NEMA STANDARDS PUBLICATION NO. ICS 7

nema

Industrial Control and Systems Adjustable-Speed Drives

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 2101 L STREET, N.W., WASHINGTON, D.C. 20037

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NEMA Standards Publication No. ICS 7-1993

INDUSTRIAL CONTROL AND SYSTEMS
ADJUSTABLE-SPEED DRIVES

Published by

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Foreword

This Standards Publication was prepared by a technical committee of the NEMA Industrial Control and Systems Section. It was approved in accordance with the by laws of NEMA and supersedes the indicated NEMA Standards.

Replacement: The seven parts of ICS 7-1993 supersede the following parts of ICS 3-1988:

Part 1 supersedes Part ICS 3-100, 3-104 and 3-106A
Part 2 supersedes Part ICS 3-106B
Part 3 supersedes Part ICS 3-106C
Part 4 supersedes Part ICS 3-301
Part 5 supersedes Part ICS 3-302
Part 6 supersedes Part ICS 3-303
Part 7 new material
Annex A supersedes Appendix B of ICS 3
Annex B new material

In 1988, unrevised portions of all NEMA Standards Publications for Industrial Controls and Systems (the ICS series) were reaffirmed.

This Standards Publication provides practical information concerning ratings, construction, test, performance and manufacture of industrial control equipment. These standards are used by the electrical industry to provide guidelines for the manufacture and proper application of reliable products and equipment and to promote the benefits of repetitive manufacturing and widespread product availability.

NEMA Standards represent the result of many years of research, investigation and experience by the members of NEMA, its predecessors, its Sections and Committees. They have been developed through continuing consultation among manufacturers, users and national engineering societies and have resulted in improved serviceability of electrical products with economies to manufacturers and users.

One of the primary purposes of this Standards Publication is to encourage the production of reliable control equipment which, in itself, functions in accordance with these accepted standards. Some portions of these standards, such as electrical spacings and interrupting ratings, have a direct bearing on safety; almost all of the items in this publication, when applied properly, contribute to safety in one way or another.

Properly constructed industrial control equipment is, however, only one factor in minimizing the hazards which may be associated with the use of electricity. The reduction of hazard involves the joint efforts of the various equipment manufacturers, the system designer, the installer and the user. Information is provided herein to assist users and others in the proper selection of control equipment.

The industrial control manufacturer has limited or no control over the following factors which are vital to a safe installation:

a. Environmental conditions
b. System design
c. Equipment selection and application
d. Installation
e. Operating practices
f. Maintenance

This publication is not intended to instruct the user of control equipment with regard to these factors except insofar as suitable equipment to meet needs can be recognized in this publication and some application guidance is given.

This Standards Publication is necessarily confined to defining the construction requirements for industrial control equipment and to providing recommendations for proper selection for use under normal or certain specific conditions. Since any piece of industrial control equipment can be installed, operated and maintained in such a manner that hazardous conditions may result, conformance with this publication does not by itself assure a safe installation. When, however, equipment conforming with these standards is properly selected and is installed in accordance with the National Electrical Code and properly maintained, the hazards to persons and property will be reduced.

To continue to serve the best interests of users of Industrial Control and Systems equipment, the Industrial Control and Systems Section is actively cooperating with other standardization organizations

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in the development of simple and more universal metrology practices. In this publication, the U.S. customary units are gradually being supplemented by those of the modernized metric system known as the International Systems of Units (SI). This transition involves no changes in standard dimensions, tolerances, or performance specifications.

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.

Proposed revisions to this Standards Publication should be submitted:

Vice President, Engineering Department
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INTRODUCTION

The standards pertaining to adjustable-speed drives in NEMA Standards Publication ICS 7 are subdivided into the following clauses:

1 General
  Referenced Standards
  Scope
  Normative Standards
2 Definitions
  Terms which supplement the IEEE Standard Dictionary of Electrical and Electronics Terms (Std 100) or assist in clarifying the product standard.
3 Classification
  Product classifications where they have been established.
4 Characteristics and Ratings
  Descriptions of the kinds of ratings applicable to the product and tables of standard ratings for the product where they have been established.
5 Product Marking, Installation and Maintenance Information
  Product information to be provided to assist the user in the installation, use and maintenance of the devices.
6 Service and Storage Conditions
  A description of service and storage conditions for which the devices are intended.
7 Construction
  Marking, color coding and similar production requirements to be incorporated into the product as manufactured, as well as production test requirements where they have been established, i.e., the rules that the manufacturer follows in producing the product.
8 Performance Requirements and Tests
  The performance required to pass each design test specified for the product.
9 Application
  Information and performance considerations of importance to those who specify or use the product.

The standards for the products included within the scope of the Industrial Control and Systems Section are organized as follows:

NEMA Standards Publication No.	Title
ICS 1-1993	Industrial Control and Systems General Requirements
ICS 2-1993	Industrial Control and Systems Controllers, Contactors, and Overload Relays, Rated Not More Than 2000 Volts AC or 750 Volts DC.

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Part 1: *General Standards for Manual and Magnetic Controllers*
Part 2: *AC Noncombination Magnetic Motor Controllers, Rated 600 Volts*
Part 3: *Nonmagnetic Motor Controllers*
Part 4: *Overload Relays*
Part 5: *DC General-Purpose Constant-Voltage Controllers*
Part 6: *AC Combination Motor Controllers*
Part 7: *Magnetic Lighting Contactors*

ICS 3-1993 Industrial Control and Systems
Factory-built Assemblies

Part 1: *Motor Control Centers Rated Not More Than 600 Volts AC*
Part 2: *Medium Voltage Controllers Rated 2001 to 7200 Volts AC*
Part 3: *AC General-Purpose Controllers for Synchronous Motors*

ICS 4-1993 Industrial Control and Systems
Terminal Blocks

ICS 5-1993 Industrial Control and Systems
Control Circuit and Pilot Devices

Part 1: *General Standards for Control Circuit and Pilot Devices*
Part 2: *Industrial Control Relays*
Part 3: *Industrial Control Input Devices Actuated by Force, Temperature and Pressure*
Part 4: *Proximity Switches*
Part 5: *Pushbuttons, Selector Switches, Indicating Lights and Pushbutton Stations*

ICS 6-1993 Industrial Control and Systems
Enclosures

ICS 7-1993 Industrial Control and Systems
Adjustable Speed Drives

Part 1: *General Standards for Drive Converters, Drives, and Drive Systems*
Part 2: *Loop Position and Tension Control Drive Systems*
Part 3: *Wind and Unwind Drive Systems*
Part 4: *Variable-Frequency, Three-Phase Controllers, Rated Not More Than 600 Volts*
Part 5: *Adjustable-Voltage Packaged-Drive Systems (Where DC Armature Power Is Obtained from AC Lines Using Controlled Semiconductor Rectifiers)*
Part 6: *Variable-Frequency Drive Systems Rated Not More Than 600 Volts Using Semiconductor Power Conversion*
Part 7: *Variable-Frequency. Three-Phase Drives, Rated 601 to 7,200 Volts*

ICS 8-1993 Industrial Control and Systems
Crane and Hoist Controllers

Part 1: *General Standards for Crane Controllers Rated 600 Volts or Less AC and DC*
Part 2: *Constant-Voltage DC Magnetic Controllers for Motors on Cranes*
Part 3: *Adjustable-Voltage DC Controllers for Motors on Cranes*
Part 4: *Magnetic Controllers for AC Wound-Rotor Motors on Cranes*
Part 5: *Static Controllers for AC Wound-Rotor Motors on Cranes*
Part 6: *Crane and Hoist Power-Circuit Limit Switches*
Part 7: *Heavy-Duty DC Magnetic Contactors Rated 600 Volts*

ICS 9-1993 Industrial Control and Systems
Power-Circuit Accessories

Part 1: *Electromagnetic Brakes*
Part 2: *Resistors and Rheostats*
Part 3: *Autotransformers and Reactors*

ICS 10-1993 Industrial Control and Systems
AC Transfer Switch Equipment

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Part 1
GENERAL STANDARDS FOR DRIVE CONVERTERS, DRIVES AND DRIVE SYSTEMS

1 General

1.1 Referenced Standards

In this NEMA Standards Publication reference is made to the standards listed below. Copies are available from the indicated sources.

National Electrical Manufacturers Association
2101 L Street, NW
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NEMA ICS 1-1993	*General Requirements*
NEMA ICS 1.3-1986 (R1991)	*Preventive Maintenance of Industrial Control and Systems Equipment*
NEMA ICS 3.1-1990	*Safety Standards for Construction and Guide for Selection, Installation, and Operation of Adjustable-Speed Drive Systems*
NEMA ICS 6-1993	*Enclosures*
NEMA MG 1-1993	*Motors and Generators*
NEMA 250-1991	*Enclosures for Electrical Equipment (1000 volts maximum)*

IEEE Customer Service
445 Hoes Lane
P. O. Box 1331
Piscataway, NJ 08855

ANSI/IEEE 519-1992	*IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems*
ANSI/IEEE 597-1983	*Practice and Requirements for General Purpose Thyristor DC Drives*

National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

ANSI/NFPA 70-1993	*National Electrical Code*

Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062

ANSI/UL 347	*High Voltage Industrial Control Equipment*
ANSI/UL 508C	*Outline of Investigation for Power Conversion Equipment*

1.2 Scope

The standards in this part apply to drive converters, drives and drive systems. The standards in this part apply to all other parts of ICS 7 unless otherwise specified.

1.3 Normative References

The definitions and standards of NEMA Standards Publication 250, ICS 1, ICS 3.1 and ICS 6 also apply to this part unless otherwise stated.

2 Definitions

For the purposes of this standards publication, the following definitions apply:

adjustable voltage inverter: a voltage source inverter whose filtered DC bus voltage is controlled to adjust the output voltage of the inverter.

bandwidth (in a feedback system): The interval separating two frequencies between which both the gain and the phase difference (of sinusoidal output referred to sinusoidal input) remain within specified limits.

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Bode diagram: A plot of a transfer function in terms of gain and phase angle values against a frequency base, where both gain and frequency are plotted as logarithmic values.

closed loop (feedback loop): A signal path which includes a forward path, a feedback path and a summing point and which forms a closed circuit.

control circuit: A circuit containing those parts of a power converter which perform logic functions or which furnish control signals to the power circuit.

Examples of functions encompassed by the control circuit are gating, sequencing, regulation, protection, control interface, and local control. (See Figure 1-2-1)

controller: see power converter

coordinated drive system: One or several drive systems operated in coordinated fashion under the control of a system director to achieve the required control of a process. (See Figure 1-2-1)

current source inverter: An intermediate DC bus link converter whose output impedance magnitude is large with increasing frequency. Such a scheme uses a series DC choke in the DC link as a current smoothing component in conjunction with a closed loop DC current regulator.

direct vector control: A field oriented control scheme that directly regulates the motor flux vector in order to produce controllable motor torque. Such a scheme could employ the use of Hall effect transducers or air gap flux sense windings for the measurement of the motor air gap flux with the necessary modifications to approximate the rotor flux. The rotor flux would then be used as the feedback in the direct vector control regulator.

displacement power factor: The cosine of the phase displacement angle between the fundamental component of the voltage and current.

drive: A combination of the power converter, motor, and motor mounted auxiliary devices. Examples of motor mounted auxiliary devices are encoders, tachometers, thermal switches and detectors, air blowers, heaters, and vibration sensors. (See Figure 1-2-1)

drive system: An interconnected combination of equipment which provides a means of adjusting the speed of a mechanical load coupled to a motor.

A drive system typically consists of a drive and auxiliary electrical apparatus. (See Figure 1-2-1.)

dynamic-braking: An operation where the drive system functions to convert energy from the motor shaft into electrical energy and dissipates it into a resistor or similar device.

efficiency (converter): The ratio of the power delivered by the converter to the total power drawn from the plant electrical power system.

Efficiency is usually expressed in percentage.

efficiency (drive system): The efficiency of the drive system is the ratio of the power delivered by the machine shaft to the total power drawn from the plant electrical power system and it is usually expressed in percentage. The input power includes that for the auxiliary functions, such as motor field, phase control, switching equipment, overload protection and fans.

feedback control system: A control system which operates to achieve prescribed relationships between selected system variables by comparing the functions of those variables and using the difference to effect control.

(See Clause 3.1.1 of Part 1 for types of feedback control systems.)

feedback elements: Those elements in the control system which operate in response to the directly controlled variable to produce a suitable feedback signal and transmit it to the summing point. (See Figure 1-2-2.)

field oriented control: a method of controlling a general vector (such as flux, current, or voltage) by the decomposition of the vector into its orthogonal components, and the manipulation of the necessary intervening variables (such as motor current, voltage, and frequency) in order to control the desired magnitudes.

fundamental RMS amperes: The root mean square function of a periodically varying current waveform that contains no other function than a sinusoidal function. Such a periodically varying current waveform can be represented by the funtion:

$I(t) = I_p \sin(\omega t + \varphi)$, where I_p is the peak current in amperes, ω is the fundamental angular frequency in radians/second, t is time in seconds, and φ is the phase shift in radians. The fundamental RMS amperes is then defined as:

$$I_{RMS} = \sqrt{\frac{1}{T}\int_0^T I_p^2 \sin^2(\omega t+\varphi)dt}$$

Where:

$T = 2\pi/\omega$ seconds

indirect vector control: A field oriented control scheme that indirectly regulates the motor flux vector without torque or flux feedback. Such a scheme popularly employs the use of a shaft mounted pulse tachometer or encoder to determine rotor angular position, and torque angle for synchronous motors or rotor slip frequency for induction motors. The torque angle or slip frequency then controls the motor torque by the necessary inverse motor transformation equation.

