Electric Motors *and* Control Systems

Second Edition

Frank D. Petruzella

McGraw Hill Education

Electric Motors and Control Systems

Frank D. Petruzella

McGraw Hill Education

ELECTRIC MOTORS AND CONTROL SYSTEMS, SECOND EDITION

Published by McGraw-Hill Education, 2 Penn Plaza, New York, NY 10121.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 0 DOW/DOW 1 0 9 8 7 6 5

ISBN 978-0-07-337381-2
MHID 0-07-337381-8

Senior Vice President, Products & Markets: *Kurt L. Strand*
Vice President, General Manager, Products & Markets: *Marty Lange*
Vice President, Content Design & Delivery: *Kimberly Meriwether David*
Director: *Thomas Timp*
Global Brand Manager: *Raghu Srinivasan*
Director, Product Development: *Rose Koos*
Director of Digital Content: *Thomas Scaife, Ph.D*
Product Developer: *Vincent Bradshaw*
Marketing Manager: *Nick McFadden*
Director, Content Design & Delivery: *Linda Avenarius*
Executive Program Manager: *Faye M. Herrig*
Content Project Managers: *Jessica Portz, Tammy Juran, and Sandra Schnee*
Buyer: *Jennifer Pickel*
Content Licensing Specialists: *Lenny Behnke*
Cover Image: © *Deyan Georgiev Authentic collection/Alamy RF (background); Photos courtesy Rockwell Automation, www.rockwellautomation.com (insets)*
Compositor: *MPS Limited*
Typeface: *11/13 Times Lt Std*
Printer: *R. R. Donnelley*

Library of Congress Cataloging-in-Publication Data

Petruzella, Frank D.
Electric motors and control systems / Frank D. Petruzella. -- Second edition.
pages cm
Includes index.
ISBN 978-0-07-337381-2 (alk. paper) -- ISBN 0-07-337381-8 (alk. paper) 1. Electric motors. 2. Electric controllers. 3. Electric driving. I. Title.
TK2514.P48 2016
621.46--dc23
2014041288

Contents

Preface . . . vii
Acknowledgments . . . x
About the Author . . . xi
Walkthrough . . . xii

Chapter 1 Safety in the Workplace 1

Part 1 Protecting against Electrical Shock . . . 1
Electrical Shock . . . 1
Arc Flash Hazards . . . 4
Personal Protective Equipment . . . 5
Part 2 Grounding—Lockout—Codes . . . 7
Grounding and Bonding . . . 7
Lockout and Tagout . . . 9
Electrical Codes and Standards . . . 11

Chapter 2 Understanding Electrical Drawings 15

Part 1 Symbols—Abbreviations—Ladder Diagrams . . . 15
Motor Symbols . . . 15
Abbreviations for Motor Terms . . . 16
Motor Ladder Diagrams . . . 16
Part 2 Wiring—Single Line—Block Diagrams . . . 23
Wiring Diagrams . . . 23
Single-Line Diagrams . . . 24
Block Diagrams . . . 25
Part 3 Motor Terminal Connections . . . 26
Motor Classification . . . 26
DC Motor Connections . . . 26
AC Motor Connections . . . 28
Part 4 Motor Nameplate and Terminology . . . 34
NEC Required Nameplate Information . . . 34
Optional Nameplate Information . . . 36
Guide to Motor Terminology . . . 38
Part 5 Manual and Magnetic Motor Starters . . . 39
Manual Starter . . . 39
Magnetic Starter . . . 40

Chapter 3 Motor Transformers and Distribution Systems 43

Part 1 Power Distribution Systems . . . 43
Transmission Systems . . . 43
Unit Substations . . . 44
Distribution Systems . . . 46
Power Losses . . . 47
Switchboards and Panelboards . . . 48
Motor Control Centers (MCCs) . . . 50
Part 2 Transformer Principles . . . 52
Transformer Operation . . . 52
Transformer Voltage, Current, and Turns Ratio . . . 53
Transformer Power Rating . . . 55
Transformer Performance . . . 56
Part 3 Transformer Connections and Systems . . . 57
Transformer Polarity . . . 57
Single-Phase Transformers . . . 58
Three-Phase Transformers . . . 60
Instrument Transformers . . . 62

Chapter 4 Motor Control Devices 66

Part 1 Manually Operated Switches . . . 66
Primary and Pilot Control Devices . . . 66
Toggle Switches . . . 67
Pushbutton Switches . . . 67
Pilot Lights . . . 70
Selector Switch . . . 71
Drum Switch . . . 72
Part 2 Mechanically Operated Switches . . . 73
Limit Switches . . . 73
Temperature Control Devices . . . 75
Pressure Switches . . . 76
Float and Flow Switches . . . 77
Part 3 Sensors . . . 78
Proximity Sensors . . . 78
Photoelectric Sensors . . . 80
Hall Effect Sensors . . . 82
Ultrasonic Sensors . . . 83
Temperature Sensors . . . 84
Velocity and Position Sensors . . . 86
Flow Measurement . . . 87
Magnetic Flowmeters . . . 87
Part 4 Actuators . . . 88
Relays . . . 88

Solenoids. 90
Solenoid Valves. 90
Stepper Motors 92
Servo Motors. 93

Chapter 5 Electric Motors 96

Part 1 Motor Principle 96
Magnetism 96
Electromagnetism 97
Generators. 97
Motor Rotation 98
Part 2 Direct Current Motors. 101
Permanent-Magnet DC Motor 102
Series DC Motor. 103
Shunt DC Motor 104
Compound DC Motor. 105
Direction of Rotation 106
Motor Counter Electromotive Force (CEMF). 107
Armature Reaction 108
Speed Regulation 109
Varying DC Motor Speed 109
DC Motor Drives 110
Part 3 Three-Phase Alternating Current Motors. 112
Rotating Magnetic Field 112
Induction Motor 114
Squirrel-Cage Induction Motor. 114
Wound-Rotor Induction Motor 118
Three-Phase Synchronous Motor 119
Part 4 Single-Phase Alternating Current Motors. 121
Split-Phase Motor 121
Split-Phase Capacitor Motor. 123
Shaded-Pole Motor 125
Universal Motor 125
Part 5 Alternating Current Motor Drives. 126
Variable-Frequency Drive 126
Inverter Duty Motor 128
Part 6 Motor Selection. 130
Mechanical Power Rating 130
Current 130
Code Letter 130
Design Letter. 131
Efficiency 131
Energy-Efficient Motors 131
Frame Size 131
Frequency 132
Full-Load Speed 132
Load Requirements 132
Motor Temperature Ratings 133
Duty Cycle 133
Torque 133
Motor Enclosures 134
Metric Motors 135
Part 7 Motor Installation 136
Foundation 136
Mounting. 136
Motor and Load Alignment. 137
Motor Bearings 138
Electrical Connections 139
Grounding 139
Conductor Size 140
Voltage Levels and Balance 140
Built-in Thermal Protection 141
Part 8 Motor Maintenance and Troubleshooting 142
Motor Maintenance. 142
Troubleshooting Motors 142

Chapter 6 Contactors and Motor Starters 149

Part 1 Magnetic Contactor. 149
Switching Loads 150
Contactor Assemblies 153
Arc Suppression 157
Part 2 Contactor Ratings, Enclosures, and Solid-State Types 160
NEMA Ratings 160
IEC Ratings. 161
Contactor Enclosures 161
Solid-State Contactor 162
Part 3 Motor Starters 165
Magnetic Motor Starters 165
Motor Overcurrent Protection. 166
Motor Overload Relays. 168
NEMA and IEC Symbols 173

