

IEEE Std 3001.11™-2017

Recommended Practice for
Application of Controllers and
Automation to Industrial and
Commercial Power Systems



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IEEE Recommended Practice for Application of Controllers and Automation to Industrial and Commercial Power Systems

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Abstract: The selection and application of controllers and automation to industrial and commercial power systems is covered by this recommended practice. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Keywords: automation, building automation system (BAS), contactor, controller, facility automation system (FAS), heater controller, IEEE 3001.11™, industrial controller, motor control, motor control center (MCC), motor controller, motor starter, power controller, starter

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Introduction

This introduction is not part of IEEE Std 3001.11–2017, IEEE Recommended Practice for Application of Controllers and Automation to Industrial and Commercial Power Systems.

IEEE 3000 Standards Collection™

This recommended practice was developed by the Technical Books Coordinating Committee of the Industrial and Commercial Power Systems Department of the Industry Applications Society as part of a project to repackage the popular IEEE Color Books®. The goal of this project is to speed up the revision process, eliminate duplicate material, and facilitate use of modern publishing and distribution technologies.

When this project is completed, the technical material in the 13 IEEE Color Books will be included in a series of new standards—the most significant of which will be a new standard, IEEE Std 3000™, IEEE Recommended Practice for the Engineering of Industrial and Commercial Power Systems. The new standard will cover the fundamentals of planning, design, analysis, construction, installation, startup, operation, and maintenance of electrical systems in industrial and commercial facilities. Approximately 60 additional dot standards, organized into the following categories, will provide in-depth treatment of many of the topics introduced by IEEE Std 3000™:

- Power Systems Design (3001 series)
- Power Systems Analysis (3002 series)
- Power Systems Grounding (3003 series)
- Protection and Coordination (3004 series)
- Emergency, Standby Power, and Energy Management Systems (3005 series)
- Power Systems Reliability (3006 series)
- Power Systems Maintenance, Operations, and Safety (3007 series)

In many cases, the material in a dot standard comes from a particular chapter of a particular IEEE Color Book. In other cases, material from several IEEE Color Books has been combined into a new dot standard.

IEEE Std 3001.11

The material in this recommended practice largely comes from subclauses 10.6 and 10.7 of the *IEEE Red Book*™, IEEE Std 141™-1993, IEEE Recommended Practice for Electric Power Distribution in Industrial Plants, and Chapters 6 and 14 of the *IEEE Grey Book*™, IEEE Std 241™-1990, IEEE Recommended Practice for Electric Power Systems in Commercial Buildings.

This publication provides a recommended practice for the electrical design of commercial and industrial facilities. It is likely to be of greatest value to the power-oriented engineer with limited commercial or industrial plant experience. It can also be an aid to all engineers responsible for the electrical design of commercial and industrial facilities. However, it is not intended as a replacement for the many excellent engineering texts and handbooks commonly in use, nor is it detailed enough to be a design manual. It should be considered a guide and general reference on electrical design for commercial and industrial facilities.

Tables, charts, and other information that have been extracted from codes, standards, and other technical literature are included in this publication. Their inclusion is for illustrative purposes; where technical accuracy is important, the latest version of the referenced document should be consulted to assure use of complete, up-to-date, and accurate information.

Contents

1. Overview.....	9
1.1 Scope.....	9
2. Normative references	9
3. Definitions and acronyms.....	10
3.1 Definitions	10
3.2 Acronyms	11
4. Controllers.....	12
4.1 General discussion.....	12
4.2 Controllers.....	13
4.3 Motor controllers.....	15
4.4 Full-voltage (across-the-line) non-reversing starters.....	20
4.5 Reduced-voltage controllers.....	21
4.6 Wound-rotor motor controllers	27
4.7 Multispeed motor controllers	27
4.8 Single-phase motor starting.....	28
4.9 Controllers for dc motors.....	29
4.10 Adjustable-speed drives (ASDs).....	29
4.11 Controller arrangements	33
4.12 Loads	43
5. Automation.....	49
5.1 Introduction	49
5.2 Relay-based control systems	49
5.3 Microprocessor-based controls.....	50
5.4 Industrial automation.....	50
5.5 Facility automation system (FAS)	51
Annex A (informative) Bibliography.....	84

IEEE Recommended Practice for Application of Controllers and Automation to Industrial and Commercial Power Systems

1. Overview

1.1 Scope

This recommended practice covers the selection and application of controllers and automation to industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

The present edition of this recommended practice focuses on the application of ANSI/NEMA design controllers. There are differences in the design of IEC controllers which require additional application considerations which are beyond the scope of the present edition.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

CSA C22.1, Canadian Electrical Code, Part I (CE Code).¹

IEEE Std 141TM, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (*IEEE Red Book*TM).^{2,3}

IEEE Std 242TM, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (*IEEE Buff Book*TM).

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NEMA ICS 2, Industrial Control and Systems Controllers, Contactors, and Overload Relays Rated 600 Volts.⁴

NEMA ICS 3, Industrial Control and Systems: Medium Voltage Controllers Rated 2001 to 7200 Volts AC.

NFPA 70, National Electrical Code® (NEC®).^{5,6}

3. Definitions and acronyms

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁷

building automation system (BAS): A system that performs the functions of supervision, control, and monitoring of a building.

data transmission medium (DTM): The pathway by which signals are transmitted within a facility automation system.

NOTE—Examples include wire, radio transmission, and fiber-optic links. A combination of several types of DTMs may be used, as appropriate, within the facility automation system.⁸

facility automation system (FAS): A system that performs the functions of supervision, control, and monitoring of a facility.

NOTE—One FAS may incorporate many building automation systems (BASs).

field device: Equipment that receives or transmits a signal, such as controllers, sensors, and relays.

field interface device (FID): A mid-level or lower-level data-processing unit that operates compatibly with the central processing unit (CPU), but generally at a different location.

NOTE—These devices are sometimes referred to as satellite processing units (SPUs), remote terminal devices (RTDs), or slave stations.

intelligent multiplexer (IMUX): A device that combines data from a number of points in the data environment and communicates on a single channel.

human/machine interface (HMI): The displays, keyboards, printers, etc., used to allow a human to monitor or modify the operation of a machine, including a system. *Syn:* man/machine interface (MMI) or operator/machine interface (OMI).

low voltage (LV): Voltages less than 1000 Volts.

NOTE—Refer to 4.2.3 for discussion.

medium voltage (MV): Voltages greater than low voltage, but less than 35 kV.

⁴NEMA publications are available from the National Electrical Manufacturers Association (<http://www.nema.org/>).

⁵NFPA publications are published by the National Fire Protection Association (<http://www.nfpa.org/>).

⁶The electrical installation code is location specific; consult the version authorized by the relevant AHJ.

⁷*IEEE Standards Dictionary Online* subscription is available at: http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

⁸Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

NOTE—Refer to 4.2.3 for discussion.

