

UGLY'S™

ELECTRICAL REFERENCES

Charles R. Miller | Daniel Sandefur



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LEARNING

TABLE OF CONTENTS

Ohm's Law1
Series Circuits3
Parallel Circuits5
Combination Circuits8
Common Electrical Distribution Systems13
 120/240-Volt, Single-Phase, Three-Wire System13
 120/240-Volt, Three-Phase, Four-Wire System (Delta High Leg)13
 120/208-Volt, Three-Phase, Four-Wire System (Wye Connected)14
 277/480-Volt, Three-Phase, Four-Wire System (Wye Connected)14
Electrical Formulas for Calculating Amperes, Horsepower, Kilowatts, and kVA15
To Find Amperes16
 Direct Current16
 Single Phase16
 Three Phase18
To Find Horsepower20
 Direct Current20
 Single Phase20
 Three Phase20
To Find Watts21
To Find Kilowatts22
 Direct Current22
 Single Phase22
 Three Phase22
To Find Kilovolt-Amperes23
 Single Phase23
 Three Phase23
 Kirchhoff's Laws23
To Find Capacitance24
 Capacitance (C)24
Six-Dot Color Code for Mica and Molded Paper Capacitors25
Resistor Color Code25
Maximum Permissible Capacitor KVAR for Use with Open-Type, Three-Phase, 60-Cycle Induction Motors26
Power Factor Correction27
 Table Values \times Kilowatt of Capacitors Needed to Correct from Existing to Desired Power Factor27
Power Factor and Efficiency Example28
To Find Inductance29
 Inductance (L)29
To Find Impedance30
 Impedance (Z)30
To Find Reactance31
 Reactance (X)31
Full-Load Current in Amperes: Direct-Current (dc) Motors32
Direct-Current Motors33
 Terminal Markings33

TABLE OF CONTENTS

Shunt-Wound Motors	33
Series-Wound Motors	33
Compound-Wound Motors	33
Full-Load Current in Amperes: Single-Phase Alternating-Current (ac) Motors	34
Single-Phase Motor Using Standard Three-Phase Starter	35
Single-Phase Motors	36
Split-Phase, Squirrel-Cage, Dual-Voltage Motor	36
Classes of Single-Phase Motors	36
Terminal Color Marking	36
Split-Phase, Squirrel-Cage Motor	37
Running Overload Units	38
Motor Branch-Circuit Protective Devices: Maximum Rating or Setting	38
Full-Load Current: Three-Phase Alternating-Current (ac) Motors	39
Full-Load Current and Other Data: Three-Phase ac Motors	40
Motor and Motor Circuit Conductor Protection	41
General Motor Rules	41
Motor Branch Circuit and Feeder Example	42
General Motor Applications	42
Locked-Rotor Indicating Code Letters	43
Maximum Motor Locked-Rotor Current in Amperes, Single Phase	44
Maximum Motor Locked-Rotor Current in Amperes, Two and Three Phase, Design B, C, and D	44
Three-Phase ac Motor Windings and Connections	45
Three-Wire Stop-Start Station	46
Two Three-Wire Stop-Start Stations	47
Hand-Off Automatic Control	48
Jogging with Selector Switch	49
Voltage Drop Calculations: Inductance Negligible	50
Single-Phase Circuits	50
Three-Phase Circuits	50
Voltage Drop Examples	50
Typical Voltage Drop Values Based on Conductor Size and One-Way Length (60°C [140°F] Termination and Insulation)	51
Voltage Drop Calculation Examples	52
Single-Phase Voltage Drop	52
Three-Phase Voltage Drop	52
Short-Circuit Calculation	53
Basic Short-Circuit Calculation Procedure	53
Example: Short-Circuit Calculation	54
"C" Values for Conductors	55
Component Protection	57
How to Use Current-Limitation Charts	57
Single-Phase Transformer Connections	58
Buck-and-Boost Transformer Connections	59
Full-Load Currents	60
Transformer Calculations	61

TABLE OF CONTENTS

Sizing Transformers62
 Single-Phase Transformers62
 Three-Phase Transformers62
Single-Phase Transformer63
 Primary and Secondary Amperes63
Three-Phase Transformer63
 Primary and Secondary Amperes63
Three-Phase Connections64
 Wye (Star)64
 Delta64
Three-Phase Standard Phase Rotation65
 Transformers65
Transformer Connections66
 Series Connections of Low-Voltage Windings66
Miscellaneous Wiring Diagrams69
 Two Three-Way Switches69
 Two Three-Way Switches and One Four-Way Switch69
 Bell Circuit69
 Remote-Control Circuit: One Relay and One Switch70
Supports for Rigid Metal Conduit70
Supports for Rigid PVC Conduit70
Conductor Properties71
**ac Resistance and Reactance for 600-Volt Cables, Three-Phase,
 60-Hz, 75°C (167°F): Three Single Conductors in Conduit**72
Ampacities of Insulated Conductors73
Ampacity Correction and Adjustment Factors77
 Examples77
Adjustment Factors78
 For More Than Three Current-Carrying Conductors
 in a Raceway or Cable78
 Conductor and Equipment Termination Ratings78
Conductor Applications and Insulations80
Maximum Number of Conductors in Trade Sizes of Conduit or Tubing83
 Example #1: All Same Wire Size and Type Insulation83
 Example #2: Different Wire Sizes or Types Insulation83
Maximum Number of Conductors in Electrical Metallic Tubing84
Maximum Number of Conductors in Electrical Nonmetallic Tubing86
Maximum Number of Conductors in Rigid PVC Conduit, Schedule 4088
Maximum Number of Conductors in Rigid PVC Conduit, Schedule 8090
Maximum Number of Conductors in Rigid Metal Conduit92
Maximum Number of Conductors in Flexible Metal Conduit94
**Maximum Number of Conductors in Liquidtight Flexible
 Metal Conduit**96
Dimensions of Insulated Conductors and Fixture Wires98
Compact (Stranded Type) Copper and Aluminum Building Wire
 Nominal Dimensions and Areas100
Dimensions and Percent Area of Conduit and Tubing101

TABLE OF CONTENTS

Thread Dimensions and Tap Drill Sizes 104
Metal Boxes. 105
**Minimum Cover Requirements, 0 to 1000 Volts ac, 1500 Volts dc,
Nominal. 106**
Volume Required per Conductor 106
**Supporting Conductors in Vertical Raceways – Spacings
for Conductor Supports 106**
Minimum Depth of Clear Working Space at Electrical Equipment 107
**Minimum Clearance of Live Parts, Over 1000 Volts ac,
1500 Volts dc, Nominal 108**
**Minimum Size Equipment Grounding Conductors (EGCs)
for Grounding Raceway and Equipment 109**
Grounding Electrode Conductor for Alternating-Current Systems 110
**Grounded Conductor, Main Bonding Jumper, System Bonding
Jumper, and Supply-Side Bonding Jumper for Alternating-
Current Systems 111**
General Lighting Loads by Non-Dwelling Occupancy 112
Lighting Load Demand Factors 113
Demand Factors for Receptacle Loads—Other Than Dwelling Units 113
Demand Factors for Household Electric Clothes Dryers 114
**Demand Factors for Instantaneous Water Heaters and Kitchen
Equipment—Other Than Dwelling Unit(s) 114**
**Demand Loads for Household Electric Ranges, Wall-Mounted
Ovens, Counter-Mounted Cooking Units, and Other
Household Cooking Appliances Over 1¼ kW Rating. 115**
Calculating Cost of Operating an Electrical Appliance 117
Changing Incandescent Lamp to Energy-Saving Lamp. 117
Partial 2026 National Electrical Code Summary 118
 Article 120—Branch-Circuit, Feeder, and Service Load
 Calculations (Moved). 118
 Article 130—Energy Management Systems (Moved) 118
 Article 206—Non-Power-Limited Remote-Control
 and Signaling Circuits (New). 118
 Article 265—Branch Circuits Over 1000 Volts ac,
 1500 Volts dc, Nominal (New). 118
 Article 266—Feeders Over 1000 Volts ac, 1500 Volts dc,
 Nominal (New) 119
 Article 267—Outside Branch Circuits and Feeders Over
 1000 Volts ac, 1500 Volts dc, Nominal (New) 119
 Article 268—Services Over 1000 Volts ac, 1500 Volts dc,
 Nominal (New) 119
 Article 270—Grounding and Bonding of Systems
 Over 1000 Volts ac, 1500 Volts dc, Nominal (New). 119
 Article 624—Electric Self-Propelled Vehicle Power Transfer
 Systems (ESVSEs) (New) 119
 Article 720—General Requirements for Limited-Energy
 System Wiring Methods and Materials (New) 120