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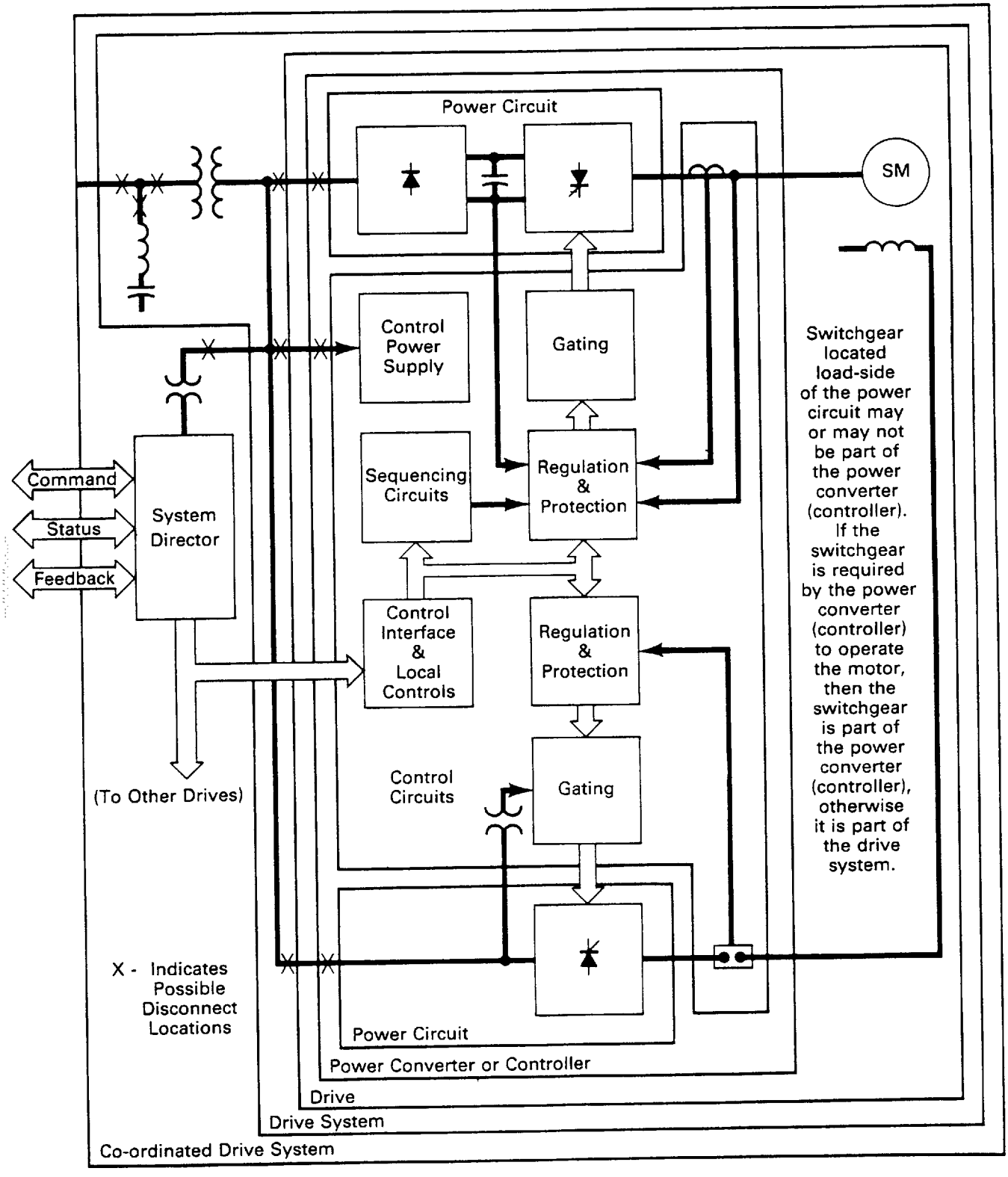


Figure 1-2-1
BLOCK DIAGRAM OF A TYPICAL COORDINATED DRIVE SYSTEM

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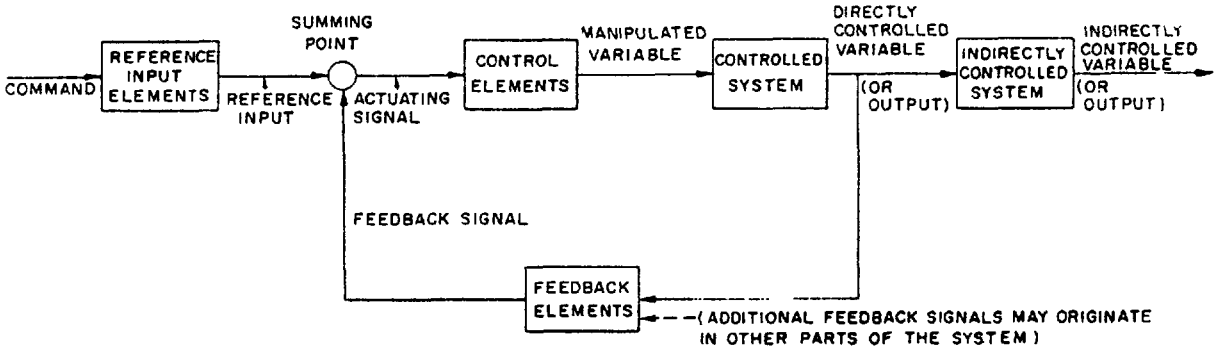


Figure 1-2-2
BLOCK DIAGRAM OF FEEDBACK CONTROL SYSTEM CONTAINING ALL BASIC ELEMENTS

inverter: A converter that changes DC power to AC power.

operating deviation band: The total excursion (see Figure 1-8-1) of the directly controlled variable (unless another variable is specified) as a result of specified operating variables under steady-state conditions and within a specified range of these operating variables.

Operating deviation band is expressed:

a. As a percentage of the maximum rated value of the directly controlled (or other specified) variable

b. For systems which have no readily definable base, such as position or temperature control systems, as absolute numbers

operating variable: A specified variable, other than those arising from service conditions and drift, for which the feedback control system must correct in attempting to maintain the ideal value of the directly controlled variable.

position control system: A control system which attempts to establish or maintain an exact correspondence between the reference input and the directly controlled variable, namely physical position. Further characteristics of position control systems are defined by the system type number given in Clause 3.1.1 of Part 1.

power circuit: Those parts of a power converter employing semiconductors for the transformation of electric power to be supplied to a motor (See Figure 1-2-1.)

power converter: A combination of the power circuit and control circuit included on one chassis.

The power converter may include a disconnecting means. (See Figure 1-2-1.)

When used in the context of drive systems, the term "controller" is representative of the same function as denoted by the term "power converter" as used in ICS 7. The term "power converter is the preferred usage in ICS 7.

pulse-width modulated inverter (PWM): An inverter whose switching will vary the time duration of voltage or current for control of the output.

rectifier: A converter that changes AC power to DC power.

regenerative operation: An operation where the drive system converts mechanical power from the motor shaft to the electrical power supply system.

reference-input elements: Those elements which operate in response to the command to produce a suitable reference input signal and transmit it to the summing point.

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response time: The time required, following the initiation of a specified stimulus to a system, for an output going in the direction of necessary corrective action to first reach a specified value.

The response time is expressed in seconds. (See Figures 1-2-3, 1-2-4 and 1-2-5.)

rise time: The time required for the output of a feedback system (other than first-order) to make the change from a small specified percentage (often in the range of five to ten) of the steady-state increment to a large specified percentage (often 90 or 95), either before overshoot or in the absence of overshoot.

If the term "rise time" is unqualified, response to a step change is understood; otherwise the pattern and magnitude of the stimulus should be specified.

self-commutated converter (forced-commutated converter): A converter in which commutation is accomplished by components within the converter.

In converters using switching devices that can interrupt or turn off current, such as transistors or gate turn-off thyristors, rejection of the current produces a voltage across the device to commutate the current to another device. In converters using circuit-commutated thyristors, the commutating voltages required to transfer current from one device to another are usually supplied by capacitors.

service deviation band: The total excursion (see Figure 1-8-1) of the directly controlled variable (unless another variable is specified) as a result of drift and changes in service conditions within specified limits.

A service deviation band is expressed:

a. As a percentage of the maximum rated value of the directly controlled (or other specified) variable

b. For systems which have no readily definable base, such as position or temperature control systems, as absolute numbers

settling time: The time required, following the initiation of a specified stimulus to a system, for a specified variable to enter and remain within a specified narrow band centered on its final value.

Settling time is expressed in seconds. (See Figures 1-2-3 and 1-2-4.)

speed ratio control: A control function which operates two drives at a preset ratio of speeds. The adjustment range of a speed ratio control, when direct proportionality exists between the two drives as shown in Figure 1-2-6, is expressed in percent plus and percent minus of the master drive speed setting over which the follower drive can be adjusted relative to the master drive speed. Where the master drive and follower drive have different speed ranges, the speed of the follower must be multiplied by the ratio of the rated speed of the master drive to the rated speed of the follower drive.

system director: Apparatus associated with coordinating the operation of a drive or a group of drives for the purpose of controlling a process. (See Figure 1-2-1.)

time response: The output resulting from the application of a specified input expressed in the form of a curve as a function of time, under specified operating conditions. (See Figure 1-2-3 and 1-2-4.)

total power factor: The ratio of the total power input in watts to the total volt-ampere input at the point of connection to the power supply system.

Total power factor includes the effect of harmonic components of current and voltage and the effect of phase displacement between current and voltage. Volt-amperes is the product of rms voltage and rms current.

total RMS amperes: The root mean square function of a periodically varying current waveform, I(t). The total RMS amperes is defined as:

$$I_{RMS} = \sqrt{\frac{1}{T}\int_0^T I^2(t)dt}$$

Where $T=2\pi/\omega$ seconds; I(t) is the function of the current waveform, amperes; and t is time, seconds.

An alternate definition, assuming that the periodically varying current waveform can be decomposed into the Fourier series is:

$$I_{RMS} = \sqrt{\sum_{m=0}^{m+\infty} I_m^2}$$

Where m is the harmonic number and I_m is the RMS current magnitude at the m^{th} harmonic frequency. This alternate definition is known as the root sum of squares (RSS).

voltage source inverter: An intermediate DC bus link converter whose output impedence magnitude is small with increasing frequency. Such a scheme uses a parallel DC capacitor in the DC link as a voltage smoothing component in conjunction with a closed loop voltage or current regulator.

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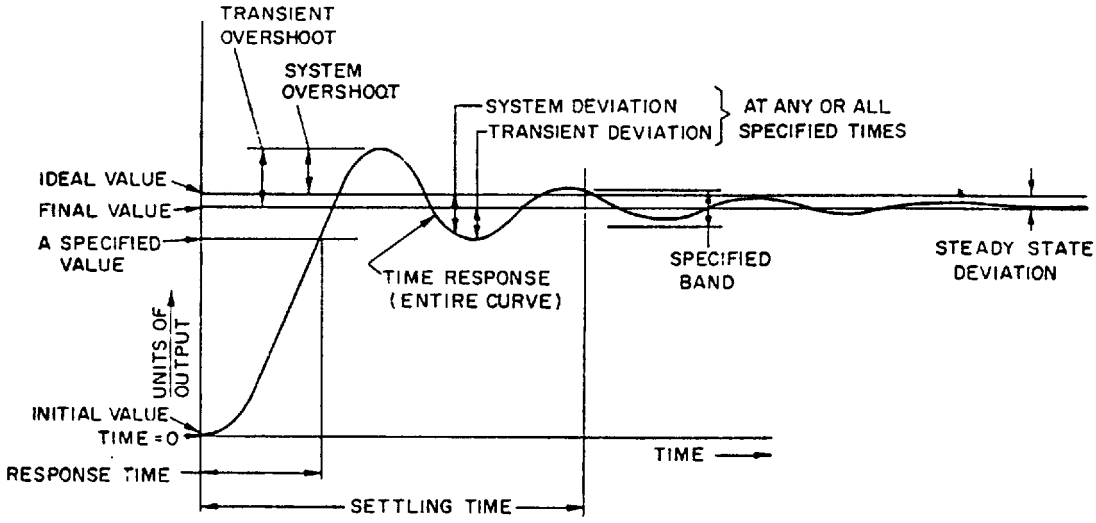


Figure 1-2-3
RESPONSE FOLLOWING A STEP CHANGE OF REFERENCE INPUT

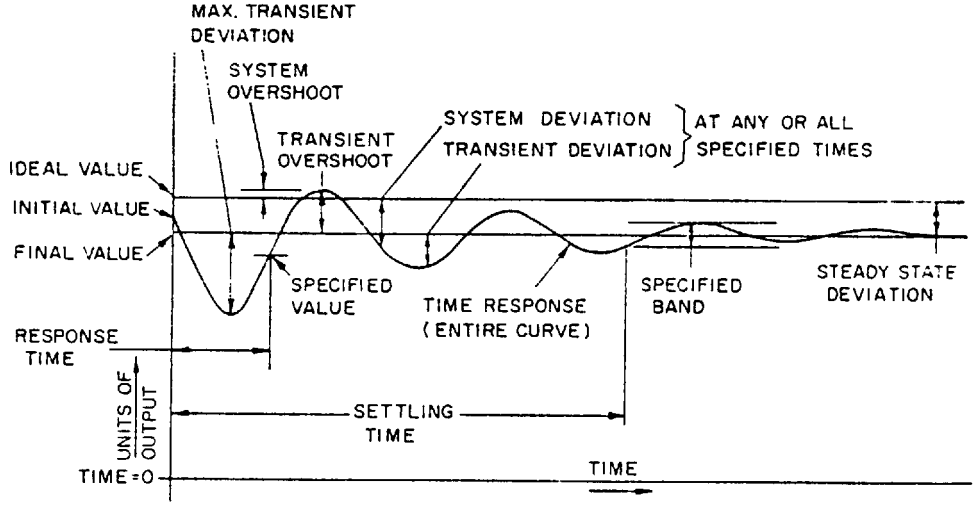


Figure 1-2-4
RESPONSE FOLLOWING A STEP INCREASE IN LOAD

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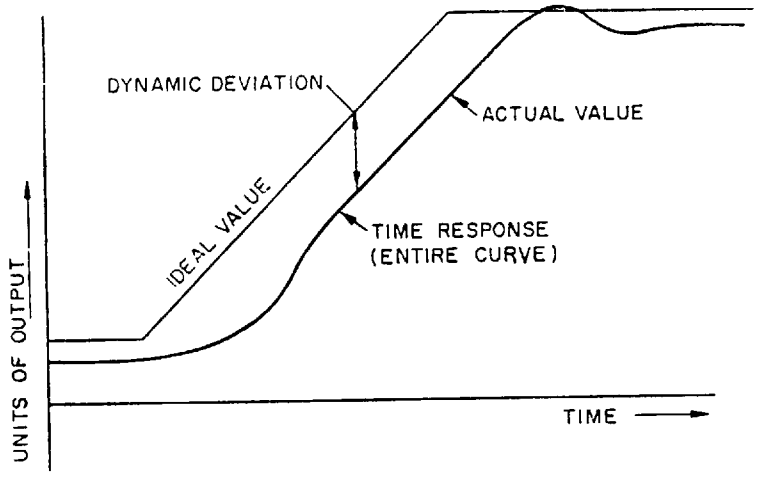


Figure 1-2-5
RESPONSE WHEN REFERENCE INPUT IS CHANGED AT A SPECIFIED RATE

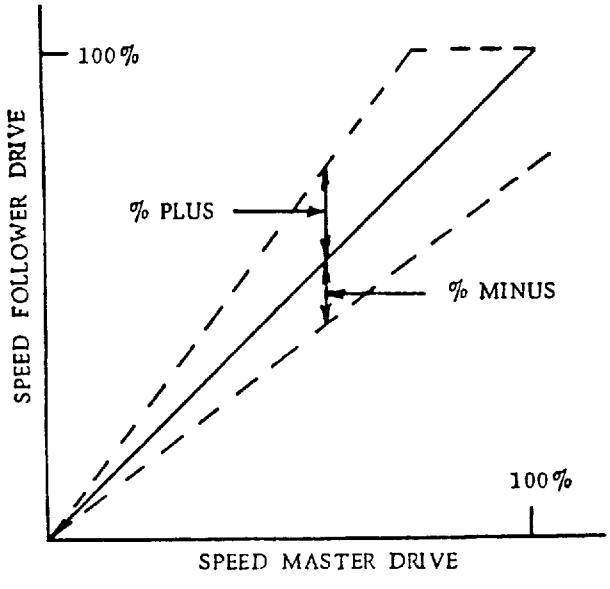


Figure 1-2-6
SPEED MASTER DRIVE

3 Classification

3.1 Classifications Relating to All Types of Drive Converters, Drives and Drive Systems

3.1.1 Classification of Feedback Control Systems by Basic Types

See Figure 1-3-1.

3.1.1.1 Type O System

A Type O feedback control system is one in which the directly controlled variable has both dynamic and steady-state deviations from the ideal value.

