



**6<sup>TH</sup>**  
**EDITION**

# **INDUSTRIAL MOTOR CONTROL**

**Stephen L. Herman**



# INDUSTRIAL MOTOR CONTROL

---

Sixth Edition

Stephen L. Herman



 DELMAR  
CENGAGE Learning

Australia • Brazil • Japan • Korea • Mexico • Singapore • Spain • United Kingdom • United States

**Industrial Motor Control,  
6th Edition  
Stephen L. Herman**

Vice President, Career and  
Professional Editorial: Dave Garza

Director of Learning Solutions:  
Sandy Clark

Managing Editor:  
Larry Main

Senior Product Manager:  
John Fisher

Senior Editorial Assistant:  
Dawn Daugherty

Vice President, Career and  
Professional Marketing:  
Jennifer McAvey

Marketing Manager:  
Deborah S. Yarnell

Marketing Manager:  
Jimmy Stephens

Marketing Coordinator:  
Mark Pierro

Production Director:  
Wendy Troeger

Production Manager:  
Mark Bernard

Content Project Manager:  
Christopher Chien

Art Director:  
David Arsenault

Technology Project Manager:  
Christopher Catalina

Production Technology Analyst:  
Thomas Stover

© 2010, 2005, 1999, 1993, 1990, and 1985 Delmar, Cengage Learning

ALL RIGHTS RESERVED. No part of this work covered by the copyright herein may be reproduced, transmitted, stored, or used in any form or by any means graphic, electronic, or mechanical, including but not limited to photocopying, recording, scanning, digitizing, taping, Web distribution, information networks, or information storage and retrieval systems, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without the prior written permission of the publisher.

For product information and technology assistance, contact us at

**Professional Group Cengage Learning  
Customer & Sales Support, 1-800-354-9706**

For permission to use material from this text or product,  
submit all requests online at **cengage.com/permissions**.

Further permissions questions can be e-mailed to  
**permissionrequest@cengage.com**.

Library of Congress Control Number: 2008935164

ISBN-13: 978-1-4354-4239-9

ISBN-10: 1-4354-4239-3

**Delmar**

5 Maxwell Drive  
Clifton Park, NY 12065-2919  
USA

Cengage Learning is a leading provider of customized learning solutions with office locations around the globe, including Singapore, the United Kingdom, Australia, Mexico, Brazil and Japan. Locate your local office at:  
**international.cengage.com/region**

Cengage Learning products are represented in Canada by Nelson Education, Ltd.

For your lifelong learning solutions, visit **delmar.cengage.com**  
Visit our corporate website at **cengage.com**.

**Notice to the Reader**

Publisher does not warrant or guarantee any of the products described herein or perform any independent analysis in connection with any of the product information contained herein. Publisher does not assume, and expressly disclaims, any obligation to obtain and include information other than that provided to it by the manufacturer. The reader is expressly warned to consider and adopt all safety precautions that might be indicated by the activities described herein and to avoid all potential hazards. By following the instructions contained herein, the reader willingly assumes all risks in connection with such instructions. The publisher makes no representations or warranties of any kind, including but not limited to, the warranties of fitness for particular purpose or merchantability, nor are any such representations implied with respect to the material set forth herein, and the publisher takes no responsibility with respect to such material. The publisher shall not be liable for any special, consequential, or exemplary damages resulting, in whole or part, from the readers' use of, or reliance upon, this material.



# PREFACE

The amount of knowledge an electrician must possess to be able to install and troubleshoot control systems in today's industry has increased dramatically in recent years. A continuous influx of improved control components allows engineers and electricians to design and install even more sophisticated and complex control systems. *Industrial Motor Control* presents the solid-state devices common in an industrial environment. This is intended to help the student understand how many of the control components operate, such as solid-state relays, rectifiers, SCR drives for direct current motors, variable frequency drives for alternating current motors, and the inputs and outputs of programmable controllers. Although most electricians do not troubleshoot circuits on a component level, a basic knowledge of how these electronic devices operate is necessary in understanding how various control components perform their functions.

The influx of programmable logic controllers into industry has bridged the gap between the responsibilities of the electrician and the instrumentation technician. Many industries now insist that electricians and instrumentation technicians be cross-trained so they can work more closely together. *Industrial Motor Control* helps fulfill this requirement. Many of the common control devices found throughout industry are also discussed from a basic instrumentation standpoint by providing information on analog sensing of pressure, flow, temperature, and liquid level.