TABLE OF CONTENTS

Article 721—Power Sources for Limited-Energy Systems (New) 120

Article 722—Limited-Energy Cables for Power-Limited Circuits, Fault-Managed-Power Circuits, Optical Fiber Circuits, and Communications Circuits (New) 120

Article 723—Raceways, Cable-Routing Assemblies, and Cable Trays for Limited-Energy Systems (New) 120

Article 742—Overvoltage Protection of Limited-Energy Systems (New) 120

Article 750—Grounding and Bonding of Limited-Energy Systems (New) 121

Article 772—Fire-Resistive Cable Systems (Moved) 121

Code Arrangement [90.3] 121

Definitions [Article 100] 121

Arc-Flash Hazard Marking [110.16] 121

GFCI Protection for Personnel [210.8] 122

10-Ampere Branch Circuits [210.23(A)] 122

Dwelling Unit Receptacle Outlets [210.52] 122

Minimum Size of Conductors [310.5(A)] 123

Wiring Devices [Article 406] 123

Annex L—Proposed Organization of the 2029 National Electrical Code 123

Field Terms Versus NEC Terms 124

Electrical Symbols 125

Wiring Diagrams for NEMA Configurations 128

NEMA Enclosure Types 133

U.S. Weights and Measures 137

Linear Measures 137

Square Measures 137

Cubic or Solid Measures 137

Liquid Measurements 138

Dry Measure 138

Weight Measurement (Mass) 138

Metric System 139

Prefixes 139

Linear Measure 139

Square Measure 139

Cubic Measure 139

Measures of Weight 140

Measures of Capacity 140

Metric Designator and Trade Sizes 141

U.S. Weights and Measures/Metric Equivalent Chart 141

Explanation of Scientific Notation 141

Useful Conversions/Equivalents 141

Decimal Equivalents 142

Two-Way Conversion Table 143

Metals 146

Specific Resistance (K) 148

TABLE OF CONTENTS

Centigrade and Fahrenheit Thermometer Scales	149
Useful Math Formulas	150
The Circle	151
Fractions	152
Definitions	152
To Add or Subtract	152
To Multiply	153
To Divide	154
Equations	155
Rules	155
Signs	156
Natural Trigonometric Functions	158
Trigonometry	160
Bending Offsets with Trigonometry	161
Example	161
Rolling Offsets	161
One Shot Bends	162
Chicago-Type Benders: 90° Bending	163
Chicago-Type Benders: Offsets	164
Multi-Shot: 90° Conduit Bending	165
Offset Bends	168
EMT: Using Hand Bender	168
90° Bends	169
EMT: Using Hand Bender	169
Back-to-Back Bends	170
EMT: Using Hand Bender	170
Three-Point Saddle Bends	171
EMT: Using Hand Bender	171
Pulley Calculations	172
Useful Knots	173
Hand Signals	174
Electrical Safety Definitions	176
Who Is Responsible for Electrical Safety?	178
Lockout-Tagout and Electrically Safe Work Condition	179
Electrical Safety: Shock Protection Boundaries	180
130.4(E)(a) Approach Boundaries for Electric Shock Protection, Alternating-Current Systems	180
Information Usually Found on an Arc-Flash Equipment Label	181
Electrical Safety: Personal Protection Equipment Guide	182
Alternative Energy	184
Engine-Generation Systems	184
Solar Photovoltaic Systems	185
Wind Turbines	186
Fuel Cells	187
Microturbines	188
Interconnected Generation Systems	189
Junction Box Sizing	190

TABLE OF CONTENTS

Selecting and Using Test Instruments191
Single Instrument191
Instrument Safety Categories192
Selecting an Appropriate Multimeter194
Testing a Multimeter.194
Common Testing Errors196
Using a Multimeter to Measure Voltage.197
Using a Multimeter to Measure Resistance.197
Using a Multimeter to Measure Current.198
Selecting a Clamp-On Ammeter198
Testing a Clamp-On Ammeter201
Using a Clamp-On Ammeter to Measure Current201
Non-Contact Voltage Tester202
Selecting a Non-Contact Voltage Tester204
Testing a Non-Contact Voltage Tester204
Using a Non-Contact Voltage Tester204

OHM'S LAW

Ohm's Law is the relationship between voltage (E), current (I), and resistance (R). The rate of the current flow is equal to electromotive force divided by resistance.

I = Intensity of Current = Amperes

E = Electromotive Force = Volts

R = Resistance = Ohms

P = Power = Watts

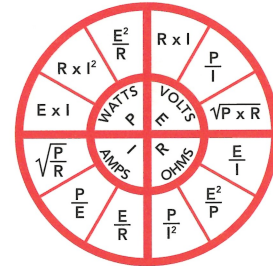
The three basic Ohm's Law formulas are:

$$I = \frac{E}{R}$$

$$R = \frac{E}{I}$$

$$E = I \times R$$

Below is a chart containing the formulas related to Ohm's Law. To use the chart, start in the center circle and select the value you need to find, I (Amps), R (Ohms), E (Volts), or P (Watts). Then select the formula containing the values you know from the corresponding chart quadrant.



Example:

An electrical appliance is rated at 1200 watts and is connected to 120 volts. How much current will it draw?

$$\text{Amperes} = \frac{\text{Watts}}{\text{Volts}} \quad I = \frac{P}{E} \quad I = \frac{1200}{120} = 10 \text{ Amps}$$

What is the resistance of the same appliance?

