Mike Holt's

2026 NEC®

MASTER SUPREME VIDEO LIBRARY

Table of Contents

Explore the library

This document includes the Table of Contents from each book that is included in this library. Click on the title to navigate to the page with the content details for that book.

INCLUDED BOOKS

Electrical Fundamentals

- Understanding Electrical Theory
- Basic Motor Controls

Electrical Exam Preparation

- Fundamental NEC Calculations
- Electrical Exam Preparation
- Master Electrician Simulated Exams

National Electrical Code

- Understanding the NEC Volume 1
- Understanding the NEC Workbook
- Bonding and Grounding
- Understanding the NEC Volume 2
- Solar PV and Interconnected Power Systems

Business and Personal Development

- Life Skills

TABLE OF CONTENTS

About This Textbook ix

Additional Products to Help You Learn xii

CHAPTER 1—ELECTRICAL FUNDAMENTALS 1

Unit 1—Atomic Structure 3
1.1 Introduction 3
1.2 Atomic Theory 3
1.3 Electrostatic Field 4
1.4 Atomic Charge of an Atom 5
1.5 Electrostatic Charge and Discharge 6
1.6 Lightning 7
1.7 Lightning Protection System 8

Unit 2—Electron Theory and Chemical Bonding 9
2.1 Introduction 9
2.2 Electron Orbitals 9
2.3 Valence Electrons 9
2.4 Freeing Valence Electron(s) from an Atom 10
2.5 Conductance 10
2.6 Insulators 12
2.7 Semiconductors 12
2.8 Chemical Bonding 13

Unit 3—Electrical Circuits and Power Sources 15
3.1 Introduction 15
3.2 The Electrical Circuit 15
3.3 Electric Current Flow (Electricity) 15
3.4 Electrical Power Sources 16

Unit 4—The Electrical System 21
4.1 Introduction 21
4.2 Source of Electrical Generation 21
4.3 Step-Up Transmission Voltage 21
4.4 High-Voltage Transmission Lines 22
4.5 Primary Distribution Voltage 22
4.6 Primary Distribution Wires 22
4.7 Secondary Distribution Voltage 23
4.8 Service Drop and Service Lateral 23

Chapter 1—Practice Questions 25

CHAPTER 2—USES AND DANGERS OF ELECTRICITY 33

Unit 5—Uses of Electricity 35
5.1 Introduction 35
5.2 Uses of Electricity 35
5.3 Electrochemical Processes 35
5.4 Electromagnetism 35
5.5 Photoelectricity 36
5.6 Electric Heating 37
5.7 Lighting 39

Unit 6—Dangers of Electricity 41
6.1 Introduction 41
6.2 *National Electrical Code (NEC)* 41
6.3 Electrical Fire 41
6.4 Electric Shock 42
6.5 Electric Arc Flash and Arc Blast 43
6.6 Arc Flash Incident Energy 44
6.7 Electrically Safe Work Condition 45
6.8 Personal Protective Equipment 46

Chapter 2—Practice Questions 49

CHAPTER 3—MAGNETISM AND ELECTROMAGNETISM 55

Unit 7—Basics of Magnetism 57
7.1 Introduction 57
7.2 The Natural Magnet 57
7.3 Magnetic Polarities 57
7.4 Theory of Magnetism 58
7.5 Permanent and Temporary Magnets 58
7.6 Magnetizing and Demagnetizing Magnets 58

Table of Contents

7.7 Magnetic Lines of Force 59
7.8 Law of Attraction and Repulsion of Magnets 59

Unit 8—Electromagnetism 61
8.1 Introduction 61
8.2 Electromagnetism in a Wire 61
8.3 Electromagnet Field Interaction 62
8.4 Electromagnetic Field Interaction of Wire Loops 62
8.5 Electromagnetic Core 63

Unit 9—Uses of Electromagnetism 65
9.1 Introduction 65
9.2 Motors 65
9.3 Generators 66
9.4 Relays 66
9.5 Transformers 66

Chapter 3—Practice Questions 67

CHAPTER 4—MATHEMATICS 71

Unit 10—Basic Math 73
10.1 Introduction 73
10.2 Whole Numbers 73
10.3 Fractional Numbers 73
10.4 Decimal Numbers 73
10.5 Percentages 74
10.6 Parentheses 75
10.7 Squaring a Number 75
10.8 Square Root 75
10.9 Kilo 76
10.10 Rounding 76
10.11 Surface Area of a Rectangle or Square 76
10.12 Surface Area of a Circle 77
10.13 Volume 79
10.14 Reciprocal 79
10.15 Testing Your Answer 79

Unit 11—Trigonometry 81
11.1 Introduction 81
11.2 Triangles 81
11.3 Right Triangle 81
11.4 Pythagorean Theorem 82
11.5 Practical Use of Trigonometry 83

Chapter 4—Practice Questions 85

CHAPTER 5—OHM'S LAW AND WATT'S LAW 91

Unit 12—Ohm's Law 93
12.1 Introduction 93
12.2 The Electrical Circuit 93
12.3 Electromotive Force (Pressure) 93
12.4 Circuit Resistance 94
12.5 Circuit Intensity 95
12.6 Ohm's Law 95
12.7 Ohm's Law Formula Circle 96

Unit 13—Watt's Law 99
13.1 Introduction 99
13.2 Watt's Law 99
13.3 Power Formula Circle 100
13.4 Power Changes with the Square of the Voltage 101

Chapter 5—Practice Questions 103

CHAPTER 6—ELECTRICAL CIRCUIT TYPES 107

Unit 14—Series Circuits 109
14.1 Introduction 109
14.2 Series Circuits 109
14.3 Understanding Series Circuits 109
14.4 Series Circuit Summary 113
14.5 Series-Connected Power Supplies 113
14.6 Applications of Series Circuits 114

Unit 15—Parallel Circuits 117
15.1 Introduction 117
15.2 Understanding Parallel Circuits 117
15.3 Parallel Circuit Resistance Calculations 119
15.4 Parallel Circuit Summary 122
15.5 Parallel-Connected Power Supplies 122
15.6 Practical Uses of Parallel Circuits 123

Unit 16—Series-Parallel Circuits 125
16.1 Introduction 125
16.2 Understanding Series-Parallel Circuits 125
16.3 Calculating Resistance in Series-Parallel Circuits 126

Chapter 6—Practice Questions 129

CHAPTER 7—ALTERNATING CURRENT 137

Unit 17—Alternating Current Fundamentals 139
17.1 Introduction 139
17.2 How Alternating Current is Produced 139
17.3 Waveforms 140
17.4 Frequency 143
17.5 In-Phase Waveforms 143
17.6 Out-of-Phase Waveforms 143
17.7 Alternating-Current Waveform Values 144

Unit 18—Inductance 147
18.1 Introduction 147
18.2 How Inductance Works 147
18.3 Self-Inductance 147
18.4 Mutual Inductance 148
18.5 Inductive Reactance 149
18.6 Uses of Induction 150

Unit 19—Capacitance 151
19.1 Introduction 151
19.2 Capacitance in Capacitors 151
19.3 Capacitor Charge and Discharge 152
19.4 Capacitive Reactance 152
19.5 Uses of Capacitors 153

Unit 20—True Power, Power Factor, and Apparent Power 155
20.1 Introduction 155
20.2 True Power 155
20.3 Power Losses of Wires 156
20.4 Power Losses at Terminals 156
20.5 Equipment Efficiency 157
20.6 Cost of Power 158
20.7 Power Factor 159
20.8 Apparent Power 160
20.9 Apparent Power versus True Power 161
20.10 Effects of Power Factor on Circuits 162

Chapter 7—Practice Questions 165

CHAPTER 8—MOTORS, GENERATORS, RELAYS, AND TRANSFORMERS 177

Unit 21—Motors 179
21.1 Introduction 179
21.2 Alternating-Current Motor Principles 179
21.3 Motor Horsepower Rating 180
21.4 Motor Amperes 181
21.5 Motor Nameplate Amperes 182
21.6 Dual-Voltage Motors 184
21.7 Reversing the Rotation of Alternating-Current Motors 185
21.8 Alternating-Current Motor Types 186

Unit 22—Generators 187
22.1 Introduction 187
22.2 Generator Prime Mover 187
22.3 Alternating-Current Generators 187
22.4 Generator Output Current 188
22.5 Single-Phase and Three-Phase Generator Voltages 189
22.6 Electrical Industry Voltages 189

Unit 23—Relays 191
23.1 Introduction 191
23.2 How Relays Operate 191
23.3 Relay Contacts 192

Unit 24—Transformers 193
24.1 Introduction 193
24.2 Types of Transformers 193
24.3 Primary versus Secondary 193
24.4 Transformer Mutual Induction 194
24.5 Secondary Induced Voltage 194
24.6 Transformer Turns Ratios 194
24.7 Isolation Transformer (1:1) 196
24.8 Autotransformer 197
24.9 Transformer kVA Rating 197
24.10 Transformer Current Flow 197
24.11 Transformer Current Rating 197
24.12 Transformer Configurations 200
24.13 Delta/Wye Transformers 201
24.14 Delta/Delta (High-Leg) Transformer 203

Chapter 8—Practice Questions 205

Table of Contents

CHAPTER 9—PROTECTIVE DEVICES 215

Unit 25—Overcurrent Protection 217
25.1 Introduction 217
25.2 Overcurrent Protection 217
25.3 Fuses 219
25.4 Circuit Breakers 221
25.5 Overcurrent Protective Devices, Time-Current Curves 222
25.6 Available Short-Circuit Current 223
25.7 Overcurrent Protective Devices, Interrupting Rating 225
25.8 Equipment Short-Circuit Current Rating (SCCR) 225
25.9 Coordination of Overcurrent Protective Devices 226

UNIT 26—GFCIs, GFPEs, AFCIs, AND SPDs 229
26.1 Introduction 229
26.2 Ground-Fault Circuit Interrupters (GFCIs) 229
26.3 Special Purpose Ground-Fault Circuit Interrupters (SPGFCIs) 231
26.4 Ground-Fault Protection of Equipment (GFPEs) 231
26.5 Arc-Fault Circuit Interrupters (AFCIs) 232
26.6 Clearing Arcing Faults 232
26.7 Surge Protective Devices (SPDs) 233
26.8 How Surge Protective Device Functions 234

Chapter 9—Practice Questions 235

CHAPTER 10—GENERAL KNOWLEDGE 241

Unit 27—Wire Resistance and Voltage Drop 243
27.1 Introduction 243
27.2 Wire Sizes 243
27.3 Direct-Current Wire Resistance 243
27.4 *NEC* Wire Direct-Current Resistance 244
27.5 Alternating-Current Wire Resistance 245
27.6 Alternating-Current Resistance versus Direct-Current Resistance 246
27.7 Wire Voltage Drop—Ohm's Law Method 246

Unit 28—Multiwire Circuits 249
28.1 Introduction 249
28.2 Neutral Wire 249
28.3 Grounded Wire 250
28.4 Current Flow on the Neutral Wire 250
28.5 Multiwire Branch Circuits 251
28.6 Dangers of Multiwire Circuits 253
28.7 *NEC* Requirements 254

Unit 29—The Formula Wheel 255
29.1 Introduction 255
29.2 Formula Wheel Quadrants 255
29.3 Using the Formula Wheel 256

Chapter 10—Practice Questions 259

FINAL EXAM 267

INDEX 279

About the Author 283

About the Illustrator 284

About the Mike Holt Team 285

Table of Contents

Introduction ix
Scope of *Understanding Basic Motor Controls* ix
How to Use This Textbook ix

CHAPTER 1—INTRODUCTION TO MOTOR CONTROLS 1

UNIT 1—BASIC PRINCIPLES OF MOTOR CONTROLS 3
Unit 1—Introduction 3
1.1 Motor Control Language 4
1.2 Motor Control Basics 8
Unit 1—Conclusion 8
Unit 1—Practice Questions 9

UNIT 2—DEFINITIONS, ABBREVIATIONS, AND SYMBOLS 11
Unit 2—Introduction 11
2.1 Definitions of Control Terminology 11
2.2 Common Abbreviations Used for Electrical Terms and Devices 18
2.3 Standard Symbols 19
Unit 2—Conclusion 20
Unit 2—Practice Questions 21

UNIT 3—COMMON CONTROL EQUIPMENT, DEVICES, AND SYMBOLS 23
Unit 3—Introduction 23
3.1 Auxiliary Contacts 23
3.2 Relays 24
3.3 Drum Switch 25
3.4 Float Switch 26
3.5 Flow Switch 26
3.6 Limit Switch—Mechanical 27
3.7 Limit Switch—Proximity 28
3.8 Limit Switch—Optical 28
3.9 Pressure Switch 28
3.10 Pushbutton Switch 29
3.11 Solenoid 31
3.12 Switch Operations 31
3.13 Temperature Switch 34
3.14 Timing Relay—Pneumatic 35
3.15 Timing Relay with Instantaneous Contacts 35
3.16 Timing Relay—Solid-State 36
3.17 Timing Relay Terminology 36
3.18 Reading a Motor Control Schematic 37
Unit 3—Conclusion 39
Unit 3—Practice Questions 40

CHAPTER 2—MOTOR CONTROLS AND SCHEMATICS 43

UNIT 4—COMPONENTS OF CONTROL CIRCUIT SCHEMATICS 45
Unit 4—Introduction 45
4.1 A Simple Control Circuit 45
4.2 Control Devices with Multiple Contacts 48
Unit 4—Conclusion 49
Unit 4—Practice Questions 50

UNIT 5—MAGNETIC CONTROL 53
Unit 5—Introduction 53
5.1 Electromagnetic Control 53
5.2 Power Sources for the Coil and Control Circuit 54
5.3 Coil Applications 55
5.4 Remote Control—Introduction 59
5.5 Lighting Contactor 61
5.6 Feeder Disconnect Contactor with Automatic Control 64
Unit 5—Conclusion 65
Unit 5—Practice Questions 66

UNIT 6—MAGNETIC MOTOR STARTERS 69
Unit 6—Introduction 69
6.1 Magnetic Motor Starters 69
6.2 Other Overload Protection Methods 75
6.3 Auxiliary Contacts 75
6.4 Motor Starter Add-On Accessory Devices 76
Unit 6—Conclusion 76
Unit 6—Practice Questions 77

Table of Contents

UNIT 7—BASIC CONTROL CIRCUITS 81
Unit 7—Introduction 81
7.1 2-Wire Control Circuits 81
7.2 3-Wire Control Circuits 84
7.3 3-Wire Circuit in a Wiring (Connection) Diagram 87
7.4 Multiple Start-Stop Pushbutton Stations 89
7.5 Option of Using a 2- or 3-Wire Circuit in One Diagram 92
Unit 7—Conclusion 93
Unit 7—Practice Questions 94

UNIT 8—OVERCURRENT PROTECTION FOR CONTROL CIRCUITS 99
Unit 8—Introduction 99
8.1 Protection for Control Circuits 99
8.2 Common (Tapped) versus Separate Control Circuits 99
8.3 Control Conductor Sizes 16 AWG and 18 AWG 100
8.4 Control Transformer Protection 102
8.5 Other Standard Control Circuit Overcurrent Protection Arrangements 103
Unit 8—Conclusion 104
Unit 8—Practice Questions 105

UNIT 9—INDICATOR (PILOT) LIGHTS AND ILLUMINATED PUSHBUTTONS 107
Unit 9—Introduction 107
9.1 Pilot (Indicator) Lights 107
9.2 Typical Applications for Pilot Lights in Control Circuits 108
9.3 Illuminated Pushbuttons 112
Unit 9—Conclusion 113
Unit 9—Practice Questions 114

UNIT 10—SELECTOR SWITCHES AND TRUTH TABLES 117
Unit 10—Introduction 117
10.1 Truth Tables 117
10.2 Two-Position Selector Switch 117
10.3 Three-Position Selector Switch 118
10.4 Selector Switches—Variations 120
Unit 10—Conclusion 123
Unit 10—Practice Questions 124

CHAPTER 3—REVERSING CONTROLS 127

UNIT 11—REVERSING CONTROLS FOR THREE-PHASE MOTORS 129
Unit 11—Introduction 129
11.1 Reversing Three-Phase Motors 129
11.2 Forward and Reverse Contactors 129
11.3 Interlocking Devices 130
11.4 Electrical Interlock for Magnetic Reversing Controls 131
11.5 Combined Interlock Methods for Reversing Starters 134
11.6 Wiring a Reversing Control Pushbutton Station 136
11.7 Wiring a Reversing Control with a Selector Switch 136
Unit 11—Conclusion 137
Unit 11—Practice Questions 138

UNIT 12—REVERSING CONTROLS WITH INDICATOR (PILOT) LIGHTS FOR THREE-PHASE MOTORS 141
Unit 12—Introduction 141
12.1 Adding Forward and Reverse Pilot Lights 141
12.2 Alternate Pilot Light Connection Points 142
Unit 12—Conclusion 143
Unit 12—Practice Questions 144

UNIT 13—REVERSING CONTROLS WITH LIMIT SWITCHES FOR THREE-PHASE MOTORS 147
Unit 13—Introduction 147
13.1 Reversing Controls with Limit Switches Used to Automatically Stop a Motor 147
13.2 Reversing Controls—Limit Switches for Automatic Forward and Reverse 148
13.3 Reversing Controls and Limit Switches for Garage Door Applications 150
13.4 Forward-Reverse Control With 2-Wire Circuits 153
Unit 13—Conclusion 153
Unit 13—Practice Questions 154

