

Table of Contents

| | |
|--|-------|
| Introduction | x |
| About This Textbook | xi |
| Passing Your Exam | xiv |
| How to Use the <i>National Electrical Code</i> | xviii |
| About the Author | xxi |
| About the Graphic Illustrator | xxii |
| Mike Holt Enterprises Team | xxiii |

CHAPTER 1—BASIC ELECTRICAL THEORY (Essential for Journeyman and Master’s Licensing Exams)

| | |
|--|----|
| UNIT 1—ELECTRICIAN’S MATH AND BASIC ELECTRICAL FORMULAS | 3 |
| Part A—Electrician’s Math | 3 |
| 1.1 Whole Numbers | 3 |
| 1.2 Decimals | 3 |
| 1.3 Fractions | 3 |
| 1.4 Percentages | 4 |
| 1.5 Multiplier | 4 |
| 1.6 Percent Increase | 5 |
| 1.7 Reciprocals | 5 |
| 1.8 Squaring a Number | 6 |
| 1.9 Parentheses | 7 |
| 1.10 Square Root | 7 |
| 1.11 Volume | 8 |
| 1.12 Kilo | 8 |
| 1.13 Rounding Off | 9 |
| 1.14 Testing Your Answer for Reasonableness | 9 |
| Part B—Basic Electrical Formulas | 10 |
| 1.15 Electrical Circuit | 10 |
| 1.16 Power Source | 10 |
| 1.17 Conductance | 11 |
| 1.18 Circuit Resistance | 11 |
| 1.19 Ohm’s Law | 12 |
| 1.20 Ohm’s Law and Alternating Current | 12 |
| 1.21 Ohm’s Law Formula Circle | 12 |
| 1.22 PIE Formula Circle | 14 |
| 1.23 Formula Wheel | 15 |

| | |
|---|----|
| 1.24 Using the Formula Wheel | 16 |
| 1.25 Power Losses of Conductors | 17 |
| 1.26 Cost of Power | 17 |
| 1.27 Power Changes with the Square of the Voltage | 18 |
| Conclusion to Unit 1 | 20 |
| Practice Questions for Unit 1 | 21 |
| Challenge Questions for Unit 1 | 27 |
| UNIT 2—ELECTRICAL CIRCUITS | 29 |
| Part A—Series Circuits | 29 |
| 2.1 Practical Uses of the Series Circuit | 29 |
| 2.2 Understanding Series Calculations | 30 |
| 2.3 Series Circuit Calculations | 33 |
| 2.4 Power Calculations | 34 |
| 2.5 Variations | 34 |
| 2.6 Series Circuit Notes | 34 |
| 2.7 Series-Connected Power Supplies | 34 |
| Part B—Parallel Circuits | 34 |
| 2.8 Practical Uses of the Parallel Circuit | 35 |
| 2.9 Understanding Parallel Calculations | 37 |
| 2.10 Circuit Resistance | 38 |
| 2.11 Parallel Circuit Notes | 40 |
| 2.12 Parallel-Connected Power Supplies | 40 |
| Part C—Series-Parallel Circuits | 41 |
| 2.13 Review of Series and Parallel Circuits | 41 |
| 2.14 Working With Series-Parallel Circuits | 42 |
| 2.15 Voltage | 42 |
| Part D—Multiwire Branch Circuits | 43 |
| 2.16 Neutral Conductor | 43 |
| 2.17 Grounded Conductor | 43 |
| 2.18 Current Flow on the Neutral Conductor | 44 |
| 2.19 Balanced Systems | 45 |
| 2.20 Unbalanced Current | 45 |
| 2.21 Multiwire Branch Circuits | 46 |
| 2.22 Dangers of Multiwire Branch Circuits | 48 |
| 2.23 <i>NEC</i> Requirements | 49 |
| Conclusion to Unit 2 | 49 |
| Practice Questions for Unit 2 | 51 |
| Challenge Questions for Unit 2 | 57 |