3.1.1.2 Type I System

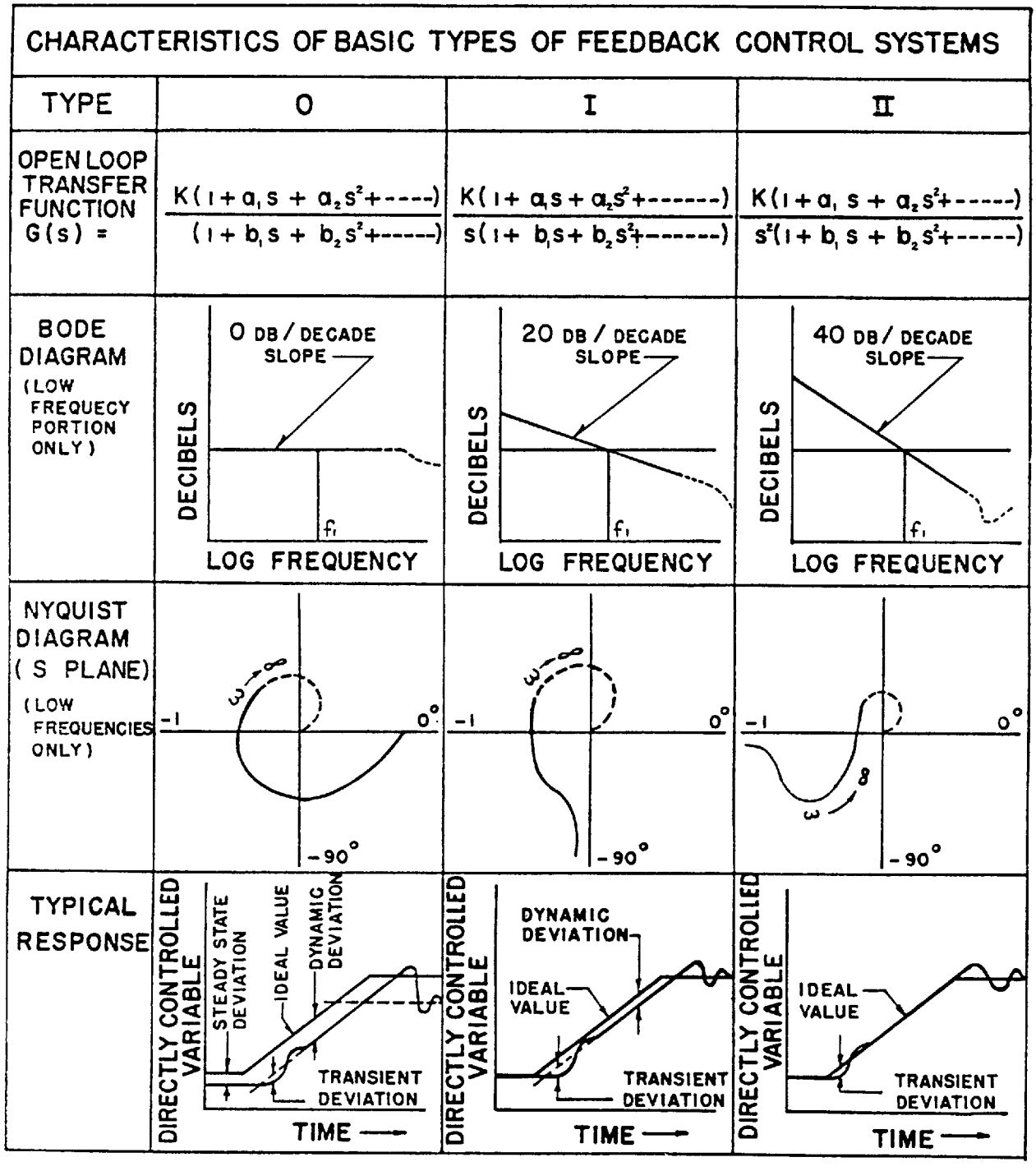
A Type I feedback control system is one in which the directly controlled variable has a dynamic but no steady-state deviation from the ideal value.

3.1.1.3 Type II System

A Type II feedback control system is one in which the directly controlled variable has neither a dynamic nor steady-state deviation from the ideal value.

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Transient and other deviations may be present but do not determine the type of system.

Figure 1-3-1
CHARACTERISTICS OF BASIC TYPES OF FEEDBACK CONTROL SYSTEMS CLAUSE

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3.1.2 Classification of Feedback Control Systems by Control Signal

3.1.2.1 Continuous-Data Control System

A continuous-data control system is one in which the control signals are maintained substantially in a continuous form. The control signals may be analog or may be digital with a sampling cycle which is short with respect to system response.

3.1.2.2 Sampling Control System

A sampling control system is one using intermittently observed values of signals such as the feedback signal or the actuating signal. The sampling is often done periodically.

3.1.2.3 Step Control System

A step control system is one in which the manipulated variable assumes discrete predetermined values.

The condition for change from one predetermined value to another is often a function of the value of the actuating signal.

When the number of values of the manipulated variable is two, it is called a two-step control system; when more than two, a multistep control system.

3.1.2.4 Two-Step Control System

A two-step control system is one in which the manipulated variable alternates between two predetermined values.

3.1.2.5 On-Off Control System

An on-off control system is a two-step control system in which a supply of energy to the controlled system is either ON or OFF.

3.1.3 Classification of Feedback Control Systems by Directly Controlled Variable

3.1.3.1 Controlled Variables

The basic function of a control system is the regulation of the directly controlled variable. These variables may be, for example:

a. Current
b. Frequency
c. Position
d. Power
e. Pressure
f. Speed
g. Temperature
h. Tension
i. Voltage

3.1.3.2 Auxiliary Functions

It may be desirable to identify functions in addition to the directly controlled variable in order to assure proper system operation. These auxiliary functions may include, for example:

a. Acceleration rate
b. Current limit
c. Inertia compensation
d. Speed limit
e. Voltage limit
f. IR compensation

3.2 Classification of Drive Converters, Drives and Drive Systems with AC Input—AC Electrical Service Categories as a Basis of Ratings

Service categories are determined by variations in power supply voltage, frequency as well as voltage unbalance, where voltage unbalance is defined as:

$$\text{Voltage Unbalance} = [\,(V_{max} - V_{min}) / V_{avg}\,] \times 100$$

Where:

V_{max} = Maximum line-to-line voltage

V_{min} = Minimum line-to-line voltage

V_{avg} = Average of the three line-to-line voltages

Unless otherwise specified, the converter shall be designed to operate under a service category specified in Tables 1-3-1, 1-3-2 and 1-3-3, which include the effect of the converter. Service Category IV in these tables only applies to products covered under Part 7.

Where no service category is specified, service category I shall be considered the basis of rating.

The values given in these tables are the basis of ratings and are not definitions of the normal power supply available at a location, since disturbances, e.g., voltage reductions, exceeding the service limits inevitably occur occasionally on AC supply systems as a result of particular operating conditions.

Where overload conditions exist, the limits shown in Tables 1-3-1, 1-3-2 and 1-3-3 may not apply.

3.3 Classification of Drive Converters, Drives and Drive Systems with DC Output

The following designations are intended to describe the functional characteristics of line-commutated converters, but not necessarily the circuits or components used:

a. **Form A (Nonreversing, Noninverting) Converter**—A controlled rectifier which can produce a DC output of one polarity only and which

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Table 1-3-1
SERVICE CATEGORIES BY AC INPUT FREQUENCY VARATIONS

Variation	Service Category I	II	III	IV*	Possible Consequence if Exceeded
Range	±1%	± 2%	±2%	±5%	DP
Rate of Change	± 1%/sec	±1 %/sec	±2 %/sec	±5 %/sec	DP

* Applies only to products covered under Part 7
DP - Drive is functional with degraded performance

A decrease in frequency is assumed not to coincide with an increase in line voltage and vice versa.

Table 1-3-2
SERVICE CATEGORIES BY AC VOLTAGE AT INPUT TO CONVERTER

Variation	Service Category I	II	III	IV*	Possible Consequences if Exceeded
a. Steady State (%)	+10/-5	±10	±10	±10	DP
b. Short Time (0.5 to 30 cycles)					
Rectifier Operation only, up to rated current (%)	+15/-10	+15/-10	±15	N/A	T
Inverter operation, up to rated current (%)	+15/-7.5	+15/-10	±15	N/A	T
c. Short Time 0 to 30 sec				+10/-20	T

* Applies only to products covered under Part 7

DP - Drive is functional with degraded performance

T - Interruption of service by protective devices

Table 1-3-3
SERVICE CATEGORIES BY AC INPUT VOLTAGE UNBALANCE**

Variation	Service Category I	II	III	IV*	Possible Consequence if Exceeded
a. Steady State (%)	2%	2%	2%	2%	DP/T

* Applies only to products covered under Part 7

DP - Drive is functional with degraded performance

**Voltage Unbalance = $[(V_{max} - V_{min})/V_{avg}] \times 100$

T - Interruption of service by protective devices

Where: V_{max} = Maximum line to line voltage
V_{min} = Minimum line to line voltage
V_{avg} = Average of the three line to line voltages

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is not capable of inverting energy from the load to the AC power supply.

b. **Form B (Reversing, Noninverting) Converter**—A controlled rectifier which can produce a DC output of either polarity and which is not capable of inverting energy from the load to the AC power supply.

c. **Form C (Inverting, Nonreversing) Converter**—A controlled rectifier which can produce a DC output of one polarity only and which is capable of inverting energy from the load to the AC power supply.

d. **Form D (Inverting, Reversing) Converter**—A controlled rectifier which can produce a DC output of either polarity and which is capable of inverting energy in either polarity from the load to the AC power supply.

3.4 Classification of Drive Converters, Drives and Drive Systems with AC Output

There are several forms of adjustable-frequency converters whose function is to produce a fixed or adjustable-frequency output. In addition, the converter will produce either a fixed or an adjustable-voltage output. The following designations are intended to describe functional characteristics and may apply to both rotary and static-type converters.

a. **Form FA Converter**—A converter whose input and output are both AC and where the frequency conversion is accomplished without intermediate conversion to DC.

b. **Form FB Converter**—A converter whose input is DC and whose output is AC.

c. **Form FC Converter**—A converter whose input and output are both AC and where the frequency conversion is accomplished with intermediate conversion to DC.

4 Characteristics and Ratings

4.1 Modes of Operation

Drive systems are typically designed to operate in one or more of the operating modes listed below:

a. Variable torque, increasing as a function of speed, or speed squared, such as in pump, fan and compressor applications

b. Constant torque over a specific speed range

c. Constant power over a specific speed range in which the torque decreases when speed increases

d. Regenerative operation

e. Dynamic-braking slowdown

f. Dynamic-braking stop

4.1.1 The regenerative operation may be in any of the three modes defined above: variable torque, constant torque or constant power.

4.2 Monitoring Features for Adjustable-Speed Converters

An adjustable-speed drive converter may include provisions for monitoring:

a. motor speed (frequency)

b. motor voltage

c. motor current(s)

These may be electrical signals, indicating meters, or data logging.

4.3 Features for Particular Applications

Certain features may be required for particular applications and, if so, should be specified by the user. Among such features are:

a. Motor reversing

b. Jogging

c. Timed acceleration

d. Timed deceleration

e. Dynamic-braking slowdown

f. Dynamic-braking stop

g. Current limit

h. Regeneration

i. Extended speed (frequency) range

j. Overspeed (overfrequency) protection

4.4 Special Considerations for AC Drives

4.4.1 Dynamic Braking

In any adjustable frequency converter, dynamic-braking is considered to apply only to the use of a resistor across or in the DC link of an adjustable-frequency converter for an induction motor. Dynamic-braking cannot occur in an induction motor AC drive unless both the power circuit and control circuit are fully functional. This fact should be considered when the dynamic-braking feature of an AC drive is used to stop an induction motor from rotating. This method is not necessarily the only or best method for stopping quickly.

Permanent magnet or synchronous motors may have the dynamic-braking resistors applied across the motor winding. During dynamic-braking the inverter is turned off.

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4.4.2 Adjustable Frequency Converter Frequency Ranges

Adjustable frequency converters are typically designed to have one frequency range over which the ratio of volts to hertz remains constant, and another range over which voltage remains constant while the frequency varies. The frequency at which the transition, from one range to the other, occurs is defined as Base Frequency. Depending on motor characteristics, these two ranges can correspond to constant torque (constant volts/hertz) and constant power (constant voltage with an adjustable frequency). Power and corresponding torque capabilities of the motor in the region above base frequency should be reviewed with the motor manufacturer. Direct or indirect vector control may be incorporated.

4.5 Ratings

The following ratings apply to drives, drive converters and drive systems rated not more than 600 volts. See Section 7 for drive systems rated 601–7200 volts.

4.5.1 Preferred AC Input Voltage Ratings

Preferred input voltage ratings are 60 hertz-115, 200, 230, 460 and 575 volts; 50 hertz-220, 380, 415, and 500 volts; line-to-line, three-phase, or single-phase.

4.5.2 Input Current Ratings

Maximum continuous input current ratings shall be established bythe manufacturer of the converter.

Maximum continuous input current is dependent upon the type of power conversion (DC, PWM, AVI, CSI) converter input configuration and system impedance.

4.5.3 Converter Output Ratings

Continuous output ratings shall be stated in voltage, current, and frequency range (if applicable). A horsepower, kilowatt or kilovolt-ampere (KVA) rating shall be permitted as a general guide to assist the user in motor selection.

4.5.4 Overload Capacity Rating

Where an overload capacity is specified, the drive converter shall be rated for at least one of the basic overload capacities as specified in Table 1-4-1.

Table 1-4-1
OVERLOAD CAPACITY

As Percent of Rated Load	110%	125%	150%
Overload Duration	60 sec.	60 sec.	60 sec.
Repetition Interval	not less than 9 min.	not less than 28 min.	not less than 60 min.

4.5.5 Short-Circuit Rating

A converter (with a specified short-circuit protective device) shall have one or more short-circuit current ratings expressed in terms of maximum available fault current (rms symmetrical amperes) and the rated system voltage.

4.5.6 Service Factor

The service factor for a drive system shall be 1.0.

4.5.7 Rated Output Current

The drive converter rated output current shall be established at the base speed (frequency) with rated input voltage and frequency applied to the converter.

5 Product Marking, Installation and Maintenance Information

5.1 Maintenance

See ICS 1.3 for preventive maintenance instructions.

5.2 Operating and Maintenance Data

Operating and maintenance data in accordance with ICS 3.1 shall be supplied with the converter.

5.3 External Overload Protection

Where converters are not equipped with integral overload protection the converter manufacturer should provide information to permit the user to select an external overload protective device for the converter.

5.4 Dynamic-Braking

To assist the user in applying a converter with dynamic-braking slowdown or dynamic-braking stop, the energy absorbing rating of the dynamic-braking circuit shall be made available to the user.

5.5 Instrumentation for Performance Testing

The manufacturer shall, upon request, advise what type of instruments (ammeters, voltmeters) are to be used in measuring these quantities. The input and output currents and voltages of the converters will have varying amounts of harmonics which may lead to measurement inaccuracies.

6 Service and Storage Conditions

6.1 Transportation

When equipment is transported from place to place it should be considered to be in storage. ICS 1, Clause 6 applies with the following exception: The ambient temperature for transport and storage must be above -20°C, but must not exceed 65°C.

6.2 Usual Service and Installation Conditions

Unless modified herein, the equipment which is within the scope of this standard shall be capable of operation within its performance specification under the usual service conditions listed in ICS 1, Clause 6.

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6.3 Electrical Service Categories as a Basis of Ratings

See Clause 3.2 Part 1 for effects of service conditions.

6.4 Installation

The equipment should be installed on a rigid mounting surface in areas or supplementary enclosures which do not seriously interfere with the ventilation or cooling system.

6.5 Other Service Conditions

The manufacturer should be consulted if other service conditions exist than as shown in ICS 1, Clause 6, conditions that may affect the construction or operation of the drive system. Unusual service conditions in addition to those shown in ICS 1, Clause 6, that must be brought to the attention of the manufacturer are:

a. Combustible, explosive, abrasive or conducting dust

b. Lint or very dirty operating conditions where the accumulation of dirt will interfere with normal ventilation

c. Chemical or corrosive fumes, flammable or explosive gases

d. Salt-laden air or oil vapor

e. Damp or very dry locations and radiant heat

f. Mechanical loading from external sources

g. Cooling water containing acid or impurities which may cause excessive scale, sludge, electrolysis, or corrosion of parts exposed to water

h. Supply system voltage and frequency deviations in excess of those specified in Tables 1-3-1, 1-3-2 and 1-3-3

i. Supply systems voltage distortion as defined in IEEE 519

See ICS 3.1 for additional service and installation conditions.