UNIT 14—REVERSING SINGLE-PHASE MOTORS 157
Unit 14—Introduction 157
14.1 Types of Motors 157
14.2 Reversing Control Circuit 159
14.3 Sequence of Operation 159

Table of Contents

Part IV. Branch-Circuit Short-Circuit and Ground-Fault Protection 225
430.51 General 225
430.52 Branch-Circuit Short-Circuit and Ground-Fault Protection 226
430.55 Combined Overcurrent Protection Device 229

Part V. Feeder Short-Circuit and Ground-Fault Protection 229
430.62 Motor Feeder Protection 229

Part VI. Motor Control Circuits 231
430.72 Overcurrent Protection for Control Circuits 231
430.75 Disconnect for Control Circuits 232

Part VII. Motor Controllers 232
430.83 Motor Controller Horsepower Rating 232

Part IX. Disconnecting Means 233
430.102 Disconnect Location 233
430.107 Readily Accessible 233
430.109 Type of Disconnecting Means 234

Part X. Adjustable-Speed Drive Systems 234
430.120 General 234
430.122 Conductor Sizing 234
430.124 Overload Protection 236
430.128 Disconnecting Means 236
430.130 Branch-Circuit Short-Circuit and Ground-Fault Protection 236

Part XIV. Tables 237
Table 430.248 Full-Load Current, Single-Phase Motors 237
Table 430.250 Full-Load Current, Three-Phase Motors 238
Article 430—Practice Questions 239

FINAL EXAM 241

INDEX 257

TABLE OF CONTENTS

About This Textbook xv

Additional Products to Help You Learn xix

How to Use the *National Electrical Code* 1

Article 90—Introduction to the *National Electrical Code* 7
90.1 Scope 7
90.2 Scope and Application of the *NEC* 7
90.3 *Code* Arrangement 11
90.4 *NEC* Enforcement 12
90.5 Mandatory and Permissive Rules, and Explanatory Material 13
90.7 Examination of Equipment for Safety 13
Article 90—Review Questions 15

CHAPTER 1—GENERAL RULES 17
Article 100—Definitions 19
100 Scope 19

Article 110—General Requirements for Electrical Installations 55
Part I. General Requirements 55
110.1 Scope 55
110.2 Approval of Conductors and Equipment 55
110.3 Installation and Use of Equipment 56
110.5 Conductor Material 57
110.6 Conductor Sizes 57
110.7 Wiring Integrity 58
110.8 Suitable Wiring Methods 58
110.9 Overcurrent Protective Device Interrupting Rating 59
Available Fault Current 60
110.10 Equipment Short-Circuit Current Rating, Available Fault Current 61
110.11 Deteriorating Agents 61
110.12 Mechanical Execution of Work 63
110.13 Equipment Mounting and Cooling 64
110.14 Electrical Connections 65
110.15 High-Leg Conductor Identification 73
110.16 Arc-Flash Hazard Marking, Other Than Dwelling Units 73
110.21 Hazard Markings 74
110.22 Identification of Disconnecting Means 75
110.24 Available Fault-Current Marking 75
110.25 Lockable Disconnecting Means 76
Part II. Not Over 1000V 76
110.26 Working Spaces About Electrical Equipment 76
110.27 Protection Against Physical Damage 86
110.28 NEMA Enclosure Types 86
ANSI/NEMA 250-2020 Enclosures for Electrical Equipment 86
110.29 In Sight From (Within Sight From, Within Sight) 88

Article 120—Branch-Circuit, Feeder, and Service Load Calculations 89
Part I. General 89
120.1 Scope 89
120.3 Application of Other Articles 89
120.5 Load Calculations 89
120.6 Noncoincident Loads 91
120.7 Power Control Systems (PCS) 91
Part II. Branch-Circuit Load Calculations 92
120.13 Dwelling Units—Branch Circuit Load 92
120.14 Branch-Circuit Load Calculations 93
Part III. Feeder and Service Load Calculations 96
120.40 General 96
120.41 Dwelling Unit Load Calculations 96
120.50 Motor and Air-Conditioning Loads 97
120.51 Fixed Electric Space-Heating Load 97
120.52 Dwelling Unit Small-Appliance and Laundry Loads 98
120.53 Dwelling Unit Appliance Demand Load 98
120.54 Dwelling Unit Clothes Dryer Demand Load 99
120.55 Dwelling Unit Cooking Appliance Demand Load 100
120.57 Electric Vehicle Supply Equipment Load 102
120.61 Neutral Calculated Load 102
Part IV. Optional Feeder and Service Load Calculations 103
120.82 Dwelling Unit Optional Load Calculations 103
120.83 Existing Dwelling Unit Optional Load Calculation 105
120.87 Determining Existing Loads 105

Table of Contents

Article 130—Energy Management Systems 107
Part I. General 107
130.1 Scope 107
130.2 Listing Requirements 108
130.30 Load Management 108
Part II. Power Control Systems (PCS) 108
130.50 General 108
130.60 Conductors and Equipment 108
130.70 Settings 109
130.80 Marking and Documentation 109
Chapter 1—Review Questions 111

CHAPTER 2—WIRING AND PROTECTION 115

Article 200—Use and Identification of Grounded Conductors 117
200.1 Scope 118
200.4 General 118
200.6 Neutral Conductor 118
200.7 Identification of Grounded Conductors 120
200.8 Use of White or Gray Color 122
200.10 Receptacle and Screw Shell Terminal 123

Article 206—Non-Power-Limited Remote-Control and Signaling Circuits 125
206.1 Scope 125
206.4 Installation 125

Article 210—Branch Circuits 127
Part I. General 127
210.1 Scope 127
210.4 Multiwire Branch Circuits 128
210.5 Conductor Identification 132
210.6 Branch-Circuit Voltage 134
210.7 Multiple Branch Circuits 134
210.8 GFCI Protection 135
210.11 Branch Circuits Required 146
210.12 Arc-Fault Circuit-Interrupter Protection 149
Part II. Branch-Circuit Ratings 153
210.18 Branch Circuit Rating 153
210.19 Conductor Sizing 153
210.20 Overcurrent Protection 157
210.21 Receptacle Rating 157
210.22 Permissible Loads, Individual Branch Circuits 159
210.23 Multiple-Outlet Branch Circuits 159
Part III. Required Outlets 160
210.50 Receptacle Outlets 160
210.52 Dwelling Unit Receptacle Outlet Requirements 160
210.62 Show-Window Receptacles 168
210.63 Equipment Requiring Servicing 169
210.65 Meeting Rooms 169
210.70 Lighting Outlet Requirements 171

Article 215—Feeders 175
215.1 Scope 175
215.4 Conductor Sizing 176
215.5 Overcurrent Protection Sizing 178
215.12 Conductor Identification 179
215.15 Barriers 180
215.18 Surge Protection 181

Article 225—Outside Branch Circuits and Feeders 183
Part I. General 183
225.1 Scope 183
225.6 Minimum Conductor Size and Support 183
225.16 Attachment to Buildings 184
225.17 Masts as Supports 184
225.18 Clearance for Overhead Conductors 184
225.19 Clearances from Buildings 185
225.22 Raceways on Exterior Surfaces of Buildings 186
225.26 Trees for Conductor Support 187
225.27 Raceway Seals 187
Part II. Buildings or Other Structures Supplied by a Feeder 187
225.30 Number of Supplies 187
225.31 Disconnecting Means 188
225.33 Maximum Number of Disconnects 189
225.34 Grouping of Disconnects 189
225.37 Identification of Multiple Supplies 190
225.39 Rating of Disconnecting Means 190
225.41 Emergency Disconnect 190

Article 230—Services 193
Part I. General 194
230.1 Scope 194
230.2 Listing Requirements 194
230.4 Number of Services 195
230.6 Conductors Considered Outside a Building 196
230.7 Service Conductors Separate from Other Conductors 196
230.8 Raceway Seals 197
230.9 Clearances on Buildings 197
230.10 Vegetation as Support 198

Part II. Overhead Service Conductors 198
230.23 Overhead Service Conductor Size and Ampacity 198
230.24 Vertical Clearance for Overhead Service Conductors 199
230.26 Point of Attachment 199
230.27 Means of Attachment 199
230.28 Service Masts as Support 199
Part III. Underground Service Conductors 200
230.30 Installation 200
230.31 Underground Service Conductor Ampacity 200
230.32 Protection Against Damage 201
Part IV. Service-Entrance Conductors 201
230.42 Conductor Sizing 201
230.43 Wiring Methods 202
230.46 Spliced and Tapped Connections 203
230.50 Protection Against Physical Damage 203
230.51 Cable Supports 204
230.53 Raceways to Drain 204
230.54 Overhead Service Locations 204
Part V. Service Equipment (Disconnect)—General 205
230.62 Service Equipment—Barrier Placement 205
230.66 Marking for Service Equipment 205
230.67 Surge Protection 205
230.68 Meter Socket 207
Part VI. Service Disconnect—Disconnecting Means 207
230.70 Service Disconnect Requirements 207
230.71 Number of Service Disconnects 209
230.72 Grouping of Service Disconnects 210
230.79 Rating of Disconnect 211
230.82 Connected on Supply Side of the Service Disconnect 211
Part VII. Service Conductor Overcurrent Protection 213
230.90 Overload Protection—Where Required 213

Article 240—Overcurrent Protection 215
Part I. General 216
240.1 Scope 216
240.2 Listing Requirements 216
240.4 Overcurrent Protection of Conductors 217
240.5 Overcurrent Protection of Flexible Cords, Flexible Cables, and Fixture Wires 220
240.6 Standard Ampere Ratings 220
240.15 Circuit Breaker Handle Ties 221
Part II. Location of Overcurrent Protective Device 223
240.21 Location of Overcurrent Protective Device in Circuit 223
240.22 Grounded-Phase Conductor on Overcurrent Protective Device 230
240.24 Location of Overcurrent Protective Devices 231
Part III. Enclosures Containing Overcurrent Protective Devices 233
240.33 Vertical Position of Enclosures 233
Part V. Plug Fuses, Fuseholders, and Adapters 233
240.51 Edison-Base Fuses 233
Part VI. Cartridge Fuses 234
240.60 General 234
Part VII. Circuit Breakers 234
240.80 Method of Operation 234
240.81 Indicating 234
240.85 Circuit Breaker Applications 235

Article 242—Overvoltage Protection (SPD) 237
Part I. General 238
242.1 Scope 238
Part II. Surge-Protective Devices (SPDs), Not over 1000V 238
242.2 Listing 238
242.8 Short-Circuit Current Rating 238
242.13 Type 1 Surge-Protective Device (SPD)—Supply Side of Service Equipment 238
242.14 Type 2 Surge-Protective Devices (SPD) Feeder Circuits 239
242.24 Routing of Surge-Protective Device Conductors 240

Article 250—Grounding and Bonding 241
Part I. General 241
250.1 Scope 241
250.4 Performance Requirements for Grounding and Bonding 242
Earth Shells 246
250.6 Objectionable Current (Ground Loop) 247
Objectionable Neutral Currents 248
Dangers of Objectionable Current 249
250.8 Connection of Grounding and Bonding Conductors and Terminals 250
250.10 Protection of Ground Clamps and Fittings 251
250.12 Clean Surfaces 251
Part II. System Grounding and Bonding 251
250.20 Systems Required to be Grounded 251
250.24 Service Grounding 252
250.25 Grounding of Systems on the Supply Side of the Service Disconnect 255
250.28 Main Bonding Jumper and System Bonding Jumper 255
250.30 Transformer Separately Derived Systems 258
250.32 Buildings Supplied by a Feeder 266
250.34 Portable and Vehicle- or Trailer-Mounted Generators 268
250.35 Permanently Installed Generators 269
250.36 Impedance Grounded Systems—480V to 1000V 269

Table of Contents

Part III. Grounding Electrode System and Grounding Electrode Conductor 270
250.50 Grounding Electrode System 270
250.52 Grounding Electrode Types 271
250.53 Grounding Electrode Installation 275
Measuring Contact Resistance of Electrodes to Earth 275
250.54 Auxiliary Grounding Electrodes 279
250.60 Lightning Protection Electrode 281
250.64 Grounding Electrode Conductor Installation 281
250.66 Sizing Grounding Electrode Conductors 285
250.68 Grounding Electrode Conductor Termination 287
250.70 Grounding Electrode Conductor Fittings 289
Part IV. Enclosure and Raceway 290
250.80 Service Raceways and Enclosures 290
250.86 Other than Service Enclosures and Raceways 290
Part V. Bonding 291
250.92 Bonding Metal Service Raceways and Enclosures 291
250.94 Intersystem Bonding Termination 293
250.96 Bonding Metal Parts 295
250.97 Bonding Metal Raceways and Metal Cables Containing 480Y/277V Circuits 296
250.98 Bonding Loosely Jointed Metal Raceways 297
250.102 Bonding Jumper Sizing 297
250.104 Bonding of Metal Piping Systems and Exposed Structural Metal 300
250.106 Lightning Protection Systems 304
Part VI. Equipment Grounding Conductors 304
250.109 Bonding Metal and Nonmetallic Enclosures 304
250.114 Equipment Connected by Cord and Plug 305
250.118 Types of Equipment Grounding Conductors 306
250.119 Identification of Wire-Type Equipment Grounding Conductors 309
250.120 Equipment Grounding Conductor Installation 310
250.122 Sizing Wire-Type Equipment Grounding Conductors 310
250.124 Equipment Grounding Conductor Continuity 313
Part VII. Equipment Grounding Conductor Connections 314
250.134 Equipment Connected by Permanent Wiring Methods 314
250.138 Cord-and-Plug-Connected 314
250.140 Ranges, Ovens, Cooktops, and Clothes Dryers 314
250.142 Use of Neutral Conductor for Grounding Equipment 315
250.146 Receptacle Grounding Terminal Bonding 317
250.148 Continuity and Connections of Equipment Grounding Conductors in Boxes 320
Chapter 2—Review Questions 323

CHAPTER 3—WIRING METHODS AND MATERIALS 329
Article 300—General Requirements for Wiring Methods and Materials 331
Part I. General Requirements 331
300.1 Scope 331
300.4 Fire and Water Damage 332
300.5 Conductors 332
300.6 Protection Against Physical Damage 335
300.7 Underground Installations 339
300.8 Protection Against Corrosion 342
300.9 Raceways Exposed to Different Temperatures 343
300.11 Raceways in Wet Locations 344
300.12 Electrical Continuity 344
300.13 Securing and Supporting 345
300.14 Mechanical Continuity 347
300.15 Mechanical and Electrical Continuity of Conductors 348
300.16 Conductor Length at Boxes 349
300.17 Boxes or Fittings, Splices and Terminations 350
300.19 Number and Size of Conductors in a Raceway 352
300.20 Raceway Installations 354
300.21 Supporting Conductors in Vertical Raceways 354
300.22 Reducing Hysteresis Heating 354
300.23 Spread of Fire or Products of Combustion 356
300.24 Total Raceway Bends 357
300.25 Wiring in Ducts and Plenum Spaces 357
300.26 Panels Designed to Allow Access 359

Article 310—Conductors for General Wiring 361
Part I. General 361
310.1 Scope 361
310.2 Listing Requirements 361
Part II. Construction Specifications 361
310.4 Conductor Construction and Application 361
310.5 Conductors, Minimum Size and Material 363
310.6 Conductor Identification 364
Part III. Installation 365
310.10 Uses Permitted 365
310.12 Dwelling Services and Feeders 367
310.14 Ampacities for Conductors 370
310.15 Ampacity Tables 370
310.16 Insulated Conductors 378

Article 312—Cabinets and Meter Socket Enclosures 381
Part I. General 381
312.1 Scope 381

312.2 Listing Requirements 381
312.4 Damp or Wet Locations 381
312.5 Position in Walls 382
312.7 Repairing Gaps in Noncombustible Surfaces 382
312.8 Cable Termination to Enclosures 382
312.11 Overcurrent Protective Device and Switch Enclosures 384
312.13 Screws or Other Fasteners 385

Article 314—Boxes, Conduit Bodies, and Handhole Enclosures 387
Part I. General 387
314.1 Scope 387
314.2 Listing Requirements 387
314.5 Nonmetallic Boxes 388
314.6 Metal Boxes 388
314.7 Screws or Other Fasteners 388
Part II. Installation 388
314.15 Wet Locations 388
314.16 Outlet Box Sizing 389
314.17 Cables That Enter Boxes 396
314.20 Flush-Mounted Boxes 397
314.21 Repairing Noncombustible Surfaces 398
314.22 Surface Extensions 398
314.23 Supporting Enclosures 399
314.25 Box Covers 401
314.27 Box Requirements 402
314.28 Pull and Junction Boxes 404
314.29 Wiring to be Accessible 406
314.30 Handhole Enclosures 407

Article 320—Armored Cable (AC Cable) 411
Part I. General 411
320.1 Scope 411
320.2 Listing Requirements 412
Part II. Installation 412
320.10 Uses Permitted 412
320.12 Uses Not Permitted 412
320.15 Exposed Work 412
320.17 Through or Parallel to Framing Members 412
320.23 In Accessible Attic Spaces 413
320.24 Bending Radius 413
320.30 Securing and Supporting 413
320.40 Boxes and Fittings 414
320.80 Conductor Ampacity 415
Part III. Construction Specifications 416
320.108 Equipment Grounding Conductor 416