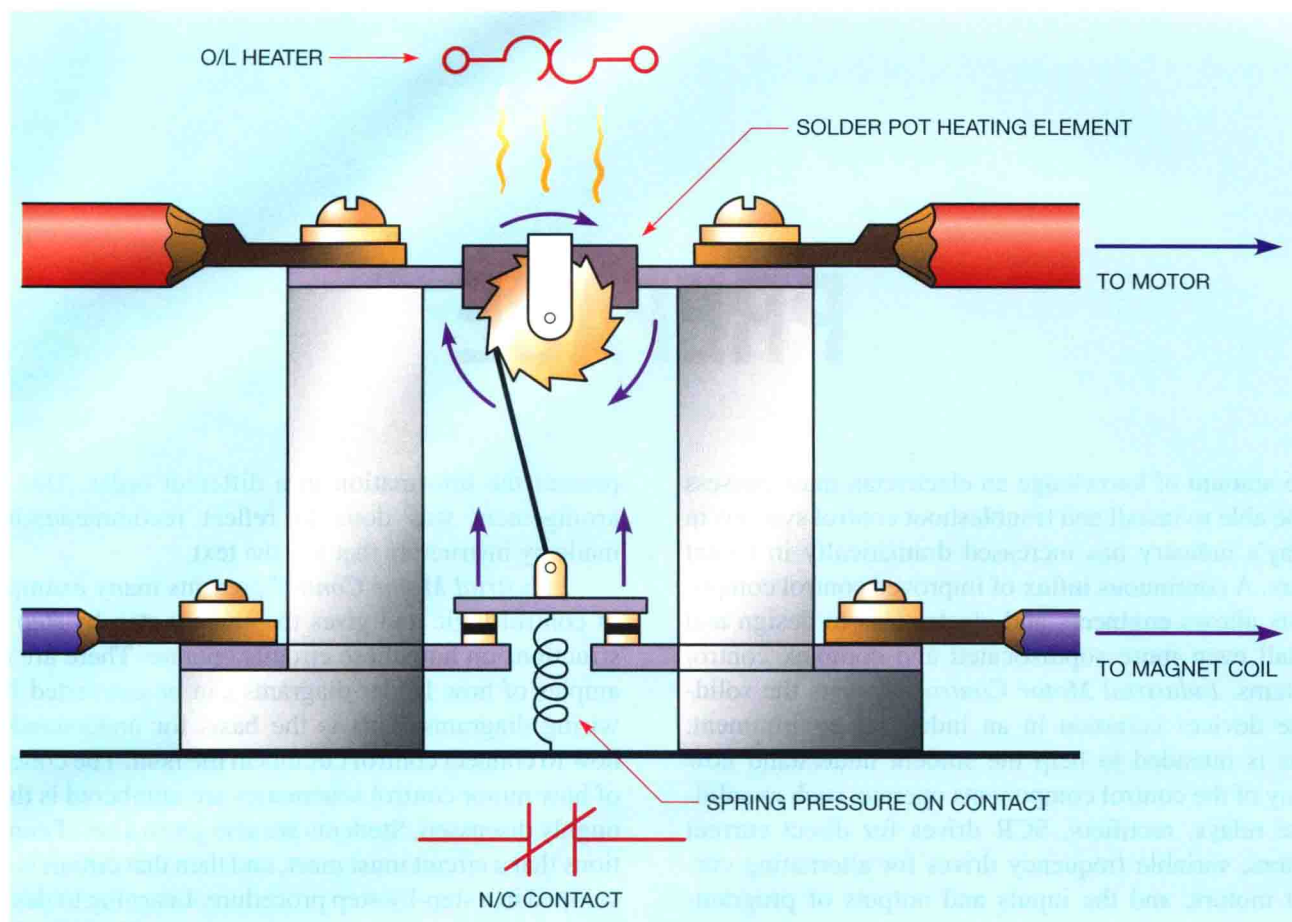
The sixth edition of *Industrial Motor Control* is the most comprehensive revision since the text was first published over twenty years ago. The chapter on motor installation has been updated to reflect changes in the 2008 *National Electrical Code*®, and a new unit that instructs students in basic troubleshooting techniques has been included. The chapters have been rearranged to

present the information in a different order. This rearrangement was done to reflect recommendations made by instructors that use the text.

*Industrial Motor Control* presents many examples of control logic and gives the student step-by-step instructions on how these circuits operate. There are examples of how ladder diagrams can be converted into wiring diagrams. This is the basis for understanding how to connect control circuits in the field. The concept of how motor control schematics are numbered is thoroughly discussed. Students are also given a set of conditions that a circuit must meet, and then that circuit is developed in a step-by-step procedure. Learning to design control circuits is a very effective means of learning how circuit logic works. It is impossible to effectively troubleshoot a control circuit if you don't understand the logic of what the circuit is intended to do.

*Industrial Motor Control* is based on the results of extensive research into content, organization, and effective learning styles. Short chapters help the student to completely understand the content before progressing to the next subject, and they permit the instructor to choose the order of presentation. Each chapter contains extensive illustrations, which have been designed for maximum learning. Color is used to help the student understand exactly what is being conveyed in a particular illustration.

*Industrial Motor Control*, Sixth Edition, is a complete learning package that includes this comprehensive textbook, a hands-on Lab Manual, an Interactive Companion on CD, an *Instructor's Guide*, and an *Instructor's e-resource*. The Lab Manual offers practical hands-on circuits to be wired by the student. Each of the labs uses standard components that most electrical laboratories either have on hand or can obtain without difficulty. The Lab Manual lets students learn by doing.



Sample Illustration

## New for the Sixth Edition

- Rearrangement of chapters to reflect the recommendations made by instructors that used the text.
- A new chapter on troubleshooting techniques.
- The chapter on motor installation has been updated in accord with the 2008 *National Electrical Code*®.
- Many of the chapters have been rewritten in an effort to make the material more understandable for beginning students.
- Many of the drawings and illustrations have been updated and improved.

The Interactive Companion CD, which can be found in a sleeve on the inside back cover of this textbook, includes applications and explanations of the concepts developed in the textbook. This exciting CD includes outstanding graphics, animations, and video segments and provides students with reinforcement of important concepts. The text of the licensing agreement for this soft-

ware, along with instructions for installing and operating it, can be found on the pages following the index.

The *Instructor's Guide* includes the learning objectives from the textbook for the instructor's convenience, as well as a bank of test questions, and the answers to all of the test questions and textbook Chapter Review Questions.