7 Construction

7.1 Protective Features

The drive system should contain protection circuits which provide operator safety, system component protection and high system availability. System availability refers to continuing performance of the drive system such that the function for which it was designed can be achieved. These protection circuits shall be provided by agreement between the manufacturer and the user.

7.1.1 Undervoltage Protection

Undervoltage protection shall be provided by agreement between the manufacturer and the user.

7.1.2 Overcurrent Protection

Motor running overcurrent protection capability shall be provided for equipment in ICS 7 Part 5 and Part 6, and for other products by agreement between the manufacturer and the user to protect each motor against excessive current due to operating overloads.

7.2 Required Basic Controls for Adjustable-Speed Converters

An adjustable-speed converter shall include provision to start, stop and adjust the speed of the drive motor.

7.3 Positive Blocking Means

For equipment covered in ICS 7 Part 5 and 6, and except for applications in which the operator does not have access to the driven motor, the manually-operated STOP command of the controller or a separate ON and OFF switch shall provide a positive means of blocking rotational power to the motor from the line.

The intent of 7.3 is to minimize the hazards to personnel from an unexpected motion of the motor or driven equipment due to malfunction of a control element or power semiconductor.

7.4 Acceleration Control

Converters shall be provided with either current-limit, torque limit or timed acceleration except where an externally applied reference signal is used and is sloped so as to limit the acceleration rate to a value that is compatible with the drive system.

8 Performance Requirements and Test

8.1 Feedback Control System Deviation Bands

The steady-state performance of a feedback control system shall be described by two numbers selected from Table 1-8-1. The first number, representing the operating deviation band, shall correspond to the maximum deviation band due to the principal operating variable(s), and the second number, representing the service deviation band, shall correspond to the maximum deviation band due to service conditions.

Table 1-8-1
DEVIATION BANDS FOR FEEDBACK CONTROL SYSTEMS

Maximum Operating or Service Deviation Bands (Percent)		
20	1	0.05
10	0.5	0.02
5	0.2	0.01
2	0.1	—

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While the total deviation may possibly be equal to the sum of the above deviations, in practice, it is unlikely that this extreme will be reached.

EXAMPLE—"Operating Deviation Band 0.1 percent / Service Deviation Band 0.2 percent" designates a system with an 0.1 percent maximum deviation band due to the principal operating variable and other specified operating variables, and an 0.2 percent maximum deviation band due to service conditions.

The range of the directly controlled variable within which operating and service deviations apply shall be specified.

8.2 Operating Deviation

The operating deviation band of the directly controlled variable when selected from Table 1-8-2 (see Figure 1-8-1) for the commonly used systems shown shall not be exceeded for the range of the principal operating variable indicated. For ranges of principal operating vari-

Table 1-8-2
OPERATING DEVIATION BANDS

System	Principal Operating Variable		
	Name	Range in Percent of Rated Value	Operating Deviation Bands
Speed control with speed signal feedback	Torque	10 to 100	5, 2, 1, 0.5, 0.2 & 0.1 percent of rated speed
Speed control with motor armature voltage feedback	Torque	10 to 100	20, 10, 5 & 2 percent of rated speed
DC voltage control with voltage feedback	Load current (avg.)	10 to 100	5, 2, 1, 0.5, 0.2 & 0.1 percent of rated voltage
AC voltage control with voltage feedback	Load current (rms)	10 to 100	5, 2, 1 & 0.5 percent of rated voltage
DC current control with current feedback for resistive or resistive/inductive load	Resistance	25 to 100	5, 2, 1, & 0.5 percent of rated current

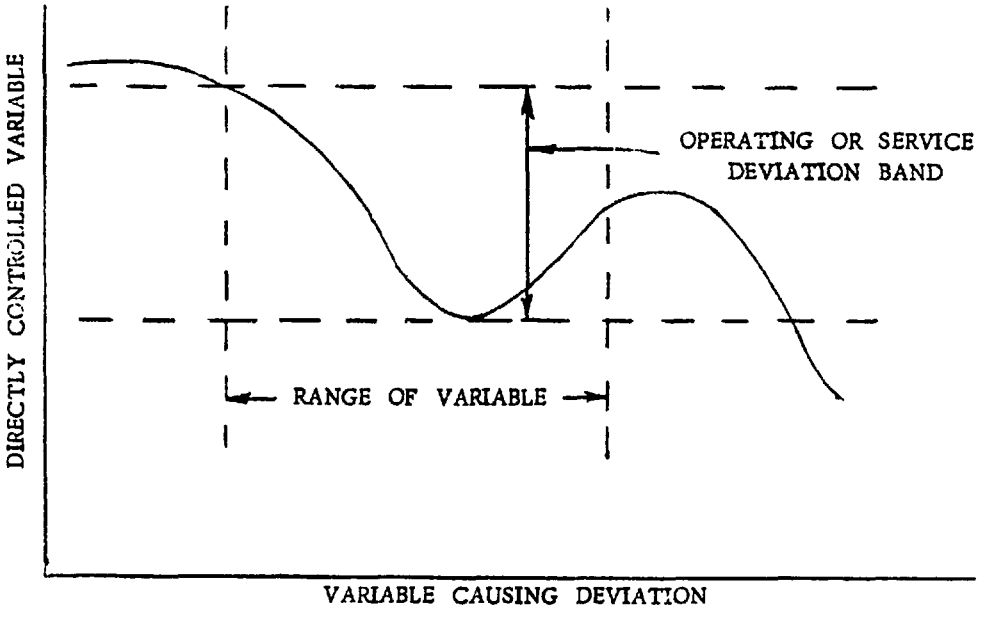


Figure 1-8-1
OPERATING AND SERVICE DEVIATION BAND

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ables and operating deviation bands not included in this table, the specified operating deviation bands shall be selected from Table 1-8-1 and the range of operating variables shall be specified. Service conditions shall be held constant.

8.3 Service Deviation

The specified service deviation band selected from Table 1-8-1 (see Figure 1-8-1) shall not be exceeded under any combination of applicable service conditions at any time during any 1-hour interval following a warm-up period of at least 30 minutes. Variation of the ambient temperature, within the limits of the applicable service conditions, shall be limited to a range of 15°C. Variation of the supply voltage, within the limits of the applicable service conditions, shall be limited to a range of 10 percent of rated voltage. The operating variables shall be held constant.

8.4 Relation to Reference

The operating and service deviation bands apply for any selected value of the controlled variable within its specified range. Where required by the application, the performance information should also include data on the steady-state relationship of the directly controlled variable to the reference. This aspect of performance is not included in the operating or service deviation bands.

8.5 Transient Performance

If transient performance is important, the required transient responses to specific disturbances should be specified. Such disturbances might include those to the reference, those to the power source, and those reacting upon the controlled variable.

8.6 Overload Capacity Performance

8.6.1 Where an overload capacity is specified, following continuous operation at rated output current the converter shall be capable of carrying an overload for one minute followed by operation at rated output current.

Each overload condition shall be permitted to be repeated at intervals as shown for that condition in Table 1-4-1.

8.6.2 For a repetitive interval less than that shown in Table 1-4-1, the converter output current during the interval shall be decreased to limit the rms output current during the entire cycle to a value not exceeding the converter rated output current. The temperature rise limitations of ICS 1, Clause 8 shall not be exceeded during the overload cycle.

The drive converter rated output amperes shall be established at the base output rating, with rated voltage and frequency at the input to the drive system.

9 Application

9.1 Guide for Selection, Installation and Operation of Adjustable Speed Drives

See ICS 3.1

9.2 Other Motor Considerations

The mode or modes of operation for the drive system should be compatible with the torque and speed requirements of the load.

9.3 Dynamic-Braking

In an adjustable-frequency converter, dynamic-braking is considered to apply only to the use of a resistor across or in the DC link for a drive. Dynamic-braking cannot occur in an AC induction motor drive unless both the power circuit and control circuit are fully functional. This fact should be considered when the dynamic braking feature of an induction motor AC drive is used to stop rotating machinery. A mechanical brake, actuated in case of a power failure, may be required for stopping the motor.

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Part 2
LOOP POSITION AND TENSION CONTROL SYSTEMS

1 General

1.1 Scope

The standards in this part apply to processing systems whose object is to control the loop position, or tension, or both, of a material in such forms as strip, web, rod or wire. Unwind and rewind reel systems are not included. See Part 3.

1.2 Normative References

The definitions and standards of NEMA Standards Publication ICS 1 and ICS 7, Part 1 also apply to this part unless otherwise stated.

2 Definitions

For the purposes of this part, the following definitions apply:

dancer control: A form of loop control in which the feedback signal is derived from a transducer which responds to the position of a roll (dancer) which rides in the loop of the material.

loop control: The effect of a control function or a device to maintain a specified loop of material between two machine sections by automatically adjusting the speed of at least one of the driven sections.

maximum loop travel: The maximum permissible movement of the bottom of the loop during any operation, including transients. See Figure 2-2-1.

operating loop travel: The maximum movement of the bottom of the loop during steady-state operation. See Figure 2-2-1.

operating storage: The change in the length of material in the loop as the result of the operating loop travel.

operating storage time: The operating storage divided by the maximum rated line speed, expressed in seconds.

running tension control: A control function which maintains tension in the material at operating speeds.

stalled tension control: A control function which maintains tension in the material at zero speed.

total storage: The change in the length of material in the loop as the result of maximum loop travel.

total storage time: The total storage divided by the maximum rated line speed, expressed in seconds.

3 Classifications

This section contains no classifications.

4 Characteristics and Ratings

4.1 Torque Control Systems (With Motor Armature Current Feedback)

4.1.1 Torque Control Operation

Motor armature current is maintained at a desired value by the regulating action of a converter provided with motor armature current feedback. Substantially constant motor field flux is assumed. In some cases, it is necessary to regulate field current. (Although compensation is not made for machinery and motor losses, sufficient control of tension is established for many applications.) See Figure 2-4-1.

The tension deviation will exceed the motor torque deviation because of variations in the losses in the driven machine. This is an important consideration when systems are operated at tension values where the torque necessary for tension is of a magnitude comparable to or lower than that required to overcome the losses in the driven machine.

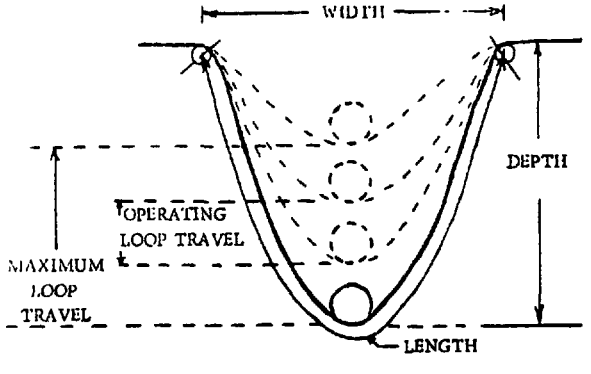


Figure 2-2-1
OPERATING LOOP TRAVEL

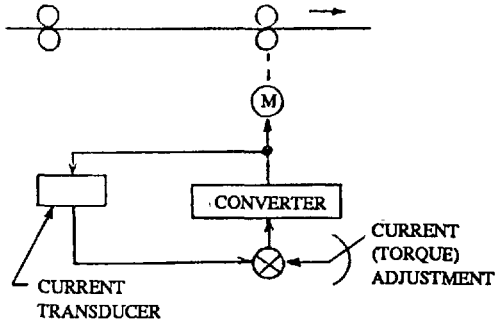


Figure 2-4-1
TORQUE CONTROL SYSTEMS
(WITH MOTOR ARMATURE
CURRENT FEED BACK)

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4.1.2 Torque Control Operating Variables and Deviation Bands

Directly controlled variable	Motor armature current
Indirectly controlled variable	Motor torque
Principal operating variable	Line or motor speed
Range of principal operating variable	10–100 percent of rated value
Operating deviation bands (see Section 1)	20,10 and 5 percent of rated motor torque
Service deviation bands	See Part 1 definition of "service deviation band"

Other operating deviation bands, if required, shall be selected from Table 1-4-1.

4.2 Constant-Force Loop-Position Control Systems

4.2.1 Constant-Force Operation

Tension is set and maintained by a constant force on a loop in the material, the force being provided by pneumatic or hydraulic cylinder, gravity, or a spring with substantially constant force over its operating range. The action of the converter is to maintain the loop position within prescribed limits. The steady-state tension is substantially constant provided the sides of the loop are parallel. See Figure 2-4-2.

In those cases where the design is such that the changing force characteristics of the spring are used to change the strip tension as a function of position, the characteristics of the tension feedback control system apply.

4.2.2 Loop Position Operating Variables and Deviation Band

Systems which require regulation at zero speed require reversible drives.

4.3 Hanging and Storage Loop-Position Control

4.3.1 Loop operation hanging and storage loops are used in process systems to provide storage or tension isolation, or both, between sections of the system. These are position control systems with position feedback from such devices as photoelectric cells, proximity detectors, or lightly-loaded dancers. Where the primary purpose of the loop is storage, the total storage time is usually large relative to the operating storage time. See Figure 2-4-3.

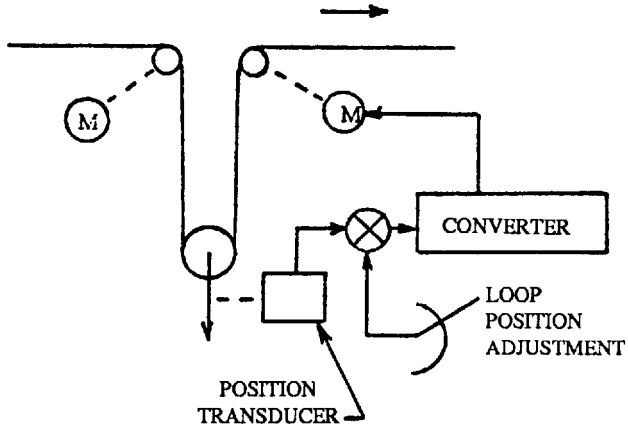


Figure 2-4-2
CONSTANT FORCE LOADED LOOP POSITION CONTROL SYSTEM

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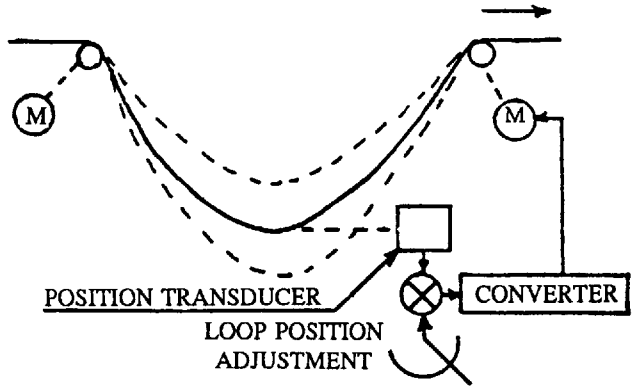


Figure 2-4-3
HANGING AND STORAGE LOOP CONTROL SYSTEM

When the operating storage time is to be very small, the manufacturer should be consulted.

Directly controlled variable.....Loop position

Principal operating variable.....Line or motor speed

Range of principal operating.....0–100 percent of rated value variable

Operating storage time, including service deviation.....0.1, 0.2, 0.5 and 1.0 seconds

4.3.2 Loop Operation Operating Variables and Deviation Bands

Systems which require regulation at zero speed require reversible drives.