Article 330—Metal-Clad Cable (MC Cable) 417
Part I. General 417
330.1 Scope 417
330.2 Listing Requirements 418
Part II. Installation 418
330.10 Uses Permitted 418
330.12 Uses Not Permitted 419
330.15 Exposed Work 419
330.17 Through or Parallel to Framing Members 419
330.23 In Accessible Attics Spaces 419
330.24 Bending Radius 420
330.30 Securing and Supporting 420
330.80 Conductor Ampacities 421
Part III. Construction Specifications 422
330.108 Equipment Grounding Conductor 422

Article 334—Nonmetallic-Sheathed Cable (NM Cable) 423
Part I. General 423
334.1 Scope 423
334.2 Listing Requirements 424
Part II. Installation 424
334.10 Uses Permitted 424
334.12 Uses Not Permitted 425
334.15 Exposed Work 426
334.17 Through or Parallel to Framing Members 427
334.19 Cables Entering Enclosures 428
334.23 In Accessible Attic Spaces 428
334.24 Bending Radius 429
334.30 Securing and Supporting 429
334.40 Boxes and Fittings 430
334.80 Conductor Ampacity 430
Part III. Construction Specifications 432
334.108 Equipment Grounding Conductor 432

Article 336—Power and Control Tray Cable (TC Cable) 433
Part I. General 433
336.1 Scope 433
336.2 Listing Requirements 433
Part II. Installation 434
336.10 Uses Permitted 434
336.12 Uses Not Permitted 434
336.24 Bending Radius 434
336.30 Securing and Supporting 434

Table of Contents

Article 338—Service-Entrance Cable (SE and USE Cable) 435
Part I. General 435
338.1 Scope 435
338.2 Listing Requirements 436
Part II. Installation 436
338.10 Uses Permitted 436
338.12 Uses Not Permitted 436
338.24 Bending Radius 437

Article 340—Underground Feeder and Branch-Circuit Cable (UF Cable) 439
Part I. General 439
340.1 Scope 439
340.2 Listing Requirements 439
Part II. Installation 440
340.10 Uses Permitted 440
340.12 Uses Not Permitted 440
340.24 Bends 440
340.80 Ampacity 440

Article 342—Intermediate Metal Conduit (IMC) 443
Part I. General 443
342.1 Scope 443
342.2 Listing Requirements 443
Part II. Installation 444
342.10 Uses Permitted 444
342.14 Dissimilar Metals 444
342.20 Trade Size 444
342.22 Number of Conductors 444
342.24 Bends 444
342.28 Reaming 444
342.29 Paired Locknuts 445
342.30 Securing and Supporting 445
342.42 Couplings and Connectors 447
342.46 Bushings 448
342.60 Equipment Grounding Conductor 448

Article 344—Rigid Metal Conduit (RMC) 449
Part I. General 449
344.1 Scope 449
344.2 Listing Requirements 449
Part II. Installation 450
344.10 Uses Permitted 450
344.14 Dissimilar Metals 450
344.20 Trade Size 450
344.22 Number of Conductors 450
344.24 Bends 450
344.28 Reaming 451
344.29 Paired Locknuts 451
344.30 Securing and Supporting 451
344.42 Couplings and Connectors 453
344.46 Bushings 454
344.60 Equipment Grounding Conductor 455

Article 348—Flexible Metal Conduit (FMC) 457
Part I. General 457
348.1 Scope 457
348.2 Listing Requirements 457
Part II. Installation 457
348.10 Uses Permitted 457
348.12 Uses Not Permitted 458
348.20 Trade Size 458
348.22 Number of Conductors 458
348.24 Bends 459
348.28 Trimming 459
348.30 Securing and Supporting 459
348.42 Connectors 460
348.60 Equipment Grounding and Bonding Conductors 460

Article 350—Liquidtight Flexible Metal Conduit (LFMC) 461
Part I. General 461
350.1 Scope 461
350.2 Listing Requirements 462
Part II. Installation 462
350.10 Uses Permitted 462
350.12 Uses Not Permitted 462
350.20 Trade Size 462
350.22 Number of Conductors 462
350.24 Bends 463
350.28 Trimming 463
350.30 Securing and Supporting 463
350.42 Connectors 464
350.60 Equipment Grounding and Bonding Conductors 464

Article 352—Rigid Polyvinyl Chloride Conduit (PVC) 465
Part I. General 465
352.1 Scope 465
352.2 Listing 466
Part II. Installation 466
352.10 Uses Permitted 466

352.12 Uses Not Permitted....467
352.20 Trade Size....467
352.22 Number of Conductors....468
352.24 Bends....468
352.28 Trimming....469
352.30 Securing and Supporting....469
352.44 Expansion Fittings....470
352.46 Bushing or Adapter....470

Article 356—Liquidtight Flexible Nonmetallic Conduit (LFNC)....473
Part I. General....473
356.1 Scope....473
356.2 Listing Requirements....473
Part II. Installation....474
356.10 Uses Permitted....474
356.12 Uses Not Permitted....474
356.20 Trade Size....474
356.22 Number of Conductors....474
356.24 Bends....475
356.30 Securing and Supporting....475
356.42 Fittings....475

Article 358—Electrical Metallic Tubing (EMT)....477
Part I. General....477
358.1 Scope....477
358.2 Listing Requirements....477
Part II. Installation....478
358.10 Uses Permitted....478
358.12 Uses Not Permitted....479
358.20 Trade Size....479
358.22 Number of Conductors....479
358.24 Bends....480
358.28 Reaming....480
358.30 Securing and Supporting....480
358.42 Couplings and Connectors....481
358.60 Equipment Grounding Conductor....482

Article 362—Electrical Nonmetallic Tubing (ENT)....483
Part I. General....483
362.1 Scope....483
362.2 Listing....484
Part II. Installation....484
362.10 Uses Permitted....484
362.12 Uses Not Permitted....485
362.20 Trade Sizes....486
362.22 Number of Conductors....486
362.24 Bends....486
362.28 Trimming....486
362.30 Securing and Supporting....486
362.46 Bushings....487
362.48 Joints....487

Article 376—Metal Wireways....489
Part I. General....489
376.1 Scope....489
Part II. Installation....489
376.10 Uses Permitted....489
376.12 Uses Not Permitted....490
376.20 Conductors Connected in Parallel....490
376.21 Size of Conductors....490
376.22 Number of Conductors and Ampacity....490
376.23 Wireway Sizing....492
376.30 Supports....493
376.56 Splices, Taps, and Power Distribution Blocks....493
376.60 Equipment Grounding Conductor....494

Article 380—Multioutlet Assemblies....495
Part I. General....495
380.1 Scope....495
380.2 Listing Requirements....495
Part II. Installation....495
380.10 Uses Permitted....495
380.12 Uses Not Permitted....496
380.76 Through Partitions....496

Article 386—Surface Metal Raceways....497
Part I. General....497
386.1 Scope....497
386.2 Listing Requirements....497
Part II. Installation....498
386.10 Uses Permitted....498
386.12 Uses Not Permitted....498
386.21 Size of Conductors....498
386.22 Number of Conductors....498
386.30 Supporting....499
386.56 Splices and Taps....499
386.60 Equipment Grounding Conductor....499

Table of Contents

Article 392—Cable Trays 501
Part I. General 501
392.1 Scope 501
Part II. Installation 501
392.10 Uses Permitted 501
392.12 Uses Not Permitted 503
392.18 Cable Tray Installations 503
392.20 Cable and Conductor Installation 504
392.30 Securing and Supporting 504
392.44 Expansion Splice Plates 504
392.46 Bushed Conduit and Tubing 504
392.56 Cable Splices 505
Chapter 3—Review Questions 507

CHAPTER 4—EQUIPMENT FOR GENERAL USE 513
Article 400—Flexible Cords 515
400.1 Scope 515
400.4 Flexible Cords Types 515
400.5 Flexible Cord Ampacity 516
400.7 Suitability 516
400.10 Uses Permitted 516
400.12 Uses Not Permitted 518
400.13 Splices 519
400.14 Pull at Joints and Terminals 519
400.17 Protection from Damage 519

Article 404—Switches 521
Part I. Installation 521
404.1 Scope 521
404.2 Listing Requirements 521
404.5 Switch and Circuit Breaker Enclosures 522
404.6 Damp or Wet Locations 522
404.9 Indicating 523
404.10 Accessibility and Grouping 523
404.12 Bonding of Enclosures 524
Part II. Construction Specifications 524
404.20 Switch Marking 524

Article 406—Wiring Devices 527
Part I. General 527
406.1 Scope 527
406.2 Listing Requirements 527
406.9 Wiring Devices in Damp or Wet Locations 527
406.10 Wiring Device Terminations 531
Part II. Receptacles, Cord Connectors, and Attachment Plugs (Caps) 532
406.11 Receptacle Rating and Type 532
406.12 General Installation Requirements 533
406.14 Receptacle Mounting 536
406.16 Receptacle Faceplates or Cover Plates 538
406.18 Attachment Plugs and Flanged Surface Inlets 538
406.26 Tamper-Resistant Receptacles 539
Part III. General-Use Snap Switches, Dimmers, and Electronic Control Switches 540
406.30 Switch Connections 540
406.38 Accessibility and Grouping 542
406.40 Switches, Dimmers, and Control Switches 543
406.42 Snap Switches, Dimmers, and Control Switches Mounting 544
406.46 Snap Switch Rating and Use 545

Article 408—Switchboards and Panelboards 547
Part I. General 547
408.1 Scope 547
408.4 Circuit Directory and Description 547
408.5 Clearance for Conductors Entering Bus Enclosures 549
408.6 Short-Circuit Current Rating 549
408.7 Unused Openings 550
408.9 Replacement Panelboards 550
408.10 Busbars and Conductors Arrangement 551
408.14 Panelboard and Switchboard Ampere Rating 552
Part III. Panelboards 552
408.36 Overcurrent Protection 552
408.40 Equipment Grounding Conductor 553
408.41 Neutral Conductor Terminations 554
408.43 Panelboard Orientation 554

Article 410—Luminaires 555
Part I. General 555
410.1 Scope 555
410.2 Listing Required 555
Part II. Luminaire Locations 556
410.10 Luminaires in Specific Locations 556
410.16 Luminaires in Clothes Closets 557
Part III. Luminaire Outlet Boxes and Covers 559
410.22 Outlet Boxes to be Covered 559
410.24 Electric-Discharge and LED Luminaire Connection 559
Part IV. Luminaire Supports 560
410.30 Luminaire Supports 560
410.36 Means of Support 561

Part V. Grounding (Bonding) 562
410.44 Connection to the Equipment Grounding Conductor 562
Part X. Special Provisions for Flush and Recessed Luminaires 562
410.116 Clearance and Installation 562
Part XIII. Track Lighting 563
410.150 Installation 563
410.154 Fastening 563

Article 411—Low-Voltage Lighting 565
411.1 Scope 565
411.2 Listing Requirements 565
411.4 Low-Voltage Lighting Systems 566
411.6 Specific Location Requirements 566
411.8 Branch Circuit 566

Article 422—Appliances 569
Part I. General 569
422.1 Scope 569
422.2 Listing Required 569
422.5 GFCI Protection 569
Part II. Branch-Circuit Requirements 571
422.10 Branch Circuits 571
422.11 Overcurrent Protection 571
422.13 Storage Water Heaters 572
422.16 Flexible Cords 573
422.18 Ceiling Paddle Fans 575
422.20 Outlet Boxes to be Covered 575
Part III. Disconnecting Means 576
422.30 Disconnect—General 576
422.31 Permanently Connected Appliance Disconnects 576
422.33 Cord-and-Plug-Connected Appliances 576

Article 424—Fixed Electric Space-Heating Equipment 577
Part I. General 577
424.1 Scope 577
424.2 Listing Requirements 577
424.5 Continuous Load 577
Part III. Fixed Electric Space-Heating Equipment 578
424.19 Disconnecting Means 578
Part VI. Duct Heaters 579
424.65 Location of Disconnecting Means for Electric Duct Heater 579

Article 430—Motor Circuits, Controllers, and Adjustable-Speed Drives 581
Part I. General 581
430.1 Scope 581
430.6 Motor Table Full-Load Current versus Motor Nameplate Current Rating 582
Part II. Conductor Ampacity 583
430.22 Motor Conductor Ampacity 583
430.24 Feeder Conductor Ampacity 585
Part III. Motor and Branch-Circuit Overload Protection 586
430.31 Overload Protection 586
430.32 Overload Protection for Continuous-Duty Motors 587
Part IV. Branch-Circuit Short-Circuit and Ground-Fault Protection 589
430.51 General 589
430.52 Branch-Circuit Short-Circuit and Ground-Fault Protection 589
430.55 Combined Overcurrent Protective Device 592
Part V. Feeder Short-Circuit and Ground-Fault Protection 593
430.62 Motor Feeder Protection 593
Part VI. Motor Control Circuits 594
430.72 Overcurrent Protection for Control Circuits 594
430.75 Control Circuit Disconnect 594
Part VII. Motor Controllers 594
430.83 Motor Controller Types 594
Part IX. Disconnecting Means 595
430.101 General 595
430.102 Disconnect Location 595
430.107 Readily Accessible Disconnect 596
430.109 Motor Disconnecting Mean Types 596
Part X. Adjustable-Speed Drive Systems 597
430.120 General 597
430.122 Conductor Ampacity 597
430.124 Overload Protection 599
430.128 Disconnecting Means 599
430.130 Branch-Circuit Short-Circuit and Ground-Fault Protection 599
430.131 Several Motors or Loads on One Branch Circuit Including Power Conversion Equipment 600
430.132 GFCI and SPGFCI Between Power Conversion Equipment and Motors 601
Part XIV. Tables 601
430.248 Full-Load Current, Single-Phase Motors 601
430.250 Full-Load Current, Three-Phase Motors 601

Article 440—Air-Conditioning and Refrigeration Equipment 603
Part I. General 603
440.1 Scope 603

Table of Contents

440.4 Marking on Hermetic Refrigerant Motor-Compressors and Equipment 603
440.9 Equipment Grounding Conductor 605
Part II. Disconnecting Means 605
440.14 Location 605
440.15 Split-System Indoor Unit Identification 606
Part III. Overcurrent Protection 606
440.21 General 606
440.22 Short-Circuit and Ground-Fault Overcurrent Protective Device Size 606
Part IV. Conductor Sizing 607
440.33 Motor-Compressor(s) With or Without Additional Motor Loads 607

Article 445—Generators 609
445.1 Scope 609
445.2 Listing Requirements 609
445.11 Marking 610
445.13 Conductor Minimum Ampacity and Size 610
445.18 Disconnecting Means 610
445.19 Prime Mover Emergency Shutdowns 611

Article 450—Transformers 613
450.1 Scope 613
450.5 Primary Overcurrent Protection 614
450.6 Autotransformers 616
450.11 Ventilation 616
450.12 Grounding and Bonding 616
450.15 Transformer Accessibility 617
450.16 Disconnecting Means 617

Article 480—Stationary Batteries 619
480.1 Scope 619
480.4 Battery and Cell Terminations 619
480.9 Battery Support Systems 620
480.10 Battery Locations 620
480.12 Battery Interconnections 621
480.14 Overcharge Control 621
Chapter 4—Review Questions 623

FINAL EXAM A—STRAIGHT ORDER 629
FINAL EXAM B—RANDOM ORDER 639

INDEX 649

About the Author 659

About the Mike Holt Team 661

TABLE OF CONTENTS

About This Workbook vii

Additional Products to Help You Learn ix

How to Use the *National Electrical Code* 1

Article 90—Introduction to the *National Electrical Code* 9

CHAPTER 1—GENERAL RULES 11

Article 100—Definitions 13

Article 110—General Requirements for Electrical Installations 17

Article 120—Branch-Circuit, Feeder, and Service Load Calculations 21

Article 130—Energy Management Systems 23

CHAPTER 2—WIRING AND PROTECTION 25

Article 200—Use and Identification of Grounded Conductors 27

Article 206—Non-Power-Limited Remote-Control and Signaling Circuits 29

Article 210—Branch Circuits 31

Article 215—Feeders 35

Article 225—Outside Branch Circuits and Feeders 37

Article 230—Services 39

Article 240—Overcurrent Protection 43

Article 242—Overvoltage Protection (SPD) 45

Article 250—Grounding and Bonding 47

CHAPTER 3—WIRING METHODS AND MATERIALS 51

Article 300—General Requirements for Wiring Methods and Materials 53

Article 310—Conductors for General Wiring 57

Article 312—Cabinets and Meter Socket Enclosures 59

Article 314—Boxes, Conduit Bodies, and Handhole Enclosures 61

Article 320—Armored Cable (AC Cable) 65

Article 330—Metal-Clad Cable (MC Cable) 67

Article 334—Nonmetallic-Sheathed Cable (NM Cable) 69

Article 336—Power and Control Tray Cable (TC Cable) 71

Article 338—Service-Entrance Cable (SE and USE Cable) 73

Article 340—Underground Feeder and Branch-Circuit Cable (UF Cable) 75

Article 342—Intermediate Metal Conduit (IMC) 77

Article 344—Rigid Metal Conduit (RMC) 79

Article 348—Flexible Metal Conduit (FMC) 81

Article 350—Liquidtight Flexible Metal Conduit (LFMC) 83

Article 352—Rigid Polyvinyl Chloride Conduit (PVC) 85

Article 356—Liquidtight Flexible Nonmetallic Conduit (LFNC) 87

Article 358—Electrical Metallic Tubing (EMT) 89

Table of Contents

Article 362—Electrical Nonmetallic Tubing (ENT) 91

Article 376—Metal Wireways 93

Article 380—Multioutlet Assemblies 95

Article 386—Surface Metal Raceways 97

Article 392—Cable Trays 99

CHAPTER 4—EQUIPMENT FOR GENERAL USE 101

Article 400—Flexible Cords 103

Article 404—Switches 105

Article 406—Wiring Devices 107

Article 408—Switchboards and Panelboards 111

Article 410—Luminaires 113

Article 411—Low-Voltage Lighting 115

Article 422—Appliances 117

Article 424—Fixed Electric Space-Heating Equipment 119

Article 430—Motor Circuits, Controllers, and Adjustable-Speed Drives 121

Article 440—Air-Conditioning and Refrigeration Equipment 123

Article 445—Generators 125

Article 450—Transformers 127

Article 480—Stationary Batteries 129

FINAL EXAM A—STRAIGHT ORDER 133

FINAL EXAM B—RANDOM ORDER 145

About the Author 159

About the Mike Holt Team 161

TABLE OF CONTENTS

About This Textbook x

Additional Products to Help You Learn xiv

How to Use the *National Electrical Code* 1

SECTION I—ELECTRICAL THEORY 7

Unit 1—Atomic Structure 9
1.1 Introduction 9
1.2 Atomic Theory 9
1.3 Electrostatic Field 10
1.4 Atomic Charge of an Atom 11
1.5 Electrostatic Charge and Discharge 12
1.6 Lightning 12
1.7 Lightning Protection System 14
Unit 1—Review Questions 15