The new *Instructor's e.resource* is an invaluable addition to the Industrial Motor Control package. It includes PowerPoint slides for each unit (a total of nearly 500), nearly 1,000 Computerized Test Bank questions, and an image library containing hundreds of full-color images in electronic format.

## Content Highlights

- The most commonly used solid-state devices are thoroughly described, in terms of both operation and typical application.



- Information on analog devices that sense pressure, flow, and temperature has been added to help bridge the gap between the industrial electrician and the instrumentation technician.
- DC and AC motor theory is included so students will understand the effects of control circuits on motor characteristics.
- The text covers the operating characteristics of stepping motors when connected to either DC or AC voltage.
- Detailed instructions are given for connecting motors in the field, including the size of conductors, overload relays, and fuses or circuit breakers. All calculations are taken from the *National Electrical Code*®.
- The principles of digital logic are described in sufficient detail for students to understand programmable controllers and prepare basic programs.
- A step-by-step testing procedure for electronic components is provided in the Appendix.
- Starting methods for hermetically sealed single-phase motors includes the hot-wire relay, solid-state starting relay, current relay, and potential relay.
- Extensive coverage on overload relays and methods of protecting large horsepower motors.
- Extensive coverage of variable frequency drives.
- Extensive coverage of solid-state control devices in addition to electromagnetic devices.
- Basic electronics is not a prerequisite for studying this text. Sufficient solid-state theory is presented to enable the student to understand and apply the concepts discussed.

## About the Author

Stephen L. Herman has been both a teacher of industrial electricity and an industrial electrician for many years. He obtained formal training at Catawba Valley Technical College in Hickory, North Carolina, and at numerous seminars and manufacturers' schools. He also attended Stephen F. Austin University in Nacogdoches, Texas, and earned an Associates Degree in Electrical Technology from Lee College in Baytown, Texas. He was employed as an electrical installation and maintenance instructor at Randolph Technical College in Asheboro, North Carolina, for nine years. Mr. Herman then returned to industry for a period of time before becoming the lead instructor for the Electrical Technology Pro-

gram at Lee College in Baytown, Texas. He retired from Lee College with twenty years of service and presently lives with his wife in Pittsburg, Texas. Mr. Herman is a recipient of the Excellence in Teaching Award presented by the Halliburton Education Foundation.

## Acknowledgments

The following individuals provided detailed critiques of the manuscript and offered valuable suggestions for improvement of the sixth edition of this text:

*Salvador Aranda*  
Savannah Technical College  
5717 White Bluff Road  
Savannah, GA 31405-5521

*Richard Cutbirth*  
Electrical JATC  
620 Legion Way  
Las Vegas, NV 89110

*Harry Katz*  
South Texas Electrical JATC  
1223 East Euclid  
San Antonio, TX 78212

*Rick Hecklinger*  
Toledo Electrical JATC  
803 Lime City Road  
Rossford, OH 43460

*Ivan Nickerson*  
North Platte Community College  
1101 Halligan Drive  
North Platte, NE 69101

*Alan Bowden*  
Central Westmoreland Area Vocational School  
Arona Road  
New Stanton, PA 15672

The following companies provided the photographs used in this text:

*Allen-Bradley Company*  
1201 South Second Street  
Milwaukee, WI 53204

*Automatic Switch Company*  
50-A Hanover Road  
Florham Park, NJ 07932

*Eaton Corporation*  
*Cutler-Hammer Products*  
4201 North 27th Street  
Milwaukee, WI 53216

*Eagle Signal Controls*  
A Division of Gulf & Western Manufacturing Company  
736 Federal Street  
Davenport, IA 52803

*Emerson Electric Company*  
Industrial Controls Division  
3300 South Standard Street  
Santa Ana, CA 92702

*Furnas Electric Company*  
1007 McKee Street  
Batavia, IL 60510

*GE Fanuc Automation North America, Inc.*  
P.O. Box 8106  
Charlottesville, VA 22906

*General Electric Company*  
101 Merritt 7, P.O. Box 5900  
Norwalk, CT 06856

*Hevi-Duty Electric*  
A Division of General Signal Corporation  
P.O. Box 268, Highway 17 South  
Goldsboro, NC 27530

*International Rectifier*  
Semiconductor Division  
233 Kansas  
El Segundo, CA 90245

*McDonnell & Miller, ITT*  
3500 N. Spaulding Avenue  
Chicago, IL 60618

*McGraw-Edison Company*  
Electric Machinery  
800 Central Avenue  
Minneapolis, MN 55413

*Micro Switch*  
A Honeywell Division  
11 West Spring Street  
Freeport, IL 61032

*RCA*  
Solid State Division  
Route 202  
Somerville, NJ 08876

*Ramsey Controls, Inc.*  
335 Route 17  
Mahwah, NJ 07430

*Reliance Electric*  
24701 Euclid Avenue  
Cleveland, OH 44117

*Sparling Instruments, Co. Inc.*  
4097 North Temple City Boulevard  
El Monte, CA 91734

*Square D Company*  
P.O. Box 472  
Milwaukee, WI 53201

*The Superior Electric Company*  
Bristol, CT 06010

*Struthers-Dunn, Inc.*  
Systems Division  
4140 Utica Ridge Road  
P.O. Box 1327  
Bettendorf, IA 52722-1327