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}} \quad R = \frac{E}{I} \quad R = \frac{120}{10} = 12 \text{ Ohms}$$

OHM'S LAW

In the preceding example, we know the following values:

$$I = \text{Amps} = 10 \text{ Amps} \quad R = \text{Ohms} = 12 \text{ Ohms}$$

$$E = \text{Volts} = 120 \text{ Volts} \quad P = \text{Watts} = 1200 \text{ Watts}$$

We can now see how the 12 formulas in the Ohm's Law chart can be applied.

$$\text{Amps} = \sqrt{\frac{\text{Watts}}{\text{Ohms}}} \quad I = \sqrt{\frac{P}{R}} = \sqrt{\frac{1200}{12}} = \sqrt{100} = 10 \text{ Amps}$$

$$\text{Amps} = \frac{\text{Watts}}{\text{Volts}} \quad I = \frac{P}{E} = \frac{1200}{120} = 10 \text{ Amps}$$

$$\text{Amps} = \frac{\text{Volts}}{\text{Ohms}} \quad I = \frac{E}{R} = \frac{120}{12} = 10 \text{ Amps}$$

$$\text{Watts} = \frac{\text{Volts}^2}{\text{Ohms}} \quad P = \frac{E^2}{R} = \frac{120^2}{12} = \frac{14400}{12} = 1200 \text{ Watts}$$

$$\text{Watts} = \text{Volts} \times \text{Amps} \quad P = E \times I = 120 \times 10 = 1200 \text{ Watts}$$

$$\text{Watts} = \text{Amps}^2 \times \text{Ohms} \quad P = I^2 \times R = 10^2 \times 12 = 1200 \text{ Watts}$$

$$\text{Volts} = \sqrt{\text{Watts} \times \text{Ohms}} \quad E = \sqrt{P \times R} = \sqrt{1200 \times 12} = \sqrt{14400} = 120 \text{ Volts}$$

$$\text{Volts} = \text{Amps} \times \text{Ohms} \quad E = I \times R = 10 \times 12 = 120 \text{ Volts}$$

$$\text{Volts} = \frac{\text{Watts}}{\text{Amps}} \quad E = \frac{P}{I} = \frac{1200}{10} = 120 \text{ Volts}$$

$$\text{Ohms} = \frac{\text{Volts}^2}{\text{Watts}} \quad R = \frac{E^2}{P} = \frac{120^2}{1200} = \frac{14400}{1200} = 12 \text{ Ohms}$$

$$\text{Ohms} = \frac{\text{Watts}}{\text{Amps}^2} \quad R = \frac{P}{I^2} = \frac{1200}{10^2} = 12 \text{ Ohms}$$

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amps}} \quad R = \frac{E}{I} = \frac{120}{10} = 12 \text{ Ohms}$$

SERIES CIRCUITS

A series circuit is a circuit that has only one path through which the electrons may flow.

Rule 1: The total current in a series circuit is equal to the current in any other part of the circuit.

Total Current $I_T = I_1 = I_2 = I_3$, etc.

Rule 2: The total voltage in a series circuit is equal to the sum of the voltages across all parts of the circuit.

Total Voltage $E_T = E_1 + E_2 + E_3$, etc.

Rule 3: The total resistance of a series circuit is equal to the sum of the resistances of all the parts of the circuit.

Total Resistance $R_T = R_1 + R_2 + R_3$, etc.

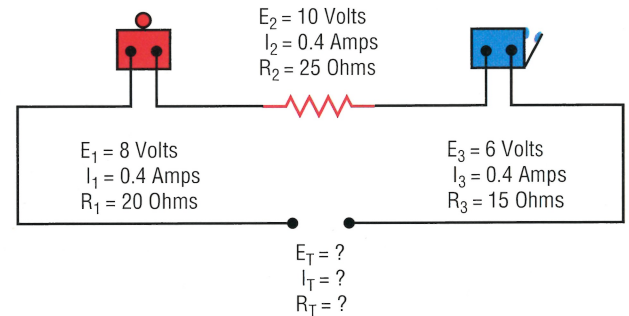
Formulas from Ohm's Law

$$\text{Amperes} = \frac{\text{Volts}}{\text{Resistance}} \quad \text{or} \quad I = \frac{E}{R}$$

$$\text{Resistance} = \frac{\text{Volts}}{\text{Amperes}} \quad \text{or} \quad R = \frac{E}{I}$$

$$\text{Volts} = \text{Amperes} \times \text{Resistance} \quad \text{or} \quad E = I \times R$$

Example 1: Find the total voltage, total current, and total resistance of the following series circuit.



5 SERIES CIRCUITS

$$\begin{aligned} E_T &= E_1 + E_2 + E_3 \\ &= 8 + 10 + 6 \\ E_T &= 24 \text{ Volts} \end{aligned}$$

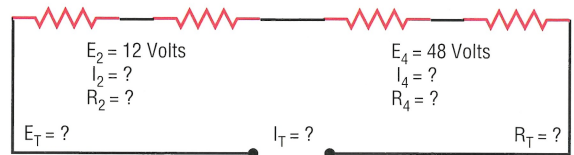
$$\begin{aligned} I_T &= I_1 = I_2 = I_3 \\ &= 0.4 = 0.4 = 0.4 \\ I_T &= 0.4 \text{ Amps} \end{aligned}$$

$$\begin{aligned} R_T &= R_1 + R_2 + R_3 \\ &= 20 + 25 + 15 \\ R_T &= 60 \text{ Ohms} \end{aligned}$$

Example 2: Find E_T , E_1 , E_3 , I_T , I_1 , I_2 , I_4 , R_T , R_2 , and R_4 .

Remember that the total current in a series circuit is equal to the current in any other part of the circuit.

$$\begin{aligned} E_1 &= ? & E_3 &= ? \\ I_1 &= ? & I_3 &= 0.5 \text{ Amps} \\ R_1 &= 72 \text{ Ohms} & R_3 &= 48 \text{ Ohms} \end{aligned}$$



$$\begin{aligned} I_T &= I_1 = I_2 = I_3 = I_4 \\ I_T &= I_1 = I_2 = 0.5 = I_4 \\ 0.5 &= 0.5 = 0.5 = 0.5 = 0.5 \\ I_T &= 0.5 \text{ Amps} \quad I_2 = 0.5 \text{ Amps} \\ I_1 &= 0.5 \text{ Amps} \quad I_4 = 0.5 \text{ Amps} \end{aligned}$$

$$\begin{aligned} E_1 &= I_1 \times R_1 \\ &= 0.5 \times 72 \\ E_1 &= 36 \text{ Volts} \end{aligned}$$

$$\begin{aligned} E_T &= E_1 + E_2 + E_3 + E_4 \\ &= 36 + 12 + 24 + 48 \\ E_T &= 120 \text{ Volts} \end{aligned}$$

$$\begin{aligned} E_3 &= I_3 \times R_3 \\ &= 0.5 \times 48 \\ E_3 &= 24 \text{ Volts} \end{aligned}$$

$$\begin{aligned} R_T &= R_1 + R_2 + R_3 + R_4 \\ &= 72 + 24 + 48 + 96 \\ R_T &= 240 \text{ Ohms} \end{aligned}$$

$$\begin{aligned} R_2 &= \frac{E_2}{I_2} = \frac{12}{0.5} \\ R_2 &= 24 \text{ Ohms} \end{aligned}$$

$$\begin{aligned} R_4 &= \frac{E_4}{I_4} = \frac{48}{0.5} \\ R_4 &= 96 \text{ Ohms} \end{aligned}$$

PARALLEL CIRCUITS

A parallel circuit is a circuit that has more than one path through which the electrons may flow.

Rule 1: The total current in a parallel circuit is equal to the sum of the currents in all the branches of the circuit.

Total Current $I_T = I_1 + I_2 + I_3$, etc.

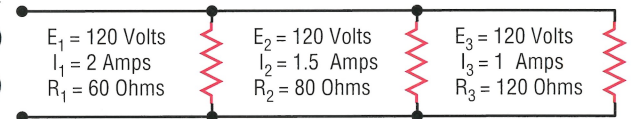
Rule 2: The total voltage across any branch in parallel is equal to the voltage across any other branch and is also equal to the total voltage.

Total Voltage $E_T = E_1 = E_2 = E_3$, etc.

Rule 3: The total resistance of a parallel circuit is found by applying Ohm's Law to the total values of the circuit.