| | | | |
|---|----|--|-----|
| UNIT 3—UNDERSTANDING ALTERNATING CURRENT | 61 | UNIT 4—MOTORS AND TRANSFORMERS | 95 |
| Part A—Understanding Alternating Current | 61 | Part A—Motor Basics | 95 |
| 3.1 Current Flow | 61 | 4.1 Motor Principles | 95 |
| 3.2 Why Alternating Current Is Used | 62 | 4.2 Dual-Voltage Alternating-Current Motors | 96 |
| 3.3 How Alternating Current Is Produced | 62 | 4.3 Motor Horsepower Ratings | 96 |
| 3.4 Alternating-Current Generator | 62 | 4.4 Motor Current Ratings | 97 |
| 3.5 Waveform | 63 | 4.5 Calculating Motor FLA | 97 |
| 3.6 Sine Wave | 64 | 4.6 Motor-Starting Current | 98 |
| 3.7 Frequency | 64 | 4.7 Motor-Running Current | 99 |
| 3.8 Phase | 64 | 4.8 Motor Locked-Rotor Current (LRC) | 99 |
| 3.9 Degrees | 65 | 4.9 Motor Overload Protection | 99 |
| 3.10 Lead or Lag | 65 | 4.10 Direct-Current Motor Principles | 100 |
| 3.11 Values of Alternating Current | 65 | 4.11 Direct-Current Motor Types | 100 |
| Part B—Capacitance | 66 | 4.12 Reversing the Rotation of a Direct-Current Motor | 101 |
| 3.12 Charged Capacitor | 67 | 4.13 Alternating-Current Induction Motor | 101 |
| 3.13 Electrical Field | 67 | 4.14 Alternating-Current Motor Types | 101 |
| 3.14 Discharging a Capacitor | 68 | 4.15 Reversing the Rotation of an Alternating-Current Motor | 102 |
| 3.15 Determining Capacitance | 68 | Part B—Transformers | 102 |
| 3.16 Uses of Capacitors | 69 | 4.16 Transformer Basics | 102 |
| 3.17 Phase Relationship | 69 | 4.17 Secondary Induced Voltage | 103 |
| Part C—Induction | 70 | 4.18 Efficiency | 103 |
| 3.18 Self-Induction | 71 | 4.19 Transformer Turns Ratio | 104 |
| 3.19 Induced Voltage and Applied Current | 71 | 4.20 Autotransformers | 106 |
| 3.20 Conductor Alternating-Current Resistance | 72 | 4.21 Power Losses | 106 |
| 3.21 Conductor Shape | 72 | 4.22 Transformer kVA Rating | 108 |
| 3.22 Magnetic Cores | 73 | 4.23 Current Flow | 108 |
| 3.23 Self-Induced and Applied Voltage | 74 | 4.24 Current Rating | 108 |
| 3.24 Inductive Reactance | 75 | Conclusion to Unit 4 | 109 |
| 3.25 Phase Relationship | 75 | Practice Questions for Unit 4 | 110 |
| 3.26 Uses of Induction | 75 | Challenge Questions for Unit 4 | 115 |
| Part D—Power Factor | 75 | CHAPTER 2—NEC CALCULATIONS | |
| 3.27 Apparent Power (Volt-Amperes) | 76 | (Essential for Journeyman and Master’s | |
| 3.28 True Power (Watts) | 76 | Licensing Exams) | 119 |
| 3.29 Power Factor | 77 | UNIT 5—RACEWAY AND BOX CALCULATIONS | 121 |
| 3.30 Unity Power Factor | 77 | Part A—Raceway Fill | 121 |
| 3.31 Power Factor Formulas | 77 | 5.1 Understanding the <i>NEC</i> , Chapter 9 Tables | 121 |
| 3.32 Cost of True Power | 78 | 5.2 Raceway Calculations | 131 |
| 3.33 Effects of Power Factor | 79 | 5.3 Wireways | 132 |
| Part E—Efficiency | 80 | 5.4 Tips for Raceway Calculations | 135 |
| 3.34 Efficiency Formulas | 81 | Part B—Outlet Box Fill Calculations [314.16] | 135 |
| Conclusion to Unit 3 | 82 | 5.5 Sizing Box—Conductors All the Same Size [Table 314.16(A)] | 135 |
| Practice Questions for Unit 3 | 83 | | |
| Challenge Questions for Unit 3 | 91 | | |