*Tektronix, Inc.*  
P.O. Box 500  
Beaverton, OR 97077

*Telemecanique, Inc.*  
2525 S. Clearbrook Drive  
Arlington Heights, IL 60005

*Turck Inc.*  
3000 Campus Drive  
Plymouth, MN 55441

*U.S. Electrical Motors Division*  
Emerson Electric Company  
125 Old Gate Lane  
Milford, CT 06460

*Vactec, Inc.*  
10900 Page Boulevard  
St. Louis, MO 63132

*Warner Electric Brake & Clutch Company*  
449 Gardner Street  
South Beloit, IL 61080

The following individuals provided detailed review comments and suggestions for this edition of the text:

Bob Keller  
Dayton Electrical JATC  
Green County Career Center  
Xenia, OH 45385

Madison Burnett  
Assistant Training Director/Instructor  
Electrical JATC of Southern Nevada  
Las Vegas, Nevada 89110

Richard Paredes  
Training Instructor  
IBEW Local Union 164  
Jersey City, NJ



# CONTENTS

<b>Preface</b>	<b>ix</b>	<b>Chapter 5 Relays, Contactors, and Motor Starters</b>	<b>52</b>
New for the Sixth Edition	x	Relays	52
Content Highlights	x	Electromagnet Construction	53
About the Author	xi	Contactors	61
Acknowledgments	xi	Mechanically Held Contactors and Relays	64
		Mercury Relays	65
		Motor Starters	67
		Review Questions	75
<b>Chapter 1 General Principles of Motor Control</b>	<b>1</b>	<b>Chapter 6 The Control Transformer</b>	<b>77</b>
Installation of Motors and Control Equipment	1	Review Questions	83
Types of Control Systems	4		
Functions of Motor Control	7	<b>Chapter 7 Timing Relays</b>	<b>84</b>
Review Questions	9	Pneumatic Timers	85
		Clock Timers	86
<b>Chapter 2 Symbols and Schematic Diagrams</b>	<b>10</b>	Motor-Driven Timers	87
Push Buttons	10	Capacitor Time Limit Relay	87
Switch Symbols	13	Electronic Timers	88
Basic Schematics	15	Review Questions	94
Sensing Devices	18		
Selector Switches	22	<b>Chapter 8 Pressure Switches and Sensors</b>	<b>95</b>
Review Questions	26	Pressure Switches	95
		Pressure Sensors	97
<b>Chapter 3 Manual Starters</b>	<b>27</b>	Review Questions	100
Fractional Horsepower Single-Phase Starters	27	<b>Chapter 9 Float Switches</b>	<b>101</b>
Manual Push-Button Starters	30	Mercury Bulb Float Switch	102
Troubleshooting	33	The Bubbler System	103
Review Questions	33	Review Questions	107
		<b>Chapter 10 Flow Switches and Sensors</b>	<b>108</b>
<b>Chapter 4 Overload Relays</b>	<b>35</b>	Flow Switches	108
Overloads	35	Flow Sensors	110
Dual Element Fuses	36	Review Questions	117
Thermal Overload Relays	36		
Magnetic Overload Relays	43		
Overload Contacts	47		
Protecting Large Horsepower Motors	49		
Review Questions	51		

<b>Chapter 11</b>	<b>Limit Switches</b>	<b>118</b>	<b>Chapter 20</b>	<b>Timed Starting for Three Motors (Circuit #2)</b>	<b>172</b>
Micro Limit Switches	119	Review Questions	175		
Subminiature Micro Switches	121	<b>Chapter 21</b>	<b>Float Switch Control of a Pump and Pilot Lights (Circuit #3)</b>	<b>176</b>	
Limit Switch Application	121	Review Questions	178		
Review Questions	123	<b>Chapter 22</b>	<b>Developing a Wiring Diagram (Circuit #1)</b>	<b>179</b>	
<b>Chapter 12</b>	<b>Phase Failure Relays</b>	<b>124</b>	Review Questions	182	
Effects of Voltage Variation on Motors	124	<b>Chapter 23</b>	<b>Developing a Wiring Diagram (Circuit #2)</b>	<b>183</b>	
Review Questions	125	Review Question	184		
<b>Chapter 13</b>	<b>Solenoid and Motor Operated Valves</b>	<b>126</b>	<b>Chapter 24</b>	<b>Developing a Wiring Diagram (Circuit #3)</b>	<b>187</b>
Solenoid Valves	126	Review Question	188		
Motor Operated Valves	127	<b>Chapter 25</b>	<b>Reading Large Schematic Diagrams</b>	<b>191</b>	
Review Questions	131	Review Questions	197		
<b>Chapter 14</b>	<b>Temperature Sensing Devices</b>	<b>132</b>	<b>Chapter 26</b>	<b>Installing Control Systems</b>	<b>198</b>
Expansion of Metal	132	Review Questions	202		
Resistance Temperature Detectors	137	<b>Chapter 27</b>	<b>Hand-Off-Automatic Controls</b>	<b>203</b>	
Expansion Due to Pressure	140	Review Questions	205		
Smart Temperature Transmitters	141	<b>Chapter 28</b>	<b>Multiple Push-Button Stations</b>	<b>207</b>	
Review Questions	142	Developing a Wiring Diagram	207		
<b>Chapter 15</b>	<b>Hall Effect Sensors</b>	<b>143</b>	Review Questions	211	
Principles of Operation	143	<b>Chapter 29</b>	<b>Forward-Reverse Control</b>	<b>214</b>	
Hall Generator Applications	144	Interlocking	214		
Review Questions	147	Developing a Wiring Diagram	215		
<b>Chapter 16</b>	<b>Proximity Detectors</b>	<b>148</b>	Reversing Single-Phase Split-Phase Motors	216	
Applications	148	Review Questions	225		
Circuit Operation	148	<b>Chapter 30</b>	<b>Jogging and Inching</b>	<b>226</b>	
Mounting	150	Jogging Circuits	226		
Capacitive Proximity Detectors	151	Inching Controls	228		
Ultrasonic Proximity Detectors	151	Review Questions	232		
Review Questions	153	<b>Chapter 31</b>	<b>Sequence Control</b>	<b>235</b>	
<b>Chapter 17</b>	<b>Photodetectors</b>	<b>154</b>	Sequence Control Circuit #1	235	
Applications	154	Sequence Control Circuit #2	235		
Types of Detectors	154	Sequence Control Circuit #3	236		
Mounting	159				
Review Questions	161				
<b>Chapter 18</b>	<b>Basic Control Circuits</b>	<b>162</b>			
Three-Wire Control Circuits	164				
Review Questions	167				
<b>Chapter 19</b>	<b>Schematics and Wiring Diagrams (Circuit #1)</b>	<b>168</b>			
Review Questions	171				