3.2 Acronyms

AHJ	authority having jurisdiction
AHU	air-handling unit
ASD	adjustable-speed drive
ATC	automatic temperature control
BAS	building automation system
CCTV	closed-circuit television
CMMS	computerized maintenance management system
CPU	central processing unit
DCS	distributed control system
DDC	direct digital control
DGP	data-gathering panel
DTC	data terminal cabinet
DTM	data transmission medium
EMS	energy management system
FAS	facility automation system
FID	field interface device
HMI	human machine interface
HVAC	heating, ventilating, and air conditioning
IMUX	intelligent multiplexer
LAN	local area network
MCC	motor control center
MTTR	mean time to repair
MUX	multiplexer
PID	proportional-integral-derivative
PLC	programmable logic controller
PWM	pulse-width modulation
RTU	remote terminal unit (a component of a SCADA system)
SCADA	supervisory control and data acquisition
UPS	uninterruptible power supply
VDU	video display unit
VFD	variable frequency drive

4. Controllers

4.1 General discussion

A controller⁹, according to the *IEEE Standards Dictionary*, is “a device or group of devices that serves to govern, in some predetermined manner, the electric power delivered to the apparatus to which it is connected.” This definition is essentially the same as is found in the National Electrical Code® (NEC®) and Canadian Electrical Code (CE Code). As such, a controller can be as simple as a manually-operated overload switch mounted on the wall to control a fractional horsepower ventilation fan, or as complex as a variable frequency adjustable-speed drive in a dedicated building, controlling a medium-voltage motor which drives a large compressor. Most industrial loads are motors, so they will be discussed in more detail, but there are other loads in both industrial and commercial facilities which require controllers as well. Electrical heaters are applied for process heating, space heating, and pipe or vessel heating; controllers are required for all of these loads. Lighting is often provided with controllers. Capacitor banks installed for power factor improvement or some other purposes utilize controllers. Other more-specialized loads have specialized controllers associated with them as well. The selection of a controller needs to be based on the electrical and mechanical characteristics of the loads to be controlled. Loads are discussed briefly in 4.11. The majority of motors utilized by industrial facilities are integral horsepower induction motors of squirrel-cage design supplied from distribution systems of three-phase 600 V ac and below. The choice of an integral horsepower motor controller depends on a number of factors:

- a) *Power source.* Does it use dc or ac? Is it single-phase or three-phase? What is the voltage and frequency? Will the system permit large inrush currents during full voltage starting without excessive voltage drop?
- b) *Motor.* Is the controller to be used with dc, squirrel-cage induction, wound-rotor induction, synchronous motor, or adjustable frequency drives? What is the horsepower? Will the motor be jogged or reversed frequently? What is the acceleration time from start to full speed? Will the motor design specify reduced current inrush?
- c) *Driven load.* Is the load geared, belt-driven, or direct-coupled? Loaded or unloaded start? Is it either necessary or desirable to vary the speed of the load?
- d) *Operation.* Is operation to be manual or automatic? What control interfaces are required?
- e) *Protection.* Motor protection is very generally considered to have two separate components: short-circuit and overload protection. Are fuses or circuit protectors to be used for short-circuit protection? To size the elements of motor overload relays, the full-load current of the motor, the ambient temperature at the motor and controller, and the service factor of the motor should be known.
- f) *Environment.* Will either the motor or the controller be subjected to excessive vibration, dirt, dust, oil, or water? Will either be located in a hazardous or corrosive area? What type of enclosure is required?
- g) *Cable connections and space.* Will there be the required space for cable entrance, bending radius, terminations, and for reliable connections to line and load buses? Will capacitors be installed at either the motor terminal box or the controller for power factor improvement¹⁰? Will surge-protective equipment, surge arresters, and capacitors be installed at the motor terminal box? Will current transformers for motor differential protection be installed at the motor terminal box?

To answer these questions for the proper application of motor controllers, the specifying engineer should seek the assistance of the application engineers from the power supply utility and the manufacturers. In addition, process engineers and operating personnel associated with the installation should be consulted. The proper

⁹The term *controller* is also used in process control applications as “a device that operates automatically to regulate a controlled variable in response to a command and a feedback signal.” (*IEEE Standards Dictionary*). While in a very general manner this device is often included in automation (Clause 5), it is not the focus of IEEE Std 3001.11.

¹⁰KVAR ratings of power factor improvement capacitors, located either on individual motors or in banks should be selected with care to avoid the possibility of overvoltages caused by motor self-excitation. Refer to IEEE Std 141, Chapter 8, for more information.

application of a controller to a load requires consideration of the load, the controller, and the power system the controller is connected to.

4.2 Controllers

4.2.1 General

Controllers in general are usually, but not always, specially designed for the load to be controlled. Manually-operated motor controllers are essentially a manual switch of some form, with an integrated overload component.¹¹ All other motor controllers are electrically operated. Motor controllers which do not require adjustable speed operation generally utilize contactors for the control element, unless they are so large that contactors are not available, in which case general purpose circuit breakers are used. Contactors are electro-mechanical switching devices that are available in electrically-held and mechanically-held models. Electrically-held models are the most commonly applied; mechanically-held models are preferred for applications where the dropout of the contactor upon loss of supply voltage is disadvantageous. Contactors have much higher mechanical endurance ratings than other types of switching devices, with some published ratings stated in millions of operations.

Fixed-speed motor controllers are available in a wide variety of configurations, depending on voltage, motor-starting considerations, and motor winding details. The common configurations are discussed below. Fixed-speed motor controllers¹² are often called *motor starters*. Controllers for non-motor loads are also available. Any application of a controller to a load requires consideration of the characteristics of that load. Some comments are made under the discussion of load characteristics in 4.11.

Power can be provided to a mechanical load at adjustable speed by electrical or mechanical means. Electrical adjustable-speed drives are available in a wide variety of ratings and configurations which appear to be continuously increasing. In some situations, a mechanical adjustable speed mechanism will be utilized in the form of a fluid coupling or a hydraulic pump/hydraulic motor combination.

4.2.2 Disconnects

A controller requires a means of isolation from the power-distribution system for the purpose of servicing and maintaining the controller more safely. Almost any switching device can be used as a disconnect. It is common to combine the function of short-circuit protection into the disconnect device through the use of instantaneous-trip circuit breakers or fusible switches. In facilities where the NEC applies, the disconnecting means for a motor branch circuit must comply with Article 430, Part IX. Disconnects are generally marked with continuous current ratings, but may also be marked with a horsepower rating.

Besides providing isolation at the controller, additional disconnects may be required local to the load to provide a disconnecting means for the load that can be more closely monitored by the servicing personnel should the load be located out of sight of its controller. These requirements are specified in the NEC and CE Code.

4.2.3 Voltage considerations

While most applications will involve controllers at the same nominal voltage as the connected load, there are situations where a controller will be provided at a different voltage from the load, with a suitable voltage transformation means provided between the two. While this transformation is usually in the form of a power transformer, this may in some applications be accomplished with a solid-state drive.

¹¹Some special motor designs, typically very small fractional horsepower motors, do not require external overload protection.

¹²Discrete multiple-speed motor controllers, such as two-speed controllers, are typically also included in the term *motor starters* in common usage in North America.