Unit 2—Electron Theory and Chemical Bonding 19
2.1 Introduction 19
2.2 Electron Orbitals 19
2.3 Valence Electrons 19
2.4 Freeing Valence Electron(s) from an Atom 20
2.5 Conductance 20
2.6 Insulators 22
2.7 Semiconductors 22
2.8 Chemical Bonding 23
Unit 2—Review Questions 25

Unit 3—Electrical Circuits and Power Sources 27
3.1 Introduction 27
3.2 The Electrical Circuit 27
3.3 Electric Current Flow (Electricity) 27
3.4 Electrical Power Sources 28
Unit 3—Review Questions 31

Unit 4—The Electrical System 33
4.1 Introduction 33
4.2 Source of Electrical Generation 33
4.3 Step-Up Transmission Voltage 33
4.4 High-Voltage Transmission Lines 34
4.5 Primary Distribution Voltage 34
4.6 Primary Distribution Wires 34
4.7 Secondary Distribution Voltage 34
4.8 Service Drop and Service Lateral 35
Unit 4—Review Questions 37

Unit 6—Dangers of Electricity 39
6.1 Introduction 39
6.2 *National Electrical Code* (*NEC*) 39
6.3 Electrical Fire 39
6.4 Electric Shock and Electrocution 40
6.5 Electric Arc Flash and Arc Blast 41
6.6 Arc Flash Incident Energy 42
6.7 Electrically Safe Work Condition 43
6.8 Personal Protective Equipment (PPE) 43
Unit 6—Review Questions 45

Unit 25—Overcurrent Protection 49
25.1 Introduction 49
25.2 Overcurrent Protection 49
25.3 Fuses 50
25.4 Circuit Breakers 52
25.5 Overcurrent Protective Devices, Time-Current Curves 53
25.6 Available Short-Circuit Current 55
25.7 Overcurrent Protective Devices, Interrupting Rating 56
25.8 Equipment Short-Circuit Current Rating (SCCR) 57
25.9 Coordination of Overcurrent Protective Devices 57
Unit 25—Review Questions 59

SECTION II—*NEC* RULES FOR BONDING AND GROUNDING 63

Article 90—Introduction to the *National Electrical Code* 65
90.1 Scope 65
90.2 Scope and Application of the *NEC* 65
90.3 *Code* Arrangement 69

Table of Contents

90.4 *NEC* Enforcement 70
90.5 Mandatory and Permissive Rules, and Explanatory Material 71
90.7 Examination of Equipment for Safety 71
Article 90—Review Questions 73

CHAPTER 1—GENERAL RULES 75
Article 100—Definitions 77
100 Scope 77

Article 110—General Requirements for Electrical Installations 95
Part I. General Requirements 95
110.1 Scope 95
110.2 Approval of Conductors and Equipment 95
110.3 Installation and Use of Equipment 96
110.5 Conductor Material 97
110.6 Conductor Sizes 97
110.7 Wiring Integrity 98
110.8 Suitable Wiring Methods 98
110.11 Deteriorating Agents 99
110.12 Mechanical Execution of Work 100
110.14 Electrical Connections 101
Chapter 1—Review Questions 107

CHAPTER 2—WIRING AND PROTECTION 109
Article 200—Use and Identification of Grounded Conductors 111
200.1 Scope 111
200.4 General 112

Article 250—Grounding and Bonding 113
Part I. General 113
250.1 Scope 113
250.4 Performance Requirements for Grounding and Bonding 114
Earth Shells 118
250.6 Objectionable Current (Ground Loop) 119
Objectionable Neutral Currents 120
Dangers of Objectionable Current 121
250.8 Connection of Grounding and Bonding Conductors and Terminals 122
250.10 Protection of Ground Clamps and Fittings 123
250.12 Clean Surfaces 123
Part II. System Grounding and Bonding 123
250.20 Systems Required to be Grounded 123
250.24 Service Grounding 124
250.25 Grounding of Systems on the Supply Side of the Service Disconnect 127
250.28 Main Bonding Jumper and System Bonding Jumper 127
250.30 Transformer Separately Derived Systems 130
250.32 Buildings Supplied by a Feeder 138
250.34 Portable and Vehicle- or Trailer-Mounted Generators 140
250.35 Permanently Installed Generators 141
250.36 Impedance Grounded Systems—480V to 1000V 142
Part III. Grounding Electrode System and Grounding Electrode Conductor 143
250.50 Grounding Electrode System 143
250.52 Grounding Electrode Types 144
250.53 Grounding Electrode Installation 147
Measuring Contact Resistance of Electrodes to Earth 148
250.54 Auxiliary Grounding Electrodes 151
250.60 Lightning Protection Electrode 153
250.64 Grounding Electrode Conductor Installation 153
250.66 Sizing Grounding Electrode Conductors 157
250.68 Grounding Electrode Conductor Termination 159
250.70 Grounding Electrode Conductor Fittings 161
Part IV. Enclosure and Raceway 162
250.80 Service Raceways and Enclosures 162
250.86 Other than Service Enclosures and Raceways 162
Part V. Bonding 163
250.92 Bonding Metal Service Raceways and Enclosures 163
250.94 Intersystem Bonding Termination 165
250.96 Bonding Metal Parts 167
250.97 Bonding Metal Raceways and Metal Cables Containing 480Y/277V Circuits 167
250.98 Bonding Loosely Jointed Metal Raceways 168
250.102 Bonding Jumper Sizing 169
250.104 Bonding of Metal Piping Systems and Exposed Structural Metal 172
250.106 Lightning Protection Systems 176
Part VI. Equipment Grounding Conductors 176
250.109 Bonding Metal and Nonmetallic Enclosures 176
250.114 Equipment Connected by Cord and Plug 177
250.118 Types of Equipment Grounding Conductors 177
250.119 Identification of Wire-Type Equipment Grounding Conductors 181
250.120 Equipment Grounding Conductor Installation 182
250.122 Sizing Wire-Type Equipment Grounding Conductors 182
250.124 Equipment Grounding Conductor Continuity 185
Part VII. Equipment Grounding Conductor Connections 185
250.134 Equipment Connected by Permanent Wiring Methods 185

250.138 Cord-and-Plug-Connected 185
250.140 Ranges, Ovens, Cooktops, and Clothes Dryers 186
250.142 Use of Neutral Conductor for Grounding Equipment 187
250.146 Receptacle Grounding Terminal Bonding 188
250.148 Continuity and Connections of Equipment Grounding Conductors in Boxes 191
Chapter 2—Review Questions 193

CHAPTER 3—WIRING METHODS AND MATERIALS 197

Article 300—General Requirements for Wiring Methods and Materials 199
Part I. General Requirements 199
300.1 Scope 199
300.12 Electrical Continuity 199
300.14 Mechanical Continuity 200

Article 314—Boxes, Conduit Bodies, and Handhole Enclosures 201
Part I. General 201
314.1 Scope 201
314.5 Nonmetallic Boxes 201
314.6 Metal Boxes 201
314.25 Box Covers 202
314.30 Handhole Enclosures 203

Article 320—Armored Cable (AC Cable) 205
Part I. General 205
320.1 Scope 205
Part III. Construction Specifications 206
320.108 Equipment Grounding Conductor 206

Article 330—Metal-Clad Cable (MC Cable) 207
Part I. General 207
330.1 Scope 207
Part III. Construction Specifications 208
330.108 Equipment Grounding Conductor 208

Article 334—Nonmetallic-Sheathed Cable (NM Cable) 209
Part I. General 209
334.1 Scope 209
Part III. Construction Specifications 210
334.108 Equipment Grounding Conductor 210

Article 342—Intermediate Metal Conduit (IMC) 211
Part I. General 211
342.1 Scope 211
Part II. Installation 211
342.29 Paired Locknuts 211
342.42 Couplings and Connectors 212
342.60 Equipment Grounding Conductor 212

Article 344—Rigid Metal Conduit (RMC) 213
Part I. General 213
344.1 Scope 213
Part II. Installation 213
344.29 Paired Locknuts 213
344.42 Couplings and Connectors 214
344.60 Equipment Grounding Conductor 214

Article 348—Flexible Metal Conduit (FMC) 215
Part I. General 215
348.1 Scope 215
Part II. Installation 215
348.60 Equipment Grounding and Bonding Conductors 215

Article 350—Liquidtight Flexible Metal Conduit (LFMC) 217
Part I. General 217
350.1 Scope 217
Part II. Installation 218
350.60 Equipment Grounding and Bonding Conductors 218

Article 358—Electrical Metallic Tubing (EMT) 219
Part I. General 219
358.1 Scope 219
Part II. Installation 219
358.42 Couplings and Connectors 219
358.60 Equipment Grounding Conductor 220

Article 376—Metal Wireways 221
Part I. General 221
376.1 Scope 221
Part II. Installation 221
376.60 Equipment Grounding Conductor 221

Table of Contents

Article 386—Surface Metal Raceways....223
Part I. General....223
386.1 Scope....223
Part II. Installation....223
386.60 Equipment Grounding Conductor....223
Chapter 3—Review Questions....225

CHAPTER 4—EQUIPMENT FOR GENERAL USE....227
Article 404—Switches....229
Part I. Installation....229
404.1 Scope....229
404.12 Bonding of Enclosures....229

Article 406—Wiring Devices....231
Part I. General....231
406.1 Scope....231
Part II. Receptacles, Cord Connectors, and Attachment Plugs (Caps)....231
406.11 Receptacle Rating and Type....231
406.12 General Installation Requirements....232
406.16 Receptacle Faceplates or Cover Plates....233
Part III. General-Use Snap Switches, Dimmers, and Electronic Control Switches....234
406.40 Switches, Dimmers, and Control Switches....234

Article 408—Switchboards and Panelboards....237
Part I. General....237
408.1 Scope....237
Part III. Panelboards....238
408.40 Equipment Grounding Conductor....238

Article 410—Luminaires....239
Part I. General....239
410.1 Scope....239
Part IV. Luminaire Supports....239
410.30 Luminaire Supports....239
Part V. Grounding (Bonding)....241
410.44 Connection to the Equipment Grounding Conductor....241

Article 440—Air-Conditioning and Refrigeration Equipment....243
Part I. General....243
440.1 Scope....243
440.9 Equipment Grounding Conductor....243

Article 450—Transformers....245
450.1 Scope....245
450.12 Grounding and Bonding....246
Chapter 4—Review Questions....247

CHAPTER 5—SPECIFIC OCCUPANCIES AND LOCATIONS....249
Article 500—Hazardous (Classified) Locations....251
500.1 Scope....251
500.30 Bonding....252

Article 517—Health Care Facilities....255
Part I. General....256
517.1 Scope....256
Part II. Wiring and Protection....256
517.13 Equipment Grounding Conductor for Receptacles and Fixed Electrical Equipment in Patient Care Spaces....256

Article 547—Agricultural Buildings....259
Part I. General....259
547.1 Scope....259
Part II. Installations....259
547.27 Equipment Grounding Conductor....259
Part III. Distribution and Equipotential Plane....260
547.44 Equipotential Planes....260

Article 555—Marinas, Boatyards, and Docking Facilities....263
Part I. General....264
555.1 Scope....264
555.13 Non-Current-Carrying Metal Parts Bonding....264
555.14 Equipotential Planes and Bonding of Equipotential Planes....264
Part II. Marinas, Boatyards, and Docking Facilities....264
555.34 Wiring Methods and Installation....264
555.37 Equipment Grounding Conductor....265
Chapter 5—Review Questions....267

CHAPTER 6—SPECIFIC EQUIPMENT....269
Article 600—Electric Signs....271
Part I. General....271
600.1 Scope....271
600.7 Grounding and Bonding....271

Article 645—Information Technology Equipment (ITE)....273
645.1 Scope 273
645.15 Equipment Grounding and Bonding 273

Article 680—Swimming Pools, Spas, Hot Tubs, and Fountains 275
Part I. General Requirements for Swimming Pools, Spas, Hot Tubs, and Fountains 275
680.1 Scope 275
680.7 Grounding and Bonding 276
Part II. Permanently Installed Pools 277
680.23 Underwater Pool Luminaires 277
680.24 Pool Junction Box 279
680.26 Equipotential Bonding 280
Part III. Storable Pools 287
680.30 General 287
Part IV. Permanently Installed and Self-Contained Spas and Hot Tubs 288
680.40 General 288
680.42 Outdoor Installations 288
680.43 Indoor Installations 289
Part V. Fountains 289
680.50 General 289
680.54 Connection to an Equipment Grounding Conductor 290
Part VII. Hydromassage Bathtubs 290
680.70 General 291
680.74 Bonding 291

Article 690—Solar Photovoltaic (PV) Systems 293
Part I. General 293
690.1 Scope 293
Part V. Grounding and Bonding 294
690.43 Equipment Grounding Conductor 294
690.45 Equipment Grounding Conductor Sizes 295
690.47 Grounding Electrode System 296
Chapter 6—Review Questions 297

CHAPTER 7—SPECIFIC CONDITIONS AND SYSTEMS 299
Article 750—Grounding and Bonding of Limited-Energy Systems 301
Part I. General 301
750.1 Scope 301
750.2 Listing 301
Part II. Conductors and Equipment Outside and Entering Buildings 302
750.60 Metal Antenna Systems—Bonding or Grounding 302
750.66 Antenna Systems Bonding Conductors and Grounding Electrode Conductors 302
Chapter 7—Review Questions 305

***NEC* FINAL EXAM A—STRAIGHT ORDER** 309
***NEC* FINAL EXAM B—RANDOM ORDER** 315

INDEX 321

About the Author 327

About the Mike Holt Team 329

TABLE OF CONTENTS

About This Textbook xii

Additional Products to Help You Learn xvi

How to Use the *National Electrical Code* 1

Article 90—Introduction to the *National Electrical Code* . 7
90.1 Scope 7
90.2 Scope and Application of the *NEC* 7
90.3 *Code* Arrangement 11
90.4 *NEC* Enforcement 12
90.5 Mandatory and Permissive Rules, and Explanatory Material ... 13
90.7 Examination of Equipment for Safety 13
Article 90—Review Questions 15

CHAPTER 1—GENERAL RULES 17

Article 100—Definitions 19
100 Scope 19
Chapter 1—Review Questions 41

CHAPTER 5—SPECIFIC OCCUPANCIES AND LOCATIONS 45

Article 500—Hazardous (Classified) Locations 47
500.1 Scope 47
500.4 Documentation 48
500.5 Classifications of Hazardous Locations 48
500.7 Protection Techniques 50
500.8 Equipment Characteristics 52
500.30 Bonding 54

Article 501—Class I Hazardous Locations 57
Part I. General 57
501.1 Scope 57
Part II. Wiring 57
501.10 Wiring Methods 57
501.15 Conduit and Cable Seals 59
Part III. Equipment 65
501.115 Enclosures Containing Make-and-Break Contact Devices 65
501.125 Motors and Generators 66
501.130 Luminaires 66
501.135 Utilization Equipment 66
501.145 Receptacles 66

Article 502—Class II Hazardous Locations 69
Part I. General 69
502.1 Scope 69
502.5 Explosionproof Equipment 69
Part II. Wiring 70
502.10 Wiring Methods 70
502.15 Sealing 71
Part III. Equipment 72
502.115 Enclosures Containing Make-and-Break Contacts 72
502.125 Motors and Generators 72
502.130 Luminaires 72
502.135 Utilization Equipment 73
502.145 Receptacles and Attachment Plugs 73