Automatic Sequence Control	238	<b>Chapter 39 Wye-Delta Starting</b>	<b>300</b>
Stopping the Motors in Sequence	238	Wye-Delta Starting Requirements	301
Review Questions	246	Dual Voltage Connections	302
<b>Chapter 32 DC Motors</b>	<b>249</b>	Connecting the Stator Leads	303
Application	249	Closed Transition Starting	303
Speed Control	249	Overload Setting	305
Motor Construction	249	Review Questions	310
Identifying Windings	250	<b>Chapter 40 Part Winding Starters</b>	<b>311</b>
Types of DC Motors	251	Overload Protection	312
Direction of Rotation	252	Dual Voltage Motors	313
Standard Connections	254	Motor Applications	313
Review Questions	255	Three-Step Starting	314
<b>Chapter 33 Starting Methods for DC Motors</b>	<b>256</b>	Automatic Shut-Down	314
Review Questions	261	Review Questions	314
<b>Chapter 34 Solid-State DC Drives</b>	<b>262</b>	<b>Chapter 41 Consequent Pole Motors</b>	<b>317</b>
The Shunt Field Power Supply	263	Three-Speed Consequent Pole Motors	319
The Armature Power Supply	263	Four-Speed Consequent Pole Motors	326
Voltage Control	264	Review Questions	331
Field Failure Control	264	<b>Chapter 42 Variable Voltage and Magnetic Clutches</b>	<b>332</b>
Current Limit Control	265	Voltage Control Methods	333
Speed Control	266	Magnetic Clutches	334
Review Questions	268	Eddy Current Clutches	335
<b>Chapter 35 Stepping Motors</b>	<b>269</b>	Review Questions	336
Theory of Operation	269	<b>Chapter 43 Braking</b>	<b>338</b>
Windings	271	Mechanical Brakes	338
Four-Step Switching (Full Stepping)	271	Dynamic Braking	338
Eight-Step Switching (Half Stepping)	272	Plugging	342
AC Operation	272	Review Questions	350
Motor Characteristics	273	<b>Chapter 44 Wound Rotor Induction Motors</b>	<b>351</b>
Review Questions	276	Manual Control of a Wound Rotor Motor	353
<b>Chapter 36 The Motor and Starting Methods</b>	<b>277</b>	Timed Controlled Starting	353
Review Questions	285	Wound Rotor Speed Control	355
<b>Chapter 37 Resistor and Reactor Starting for AC Motors</b>	<b>286</b>	Frequency Control	355
Resistor Starting	286	Review Questions	358
Reactor Starting	288	<b>Chapter 45 Synchronous Motors</b>	<b>360</b>
Step-Starting	288	Starting a Synchronous Motor	360
Review Questions	292	Excitation Current	361
<b>Chapter 38 Autotransformer Starting</b>	<b>294</b>	The Brushless Exciter	361
Open and Closed Transition Starting	295	Direct Current Generator	362
Review Questions	299	Automatic Starting for Synchronous Motors	362