Chapter 7 Relays 177

Part 1 Electromechanical Control Relays 177
Relay Operation 177
Relay Applications 179
Relay Styles and Specifications 179
Part 2 Solid-State Relays. 182
Operation 182
Specifications 183
Switching Methods 184
Part 3 Timing Relays. 186
Motor-Driven Timers 186
Dashpot Timers. 186

Solid-State Timing Relays 187
Timing Functions 187
Multifunction and PLC Timers 190
Part 4 Latching Relays 192
Mechanical Latching Relays. 192
Magnetic Latching Relays 192
Latching Relay Applications. 193
Alternating Relays 193
Part 5 Relay Control Logic 195
Control Circuit Inputs and Outputs. 195
AND Logic Function 196
OR Logic Function 196
Combination Logic Functions 196
NOT Logic Function. 197
NAND Logic Function 197
NOR Logic Function 197

Chapter 8 Motor Control Circuits 200

Part 1 NEC Motor Installation Requirements 200
Sizing Motor Branch Circuit Conductors 201
Branch Circuit Motor Protection 201
Selecting a Motor Controller 204
Disconnecting Means for Motor and Controller 204
Providing a Control Circuit. 205
Part 2 Motor Starting. 207
Full-Voltage Starting of AC Induction Motors. 207
Reduced-Voltage Starting of Induction Motors. 212
DC Motor Starting 218
Part 3 Motor Reversing and Jogging. 219
Reversing of AC Induction Motors. 219
Reversing of DC Motors. 224
Jogging 224
Part 4 Motor Stopping. 226
Plugging and Antiplugging. 226
Dynamic Braking 227
DC Injection Braking 228
Electromechanical Friction Brakes. 228
Part 5 Motor Speed 229
Multispeed Motors 229
Wound-Rotor Motors 230

Chapter 9 Motor Control Electronics 232

Part 1 Semiconductor Diodes 232
Diode Operation 232
Rectifier Diode 233
Zener Diode 235
Light-Emitting Diode 236
Photodiodes. 237
Part 2 Transistors. 238
Bipolar Junction Transistor (BJT). 238
Field-Effect Transistor 241
Metal Oxide Semiconductor Field-Effect Transistor (MOSFET). 242
Insulated-Gate Bipolar Transistor (IGBT) 243
Part 3 Thyristors 245
Silicon-Controlled Rectifiers (SCRs) 245
Triac 249
Part 4 Integrated Circuits (ICs) 252
Fabrication 252
Operational Amplifier ICs. 252
555 Timer IC. 253
Microcontroller. 254
Electrostatic Discharge (ESD) 255
Digital Logic. 257

Chapter 10 Adjustable-Speed Drives and PLC Installations 261

Part 1 AC Motor Drive Fundamentals. 261
Variable-Frequency Drives (VFD) 262
Volts per Hertz Drive 266
Flux Vector Drive 267
Part 2 VFD Installation and Programming Parameters. 270
Selecting the Drive 270
Line and Load Reactors 270
Location 270
Enclosures. 270
Mounting Techniques 271
Operator Interface. 271
Electromagnetic Interference 271
Grounding. 272
Bypass Contactor 272
Disconnecting Means 272
Motor Protection. 273
Braking 274
Ramping 274
Control Inputs and Outputs. 275
Motor Nameplate Data 277
Derating 277
Types of Variable-Frequency Drives. 278
PID Control. 279
Parameter Programming. 279
Diagnostics and Troubleshooting 280

Part 3 DC Motor Drive Fundamentals 282
Applications 282
DC Drives—Principles of Operation 282
Single-Phase Input—DC Drive. 283
Three-Phase Input—DC Drive 285
Field Voltage Control 285
Nonregenerative and Regenerative
DC Drives 286
Parameter Programming 287

Part 4 Programmable Logic Controllers (PLCs) . . . 289
PLC Sections and Configurations. 289
Ladder Logic Programming 290
Programming Timers 294
Programming Counters. 295

Index 300

Preface

This book has been written for a course of study that will introduce the reader to a broad range of motor types and control systems. It provides an overview of electric motor operation, selection, installation, control, and maintenance. Every effort has been made to present the most up-to-date information, reflecting the current needs of the industry.

The broad-based approach taken makes this text viable for a variety of motor and control system courses. Content is suitable for colleges, technical institutions, and vocational/technical schools as well as apprenticeship and journeymen training. Electrical apprentices and journeymen will find this book to be invaluable because of National Electrical Code references as well as information on maintenance and troubleshooting techniques. Personnel involved in motor maintenance and repair will find the book to be a useful reference text.

The text is comprehensive! It includes coverage of how motors operate in conjunction with their associated control circuitry. Both older and newer motor technologies are examined. Topics covered range from motor types and controls to installing and maintaining conventional controllers, electronic motor drives, and programmable logic controllers.

Features you will find unique to this motors and controls text include:

Self-Contained Chapters. Each chapter constitutes a complete and independent unit of study. All chapters are divided into parts designed to serve as individual lessons. Instructors can easily pick and choose chapters or parts of chapters that meet their particular curriculum needs.

How Circuits Operate. When understanding the operation of a circuit is called for, a bulleted list is used to summarize its operation. The lists are used in place of paragraphs and are especially helpful for explaining the sequenced steps of a motor control operation.

Integration of Diagrams and Photos. When the operation of a piece of equipment is illustrated by means of a diagram, a photo of the device is included. This feature is designed to increase the level of recognition of devices associated with motor and control systems.

Troubleshooting Scenarios. Troubleshooting is an important element of any motors and controls course. The chapter troubleshooting scenarios are designed to help students with the aid of the instructor to develop a systematic approach to troubleshooting.

Discussion and Critical Thinking Questions. These open-ended questions are designed to give students an opportunity to reflect on the material covered in the chapter. In most cases, they allow for a wide range of responses and provide an opportunity for the student to share more than just facts.

The second edition has been revised to include the following:

- **Key concepts** and terms, which are now **highlighted** the first time they appear.
- New/updated **photos** and **line art** for **every chapter**.
- An expanded use of **bulleted lists** for lengthy explanations.
- **Additional review questions** for new topics.
- **Additional** end of chapter **Troubleshooting Scenarios** with suggested solutions.
- **Additional** end of chapter **Discussion topics** with suggested talking points.
- Updated **PowerPoint** slides for instructors.

The following content has been added to the chapters listed below:

Chapter 1 - Arc flash hazards.

Chapter 2 - DC motor applications.
- Reverse phase relay operation.

Chapter 3 - Transformer power losses.
- Transformer performance.
- Current and potential transformer connections.

Chapter 4 - Pushbutton assembly.
- Ultrasonic wind sensors.
- Thermowells.
- Double-break and dry contacts.
- Stepper motor operation.

Chapter 5 - AC and DC generators.
- Industrial motor applications.
- Asynchronous motor.
- Instruments used for troubleshooting motors.

Chapter 6 - Auxiliary contact blocks.
- Inductive loads and voltage spikes.
- Solid-state contactors.
- Microprocessor -based modular overload relay.
- Comparison of NEMA and IEC symbols and circuits.

Chapter 7 - DIN rail mounting
- Solid-state relay issues
- Relay timing diagrams

Chapter 8 - Multiple motor start-stop stations
- IEC reversing motor starter power and control circuit.
- HOA motor control circuit.
- E-stop motor control circuit.
- Soft starter versus variable frequency drive.
- Limit switch motor control applications.

Chapter 9 - Diode Testing.
- Bipolar junction transistor testing.
- Field-effect transistor testing.
- SCR testing.
- Triac testing.

Chapter 10 - Open and closed loop control.
- Vector drives.
- Four-quadrant control.
- Fixed PLC controllers.

Ancillaries

- **Activities Manual for *Electric Motors and Control Systems.*** This manual contains quizzes, practical assignments, and computer-generated simulated circuit analysis assignments.

