personnel or damage to a machine, the motor should be stopped as quickly as practical.

Separate manual operators and connections to control circuits may be required to achieve this performance. Distinction for various stopping functions is achieved by identifying manual operators and terminal connections to control circuits by STOP or EMERGENCY STOP nomenclature. Consult the manufacturer's documentation for appropriate connections for stopping functions.

NOTE—For some drives STOP and EMERGENCY-STOP functions may be identical.

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For emergency stops, reliability considerations may give preference to a particular stopping method. For example, a springset friction brake, properly maintained, is usually more reliable than a method that depends upon the availability of adequate electric power supply. For some applications, redundant stopping means may be necessary.

Where there is more than one mode of system operation, the modes for which each operator device and protective function is to be effective should be specified.

4.1.5.2.5 Zero Speed Requirements

a. STOP Command

A STOP (or OFF) command calls for the drive to come to a complete standstill.

Stopping is usually called for by the definite action of an operator such as operation of a pushbutton or selector switch, or by some switch or other relay contact. To restart the drive again requires a positive action such as operation of a pushbutton or sequencing contact. When stopped, the motor may be held from rotating by a mechanical brake if required by the application.

b. Zero Speed Command

A zero speed command calls for the drive to provide regulation at zero speed with the motor remaining connected to the power converter (controller). This is normally accomplished by turning the speed setting potentiometer to zero or by having an output from a transducer or signal source go to zero. The drive is then ready to accelerate to any other speed upon the receipt of a change in the command signal.

4.1.5.2.6 Exposure to Moving Parts

Operating and maintenance personnel should not be exposed to the moving parts of a machine. See also clauses 4.3 and 4.4.

Some machinery requires that the operator normally contact parts of the machine which have been stopped but normally move. Examples of such operations include, but are not limited to, loading and unloading of reels, spools or spindles, tool changing, and threading. In addition to the applicable industry and government standards which may apply to mechanical or electrical guarding requirements of such applications, the zero speed requirements of the drive system must also be considered.

The use of a stop command (see 4.1.5.2.5.1) is recommended. In addition, some applications may also require that motor rotational power be positively blocked by isolation devices (contactors or switches). These isolation devices may be either mechanically or electrically sequenced. The isolation devices may be located between the motor and the output of the controller or between the input line and the controller depending upon the drive controller type. Where isolation is required by the application, this should be specified, and complete information concerning the type, expected sequencing, and location in the power circuit of the isolation device should be furnished.

If a zero speed command (see 4.1.5.2.5.2) must be used (for example, during holding or position keeping operation). the maintaining of zero speed condition during normal operation is dependent upon the drift or accuracy of the signal source as well as the characteristics of the drive controller. These factors must be carefully considered when determining the suitability of this method for achieving and maintaining zero speed. Where zero speed regulation is required by the application, this should be specified, and complete information concerning load characteristics and accuracy requirements should be furnished.

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4.1.5.2.7 Speed Limitation

Adjustable-speed drives should be prevented from operating at speeds which could cause injury to personnel or damage to the driving or driven machinery.

In many cases, the nature of the machines, the system or the load will inherently prevent excessive speed. When the machine is always under the manual control of a qualified operator, it may be satisfactory to depend upon the machine operator to safely limit the speed. In other cases, it is necessary for the purchaser to specify additional equipment, such as brakes, relays, or mechanical speed-limit devices, or to specify that the speed be held to selected limits, even in the event of specified malfunctions of the system.

Particular attention should be given to the following situations which may require speed-limiting devices:

a. An overhauling load

b. Machine loading or adjustment requiring the speed to be held below the maximum rated speed of the drive equipment

c. A direct-current motor operating with weakened field excitation

d. A possible loss of load on a series-wound motor, or on motors connected in series, or on a motor controlled by a torque regulator

Speed-limiting devices are seldom necessary for situations such as the following, in which the inherent characteristics of the motor tend to limit speed:

a. When the motor drives a fan or other load for which the required torque increases greatly with speed

b. When alternating-current motors operate from a fixed-frequency supply

Section 430-89 in the *National Electrical Code* should be considered when determining the need for speed-limiting devices.