Article 511—Commercial Garages 75
511.1 Scope 75
511.5 Classification of Hazardous Areas 75
511.7 Wiring and Equipment Above Hazardous Locations 78
511.8 Underground Wiring Below Hazardous Locations 79
511.9 Seals 79

Article 514—Motor Fuel Dispensing Facilities 81
514.1 Scope 81
514.5 Classification of Locations 81
514.6 Wiring and Equipment Within Hazardous Locations 82
514.7 Wiring and Equipment Above Hazardous Locations 82
514.8 Underground Wiring 82
514.9 Conduit Seal 83
514.16 Bonding Requirements 83

Table of Contents

Article 517—Health Care Facilities 85
Part I. General 86
517.1 Scope 86
Part II. Wiring and Protection 86
517.10 Applicability 86
517.13 Equipment Grounding Conductor for Receptacles and Fixed Electrical Equipment in Patient Care Spaces 87

Article 518—Assembly Occupancies 91
518.1 Scope 91
518.4 General Classifications 91
518.6 Wiring Methods 92

Article 547—Agricultural Buildings 93
Part I. General 93
547.1 Scope 93
Part II. Installations 93
547.20 Wiring Methods 93
547.22 Enclosures, Boxes, Conduit Bodies, and Fittings 94
547.23 Wet Locations 94
547.24 Corrosive Atmosphere 94
547.25 Flexible Connections 94
547.26 Physical Protection 94
547.27 Equipment Grounding Conductor 94
547.28 Receptacle GFCI Protection 95
547.31 Luminaires 95
Part III. Distribution and Equipotential Plane 95
547.44 Equipotential Planes 95

Article 555—Marinas, Boatyards, and Docking Facilities 99
Part I. General 99
555.1 Scope 99
555.2 Listing Requirements 99
555.9 Engineered Design 100
555.10 Electric Shock Hazard Sign 100
555.11 Motor Fuel Dispensing Stations—Hazardous Locations 100
555.12 Repair Facilities—Hazardous Locations 101
555.13 Non-Current-Carrying Metal Parts Bonding 101
555.14 Equipotential Planes and Bonding of Equipotential Planes 101
555.15 Equipment Servicing and Replacing 101
555.16 Electrical Datum Plane Distances 102
Part II. Marinas, Boatyards, and Docking Facilities 103
555.30 Electrical Connections 103
555.33 Receptacles 103
555.34 Wiring Methods and Installation 104
555.35 GFPE and GFCI Protection 105
555.36 Shore Power Receptacle Disconnecting Means 106
555.37 Equipment Grounding Conductor 107
555.38 Luminaires 107

Article 590—Temporary Installations 109
590.1 Scope 109
590.4 All Wiring Installations 109
590.5 Time Constraints 109
590.6 General 110
590.7 GFCI Protection 112
Chapter 5—Review Questions 115

CHAPTER 6—SPECIFIC EQUIPMENT 125

Article 600—Electric Signs 127
Part I. General 127
600.1 Scope 127
600.2 Listing Requirement 127
600.4 Markings 127
600.5 Branch Circuits 128
600.6 Disconnecting Means 128
600.7 Grounding and Bonding 130

Article 620—Elevators 131
Part I. General 131
620.1 Scope 131
620.7 GFCI Protection for Receptacles 131
Part III. Wiring 132
620.23 Branch Circuits for Elevator Machine Room and Machinery Space 132
620.24 Branch Circuit for Elevator Hoistway Pits 133
Part IV. Installation of Conductors 133
620.37 Wiring in Elevator Hoistways, Machine Rooms and Machinery Spaces 133
Part VI. Disconnecting Means and Control 134
620.51 Disconnecting Means 134

Article 624—Electric Self-Propelled Vehicle Power Transfer Systems 135
Part I. General 135
624.1 Scope 135
624.2 Listing Requirements 136
Part III. Installation 136
624.40 ESVSE Branch Circuits....136
624.41 Overcurrent Protection....136
624.42 Rating....136
624.43 Disconnecting Means....136
624.48 Interactive Equipment 136
624.49 Island Mode 137
624.54 GFCI Protection....137

Article 625—Electric Vehicle Power Transfer System 139
Part I. General 139
625.1 Scope 139
625.2 Listing Requirements 140
625.4 Qualified Persons 140
625.5 Field Installed Rating Label....141
Part III. Installation 141
625.40 Electric Vehicle Branch Circuit....141
625.41 Continuous Loads 142
625.42 EVSE Rating....144
625.43 Disconnecting Means....144
625.44 Equipment Connections 145
625.48 Interactive (Grid-Tied) Equipment 146
625.54 GFCI Protection....146
Part IV. Wireless Power Transfer Equipment....146
625.101 Grounding 146
625.102 Installation 147

Article 630—Electric Welders....149
Part I. General 149
630.1 Scope 149
630.2 Listing Requirements 149
630.8 Receptacle, GFCI Protection 149
Part II. Arc Welders 150
630.11 Conductor Ampacity....150
630.12 Overcurrent Protection....153
630.13 Disconnecting Means....154
Part III. Resistance Welders....154
630.31 Conductor Ampacity....154
630.32 Overcurrent Protection....156
630.33 Disconnecting Means....156

Article 645—Information Technology Equipment (ITE)....157
645.1 Scope 157
645.5 Special Requirements 158
645.6 Supply Circuits and Interconnecting Cables 158
645.10 Disconnecting Means....160
645.15 Equipment Grounding and Bonding....160

Article 680—Swimming Pools, Spas, Hot Tubs, and Fountains 161
Part I. General Requirements....161
680.1 Scope 161
680.2 Listing Requirements 162
680.4 Inspections After Installation....162
680.5 Ground-Fault Protection 162
680.7 Grounding and Bonding....163
680.9 Overhead Conductor Clearance 164
680.10 Electric Pool Water Heaters and Heat Pumps....164
680.11 Underground Wiring....165
680.12 Equipment Rooms, Vaults, and Pits 165
680.13 Equipment Disconnecting Means....166
680.14 Corrosive Environment 166
Part II. Permanently Installed Pools....167
680.20 General....167
680.21 Pool Motors....167
680.22 Receptacles, Luminaires, and Switches....168
680.23 Underwater Pool Luminaires 170
680.24 Pool Junction Box 174
680.26 Equipotential Bonding 175
680.27 Specialized Equipment 181
Part III. Storable Pools....181
680.30 General....181
680.32 Ground-Fault Protection 182
680.34 Receptacle Locations....182
680.35 Storable Pools 183
Part IV. Permanently Installed and Self-Contained Spas and Hot Tubs....183
680.40 General....183
680.41 Emergency Shutoff Switch 183
680.42 Outdoor Installations....184
680.43 Indoor Installations 184
680.44 Ground-Fault Protection 186
Part V. Fountains....186
680.50 General....186

Table of Contents

680.51 Luminaires and Submersible Equipment 187
680.54 Connection to an Equipment Grounding Conductor....187
680.56 Flexible Cord-Connected Equipment....188
680.57 Electric Signs In or Adjacent to Fountains....188
680.58 Ground-Fault Protection 188
680.59 Ground-Fault Protection for Permanently Installed Nonsubmersible Pumps 188
Part VII. Hydromassage Bathtubs....189
680.70 General....189
680.71 Branch Circuit....189
680.73 Accessibility....189
680.74 Bonding 189
680.75 GFCI Protection....190

Article 690—Solar Photovoltaic (PV) Systems....191
Part I. General 191
690.1 Scope 191
690.2 Listing Requirements 192
690.4 General Requirements....192
690.6 Alternating-Current Modules 195
Part II. Circuit Requirements 195
690.7 Maximum PV System dc Circuit Voltage....195
690.8 Current Calculations and Conductor Ampacity....201
690.9 Overcurrent Protection 211
690.12 PV Rapid Shutdown 213
Part III. Disconnect 218
690.13 PV System Disconnecting Means....218
690.15 PV Equipment Disconnecting Means 220
Part IV. Wiring Methods....222
690.31 Wiring Methods 222
690.32 Concealed Interconnections 227
690.33 Mating Connectors....227
690.34 Access to Boxes 228
Part V. Grounding and Bonding....228
690.41 PV System dc Circuit Grounding....228
690.43 Equipment Grounding Conductor 229
690.45 Equipment Grounding Conductor Sizing....230
690.47 Grounding Electrode System 231
Part VI. Source Connections....231
690.59 Connection to Other Power Sources....231

Article 691—Large-Scale Photovoltaic (PV) Electric Supply Stations 233
691.1 Scope 233
691.2 Listing Requirements 233
691.4 Special Requirements for Large-Scale PV Electric Supply Stations 233
691.6 Engineered Design....234
691.7 Conformance of Construction to Engineered Design....234
691.8 Direct-Current Operating Voltage 234
691.9 Disconnect for Isolating Photovoltaic Equipment....234
691.10 Fire Mitigation....234
691.11 Bonding and Grounding....234

Article 695—Fire Pumps 237
695.1 Scope 237
695.2 Listing Requirements 237
695.5 Continuity of Power....238
695.7 Power Wiring 238
695.8 Fire Pump Controller Voltage Drop....240
695.12 Equipment Location....241
695.14 Control Wiring....241
695.15 Surge Protection 241
Chapter 6—Review Questions 243

CHAPTER 7—SPECIFIC CONDITIONS AND SYSTEMS....257
Article 700—Emergency Systems....259
Part I. General 259
700.1 Scope 259
700.4 Commissioning and Servicing 260
700.5 Capacity and Rating....260
700.6 Transfer Equipment 260
700.8 Signs....261
700.9 Surge Protection 261
Part II. Circuit Wiring....261
700.10 Wiring to Emergency Loads....261
700.11 Wiring, Class 2, and Class 4 Powered Emergency Lighting Systems....263
Part III. Sources of Power 263
700.12 General Requirements....263
Part IV. Emergency System Circuits for Lighting and Power....265
700.15 Loads on Emergency Branch Circuits....265
700.16 Emergency Illumination....266
700.19 Multiwire Branch Circuits....266
700.27 Class 2 Powered Emergency Lighting Systems 266
700.28 Class 4 Powered Emergency Lighting Systems 266
Part VI. Overcurrent Protection....266
700.30 Accessibility....266
700.32 Selective Coordination....266

Article 701—Legally Required Standby Systems 269
Part I. General 269
701.1 Scope 269
701.4 Commissioning and Servicing 269
701.5 Capacity and Rating 270
701.6 Transfer Equipment 270
701.8 Signs 270
701.9 Surge Protection 270
Part II. Circuit Wiring 271
701.10 Wiring 271
Part III. Sources of Power 271
701.12 General Requirements 271
Part IV. Overcurrent Protection 272
701.30 Accessibility 272
701.32 Selective Coordination 272

Article 702—Optional Standby Systems 273
Part I. General 273
702.1 Scope 273
702.4 Capacity and Rating 274
702.5 Interconnection or Transfer Equipment 276
702.7 Signs 278
Part II. Circuit Wiring 278
702.10 Wiring 278
702.12 Outdoor Generators 278

Article 705—Interconnected Electric Power Production Sources 281
Part I. General 281
705.1 Scope 281
705.2 Listing Requirements 281
705.8 Qualified Persons 282
705.10 Power Source Identification 283
705.11 Service Connection 284
705.12 Load-Side Connection 285
705.13 Power Control Systems 290
705.20 Power Source Output Conductor Disconnect 290
705.25 Wiring Methods 291
705.28 Power Source Output Current and Circuit Sizing 292
705.30 Overcurrent Protection 293
705.40 Primary Source Loss 296
705.45 Unbalanced Interconnections 298
Part II. Microgrid Systems 298
705.50 Microgrid System Operation 298
705.60 Connections to Utility Power 298
705.70 Microgrid Interconnect Devices (MID) 299

Article 706—Energy Storage Systems 301
Part I. General 301
706.1 Scope 301
706.2 Listing Requirements 301
706.4 Markings 301
706.5 Qualified Persons 302
706.6 Multiple Systems 303
706.7 Commissioning and Servicing 303
Part II. Disconnect 304
706.15 Disconnect 304
Part IV. Energy Storage System Circuit Requirements 306
706.30 Circuit Current Rating 306
706.31 Overcurrent Protection 307

Article 710—Stand-Alone Systems 309
710.1 Scope 309
710.2 Listing Requirements 309
710.10 Power Source Identification 309
710.15 System and Circuit Sizing 310

Article 720—Limited-Energy System Wiring Methods and Materials 311
Part I. General 311
720.1 Scope 311
720.4 Other Articles 311
Part II. Installation 312
720.5 Underground Installations 312
720.6 Protection Against Physical Damage 312
720.7 Protection Against Corrosion and Deterioration 315
720.8 Raceways Exposed to Different Temperatures 315
720.9 Dwelling Unit Communication Outlet 316
720.11 Limited-Energy System Raceways in Wet Locations Above Grade 316
720.19 Supporting Cables and Conductors in Vertical Raceways 316
720.21 Spread of Fire or Products of Combustion 317
720.22 Wiring in Ducts Plenum Spaces 318
720.23 Panels Designed to Allow Access 320
720.24 Bends 320
720.25 Abandoned Cables 320
720.30 Securing and Supporting 321
720.32 Boxes, Conduit Bodies, or Fittings-Where Required 323

Table of Contents

Article 722—Limited-Energy Cables 325
Part I. General 325
722.1 Scope 325
722.2 Limited-Energy Cable Listings 325
722.15 Separation from Power Conductors 326
Part III. Wiring Methods, Applications, and Installations Inside Buildings 327
722.120 Installation of Limited-Energy Cables 327
Part IV. Communication Cables and Wiring Methods 329
722.131 Installation of Communications and Coaxial Cables and Raceways 329
722.133 Communication and Coaxial Cables and Equipment Installation 330
Part V. Class 2 or Class 3 Cables and Wiring Methods 330
722.140 Wiring Methods on Load Side of the Class 2 Power-Limited Power Source 330
Part VI. Class 4 Cables and Wiring Methods 331
722.150 Class 4 Circuit Cables 331
722.152 Installation and Wiring Methods for Class 4 Circuit Cables 331
Part VIII. Power-Limited Fire Alarm (PLFA) Cables and Wiring Methods 332
722.171 Load Side of the Power-Limited Fire Alarm Power Source 332

Article 723—Raceways, Cable Routing Assemblies, and Cable Trays for Limited-Energy Systems 333
Part I. General 333
723.1 Scope 333
Part II. Application and Installation of Raceways for Limited-Energy Systems 333
723.22 Installation of Raceways for Limited-Energy Systems 333
Part IV. Cable Trays for Limited-Energy Systems 333
723.40 Cable Trays 333

Article 724—Class 1 Power-Limited Circuits 335
Part I. General 335
724.1 Scope 335
724.30 Class 1 Circuit Identification 335
724.40 Class 1 Power Source 335
724.43 Class 1 Circuit Overcurrent Protection 336
724.45 Class 1 Circuit Overcurrent Protective Device Location 336
724.46 Class 1 Circuit Wiring Method 336
724.48 Different Circuits in Same Cable, Cable Tray, Enclosure, or Raceway Conductors 336
724.49 Class 1 Circuit Conductors 337
724.51 Number of Conductors in a Raceway 337

Article 725—Class 2 Power-Limited Circuits 339
Part I. General 339
725.1 Scope 339
Part II. Installation Requirements 340
725.127 Wiring Methods on Supply Side of the Class 2 Power-Limited Power Source 340

Article 726—Class 4 Fault-Managed Power Systems 341
Part I. General 341
726.1 Scope 341
726.2 Listing Requirements 341
Part II. Class 4 Circuits 342
726.124 Class 4 Marking 342
726.130 Terminals and Connectors 342

Article 750—Grounding and Bonding of Limited-Energy Systems 343
Part I. General 343
750.1 Scope 343
750.2 Listing Requirements 343
Part II. Conductors and Equipment Outside and Entering Buildings 344
750.60 Metal Antenna Systems—Bonding or Grounding 344
750.66 Antenna Systems Bonding Conductors and Grounding Electrode Conductors 344

Article 760—Fire Alarm Systems 347
Part I. General 347
760.1 Scope 347
760.4 Other Articles 348
760.21 Access to Electrical Equipment Behind Panels Designed to Allow Access 349
760.25 Abandoned Cables 349
760.30 Fire Alarm Circuit Identification 350
760.33 Supply-Side Surge Protection 350
Part III. Power-Limited Fire Alarm (PLFA) Circuits 351
760.121 Power Sources for Power-Limited Fire Alarm Equipment 351
760.124 Marking 352
760.127 Power-Limited Fire Alarm Source Overcurrent Protection 352
Chapter 7—Review Questions 353

TABLE OF CONTENTS

About This Textbook xiv

Additional Products to Help You Learn xviii

How to Use the *National Electrical Code* 1

Article 90—Introduction to the *National Electrical Code* 7
90.1 Scope 7
90.2 Scope and Application of the *NEC* 7
90.3 *Code* Arrangement 11
90.4 *NEC* Enforcement 12
90.5 Mandatory and Permissive Rules, and Explanatory Material 13
90.7 Examination of Equipment for Safety 13