  Quizzes made up of multiple choice, true/false, and completion-type questions are provided for each part of each chapter. These serve as an excellent review of the material presented.

  Practical assignments are designed to give the student an opportunity to apply the information covered in the text in a hands-on motor installation.

  The Constructor motor control simulation software is included as part of the manual. This special edition of the program contains some 45 preconstructed simulated motor control circuits constructed using both NEMA and IEC symbols. The Constructor analysis assignments provide students with the opportunity to test and troubleshoot the motor control circuits discussed in the text. The Constructor simulation engine visually displays power flow to each component and using animation and sound effects, each component will react accordingly once power is supplied.

Connect Engineering Technology®

Get Connected. Get Results.

McGraw-Hill Connect is a digital teaching and learning environment that improves performance over a variety of critical outcomes; it is easy to use; and it is proven effective.

McGraw-Hill Connect strengthens the link between faculty, students, and coursework. Innovative, adaptive technology aligns the goals of students and faculty, allowing them to work together to accomplish more, in less time. It engages students in the course content so they are better prepared, are more active in discussion, and achieve better results. Faculty get it. Students get it. Now that's Connected. Ask your McGraw-Hill Representative for more detail and check it out at http://connect.mheducation.com/.

McGraw-Hill LearnSmart®

LearnSmart is one of the most effective and successful adaptive learning resources available on the market today. More than 2 million students have answered more than 1.3 billion questions in LearnSmart since 2009, making it the most widely used and intelligent adaptive study tool that's proven to strengthen memory recall, keep students in class, and boost grades. Students using LearnSmart are 13% more likely to pass their classes, and 35% less likely to dropout.

Distinguishing what students know from what they don't, and honing in on concepts they are most likely to forget, LearnSmart continuously adapts to each student's needs by building an individual learning path so students study smarter and retain more knowledge. Turnkey reports provide valuable insight to instructors, so precious class time can be spent on higher-level concepts and discussion.

This revolutionary learning resource is available only from McGraw-Hill Education, and because LearnSmart is available for most course areas, instructors can recommend it to students in almost every class they teach. Ask your McGraw-Hill Representative for more detail and check it out at http://learnsmartadvantage.com/products/learnsmart/.

McGraw-Hill SmartBook®

Fueled by LearnSmart—the most widely used and intelligent adaptive learning resource—SmartBook is the first and only adaptive reading experience available today.

Distinguishing what a student knows from what they don't, and honing in on concepts they are most likely to forget, SmartBook personalizes content for each student in a continuously adapting reading experience. Reading is no longer a passive and linear experience, but an engaging and dynamic one where students are more likely to master and retain important concepts, coming to class better prepared. Valuable reports provide instructors insight as to how students are progressing through textbook content, and are useful for shaping in-class time or assessment.

As a result of the adaptive reading experience found in SmartBook, students are more likely to retain knowledge, stay in class and get better grades.

This revolutionary technology is available only from McGraw-Hill Education and for hundreds of course areas as part of the LearnSmart Advantage series. Ask your McGraw-Hill Representative for more detail and check it out at http://learnsmartadvantage.com/products/smartbook/.

Electronic Textbook

This text is available as an eBook at www.CourseSmart.com. At CourseSmart your students can take advantage of significant savings off the cost of a print textbook, reduce their impact on the environment, and gain access to powerful web tools for learning. CourseSmart eBooks can be viewed online or downloaded to a computer.

The eBooks allow students to do fully text searches, add highlighting and notes, and share notes with classmates. CourseSmart has the largest selection of eBooks available anywhere. Visit www.CourseSmart.com to learn more and to try a sample chapter.

McGraw-Hill Create™

McGraw-Hill Create™ is a self-service website that allows you to create customized course materials using McGraw-Hill's comprehensive, cross-disciplinary content and digital products. You can even access third party content such as readings, articles, cases, videos, and more. Arrange the content you've selected to match the scope and sequence of your course. Personalize your book with a cover design and choose the best format for your students–eBook, color print, or black-and-white print. And, when you are done, you'll receive a PDF review copy in just minutes! Check out Create at http://create.mheducation.com/.

- **Instructor's Resources** are available to instructors who adopt *Electric Motors and Control Systems*. They can be found on the Instructor Library on Connect and include:

  Answers to the textbook review questions and the Activities Manual quizzes and assignments.

  PowerPoint presentations that feature enhanced graphics along with explanatory text and objective-type questions.

  EZ Test testing software with text-coordinated question banks.

  ExamView text coordinated question banks.

Directions for accessing the Instructor Resources through Connect

To access the Instructor Resources through Connect, you must first contact your McGraw-Hill Learning Technology Representative to obtain a password. If you do not know your McGraw-Hill representative, please go to www.mhhe.com/rep, to find your representative.

Once you have your password, please go to connect.mheducation.com, and log in. Click on the course for which you are using *Electric Motors and Control Systems*. If you have not added a course, click "Add Course," and select "Engineering Technology" from the drop-down menu. Select *Electric Motors and Control Systems,* 2e and click "Next."

Once you have added the course, Click on the "Library" link, and then click "Instructor Resources."

Acknowledgments

The efforts of many people are needed to develop and improve a text. Among these people are the reviewers and consultants who point out areas of concern, cite areas of strength, and make recommendations for change. In this regard, the following people provided feedback that was enormously helpful in preparing *Electric Motors and Control Systems*. Each of those who have offered comments and suggestions has our thanks.

Iry Rice
Southeast Arkansas College

Tom Newman
Bates Technical College

Kyle Brown
College of Southern Idaho

Gholam H. Massiha
University of Louisiana at Lafayette

Rick Peters
Yavapai College

Alan Stanfield
Southern Crescent Technical College

William Walker
Truckee Meadows Community College

Radian Belu
Drexel University

Philip David Weinsiser
Bowling Green State University

John Pierce
Central Alabama Community College

Ed Dyvig
Iowa Central Community College

Omar Zia
Southern Polytechnic State University

Fred Cope
Northeast State Community College

Steven Gonzales
The College of San Mateo

About the Author

Frank D. Petruzella has extensive practical experience in the electrical motor control field, as well as many years of experience teaching and authoring textbooks. Before becoming a full time educator, he was employed as an apprentice and electrician in areas of electrical installation and maintenance. He holds a Master of Science degree from Niagara University, a Bachelor of Science degree from the State University of New York College–Buffalo, as well as diplomas in Electrical Power and Electronics from the Erie County Technical Institute.

E*lectric Motors and Control Systems*, 2e contains the most up-to-date information on electric motor operation, selection, installation, control and maintenance. The text provides a balance between concepts and applications to offer students an accessible framework to introduce a broad range of motor types and control systems.

Electric Motors and Control Systems provides . . .

CHAPTER OBJECTIVES provide an outline of the concepts that will be presented in the chapter. These objectives provide a roadmap to students and instructors on what new material will be presented.

Chapter Objectives

This chapter will help you:

1. Recognize symbols frequently used on motor and control diagrams.
2. Read and construct ladder diagrams.
3. Read wiring, single-line, and block diagrams.
4. Become familiar with the terminal connections for different types of motors.
5. Interpret information found on motor nameplates.
6. Become familiar with the terminology used in motor circuits.
7. Understand the operation of manual and magnetic motor starters.

CIRCUIT LISTS When a new operation of a circuit is presented, a bulleted list is used to summarize the operation. The lists are used in place of paragraphs to provide a more accessible summary of the necessary steps of a motor control operation.