Directly controlled variable.....Loop position

Principal operating variable.....Line or motor speed

Range of principal operating variable.....0–100 percent of rated value

Operating storage time, including service deviation.....0.1, 0.2, 0.5 and 1.0 seconds

4.4 Tension Feedback Control System

4.4.1 Description of Tension Operation

Tension is controlled in response to a signal from a tension sensing transducer. See Figure 2-4-4.

4.4.2 Tension Control Operating Variables and Deviation Bands

Directly controlled variable.....Tension (range specified)

Principal operating variable.....Line or motor speed

Range of principal operating variable.....10–100 percent of rated value

Operating deviation bands.....20, 10, 5 and 2 percent of rated tension (see Section 1) maximum

Service deviation bands.....See Part 1 definition of "service deviation band"

Other operating deviation bands, if required, shall be selected from Table 1-4-1.

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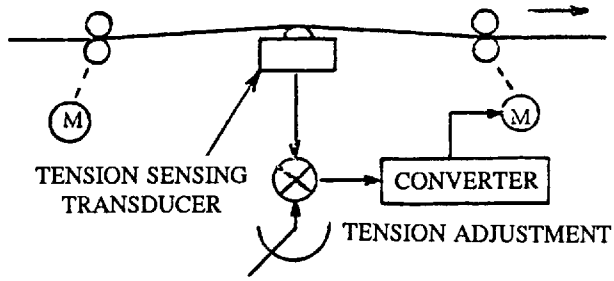


Figure 2-4-4
TENSION FEEDBACK CONTROL SYSTEM

5 Product Marking, Installation and Maintenance Information

The following information should be furnished by the user or equipment builder:

a. System Arrangement —A flow diagram including the relative position of mechanical features such as rolls, gearing, motors, looping pits, and reels.

b. Driven System Inertia—The total inertia of each section of the driven equipment, referred to a single shaft (such as the motor shaft). Include inertia of driven and idler rolls and gearing. System inertia affects system stability and performance during normal running as well as during acceleration and deceleration. Where the control supplier does not supply motors, the motor inertia data should be provided as separate items.

c. Driven Roll Diameter and Gear Ratio

d. Required Acceleration and Deceleration Rates

e. Low–Speed Operation—Means of threading and requirements for stalled and start-up tension. Limitations on tension variation values and the speed ranges involved must be included.

f. Broken Material Considerations—Maximum permissible speed and requirements for automatic shutdown when material breaks.

g. Steady–State Tension Range —To be specified in pounds force or newtons. The material to be processed will have a range of normal operating tensions. The specific running tension desired will vary with the cross section and yield strength of the material being run.

h. Transient Limitations—Limitations on permissible torque, tension or position deviations during starting, stopping, acceleration and deceleration. Factors such as breakaway friction, operation of mechanical brakes, electrical braking, windage, and overcoming inertia may cause the operating loop travel or the operating deviation band to be exceeded. Expected line speed transients should be identified.

i. Line–Speed Feedback—In order to limit deviations in loop height during acceleration and deceleration the rate of change of line speed should be available as feedback for the regulator.

j. Driven System Losses—The total losses of the drive equipment, referred to a single shaft (such as the motor shaft). Consideration should be given to losses which may be a function of speed.

k. Speed Range—To be specified in terms of the linear velocity of the material. The operating speed range may differ from the total speed range. The operating speed range pertains only to that range wherein the limits of deviation bands apply. Both the operating range and the total range should be specified in such cases.

The motor may be of such a size that it cannot provide maximum tension at all line speeds. A schedule of tensions and line speeds should be

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provided to permit choosing the optimum size of the drive equipment.

l. Pit Dimensions—A sketch should be provided indicating the geometry of the pit, the pass line, and the loop. The sketch should indicate the normal range of position of the loop in the pit during controlled operation.

m. Loop Geometry—For both intrastand and looping pit applications, it is important to know the depth, width, and length of the loop together with a schedule of material cross sectional areas, tension and modulus of elasticity. For looping pit applications, additional information on the maximum loop travel and operating loop travel should be provided. See Figure 2-2-1.

n. Material—The types of material, including dimensions and characteristics, should be listed, indicating any environmental conditions in the process which will affect these characteristics.

o. Coordination—When the loop or tension control system is supplied separately from the rest of the process control, additional information should be provided as follows: signal isolation, signal level and ground requirements.

6 Service and Storage Conditions

See ICS 1, Clause 6.

7 Construction

See Clause 7 of Part 1.

8 Performance Requirements and Tests

This section contains no performance requirements or tests.

9 Application

See Clause 5 of Part 2.

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Part 3
WIND AND UNWIND DRIVE SYSTEMS

1 General

1.1 Scope

The standards in this part apply to drive systems whose objective is to control tension, or speed, or both, for the winding, or unwinding, or both, of material in such forms as strip, web, rod or wire. The machine for performing the function of winding or unwinding is known as a reeler, winder, beamer, coiler or spooler, depending on the industry or application. In these standards, the machine will be referred to as a winder or unwinder.

1.2 Normative References

The definitions and standards of NEMA Standards Publications ICS 1 and ICS 7, Part 1 apply to this part unless otherwise stated.

2 Definitions

For the purposes of this part, the following definitions apply:

center winder (unwinder): A winder in which the roll of material is driven (or held back in the case of an unwinder) through the reel on which the material is wound (see Figure 3-2-1).

line speed: The rate of linear travel of material being conveyed or processed.

Line speed is expressed in linear units, such as feet or meters per minute.

line speed range: The maximum and minimum line speeds between which the system is designed to operate.

The drive system must remain within specified deviation bands throughout this range. (This requirement does not normally include thread speed operation.)

maximum roll build-up: The build-up from the empty reel diameter to the full roll diameter.

maximum roll build-up ratio: The ratio of the maximum roll diameter to the empty reel diameter.

reel: A core, with or without flanges, upon which the material is wound.

roll; coil: The material wound upon the reel.

roll build-up (build-down): The change in roll diameter while winding (unwinding).

roll build-up ratio: The ratio of the roll diameter to the empty reel diameter.

surface winder: A winder in which the roll of material is driven by friction rolls or belts in contact with the outer surface of the roll (see Figure 3-2-2).

taper tension: Provision for varying tension with build-up, or line speed, or both, as opposed to constant tension.

tension: The total force in pounds or newtons acting on the cross section and tending to cause extension of the material being processed.

3 Classifications

This part contains no additional classifications.

4 Characteristics and Ratings

This part contains no additional characteristics or ratings.

5 Product Marking, Installation and Maintenance Information

This part contains no additional marking or information requirements.

6 Service and Storage Conditions

This part contains no additional service and storage requirements.

7 Construction

This part contains no additional construction requirements.

8 Performance Requirements and Test

This part contains no additional performance or test requirements.

9 Application

The following information may be required by the electrical equipment supplier and should be furnished by the user or machine builder to the electrical equipment supplier:

a. System Arrangement—A flow diagram and physical layout, including dimensions, of mechanical features such as rolls, transducers, gearing and gear ratios, motors, interstand loop and looping pit (or accumulator) and reels. Limiting dimensions of control panels should be included.

b. Line Speed and Steady-state Tension—A table showing, for each material, line speed range, steady-state tension range with material cross-section and modulus of elasticity, as shown in Table 3-9-1.

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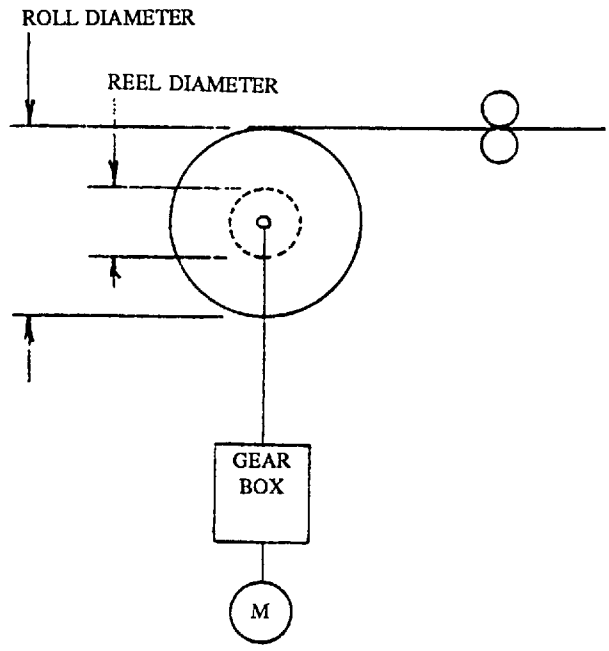


Figure 3-2-1
CENTER WINDER (UNWINDER)

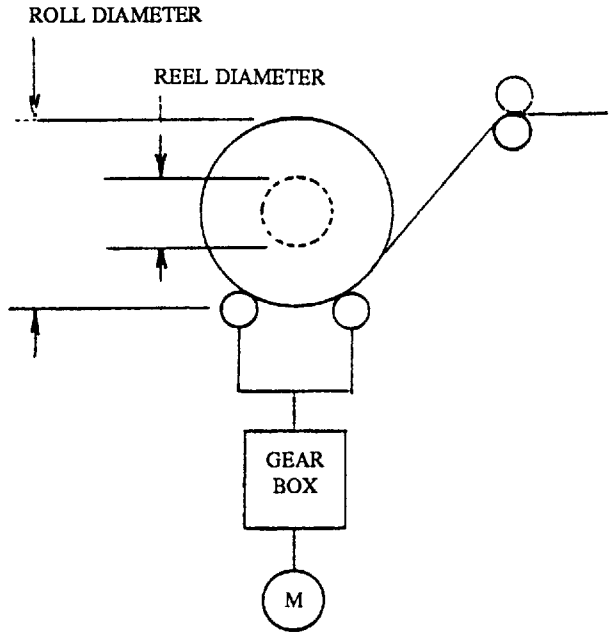


Figure 3-2-2
SURFACE WINDER

Table 3-9-1
TABLE FORMAT FOR LINE SPEED AND TENSION DATA

Product Description a. Material Type b. Dimensions c. Density and Other Pertinent Information such as Temperature	Tension Pounds (Newtons) Maximum	 Minimum	Line Speed Feet/Minute (Meters/Minute) Maximum	 Minimum	Modulus of Elasticity, Pounds/ Square Inch (Newtons/ Square Meter)

c. Operating Schedule—Time sequence of operating schedule, including stops for inspection, splicing, reel changes, etc., to enable motor rms loading to be established.

d. Taper Tension—Where it is necessary or permissible to change tension as a function of build-up, a schedule indicating this relationship should be provided.

e. Transient Limitations—Limitations on permissible tension and speed deviations during starting, stopping, acceleration and deceleration. (Factors such as breakaway friction, operation of mechanical brakes, electrical braking, windage, roll changes, splicing, and overcoming inertia may cause the operating deviation band to be exceeded.)

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f. Driven-System Inertia—The total inertia of each section of the driven equipment, complete with empty reel, referred to a single shaft (such as the motor shaft). The inertia of driven and idler rolls and gearing should be included.

g. Acceleration and Deceleration—The required range of controlled acceleration and deceleration rates in feet or meters per minute per second.

h. Driven-Equipment Losses—The total losses of the driven equipment at maximum and minimum line speed.

i. Low-Speed Operation—Means of threading and requirements for stalled and start-up tension.

Limitations on tension variation values and the speed ranges involved should be included.

j. Broken Material—Requirements for automatic shutdown when material breaks, including maximum permissible overspeed.

k. Emergency Stop—Detailed requirements for emergency stops, including stopping time or stopping travel, and location and type of equipment for initiating such stops.

l. Steady-State Tension Deviation—Permissible steady-state tension deviation, expressed as a percentage of maximum rated tension. (Equipment complexity increases as a product of line speed range, tension range and roll build-up ratio. It is important, therefore, to be realistic in specifying steady-state tension deviation.)

m. Coordination—Where the winder control is supplied separately from the rest of the process control, additional information, such as the following, is required:

1. Signal isolation
2. Signal level
3. Grounding requirements

n. Motor Data—Where the control supplier does not supply motors, the user or machine builder should supply motor nameplate data, armature resistance, armature inductance and inertia, and field inductance.

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Part 4
ADJUSTABLE FREQUENCY CONVERTERS RATED NOT MORE THAN 600 VOLTS

1 General

1.1 Scope

The standards in this part apply to general-purpose adjustable frequency converters, rated not more than 600 volts, with a base output frequency up to 500 hertz. Where the output terminals of these converters are connected to the line terminals of AC synchronous or induction motors, an adjustable-frequency output can be applied to the motor by controlled semiconductors in Form FC. See Part 3. For the purpose of this part, an adjustable-frequency converter is one which includes the power conversion and control equipment, but not the one or more AC motors to which its output is connected.

These converters are generally rated one horsepower and above.

1.2 Normative References

The definitions and standards of NEMA Standards Publication No. 250, ICS 1, ICS 6, ICS 7 Part 1, and UL 508C also apply to this part unless otherwise stated.

2 Definitions

For the purposes of this part the following definitions apply:

base frequency: The lowest frequency at which the converter produces rated output voltage.

frequency range: The range over which the converter is capable of maintaining its continuous rated output.

NOTE: In some equipment, current may vary with frequency and may not have a constant current mode of operation. The horsepower (or kW) may be specified to vary with frequency.

3 Classification

See Clause 3.4 of Part 1 for converter classifications.

4 Characteristics and Ratings

4.1 Modes of Operation

Adjustable frequency converters are typically designed to have one frequency range over which the ratio of volts to hertz remains constant, and another range over which the voltage remains constant while the frequency varies. The frequency at which the transition, from one range to the other, occurs is base frequency. Depending on motor characteristics,these two ranges can correspond to constant torque (constant volts/hertz) and constant power (constant voltage with a variable frequency). Power and corresponding torque capabilities of the motor in the region above base frequency should be reviewed with the motor manufacturer. Direct or indirect vector control may be incorporated.

4.2 Frequency Range

The output frequency range shall be specified by the manufacturer.

4.3 Output Voltage As a Function of Output Frequency

Rated output voltage remains constant between base and maximum frequency. Below base frequency output voltage is less than rated, and is based on a constant volts per hertz ratio as shown in Figure 4-4-1.

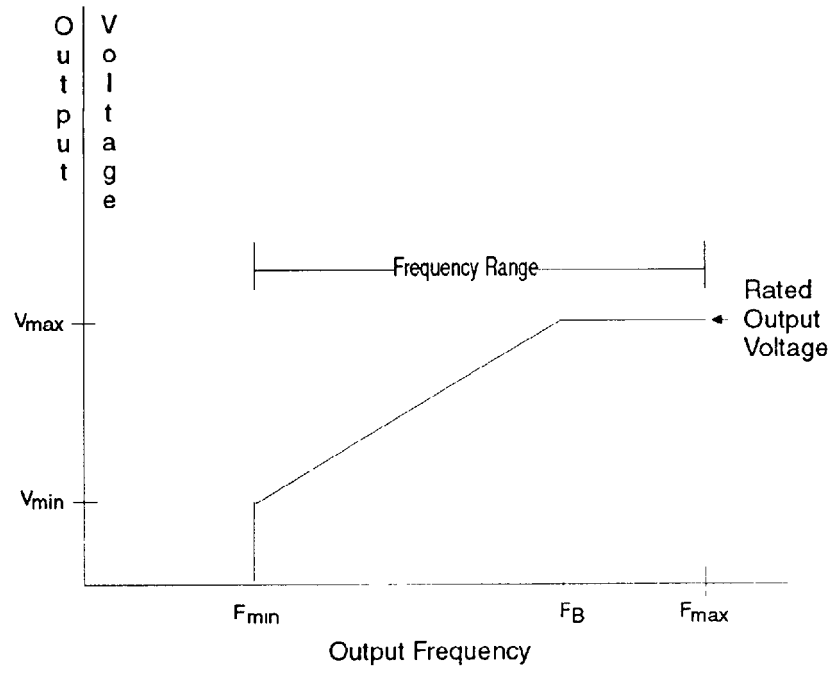
5 Product Marking, Installation and Maintenance Information

5.1 Product Information

The following information shall be included on the converter nameplate:

a. Manufacturer's name
b. Equipment identification
c. Input rating
    1. Voltage
    2. Maximum continuous current, total rms amperes (including harmonics)
    3. Frequency
    4. Number of phases
    5. Maximum allowable AC system symmetrical short-circuit current (See application guidelines in Annex A.)
    6. Service category
d. Output Rating
    1. Maximum output voltage
    2. Rated continuous current, fundamental rms amperes (excluding harmonics)
    3. Overload capacity
    4. Frequency range
    5. Number of phases
    6. Nominal HP or kW or kVA output (optional)
    7. Phase rotation of output

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V_{min} = Minimum Output Voltage

V_{max} = Maximum Output Voltage

F_{min} = Minimum Frequency

F_{max} = Maximum Frequency

F_B = Base Frequency

Figure 4-4-1
OPERATING FREQUENCY RANGE

6 Service and Storage Conditions

Equipment conforming to these standards shall be capable of operating at its rating under the usual service conditions specified in Clause 6 of Part 1.