Total Resistance $= \frac{\text{Total Voltage}}{\text{Total Amperes}}$ or $R_T = \frac{E_T}{I_T}$

Example 1: Find the total current, total voltage, and total resistance of the following parallel circuit.



$$\begin{aligned} I_T &= I_1 + I_2 + I_3 \\ &= 2 + 1.5 + 1 \\ I_T &= 4.5 \text{ Amps} \end{aligned}$$

$$\begin{aligned} E_T &= E_1 = E_2 = E_3 \\ &= 120 = 120 = 120 \\ E_T &= 120 \text{ Volts} \end{aligned}$$

$$R_T = \frac{E_T}{I_T} = \frac{120 \text{ Volts}}{4.5 \text{ Amps}} = 26.66 \text{ Ohms Resistance}$$

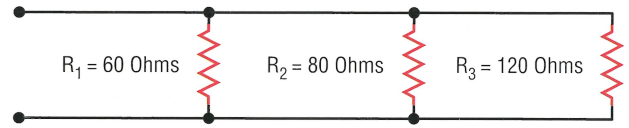
Note: In a parallel circuit, the total resistance is always less than the resistance of any branch. If the branches of a parallel circuit have the same resistance, then each will draw the same current. If the branches of a parallel circuit have different resistances, then each will draw a different current. In either series or parallel circuits, the larger the resistance, the smaller the current drawn.

PARALLEL CIRCUITS

To determine the total resistance in a parallel circuit when the total current and total voltage are unknown:

$$\frac{1}{\text{Total Resistance}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots \text{ etc.}$$

Example 2: Find the total resistance.



$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{60} + \frac{1}{80} + \frac{1}{120}$$

$$\frac{1}{R_T} = \frac{4}{240} + \frac{3}{240} + \frac{2}{240} = \frac{9}{240} \quad \text{Use lowest common denominator (240).}$$

$$\frac{1}{R_T} = \frac{9}{240} \quad \text{Cross multiply.}$$

For a review of Adding Fractions and Common Denominators, see Ugly's pages 152–154.

$$9 \times R_T = 1 \times 240 \quad \text{or} \quad 9R_T = 240$$

Divide both sides of the equation by 9.

$$R_T = 26.66 \text{ Ohms Resistance}$$

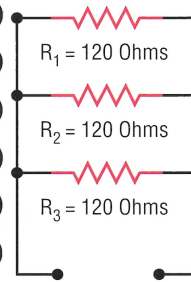
Note: The total resistance of a number of equal resistors in parallel is equal to the resistance of one resistor divided by the number of resistors.

$$\text{Total Resistance} = \frac{\text{Resistance of One Resistor}}{\text{Number of Resistors in Circuit}}$$

PARALLEL CIRCUITS

Formula: $R_T = \frac{R}{N}$

Example 3: Find the total resistance.



There are three resistors in parallel. Each has a value of 120 Ohms resistance. According to the formula, if we divide the resistance of any one of the resistors by three, we will obtain the total resistance of the circuit.

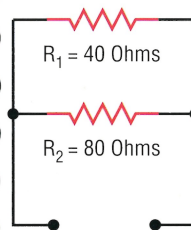
$$R_T = \frac{R}{N} \quad \text{or} \quad R_T = \frac{120}{3}$$

$$\text{Total Resistance} = 40 \text{ Ohms}$$

Note: To find the total resistance of only two resistors in parallel, multiply the resistances, and then divide the product by the sum of the resistors.

Formula: $\text{Total Resistance} = \frac{R_1 \times R_2}{R_1 + R_2}$

Example 4: Find the total resistance.



$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$= \frac{40 \times 80}{40 + 80}$$

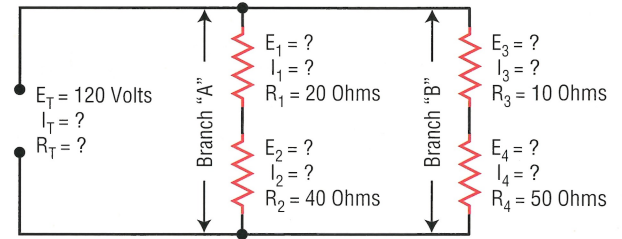
$$R_T = \frac{3200}{120} = 26.66 \text{ Ohms}$$

COMBINATION CIRCUITS

In combination circuits, we combine series circuits with parallel circuits. Combination circuits make it possible to obtain the different voltages of series circuits and the different currents of parallel circuits.

Example 1: Parallel-Series Circuit.

Solve for all missing values.



To solve:

- Find the total resistance of each branch. Both branches are simple series circuits, so:

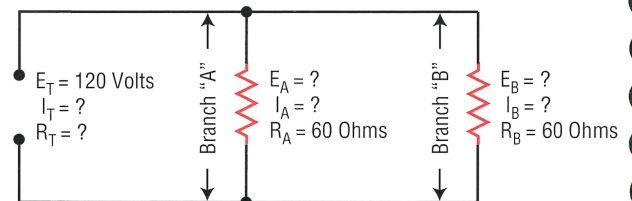
$$R_1 + R_2 = R_A$$

$$20 + 40 = 60 \text{ Ohms total resistance of branch "A"}$$

$$R_3 + R_4 = R_B$$

$$10 + 50 = 60 \text{ Ohms total resistance of branch "B"}$$

- Redraw the circuit, combining resistors ($R_1 + R_2$) and ($R_3 + R_4$) so that each branch will have only one resistor.



COMBINATION CIRCUITS

Note: We now have a simple parallel circuit, so:

$$E_T = E_A = E_B \\ 120 \text{ Volts} = 120 \text{ Volts} = 120 \text{ Volts}$$

We now have a parallel circuit with only two resistors, and they are of equal value. We have a choice of three different formulas that can be used to find the total resistance of the circuit.

$$(1) R_T = \frac{R_A \times R_B}{R_A + R_B} = \frac{60 \times 60}{60 + 60} = \frac{3600}{120} = 30 \text{ Ohms}$$

(2) When the resistors of a parallel circuit are of equal value,

$$R_T = \frac{R}{N} = \frac{60}{2} = 30 \text{ Ohms} \quad \text{or}$$

$$(3) \frac{1}{R_T} = \frac{1}{R_A} + \frac{1}{R_B} = \frac{1}{60} + \frac{1}{60} = \frac{2}{60} = \frac{1}{30}$$

$$\frac{1}{R_T} = \frac{1}{30} \quad \text{or} \quad 1 \times R_T = 1 \times 30 \quad \text{or} \quad R_T = 30 \text{ Ohms}$$

3. We know the values of E_T , R_T , E_A , R_A , E_B , R_B , R_1 , R_2 , R_3 , and R_4 . Next we will find the values of I_T , I_A , I_B , I_1 , I_2 , I_3 , and I_4 .

$$I_T = \frac{E_T}{R_T} \quad \text{or} \quad \frac{120}{30} = 4 \quad I_T = 4 \text{ Amps}$$

$$I_A = \frac{E_A}{R_A} \quad \text{or} \quad \frac{120}{60} = 2 \quad I_A = 2 \text{ Amps}$$

$$I_A = I_1 = I_2 \quad \text{or} \quad 2 = 2 = 2 \quad I_1 = 2 \text{ Amps} \\ I_2 = 2 \text{ Amps}$$

$$I_B = \frac{E_B}{R_B} = \quad \text{or} \quad \frac{120}{60} = 2 \quad I_B = 2 \text{ Amps}$$

$$I_B = I_3 = I_4 \quad \text{or} \quad 2 = 2 = 2 \quad I_3 = 2 \text{ Amps} \\ I_4 = 2 \text{ Amps}$$

COMBINATION CIRCUITS

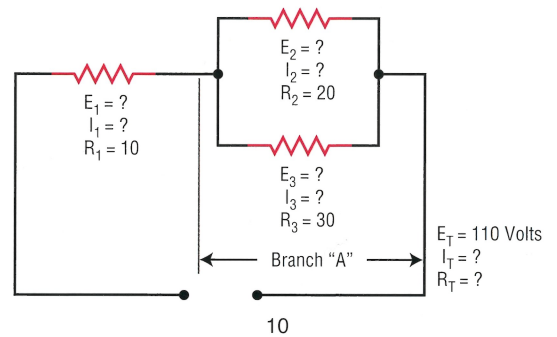
4. We know that resistors #1 and #2 of branch "A" are in series. We also know that resistors #3 and #4 of branch "B" are in series. We have determined that the total current of branch "A" is 2 amps, and the total current of branch "B" is 2 amps. By using the series formula, we can find the current of each branch.