CHAPTER 1—GENERAL RULES 15

Article 100—Definitions 17
100 Scope 17

Article 110—General Requirements for Electrical Installations 57
Part I. General Requirements 57
110.1 Scope 57
110.2 Approval of Conductors and Equipment 57
110.3 Installation and Use of Equipment 58
110.5 Conductor Material 59
110.6 Conductor Sizes 59
110.7 Wiring Integrity 59
110.8 Suitable Wiring Methods 60
110.9 Overcurrent Protective Device Interrupting Rating 60
110.10 Equipment Short-Circuit Current Rating 62
Available Fault Current 62
110.11 Deteriorating Agents 63
110.12 Mechanical Execution of Work 64
110.13 Equipment Mounting and Cooling 66
110.14 Electrical Connections 66
110.15 High-Leg Conductor Identification 75
110.16 Arc-Flash Hazard Marking, Other Than Dwelling Units 75
110.21 Hazard Markings 76
110.22 Identification of Disconnecting Means 77
110.24 Available Fault-Current Marking 77
110.25 Lockable Disconnecting Means 77
Part II. Not Over 1000V 78
110.26 Working Spaces About Electrical Equipment 78
110.27 Protection Against Physical Damage 88
110.28 NEMA Enclosure Types 88
ANSI/NEMA 250-2020 Enclosures for Electrical Equipment 88
110.29 In Sight From (Within Sight From, Within Sight) 90

Article 130—Energy Management Systems 91
Part I. General 91
130.1 Scope 91
130.2 Listing Requirements 92
130.30 Load Management 92
Part II. Power Control Systems (PCS) 92
130.50 General 92
130.60 Conductors and Equipment 92
130.70 Settings 92
130.80 Marking and Documentation 93

CHAPTER 2—WIRING AND PROTECTION 95

Article 200—Use and Identification of Grounded Conductors 97
200.1 Scope 98
200.4 General 98
200.6 Neutral Conductor 98
200.7 Identification of Grounded Conductors 100
200.8 Use of White or Gray Color 101
200.10 Receptacle and Screw Shell Terminal 102

Article 206—Non-Power-Limited Remote-Control and Signaling Circuits 105
206.1 Scope 105

Article 210—Branch Circuits 107
Part I. General 107
210.1 Scope 107
210.4 Multiwire Branch Circuits 108
210.5 Conductor Identification 112

Table of Contents

210.6 Branch-Circuit Voltage 113
210.7 Multiple Branch Circuits 114
210.8 GFCI Protection 114
210.11 Branch Circuits Required 125
210.12 Arc-Fault Circuit-Interrupter Protection 129
Part II. Branch-Circuit Ratings 132
210.18 Branch Circuit Rating 132
210.19 Conductor Sizing 133
210.20 Overcurrent Protection 135

Article 215—Feeders 137
215.1 Scope 137
215.4 Conductor Sizing 138
215.5 Overcurrent Protection Sizing 141
215.12 Conductor Identification 141
215.15 Barriers 142
215.18 Surge Protection 143

Article 225—Outside Branch Circuits and Feeders 145
Part I. General 145
225.1 Scope 145
225.6 Minimum Conductor Size and Support 145
225.16 Attachment to Buildings 146
225.17 Masts as Supports 146
225.18 Clearance for Overhead Conductors 146
225.19 Clearances from Buildings 147
225.22 Raceways on Exterior Surfaces of Buildings 148
225.26 Trees for Conductor Support 149
225.27 Raceway Seals 149
Part II. Buildings or Other Structures Supplied by a Feeder 149
225.30 Number of Supplies 149
225.31 Disconnecting Means 150
225.33 Maximum Number of Disconnects 151
225.34 Grouping of Disconnects 151
225.37 Identification of Multiple Supplies 152
225.39 Rating of Disconnecting Means 152
225.41 Emergency Disconnect 152

Article 230—Services 155
Part I. General 156
230.1 Scope 156
230.2 Listing Requirements 156
230.4 Number of Services 157
230.6 Conductors Considered Outside a Building 158
230.7 Service Conductors Separate from Other Conductors 158
230.8 Raceway Seals 159
230.9 Clearances on Buildings 159
230.10 Vegetation as Support 160
Part II. Overhead Service Conductors 160
230.23 Overhead Service Conductor Size and Ampacity 160
230.24 Vertical Clearance for Overhead Service Conductors 161
230.26 Point of Attachment 161
230.27 Means of Attachment 161
230.28 Service Masts as Support 161
Part III. Underground Service Conductors 162
230.30 Installation 162
230.31 Underground Service Conductor Ampacity 163
230.32 Protection Against Damage 163
Part IV. Service-Entrance Conductors 163
230.42 Conductor Sizing 163
230.43 Wiring Methods 164
230.46 Spliced and Tapped Connections 165
230.50 Protection Against Physical Damage 165
230.51 Cable Supports 166
230.53 Raceways to Drain 166
230.54 Overhead Service Locations 166
Part V. Service Equipment (Disconnect)—General 167
230.62 Service Equipment—Barrier Placement 167
230.66 Marking for Service Equipment 167
230.67 Surge Protection 167
230.68 Meter Socket 168
Part VI. Service Disconnect—Disconnecting Means 169
230.70 Service Disconnect Requirements 169
230.71 Number of Service Disconnects 171
230.72 Grouping of Service Disconnects 172
230.79 Rating of Disconnect 173
230.82 Connected on Supply Side of the Service Disconnect 173
Part VII. Service Conductor Overcurrent Protection 175
230.90 Overload Protection—Where Required 175

Article 240—Overcurrent Protection 177
Part I. General 178
240.1 Scope 178
240.2 Listing Requirements 178
240.4 Overcurrent Protection of Conductors 178
240.5 Overcurrent Protection of Flexible Cords, Flexible Cables, and Fixture Wires 182
240.6 Standard Ampere Ratings 182
240.15 Circuit Breaker Handle Ties 183
Part II. Location of Overcurrent Protective Device 185
240.21 Location of Overcurrent Protective Device in Circuit 185
240.22 Grounded-Phase Conductor on Overcurrent Protective Device 192
240.24 Location of Overcurrent Protective Devices 193

Part III. Enclosures Containing Overcurrent Protective Devices 195
240.33 Vertical Position of Enclosures 195
Part V. Plug Fuses, Fuseholders, and Adapters.....195
240.51 Edison-Base Fuses 195
Part VI. Cartridge Fuses 196
240.60 General.....196
Part VII. Circuit Breakers.....196
240.80 Method of Operation.....196
240.81 Indicating 196
240.85 Circuit Breaker Applications 197

Article 250—Grounding and Bonding.....199
Part I. General 200
250.1 Scope 200
250.4 Performance Requirements for Grounding and Bonding 200
Earth Shells.....204
250.6 Objectionable Current (Ground Loop).....205
Objectionable Neutral Currents.....206
Dangers of Objectionable Current 207
250.8 Connection of Grounding and Bonding Conductors and Terminals 208
250.10 Protection of Ground Clamps and Fittings 209
250.12 Clean Surfaces 209
Part II. System Grounding and Bonding 209
250.20 Systems Required to be Grounded 209
250.24 Service Grounding 210
250.25 Grounding of Systems on the Supply Side of the Service Disconnect.....213
250.28 Main Bonding Jumper and System Bonding Jumper.....213
250.30 Transformer Separately Derived Systems.....216
250.32 Buildings Supplied by a Feeder 224
250.34 Portable and Vehicle- or Trailer-Mounted Generators.....226
250.35 Permanently Installed Generators.....227
250.36 Impedance Grounded Systems—480V to 1000V.....228
Part III. Grounding Electrode System and Grounding Electrode Conductor.....229
250.50 Grounding Electrode System 229
250.52 Grounding Electrode Types.....230
250.53 Grounding Electrode Installation.....233
Measuring Contact Resistance of Electrodes to Earth 234
250.54 Auxiliary Grounding Electrodes 237
250.60 Lightning Protection Electrode.....239
250.64 Grounding Electrode Conductor Installation.....240
250.66 Sizing Grounding Electrode Conductors.....244
250.68 Grounding Electrode Conductor Termination.....245
250.70 Grounding Electrode Conductor Fittings 247
Part IV. Enclosure and Raceway.....248
250.80 Service Raceways and Enclosures 248
250.86 Other than Service Enclosures and Raceways 249
Part V. Bonding.....249
250.92 Bonding Metal Service Raceways and Enclosures 249
250.94 Intersystem Bonding Termination 252
250.96 Bonding Metal Parts 253
250.97 Bonding Metal Raceways and Metal Cables Containing 480Y/277V Circuits 254
250.98 Bonding Loosely Jointed Metal Raceways.....255
250.102 Bonding Jumper Sizing.....255
250.104 Bonding of Metal Piping Systems and Exposed Structural Metal.....258
250.106 Lightning Protection Systems.....262
Part VI. Equipment Grounding Conductors.....263
250.109 Bonding Metal and Nonmetallic Enclosures 263
250.114 Equipment Connected by Cord and Plug 264
250.118 Types of Equipment Grounding Conductors.....264
250.119 Identification of Wire-Type Equipment Grounding Conductors 268
250.120 Equipment Grounding Conductor Installation.....268
250.122 Sizing Wire-Type Equipment Grounding Conductors.....269
250.124 Equipment Grounding Conductor Continuity 272
Part VII. Equipment Grounding Conductor Connections 272
250.134 Equipment Connected by Permanent Wiring Methods.....272
250.138 Cord-and-Plug-Connected 272
250.140 Ranges, Ovens, Cooktops, and Clothes Dryers.....273
250.142 Use of Neutral Conductor for Grounding Equipment.....274
250.146 Receptacle Grounding Terminal Bonding.....275
250.148 Continuity and Connections of Equipment Grounding Conductors in Boxes.....278

CHAPTER 3—WIRING METHODS AND MATERIALS.....281

Article 300—General Requirements for Wiring Methods and Materials.....283
Part I. General Requirements.....283
300.1 Scope 283
300.4 Fire and Water Damage.....284
300.5 Conductors 284
300.6 Protection Against Physical Damage.....287
300.7 Underground Installations.....291
300.8 Protection Against Corrosion.....294
300.9 Raceways Exposed to Different Temperatures.....295
300.11 Raceways in Wet Locations 296

Table of Contents

300.12 Electrical Continuity 296
300.13 Securing and Supporting 297
300.14 Mechanical Continuity 299
300.15 Mechanical and Electrical Continuity of Conductors 300
300.16 Conductor Length at Boxes 302
300.17 Boxes or Fittings, Splices and Terminations 302
300.19 Number and Size of Conductors in a Raceway 304
300.20 Raceway Installations 306
300.21 Supporting Conductors in Vertical Raceways 306
300.22 Reducing Hysteresis Heating 306
300.23 Spread of Fire or Products of Combustion 307
300.24 Total Raceway Bends 309
300.25 Wiring in Ducts and Plenum Spaces 309
300.26 Panels Designed to Allow Access 311

Article 310—Conductors for General Wiring 313
Part I. General 313
310.1 Scope 313
310.2 Listing Requirements 313
Part II. Construction Specifications 313
310.4 Conductor Construction and Application 313
310.5 Conductors, Minimum Size and Material 315
310.6 Conductor Identification 316
Part III. Installation 317
310.10 Uses Permitted 317
310.12 Dwelling Services and Feeders 320
310.14 Ampacities for Conductors 322
310.15 Ampacity Tables 322
310.16 Insulated Conductors 330

Article 312—Cabinets and Meter Socket Enclosures 333
Part I. General 333
312.1 Scope 333
312.2 Listing Requirements 333
312.4 Damp or Wet Locations 333
312.5 Position in Walls 334
312.7 Repairing Gaps in Noncombustible Surfaces 334
312.8 Cable Termination to Enclosures 334
312.11 Overcurrent Protective Device and Switch Enclosures 336
312.13 Screws or Other Fasteners 337

Article 314—Boxes, Conduit Bodies, and Handhole Enclosures 339
Part I. General 339
314.1 Scope 339
314.2 Listing Requirements 339
314.5 Nonmetallic Boxes 340
314.6 Metal Boxes 340
314.7 Screws or Other Fasteners 340
Part II. Installation 340
314.15 Wet Locations 340
314.16 Outlet Box Sizing 341
314.17 Cables That Enter Boxes 348
314.20 Flush-Mounted Boxes 348
314.21 Repairing Noncombustible Surfaces 349
314.22 Surface Extensions 350
314.23 Supporting Enclosures 350
314.25 Box Covers 353
314.27 Box Requirements 354
314.28 Pull and Junction Boxes 356
314.29 Wiring to be Accessible 357
314.30 Handhole Enclosures 359

Article 320—Armored Cable (AC Cable) 361
Part I. General 361
320.1 Scope 361
320.2 Listing Requirements 361
Part II. Installation 362
320.10 Uses Permitted 362
320.12 Uses Not Permitted 362
320.15 Exposed Work 362
320.17 Through or Parallel to Framing Members 362
320.23 In Accessible Attic Spaces 362
320.24 Bending Radius 363
320.30 Securing and Supporting 363
320.40 Boxes and Fittings 364
320.80 Conductor Ampacity 365
Part III. Construction Specifications 365
320.108 Equipment Grounding Conductor 365

Article 330—Metal-Clad Cable (MC Cable) 367
Part I. General 367
330.1 Scope 367
330.2 Listing Requirements 367
Part II. Installation 368
330.10 Uses Permitted 368
330.12 Uses Not Permitted 368
330.15 Exposed Work 369
330.17 Through or Parallel to Framing Members 369
330.23 In Accessible Attics Spaces 369
330.24 Bending Radius 370
330.30 Securing and Supporting 370
330.80 Conductor Ampacities 371

Part III. Construction Specifications....371
330.108 Equipment Grounding Conductor....371

Article 334—Nonmetallic-Sheathed Cable (NM Cable)....373
Part I. General....373
334.1 Scope....373
334.2 Listing Requirements....374
Part II. Installation....374
334.10 Uses Permitted....374
334.12 Uses Not Permitted....375
334.15 Exposed Work....376
334.17 Through or Parallel to Framing Members....377
334.19 Cables Entering Enclosures....378
334.23 In Accessible Attic Spaces....378
334.24 Bending Radius....379
334.30 Securing and Supporting....379
334.40 Boxes and Fittings....380
334.80 Conductor Ampacity....380
Part III. Construction Specifications....382
334.108 Equipment Grounding Conductor....382

Article 336—Power and Control Tray Cable (TC Cable)....383
Part I. General....383
336.1 Scope....383
336.2 Listing Requirements....383
Part II. Installation....384
336.10 Uses Permitted....384
336.12 Uses Not Permitted....384
336.24 Bending Radius....384
336.30 Securing and Supporting....384

Article 338—Service-Entrance Cable (SE and USE Cable)....385
Part I. General....385
338.1 Scope....385
338.2 Listing Requirements....386
Part II. Installation....386
338.10 Uses Permitted....386
338.12 Uses Not Permitted....386
338.24 Bending Radius....387

Article 340—Underground Feeder and Branch-Circuit Cable (UF Cable)....389
Part I. General....389
340.1 Scope....389
340.2 Listing Requirements....389
Part II. Installation....390
340.10 Uses Permitted....390
340.12 Uses Not Permitted....390
340.24 Bends....390
340.80 Conductor Ampacity....390

Article 342—Intermediate Metal Conduit (IMC)....393
Part I. General....393
342.1 Scope....393
342.2 Listing Requirements....393
Part II. Installation....394
342.10 Uses Permitted....394
342.14 Dissimilar Metals....394
342.20 Trade Size....394
342.22 Number of Conductors....394
342.24 Bends....394
342.28 Reaming....394
342.29 Paired Locknuts....395
342.30 Securing and Supporting....395
342.42 Couplings and Connectors....397
342.46 Bushings....397
342.60 Equipment Grounding Conductor....398

Article 344—Rigid Metal Conduit (RMC)....399
Part I. General....399
344.1 Scope....399
344.2 Listing Requirements....399
Part II. Installation....400
344.10 Uses Permitted....400
344.14 Dissimilar Metals....400
344.20 Trade Size....400
344.22 Number of Conductors....400
344.24 Bends....400
344.28 Reaming....401
344.29 Paired Locknuts....401
344.30 Securing and Supporting....401
344.42 Couplings and Connectors....403
344.46 Bushings....404
344.60 Equipment Grounding Conductor....404

Article 348—Flexible Metal Conduit (FMC)....407
Part I. General....407
348.1 Scope....407
348.2 Listing Requirements....407
Part II. Installation....407
348.10 Uses Permitted....407
348.12 Uses Not Permitted....408

Table of Contents

348.20 Trade Size 408
348.22 Number of Conductors 408
348.24 Bends 409
348.28 Trimming 409
348.30 Securing and Supporting 409
348.42 Connectors 410
348.60 Equipment Grounding and Bonding Conductors 410

Article 350—Liquidtight Flexible Metal Conduit (LFMC) 411
Part I. General 411
350.1 Scope 411
350.2 Listing Requirements 412
Part II. Installation 412
350.10 Uses Permitted 412
350.12 Uses Not Permitted 412
350.20 Trade Size 412
350.22 Number of Conductors 412
350.24 Bends 413
350.28 Trimming 413
350.30 Securing and Supporting 413
350.42 Connectors 414
350.60 Equipment Grounding and Bonding Conductors 414

Article 352—Rigid Polyvinyl Chloride Conduit (PVC) 415
Part I. General 415
352.1 Scope 415
352.2 Listing 416
Part II. Installation 416
352.10 Uses Permitted 416
352.12 Uses Not Permitted 417
352.20 Trade Size 417
352.22 Number of Conductors 417
352.24 Bends 418
352.28 Trimming 418
352.30 Securing and Supporting 419
352.44 Expansion Fittings 419
352.46 Bushing or Adapter 420