4.1.5.2.8 Equipment Protection

Some functions designed to protect equipment from accidental damage also contribute to safety for personnel. Usual protective functions which apply to all systems include the following:

a. Main and branch overcurrent protection

b. Control-circuit overcurrent protection

c. Undervoltage protection

d. Motor running overcurrent protection

e. Motor disconnecting means

Additional protective functions which may contribute to the safety of personnel on a particular system should be specified. Such functions include:

a. Field loss protection—shunt and compound-wound direct-current motors can be specified to have protection against loss of motor field

b. Motor overspeed protection

c. Current or torque limit

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d. Voltage limit to prevent excessive armature voltage

e. Ground fault protection or indication

f. Instantaneous overload protection or indication

g. Friction brakes

h. Dynamic braking

i. Strip break detection

4.1.5.2.9 Isolation

The following requirements apply to any power isolating switch that is furnished to isolate a portion of the electrical equipment of a drive system and that is not any part of the supply circuit disconnecting means required by the *National Electrical Code*, Article 430, Part J.

a. A warning label shall be placed adjacent to the operating handle stating that it does not disconnect power from the equipment.

b. Where the isolating means is not intended to interrupt load current, a warning label shall state DO NOT OPEN UNDER LOAD. This warning may be combined with the warning in a. above.

4.1.5.2.10 Additional Control Safety Considerations

The applications for adjustable-speed drive systems are so numerous that exceptions can be cited to almost every recommendation for safe application. Among the many factors that must be considered are the following:

a. Overhauling loads

Where the load is capable of delivering torque to the drive motor, as in hoists, the usual non-reversing non-inverting adjustable-speed drive may not be satisfactory.

b. High inertia loads

Where the reflected inertia of the load at the motor shaft is larger than the motor rotor inertia, additional consideration should be given to the rating and design of the drive, such as the selection of the dynamic braking resistors.

c. Loss of conductor

Where connections between the power source, power converter (controller) and motor are made through sliding contacts, plug connectors or in any way in which continuity may be lost, resulting in loss of control of the motor, specific precautions may be necessary to prevent motor overspeed.

d. Overtravel protection

Where reversing or stopping of the drive is required at the end of travel, it may be desirable to provide back-up circuitry.

e. Redundant systems

Where the application requires exceptional reliability for the protection of life, health, property, or perishable products, the use of back-up equipment may be necessary.

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4.2 SAFETY IN INSTALLATION

4.2.1 Installation of Motors

Recommendations concerning installation of motors are provided in clause 2-3.16 of MG 2.

4.2.2 Installation of Control Equipment

4.2.2.1.1 Lifting

When lifting or moving equipment, the manufacturer's recommendations should be followed.

4.2.2.2 Location

The following considerations should be observed whenever equipment is mounted, installed or relocated.

a. Motor control and power conversion equipment should be placed in locations appropriate for the type of construction and enclosure used.

b. Equipment should be located in adequately ventilated areas. Ventilating openings should not be obstructed.

c. Adequate working space should be provided for adjustment, inspection and maintenance.

d. Operator's control stations should be convenient to permit observation of machine operation when this is necessary. The location should be such that the operator is free of hazard from moving parts of the machine or work in process and such that the control station is not subject to accidental operation or damage.

e. Operator's devices, such as emergency-stop pushbuttons, which are installed to provide safety, should be located so that they can be operated conveniently in the event that the condition for which they were selected occurs.

f. Accessories such as limit switches should be located or protected so that they are accessible for inspection, adjustment, and maintenance and are not subject to accidental operation, damage, or contamination.

4.2.2.3 Mounting

Control and power conversion apparatus should be securely fastened or supported (or both) in the manner recommended by the manufacturer. The method of support should avoid excessive shock and vibration, using shock and vibration absorbent mountings if necessary to prevent damage to the equipment or connections to it. The manufacturer's recommendations should be followed.

4.2.2.4 Grounding

Equipment should be grounded in accordance with the *National Electrical Code*.

4.2.2.5 Codes and standards requirements

Installation of controllers and drive systems should be made in conformance with the *National Electrical Code*, regulations of the Occupational Safety and Health Administration or other national, regional, or industry codes and standards, or all of the above.