In general, controllers are classified in accordance with the installation code (NEC or CE Code) designations of low voltage or high voltage. Low voltage in these codes is defined as anything less than 1000 V¹³, and high voltage as anything higher than low voltage. In most industrial and commercial facilities, the voltage level above 1000 V is informally called *medium voltage* to distinguish from the common power transmission system voltages and the outdoor pole- or structure-mounted equipment commonly employed at those voltages. This standard applies the term *medium voltage* to voltages between 1 kV and 35 kV. Note that some standards, for example the IEEE C37 breaker standards, include this definition of medium voltage under the term *high voltage*, in compliance with the installation code usage. ANSI C84.1 defines medium voltage as greater than 1000 V and less than 100 kV; some IEEE standards (including IEEE Std 141™) follow this practice. However, there is a tendency in some newer IEEE standards to adopt either 34.5 kV or 35 kV as the upper limit of medium voltage. There is presently no consensus in a definition of medium voltage, as noted in the *IEEE Standards Dictionary*.

4.2.4 Medium-voltage controllers

Controllers are routinely available for system voltages from 1500 V ac to 7200 V ac. At present, there is a limited availability of 13.8 kV controllers; work is progressing on extending the certification standard to include 15 kV rated controllers. There is a tri-national certification listing standard (CSA C22.2 No. 253 [B15], NMX-J-564/106-ANCE [B86], UL 347 [B92]) for this equipment, which supersedes NEMA ICS 3 which was previously the key reference standard.

Two types of controllers are generally available:

- a) Class E1 controllers utilize the main contactor to make and break currents up to the rated breaking capacity of the controller. In contrast to Class E2 controllers, the fault interrupting capacity of a Class E1 controller depends on the capacity of the main contactor, which is much smaller than a power fuse.
- b) Class E2 controllers utilize the main contactor to make and break operating currents, and utilize medium-voltage fuses to interrupt fault currents which exceed the breaking capacity of the main contactor. E2 controllers provide an interrupting fault capacity of 40 kA or 50 kA rms symmetrical, depending on the power fuse used.

A medium-voltage contactor is designed differently from a medium-voltage circuit breaker. The circuit breaker is designed to interrupt a rated (high) fault current, but is not expected to do it thousands of times in its life, while a contactor is designed to interrupt a much lower operating current, but it is expected to do this for many thousands of operations. In applying medium-voltage contactors, it is important to coordinate the protection relay settings with the fuse characteristics and the contactor rated interrupting current. Some situations where this may be a consideration are motor overcurrent (50/51), motor differential current (87M), and ground fault (50/51G) elements.

Additionally, while all the vacuum interrupters (which predominate in new installations) exhibit a current chopping phenomena, the vacuum contactor is designed to have a low chopping current while, due to the more severe fault interrupting duty, a vacuum circuit breaker will have a higher chopping current. This chopping current is important in determining what additional surge protection may be required for controlled motors. For motors too large for any available contactor, where circuit breakers need to be employed, this becomes an important application consideration. For additional information regarding the application of circuit breakers in industrial and commercial applications, refer to IEEE Std 3001.5™ [B38].

Starters for medium-voltage motors are designed as integrated complete units based on maximum horsepower ratings for use with squirrel-cage, wound-rotor, synchronous, and multispeed motors for full- or reduced-voltage starting. Class E2 controllers are normally used. Each starter will be completely self-contained and pre-wired by the vendor, with all components in place. Contactors will be current rated based on motor horse-

¹³Some certification standards commonly used for low-voltage controllers are limited to 600 V ac and 1000 V dc. The installation codes variously define low voltage as below 750 V ac to 1500 V ac.

power requirements. Combinations of motor starters and switchgear are available as assemblies. Starters are available with air-break contactors or vacuum contactors; vacuum contactors predominate in current vendor offerings. While most medium-voltage motor controllers are “across-the-line” types, other starting schemes are available. While the general information on motor-starting schemes in this standard is based on low-voltage designs and standards, it is adaptable to medium-voltage systems when required.

4.2.5 Low-voltage controllers

NEMA ICS 2 summarizes the NEMA standard for low-voltage magnetic controllers. The related certification standard is a tri-national standard (CSA C22.2.No. 254 [B16], NMX-J-353-ANCE-2006 [B85], UL 845 [B93]).

In low-voltage ac motor starters, contactors are generally used for controlling the circuit to the motor. Contactors should be carefully applied on circuits and in combination with associated short-circuit protective devices (circuit breakers, motor circuit protectors, or fusible disconnects) that will limit the available fault current and the let-through energy to a level the contactor can withstand. These withstand ratings should be in accordance with the certification standards.

Unlike medium-voltage controllers where vacuum interrupters predominate, most low-voltage controllers employ air-break contactors. Some vacuum contactors are available, and are sometimes used for higher power rated controllers, often due to the large physical size of the higher current rated air-break contactors.

A variety of specialty controllers is available for low-voltage non-motor loads.

4.3 Motor controllers

4.3.1 Introduction

The primary function of a motor controller is starting, stopping, and protecting the motor that it serves. In some applications, motor controllers are additionally required to control the speed of the motor, or to facilitate rapid stopping (braking) of the motor. The type of controller used depends upon the motor size and type, the distribution system, any limitations imposed by the local power source, and the desired control functions or operations.

In a typical three-phase ac motor controller, a magnetically-operated contactor connects the motor to the power source. This contactor is designed for a large number of repetitive operations in contrast with the typical circuit breaker. Energizing the contactor’s operating coil with a small amount of control power causes it to close its contacts, connecting each line of the motor to the power supply. If the starter is to be reversing, two contactors, one forward and one reverse, are used to connect the motor with the necessary phase relation for the desired shaft rotation.

4.3.2 Physical protection

The controllers themselves are protected from physical damage, as opposed to electrical damage, by the controller enclosure. NEMA standards ICS 6 [B69] and 250 [B62] cover the classification of enclosures and their associated degree of protection. For example, a NEMA 1 (general purpose indoor) enclosure would be used in dry indoor locations. A NEMA 3R (rainproof and sleet-resistant) or 4 X (watertight, dust-tight, and corrosion resistant) enclosures is typically used outdoors. Sprinkler-resistant enclosures are available for installation in areas serviced by fire-suppression sprinklers. Special enclosures are listed for installation in hazardous locations as defined by NEC sections 500 and 505 or CE Code sections 18, 20, J18, or J20.

4.3.3 Overload protection

An overload is an operating condition where the full-load ratings or ampacities of a motor are exceeded. It is not a short-circuit or fault current condition. A running overload is an overcurrent greater than the rated maxi-

imum running current, but no greater than the locked-rotor current, which is commonly 6.5 times the full-load motor current¹⁴. If the situation continues for too long a time period, damage due to overheating can result. Motor life can be shortened due to heating. Overloads cause a rise in the temperature in the motor windings due to the higher than normal current. This increased temperature causes damage and deterioration to the winding insulation.

Motors are required to be protected against overloads by the NEC and CE Code. NEC Article 430¹⁵, Part III gives the requirements for motor and branch circuit overload protection for motors of less than 600 V. The various requirements for overload protection are based upon motor duty, horsepower, and type. NEC Table 430.37 gives the number and location of overloads required for various types of motor and supply system combinations. Under certain conditions, the motor overloads are permitted to be shunted during motor starting; see NEC section 430.35.

Motor overload protection is typically provided by overload relays. Overload relays can be thermal, magnetic, or solid-state type, and have inverse time-overcurrent tripping characteristics to allow for starting inrush current or momentary overloads. This means that for small overcurrents, a longer time will elapse before tripping occurs. At high overcurrents (locked-rotor current) tripping occurs in a shorter time period.