The Field Contactor	362	<b>Chapter 52 Start-Stop Push-Button Control</b>	<b>437</b>
Out-of-Step Relay	362	Review Questions	444
The Polarized Field Frequency Relay	363	<b>Chapter 53 Programmable Logic Controllers</b>	<b>445</b>
Power Factor Correction	365	Differences Between PLCs and PCs	445
Applications	366	Basic Components	446
Review Questions	366	Review Questions	454
<b>Chapter 46 Variable Frequency Control</b>	<b>367</b>	<b>Chapter 54 Programming a PLC</b>	<b>455</b>
Alternator Control	368	Circuit Operation	455
Solid-State Control	368	Developing a Program	457
IGBTs	369	Converting the Program	459
Inverter Rated Motors	371	Programming in Boolean	461
Variable Frequency Drives Using		Developing the Program	461
SCRs and GTOs	372	Parameters of the Programmable Controller	461
Review Questions	375	Operation of the Circuit	462
<b>Chapter 47 Motor Installation</b>	<b>377</b>	Entering the Program	465
Determining Motor Current	377	Review Questions	466
Overload Size	384	<b>Chapter 55 Analog Sensing for Programmable</b>	<b>467</b>
Example Problems	391	<b>Controllers</b>	
Review Questions	396	Installation	469
<b>Chapter 48 Developing Control Circuits</b>	<b>397</b>	The Differential Amplifier	470
Developing Control Circuits	397	Review Questions	470
Review Questions	409	<b>Chapter 56 Semiconductors</b>	<b>471</b>
<b>Chapter 49 Troubleshooting</b>	<b>410</b>	Conductors	471
Safety Precautions	410	Insulators	472
Voltmeter Basics	411	Semiconductors	472
Test Procedure Example 1	414	Review Questions	476
Test Procedure Example 2	416	<b>Chapter 57 The PN Junction</b>	<b>477</b>
Test Procedure Example 3	419	The PN Junction	477
Review Questions	424	Review Questions	481
<b>Chapter 50 Digital Logic</b>	<b>425</b>	<b>Chapter 58 The Zener Diode</b>	<b>482</b>
The AND Gate	426	The Zener Diode	482
The OR Gate	427	Review Questions	484
The INVERTER	427	<b>Chapter 59 The Transistor</b>	<b>485</b>
The NOR Gate	428	The Transistor	485
The NAND Gate	429	Review Questions	488
Integrated Circuits	429		
Testing Integrated Circuits	432		
Review Questions	432		
<b>Chapter 51 The Bounceless Switch</b>	<b>433</b>		
Review Questions	436		

<b>Chapter 60 The Unijunction Transistor</b>	<b>489</b>	<b>Chapter 64 The 555 Timer</b>	<b>503</b>
The Unijunction Transistor	489	Circuit Applications	505
Review Questions	491	Review Questions	509
<b>Chapter 61 The SCR</b>	<b>492</b>	<b>Chapter 65 The Operational Amplifier</b>	<b>510</b>
The SCR in a DC Circuit	493	Basic Circuits	512
The SCR in an AC Circuit	494	Circuit Applications	514
Phase Shifting the SCR	495	Review Questions	520
Testing the SCR	496		
Review Questions	496	<b>Appendix</b>	<b>523</b>
<b>Chapter 62 The Diac</b>	<b>497</b>	Testing Solid-State Components	523
The Diac	497	Identifying the Leads of a Three-Phase, Wye-Connected, Dual-Voltage Motor	530
Review Questions	498	Ohm's Law Formulas	534
<b>Chapter 63 The Triac</b>	<b>499</b>	Standard Wiring Diagram Symbols	535
The Triac Used as an AC Switch	500	Electronic Symbols	536
The Triac Used for AC Voltage Control	500		
Phase Shifting the Triac	500	<b>Glossary</b>	<b>537</b>
Testing the Triac	501		
Review Questions	502	<b>Index</b>	<b>547</b>

# CHAPTER 1

## GENERAL PRINCIPLES OF MOTOR CONTROL

### OBJECTIVES

*After studying this chapter, the student will be able to:*

- State the purpose and general principles of motor control.
- Discuss the differences between manual and automatic motor control.
- Discuss considerations when installing motors or control equipment.
- Discuss the basic functions of a control system.
- Discuss surge protection for control systems.

The term “motor control” can have very broad meanings. It can mean anything from a simple toggle switch intended to turn a motor on or off (Figure 1–1) to an extremely complex system intended to control several motors, with literally hundreds of sensing devices that govern the operation of the circuit. The electrician working in industry should be able to install different types of motors and the controls necessary to control and protect them and also to troubleshoot systems when they fail.

### Installation of Motors and Control Equipment

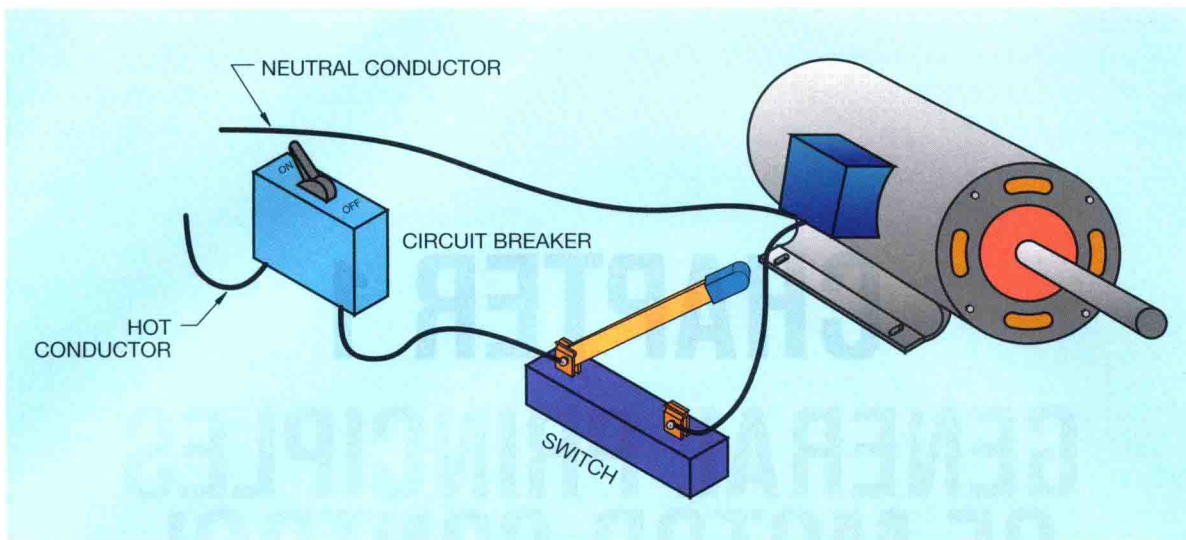
When installing electric motors and equipment, several factors should be considered. When a machine is installed, the motor, machine, and controls are all inter-