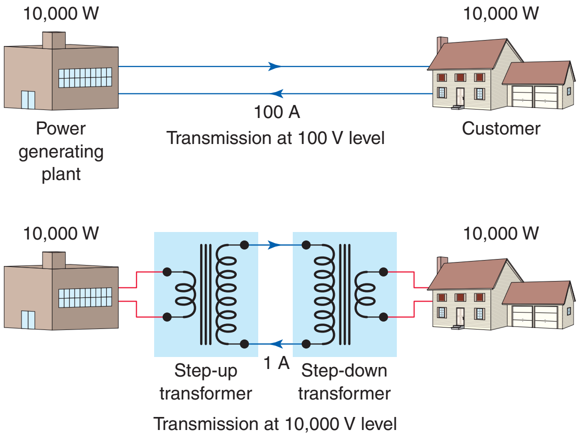

Figure 3-2 High voltage reduces the required amount of transmission current required.

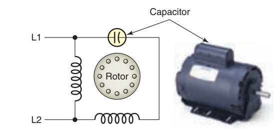

Figure 2-32 Permanent-split capacitor motor.
Photo courtesy Leeson, www.leeson.com.

three-phase motors. In addition, single-phase motors are not self-starting on their running windings, as are three-phase motors.

Large horsepower AC motors are usually three-phase. All three-phase motors are constructed internally with a number of individually wound coils. Regardless of how many individual coils there are, the individual coils will always be wired together (series or parallel) to produce three distinct windings, which are referred to as phase A, phase B, and phase C. All three-phase motors are wired so that the phases are connected in either **wye (Y)** or **delta (Δ)** configuration, as illustrated in Figure 2-33.

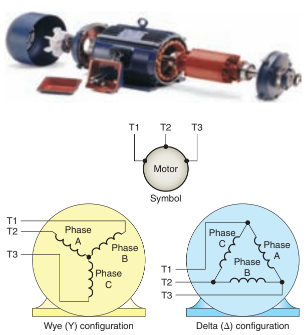

Figure 2-33 Three-phase wye and delta motor connections.
Photo courtesy Leeson, www.leeson.com.

DIAGRAMS AND PHOTOS When the operation of a piece of equipment is illustrated, a photo of the device is included. The integration of diagrams and photos increases the students' recognition of devices associated with motor and control systems.

an engaging framework in every chapter to help students master concepts and realize success beyond the classroom.

REVIEW QUESTIONS Each chapter is divided into parts designed to represent individual lessons. These parts provide professors and students the flexibility to pick and choose topics that best represent their needs. Review questions follow each part to reinforce the new concepts that have been introduced.

PART 1 *Review Questions*

1. Define the term *motor control circuit*.
2. Why are symbols used to represent components on electrical diagrams?
3. An electrical circuit contains three pilot lights. What acceptable symbol could be used to designate each light?
4. Describe the basic structure of an electrical ladder diagram schematic.
5. Lines are used to represent electrical wires on diagrams.
   a. How are wires that carry high current differentiated from those that carry low current?
   b. How are wires that cross but do not electrically connect differentiated from those that connect electrically?
6. The contacts of a pushbutton switch open when the button is pressed. What type of push button would this be classified as? Why?
7. A relay coil labeled TR contains three contacts. What acceptable coding could be used to identify each of the contacts?
8. A rung on a ladder diagram requires that two loads, each rated for the full line voltage, be energized when a switch is closed. What connection of loads must be used? Why?
9. One requirement for a particular motor application is that six pressure switches be closed before the motor is allowed to operate. What connections of switches should be used?
10. The wire identification labels on several wires of an electrical panel are examined and found to have the same number. What does this mean?
11. A broken line representing a mechanical function on an electrical diagram is mistaken for a conductor and wired as such. What two types of problems could this result in?

DISCUSSION TOPICS AND CRITICAL THINKING QUESTIONS These open-ended questions are designed to give students an opportunity to review the material covered in the chapter. These questions cover all the parts presented in each chapter and provide an opportunity for the student to show comprehension of the concepts covered.

DISCUSSION TOPICS *AND CRITICAL THINKING QUESTIONS*

1. Why are contacts from control devices not placed in parallel with loads?
2. Record all the nameplate data for a given motor and write a short description of what each item specifies.
3. Search the Internet for electric motor connection diagrams. Record all information given for the connection of the following types of motors:
   a. DC compound motor
   b. AC single-phase dual-voltage induction motor
   c. AC three-phase two-speed induction motor
4. The AC squirrel-cage induction motor is the dominant motor technology in use today. Why?
5. In general, how do NEMA motor standards compare to IEC standards?

TROUBLESHOOTING SCENARIOS These scenarios are designed to help students develop a systematic approach to troubleshooting which is vital in this course.

TROUBLESHOOTING *SCENARIOS*

Photo courtesy Fluke, www.fluke.com. Reproduced with Permission.

1. Heat is the greatest enemy of a motor. Discuss in what way nonadherence to each of the following motor nameplate parameters could cause a motor to overheat: (*a*) voltage rating; (*b*) current rating; (*c*) ambient temperature; (*d*) duty cycle.
2. Two identical control relay coils are incorrectly connected in series instead of parallel across a 230 V source. Discuss how this might affect the operation of the circuit.
3. A two-wire magnetic motor control circuit controlling a furnace fan uses a thermostat to automatically operate the motor on and off. A single-pole switch is to be installed next to the remote thermostat and wired so that, when closed, it will override the automatic control and allow the fan to operate at all times regardless of the thermostat setting. Draw a ladder control diagram of a circuit that will accomplish this.
4. A three-wire magnetic motor control circuit uses a remote start/stop pushbutton station to operate the motor on and off. Assume the start button is pressed but the starter coil does not energize. List the possible causes of the problem.
5. How is the control voltage obtained in most motor control circuits?
6. Assume you have to purchase a motor to replace the one with the specifications shown below. Visit the website of a motor manufacturer and report on the specifications and price of a replacement motor.

Horsepower	10
Voltage	200
Hertz	60
Phase	3
Full-load amperes	33
RPM	1725
Frame size	215T
Service factor	1.15
Rating	40C AMB-CONT
Locked rotor code	J
NEMA design code	B
Insulation class	B
Full-load efficiency	85.5
Power factor	76
Enclosure	OPEN

Safety in the Workplace

1

Photo Courtesy Honeywell, www.honeywell.com.

Chapter Objectives

This chapter will help you:

1. Identify the electrical factors that determine the severity of an electric shock.
2. Be aware of general principles of electrical safety including wearing approved protective clothing and using protective equipment.
3. Familiarity with arc flash hazard recognition and prevention.
4. Explain the safety aspects of grounding an electrical motor installation.
5. Outline the basic steps in a lockout procedure.
6. Be aware of the functions of the different organizations responsible for electrical codes and standards.

Safety is the number one priority in any job. Every year, electrical accidents cause serious injury or death. Many of these casualties are young people just entering the workplace. They are involved in accidents that result from carelessness, from the pressures and distractions of a new job, or from a lack of understanding about electricity. This chapter is designed to develop an awareness of the dangers associated with electrical power and the potential dangers that can exist on the job or at a training facility.

PART 1 Protecting against Electrical Shock

Electrical Shock

The human body conducts electricity. Even low currents may cause severe health effects. Spasms, burns, muscle paralysis, or death can result, depending on the amount of the current flowing through the body, the route it takes, and the duration of exposure.

The main factor for determining the severity of an electric shock is the amount of electric current that passes through the body. This current is dependent upon the voltage and the resistance of the path it follows through the body.

Electrical **resistance** (R) is the opposition to the flow of current in a circuit and is measured in ohms (Ω). The lower the body resistance, the greater the current flow and potential electric shock hazard. Body resistance can be divided into external (skin resistance) and internal (body tissues and blood stream resistance). Dry skin is a good insulator; moisture lowers the resistance of skin, which explains why shock intensity is greater when the hands are wet. Internal resistance is low owing to the salt and moisture content of the blood. There is a wide degree of variation in body resistance. A shock that may be fatal to one person may cause only brief discomfort to another. Typical body resistance values are:

- Dry skin—100,000 to 600,000 Ω
- Wet skin—1,000 Ω
- Internal body (hand to foot)—400 to 600 Ω
- Ear to ear—100 Ω

Thin or wet skin is much less resistant than thick or dry skin. When skin resistance is low, the current may cause little or no skin damage but severely burn internal organs and tissues. Conversely, high skin resistance can produce severe skin burns but prevent the current from entering the body.