| | | | |
|--|-----|--|-----|
| 5.6 Conductor Equivalents | 136 | 7.2 FLC versus Motor Nameplate | 224 |
| 5.7 Outlet Box Sizing [314.16(B)] | 139 | 7.3 Highest Rated Motor [430.17] | 226 |
| Part C—Pull Boxes, Junction Boxes, and Conduit Bodies | 141 | 7.4 Branch-Circuit Conductor Size | 226 |
| 5.8 Pull/Junction Box Sizing Requirements | 142 | 7.5 Feeder Conductor Size [430.24] | 229 |
| 5.9 Pull/Junction Box Sizing Tips | 144 | 7.6 Overload Protection [430.6(A)(2) and 430.32(A)] | 230 |
| 5.10 Pull Box Examples | 144 | 7.7 Branch-Circuit Short-Circuit and Ground-Fault Protection [430.51] | 236 |
| Summary | 146 | 7.8 Branch-Circuit Summary | 239 |
| Conclusion to Unit 5 | 146 | 7.9 Feeder Protection [430.62] | 240 |
| Practice Questions for Unit 5 | 147 | 7.10 Motor VA Calculations | 241 |
| Challenge Questions for Unit 5 | 152 | Part B—Air-Conditioning Calculations | 243 |
| UNIT 6—CONDUCTOR SIZING AND PROTECTION CALCULATIONS | 155 | 7.12 Scope of Article 440 | 243 |
| Part A—General Conductor Requirements | 155 | 7.13 Other Articles | 243 |
| 6.1 Conductor Insulation [Table 310.104(A)] | 155 | 7.14 Short-Circuit and Ground-Fault Protection | 244 |
| 6.2 Conductor Sizing [110.6] | 158 | 7.15 Conductor Sizing for a Single Motor-Compressor | 245 |
| 6.3 Smallest Conductor Size [310.106(A)] | 159 | Conclusion to Unit 7 | 246 |
| 6.4 Conductor Size—Terminal Temperature Rating [110.14(C)] | 159 | Practice Questions for Unit 7 | 247 |
| 6.5 Conductors in Parallel | 161 | Challenge Questions for Unit 7 | 251 |
| 6.6 NEC Requirements for Conductors in Parallel [310.10(H)] | 163 | UNIT 8—VOLTAGE-DROP CALCULATIONS | 253 |
| 6.7 Overcurrent Protection [Article 240] | 165 | Part A—Conductor Resistance Calculations | 253 |
| 6.8 Overcurrent Protection of Conductors—General Requirements [240.4] | 167 | 8.1 Conductor Resistance | 253 |
| 6.9 Overcurrent Protection of Conductors—Specific Requirements | 171 | 8.2 Conductor Resistance—Direct-Current Circuits [Chapter 9, Table 8] | 256 |
| Part B—Conductor Ampacity | 185 | 8.3 Conductor Resistance—Alternating-Current Circuits | 257 |
| 6.10 Conductor Ampacity | 185 | 8.4 Alternating-Current Resistance | 257 |
| 6.11 Ambient Temperature Correction Factors [Table 310.15(B)(2)(a)] | 186 | 8.5 Alternating-Current Resistance as Compared to Direct-Current Resistance | 259 |
| 6.12 Conductor Bundling Ampacity Adjustment Factors [Table 310.15(B)(3)(a)] | 190 | Part B—Voltage-Drop Considerations | 260 |
| 6.13 Ambient and Conductor Bundling Adjustment | 193 | 8.6 NEC Voltage-Drop Recommendations | 260 |
| 6.14 Current-Carrying Conductors | 195 | 8.7 Determining Circuit Conductors' Voltage Drop—Ohm's Law Method | 262 |
| 6.15 Wireway Conductor Ampacity [376.22(B)] | 197 | 8.8 Determining Circuit Conductors' Voltage Drop— Formula Method | 262 |
| 6.16 Conductor Sizing Summary | 197 | 8.9 Sizing Conductors to Prevent Excessive Voltage Drop | 264 |
| Part C—Article 690 Solar PV systems | 198 | 8.10 Limiting Conductor Length to Minimize Voltage Drop | 265 |
| 6.17 Maximum Voltage [690.7] | 198 | 8.11 Limiting Current to Limit Voltage Drop | 267 |
| 6.18 Circuit Sizing and Protection [690.8] | 202 | Conclusion to Unit 8 | 268 |
| 6.19 Overcurrent Protection [690.9] | 209 | Practice Questions For Unit 8 | 269 |
| Conclusion to Unit 6 | 211 | Challenge Questions For Unit 8 | 275 |
| Practice Questions for Unit 6 | 212 | UNIT 9—DWELLING UNIT CALCULATIONS | 277 |
| Challenge Questions for Unit 6 | 218 | Part A—General Requirements | 277 |
| UNIT 7—MOTOR AND AIR-CONDITIONING CALCULATIONS | 223 | 9.1 General Requirements | 277 |
| Part A—Motor Calculations | 223 | 9.2 Voltages [220.5(A)] | 278 |
| 7.1 Scope of Article 430 | 223 | 9.3 Fraction of an Ampere [220.5(B)] | 278 |