Branch "A"	Branch "B"
$I_A = I_1 = I_2$	$I_B = I_3 = I_4$
$2 = 2 = 2$	$2 = 2 = 2$
$I_1 = 2 \text{ Amps}$	$I_3 = 2 \text{ Amps}$
$I_2 = 2 \text{ Amps}$	$I_4 = 2 \text{ Amps}$

5. We were given the resistance values of all resistors. $R_1 = 20 \text{ Ohms}$, $R_2 = 40 \text{ Ohms}$, $R_3 = 10 \text{ Ohms}$, and $R_4 = 50 \text{ Ohms}$. By using Ohm's Law, we can determine the voltage drop across each resistor.

$E_1 = R_1 \times I_1$	$E_3 = R_3 \times I_3$
$= 20 \times 2$	$= 10 \times 2$
$E_1 = 40 \text{ Volts}$	$E_3 = 20 \text{ Volts}$
$E_2 = R_2 \times I_2$	$E_4 = R_4 \times I_4$
$= 40 \times 2$	$= 50 \times 2$
$E_2 = 80 \text{ Volts}$	$E_4 = 100 \text{ Volts}$

Example 2: Series Parallel Circuit.
Solve for all missing values.



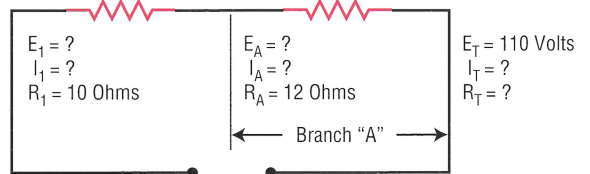
COMBINATION CIRCUITS

To solve:

- We can see that resistors #2 and #3 are in parallel, and combined they are branch "A." When there are only two resistors, we use the following formula:

$$R_A = \frac{R_2 \times R_3}{R_2 + R_3} \text{ or } \frac{20 \times 30}{20 + 30} \text{ or } \frac{600}{50} \text{ or } 12 \text{ Ohms}$$

- We can now redraw our circuit as a simple series circuit.



- In a series circuit,
 $R_T = R_1 + R_A$ or $R_T = 10 + 12$ or 22 Ohms

By using Ohm's Law,

$$I_T = \frac{E_T}{R_T} = \frac{110}{22} = 5 \text{ Amps}$$

In a series circuit,

$$I_T = I_1 = I_A \text{ or } I_T = 5 \text{ Amps, } I_1 = 5 \text{ Amps, and } I_A = 5 \text{ Amps}$$

By using Ohm's Law,

$$E_1 = I_1 \times R_1 = 5 \times 10 = 50 \text{ Volts}$$

$$E_T - E_1 = E_A \text{ or } 110 - 50 = 60 \text{ Volts} = E_A$$

In a parallel circuit,

$$E_A = E_2 = E_3 \text{ or } E_A = 60 \text{ Volts}$$

$$E_2 = 60 \text{ Volts, and } E_3 = 60 \text{ Volts}$$

By using Ohm's Law,

$$I_2 = \frac{E_2}{R_2} = \frac{60}{20} = 3 \text{ Amps}$$

$$I_3 = \frac{E_3}{R_3} = \frac{60}{30} = 2 \text{ Amps}$$

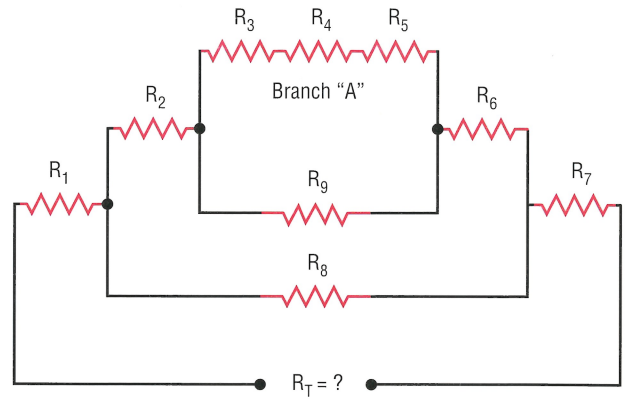
COMBINATION CIRCUITS

Problem:

Find the total resistance.

Redraw circuit as many times as necessary.

Correct answer is 100 Ohms.



Given Values:

$$R_1 = 15 \text{ Ohms}$$

$$R_2 = 35 \text{ Ohms}$$

$$R_3 = 50 \text{ Ohms}$$

$$R_4 = 40 \text{ Ohms}$$

$$R_5 = 30 \text{ Ohms}$$

$$R_6 = 25 \text{ Ohms}$$

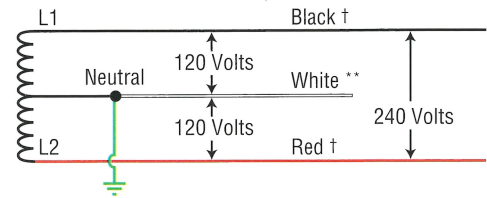
$$R_7 = 10 \text{ Ohms}$$

$$R_8 = 300 \text{ Ohms}$$

$$R_9 = 60 \text{ Ohms}$$

COMMON ELECTRICAL DISTRIBUTION SYSTEMS

120/240-Volt, Single-Phase, Three-Wire System

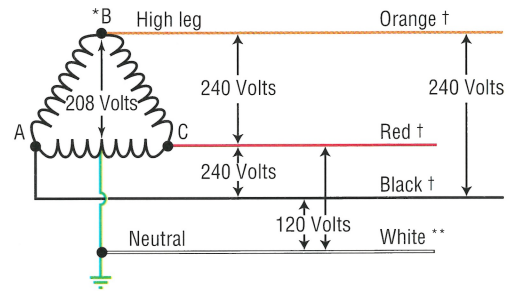


† · Line one ungrounded conductor colored **black**

† · Line two ungrounded conductor colored **red**

** · Grounded neutral conductor colored **white** or gray

120/240-Volt, Three-Phase, Four-Wire System (Delta High Leg)



† · A phase ungrounded conductor colored **black**

†* · B phase ungrounded conductor colored **orange** or tagged (high leg). (Caution: 208 volts orange to white)

† · C phase ungrounded conductor colored **red**

** · Grounded conductor colored **white** or gray (center tap)

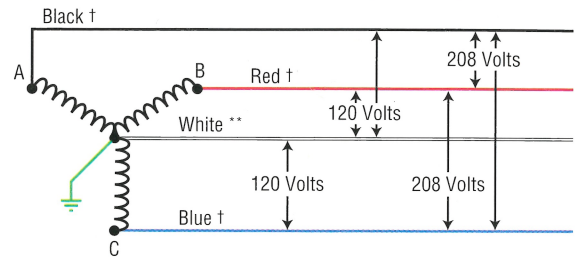
** Grounded conductors are required to be white or gray or three white or gray stripes on other than green insulation. See *NEC* 200.7.