Voltage (E) is the pressure that causes the flow of electric current in a circuit and is measured in units called volts (V). The amount of voltage that is dangerous to life varies with each individual because of differences in body resistance and heart conditions. Generally, any voltage *above 30 V* is considered dangerous.

Electric **current** (I) is the rate of flow of electrons in a circuit and is measured in amperes (A) or milliamperes (mA). One milliampere is one-thousandth of an ampere. The amount of current flowing through a person's body depends on the voltage and resistance. Body current can be calculated using the following Ohm's law formula:

$$\textbf{Current} = \frac{\textbf{Voltage}}{\textbf{Resistance}}$$

If you came into direct contact with 120 volts and your body resistance was 100,000 ohms, then the current that would flow would be:

$$I = \frac{120\text{ V}}{100{,}000\ \Omega}$$
$$= 0.0012\text{ A}$$
$$= 1.2\text{ mA } (0.0012 \times 1{,}000)$$

This is just about at the threshold of perception, so it would produce only a tingle.

If you were sweaty and barefoot, then your resistance to ground might be as low as 1,000 ohms. Then the current would be:

$$I = \frac{120\text{ V}}{1{,}000\ \Omega} = 0.12\text{ A} = 120\text{ mA}$$

This is a lethal shock, capable of producing ventricular fibrillation (rapid irregular contractions of the heart) and death!

Voltage is not as reliable an indication of shock intensity because the body's resistance varies so widely that it is impossible to predict how much current will result from a given voltage. The amount of current that passes through the body and the length of time of exposure are perhaps the two most reliable criteria of shock intensity. Once current enters the body, it follows through the circulatory system in preference to the external skin. Figure 1-1 illustrates the relative magnitude and effect of electric current. It doesn't take much current to cause a painful or even fatal shock. A current of 1 mA (1/1000 of an ampere) can be felt. A current of 10 mA will produce a shock of sufficient intensity to prevent voluntary control of muscles, which explains why, in some cases, the victim of electric shock is unable to release grip on the conductor while the current is flowing. A current of 100 mA passing through the body for a second or longer can be fatal. Generally, any current flow *above 0.005 A, or 5 mA,* is considered dangerous.

A 1.5 V flashlight cell can deliver more than enough current to kill a human being, yet it is safe to handle. This is because the resistance of human skin is high enough to limit greatly the flow of electric current. In lower voltage circuits, resistance restricts current flow to very low values. Therefore, there is little danger of an electric shock. Higher voltages, on the other hand, can force enough current though the skin to produce a shock. The danger of harmful shock increases as the voltage increases.

The pathway through the body is another factor influencing the effect of an electric shock. For example, a current from hand to foot, which passes through the heart and part of the central nervous system, is far more dangerous than a shock between two points on the same arm (Figure 1-2).

AC (alternating current) of the common 60 Hz frequency is three to five times more dangerous than DC (direct current) of the same voltage and current value. DC tends to cause a convulsive contraction of the muscles, often forcing the victim away from further current exposure. The effects of AC on the body depend to a great extent on the frequency: low-frequency currents (50–60 Hz) are usually more dangerous than high-frequency currents. AC causes muscle spasm, often "freezing" the hand (the most common part of the body to make contact) to the circuit. The fist clenches around the current source, resulting in prolonged exposure with severe burns.

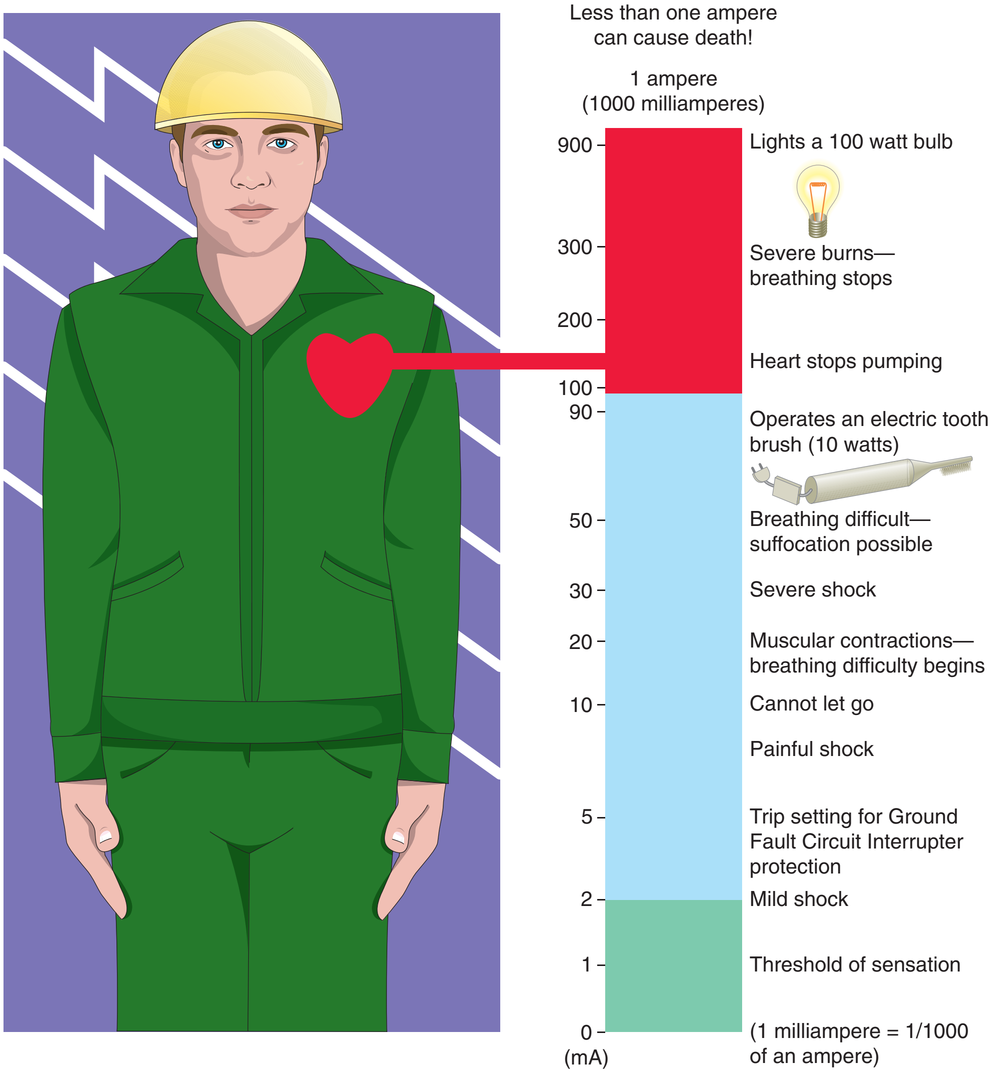

Figure 1-1 Relative magnitude and effect of electric current on the body.

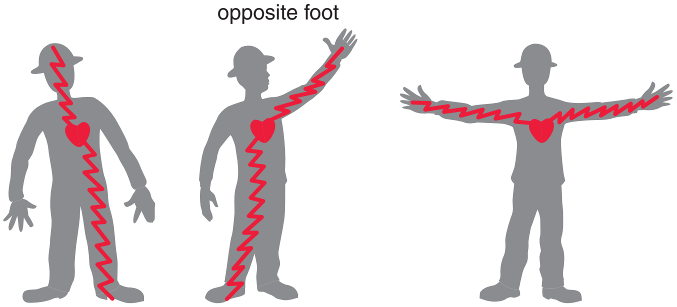

Figure 1-2 Typical electric current pathways that stop normal pumping of the heart.