Article 356—Liquidtight Flexible Nonmetallic Conduit (LFNC) 423
Part I. General 423
356.1 Scope 423
356.2 Listing Requirements 423
Part II. Installation 423
356.10 Uses Permitted 423
356.12 Uses Not Permitted 424
356.20 Trade Size 424
356.22 Number of Conductors 424
356.24 Bends 424
356.30 Securing and Supporting 425
356.42 Fittings 425

Article 358—Electrical Metallic Tubing (EMT) 427
Part I. General 427
358.1 Scope 427
358.2 Listing Requirements 427
Part II. Installation 428
358.10 Uses Permitted 428
358.12 Uses Not Permitted 428
358.20 Trade Size 429
358.22 Number of Conductors 429
358.24 Bends 429
358.28 Reaming 430
358.30 Securing and Supporting 430
358.42 Couplings and Connectors 431
358.60 Equipment Grounding Conductor 432

Article 362—Electrical Nonmetallic Tubing (ENT) 433
Part I. General 433
362.1 Scope 433
362.2 Listing 433
Part II. Installation 434
362.10 Uses Permitted 434
362.12 Uses Not Permitted 435
362.20 Trade Sizes 435
362.22 Number of Conductors 436
362.24 Bends 436
362.28 Trimming 436
362.30 Securing and Supporting 436
362.46 Bushings 437
362.48 Joints 437

Article 376—Metal Wireways 439
Part I. General 439
376.1 Scope 439
Part II. Installation 439
376.10 Uses Permitted 439
376.12 Uses Not Permitted 440
376.20 Conductors Connected in Parallel 440
376.21 Size of Conductors 440
376.22 Number of Conductors and Ampacity 440
376.23 Wireway Sizing 442
376.30 Supports 443

376.56 Splices, Taps, and Power Distribution Blocks....443
376.60 Equipment Grounding Conductor....444

Article 380—Multioutlet Assemblies....447
Part I. General....447
380.1 Scope....447
380.2 Listing Requirements....447
Part II. Installation....447
380.10 Uses Permitted....447
380.12 Uses Not Permitted....448
380.76 Through Partitions....448

Article 386—Surface Metal Raceways....449
Part I. General....449
386.1 Scope....449
386.2 Listing Requirements....449
Part II. Installation....450
386.10 Uses Permitted....450
386.12 Uses Not Permitted....450
386.21 Size of Conductors....450
386.22 Number of Conductors....450
386.30 Supporting....451
386.56 Splices and Taps....451
386.60 Equipment Grounding Conductor....451

Article 392—Cable Trays....453
Part I. General....453
392.1 Scope....453
Part II. Installation....453
392.10 Uses Permitted....453
392.12 Uses Not Permitted....455
392.18 Cable Tray Installations....455
392.20 Cable and Conductor Installation....456
392.30 Securing and Supporting....456
392.44 Expansion Splice Plates....456
392.46 Bushed Conduit and Tubing....456
392.56 Cable Splices....457

CHAPTER 4—EQUIPMENT FOR GENERAL USE....459

Article 400—Flexible Cords....461
400.1 Scope....461
400.4 Flexible Cords Types....461
400.5 Flexible Cord Ampacity....462
400.7 Suitability....462
400.10 Uses Permitted....462
400.12 Uses Not Permitted....464
400.13 Splices....465
400.14 Pull at Joints and Terminals....465
400.17 Protection from Damage....465

Article 404—Switches....467
Part I. Installation....467
404.1 Scope....467
404.2 Listing Requirements....467
404.5 Switch and Circuit Breaker Enclosures....468
404.6 Damp or Wet Locations....468
404.9 Indicating....469
404.10 Accessibility and Grouping....469
404.12 Bonding of Enclosures....469
Part II. Construction Specifications....470
404.20 Switch Marking....470

Article 406—Wiring Devices....473
Part I. General....473
406.1 Scope....473
406.2 Listing Requirements....473
406.9 Wiring Devices in Damp or Wet Locations....473
406.10 Wiring Device Terminations....477
Part II. Receptacles, Cord Connectors, and Attachment Plugs (Caps)....478
406.11 Receptacle Rating and Type....478
406.12 General Installation Requirements....479
406.14 Receptacle Mounting....481
406.16 Receptacle Faceplates or Cover Plates....484
406.18 Attachment Plugs and Flanged Surface Inlets....484
406.26 Tamper-Resistant Receptacles....484
Part III. General-Use Snap Switches, Dimmers, and Electronic Control Switches....486
406.30 Switch Connections....486
406.38 Accessibility and Grouping....488
406.40 Switches, Dimmers, and Control Switches....488
406.42 Snap Switches, Dimmers, and Control Switches Mounting....490
406.46 Snap Switch Rating and Use....491

Article 408—Switchboards and Panelboards....493
Part I. General....493
408.1 Scope....493
408.4 Circuit Directory and Description....493
408.5 Clearance for Conductors Entering Bus Enclosures....495
408.6 Short-Circuit Current Rating....495
408.7 Unused Openings....496
408.9 Replacement Panelboards....496
408.10 Busbars and Conductors Arrangement....497
408.14 Panelboard and Switchboard Ampere Rating....498

Table of Contents

Part III. Panelboards 498
408.36 Overcurrent Protection 498
408.40 Equipment Grounding Conductor 499
408.41 Neutral Conductor Terminations 500
408.43 Panelboard Orientation 500

Article 445—Generators 501
445.1 Scope 501
445.2 Listing Requirements 501
445.11 Marking 501
445.13 Conductor Minimum Ampacity and Size 502
445.18 Disconnecting Means 502
445.19 Prime Mover Emergency Shutdowns 503

Article 450—Transformers 505
450.1 Scope 505
450.5 Primary Overcurrent Protection 506
450.6 Autotransformers 508
450.11 Ventilation 508
450.12 Grounding and Bonding 508
450.15 Transformer Accessibility 509
450.16 Disconnecting Means 509

Article 480—Stationary Batteries 511
480.1 Scope 511
480.4 Battery and Cell Terminations 511
480.9 Battery Support Systems 512
480.10 Battery Locations 512
480.12 Battery Interconnections 514
480.14 Overcharge Control 514

EXAM A—STRAIGHT ORDER—ARTICLES 90–480 515

CHAPTER 6—SPECIFIC EQUIPMENT 527

Article 624—Electric Self-Propelled Vehicle Power Transfer Systems 529
Part I. General 529
624.1 Scope 529
624.2 Listing Requirements 530
Part III. Installation 530
624.40 ESVSE Branch Circuits 530
624.41 Overcurrent Protection 530
624.42 Rating 530
624.43 Disconnecting Means 530
624.48 Interactive Equipment 530
624.49 Island Mode 531
624.54 GFCI Protection 531

Article 625—Electric Vehicle Power Transfer System 533
Part I. General 533
625.1 Scope 533
625.2 Listing Requirements 533
625.4 Qualified Persons 534
625.5 Field Installed Rating Label 535
Part III. Installation 535
625.40 Electric Vehicle Branch Circuit 535
625.41 Continuous Loads 535
625.42 EVSE Rating 537
625.43 Disconnecting Means 538
625.44 Equipment Connections 539
625.48 Interactive (Grid-Tied) Equipment 540
625.54 GFCI Protection 540
Part IV. Wireless Power Transfer Equipment 540
625.101 Grounding 540
625.102 Installation 541

Article 690—Solar Photovoltaic (PV) Systems 543
Part I. General 543
690.1 Scope 543
690.2 Listed Requirements 544
690.4 General Requirements 544
690.6 Alternating-Current Modules 546
Part II. Circuit Requirements 547
690.7 Maximum PV System dc Circuit Voltage 547
690.8 Current Calculations and Conductor Ampacity 553
690.9 Overcurrent Protection 562
690.12 PV Rapid Shutdown 565
Part III. Disconnect 569
690.13 PV System Disconnecting Means 569
690.15 PV Equipment Disconnecting Means 571
Part IV. Wiring Methods 573
690.31 Wiring Methods 573
690.32 Concealed Interconnections 578
690.33 Mating Connectors 579
690.34 Access to Boxes 579
Part V. Grounding and Bonding 579
690.41 PV System dc Circuit Grounding 579
690.43 Equipment Grounding Conductor 580
690.45 Equipment Grounding Conductor Sizing 581
690.47 Grounding Electrode System 582

Part VI. Source Connections....582
690.59 Connection to Other Power Sources....582

Article 691—Large-Scale Photovoltaic (PV) Electric Supply Stations....583
691.1 Scope....583
691.2 Listing Requirements....583
691.4 Special Requirements for Large-Scale PV Electric Supply Stations....583
691.6 Engineered Design....584
691.7 Conformance of Construction to Engineered Design....584
691.8 Direct-Current Operating Voltage....584
691.9 Disconnect for Isolating Photovoltaic Equipment....584
691.10 Fire Mitigation....585
691.11 Bonding and Grounding....585

CHAPTER 7—SPECIFIC CONDITIONS AND SYSTEMS....587

Article 702—Optional Standby Systems....589
Part I. General....589
702.1 Scope....589
702.4 Capacity and Rating....590
702.5 Interconnection or Transfer Equipment....591

Article 705—Interconnected Electric Power Production Sources....595
Part I. General....595
705.1 Scope....595
705.2 Listing Requirements....595
705.8 Qualified Persons....596
705.10 Power Source Identification....597
705.11 Service Connection....598
705.12 Load-Side Connection....599
705.13 Power Control Systems....604
705.20 Power Source Output Conductor Disconnect....604
705.25 Wiring Methods....606
705.28 Power Source Output Current and Circuit Sizing....606
705.30 Overcurrent Protection....608
705.40 Primary Source Loss....611
705.45 Unbalanced Interconnections....612
Part II. Microgrid Systems....612
705.50 Microgrid System Operation....612
705.60 Connections to Utility Power....613
705.70 Microgrid Interconnect Devices (MID)....613

Article 706—Energy Storage Systems....615
Part I. General....615
706.1 Scope....615
706.2 Listing Requirements....615
706.4 Markings....615
706.5 Qualified Persons....616
706.6 Multiple Systems....617
706.7 Commissioning and Servicing....617
Part II. Disconnect....618
706.15 Disconnect....618
Part IV. Energy Storage System Circuit Requirements....620
706.30 Circuit Current Rating....620
706.31 Overcurrent Protection....621

Article 710—Stand-Alone Systems....623
710.1 Scope....623
710.2 Listing Requirements....623
710.10 Power Source Identification....623
710.15 System and Circuit Sizing....624

EXAM B—STRAIGHT ORDER—ARTICLES 624–710....625

FINAL EXAM—RANDOM ORDER—ARTICLES 90–710....635

INDEX....649

About the Author....659

About The Mike Holt Team....661

TABLE OF CONTENTS

About This Textbook vii

Additional Products to Help You Learn x

How to Use the *National Electrical Code* 1

Article 90—Introduction to the *National Electrical Code* 9
90.1 Scope 9
90.2 Scope and Application of the *NEC* 9
90.3 *Code* Arrangement 13
90.4 *NEC* Enforcement 14
90.5 Mandatory and Permissive Rules, and Explanatory Material 15
90.7 Examination of Equipment for Safety 15
Article 90—Review Questions 17

CHAPTER 1—GENERAL RULES 19

Article 100—Definitions 21
100 Scope 21

Article 110—General Requirements for Electrical Installations 27
Part I. General Requirements 27
110.1 Scope 27
110.14 Electrical Connections 27
Chapter 1—Review Questions 31

CHAPTER 2—WIRING AND PROTECTION 33

Article 210—Branch Circuits 35
Part I. General 35
210.1 Scope 35
Part II. Branch-Circuit Ratings 36
210.19 Conductor Sizing 36
210.20 Overcurrent Protection 38

Article 240—Overcurrent Protection 41
Part I. General 42
240.1 Scope 42
240.4 Overcurrent Protection of Conductors 42
240.6 Standard Ampere Ratings 46
Chapter 2—Review Questions 47

CHAPTER 3—WIRING METHODS AND MATERIALS 49

Article 300—General Requirements for Wiring Methods and Materials 51
Part I. General Requirements 51
300.1 Scope 51
300.19 Number and Size of Conductors in a Raceway 52

Article 310—Conductors for General Wiring 55
Part I. General 55
310.1 Scope 55
Part II. Construction Specifications 55
310.4 Conductor Construction and Application 55
Part III. Installation 57
310.15 Ampacity Tables 57
310.16 Insulated Conductors 64

Article 314—Boxes, Conduit Bodies, and Handhole Enclosures 67
Part I. General 67
314.1 Scope 67
Part II. Installation 67
314.16 Outlet Box Sizing 67
314.28 Pull and Junction Boxes 74

Article 334—Nonmetallic-Sheathed Cable (NM Cable) 77
Part I. General 77
334.1 Scope 77
Part II. Installation 78
334.80 Conductor Ampacity 78
Chapter 3—Review Questions 81

Table of Contents

CHAPTER 4—EQUIPMENT FOR GENERAL USE 83

Article 422—Appliances 85

Part I. General 85

422.1 Scope 85

Part II. Branch-Circuit Requirements 85

422.10 Branch Circuits 85

422.11 Overcurrent Protection 85

422.13 Storage Water Heaters 86

Article 424—Fixed Electric Space-Heating Equipment 89

Part I. General 89

424.1 Scope 89

424.5 Continuous Load 89

Article 440—Air-Conditioning and Refrigeration Equipment 91

Part I. General 91

440.1 Scope 91

440.4 Marking on Hermetic Refrigerant Motor-Compressors and Equipment 91

Chapter 4—Review Questions 93

FINAL EXAM 95

INDEX 103

About the Author 107

About the Mike Holt Team 109

TABLE OF CONTENTS

About This Textbook x

Passing Your Exam xv

Additional Products to Help You Learn xxi

How to Use the *National Electrical Code* 1

THEORY

MODULE I—ELECTRICAL FUNDAMENTALS 7

Unit10—Basic Math 9
10.1 Introduction 9
10.2 Whole Numbers 9
10.3 Fractional Numbers 9
10.4 Decimal Numbers 9
10.5 Percentages 10
10.6 Parentheses 10
10.7 Squaring a Number 11
10.8 Square Root 11
10.9 Kilo 11
10.10 Rounding 12
10.11 Surface Area of a Rectangle or Square 12
10.12 Surface Area of a Circle 13
10.13 Volume 14
10.14 Reciprocal 15
10.15 Testing Your Answer 15
Unit 10—Review Questions 16

Unit12—Ohm's Law 19
12.1 Introduction 19
12.2 The Electrical Circuit 19
12.3 Electromotive Force (Pressure) 19
12.4 Circuit Resistance 20
12.5 Circuit Intensity (Current) 20
12.6 Ohm's Law 21
12.7 Ohm's Law Formula Circle 22
Unit 12—Review Questions 24

Unit13—Watt's Law 27
13.1 Introduction 27
13.2 Watt's Law 27
13.3 Power Formula Circle 28
13.4 Power Changes with the Square of the Voltage 29
Unit 13—Review Questions 30

Unit14—Series Circuits 33
14.1 Introduction 33
14.2 Series Circuits 33
14.3 Understanding Series Circuits 33
14.4 Series Circuit Summary 37
14.5 Series-Connected Power Supplies 37
14.6 Applications of Series Circuits 38
Unit 14—Review Questions 40

Unit15—Parallel Circuits 43
15.1 Introduction 43
15.2 Understanding Parallel Circuits 43
15.3 Parallel Circuit Resistance Calculations 45
15.4 Parallel Circuit Summary 48
15.5 Parallel-Connected Power Supplies 48
15.6 Practical Uses of Parallel Circuits 49
Unit 15—Review Questions 51

Unit16—Series-Parallel Circuits 55
16.1 Introduction 55
16.2 Understanding Series-Parallel Circuits 55
16.3 Calculating Resistance in Series-Parallel Circuits 56
Unit 16—Review Questions 58

Unit 17—Alternating Current Fundamentals 59
17.1 Introduction 59
17.2 How Alternating Current is Produced 59
17.3 Waveforms 60
17.4 Frequency 62
17.5 In-Phase Waveforms 63
17.6 Out-of-Phase Waveforms 63
17.7 Alternating-Current Waveform Values 64
Unit 17—Review Questions 67

Table of Contents

Unit 20—True Power, Power Factor, and Apparent Power 71
20.1 Introduction 71
20.2 True Power 71
20.3 Power Losses of Wires 71
20.4 Power Losses at Terminals 72
20.5 Equipment Efficiency 73
20.6 Cost of Power 73
20.7 Power Factor 74
20.8 Apparent Power 76
20.9 Apparent Power versus True Power 77
Unit 20—Review Questions 78

Unit 21—Motors 83
21.1 Introduction 83
21.3 Motor Horsepower Rating 83
21.5 Motor Nameplate Amperes 84
21.7 Reversing the Rotation of Alternating-Current Motors 85
21.8 Alternating-Current Motor Types 86
Unit 21—Review Questions 87

Unit 22—Generators 89
22.1 Introduction 89
22.4 Generator Output Current 89
22.5 Single-Phase and Three-Phase Generator Voltages 90
Unit 22—Review Questions 91