In the case of magnetic relays a dashpot is used to provide the time delay. For thermal relays, the time-current characteristic is derived from the response of components of the relay to heat generated by a thermal element that simulates the heating of the motor windings due to line current. Thermal overloads can be either melting alloy (eutectic) or bimetallic type. Some old installations rely on fuses for overload as well as short-circuit protection; the fuse used in such applications needs to be examined very carefully to confirm it will interrupt reliably on overload conditions. Many motor fuses, such as the medium-voltage “R” rated fuses used in many modern medium-voltage motor starters, are ONLY suitable for short-circuit protection and are NOT suitable for overload protection.

Solid-state overload relays sense motor currents, transform them into logic level signals, and process these signals to simulate motor thermal (I^2t) models. Solid-state relays approximate the motor damage curve more closely than either the thermal or magnetic types. Some of these relays offer field selectability for overload class (or curve), and communication capabilities for centralized control or monitoring. Solid-state overload relays permit field adjustment of overload settings, thereby eliminating the need for individual heater elements calibrated to specific motor currents. Some overload relays provide for stator winding overtemperature protection based on embedded detectors, which typically are thermistors for low-voltage motors and RTDs for medium-voltage motors.

Solid-state overload relays for medium-voltage motors are available with many standard and optional motor-protective functions in a singular modular unit, which permit precise protection of motors and allow motors to be utilized very close to their ratings. Protective functions generally available in these electronic relays are inverse time overload protection, instantaneous overcurrent protection, stator winding overtemperature protection based on resistance temperature detectors (RTDs) embedded in stator windings, motor bearing overtemperature protection based on RTDs placed at motor bearings, load bearing over-temperature protection based on RTDs at load bearings, undercurrent protection, underload protection, phase reversal protection, and incomplete sequence protection. Some modern electronic relays provide many more sophisticated protection and monitoring features as well, plus programmable control logic capabilities.

The rating or setting of these units is determined by the full-load motor current and the motor controller used. Relays need to be reset after operation or “tripping.” This can be done manually through a reset button on the controller, or it can be done automatically. Automatic resetting is not permitted where restarting the motor

¹⁴Some standards still refer to locked-rotor current as 6.0 times full-load current, but this ratio increases in most modern high-efficiency motors. A compromise position adopted by many industrial users is to limit new motors to a locked-rotor ratio of 6.5 in specifying new motors. If this is not done, the default offering, especially in small integral horsepower NEMA design motors, will generally have a locked-rotor ratio substantially in excess of 6.5, which should be considered when applying controllers to those motors.

¹⁵The equivalent CE Code material is in section 28.

would place the operator or other personnel in danger. Ambient temperature compensated and noncompensated overload relays are also available. There are basically two types of applications for ambient compensated relays. The first is where the ambient compensation mechanism is utilized to provide for appropriate trip characteristics over a wide range of ambient temperature. These are intended for general use. The other application is where the controller is in a controlled environment, and the motor is in a non-controlled environment (for example, submersible pumps). In applications where the motor and controller are in the same environment, it is not advisable to use ambient compensated overload relays because the protected device (motor, cable) is not ambient compensated.

A motor damage curve shows how long a particular overcurrent can be sustained before the motor is damaged. Devices are available that react to motor overload, phase loss, phase reversal, mechanical jam, ground fault, current unbalance, voltage unbalance, low-voltage conditions, and more. The response time can be changed to fit the application. Solid-state devices can be combined with motor temperature sensors, such as thermistors (typically LV motors) or RTDs (typically MV motors). Memory can be provided if motor starts or overloads happen frequently.

NEMA standards divide overload relays into three classes: Class 10, 20, and 30. Some electronic controllers incorporate all three classes, and sometimes additional interpolations of these classes, in one device. Each class is defined by the maximum time in seconds in which the relay should function on six times its ultimate trip current (1.25 times full-load motor current for motors having a service factor of 1.15; and 1.15 times full-load motor current for motors having a service factor of 1.0). No minimum trip time is standard. Overload relays should have sufficient thermal capacity to allow the motor to start. The type of overload relays to be used on a particular application depends upon required reliability, type of load, ambient conditions, motor type and size, safety factors, acceleration time, and probability of an overload.

4.3.4 Overcurrent protection

Overcurrent protection is required to protect motors, and their branch circuits and controllers, from short circuits or ground faults. Overcurrent conditions due to faults can cause damage to motors, controllers, and conductors. NEC Article 430, Part III covers the requirements for overcurrent protection for motors under 600 V. While the overcurrent protection of a controller protects both the conductors and the load, protection of the conductor is not part of the scope of this standard. Refer to IEEE Std 242™, Chapter 9.

Overcurrent protection can be provided by circuit breakers, motor circuit protectors, or fuses. Traditional low-voltage molded case circuit breakers are referred to as thermal-magnetic circuit breakers; they have both a thermal tripping element and a magnetic tripping element. The thermal element provides an inverse time-current characteristic while the magnetic element provides instantaneous tripping. Motor circuit protectors are typically adjustable instantaneous-trip circuit breakers that have a magnetic element only. Fuses have an internal element that melts under overcurrent conditions. By varying the type of internal construction and materials, fuses can be either fast-acting or time-delay types. Time-delay fuses provide both short-circuit and backup overload protection for the motor, if they are sized correctly. Time-delay fuses are typically a dual element type of fuse, but some manufacturers utilize other fuse construction types. Special purpose motor fuses (prevalent for medium-voltage motor starters) are designed for good short-circuit interrupting characteristics, but are not designed for motor overload protection¹⁶. Fuses have to be replaced after operation while circuit breakers only need to be reset, provided they operated on an overload condition. If a circuit breaker operates under a short-circuit condition, which is typical when used for motor branch circuit, short-circuit, and ground fault protection, the fault condition should first be repaired before resetting the circuit breaker. If the fault was near the interrupting capability of the circuit breaker, the circuit breaker should be inspected, tested, and replaced if needed. The devices used to provide the overcurrent protection require a time-current characteristic that is

¹⁶Some fuses explicitly caution that they may fail at currents greater than their rated operating current but less than a specified higher current. If there is no specific guidance from the fuse manufacturer, but the provided fuse time-current curve does not extend into the long time region, (often as low as 100 s), it is prudent to assume that the fuse operation in the motor running overload region is either unpredictable or undefined and should be avoided.

capable of carrying the motor's starting current, and of operating under fault conditions. NEC Table 430.52 gives the maximum allowable ratings for various types of motor short-circuit protective devices.

When circuit breakers are used to provide motor overcurrent protection, there are two key considerations: the motor locked-rotor current, and the motor inrush current, which exceeds locked-rotor current for a very short time but can cause some circuit breakers to trip. IEEE Std 242 and NEMA MG-1 [B76] indicate that this inrush current in some cases can be as high as 2.83 times locked-rotor current, although 1.76 times locked-rotor current is traditionally used for industrial designs. Refer to IEEE Std 242, IEEE Std 3004.8™ [B39], and NEMA MG-1 for additional information.