* B phase of delta high leg must be orange or tagged. See *NEC* 110.15.

† Ungrounded conductor colors may be other than shown; see local ordinances or specifications.

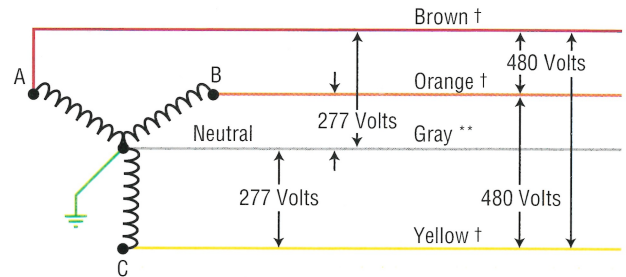
COMMON ELECTRICAL DISTRIBUTION SYSTEMS

120/208-Volt, Three-Phase, Four-Wire System (Wye Connected)



- † • A phase ungrounded conductor colored **black**
- † • B phase ungrounded conductor colored **red**
- † • C phase ungrounded conductor colored **blue**
- ** • Grounded neutral conductor colored **white** or gray

277/480-Volt, Three-Phase, Four-Wire System (Wye Connected)



- † • A phase ungrounded conductor colored **brown**
- † • B phase ungrounded conductor colored **orange**
- † • C phase ungrounded conductor colored **yellow**
- ** • Grounded neutral conductor colored **gray**

** Grounded conductors are required to be white or gray or three white or gray stripes on other than green insulation. See *NEC 200.7*.

† Ungrounded conductor colors may be other than shown; see local ordinances or specifications.



ELECTRICAL FORMULAS FOR CALCULATING AMPERES, HORSEPOWER, KILOWATTS, AND KVA

To Find	Alternating Current			
	Direct Current	Single Phase	Two Phase/Four-Wire	Three Phase
Amperes when "HP" is known	$\frac{HP \times 746}{E \times \%EFF}$	$\frac{HP \times 746}{E \times \%EFF \times PF}$	$\frac{HP \times 746}{E \times \%EFF \times PF \times 2}$	$\frac{HP \times 746}{E \times \%EFF \times PF \times 1.73}$
Amperes when "kW" is known	$\frac{KW \times 1000}{E}$	$\frac{KW \times 1000}{E \times PF}$	$\frac{KW \times 1000}{E \times PF \times 2}$	$\frac{KW \times 1000}{E \times PF \times 1.73}$
Amperes when "kVA" is known		$\frac{KVA \times 1000}{E}$	$\frac{KVA \times 1000}{E \times 2}$	$\frac{KVA \times 1000}{E \times 1.73}$
Kilowatts (True power)	$\frac{E \times I}{1000}$	$\frac{E \times I \times PF}{1000}$	$\frac{E \times I \times PF \times 2}{1000}$	$\frac{E \times I \times PF \times 1.73}{1000}$
kilovolt-Amperes "kVA" (Apparent power)		$\frac{E \times I}{1000}$	$\frac{E \times I \times 2}{1000}$	$\frac{E \times I \times 1.73}{1000}$
Horsepower	$\frac{E \times I \times \%EFF}{746}$	$\frac{E \times I \times \%EFF \times PF}{746}$	$\frac{E \times I \times \%EFF \times PF \times 2}{746}$	$\frac{E \times I \times \%EFF \times PF \times 1.73}{746}$

Percent Efficiency = $\frac{\text{Output (Watts)}}{\text{Input (Watts)}} \times 100$

Power Factor = $PF = \frac{\text{KW}}{\text{KVA}}$

Note: Direct-current formulas do not use (%EFF or 1.73).
 Single-phase formulas do not use (2 or 1.73).
 Two-phase/four-wire formulas do not use (1.73).
 Three-phase formulas do not use (2).

E = Volts
 I = Amperes
 W = Watts

TO FIND AMPERES

Direct Current

A. When *horsepower* is known:

$$\text{Amperes} = \frac{\text{Horsepower} \times 746}{\text{Volts} \times \text{Efficiency}} \quad \text{or} \quad I = \frac{\text{HP} \times 746}{E \times \%EFF}$$

What current will a travel-trailer toilet draw when equipped with a 12-volt direct-current, 1/8-HP motor that has a 96% efficiency rating?

$$I = \frac{\text{HP} \times 746}{E \times \%EFF} = \frac{746 \times \frac{1}{8}}{12 \times 0.96} = \frac{93.25}{11.52} = 8.09 \text{ Amps}$$

B. When *kilowatts* are known:

$$\text{Amperes} = \frac{\text{Kilowatts} \times 1000}{\text{Volts}} \quad \text{or} \quad I = \frac{\text{KW} \times 1000}{E}$$

A 75-kW, 240-volt direct-current generator is used to power a variable-speed conveyor belt at a rock-crushing plant. Determine the current.

$$I = \frac{\text{KW} \times 1000}{E} = \frac{75 \times 1000}{240} = 312.5 \text{ Amps}$$

Single Phase

A. When *watts*, *volts*, and *power factor* are known:

$$\text{Amperes} = \frac{\text{Watts}}{\text{Volts} \times \text{Power Factor}} \quad \text{or} \quad \frac{P}{E \times \text{PF}}$$

Determine the current when a circuit has a 1500-watt load, a power factor of 86%, and operates from a single-phase, 230-volt source.

$$I = \frac{1500}{230 \times 0.86} = \frac{1500}{197.8} = 7.58 \text{ Amps}$$

TO FIND AMPERES

Single Phase (continued)

B. When *horsepower* is known:

$$\text{Amperes} = \frac{\text{Horsepower} \times 746}{\text{Volts} \times \text{Efficiency} \times \text{Power Factor}}$$

Determine the amp-load of a single-phase, ½-HP, 115-volt motor. The motor has an efficiency rating of 92% and a power factor of 80%.

$$I = \frac{\text{HP} \times 746}{E \times \% \text{EFF} \times \text{PF}} = \frac{\frac{1}{2} \times 746}{115 \times 0.92 \times 0.80} = \frac{373}{84.64}$$

$$I = 4.4 \text{ Amps}$$

C. When *kilowatts* are known:

$$\text{Amperes} = \frac{\text{Kilowatts} \times 1000}{\text{Volts} \times \text{Power Factor}} \quad \text{or} \quad I = \frac{\text{KW} \times 1000}{E \times \text{PF}}$$

A 230-volt, single-phase circuit has a 12-kW power load, and operates at 84% power factor. Determine the current.

$$I = \frac{\text{KW} \times 1000}{E \times \text{PF}} = \frac{12 \times 1000}{230 \times 0.84} = \frac{12000}{193.2} = 62 \text{ Amps}$$

D. When *kilovolt-amperes* are known:

$$\text{Amperes} = \frac{\text{Kilovolt-Amperes} \times 1000}{\text{Volts}} \quad \text{or} \quad I = \frac{\text{KVA} \times 1000}{E}$$

A 115-volt, 2-kVA, single-phase generator operating at full load will deliver 17.4 amps.

$$I = \frac{2 \times 1000}{115} = \frac{2000}{115} = 17.4 \text{ Amps}$$

Remember: By definition, amperes is the rate of current flow.