The most common electric-related injury is a burn. The major types of burns:

- **Electrical burns,** which are a result of electric current flowing through the tissues or bones. The burn itself may be only on the skin surface or deeper layers of the skin may be affected.
- **Arc burns,** which are a result of an extremely high temperature caused by an electric arc (as high as 35,000°F) in close proximity to the body. Electric arcs can occur as a result of poor electrical contact or failed insulation.
- **Thermal contact burns,** which are a result of the skin coming in contact with the hot surfaces of overheated components. They can be caused by contact with objects dispersed as a result of the blast associated with an electric arc.

If a person does suffer a severe shock, it is important to free the victim from the current as quickly as can be done safely. Do not touch the person until the electric power is turned off. You cannot help by becoming a second victim. The victim should be attended to immediately by a person trained in CPR (cardiopulmonary resuscitation).

Figure 1-3 Arc flash.
Photo Courtesy Honeywell, www.honeywell.com.

Arc Flash Hazards

An **arc flash** is the ball of fire that explodes from an electrical **short circuit** between one exposed live conductor and another conductor or to ground. The arc flash creates an enormous amount of energy (Figure 1-3) that can damage equipment and cause severe injury or loss of life.

An arc flash can be caused by dropped tools, unintentional contact with electrical systems, or the buildup of conductive dust, dirt, corrosion, and particles.

Electrical short circuits are either bolted faults or arcing faults. A **bolted fault** is current flowing through bolted bus bars or other electric conductors. An **arcing fault** is current flowing through the air. Because air offers opposition to electric current flow, the arc fault current is always lower than the bolted fault current. An **arc blast** is a flash that causes an explosion of air and metal that produces dangerous pressure waves, sound waves, and molten steel.

In order to understand the hazards associated with an arc flash incident, it is important to understand the difference between an arcing short circuit and a bolted short circuit. A bolted short circuit occurs when the normal circuit current bypasses the load through a very low conductive path, resulting in current flow that can be hundreds or thousands of times the normal load current. In this case, assuming all equipment remains intact, the fault energy is contained within the conductors and equipment, and the power of the fault is dissipated throughout the circuit from the source to the short. All equipment needs to have adequate interrupting ratings to safely contain and clear the high fault currents associated with bolted faults.

In contrast, an arcing fault is the flow of current through a higher-resistance medium, typically the air, between phase conductors or between phase conductors and neutral or ground. Arcing fault currents can be extremely high in current magnitude approaching the bolted short-circuit current but are typically between 38 and 89 percent of the bolted fault. The inverse characteristics of typical overcurrent protective devices generally result in substantially longer clearing times for an arcing fault due to the lower fault values.

Eighty percent of electrical workplace accidents are associated with arc flash and involve burns or injuries caused by intense heat or showers of molten metal or debris. In addition to toxic smoke, shrapnel, and shock waves, the creation of an arc flash produces an intense flash of blinding light. This flash is capable of causing immediate vision damage and can increase a worker's risk of future vision impairment.

An arc flash hazard exists when a person interacts with equipment in a way that could cause an electric arc. Such tasks may include testing or troubleshooting, application of temporary protective grounds, or the racking in or out of power circuit breakers as illustrated in Figure 1-4. ***Arcs can produce temperature four times hotter than the surface of the sun.*** To address this hazard, safety standards such as National Fire Protection Association (NFPA) 70E have been developed to minimize arc flash hazards. The NFPA standards require that any panel likely to be serviced by a worker be **surveyed** and **labeled**. Injuries can be avoided with training; with proper work practices; and by using protective face shields, hoods, and clothing that are NFPA-compliant.

Figure 1-4 An arc flash hazard exists when a person interacts with equipment.

Figure 1-5 Typical safety signs.

Personal Protective Equipment

Construction and manufacturing worksites, by nature, are potentially hazardous places. For this reason, safety has become an increasingly large factor in the working environment. The electrical industry, in particular, regards **safety** to be unquestionably the most single important priority because of the hazardous nature of the business. A safe operation depends largely upon all personnel being informed and aware of potential hazards. Safety signs and tags indicate areas or tasks that can pose a hazard to personnel and/or equipment. Signs and tags may provide warnings specific to the hazard, or they may provide safety instructions (Figure 1-5).

To perform a job safely, the proper protective clothing must be used. Appropriate attire should be worn for each particular job site and work activity (Figure 1-6). The following points should be observed:

1. Hard hats, safety shoes, and goggles must be worn in areas where they are specified. In addition, hard hats shall be approved for the purpose of the electrical work being performed. ***Metal hats are not acceptable!***
2. Safety earmuffs or earplugs must be worn in noisy areas.
3. Clothing should fit snugly to avoid the danger of becoming entangled in moving machinery. Avoid wearing synthetic-fiber clothing such as polyester material as these types of materials may melt or ignite when exposed to high temperatures and may increase the severity of a burn. Instead always wear cotton clothing.

Figure 1-6 Appropriate attire should be worn for each particular job site and work activity.
Photo courtesy Capital Safety, www.capitalsafety.com.

4. Remove all metal jewelry when working on energized circuits; gold and silver are excellent conductors of electricity.
5. Confine long hair or keep hair trimmed when working around machinery.

A wide variety of electrical safety equipment is available to prevent injury from exposure to live electric circuits (Figure 1-7). Electrical workers should be familiar with safety standards such as **NFPA-70E** that pertain to the type of protective equipment required, as well as how such equipment shall be cared for. To make sure electrical protective equipment actually performs as designed, it must be inspected for damage before each day's use and immediately following any incident that can reasonably be suspected of having caused damage. All electrical protection equipment must be listed and may include the following:

Rubber Protective Equipment—Rubber gloves are used to prevent the skin from coming into contact with energized circuits. A separate outer leather cover is used to protect the rubber glove from punctures and other damage. Rubber blankets are used to prevent contact with energized conductors or circuit parts when working near exposed energized circuits. All rubber protective equipment must be marked with the appropriate voltage rating and the last inspection date. It is important that the insulating value of both rubber gloves and blankets have a voltage rating that matches that of the circuit or equipment they are to be used with. Insulating gloves must be given an air test, along with inspection. Twirl the glove around quickly or roll it down to trap air inside. Squeeze the palm, fingers,

Figure 1-7 Electrical safety equipment.
Photos courtesy W.W. Grainger, www.grainger.com.

and thumb to detect any escaping air. If the glove does not pass this inspection, it must be disposed of.

Protection Apparel—Special protective equipment available for high-voltage applications include high-voltage sleeves, high-voltage boots, nonconductive protective helmets, nonconductive eyewear and face protection, switchboard blankets, and flash suits.

Hot Sticks—Hot sticks are insulated tools designed for the manual operation of high-voltage disconnecting switches, high-voltage fuse removal and insertion, as well as the connection and removal of temporary grounds on high-voltage circuits. A hot stick is made up of two parts, the head, or hood, and the insulating rod. The head can be made of metal or hardened plastic, while the insulating section may be wood, plastic, or other effective insulating materials.

Shorting Probes—Shorting probes are used on de-energized circuits to discharge any charged capacitors or built-up static charges that may be present when power to the circuit is disconnected. Also, when working on or near any high-voltage circuits, shorting probes should be connected and left attached as an extra safety precaution in the event of any accidental application of voltage to the circuit. When installing a shorting probe, first connect the test clip to a good ground contact. Next, hold the shorting probe by the handle and hook the probe end over the part or terminal to be grounded. Never touch any metal part of the shorting probe while grounding circuits or components.