Another consideration in low-voltage motor protection is that of Type 1 versus Type 2 protection. These are two levels of protection that are defined by the International Electrotechnical Commission (IEC). They pertain to the amount of damage the controller is allowed to sustain due to a fault. Under both Types 1 and 2, there is to be no significant damage to the equipment. In Type 1 protection the controller may be damaged to the point that components, or the entire controller, need to be replaced. Under Type 2 protection, only minimal damage to the contactor and controller, in the form of light contact welding, is allowed. The controller is to be operational after fuse replacement and contact separation. No parts are allowed to be replaced except the fuses. Type 2 protection is used where minimal downtime of a process or operation is required after a fault. Type 2 protection can be achieved with both NEMA and IEC products.

Overload and overcurrent protection requirements for motors over 600 V are covered in NEC Article 430, Part XI¹⁷. For fire pumps, some of the requirements of NEC 430 are modified. NEC Article 695 and NFPA 20 [B81] cover fire pumps. NEC Article 440 has requirements that are specific to hermetic type motors for air conditioning and refrigeration equipment. These requirements are in addition to, or modify some of, the requirements in NEC Article 430.

4.3.5 Equipment protection (single phase, undervoltage, and other)

Motors may also need to be protected from adverse conditions other than overloads and overcurrents. Some of these conditions are under/overvoltages, phase reversal, and phase loss. Relays or other devices are available to provide this protection and can be added to the motor controller.

Small voltage unbalances can cause very high currents in the rotor circuit. The condition is even more severe if a three-phase motor runs on a single-phase supply (loss of one phase). Full-load speed reduces slightly when operated at unbalanced voltages. Additionally, locked-rotor and breakdown torques decrease when the voltage is unbalanced. Line monitoring relays sense and react to voltages that are higher or lower than the motor's normal operating range, but voltage magnitude monitoring does not generally detect a loss of phase on a running motor circuit. Undervoltage can result in overheating and reduced torque. A current imbalance can also result in nuisance tripping of the overloads or circuit protective device. Refer to NEMA MG-1 [B76], IEEE Std 3004.8 [B39], and IEEE Std 242 for additional information.

When a three-phase motor is started from a de-energized state with voltage on only two of the three phases, the motor should not be expected to turn, although current will flow in the windings that is substantially higher than rated motor full-load current. This creates more heat than a stalled motor is designed to dissipate. Where this event is a significant risk, protection should be provided unless replacement of a failed motor is deemed an acceptable mitigation approach. This could be especially dangerous for elevators, where motor replacement is neither trivial nor inexpensive. Suitable phase failure relays and single-phase protection can be provided to protect the motor in these situations.

When motors are transferred from one source to another, for example, from an emergency generator to the utility, both the motor controller and the motor are often momentarily de-energized. If the utility voltage is out of phase with the motor residual voltage when the motor is reconnected to the utility source, the motor will often

¹⁷Refer to CE Code section 28. CE Code section 36 provides additional "high voltage" rules, but none are specific to motors.

draw excessive current and generate high-transient torques that may cause nuisance tripping of breakers and possibly cause damage to the motor, portions of the power-distribution system, the driven equipment, the coupling to the driven equipment, or the foundation. To overcome this problem, automatic transfer switches often include optional in-phase monitors that prevent transfer until the residual voltage of the motor and the utility voltage are nearly synchronized, or alternately delay transfer until the residual voltage has decayed to a safer level. Phase reversal protection can be added to prevent the motor from operating if the phases are reversed. For applicability to medium-voltage motors, refer to the IEEE PSRC working group J9 report to the Rotating Machinery Protection Subcommittee [B43]. This report contains an extensive bibliography, in addition to providing an excellent discussion of the issues involved. The accepted criteria for safe motor bus transfer has recently been questioned by Beckwith, et al. [B10], based on field data. This is a subject of ongoing research and proposed papers which are not yet written. The user is advised to look for revisions or follow-up documents to [B43] and [B10] for possible additional guidance. The user is also cautioned that while not explicitly stated, the practical criteria for bus transfer of low-voltage motors appear to be different from that for medium-voltage motors.

In addition, ground-fault relays are sometimes used for disconnecting motors in the case of a ground fault in the motor winding or its branch circuit.

In many cases, motors have temperature sensors that are placed in the winding of the motor. These protectors are sensitive to the motor winding temperature itself, to the rate-of-rise of the temperature, or to a combination of these. These sensors commonly range from a simple embedded bi-metallic switch to thermistors (large low-voltage motors) to RTDs (many medium-voltage motors). This is discussed in IEEE Std 242 and IEEE Std 3004.8 [B39].

Other equipment protection controls include vibration of the motor and/or the driven equipment, and equipment control and safety interlocking and shutdown systems.

4.3.6 General motor-starting considerations

When electric motors are started, there is a large inrush current that can cause excessive voltage sags or dips. A sag is defined in IEEE Std 1100™ as “an RMS reduction in the ac voltage, at the power frequency, for durations from a half-cycle to a few seconds.” These sags can have a negative impact on other electrical items such as lights, electronic equipment, contactors and relays, and heavily loaded motors; refer to IEEE Std 141 and IEEE Std 1100 [B35] for more information. For guidance regarding motor-starting calculations refer to IEEE Std 399™ [B27], Chapter 9.

Voltage sags in power systems can lead to flicker in incandescent lamps and cause high intensity discharge (HID) lamps to cut off. HID fixtures may then have to cool before restriking of the lamp is possible. Lumen output also decreases as voltage decreases. Voltage sags can affect computers or other low-voltage susceptible equipment.

The starting characteristics of a motor and its load may create a voltage sag that prevents the motor from starting successfully. A large sag can cause the opening of magnetic motor contactors and control relays. If the voltage is low enough, the coil will be unable to keep the contacts closed and the motor will stop. During starting, too low a voltage will result in “contact chatter,” where the contacts open and close quickly because the coil doesn’t have enough power to stay closed. NEMA standards only require that contactors stay closed down to 0.85 pu (per unit) of normal voltage. At voltages lower than this, contactor performance may be affected. Often, control equipment will be sensitive to less severe voltage sags.

Large voltage sags can also cause heavily loaded running motors to stall. As a rule of thumb, typical NEMA design motors that are not overloaded should not stall at motor terminal voltages greater than 80% of motor rated voltage. If this may be an issue, a detailed dynamic analysis is needed.

For any manual motor starter, the motor will automatically restart upon return of power. Manual motor starters should not be used where automatic restarting of the motor could endanger personnel or equipment.

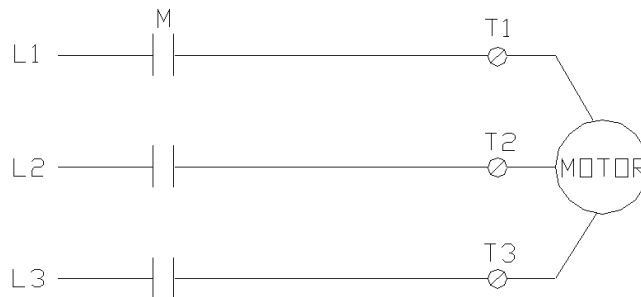
In many applications, a number of safety or operating interlocks are required to ensure that appropriate safety or operability conditions are met prior to attempting to start a motor. See also [Clause 5](#).