related and must be considered as a unit. Some machines will have the motor or motors and control equipment mounted on the machine itself when it is delivered from the manufacturer, and the electrician’s job in this case is generally to make a simple power connection to the machine. A machine of this type is shown in Figure 1–2. Other types of machines require separately mounted motors that are connected by belts, gears, or chains. Some machines also require the connection of pilot sensing devices such as photo switches, limit switches, pressure switches, and so on. Regardless of how easy or complex the connection is, several factors must be considered.

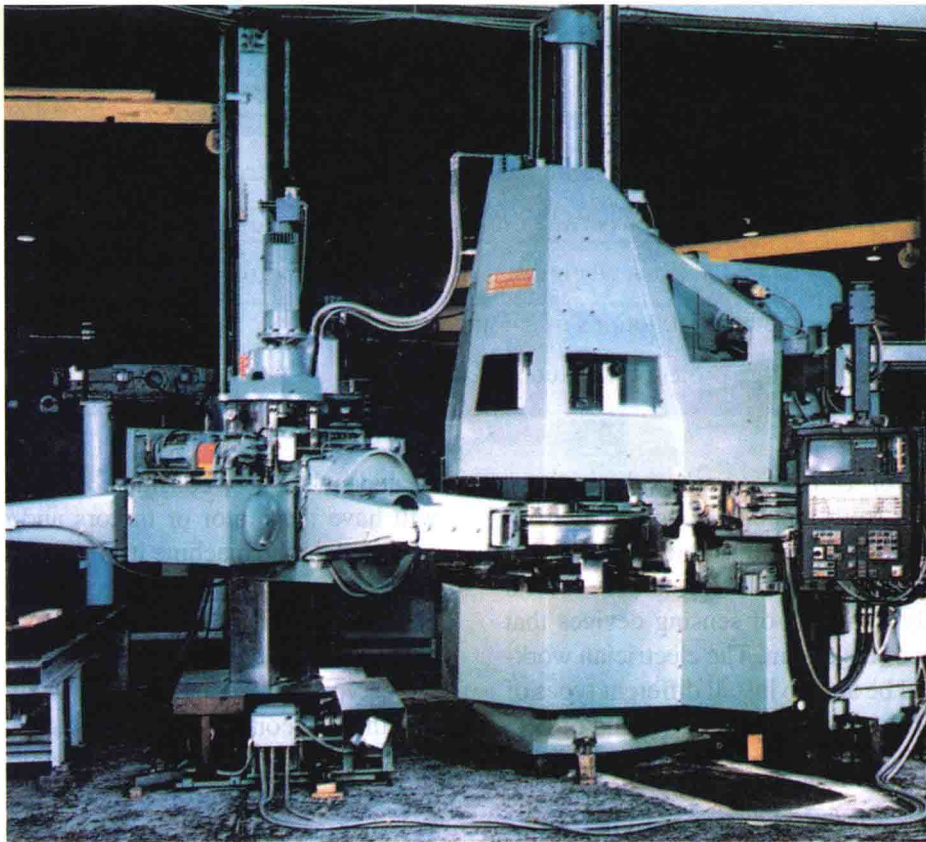
### Power Source

One of the main considerations when installing a machine is the power source. Does the machine require single-phase or three-phase power to operate?





**Figure 1-1** Motor controlled by a simple toggle switch. (Source: Delmar/Cengage Learning.)



**Figure 1-2** This machine was delivered with self-contained motors and controls. (Courtesy of Simmons Machine Tool Co.)

What is the horsepower of the motor or motors to be connected? What is the amount of in-rush current that can be expected when the motor starts? Will the motor require some type of reduced voltage starter to

limit in-rush current? Is the existing power supply capable of handling the power requirement of the machine or will it be necessary to install a new power system?

The availability of power can vary greatly from one area of the country to another. Power companies that supply power to heavily industrialized areas can generally permit larger motors to be started across-the-line than companies that supply power to areas that have light industrial needs. In some areas, the power company may permit a motor of several thousand horsepower to be started across-the-line, but in other areas the power company may require a reduced voltage starter for motors rated no more than one hundred horsepower.

## Motor Connections

When connecting motors, several factors should be considered, such as: horsepower, service factor (SF), marked temperature rise, voltage, full load current rating, and National Electrical Manufacturers Association (NEMA) Code letter. This information is found on the motor nameplate. The conductor size, fuse or circuit breaker size, and overload size are generally determined using the National Electrical Code (NEC®) and/or local codes. It should be noted that local codes generally supersede the National Electrical Code and should be followed when they apply. Motor installation based on the NEC® will be covered in this text.

## Motor Type

The type of motor best suited to operate a particular piece of equipment can be different for different types of machines. Machines that employ gears generally require a motor that can start at reduced speed and increase speed gradually. Wound rotor induction motors or squirrel cage motors controlled by variable frequency drives are generally excellent choices for this requirement. Machines that require a long starting period, such as machines that operate large inertia loads such as flywheels or centrifuges, require a motor with high starting torque and relatively low starting current. Squirrel cage motors with a type A rotor or synchronous motors are a good choice for these types of loads. Synchronous motors have an advantage in that they can provide power factor correction for themselves or other inductive loads connected to the same power line.