Face Shields—Listed face shields should be worn during all switching operations where there is a possibility of injury to the eyes or face from electrical arcs or flashes, or from flying or falling objects that may result from an electrical explosion.

With proper precautions, there is no reason for you to ever receive a serious electrical shock. Receiving an electrical shock is a clear warning that proper safety measures have not been followed. To maintain a high level of electrical safety while you work, there are a number of precautions you should follow. Your individual job will have its own unique safety requirements. However, the following are given as essential basics.

- Never take a shock on purpose.
- Keep material or equipment at least 10 feet away from high-voltage overhead power lines.
- Do not close any switch unless you are familiar with the circuit that it controls and know the reason for its being open.
- When working on any circuit, take steps to ensure that the controlling switch is not operated in your absence. Switches should be padlocked open, and warning notices should be displayed (**lockout/tagout**).
- Avoid working on "live" circuits as much as possible.
- When installing new machinery, ensure that the framework is efficiently and permanently grounded.
- Always treat circuits as "live" until you have proven them to be "dead." Presumption at this point can kill you. It is a good practice to take a meter reading before starting work on a dead circuit.
- Avoid touching any grounded objects while working on electrical equipment.
- Remember that even with a 120 V control system, you may well have a higher voltage in the panel. Always work so that you are clear of any of the higher voltages. (Even though you are testing a 120 V system, you are most certainly in close proximity to 240 V or 480 V power.)
- Don't reach into energized equipment while it is being operated. This is particularly important in high-voltage circuits.
- Use good electrical practices even in temporary wiring for testing. At times you may need to make alternate connections, but make them secure enough so that they are not in themselves an electrical hazard.
- When working on live equipment containing voltages over approximately 30 V, work with only one hand. Keeping one hand out of the way greatly reduces the possibility of passing a current through the chest.
- Safely discharge capacitors before handling them. Capacitors connected in live motor control circuits can store a lethal charge for a considerable time after the voltage to the circuits has been switched off. Although Article 460 of the National Electrical Code (NEC) requires an automatic **discharge** within 1 minute, never assume that the discharge is working! Always verify that there is no voltage present.

Confined spaces can be found in almost any workplace. Figure 1-8 illustrates examples of typical confined spaces. In general, a "confined space" is an enclosed or partially enclosed space that:

- Is not primarily designed or intended for human occupancy.
- Has a restricted entrance or exit by way of location, size, or means.
- Can represent a risk for the health and safety of anyone who enters, because of its design, construction, location, or atmosphere; the materials or substances in it; work activities being carried out in it; or the mechanical, process, and safety hazards present.

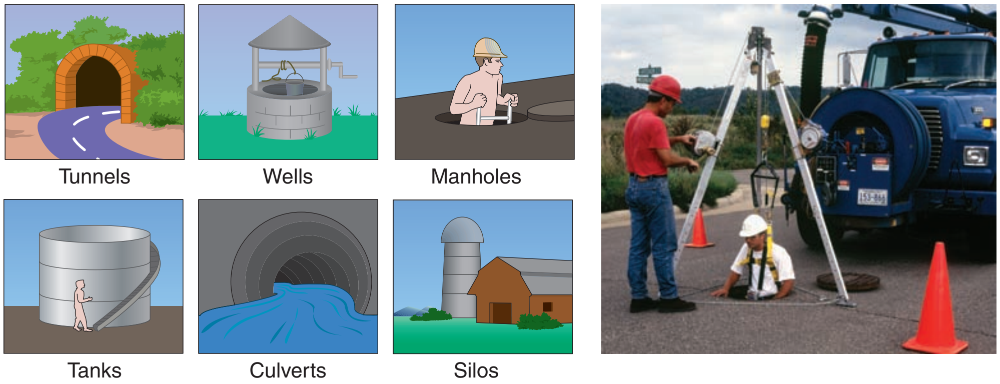

Figure 1-8 Confined spaces.
Photo courtesy Capital Safety, www.capitalsafety.com.

All hazards found in a regular workspace can also be found in a confined space. However, they can be even more hazardous in a confined space than in a regular worksite. Hazards in confined spaces can include poor air quality, fire hazard, noise, moving parts of equipment, temperature extremes, poor visibility, and barrier failure resulting in a flood or release of free-flowing solid. A "permit-required confined space" is a confined space that has specific health and safety hazards associated with it. Permit-required confined spaces require assessment of procedures in compliance with Occupational Safety and Health Administration (OSHA) standards prior to entry.

PART 1 *Review Questions*

1. Does the severity of an electric shock increase or decrease with each of the following changes?
   a. A decrease in the source voltage
   b. An increase in body current flow
   c. An increase in body resistance
   d. A decrease in the length of time of exposure
2. a. Calculate the theoretical body current flow (in amperes and milliamperes) of an electric shock victim who comes in contact with a 120 V energy source. Assume a total resistance of 15,000 Ω (skin, body, and ground contacts).
   b. What effect, if any, would this amount of current likely have on the body?
3. Normally a 6 volt lantern battery capable of delivering 2 A of current is considered safe to handle. Why?
4. Why is AC of a 60 Hz frequency considered to be potentially more dangerous than DC of the same voltage and current value?
5. What circuit fault can result in an arc flash?
6. Define each of the following terms associated with an arc flash:
   a. *Bolted fault*
   b. *Arcing fault*
   c. *Arc blast*
7. Explain why an arc flash is so potentially dangerous.
8. State the piece of electrical safety equipment that should be used to perform each of the following tasks:
   a. A switching operation where there is a risk of injury to the eyes or face from an electric arc.
   b. Using a multimeter to verify the line voltage on a 3-phase 480 volt system.
   c. Opening a manually operated high-voltage disconnect switch.
9. Outline the safety procedure to follow when you are connecting shorting probes across deenergized circuits.
10. List three pieces of personal protection equipment required to be worn on most job sites.

PART 2 Grounding—Lockout—Codes

Grounding and Bonding

Proper grounding practices protect people from the hazards of electric shock and ensure the correct operation of overcurrent protection devices. Intentional grounding is required for the safe operation of electrical systems and equipment. Unintentional or accidental grounding is considered a fault in electrical wiring systems or circuits.

"Grounding" is the intentional connection of a current-carrying conductor to the earth. For AC premises wiring systems in buildings and similar structures, this ground connection is made on the premise side of the service equipment and the supply source, such as a utility transformer. The prime reasons for grounding are:

- To limit the voltage surges caused by lightning, utility system operations, or accidental contact with higher-voltage lines.
- To provide a ground reference that stabilizes the voltage under normal operating conditions.
- To facilitate the operation of overcurrent devices such as circuit breakers, fuses, and relays under ground-fault conditions.

"Bonding" is the permanent joining together of metal parts that aren't intended to carry current during normal operation, which creates an electrically conductive path that can safely carry current under ground-fault conditions. The prime reasons for bonding are:

- To establish an effective path for fault current that facilitates the operation of overcurrent protective devices.
- To minimize shock hazard to people by providing a low-impedance path to ground. Bonding limits the touch voltage when non-current-carrying metal parts are inadvertently energized by a ground fault.

The Code requires all metal used in the construction of a wiring system to be bonded to, or connected to, the ground system. The intent is to provide a low-impedance path back to the utility transformer in order to quickly clear faults. Figure 1-9 illustrates the ground-fault current path required to ensure that overcurrent devices operate to open the circuit. The earth is not considered an effective ground-fault current path. The resistance of earth is so high that very little fault current returns to the electrical supply source through the earth. For this reason the main bonding jumper is used to provide the connection between the grounded service conductor and the equipment grounding conductor at the service. Bonding jumpers may be located throughout the electrical system, but a main bonding jumper is located only at the service entrance. Grounding is accomplished by connecting the circuit to a metal underground water pipe, the metal frame of a building, a concrete-encased electrode, or a ground ring.