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4.2.2.6 Lighting

Adequate lighting should be available for trouble-shooting and maintenance of the equipment.

4.2.2.7 Flooring

A noncombustible insulating floor or mat should be provided in the area immediately surrounding the electrical system where maintenance is required.

4.2.2.8 Locking Means

Lockout and tagout procedures will follow NFPA 70E.

4.2.2.9 Interconnecting Wiring

Where signal circuits such as those from speed-setting potentiometers and transducer outputs are remotely located from the power converter (controller), the manufacturer's recommendations concerning the isolation and wiring of signal circuits should be followed.

Since non-sinusoidal currents and voltages are generally present on the power conductors (both input and output) of the drive, particular care should also be exercised in selection, segregation, and installation of power conductors associated with the power converter and motor of the same and adjacent drives. Other power conductors associated with a drive installation may also require special consideration. The manufacturer's recommendations concerning acceptable wiring practice must be followed to maintain good service continuity, prevent apparatus damage, and provide expected performance.

4.2.2.10 Installation Workmanship

A safe and reliable installation requires careful attention to the installation of conduit and other raceways, wire pullings, connections, etc., to avoid damage to conductor insulation and nicked wire terminations, and to assure continuity of the conduit and equipment enclosure grounding system. Unskilled workmen may be unaware of the requirements or hazards involved. It is recommended that only properly skilled workmen be employed for installing electrical equipment.

Safe and reliable installation is the responsibility of the user and is beyond the oversight of the manufacturer.

4.2.3 Start-up and Test

Prior to releasing an electrical drive system for regular operation after installation, the system should be given a start-up test by competent personnel to assure correct operation of the equipment for reasons of reliability and safe performance. It is important that arrangements for such a check be made and that enough time is allowed to have it carried out well.

Such tests may be simple or complex, depending on the nature of the installation. A simple case may require only a check that a certain pushbutton starts an alternating-current motor, that the motor turns in the right direction, and that another pushbutton brings the motor to a stop. Other cases may involve the checking out of many devices and the proper operations of the overall system, including its regulators, logic functions, and protective devices.

The variety involved precludes a detailed listing of checks. However, attention should be directed to the need of such start-up tests in order to detect and correct possible serious hazards for personnel and equipment.

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4.3 SAFETY IN OPERATION

In some types of operations, persons exposed to moving parts of machinery may be subjected to significant risks of injury by inadvertent startup of the machinery. Reference should be made to NFPA 70E, which provides guidance regarding lockout-tagout procedures to control such risks.

Recommendations concerning the operation of motors are provided in clause 3.17 of MG 2.

Regardless of the care exercised in the design and manufacture of an adjustable-speed drive or in the selection and rating of components, there are hazards which can be encountered if such equipment is improperly operated.

It is sometimes possible to misadjust the equipment and thus produce unsatisfactory or unsafe operation. The manufacturer's instructions should always be used as a guide for functional adjustments. Personnel who are to have access to these adjustments (setup and operating people) should be familiar with both the drive manufacturer's instructions and the machinery being driven.

Only those operational adjustments which are actually needed by the operator, as for example, speed setting, tension adjusting means, etc., should be accessible to him. Access to other controls should be restricted to prevent unauthorized changes in operating characteristics.

Examples of improper (and perhaps unsafe) operation include:

a. Setting the speed too high or too low for the specific application

b. Changing the cycle or sequence of the machine beyond those conditions for which the drive was originally designed

c. Changing the load being driven beyond the limits for which the equipment was intended

d. Substituting an improperly rated motor or other components

e. Attempting to bypass design functions, as, for example, attempting to jog at rates higher than the preset rate by using the start and stop function. The operator of the drive equipment should be properly trained in the operation of the equipment. Provision of a written manual for use by supervisors in training new personnel should be considered.

4.4 SAFETY IN MAINTENANCE

In some types of maintenance activities, persons exposed to moving parts of machinery may be subjected to significant risks of injury by inadvertent startup of the machinery. Reference should be made to NFPA 70E, which in Part 11 provides guidance regarding lockout-tagout procedures to control such risks.

Recommendations concerning safety in maintenance can be found in ICS 1.3 and in NFPA 70B.

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