| | |
|--|-----|
| 9.4 Lighting and Receptacles | 279 |
| 9.5 Cooking Equipment—Branch Circuit [Table 220.55, Note 4].... | 280 |
| Part B—Standard Method—Feeder/Service Load Calculations | 283 |
| 9.6 Dwelling Unit Feeder/Service Load Calculations (Article 220, Part III) | 283 |
| 9.7 Dwelling Unit Example | 286 |
| Part C—Optional Method—Feeder/Service Load Calculations .. | 292 |
| 9.8 Dwelling Unit Optional Calculations [220.82]..... | 292 |
| 9.9 Optional Calculation Example..... | 293 |
| Part D—Other Topics of Interest | 294 |
| 9.10 Neutral Calculations [220.61]..... | 294 |
| 9.11 Grounding and Bonding of Service Equipment..... | 297 |
| Conclusion to Unit 9 | 301 |
| Practice Questions for Unit 9 | 302 |
| Challenge Questions For Unit 9 | 309 |
| | |
| CHAPTER 3—ADVANCED NEC CALCULATIONS (Essential for Master’s Exams) | 313 |
| | |
| UNIT 10—MULTIFAMILY DWELLING CALCULATIONS | 315 |
| 10.1 Multifamily Dwelling Calculations—General..... | 316 |
| 10.2 Multifamily Dwelling Calculation Examples— Standard Method..... | 317 |
| Part A—Standard Method—Feeder/Service Load Calculations | 317 |
| 10.3 Multifamily Dwelling Calculations—Standard Method Example | 325 |
| Part B—Optional Method—Feeder/Service Load Calculations ... | 327 |
| 10.4 Multifamily Dwelling Unit Calculations [220.84]— Optional Method..... | 327 |
| 10.5 Multifamily—Optional Method Example 1 [220.84]..... | 327 |
| 10.6 Multifamily—Optional Method Example 2 [220.84]..... | 330 |
| 10.7 Two-Family Dwelling Units [220.85]..... | 331 |
| Conclusion to Unit 10 | 334 |
| Practice Questions for Unit 10 | 335 |
| Challenge Questions for Unit 10 | 340 |
| | |
| UNIT 11—COMMERCIAL CALCULATIONS | 343 |
| Part A—General | 343 |
| 11.1 General Requirements | 343 |
| 11.2 Conductor Ampacity [Article 100]..... | 343 |
| 11.3 Conductor Overcurrent Protection [240.4]..... | 345 |
| 11.4 Voltages [220.5(A)] | 347 |
| 11.5 Fractions of an Ampere [220.5(B)]..... | 347 |
| 11.6 Lighting—Demand Factors [Tables 220.12 and 220.42] | 347 |
| 11.7 Lighting Without Demand Factors [215.2(A) (1), 230.42(A)(1), and Table 220.12] | 349 |
| 11.8 Sign Circuit [220.14(F) and 600.5] | 350 |
| 11.9 Lighting—Miscellaneous | 351 |
| 11.10 Multioutlet Receptacle Assembly [220.14(H)] | 351 |
| 11.11 Receptacle VA Load | 353 |
| 11.12 Banks and Offices—General Lighting and Receptacles [220.14(K)] | 354 |
| Part B—Examples | 356 |
| 11.13 Bank/Office Building Example | 356 |
| 11.14 Mobile/Manufactured Home Park [550.31]..... | 358 |
| 11.15 Recreational Vehicle Park [551.73]..... | 359 |
| 11.16 Marina [555.12]..... | 360 |
| Part C—Optional Method—Feeder/Service Load Calculations | 361 |
| 11.17 New Restaurant—Optional Method [220.88] | 361 |
| Part D—Welders | 362 |
| 11.18 Arc Welders | 362 |
| 11.19 Resistance Welders..... | 364 |
| 11.20 Light Industrial Calculation..... | 365 |
| Conclusion to Unit 11 | 367 |
| Practice Questions for Unit 11 | 368 |
| Challenge Questions for Unit 11 | 371 |
| | |
| UNIT 12—TRANSFORMER CALCULATIONS | 373 |
| Part A—General | 373 |
| 12.1 Transformer Basics | 374 |
| 12.2 Secondary Induced Voltage | 374 |
| 12.3 Autotransformers | 375 |
| 12.4 Power Losses | 376 |
| 12.5 Efficiency..... | 377 |
| 12.6 Delta/Delta Connected Transformers..... | 378 |
| 12.7 Delta/Wye Connected Transformers | 381 |
| 12.8 Transformer Turns Ratio | 382 |
| 12.9 Transformer kVA Rating..... | 384 |
| 12.10 Current Flow | 384 |
| 12.11 Line Currents | 385 |
| Part B—NEC Requirements | 388 |
| 12.12 Transformer Overcurrent Protection | 388 |
| 12.13 Primary Conductor Sizing..... | 390 |
| 12.14 Secondary Conductor Sizing | 391 |
| 12.15 Grounding and Bonding | 394 |
| Conclusion to Unit 12 | 397 |
| Practice Questions for Unit 12 | 398 |
| Challenge Questions for Unit 12 | 402 |