A grounding system has two distinct parts: system grounding and equipment grounding. **System grounding** is the electrical connection of one of the current carrying conductors of the electrical system to the ground. **Equipment grounding** is the electrical connection of all the metal parts that do not carry current to ground. Conductors that form parts of the grounding system include the following:

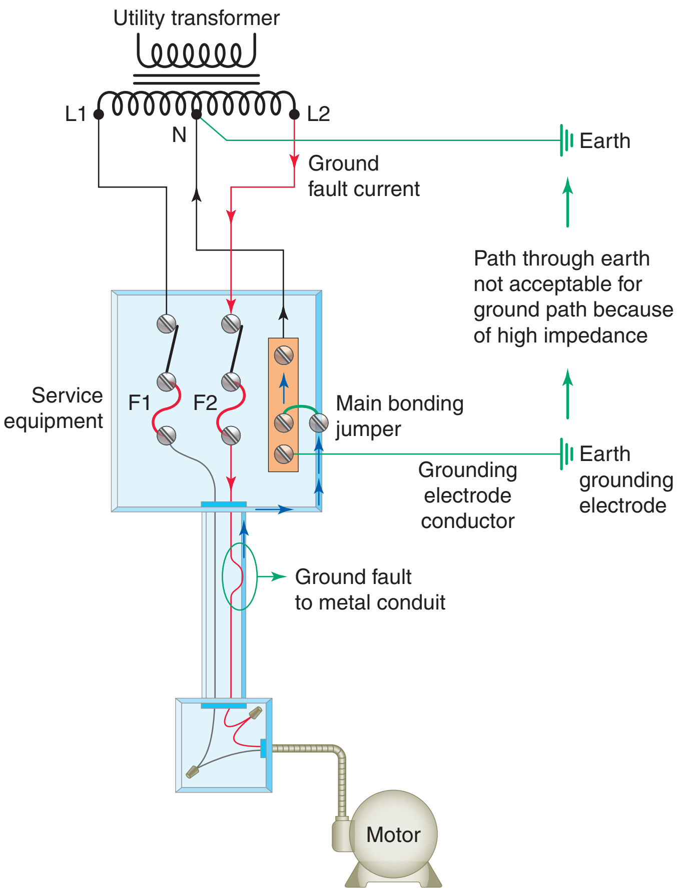

Figure 1-9 Ground-fault current path.

Equipment grounding conductor (EGC) is an electrical conductor that provides a low-impedance ground path between electrical equipment and enclosures within the distribution system. Figure 1-10 shows the connection for an EGC. Electrical motor windings are normally insulated from all exposed non-current-carrying metal parts of the motor. However, if the insulation system should fail, then the motor frame could become energized at line voltage. Any person contacting a grounded surface and the energized motor frame simultaneously could be severely injured or killed. Effectively grounding the motor frame forces it to take the same zero potential as the earth, thus preventing this possibility.

Grounded conductor is a conductor that has been intentionally grounded.

Grounding electrode conductor is a conductor used to connect the equipment grounding conductor or the grounded conductor (at the service entrance or at the separately derived system) to the grounding electrode(s). A **separately derived system** is a system that supplies electrical power derived (taken) from a source other than a service, such as the secondary of a distribution transformer.

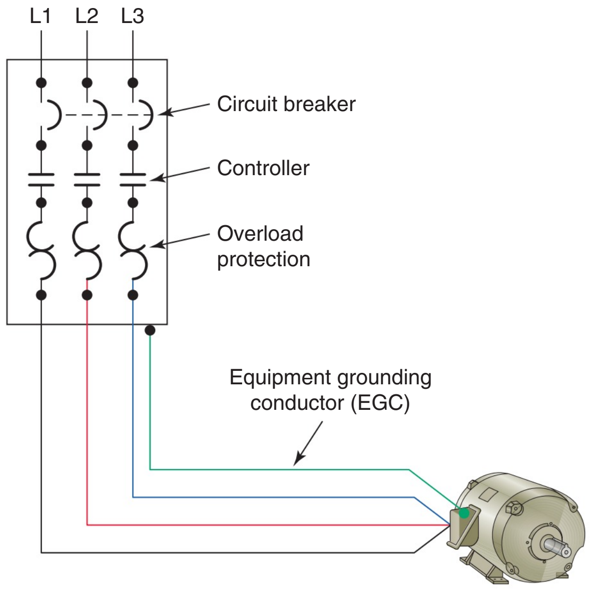

Figure 1-10 Equipment grounding conductor (EGC).

A **ground fault** is defined as an unintentional, electrically conducting connection between an ungrounded conductor of an electric circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth. The **ground-fault circuit interrupter (GFCI)** is a device that can sense small ground-fault currents. The GFCI is fast acting; the unit will shut off the current or interrupt the circuit within 1/40 second after its sensor detects a leakage as small as 5 milliamperes (mA). Most circuits are protected against overcurrent by 15 ampere or larger fuses or circuit breakers. This protection is adequate against short circuits and overloads. Leakage currents to ground may be much less than 15 amperes and still be hazardous.

Figure 1-11 shows the simplified circuit of a GFCI receptacle. The device compares the amount of current in the ungrounded (hot) conductor with the amount of current in the grounded (neutral) conductor. Under normal operating conditions, the two will be **equal** in value. If the current in the neutral conductor becomes less than the current in the hot conductor, a ground-fault condition exists. The amount of current that is missing is returned to the source by the ground-fault path. Whenever the ground-fault current exceeds approximately *5 mA,* the device automatically opens the circuit to the receptacle.

GFCIs can be used successfully to reduce electrical hazards on construction sites. The ground-fault protection rules and regulations of OSHA have been determined necessary and appropriate for employee safety and health. According to OSHA, it is the employer's responsibility to provide either (1) ground-fault circuit interrupters on construction sites for receptacle outlets in use and not part of the permanent wiring of the building or structure or (2) a

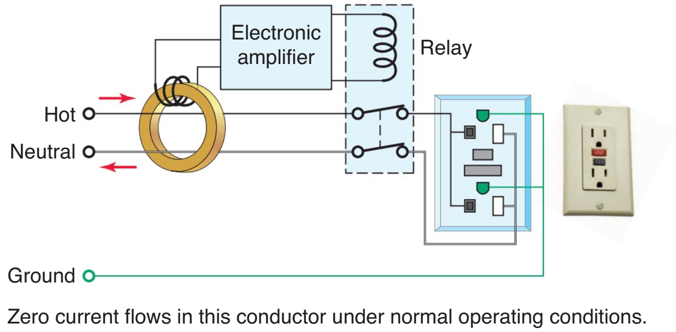

Figure 1-11 GFCI receptacle.
© TRBfoto/Getty Images RF.

scheduled and recorded assured equipment-grounding conductor program on construction sites, covering all cord sets, receptacles that are not part of the permanent wiring of the building or structure, and equipment connected by cord and plug that are available for use or used by employees.

Lockout and Tagout

Electrical "lockout" is the process of removing the source of electrical power and installing a lock, which prevents the power from being turned ON. Electrical "tagout" is the process of placing a danger tag on the source of electrical power, which indicates that the equipment may not be operated until the danger tag is removed (Figure 1-12). This procedure is necessary for the safety of personnel in that it ensures that no one will inadvertently energize the equipment while it is being worked on. Electrical lockout and tagout is used when servicing electrical equipment that does not require power to be on to perform the service as in the case of motor alignment or replacement of a motor or motor control component.

Figure 1-12 Lockout/tagout devices.
Photos courtesy Panduit Corp, www.panduit.com.