4.4 Full-voltage (across-the-line) non-reversing starters

4.4.1 General

[Figure 1](#) shows a typical full-voltage, or “across-the-line,” non-reversing motor-starting configuration. Common variations are:

- a) *Manual.* Provides overload protection, but not undervoltage protection. Controllers are commonly available for single-phase and three-phase motors no larger than 7.5 kW (10 hp) at 460 V or 575 V, for example. Operating controls are commonly available in toggle, rocker, or push-button design.
- b) *Magnetic, non-reversing.* For full-voltage frequent starting of ac motors, suitable for automatic or remote control with push-button station, control switch, or with automatic pilot devices. Undervoltage protection is obtained by using a momentary contact starting push-button in parallel with an interlock contact in the starter and a series-connected stop push button ([Figure 8](#)). For further discussion regarding controls refer to 4.10.12. Available in single-phase construction up to 11.2 kW (15 hp) at 230 V, and three-phase ratings up to 1200 kW (1600 hp) at 460 V or 575 V.



STARTING CONDITIONS:

1. MOTOR TERMINALS VOLTAGE EQUALS THE LINE VOLTAGE.
2. MOTOR CURRENT SHALL BE EQUAL TO THE LINE CURRENT.
3. STARTING TORQUE SHALL BE EQUAL TO LOCKED ROTOR TORQUE.

Figure 1—Across-the-line starting

4.4.2 Combination across-the-line starters

The combination starter adds short-circuit (“overcurrent”) protection (refer to [4.3.4](#)) and a disconnecting means to the basic starters described above.

4.4.3 Reversing starters

A reversing starter has an extra contactor that is interlocked with the forward starter to prevent both units from being operated at the same time. The reversing contactor reconnects two of the motor line connections, causing the motor to rotate in the opposite direction. Reversing is available for full-voltage and multispeed starters only. Reduced-voltage starters are not readily available with reversing capabilities.

4.5 Reduced-voltage controllers

4.5.1 General

For some applications, such as ventilating fans or small pumps, full-voltage starting is not objectionable. As a result, most of these controllers are full-voltage types. However for many larger motors, the starting inrush current may be great enough to cause objectionable voltage sags. Some couplings or driven equipment also have limitations on the torque that may be applied without damage. Sometimes the torque limitation comes from a process constraint (e.g., controlling pipeline pressure pulsations on startup). Such maximum torque limits may require reduced-voltage starting. In other applications, sudden abrupt starts and stops may be hazardous, such as in an elevator, or can cause damage to other items, such as bottles on a bottling line. Some form of reduced-voltage controller should be used in these instances. Some of the benefits of reduced-voltage starting are decreased starting torque, allowing longer life of belts, gears, couplings, pulleys, and motor shafts (which are commonly weakened with across-the-line starting) and decreased inrush current, resulting in smaller voltage sags. However, the user needs to confirm that enough torque is available with the selected controller to successfully accelerate the load. IEEE Std 399 [B27] Chapter 9 provides guidance in performing motor-starting studies.

Objectionable voltage sags are in general of two types. The first is any voltage sag which may cause unacceptable operational issues with the facility. This can include:

- Some lights dimming when certain motors are started
- Controls mis-operating when some motors are started
- Some operating motors stalling due to undervoltage when other motors are started

The other general type of objectionable voltage sag is one that is not acceptable to the local power supply authority. Details vary with different supply authorities. Additional guidance regarding voltage issues is provided in IEEE Std 141 Chapter 3.

Many kinds of reduced-voltage controllers are in common use. These controllers can be divided into the electromechanical types and the solid-state controller types. Figure 2 through Figure 5 show the principles of the most common electromechanical reduced-voltage starters for squirrel-cage motors. Figure 6 shows a solid-state reduced-voltage controller. Table 1 provides comparisons between the various types of electromechanical reduced-voltage controllers.

In selecting the type of reduced-voltage controller, consideration should be given to the motor control transition from starting to running. In a closed-circuit transition, power to the motor is not interrupted during the starting sequence, whereas on open-circuit transition it is interrupted. Closed-circuit transition is recommended for all applications to minimize inrush voltage disturbances and associated phenomena.

Many reduced-voltage controllers are rated for short time operation only, on the basis that these devices are only intended for motor starting, which is of a short duration. Sixty second and 90 s ratings are common. After the rated time, these controllers must be bypassed and not carrying current, to allow their components to cool. Applications which may benefit from operating at reduced voltage for a longer time, including continuously, need to be examined carefully to ensure the equipment selected is suitable for this service.

4.5.2 Autotransformer type

An autotransformer starter (Figure 2) is a reduced-voltage controller that uses three contactors, a timer, and an autotransformer. It has characteristics that are similar to, but more efficient than, the resistor-reactor starter (Figure 2). An autotransformer controller reduces the voltage by transformation; the motor terminal voltage is less than the line voltage by the transformer ratio. The torque is reduced by the square of the terminal voltage. For motors up to 37 kW (50 hp), autotransformer starters usually have taps for 65% and 80% of rated voltage.

For larger motors, the taps are for 50%, 65%, and 80% of rated voltage. The torque of the motor does not increase with acceleration, but remains essentially constant until the transfer is made from starting to running voltage.

Closed transition starters are usually standard. In a closed transition (also known as the Korndorfer connection), a smooth transition from reduced to full voltage is made. The motor is not disconnected from the line so there is no interruption in line current, which can cause a second inrush during the transition time. In an open transition starter, the motor is momentarily disconnected from the line on transfer from the starting connection to the run connection. This open transition may result in some voltage disturbance. Standard motors can be used with autotransformer starters. The automatic version of an autotransformer starter, which is the most common, has a timing relay, speed relay, current relay, or other mechanism for adjustment of the time at which full voltage is applied.

There is an additional consideration when the controller (usually a contactor) is either a vacuum or SF_6 interrupter. While modern vacuum contactors have a very low chopping current, such circuits have been reported to consistently result in substantial damage to autotransformers (Farr, et al., [B20]). This can in part be attributed to the extremely short conductors interconnecting the interrupters with the autotransformers. While this is predominantly considered a medium-voltage phenomena, it should be considered for a low-voltage vacuum contactor design as well. As a minimum, when such designs are contemplated, provision should be made in the starter for installation of snubbers, which must be designed by a specialist later when detailed characteristics of the components including the autotransformer become available. Refer also to IEEE Std C57.142™ [B41].

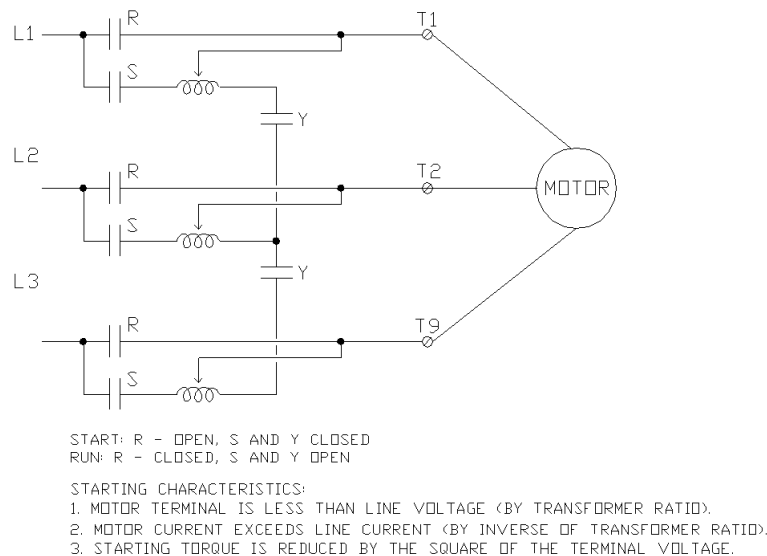


Figure 2—Autotransformer reduced-voltage starting

Autotransformer starters are suitable for hard-to-start loads such as reciprocating compressors, grinding mills and pumps. “Hard-to-start” loads are those where the motor has to overcome a large inertia to get the load started. They are used where complete acceleration at reduced current is needed. An autotransformer starter offers the greatest amount of flexibility and is the most expensive of the electromechanical reduced-voltage starters.