TO FIND AMPERES

Three Phase

A. When *watts*, *volts*, and *power factor* are known:

$$\text{Amperes} = \frac{\text{Watts}}{\text{Volts} \times \text{Power Factor} \times 1.73}$$

$$\text{or} \quad I = \frac{P}{E \times \text{PF} \times 1.73}$$

Determine the current when a circuit has a 1500-watt load, a power factor of 86%, and operates from a three-phase, 230-volt source.

$$I = \frac{P}{E \times \text{PF} \times 1.73} = \frac{1500}{230 \times 0.86 \times 1.73} = \frac{1500}{342.2}$$

$$I = 4.4 \text{ Amps}$$

B. When *horsepower* is known:

$$\text{Amperes} = \frac{\text{Horsepower} \times 746}{\text{Volts} \times \text{Efficiency} \times \text{Power Factor} \times 1.73}$$

$$\text{or} \quad I = \frac{\text{HP} \times 746}{E \times \% \text{EFF} \times \text{PF} \times 1.73}$$

Determine the current draw of a three-phase, 1/2-HP, 230-volt motor. The motor has an efficiency rating of 92% and a power factor of 80%.

$$I = \frac{\text{HP} \times 746}{E \times \% \text{EFF} \times \text{PF} \times 1.73} = \frac{1/2 \times 746}{230 \times 0.92 \times 0.80 \times 1.73}$$
$$= \frac{373}{293} = 1.27 \text{ Amps}$$

TO FIND AMPERES

Three Phase (continued)

C. When *kilowatts* are known:

$$\text{Amperes} = \frac{\text{Kilowatts} \times 1000}{\text{Volts} \times \text{Power Factor} \times 1.73}$$

$$\text{or} \quad I = \frac{\text{KW} \times 1000}{E \times \text{PF} \times 1.73}$$

A 230-volt, three-phase circuit, has a 12-kW power load and operates at 84% power factor. Determine the current.

$$I = \frac{\text{KW} \times 1000}{E \times \text{PF} \times 1.73} = \frac{12 \times 1000}{230 \times 0.84 \times 1.73} = \frac{12000}{334.24}$$

$$I = 35.9 \text{ Amps}$$

D. When *kilovolt-amperes* are known:

$$\text{Amperes} = \frac{\text{Kilovolt-Amperes} \times 1000}{E \times 1.73} = \frac{\text{KVA} \times 1000}{E \times 1.73}$$

A 230-volt, 4-kVA, three-phase generator operating at full load will deliver 10 amps.

$$I = \frac{\text{KVA} \times 1000}{E \times 1.73} = \frac{4 \times 1000}{230 \times 1.73} = \frac{4000}{397.9}$$

$$I = 10 \text{ Amps}$$

TO FIND HORSEPOWER

Direct Current

$$\text{Horsepower} = \frac{\text{Volts} \times \text{Amperes} \times \text{Efficiency}}{746}$$

A 12-volt motor draws a current of 8.1 amps and has an efficiency rating of 96%. Determine the horsepower.

$$\text{HP} = \frac{E \times I \times \% \text{EFF}}{746} = \frac{12 \times 8.09 \times 0.96}{746} = \frac{93.19}{746}$$

$$\text{HP} = 0.125 = \frac{1}{8} \text{ HP} \left(\frac{1}{8} = 1 \div 8 = 0.125 \right)$$

Single Phase

$$\text{HP} = \frac{\text{Volts} \times \text{Amperes} \times \text{Efficiency} \times \text{Power Factor}}{746}$$

A single-phase, 115-volt ac motor has an efficiency rating of 92% and a power factor of 80%. Determine the horsepower if the amp-load is 4.4 amps.

$$\text{HP} = \frac{E \times I \times \% \text{EFF} \times \text{PF}}{746} = \frac{115 \times 4.4 \times 0.92 \times 0.80}{746}$$

$$\text{HP} = \frac{372.416}{746} = 0.4992 = \frac{1}{2} \text{ HP}$$

Three Phase

$$\text{HP} = \frac{\text{Volts} \times \text{Amperes} \times \text{Efficiency} \times \text{Power Factor} \times 1.73}{746}$$

A three-phase, 460-volt motor draws a current of 52 amps. The motor has an efficiency rating of 94% and a power factor of 80%. Determine the horsepower.

$$\text{HP} = \frac{E \times I \times \% \text{EFF} \times \text{PF} \times 1.73}{746} = \frac{460 \times 52 \times 0.94 \times 0.80 \times 1.73}{746}$$

$$\text{HP} = 41.7 \text{ HP}$$

TO FIND WATTS

The electrical power in any part of a circuit is equal to the current in that part multiplied by the voltage across that part of the circuit.

A watt is the power used when 1 volt causes 1 amp to flow in a circuit.

One horsepower is the amount of energy required to lift 33000 pounds, 1 foot, in 1 minute. The electrical equivalent of 1 HP is 745.6 watts.

One watt is the amount of energy required to lift 44.26 pounds, 1 foot, in 1 minute. Watts is power, and power is the amount of work done in a given time.

When *volts* and *amperes* are known:

Power (Watts) = Volts x Amperes

A 120-volt ac circuit draws a current of 5 amps. Determine the power consumption.

$$P = E \times I = 120 \times 5 = 600 \text{ Watts}$$

Now determine the resistance of this circuit.

$$\text{Resistance} = \frac{\text{Watts}}{\text{Amps}^2}$$

$$R = \frac{P}{I^2} = \frac{600}{5 \times 5} = \frac{600}{25} = 24 \text{ Ohms}$$

or

$$\text{Resistance} = \frac{\text{Volts}^2}{\text{Watts}} \text{ or } R = \frac{E^2}{P}$$

$$R = \frac{120 \times 120}{600} = \frac{14400}{600} = 24 \text{ Ohms}$$

Note: Refer to the formulas of the Ohm's Law chart on page 1.

TO FIND KILOWATTS

Direct Current

$$\text{Kilowatts} = \frac{\text{Volts} \times \text{Amperes}}{1000}$$

A 120-volt dc motor draws a current of 40 amps. Determine the kilowatts.

$$\text{KW} = \frac{\text{E} \times \text{I}}{1000} = \frac{120 \times 40}{1000} = \frac{4800}{1000} = 4.8 \text{ kW}$$

Single Phase

$$\text{Kilowatts} = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor}}{1000}$$

A single-phase, 115-volt ac motor draws a current of 20 amps and has a power factor rating of 86%. Determine the kilowatts.

$$\text{KW} = \frac{\text{E} \times \text{I} \times \text{PF}}{1000} = \frac{115 \times 20 \times 0.86}{1000} = \frac{1978}{1000} = 1.978 = 2 \text{ kW}$$

Three Phase

$$\text{Kilowatts} = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor} \times 1.73}{1000}$$

A three-phase, 460-volt ac motor draws a current of 52 amps and has a power factor rating of 80%. Determine the kilowatts.

$$\begin{aligned} \text{KW} &= \frac{\text{E} \times \text{I} \times \text{PF} \times 1.73}{1000} = \frac{460 \times 52 \times 0.80 \times 1.73}{1000} \\ &= \frac{33105}{1000} = 33.105 = 33 \text{ kW} \end{aligned}$$

TO FIND KILOVOLT-AMPERES

Single Phase

$$\text{Kilovolt-Amperes} = \frac{\text{Volts} \times \text{Amperes}}{1000}$$

A single-phase, 240-volt generator delivers 41.66 amps at full load. Determine the kilovolt-amperes rating.

$$\text{KVA} = \frac{E \times I}{1000} = \frac{240 \times 41.66}{1000} = \frac{9998.4}{1000} = 10 \text{ kVA}$$

Three Phase

$$\text{Kilovolt-Amperes} = \frac{\text{Volts} \times \text{Amperes} \times 1.73}{1000}$$

A three-phase, 460-volt generator delivers 52 amps. Determine the kilovolt-amperes rating.

$$\begin{aligned} \text{KVA} &= \frac{E \times I \times 1.73}{1000} = \frac{460 \times 52 \times 1.73}{1000} = \frac{41382}{1000} \\ &= 41.382 = 41 \text{ kVA} \end{aligned}$$

Note: KVA = Apparent Power = Power Before Used, such as the rating of a transformer.