7 Construction

This part contains no additional construction requirements.

8 Performance Requirements and Tests

8.1 Short-Circuit Withstand Capability

The converter shall meet the test requirements of UL 508C as to short-circuit withstand capability ratings expressed in terms of available rms symmetrical amperes, maximum voltage ratings, and the type and ratings of short-circuit protective devices.

8.2 Dynamic-Braking Slowdown

Where dynamic-braking slowdown is provided, the resistors used for this purpose shall be capable of absorbing six times the stored rotational energy of the motor at base speed, with the resistors initially at ambient temperature.

For duty cycles involving repeated operation or high inertia, it may be necessary to specify resistors with higher energy absorption capability.

The torque profile versus speed during dynamic-braking slowdown is not necessarily linear.

8.3 Dynamic-Braking Stop

Where dynamic braking stop is provided, the converter shall be capable of braking a load at an initial current of 150 percent of rated current at base speed and the resistor shall be capable of absorbing six times the stored energy of the motor at base speed with the dynamic braking resistor initially at ambient temperature.

In an adjustable-frequency converter dynamic-braking is considered to apply only to the use of a resistor across or in the DC link of an adjustable-frequency converter for an induction motor. Dynamic-braking cannot occur in an induction motor AC drive unless the power circuit and control circuit are fully functional. This fact should be considered where the dynamic braking feature of an AC drive is used to stop an induction motor from rotating. Additionally a mechanical brake, actuated in case of a power failure, may be required for stopping the motor.

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9 Application

9.1 Current Limiting Inputs

See Annex A for information regarding conditions which would warrant the addition of line reactors or input transformers when selecting an adjustable frequency AC converter.

9.2 Rating Limitations

Final selection of the motor and converter combination must not exceed the converter rating (voltage, current, and frequency). Many factors preclude exclusive use of the horsepower or kilowatt rating shown on the converter nameplate, including:

a. Variations in motor nameplate current versus motor horsepower or kilowatt rating

b. Harmonic content of the converter output current and voltage

c. Variations of motor nameplate current with motor base speed (motor poles)

d. Variation of motor torque per ampere, particularly in the extended (high) frequency range

e. Possible mechanical limits that restrict the motor from operation above its designed base speed

f. Cases where the motor inductance forms an integral part of the commutation circuitry of the converter (CSI and LCI).

In all cases, motor nameplate current must be considered in selecting the converter rating.

9.3 Starting Characteristics

To assist the user in selecting a converter such that adequate starting torque can be developed by the motor, the values of momentary overcurrent and voltage boost capabilities, if any, at low or minimum starting frequency, shall be supplied with the converter.

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Part 5
GENERAL PURPOSE ADJUSTABLE-VOLTAGE DC PACKAGED-DRIVE SYSTEMS

1 General

1.1 Scope

The standards in this part apply to general-purpose adjustable-voltage integral-horsepower packaged-drive systems using shunt or compound-wound DC motors where the primary power source is AC and the conversion to DC is by controlled semiconductor rectifiers.

1.2 Normative References

The definitions and standards of NEMA Standards Publication 250, ICS 1, ICS 3.1, ICS 6, ICS 7 Part 1, and MG 1 also apply to this part unless otherwise stated.

2 Definitions

For the purposes of this part, the following definitions apply:

DC packaged-drive system: A system which includes a motor or motors and the power conversion and control equipment, the power conversion and principal control equipment being contained in a single enclosure, and which provides adjustable-speed by control of the armature voltage or a combination of armature and motor shunt-field control.

3 Classifications

Drive systems referred to in this part shall be of one of the following types:

Type I— Adjustable-speed is provided only by adjustment of the armature voltage.

Type II— Adjustable-speed is provided by a combination ofarmature voltage and motor shunt-field current adjustment.

4 Characteristics and Ratings

4.1 Converter Output Rating

In selecting the power supply capacity for the motor, it should be recognized that motors of the same horsepower rating but different speeds and in different enclosures may have different current ratings.

4.2 Motor DC Voltage Ratings

The DC voltage rating of the packaged drive system motor shall be as shown in Table 5-4-1.

Table 5-4-1
DC VOLTAGE RATINGS

AC Supply Phases	Motor Armature Voltage Ratings, Volts, DC	Motor Field Voltage Rating, Volts, DC
1	90	50 or 100
1	180	100 or 200
3	240	150 or 240
3	500	240 or 300
3	600	240 or 360

5 Product Marking, Installation and Maintenance Information

5.1 Nameplate Information

The following information shall be included on the converter nameplate:

a. Manufacturer's name
b. Equipment identification
c. Input rating
   1. Voltage
   2. Maximum continuous total rms amperes (including harmonics)
   3. Frequency
   4. Number of phases
   5. Maximum allowable AC system symmetrical short-circuit current (see Annex A.)
   6. Service category
d. Output rating
   1. Armature and field voltage
   2. Armature and field continuous average output current
   3. Nominal HP or kW (Optional)
   4. Overload capacity

5.2 Other Product Information

The following product information shall be included with the equipment by the manufacturer:

a. Maximum drive speed
b. Field current at maximum speed

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c. Maximum safe speed

d. Field current at base speed

e. Features covered in Clause 9.1 of this part

6 Service and Storage Conditions

6.1 Equipment conforming to these standards shall be capable of operating at its rating under the usual service conditions specified in Clause 6 of Part 1.

6.2 The power converter output armature voltage rating during inverter operation may be less than rectifier operation.

7 Construction

The DC motor shall be rated (insulation rating) for the equivalent AC voltage applied to the input of the rectifier.

8 Performance Requirements and Tests

8.1 Performance Requirements

8.1.1 Speed Range

The speed shall be capable of being adjusted over a range of not less than 8 to 1 by armature voltage control.

This speed range may be extended to the maximum speed of the motor rating by decreasing the motor field current.

8.1.2 Operation Below Base Speed

Drives are capable of operation at any speed within the rated speed range. When drives are operated continuously at rated torque at speeds below the rated base speed, the temperature rise of the motor may exceed the rated full-load value. To meet the specified duty cycle and torque requirements of the load for a given application, the drive system design should assure adequate torque capability at reduced speeds with a safe motor temperature rise.

8.1.3 Dynamic-Braking Slowdown

Where dynamic slowdown is provided, the resistors used for this purpose shall be capable of absorbing four times the stored energy of the motor at maximum drive speed, with the dynamic-braking resistor initially at ambient temperature.

8.1.4 Dynamic Braking Stop

Where dynamic braking is provided, a drive shall be rated for either of the following two dynamic braking capacities.

a. The drive system shall be capable of braking a load whose inertia equals that of the motor at an initial current of 150 percent of rated armature current from maximum drive speed to standstill three times in rapid succession, with the dynamic-braking resistor initially at ambient temperature.

b. A drive system with a large variable load inertia (such as winders) shall be capable of braking the maximum stored energy with the dynamic-braking resistor initially at ambient temperature. The watt-second rating of the resistor shall be capable of stopping the drive system once from any operating speed. The maximum dynamic braking armature current at maximum drive speed is 150 percent of rated armature current.

8.2 Short-Circuit Withstand Capability

The converter shall meet the test requirements of UL 508C as to short-circuit withstand capability ratings expressed in terms of available rms symmetrical amperes, rated system voltage and the type and ratings of short-circuit protective device(s) stated by the manufacturer.

9 Application

9.1 User Specification

Certain features in addition to those listed in Clause 4.3 of Part 1 may be specified for particular applications. Such features are:

a. Manual motor-field adjustment

b. Field-loss protection

c. Armature circuit isolation from the AC power supply

d. Inverting-fault protection

e. Isolation transformer or line reactors

f. Regulator or power circuit diagnostics

9.2 DC Motor Field Control

When field control of the motor could cause detrimental generated voltage or current, or both, in the armature circuit, means shall be provided to automatically prevent such a possibility.

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Part 6
ADJUSTABLE FREQUENCY DRIVE SYSTEMS RATED NOT MORE THAN 600 VOLTS, USING SEMICONDUCTOR POWER CONVERSION

1 General

1.1 Scope

The standards in this part apply to general-purpose adjustable-frequency drive systems in which the speed of AC synchronous or induction motors is adjusted by controlling the frequency. It applies to systems where the primary power source is a fixed frequency and the conversion to adjust frequency is achieved by controlled semiconductors in Form FC. See Clause 3 of Part 1.

1.2 Normative References

The definitions and standards of NEMA Standards Publication No. 250, ICS 1, ICS 3.1, ICS 6, ICS 7 Part 1, MG 1, and UL 508C also apply to this part unless otherwise stated.

2 Definitions

For the purposes of this part, the following definitions apply:

base frequency: The lowest frequency at which the converter produces rated output voltage.

base speed rating: The lowest speed at which a drive can develop rated horsepower continuously.

breakaway torque (at starting applied frequency): The minimum torque developed by the motor at rest for any initial angular position of the rotor, stated in percent of rated torque.

3 Classifications

This part contains no classifications.

4 Characteristics and Ratings

4.1 Modes of Operation

The mode or modes of operation for the drive system should be compatible with the torque and speed requirements of the load.

Adjustable-frequency converters are typically designed to have one frequency range over which the ratio of volts to hertz remains constant, and another range over which voltage remains constant while the frequency varies. The frequency at which the transition, from one range to the other, occurs is base frequency. Depending on motor characteristics, these two ranges can correspond to constant torque (constant volts/hertz) and constant power (constant voltage with a variable frequency). Power and corresponding torque capabilities of the motor in the region above base frequency should be reviewed with the motor manufacturer. Direct or indirect vector control may be incorporated.

4.2 Output Ratings

Ratings for voltage, frequency and number of phases of inverter output are not specified in the standards of this section because these standards apply to complete drive systems. These standards are based on the use of polyphase motors, three-phase being the most commonly used.

4.2.1 Preferred Horsepower Ratings

Adjustable frequency drive systems shall be rated in terms of the horsepower output of the motor. The preferred ratings are 1, 1-1/2, 2, 3, 5, 7-1/2, 10, 15, 20, 25, 30, 40, 50, 60, 75, 100, 125, 150, 200, 250, 300, 350, 400, 500, or 600 horsepower at base-speed frequency and voltage.

4.2.2 Speed Ratings

Adjustable-frequency drives shall have a base-speed rating. Drives which provide for operation above base speed by increasing the frequency shall have a maximum speed rating and a corresponding horsepower rating.

5 Product Marking, Installation and Maintenance Information

5.1 Marking and Labeling

5.1.1 Converter Nameplate

The following information shall be shown on the converter nameplate:

a. Manufacturer's name
b. Equipment identification
c. Input rating
    1. Voltage
    2. Maximum continuous total rms amperes (including harmonics)
    3. Frequency
    4. Number of phases
    5. Maximum allowable AC system symmetrical short-circuit current (See application guidelines in Annex A.)
    6. Service category
d. Output rating
    1. Maximum output voltage
    2. Rated continuous current, fundamental rms amperes

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3. Overload capacity
4. Frequency range
5. Number of phases
6. Nominal HP or kW or kVA (optional)
7. Phase rotation of output

5.1.2 Motor Information

a. Motor nameplate as per NEMA Standard Publication MG 1
b. Maximum operating speed, if different from base speed
c. Maximum continuous current over the operating speed range
d. Time rating
e. Motor rotation at a given input phase rotation
f. Insulation system designation
g. Maximum ambient temperature

5.1.3 Required Information

The following information shall be supplied with the drive system:

a. Operating modes
b. Minimum, maximum, and base speeds and corresponding horsepower, frequency and voltage

5.1.4 Optional Information

Input displacement power factor may be supplied with the drive system.

6 Service and Storage Conditions

Equipment conforming to these standards shall be capable of operating at its rating under the usual service conditions specified in Clause 6 of Part 1.

7 Construction

This part contains no additional construction requirements.

8 Performance Requirements and Tests

8.1 Performance Requirements

8.1.1 Operating Speed Range

The operating range over which the drive is capable of maintaining its specified steady-state performance shall be specified. The continuous torque capacity of the drive at the minimum speed for this operating range shall be specified.

The maximum load capacity at the minimum speed of the range shall be specified. Drives designated as constant-torque drives shall provide no less than 100 percent of rated torque. For drives with a constant-horsepower speed range, the maximum load capacity at the maximum speed shall also be specified.

8.1.2 Starting Characteristics

The starting capability of the system shall be specified, indicating at least the minumum torque available between rest and minimum speed. Breakaway torque shall be defined, at starting applied frequency, as the minimum torque developed by the motor at rest for any initial angular position of the rotor and shall be stated in percent of rated torque.

Unless otherwise specified, when synchronous motors are provided the system shall be capable of synchronizing against a torque at least equal to the rated torque with a specified load inertia at the minimum operating frequency.

The user should provide information on the load-starting torque requirements and the load inertia.

8.2 Dynamic-Braking Slowdown

Where dynamic-braking slowdown is provided, the resistors used for this purpose shall be capable of absorbing six times the stored rotational energy of the motor at base speed, with the resistors initially at ambient temperature.

For duty cycles involving repeated operation or high inertia, it may be necessary to specify resistors with higher energy absorption capability.

The torque profile versus speed during dynamic-braking slowdown is not necessarily linear.

8.3 Dynamic-Braking Stop

Where dynamic-braking stop is provided, the converter shall be capable of braking a load at an initial current of 150 percent of rated current at base speed and the resistor shall be capable of absorbing six times the stored energy of the motor at base speed with the dynamic-braking resistor initially at ambient temperature.

In an adjustable-frequency converter dynamic-braking is considered to apply only to the use of a resistor across or in the DC link of an adjustable-frequency converter for an induction motor. Dynamic-braking cannot occur in an induction motor AC drive unless the power circuit and control circuit are fully functional. This fact should be considered where the dynamic braking feature of an AC drive is used to stop an induction motor from rotating. Additionally a mechanical brake, actuated in case of a power failure, may be required for stopping the motor.

8.4 Short-Circuit Withstand Capability

The converter shall meet the test requirements of UL 508C as to short-circuit withstand capability ratings expressed in terms of available rms symmetrical amperes,

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rated system voltage and the type and ratings of short-circuit protective device(s) stated by the manufacturer.

9 Application

9.1 Annex Information

See Annex A for information regarding conditions which would warrant the addition of line reactors or input transformers when selecting a adjustable frequency AC motor speed converter, and Annex B for other considerations.