4.5.3 Primary resistor or reactor type

This is the simplest reduced-voltage starting method. It uses two contactors, a timer, and either a resistor or a reactor (see Figure 3). The voltage at the motor terminals is reduced by the voltage drop across the reactor or

resistor. The inrush current is reduced proportionately (approximately). When the motor has accelerated for a predetermined interval, a timer initiates the closing of a second contactor to short the primary resistor or reactor, connecting the motor to the full line voltage. The transition from starting to running is smooth since the motor is not disconnected during this transition. The starting torque is a function of the square of the terminal voltage. Therefore, if the initial voltage is reduced to 50%, the starting torque of the motor will be about 25% of its full-voltage starting torque. Resistor/reactor starters can be used with standard motors. Typical allowable starting times are 5 s for resistor types and 15 s for reactor types.

A three-step resistor-type starter usually does not start rotating the motor until the end of the first step. At the second step, the starting torque is 45% to 50% of normal starting torque. The time setting is also usually between 3 s and 4 s. The branch-circuit protection is the same as for full-voltage starters.

Reactor-type reduced-voltage starters have somewhat better torque speed characteristics than resistor-type starters; but resistor-type starters are less expensive. Resistor-type starters have the disadvantage that the wattage dissipation during start up can be costly for large motors that are started frequently. For this reason, resistor-type starters are not often used with large motors. Reactor-type reduced-voltage starters are difficult to adjust however, and are generally only used for larger medium-voltage motors. Typical applications are where current reduction requirements are low, or where torque during acceleration is minimal. These starters have smoother acceleration relative to the other types of starters. Where reactors are switched by either vacuum or SF₆ interrupters, there are additional considerations, similar to the switching of an autotransformer by these controllers. See 4.5.2.

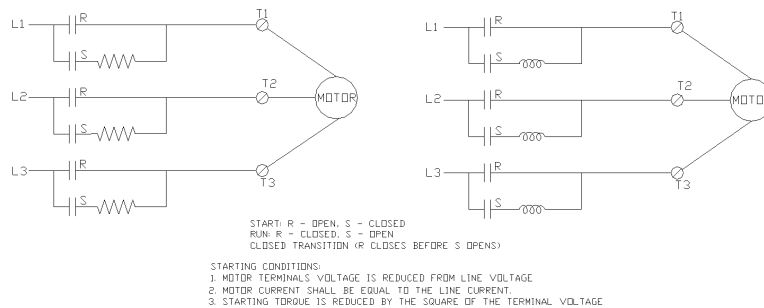


Figure 3—Series resistance and reactance reduced-voltage starting

4.5.4 Part-winding type

This type of starting connects part of the winding to the supply lines for the first step, and then connects the balance in an additional step to complete the acceleration. Typically, the motor has two equal windings, but $\frac{2}{3}$ windings are also available. The inrush current drawn from the line is about 65% of the normal inrush current. The starting torque is about 50% of the full-voltage starting torque. These numbers will vary depending upon the motor and the winding percentages. The total starting time should be set for about 2 s to 4 s. Due to severe torque dip during the transfer, the transition time should be short and at approximately half-speed.

Part-winding starting is suited to light starting (low torque) loads such as fans, blowers, motor-generator sets, and compressors with relief or unloading valves. While a part-winding starter is relatively inexpensive, the motor cost will be higher than for a normal squirrel-cage motor. Its smoothness of acceleration and application flexibility are poor.

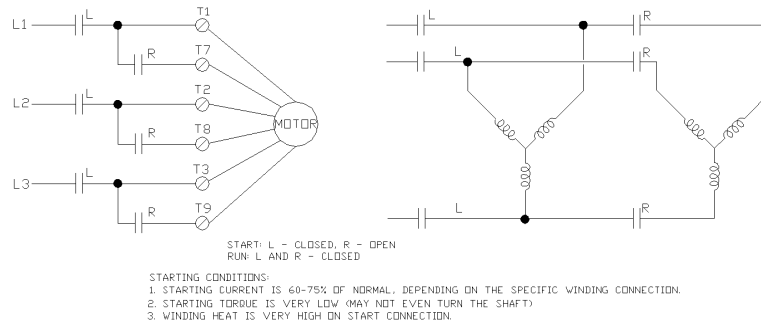
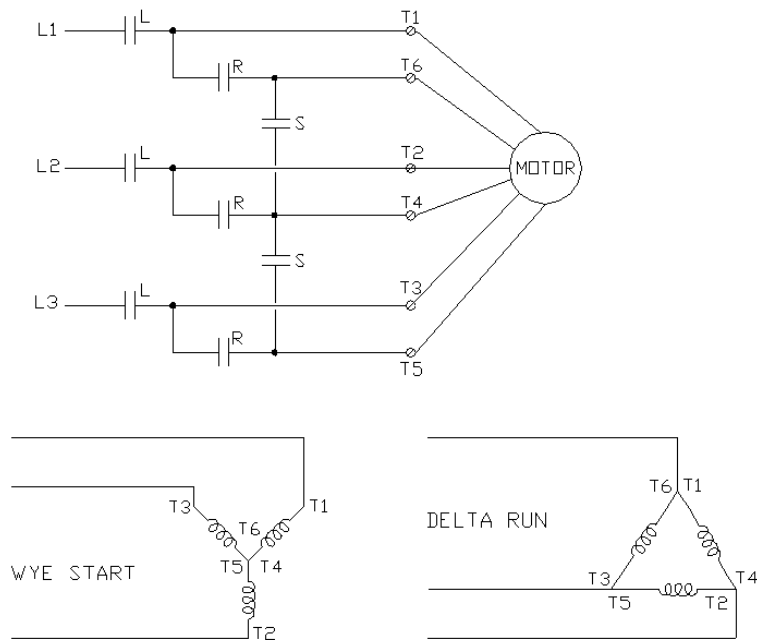


Figure 4—Part-winding starting

4.5.5 Wye-delta type

In a wye-delta starter (also known as star-delta), the motor's internal connections are changed. They are wye connected for starting and delta connected for running. This causes the impedance seen for starting to be three times that for running, reducing the starting current. Starting current and torque are approximately 33% of normal. As with autotransformer starters, these starters can be either open or closed transition types. For closed transition, resistors are used. In this instance, ventilation is required to remove the heat from the resistors. Open transition starters will have a severe current peak at the transition. The branch-circuit protection has to be selected very carefully for open transition starters so as to avoid tripping during transition. The time setting should be set somewhat longer than for part-winding starters; that is, 3 s to 4 s on open transition, and 3 s to 5 s on closed transition autotransformer and wye-delta starters. On closed transition wye-delta and autotransformer starters, the standard branch-circuit protective device is selected in the same manner as are full-voltage starters.