Squirrel cage motors controlled by variable frequency drives or direct current motors can be employed to power machines that require variable speed. Squirrel cage induction motors are used to power most of the machines throughout industry. These motors are rugged and have a proven record of service unsurpassed by any other type of power source.

## Controller Type

The type of controller can vary depending on the requirements of the motor. Motor starters can be divided into two major classifications: NEMA (National Electrical Manufacturers Association) and IEC (International Electrotechnical Commission). NEMA is an American organization that rates electrical components. NEMA starter sizes range from 00 through 8. A NEMA size 00 starter is rated to control a 2 horsepower motor connected to a 460 volt three-phase power supply. A size 8 starter will control a 900 horsepower motor connected to a 460 volt three-phase power source. IEC starter sizes range from size A through size Z. Size A starters are rated to control a 3 horsepower motor connected to a 460 volt three-phase source. Size Z starters are rated to control a 900 horsepower motor connected to a 460 volt source. It should be noted that the contact size for an IEC starter is smaller than for a NEMA starter of the same rating. It is common practice when using IEC starters to increase the listed size by one or two sizes to compensate for the difference in contact size.

## Environment

Another consideration is the type of environment in which the motor and control system operates. Can the controls be housed in a general purpose enclosure similar to the one shown in Figure 1–3, or is the system subject to moisture or dust? Are the motor and controls



Figure 1–3 General purpose enclosure (NEMA 1).





Figure 1-4 Explosion proof enclosure (NEMA 7).

to be operated in a hazardous area that requires explosion proof enclosures similar to that shown in Figure 1-4? Some locations may contain corrosive vapor or liquid, or extremes of temperature. All of these conditions should be considered when selecting motors and control components. Another type of starter commonly found in industry is the combination starter (Figure 1-5). The combination starter contains the disconnecting means, fuses or circuit breaker, starter, and control transformer. They may also have a set of push buttons or switches mounted on the front panel to control the motor.

## Codes and Standards

Another important consideration is the safety of the operator or persons that work around the machine. In 1970, the Occupational Safety and Health Act (OSHA) was established. In general, OSHA requires employers to provide an environment free of recognized hazards that are likely to cause serious injury.

Another organization that exhibits much influence on the electrical field is Underwriters Laboratories (UL). Underwriters Laboratories was established by insurance companies in an effort to reduce the number of fires caused by electrical equipment. They test equipment to determine if it is safe under different conditions. Approved equipment is listed in an annual publication that is kept current with bimonthly supplements.

Another previously mentioned organization is the *National Electrical Code*. The *NEC*<sup>®</sup> is actually part of

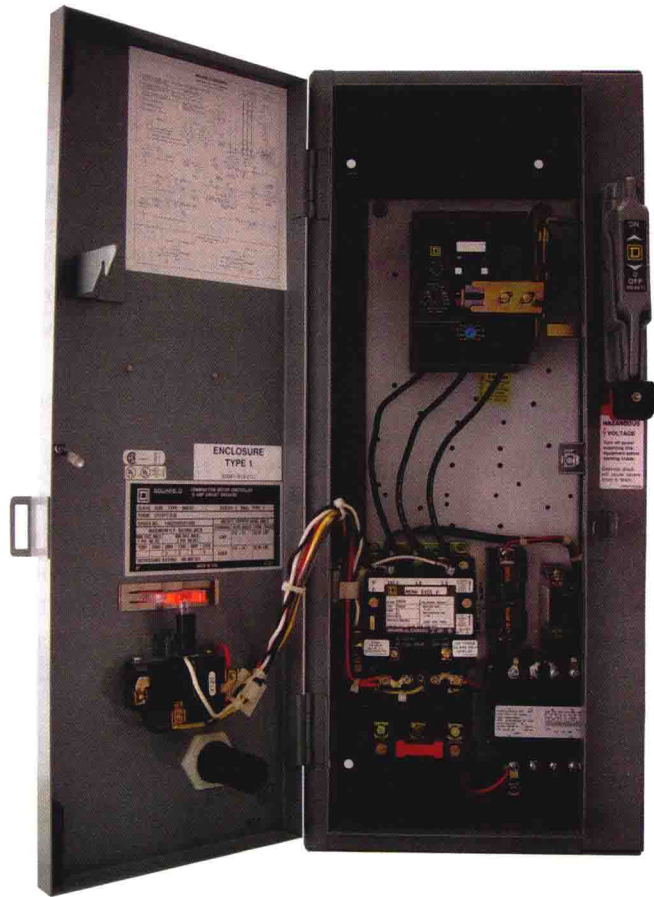


Figure 1-5 Combination motor starter with circuit breaker, disconnect switch, starter, and control transformer. (Courtesy of Square D Company.)

the National Fire Protection Association. They establish rules and specifications for the installation of electrical equipment. The National Electrical Code is not a law unless it is made law by a local authority.

Two other organizations that have great influence on control equipment are NEMA and IEC. Both of these organizations will be discussed later in the text.

## Types of Control Systems

Motor control systems can be divided into three major types: manual, semiautomatic, and automatic. Manual controls are characterized by the fact that the operator must go to the location of the controller to initiate any change in the state of the control system. Manual controllers are generally very simple devices that connect the motor directly to the line. They may or may not