CHAPTER 4—MOTOR CONTROL BASICS (Journeyman and Master’s Exams in Some States)

405

UNIT 13—MOTOR CONTROL BASICS

407

Part A Basic Motor Control Concepts

407

13.1 Motor Control Language

408

13.2 Motor Control Basics.....

411

13.3 Reading a Motor Control Schematic

411

Part B Motor Control Circuits

413

13.4 2-Wire Control Circuits.....

413

13.5 3-Wire Control Circuits.....

416

13.6 3-Wire Circuit in a Wiring (Connection) Diagram.....

419

13.7 Multiple Start-Stop Pushbutton Stations.....

420

13.8 Reversing Three-Phase Motors

423

13.9 Forward and Reverse Contactors

424

13.10 Interlocking Devices.....

424

13.11 Electrical Interlock for Magnetic Reversing Controls.....

426

Conclusion to Unit 13.....

428

Practice Questions for Unit 13

429

Challenge Questions for Unit 13.....

432

CHAPTER 5—NEC PRACTICE QUESTIONS (Essential for all Journeyman and Master’s Exams)

435

Practice Quizzes

Practice Quiz 1—Straight Order [90–210.8]

437

Practice Quiz 1—Random Order [90–210.8].....

446

Practice Quiz 2—Straight Order [210.8–240.54]

451

Practice Quiz 2—Random Order [90.2–240.60].....

460

Practice Quiz 3—Straight Order [240.60–300.8]

465

Practice Quiz 3—Random Order [90.3–300.6].....

474

Practice Quiz 4—Straight Order [300.9–344.10]

479

Practice Quiz 4—Random Order [90.2–342.26].....

488

Practice Quiz 5—Straight Order [344.10–404.9]

493

Practice Quiz 5—Random Order [215.10–404.8].....

502

Practice Quiz 6—Straight Order [404.9–430.87]

507

Practice Quiz 6—Random Order [210.21–430.81].....

516

Practice Quiz 7—Straight Order [430.103–514.11]

521

Practice Quiz 7—Random Order [100–514.11].....

530

Practice Quiz 8—Straight Order [514.13–647.4]

535

Practice Quiz 8—Random Order [200.6–640.4].....

544

Practice Quiz 9—Straight Order [647.4–700.12]

549

Practice Quiz 9—Random Order [100–690.49].....

559

Practice Quiz 10—Straight Order [700.15–Chapter 9]

564

Practice Quiz 10—Random Order [220.82–Chapter 9].....

573

NEC Challenge Quizzes

Challenge Quiz 1—Article 90 through Chapter 9

579

Challenge Quiz 2—Article 90 through Chapter 9.....

588

Challenge Quiz 3—Article 90 through Chapter 9.....

597

Challenge Quiz 4—Article 90 through Chapter 9.....

606

Challenge Quiz 5—Article 90 through Chapter 9.....

616

Challenge Quiz 6—Article 90 through Chapter 9.....

625

Challenge Quiz 7—Article 90 through Chapter 9.....

634

Final NEC Exams

Final Exam 1—Questions in Random Order for
Article 90 through Annex C.....

643

Final Exam 2—Questions in Random Order for
Article 90 through Annex C.....

652