Unit 23—Relays 93
23.1 Introduction 93
23.2 How Relays Operate 93
23.3 Relay Contacts 94
Unit 23—Review Questions 95

Unit 24—Transformers 97
24.1 Introduction 97
24.6 Transformer Turns Ratios 97
24.8 Autotransformers 99
24.11 Transformer Current Rating 99
Unit 24—Review Questions 103

Unit 25—Overcurrent Protection 105
25.1 Introduction 105
25.3 Fuses 105
25.4 Circuit Breakers 107
25.6 Available Short-Circuit Current 108
25.7 Overcurrent Protective Devices, Interrupting Rating 109
Unit 25—Review Questions 111

Unit 28—Multiwire Circuits 113
28.1 Introduction 113
28.2 Neutral Wire 113
28.3 Grounded Wire 114
28.4 Current Flow on the Neutral Wire 114
28.5 Multiwire Branch Circuits 115
28.6 Dangers of Multiwire Circuits 116
28.7 *NEC* Requirements 117
Unit 28—Review Questions 119

Unit 29—The Formula Wheel 121
29.1 Introduction 121
29.2 Formula Wheel Quadrants 121
29.3 Using the Formula Wheel 121
Unit 29—Review Questions 124

Module I—Electrical Fundamentals—Practice Exam 127

CODE

MODULE II—*NEC* PRACTICE QUIZZES AND CHALLENGE EXAMS 135
NEC Practice Quiz 1—Straight Order [90–110.26] 137
NEC Practice Quiz 2—Random Order [90–110.26] 142
NEC Practice Quiz 3—Straight Order [110.26–210.8] 145
NEC Practice Quiz 4—Random Order [110.26–210.8] 150
NEC Practice Quiz 5—Straight Order [210.8–230.54] 153
NEC Practice Quiz 6—Random Order [210.8–230.54] 158
NEC Practice Quiz 7—Straight Order [230.54–250.24] 161
NEC Practice Quiz 8—Random Order [230.54–250.24] 166
NEC Practice Quiz 9—Straight Order [250.24–250.66] 169
NEC Practice Quiz 10—Random Order [250.24–250.66] 174
NEC Practice Quiz 11—Straight Order [250.66–268] 177
NEC Practice Quiz 12—Random Order [250.66–268] 182
NEC Practice Quiz 13—Straight Order [270–310.10] 185
NEC Practice Quiz 14—Random Order [270–310.10] 190
NEC Practice Quiz 15—Straight Order [310.10–330.30] 193
NEC Practice Quiz 16—Random Order [310.10–330.30] 198
NEC Practice Quiz 17—Straight Order [330.30–362.30] 201
NEC Practice Quiz 18—Random Order [330.30–362.30] 206
NEC Practice Quiz 19—Straight Order [362.30–406.30] 209
NEC Practice Quiz 20—Random Order [362.30–406.30] 214
NEC Practice Quiz 21—Straight Order [406.30–422.11] 217
NEC Practice Quiz 22—Random Order [406.30–422.11] 222
NEC Practice Quiz 23—Straight Order [422.16–430.110] 225
NEC Practice Quiz 24—Random Order [422.16–430.110] 230

NEC Practice Quiz 25—Straight Order [430.27–501.10] 233
NEC Practice Quiz 26—Random Order [430.27–501.10] 238
NEC Practice Quiz 27—Straight Order [501.10–547.44] 241
NEC Practice Quiz 28—Random Order [501.10–547.44] 246
NEC Practice Quiz 29—Straight Order [550–620.51] 249
NEC Practice Quiz 30—Random Order [550–620.51] 254
NEC Practice Quiz 31—Straight Order [620.62–680.75] 257
NEC Practice Quiz 32—Random Order [620.62–680.75] 262
NEC Practice Quiz 33—Straight Order [690–694] 265
NEC Practice Quiz 34—Random Order [690–694] 270
NEC Practice Quiz 35—Straight Order [695–701.32] 273
NEC Practice Quiz 36—Random Order [695–701.32] 278
NEC Practice Quiz 37—Straight Order [701.32–722.122] 281
NEC Practice Quiz 38—Random Order [701.32–722.122] 286
NEC Practice Quiz 39—Straight Order [722.31–830.133] 289
NEC Practice Quiz 40—Random Order [722.31–830.133] 294

NEC Challenge Exam 1—Articles 90–830—Random Order 297
NEC Challenge Exam 2—Articles 90–830—Random Order 303
NEC Challenge Exam 3—Articles 90–830—Random Order 309
NEC Challenge Exam 4—Articles 90–830—Random Order 315

CALCULATIONS

MODULE III—*NEC* CALCULATIONS 323

Unit 1—Raceway Calculations 325
1.1 *NEC* Chapter 9, Tables 5 and 8—Conductor Cross-Sectional Area 325
1.2 Raceway Conductor Fill Area 329
1.3 Annex C—Raceway Size, Conductors All the Same Size 332
1.4 Note 6 to Chapter 9 Tables—Raceways Sizing with Different Size Conductors 336
1.5 Multiconductor and Optical Fiber Cables—Note 5 and Note 9 to Chapter 9 Tables 339
1.6 Wireways Sizing 339
1.7 Cable Tray Sizing 342
1.8 Tips for Raceway Calculations 344
Unit 1—Conclusion 344
Unit 1—Review Questions 345

Unit 2—Box Calculations 351
Part A—Outlet and Device Box Sizing 351
Introduction 351
2.1 Box Sizing—Conductors All the Same Size [Table 314.16(A)] 353
2.2 Box Fill Calculations [314.16(B)] 353
2.3 Outlet Box Sizing Examples [314.16(B)] 357
2.4 Tips for Outlet Box Sizing 359
Part B—Pull and Junction Boxes 359
Introduction 359
2.5 Pull and Junction Box Sizing 359
2.6 How to Size Pull and Junction Boxes 361
2.7 Pull Box Sizing Examples 361
2.8 Tips for Pull Box Sizing 364
Unit 2—Conclusion 364
Unit 2—Review Questions 365

Unit 3—Conductor Sizing and Protection Calculations 369
Part A—Conductor Insulation, Terminals, and Overcurrent Protection 369
Introduction 369
3.1 Conductor Insulation [Table 310.4(1)] 369
3.2 Conductor Sizes [110.6] 371
3.3 Conductor Size—Equipment Terminal Rating [110.14(C)] 371
3.4 Overcurrent Protection of Conductors [240.4] 374
Part B—Conductor Ampacity and Overcurrent Protection Sizing 376
Introduction 376
3.5 Conductor Ampacity Table [310.15(A)] 376
3.6 Conductor Ampacity Correction [310.15(B)(1)] 376
3.7 Conductor Ampacity Adjustment [310.15(C)(1)] 378
3.8 Conductor Ampacity Correction and Adjustment [310.15] 381
3.9 Neutral Considered Current-Carrying Conductor [310.15(E)] 382
3.10 Branch Circuit Conductor Sizing [210.19(A)(1)] 384
3.11 Branch Circuit Conductor Sizing—Loads Considered Continuous 387
3.12 Branch Circuit Overcurrent Protection Sizing [210.20(A)] 388
3.13 Maximum Load on Overcurrent Protective Device [210.20(A)] 389
3.14 Appliance Overcurrent Protection Sizing [422.11(E)(3)] 389
3.15 Feeder Conductor Sizing [215.4(A)(1)] 390
3.16 Feeder Neutral Conductor Size [215.4(A)(1) Ex 3] 391
3.17 Feeder Overcurrent Protection Sizing [215.5] 392
3.18 Maximum Load on Overcurrent Protective Device [215.5] 392
3.19 Feeder Tap Rules [240.21(B)] 393
Unit 3—Conclusion 397
Unit 3—Review Questions 398

Table of Contents

Unit 4—Motor, Air-Conditioning, and Transformer Calculations 407

Part A—Motor Calculations 407

Introduction 407

4.1 Motor Full-Load Current (FLC) 407

4.2 Motor Full-Load Current versus Motor Nameplate Current Rating [430.6(A)] 410

4.3 Branch-Circuit Conductor Sizing for Continuous-Duty Application Motors [430.22] 411

4.4 Branch-Circuit Conductor Sizing for Duty-Cycle Application Motors [430.22(E)] 414

4.5 Motor Overcurrent Protection 415

4.6 Motor Overload Protection 417

4.7 Branch-Circuit Short-Circuit and Ground-Fault Protection [430.52] 421

4.8 Motor Branch-Circuit Summary 424

4.9 Feeder Conductor Sizing [430.24] 425

4.10 Feeder Short-Circuit and Ground-Fault Protection [430.62(A)] 428

Part B—Air-Conditioning Calculations 430

Introduction 430

4.11 Air-Conditioning Equipment Nameplate [440.4(B)] 430

4.12 Short-Circuit and Ground-Fault Overcurrent Protective Device Size [440.22] 431

4.13 Motor-Compressor(s) With or Without Additional Motor Loads [440.33] 432

Part C—Transformers 433

Introduction 433

4.14 Transformer Primary Only Overcurrent Protection [450.5(B)] 433

4.15 Autotransformers [450.6] 436

4.16 Transformer Primary Conductor Sizing [215.4(A)(1), 240.4, and Table 310.16] 436

4.17 Transformer Secondary Conductor Sizing [240.21(C)] 438

Unit 4—Conclusion 439

Unit 4—Review Questions 440

Unit 5—Voltage-Drop Calculations 447

Part A—Conductor Resistance Calculations 447

Introduction 447

5.1 Conductor Cross-Sectional Area in Circular Mills [Chapter 9, Table 8] 447

5.2 Conductor Resistance 449

5.3 Conductor Direct-Current Resistance [Chapter 9, Table 8] 451

Part B—Voltage-Drop Calculation Formulas 452

Introduction 452

5.4 Ohm's Law Method—Conductors' Voltage Drop 452

5.5 Voltage Drop Formula Method—Single-Phase 454

5.6 Circuit Voltage Drop Formula Method—Three-Phase 456

5.7 Sizing Conductor Circuit Voltage Drop Formula Method—Single-Phase 457

5.8 Sizing Conductor Circuit Voltage Drop Formula Method—Three-Phase 458

5.9 Limiting Conductor Length (Distance) Single-Phase Circuits 460

5.10 Limiting Conductor Length (Distance) Three-Phase Circuits 461

Unit 5—Conclusion 462

Unit 5—Review Questions 463

Unit 6—Dwelling Unit Calculations 467

Part A—Dwelling Unit Optional Method Load Calculations [Article 120, Part IV] 467

Introduction 467

6.1 Dwelling Unit Optional Load Calculations [120.82] 468

6.2 Optional Method—Dwelling Unit Optional Load Calculation [120.82] 469

Part B—Dwelling Unit Standard Method Load Calculations [Article 120, Part III] 470

Introduction 470

6.3 Dwelling Unit Standard Method Load Calculations 470

6.4 General Lighting and General-Use Receptacle Demand Load [120.41 and Table 120.45] 471

6.5 Fixed Appliance Demand Load [120.53] 473

6.6 Dryer Demand Load [120.54] 474

6.7 Electric Cooking Equipment Demand Load [120.55] 475

6.8 Electric Vehicle [120.57] 477

6.9 Air-Conditioning Versus Heating [120.6] 478

6.10 Service Conductor Size [Table 310.12(A)] 480

6.11 Standard Method Load Calculations [Article 120, Part III] 480

6.12 Number of General Lighting and General-Purpose Receptacle Circuits [210.11(A) and 120.13] 481

Part C—Neutral Load Calculations 483

Introduction 483

6.13 Dryers and Ranges Neutral Calculations [120.61] 483

6.14 Service Neutral Calculation [120.61] 484

Unit 6—Conclusion 485

Unit 6—Review Questions 486

Module III—*NEC* Calculations—Practice Exam 493

ADVANCED CALCULATIONS

MODULE IV—ADVANCED *NEC* CALCULATIONS 499

Unit 7—Multifamily Dwelling Calculations 501

Part A—Optional Method Load Calculations [Article 120, Part IV] 501

Introduction.....501

7.1 Multifamily Dwelling Optional Load Calculations [120.84].....502

7.2 Multifamily Dwelling Optional Method Examples [120.84].....503

Part B—Standard Method Load Calculations [Article 120, Part III].....505

Introduction.....505

7.3 Standard Method Calculation Steps 505

7.4 General Lighting and General-Use Receptacle Demand Load [120.41 and 120.45].....506

7.5 Appliance Demand Load [120.53] 507

7.6 Dryer Demand Load [120.54].....508

7.7 Single-Phase Dryers on Three-Phase Service [120.54].....510

7.8 Single-Phase Ranges on Single-Phase Service [120.55].....512

7.9 Single-Phase Ranges on Three-Phase Service [120.55] 514

7.10 Air-Conditioning and Heating Demand Load.....517

7.11 Service Conductor Sizing [Table 310.16].....518

7.12 Multifamily Dwelling Calculations—Standard Method, Examples.....519

7.13 Two-Family (Duplex) Dwelling Units Load Calculations [120.85].....521

Part C—Neutral Load Calculations.....524

Introduction.....524

7.14 Neutral Demand Load—Dryers and Ranges [120.61(B)(1)].....524

7.15 Service Neutral Demand Load [120.61(B)].....525

Unit 7—Conclusion.....527

Unit 7—Review Questions.....528

Unit 8—Commercial Calculations.....537

Part A—General Commercial Demand Loads.....537

Introduction.....537

8.1 General Lighting Load [Table 120.42(A)] 537

8.2 General Lighting Load [Table 120.42(A)] Examples.....538

8.3 General Lighting Load Demand Factors [Table 120.45].....539

8.4 Number of General Lighting Branch Circuits [210.11(B) and Annex D, Example D3] 540

8.5 Sign Circuit and Show Window Circuit [120.14(F), 120.14(G), and 210.19(A)(1)].....542

8.6 Multioutlet Assemblies [120.14(H)].....543

8.7 Receptacle Demand Load [120.14(I)] 545

8.8 Air-Conditioning versus Heating Load [120.6].....546

Part B—Office, Mobile Home, Kitchen, Restaurants, and School Examples.....547

Introduction.....547

8.9 Office Building Example.....547

8.10 Manufactured Home Parks [120.141] 549

8.11 Kitchen Equipment and Restaurants [120.56] 549

8.12 School Optional Method Load Calculations [120.86].....552

Part C—Welder Calculations.....553

Introduction.....553

8.13 Arc Welders 554

8.14 Resistance Welders 556

Part D—Light Industrial Calculations.....558

Introduction.....558

8.15 Light Industrial Calculations.....558

Part E—Neutral Calculations.....560

8.16 Feeder Neutral Calculation Load Reductions [120.61].....560

Unit 8—Conclusion.....561

Unit 8—Review Questions.....562

Module IV—*NEC* Advanced Calculations Practice Exam.....569

About the Author 575

About the Mike Holt Team 577

TABLE OF CONTENTS

About This Book vii

CHAPTER 1—STUDY TIPS TO PASS YOUR EXAM 1

CHAPTER 2—HOW TO USE THE *NATIONAL ELECTRICAL CODE* 7

CHAPTER 3—MASTER SIMULATED EXAMS 17

- **Master Simulated Exam A** 19
- **Master Simulated Exam B** 39

CHAPTER 4—TEST-TAKING TIPS TO PASS YOUR EXAM 59

CHAPTER 5—STUDY OPTIONS 63

About Mike Holt 73

Contents

LEVEL 1
Basic Skills for Success

BASIC SKILLS FOR SUCCESS 3
Attitude 4
Balance (Life) 8
Change 12
Character 16
Coach and Mentor 20
Communication 24
Conduct 28
Continuous Learning 32
Entitlement 36
Fear 40
Forgiving 44
Gut Feeling 48
Healthy Lifestyle 52
Image 56
Inadequate Feelings 60
Life 64
Money Management 68
"No" 72
Organized 76
Peer Pressure 80
Relationships 84
Resolving Differences 88
Risk-Taking 92
Sensitive People 96
Spirituality 100
Work Ethic 104
Mike's Perspective 108

LEVEL 2
Essential Skills for Success

ESSENTIAL SKILLS FOR SUCCESS 111
Conflict Management 112
Failure 116
Intimidation 120
Pareto's Principle—The 80/20 Rule 124
Peter Principle 128
Planning 132
Problem-Solving 136
Teachable 140
Mike's Perspective 144

LEVEL 3
Advanced Skills for Success

ADVANCED SKILLS FOR SUCCESS 147
Assuming Responsibility 148
Creativity and Innovation 152
Decision-Making 156
Delegation 160
Efficiency 164
Goal Setting 168
Motivation 172
Reputation 176
Self-Confidence 180
Teamwork 184
Time Management 188
Mike's Perspective 192

LEVEL 4
Compound Skills for Success

COMPOUND SKILLS FOR SUCCESS 195
Continuous Improvement. 196
Happiness 200
Leadership 204
Leadership Style 208
Memberships 212
Procrastination 216
Self-Awareness 220
Mike's Perspective 224

LEVEL 5
Complex Skills for Success

COMPLEX SKILLS FOR SUCCESS 227
Achievement. 228
Crisis Management 232
Immediate Action 236
Overwhelmed. 240
Prepared 244
Stress 248
Mike's Perspective 252

FT
Final Thoughts

FINAL THOUGHTS. 257
Never Give Up. 258
Index and Summary. . . . 260
Resources 277
Acknowledgment 277
About the Author. 278