9.2 Motor and Converter Selection

The power conversion and control equipment for a multimotor drive are not necessarily the same as those for a single-motor drive of the same horsepower rating, and the drive systems manufacturer should be consulted. In selecting the converter output rating for the motor, the current ratings of such motors as high-speed motors, totally-enclosed fan-cooled motors, short-time-rated motors, etc., should be considered.

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Part 7
ADJUSTABLE-FREQUENCY DRIVE SYSTEMS RATED 601 TO 7200 VOLTS

1 General

1.1 Scope

The standards in this part apply to adjustable-speed drive systems in which the speed is changed by frequency adjustment, and the equipment operates at voltages between 601 and 7,200 volts, three-phase. The drive converters are of the DC-linked AC-converter type whose output is connected to the stator winding of an AC motor.

The drive system consists of all equipment utilized to convert electrical energy from the supply mains to energy in the form of shaft torque and speed of the AC motor.

This standard also applies when the converter and the motor are specified separately.

1.2 Normative References

The definitions and standards of NEMA Standards Publication No. 250, ICS 1, ICS 3.1, ICS 6, ICS 7 Part 1, MG 1, UL 347, and NFPA 70 also apply to this part unless otherwise stated.

2 Definitions

For the purpose of this part the following definitions apply:

base frequency: The lowest frequency at which the converter control shifts from constant flux to a diminishing flux condition.

Typically, where a converter is connected to a motor as part of a drive system, the range below base frequency corresponds to the constant torque region and the range above base frequency corresponds to the constant power region.

base rating: A rating consisting of the rated power and base speed.

base speed: The lowest speed at which the drive develops the rated power continuously.

converter: An operative unit for electronic power conversion, comprising one or more electronic switching devices and any associated components, such as transformers, filters, commutation aids, controls and auxiliaries.

DC-linked AC converter: A converter comprising a rectifier and an inverter, with an intermediate DC link.

This definition is intended to include only those circits in which the DC link is readily identified or explicit, and not those circuits having an implicit DC link, but no single pair of conductors that can be identified as the DC link.

externally commutated converter: A converter in which the commutating voltages are supplied by the AC supply lines, the AC load, or some other AC source outside the converter.

line-side converter AC current: The magnitude of the current expressed in amperes of the rms value of current at the input terminals of the line side converter.

line-side converter AC voltage: The rms power-frequency voltage from line to line at the AC terminals of the line side converter.

This voltage is the same as the rated system voltage multiplied by the turns ratio of the input interface equipment when supplied.

load-commutated inverter: An intermediate DC bus link converter with a series DC choke smoothing component whose inverter depends on a leading power factor load for commutation energy.

Normally the AC load of a load-commutated inverter is a synchronous motor operating at leading power factor or an induction motor and capacitor network which can provide commutation energy for the inverter.

load-side converter AC voltage: The rms value of the fundamental of the line to line voltage at the AC terminals of the load-side converter.

This is the voltage that appears at the AC output terminals of the load side converter and is not necessarily the rms fundamental voltage at the motor terminals.

motor current: The rms magnitude of the fundamental current at the terminals of the motor.

motor voltage: The rms value of the fundamental sinusoidal voltage at the terminals of the motor.

rated power: The continuous output power of a drive system at base frequency. Rated power is assigned by the manufacturer.

3 Classifications

This part contains no additional classifications.

4 Characteristics and Ratings

4.1 Input Rating

The input to the drive system shall be expressed by the manufacturer in terms of rms values of current, voltage, and harmonic current magnitudes and frequencies, at a specified system impedance for operation at rated output and base speed (base rating).

Displacement or total power factor may also be specified.

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4.2 Output Ratings

The output of the drive system shall be defined in terms of power and speed, or in terms of percent or per unit of the assigned base rating power and speed.

The output rating shall be on a continuous-duty basis unless specified otherwise. Any limitations at operating points other than those defined by the drive system output shall be clearly defined.

Where the drive system has more than one mode of operation, the drive output shall be defined for each mode.

Examples of drive output ratings are as follows:

OUTPUT RATING EXAMPLES

MODE	OUTPUT
Variable Torque	5,000 HP, 900 RPM, continuous operation 90-900 RPM. Torque is a function of speed.
Constant Torque	5,000 HP, 900 RPM continuous operation 600-900 RPM. Torque is independent of speed.
Constant Power	5,000 HP, 900 to 1,600 RPM. Torque is inversely proportional to speed

4.3 Power Converter Rating

The output rating of the adjustable-frequency converter shall be that required at the converter terminals to permit the motor to deliver the power and speed as specified by the drive system rating. All of the equipment that is a part of the drive system shall be rated to support the drive system output.

The converter output shall be defined in terms of voltage frequency, current, and displacement power factor.

4.4 Harmonic Current and Voltage Distortion

In addition to the fundamental values of motor current, voltage and power factor that produce shaft power, the harmonic currents of current-fed converters or the harmonic voltages of voltage-fed converters shall be provided to the motor manufacturers, or to the user in retrofit applications, to assure the compatibility of motor and converter. Harmonics shall be defined in terms of magnitude and frequency. Phase-voltage excursions from ground potential in excess of the fundamental phase voltage to ground shall be specified.

5 Product Marking, Installation and Maintenance Information

5.1 Marking and Labeling

5.1.1 Converter Nameplate

The following information shall be shown on the converter nameplate:

a. Manufacturer's name
b. Equipment identification
c. Input rating
    1. Voltage
    2. Maximum continuous current total rms amperes (including harmonics)
    3. Frequency
    4. Number of phases
    5. Maximum allowable AC system symmetical short-circuit current (See application guidelines in Annex A.)
    6. Service category
d. Output rating
    1. Maximum output voltage
    2. Rated continuous current, fundamental rms amperes
    3. Overload capacity
    4. Frequency range
    5. Number of phases
    6. Nominal HP or kW or kVA (optional)
    7. Phase rotation of output

5.1.2 Motor Information

a. Motor nameplate as per NEMA standard MG 1
b. Maximum operating speed, if different from base speed
c. Maximum continuous current over the operating speed range
d. Time rating
e. Motor rotation at a given input phase rotation
f. Insulation system designation
g. Maximum ambient temperature

5.2 Instructional Information

The following instructional information shall be included with the equipment.

a. Displacement or total power factor (input) (optional)

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b. Power converter rating—displacement power factor (output)
c. Input harmonic currents and amplitudes
d. Output current or voltage harmonics
e. Operating modes
f. Minimum speed
g. Drive system rating—base rating and base frequency

5.3 With Converter Only

The following information shall be supplied when the manufacturer provides the converter only:

a. 5.1.1 above
b. 5.2 except items (f) and (g)
c. Maximum output voltage to ground

5.4 Permissible Operating Speed

The operating speed range over which the drive system is capable of meeting its steady state torque shall be specified. This operating speed range shall be specified for each of the operating modes for which the drive system is designed.

6 Service and Storage Conditions

Equipment conforming to these standards shall be capable of operating at its rating under the usual service conditions specified in Clause 6 of Part 1.

7 Construction

This part contains no additional construction requirements.

8 Performance Requirements and Tests

8.1 Performance Requirements

8.1.1 Recovery After a Momentary Interruption of Input Voltage

A converter equipped to recover from momentary interruption of input voltage shall be capable of restoring power to the driven motor after restoration of rated input voltage in a time specified by the manufacturer. It is recognized that the motor may not reach set speed in that time.

8.1.2 Temperature Rise

The drive system components shall not exceed their maximum allowable temperature when the drive system is operating at rated input voltage, frequency, and maximum allowable ambient temperature, at the output power and speed assigned by the base rating.

8.2 Short-Circuit Tests

8.2.1 Short-Circuit Withstand Capability

The converter shall meet the test requirements of UL 347, as modified by the following test procedure and compliance criteria, as to short-circuit withstand capability ratings expressed in terms of available rms symmetrical amperes, rated system voltage and the type and ratings of short-circuit protective device(s) stated by the manufacturer.

8.2.2 Test Procedure

The input power supply must be calibrated to be capable of supplying fault current equal to or greater than the maximum allowable AC system symmetrical short circuit rating of the converter. The configuration of the input power supply must be corner-grounded delta or line grounded wye.

Surgical cotton balls are placed in all the enclosure ventilation holes. A 3 ampere, 5,000 volt fuse is connected between the ungrounded enclosure and ground. The specified branch-circuit protection fuses or switchgear are installed ahead of the converter, if not provided as an integral part of the converter.

The output of the converter is shorted line-to-line with all the electrical protective circuits active and the converter operating at its maximum frequency and voltage output. A small motor shall be permitted to be used on the output of the converter, if required for normal operation.

8.2.3 Test Compliance Criteria

The equipment passes the test if the fuse connected from the enclosure to ground does not open (no striking of an arc to the enclosure), there is no ignition of the cotton placed around the openings in the converter enclosure, and no other manifestation of a fire hazard occurs.

9 Application

9.1 General Protection Considerations

The following general considerations for protective features and devices are in addition to those shown in Clause 9 of Part 1.

9.1.2 Protection Circuits

Protection circuits should prevent system failures and damage to the installation or the components. Exceeding the limiting values will cause these protection circuits to come into operation. The limiting values remain always below destruction thresholds for the components. Protection circuits react primarily to the external factors that influence the drive system, factors such as voltage or load torque.

9.1.3 Component Protection

Component protection prevents the components from being subjected to stresses exceeding rated levels. The protection circuits should work selectively and in a coor-

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dinated order. Component protection either prevents the destruction of the components directly involved or, if this is impossible, protects neighboring components not directly involved in a fault.

9.2 Basic System Protection

The exact requirements for protection of the system depend on the mission and configuration of the drive system. General requirements are defined by NFPA 70. Overload and other overcurrent protection, which generally allow for the safe operation of the equipment, is required by NFPA 70 for motors, capacitor banks, isolation transformers and motor converters. However, to fully protect the equipment from damage caused by other contingencies, additional protection is recommended.

A well-designed system provides protection against contingencies internal and external to the drive system. These may include:

a. Power source irregularities
    1. Voltage surges
    2. Over and under voltage
    3. Phase reversal
    4. Voltage unbalance
b. Overcurrent conditions
    1. Fault currents
    2. Ground currents
    3. Internal faults
c. Overloads
d. Equipment overtemperature
e. Motor overspeed
f. Excessive vibration of machine
g. Lost lubrication of machine
h. Power converter protection

Power converters are protected by internal solid-state circuits for common faults. Most contingencies will cause the converter to take gate protective action which will force the internal currents and the motor current to zero. This is sufficient as long as the converter components have not failed. In the event of a component failure, the converter should signal the line protective circuit breaker or contactor to trip.

9.3 Motor Protection

Motors and motor branch circuits are effectively protected by apparatus in the motor starter or power converter, using relay devices that sequence the converter. Although NFPA 70 requires only overcurrent and overload protection, it is highly recommended that there be means of detecting winding overtemperature, bearing overtemperature, bearing vibration, and differential current in motors rated over 500 horsepower.

Surge protection for motors can be provided by surge arresters and capacitors. The possible effect of the surge capacitor on the converter must be determined to assure satisfactory operation.

Special consideration should be given to protecting induction motors against self-excitation in drives employing large capacitor banks or filters connected between the power converter and the motor. Where the kVAR rating of the capacitor bank exceeds 20 percent to 30 percent of the kVA rating of the motor, it can become self-excited which may result in higher than normal voltage across the motor terminals. Appropriate means should be considered to prevent self-excitation when power is lost. For example, capacitor banks and harmonic filters should be disconnected from motor.

9.4 Transformer Protection

Isolation transformer protection is typically provided by relays acting through a protective circuit breaker device or to remote alarms. Overcurrent protection in the transformer primary circuit is required by NFPA 70. Ground-fault and differential-current protection are commonly provided on larger units. Care should be taken in selecting relays for this application, taking into consideration adjustable-frequency drive harmonics. Surge protection is typically provided on the primary of isolation transformers. When properly coordinated, such surge protection can protect the entire drive system from line voltage surges caused by lighting and switchgear interruptions.

9.5 Harmonic Filters and Capacitor Banks

Harmonic filters and capacitor banks require overcurrent protection, which is typically provided by fuses. Voltage or current unbalance protection is also commonly provided. See Articles 430, 450 and 460 of NFPA 70 for further information regarding protection.

9.6 System Grounding

The application of DC-linked converter systems requires that proper design consideration be given to the system grounding and the voltage ratings of isolation transformers, the motor, and the power converter. An improperly grounded system can result in ground currents circulating between the source and the motor through the power converter. Higher than normal voltage to ground may occur at the terminals of the isolation transformer or the motor. These voltages are caused by common mode voltage generated by the power converter system, which displaces system neutral voltage from ground potential.

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The motor terminal-to-ground voltage can be reduced by:

a. Isolating the installation electrical system ground with a transformer

b. Utilizing separate reactors in both the positive and negative DC link

c. Connecting the motor neutral to ground through impedance

If this design practice is properly followed, motor neutral-to-ground voltage can be reduced to near zero. The drive isolation transformer insulation system should be designed for voltage to ground which may exceed rated line-to-line voltage of the secondary winding. Consult the converter equipment supplier for the specific voltage to ground insulation levels required for the motor and isolation transformer.

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Annex A
APPLICATION GUIDE FOR LINE REACTORS AND INPUT TRANSFORMERS

This annex discusses conditions which would warrant the addition of line reactors or input transformers when selecting an adjustable frequency ac motor speed converter.

A.1 Condition 1—Voltage Matching

When line voltage is other than the converter input voltage, a step-up or step-down transformer, or auto transformer on the converter input may be used. The voltage transformation may be accomplished by using feeder transformers supplying mixed loads. In the case of larger converters, separate dedicated transformers may be supplied for single converters or groups of converters.

A.2 Condition 2—Codes

Local or plant codes may specify electrical isolation, which could include the use of transformers.

A.3 Condition 3—Provide Continuity of Service for Installation Prone to Nuisance Grounding

For certain applications, engineering practice may dictate the use of ungrounded or impedance grounded branch circuits on converters and motors. Such applications are usually found in continuous process industries such as pulp and paper, food processing, chemical, cement, mining, or metals. Nuisance grounding of branch circuit conductors is common in these industries due to the effects of moisture or other environmental conditions on the branch circuit and motor insulation systems. To maintain continuity of service in a nuisance ground environment, an isolation transformer is used to galvanically isolate the converter branch circuit from the overall distribution system. In this manner, continued converter branch circuit operation is possible with a single nuisance ground. To provide continued protection, the user should clear the nuisance ground at the earliest opportunity.

The use of a transformer to provide continuity of service under nuisance ground conditions should not be confused with converter ground fault protection. Converter ground fault protection will protect the converter under ground fault conditions specified by the manufacturer but may not provide the continuity of service desired.

A.4 Condition 4—Line Voltage Unbalance

Unbalanced voltage greater than 2 percent between phases of the incoming line may cause larger than rated line currents to be drawn from the AC line. An isolation transformer or line reactor equipped with taps may be used to compensate the voltage unbalance at all rated load conditions.

A.5 Condition 5—Reduction of Converter Input Harmonic Currents

The input currents to adjustable frequency converters are generally non-sinusoidal. These non-sinusoidal currents are composed of a sinusoidal component of current at line frequency (known as the fundamental current) and additional sinusoidal components of current (known as harmonic currents) at frequencies other than the line frequency.

Since the harmonic currents do not aid in transmission of power and contribute to the volt-ampere loading of the distribution system, minimizing the magnitudes of the harmonic line currents is desirable. IEEE Standard 519 discusses in detail the effects of harmonic currents and establishes acceptable limits as to the effects of harmonic currents. The user should specify the degree of harmonic control required.