Wye-delta starters are suitable for high inertia loads with long acceleration times, such as centrifugal compressors and centrifuges. They can also be used where the load torque during acceleration is low. Wye-delta starters are extensively utilized in Europe and in the United States, particularly for large air-conditioning units. Six- or 12-lead delta connected motors can also be wye started using this type of starter. The starter cost is somewhat more expensive than a part-winding starter, and like the part-winding starter, the motor cost is also higher than a standard motor.



STARTING CHARACTERISTICS:
1. STARTING CURRENT IS APPROXIMATELY 30% OF NORMAL.
2. STARTING TORQUE IS APPROXIMATELY 25-30% OF NORMAL.

Figure 5—Wye-delta reduced-voltage starting

A comparison of starting currents and torques produced by various kinds of reduced-voltage starters is shown in Table 1.

Table 1—Comparison of electromechanical reduced-voltage starters

—	Autotransformer ^a			Primary resistor or reactor		Part winding ^b		Wye delta
	50% tap	65% tap	80% tap	65% tap	80% tap	2-step	3-step	
Starting current drawn from line as percentage of that which would be drawn upon full-voltage starting ^c	28%	45%	67%	65%	80%	60%	25%	33 1/3%
Starting torque developed as percentage of that which would be developed on full-voltage starting	25%	42%	64%	42%	64%	50%	12 1/2%	33 1/3%
	Increases slightly with speed			Increases greatly with speed		—	—	—

Table continues

Table 1—Comparison of electromechanical reduced-voltage starters (continued)

—	Autotransformer ^a			Primary resistor or reactor		Part winding ^b		Wye delta
	50% tap	65% tap	80% tap	65% tap	80% tap	2-step	3-step	
Smoothness of acceleration	Second in order of smoothness			Smoothest of reduced-voltage types. As motor gains speed, current decreases. Voltage drop across impedance decreases and motor terminal voltage increases.		Fourth in order of smoothness		Third in order of smoothness
Installed cost	High			High		Low		Medium
Starting current and torque adjustment	Adjustable within limits of various taps			Adjustable within limits of various taps		NA	NA	Fixed

^aClosed transition.

^bApproximate values only. Exact values can be obtained from the motor manufacturer.

^cFull-voltage start usually draws between 500% and 650% of full-load current.

4.5.6 Solid-state type

Most solid-state controllers (also known as “soft starters”) are of the reduced-voltage type. These are readily available for both low-voltage and medium-voltage motors. There is another variation of solid-state controller, the reduced-frequency type, which at present is semi-custom, and requires working with the applications engineers of the selected manufacturer. The reduced-frequency controller uses an adjustable-speed drive (ASD) to start the motor. ASDs are discussed in more detail in 4.10. Normally a reduced-voltage controller will be selected. However, for applications where the load torque will exceed the available starting torque at reduced voltage, the reduced-frequency controller will be needed.

Most solid-state controllers of either type are rated for short time operation only. Sixty-second and 90-s ratings are common. After the rated time, these solid-state controllers must be bypassed and not carrying current, to allow their components to cool. For some applications, detailed calculations will be required to determine the necessary component ratings, and components approaching a continuous current carrying version may be required. This will affect the size and cost of the solid-state controller, especially for medium-voltage applications.

Solid-state, or electronic, reduced-voltage (SSRV) controllers provide very similar motor output torque and inrush currents as an autotransformer, but with more options. They are designed to decrease inrush current to the motor during starting and limit the available starting torque by more smoothly ramping the voltage. The amount of starting current is field adjustable by the user, within certain limitations. Three methods of acceleration are available:

- 1) Constant current acceleration: the motor is accelerated to full speed at a field-selectable, preset current level.
- 2) Current ramp acceleration: the voltage is gradually increased to provide smooth, stepless acceleration under varying loads.
- 3) Linear timed acceleration: the motor is accelerated at a linear rate that is field-adjustable (tachometer feedback circuit required).

One simple type of reduced-voltage motor controller uses six thyristors in a full-wave configuration to vary the input voltage from zero to full on, so that the motor accelerates smoothly from zero to full running speed. The thyristors are activated by an electronic control section that has an initial step voltage adjustment. This ad-

justment, combined with a ramped voltage and current-limit over-ride, can provide constant current (torque) to the motor until it reaches full speed.

Variations in the design of starting circuit are as follows:

- a) Three power diodes replace the three return-conducting thyristors. The control circuit is simple and each thyristor is protected against reverse voltage by its associated diode. This half-wave configuration will produce more harmonics than the full-wave configuration, and generate added heat in the motor windings. Thermal protective devices should be properly sized to prevent this additional heat from damaging the motor.
- b) Thyristors are used only during the starting phase. At full voltage, a run contactor closes and the circuit operates as a conventional electromechanical starter. This is the most common configuration used for large motors.
- c) A controller with linear-timed acceleration uses a closed-loop feedback system to maintain the motor acceleration at a constant rate. The required feedback signal is provided by a tachometer coupled to the motor.

These controllers are readily available for motors rated from fractional horsepower to thousands of horsepower.

SSRV controllers are particularly suitable for applications that require extremely fast or a large number of operations, or both (several million under load). Applications include conveyors, elevators, compressors, machine tools, pumps, and fans. To a limited extent, they can also be used for speed control and other functions for ac and dc motors. SSRV controllers have some benefits that other reduced-voltage starting methods lack. Most SSRV controllers have an option to reduce the voltage when motor loading is low. This provides an opportunity for energy savings during light loading conditions. Another advantage is smooth seamless starting with an infinite number of torque/current settings, giving the SSRV controller superior flexibility.

4.6 Wound-rotor motor controllers

The wound-rotor or slip-ring motor functions in the same manner as the squirrel-cage motor, except that the rotor windings are connected through slip rings and brushes to external circuits with resistance to vary motor speed. Increasing the resistance in the rotor circuit reduces motor speed and decreasing the resistance increases motor speed. Some variations of this type of controller employ thyristors in place of contactors and resistors. Some even rectify the secondary current and invert it to line frequency to supply back into the input, appreciably raising the efficiency.

4.7 Multispeed motor controllers

These controllers are designed for the automatic control of two-, three-, or four-speed squirrel-cage motors of either the consequent-pole or separate-winding types. They are available for constant-horsepower, constant-torque, or variable-torque three-phase motors used on fans, blowers, refrigeration compressors, and similar machinery.

Multiple speed motors are used to obtain different predefined motor speeds from a single motor. There are two types of multiple speed motors: consequent pole and separate winding. Consequent pole motors have a winding for every two motor speeds while separate winding motors have a winding for each speed. The speed ratios for consequent pole motors are typically limited to a 2:1 ratio. The controller is designed for two steps, and speed cannot be varied in a wide, stepless range. If greater flexibility is desired, separate winding motors should be used. Both motors are available for constant horsepower, constant torque, and variable torque applications. Controllers for consequent pole and separate winding motors have different numbers of poles in the contactors. The consequent pole controller has a five-pole and a three-pole contactor. The separate winding controller has two three-pole contactors. Before a controller is selected, the type of motor needs to be known.