On certain types of converters, the harmonic content of the input line current may be varied by inserting impedance between the converter input and the distribution system. Transformers and line reactors are convenient devices for modifying the feeder impedance characteristics. Since the magnitude of these input harmonic currents is a function of the power conversion process within the converter, it is difficult to suggest any general guidelines for the adjustment of feeder impedance. The converter manufacturer should be consulted as to the feasibility and method of reducing the input current harmonic content to the desired level.

A.6 Condition 6—Minimize Line Voltage Notching

Adjustable speed drives utilize a solid-state input power converter connected to the AC input lines. These converters may generate a voltage transient on the AC input lines known as a line notch. Line notching generally occurs when the input line converter is operating in the continuous current conducting mode. The line notch transient is described in IEEE Standard 597. Most methods of notch area reduction involve the use of transformers or reactors to insert impedance between the distribution system and the converter input. Acceptable limits for notch area and methods of reducing the notch area are given in IEEE 519. Since the severity of the line notch transients also depends on the configuration of the controller input power converter, the user should consider this fact during application. The controller manufacturer can be consulted to determine the type of input power

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converter utilized and the recommended methods to reduce line notching transients.

A.7 Condition 7—Reduce Available Feeder Short-Circuit Capacity of Drive Converter

When the distribution feeder short circuit capacity at the converter input is greater than the converter input short-circuit withstandability level (as published on the converter nameplate), input transformers or reactors can be utilized to insert impedance between the feeder and the converter input to decrease the short-circuit capacity at the converter input terminals.

A.8 Condition 8—Maximum/Minimum Impedance for Proper Operation

A.8.1 AC Source Impedance

The AC source impedance is that defined at the input terminals of the converter equipment and is determined by the characteristics of the supply conductors, supply transformers, and other connected loads such as motors and capacitors.

A.8.2 Minimum Source Impedance

The minimum AC source impedance to be used for proper operation of the converter equipment should be specified by the supplier. Additional impedance can be provided by series reactors or transformers or both, if needed.

NOTE: To ensure adequate equipment bracing and protective coordination, the maximum allowable AC system symmetrical short circuit current at the input terminals of the converter equipment should be specified by the supplier.

Low source impedance may cause excessive circuit dv/dt, di/dt or excessive voltage and may cause component failure.

A.8.3 Maximum Source Impedance

The maximum AC source impedance to be used for proper operation of the converter equipment should be specified by the supplier.

NOTE: If the maximum source impedance is exceeded, circuit voltages may have abnormal magnitudes causing component damage or commutation failure.

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Annex B
AC ADJUSTABLE-SPEED DRIVE CONSIDERATIONS

B.1 General

The adjustable-speed drives covered by this Annex are all intended to be used with an AC motor, either induction or synchronous type. Satisfactory drive performance may not be achieved unless the characteristics of the connected motor are well understood. These characteristics help in selecting the proper motor for the application, and call attention to the possible effects on motor performance which arise from its use with a converter. The intent of this annex is to be advisory or tutorial in nature.

AC Adjustable-speed drives are designed to operate AC motors at other than the motor's rated speed and power. Special motor designs specifically intended to optimize performance when supplied from adjustable-speed drive converters are available. Examples are motors with special rotor designs intended for use with adjustable speed drives.

B.2 Mechanical Considerations

The converters covered by this annex generate a spectrum of harmonic currents in the motor stator circuit. These harmonic currents then interact in the motor to produce mechanical torques on the shaft and reaction torques on the frame. These torque harmonics can excite further natural frequencies in the mechanical system which may cause higher than normal vibration or mechanical failure. If this occurs, remedial design changes should be made to the system.

B.3 Torsional Considerations

With motors designed to be used at constant speed, there may be mechanical resonances which will be excited at other than design speed. The motor vibration should be checked over the operating speed range to assure trouble-free operation in the adjustable-speed range.

B.4 Torque Pulsations

The knowledge of the harmonic content of motor voltages and currents is also important in determining the pulsating torques excited by harmonics. Typically, large adjustable-speed drives use a basic six-pulse-modulated inverter or a multiplicity of six-pulse-modulated inverters appropriately phase-shifted to reduce harmonics.

B.5 Thermal Considerations

The temperature of the motor will be affected by power losses caused by harmonic currents and reduced cooling from shaft mounted fans at operation below rated speed. The system design should allow for these conditions. In those applications requiring a continuous overload capacity, the use of a higher horsepower rated motor is recommended.

B.6 Motor Parameters for Adjustable-Speed Drive Operation

It is recognized that the user may sometimes wish to purchase a converter and use an existing motor. In this event, the motor supplier may be asked to supply certain parameters at other than base frequency. Among these are:

a. Stator inductance at low frequency—L_1
b. Rotor inductance at low frequency—L_2
c. Magnetization inductance at low frequency—L_m
d. Stator resistance—R_1
e. Rotor resistance at low frequency—R_2

The effect of temperature on these parameters may also be required.

In addition, the optimum values of voltage boost at low frequency might be requested. The intent is to determine the levels of voltage or current boost (at other than base frequency) for the converter, such that the desired performance at other frequencies (including starting torque) can be realized.

B.7 Special Motor Designs

Possibilities exist for reducing the heating and spurious torques (produced by harmonics) in adjustable-speed drive supplied motors, by using other than the three-phase stator connections. Harmonic cancellation of the lower harmonics is usually the objective of this effort. Harmonic cancellation may take place in either or both the stator and rotor circuits.

B.8 Motor Insulation System

The insulation system of the motor may be subjected to higher dielectric stresses than in the case of supply with sinusoidal voltages and currents. These dielectric stresses occur due to increased peak voltages, motor neutral-to-ground voltage, and rate of change of voltage.

B.9 Considerations for Drives with Regenerative Capability

Some adjustable-speed drives covered by this publication have the capability of operating continuously in the regenerative mode in which the motor is converting mechanical energy from the load into electrical energy, which the drive then returns to the AC input supply. The user should be aware of this possibility in the application,

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and the ramifications with respect to the inverter, motor and input supply.

B.10 Redundancies

The adjustable-speed drives of Part 7 are often applied to critical systems which require high availability. Availability can be enhanced by designing the adjustable-speed drive system with redundancies, which can be provided at the component level, subassembly level, and at the system level.

B.11 Line Side Interface

The term line-side interface encompasses transformers or reactors where used between the line and the power converter of an adjustable-speed drive. Transformers (isolation and auto) may be used both on the input and output of adjustable-speed drive converters. Such transformers are not normally essential for converter operation but are intended to satisfy one or more of the following requirements:

a. Meet local codes
b. Provide galvanic isolation
c. Establish voltage levels
d. Establish grounding requirements
e. Reduce short-circuit fault current levels
f. Provide transient suppression
g. Reduce harmonic content of input currents
h. Reduce motor-to-ground voltages

The transformers are subjected to harmonic waveforms.

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Supplement 1
SCOPE OF THE INDUSTRIAL CONTROL AND SYSTEMS SECTION

The NEMA Standards Publications for Industrial Control and Systems cover the requirements for all industrial control apparatus except as modified below. These standards cover all devices, whether electric, magnetic, mechanical, or electronic (except those devices intended specifically for marine auxiliaries and propulsion control apparatus, mine locomotive control apparatus, and railway and railroad locomotion) which, individually or grouped, serve to govern in some predetermined manner the electric power delivered to the apparatus to which they are connected, and which are intended to function on commercial voltages of 750 volts or less, direct current and 7200 volts or less, alternating current.

Industrial Control and Systems Section equipment comprises, but is not limited to, mechanical, electromechanical and solid state devices, components, and controls.

The equipment is principally used in industrial applications for the control, or regulation, or both, of power utilization apparatus, including motors. Such equipment is rated not more than 750 volts DC or 7,200 volts AC.

These devices, components, and controls may be arranged to include one or more feedback loops. Functional elements in such arrangements include, sensors, programmable controllers, operational amplifiers, encoders, tape readers, gauging equipment and computer elements. Computer elements for the readout, logging, processing, and programming input and monitoring output of data may or may not be in the feedback loop. Devices, components and controls so arranged are used in functions such as:

a. Computer control of machines
b. Industrial process regulation
c. Integrated mill control
d. Energy management
e. Emergency and standby power control
f. Control of the cogeneration of electric power

The Industrial Control and Systems Section scope specifically includes, but is not limited to, products principally used to:

a. Start, stop, protect, accelerate, decelerate, reverse, or control the speed of electric motors
b. Automatically disconnect, connect, or transfer all classes of loads fed by primary or alternate power sources
c. Provide some mechanical movement through the action of magnets or solenoids
d. Start, stop and control AC or DC adjustable speed drives, whether unregulated, regulated automatically regulated, including semiconductor power converters and invertors for adjustable speed drives, and providing such functions as: regulating speed, tension, current, frequency and voltage
e. Start, stop and control the function and operation of machine tools, including feedback control and speed, position and torque
f. Start, stop and control the operation of automatic warehouses, including control of conveyors, stackers, and the like
g. Start, stop and control the operation of cranes and hoists
h. Start, stop and control the operation of AC motors applied to fans, pumps, and blowers, including provision for feedback control of speed by sensors such as for temperature, flow, and pressure
i. Control the management of energy under normal and emergency conditions including peak load shaving
j. Control generator equipment used in dispersed power generation systems for cogeneration, emergency, or stand-by electric power

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Also included, but not limited to, are:

a. Motor controllers
b. Motor control centers
c. Medium-voltage controllers
d. Programs and related documentation making up the software that is furnished with programmable devices for industrial control and systems equipment
e. Register and synchronizing controls
f. Digital display devices
g. Analog-digital convertors and transducers
h. Programmable controllers
i. Functional elements of systems, such as:
    1. Operational amplifiers
    2. Computer elements
    3. Encoders
    4. Tape readers
    5. Sensors
    6. Man-machine interface devices
    7. Gaging equipment
j. Renewal parts for Industrial Control and System products

Examples of Industrial Control and System products are:

a. Manual, magnetic and solid-state (static) starters and controllers
b. Relays and contactors
c. Automatic transfer switches and controllers, and associated by-pass isolation switches
d. Drum switches
e. Overload devices intended primarily for the starting and running protection of electric motors, including inherent overload protective devices
f. Rheostats and resistors
g. Autotransformers and reactors of the type principally used in reduced-voltage starters
h. Control-circuit and pilot devices including, but not limited to, timers, pushbuttons, indicating (pilot) lights, solenoids, photoelectric relays, and plugging switches, speed switches, domestic water pump pressure switches
i. Limit, pressure, vacuum, temperature and liquid-level switches
j. AC and DC brakes, clutches, and electrical operators
k. Resistance dimmers, autotransformer dimmers, reactor dimmers, and solid-state (static) dimmer systems
l. Solid-state logic devices
m. Control panels for machine tool and similar machines
n. Terminal blocks of the molded barrier or sectional type and terminal strips used for the connection of conductors, electrical and electronic circuits and equipment. These include, but are not limited to, terminal blocks using, wire binding screws, pressure wire connectors, stud and nut, quick

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connect, solder lug, and solderless wrapped terminations, and terminal blocks which incorporate fuse holders, test/disconnect features, indicator lamps, diodes, etc.

o. Automatically regulated adjustable speed drive systems such as: rolling mill drives, paper mill drives, slasher drives

p. Programmable controllers and their accessories devices used for the supervision, or control or command of industrial machines and processes

Exclusions:

Excluded from the product scope are:

a. Specific components and systems covered by the product scopes of other NEMA sections

b. Automatic and manual temperature and humidity controls and panels that are in the scope of the Residential Controls Section of the types principally used in air conditioning, refrigeration, and comfort heating of nonindustrial areas

c. Motors, generators and motor-generators, which function as control when constituting part of adjustable speed drives

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NEMA STANDARDIZATION BACKGROUND

The purpose of NEMA standards, their classification, and status are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below:

Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process, or procedure with reference to one or more of the following: nomenclature, composition, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 1)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p. 6)

Categories of Standards

National Electrical Manufacturers Association Standards are of three classes, which have received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture.
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development.
3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, pp. 5)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative.

(Standardization Policies and Procedures, pp. 5)

Identification of Status

Standards in NEMA Standards Publications are identified as "NEMA Standard," "Suggested Standard for Future Design," or "Adoptive Standard." These indicate the status of the standard. A statement incorporating the auxiliary verb "shall" indicates that compliance with a requirement is mandatory for compliance with the standard. These classes of standards are identified in the foreword or throughout the text.

The material identified as "Authorized Engineering Information" is designated similarly. Statements incorporating other auxiliary verbs such as "should," "may," etc. refer to the authorized engineering information and not to procedures required for compliance with the standard.

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INDUSTRIAL CONTROL AND SYSTEMS SECTION OF THE NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

ABB Control, Inc.
Wichita Falls, TX 76306

AEG Automation
Systems Corporation
Pittsburgh, PA 15238-0830

Allen-Bradley Company
Milwaukee, WI 53204

Amerace Electronic Components
Punta Gorda, FL 33950

Automatic Switch Company
Florham Park, NJ 07932

Balluff, Inc.
Florence, KY 41042

USD Products
Bussman, Div. of Cooper Ind.
Chicago, IL 60656

CEGELEC Automation Inc.
Macon, GA 31206

Challenger Electrical Equipment Corp.
Raleigh, NC 27609

Eaton Corporation
Cutler Hammer Products
Milwaukee, WI 53216

Electrical Power Systems Inc.
Tulsa, OK 74131

Electro Switch Corporation
Weymouth, MA 02189-2103

Elliott Control Company
Hollister, CA 95024-1329

Emerson Electric Company
Grand Island, NY 14072

Entrelec, Inc.
Irving, TX 75038-4312

Firetrol, Inc.
Cary, NC 27512

Furnas Electric Company
Batavia, IL 60510

GE
Plainville, CT 06062

General Equipment & Manufacturing
Company, Inc.
Louisville, KY 40213

Gettys Corporation
Racine, WI 53404

Giddings & Lewis, Inc.
Fond du Lac, WI 54936-1658

Halmar Robicon Group
Pittsburgh, PA 15239-2982

Harnischfeger Corporation
Milwaukee, WI 53215-1707

Honeywell, Inc.
Ft. Washington, PA 19034

Hubbell Incorporated
Madison, OH 44057

Joslyn Clark Controls, Inc.
Lancaster, SC 29720

Killark-Stahl, Inc.
St. Louis, MO 63115

Klockner Moeller Corporation
Franklin, MA 02038

Lexington Switch & Controls
Madison, OH 44057

Master Controls Systems, Inc.
Lake Bluff, IL 60044

Metron, Inc.
Denver, CO 80223

Micro Switch (Div. of Honeywell)
Freeport, IL 61032

Modicon Inc.
No. Andover, MA 01845

NAMCO Controls
An Acme Cleveland Corporation
Mentor, OH 44060

Omron Electronics, Inc.
Schaumburg, IL 60173

Onan Corporation
Minneapolis, MN 55432

OZ Gedney
Unit of General
Signal Corporation
Brooklyn, NY 11208

Pepperl + Fuchs, Inc.
Twinsburg, OH 44087

Phoenix Contact, Inc.
Harrisburg, PA 17111

Reliance Electric Company
Cleveland, OH 44117

Russelectric, Inc.
Hingham, MA 02043

Siemens Energy & Automation,Inc.
Alpharetta, GA 30201

Siemens Industrial Automation, Inc.
Johnson City, TN 37601

Square D Company
Palatine, IL 60067

R. Stahl, Inc.
Woburn, MA 01801

Texas Instruments, Inc.
Attleboro, MA 02703

Toshiba International Corporation
Houston, TX 77041

Turck, Inc.
Minneapolis, MC 55441-2656

Weidmuller Inc.
Richmond, VA 23236

Westinghouse Electric Corporation
Pittsburgh, PA 15220

Zenith Controls, Incorporated
Chicago, Il 60609

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