Kirchhoff's Laws

First Law (Current):

The sum of the currents arriving at any point in a circuit must equal the sum of the currents leaving that point.

Second Law (Voltage):

The total voltage applied to any closed circuit path is always equal to the sum of the voltage drops in that path.

or

The algebraic sum of all the voltages encountered in any loop equals zero.

TO FIND CAPACITANCE

Capacitance (C)

$$C = \frac{Q}{E} \text{ or } \text{Capacitance} = \frac{\text{Coulombs}}{\text{Volts}}$$

Capacitance is the property of a circuit or body that permits it to store an electrical charge equal to the accumulated charge divided by the voltage. Capacitance is expressed in farads.

- A. To determine the total capacity of capacitors and/or condensers connected in series:

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}$$

Determine the total capacity of four 12-microfarad capacitors connected in series.

$$\begin{aligned} \frac{1}{C_T} &= \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4} \\ &= \frac{1}{12} + \frac{1}{12} + \frac{1}{12} + \frac{1}{12} = \frac{4}{12} \end{aligned}$$

$$\frac{1}{C_T} = \frac{4}{12} \text{ or } C_T \times 4 = 12 \text{ or } C_T = \frac{12}{4} = 3 \text{ Microfarads}$$

- B. To determine the total capacity of capacitors and/or condensers connected in parallel:

$$C_T = C_1 + C_2 + C_3 + C_4$$

Determine the total capacity of four 12-microfarad capacitors connected in parallel:

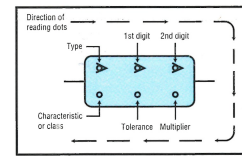
$$C_T = C_1 + C_2 + C_3 + C_4$$

$$C_T = 12 + 12 + 12 + 12 = 48 \text{ Microfarads}$$

A farad is the unit of capacitance of a condenser that retains 1 coulomb of charge with 1 volt difference of potential.

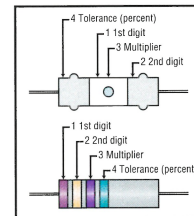
$$1 \text{ Farad} = 1000000 \text{ Microfarads}$$

SIX-DOT COLOR CODE FOR MICA AND MOLDED PAPER CAPACITORS



Type	Color	1st Digit	2nd Digit	Multiplier	Tolerance (%)	Characteristic or Class
JAN, Mica	Black	0	0	1	± 1	Applies to Temperature Coefficient or Methods of Testing
	Brown	1	1	10	± 2	
	Red	2	2	100	± 3	
	Orange	3	3	1000	± 4	
	Yellow	4	4	10000	± 5	
	Green	5	5	100000	± 6	
	Blue	6	6	1000000	± 7	
	Violet	7	7	10000000	± 8	
	Gray	8	8	100000000	± 9	
ETA, Mica	White	9	9	1000000000	0.1	
Molded Paper	Gold				± 10	
	Silver				± 20	
	Body					

RESISTOR COLOR CODE



Color	1st Digit	2nd Digit	Multiplier	Tolerance (%)
Black	0	0	1	
Brown	1	1	10	
Red	2	2	100	
Orange	3	3	1000	
Yellow	4	4	10000	
Green	5	5	100000	
Blue	6	6	1000000	
Violet	7	7	10000000	
Gray	8	8	100000000	
White	9	9	1000000000	
Gold			0.1	± 5%
Silver			0.01	± 10%
No Color				± 20%



MAXIMUM PERMISSIBLE CAPACITOR KVAR FOR USE WITH OPEN-TYPE, THREE-PHASE, 60-CYCLE INDUCTION MOTORS

Motor Rating (HP)	3600 RPM		1800 RPM		1200 RPM	
	Maximum Capacitor Rating (KVAR)	Reduction in Line Current (%)	Maximum Capacitor Rating (KVAR)	Reduction in Line Current (%)	Maximum Capacitor Rating (KVAR)	Reduction in Line Current (%)
10	3	10	3	11	3.5	14
15	4	9	4	10	5	13
20	5	9	5	10	6.5	12
25	6	9	6	10	7.5	11
30	7	8	7	9	9	11
40	9	8	9	9	11	10
50	12	8	11	9	13	10
60	14	8	14	8	15	10
75	17	8	16	8	18	10
100	22	8	21	8	25	9
125	27	8	26	8	30	9
150	32.5	8	30	8	35	9
200	40	8	37.5	8	42.5	9

Motor Rating (HP)	900 RPM		720 RPM		600 RPM	
	Maximum Capacitor Rating (KVAR)	Reduction in Line Current (%)	Maximum Capacitor Rating (KVAR)	Reduction in Line Current (%)	Maximum Capacitor Rating (KVAR)	Reduction in Line Current (%)
10	5	21	6.5	27	7.5	31
15	6.5	18	8	23	9.5	27
20	7.5	16	9	21	12	25
25	9	15	11	20	14	23
30	10	14	12	18	16	22
40	12	13	15	16	20	20
50	15	12	19	15	24	19
60	18	11	22	15	27	19
75	21	10	26	14	32.5	18
100	27	10	32.5	13	40	17
125	32.5	10	40	13	47.5	16
150	37.5	10	47.5	12	52.5	15
200	47.5	10	60	12	65	14

Note: If capacitors of a lower rating than the values given in the table are used, the percentage reduction in line current given in the table should be reduced proportionately.

POWER FACTOR CORRECTION

Table Values × Kilowatt of Capacitors Needed to Correct from Existing to Desired Power Factor

Existing Power Factor (%)	Corrected Power Factor					
	100%	95%	90%	85%	80%	75%
50	1.732	1.403	1.247	1.112	0.982	0.850
52	1.643	1.314	1.158	1.023	0.893	0.761
54	1.558	1.229	1.073	0.938	0.808	0.676
55	1.518	1.189	1.033	0.898	0.768	0.636
56	1.479	1.150	0.994	0.859	0.729	0.597
58	1.404	1.075	0.919	0.784	0.654	0.522
60	1.333	1.004	0.848	0.713	0.583	0.451
62	1.265	0.936	0.780	0.645	0.515	0.383
64	1.201	0.872	0.716	0.581	0.451	0.319
65	1.168	0.839	0.683	0.548	0.418	0.286
66	1.139	0.810	0.654	0.519	0.389	0.257
68	1.078	0.749	0.593	0.458	0.328	0.196
70	1.020	0.691	0.535	0.400	0.270	0.138
72	0.964	0.635	0.479	0.344	0.214	0.082
74	0.909	0.580	0.424	0.289	0.159	0.027
75	0.882	0.553	0.397	0.262	0.132	
76	0.855	0.526	0.370	0.235	0.105	
78	0.802	0.473	0.317	0.182	0.052	
80	0.750	0.421	0.265	0.130		
82	0.698	0.369	0.213	0.078		
84	0.646	0.317	0.161			
85	0.620	0.291	0.135			
86	0.594	0.265	0.109			
88	0.540	0.211	0.055			
90	0.485	0.156				
92	0.426	0.097				
94	0.363	0.034				
95	0.329					

Typical Problem: With a load of 500 kW at 70% power factor, it is desired to find the kVA of capacitors required to correct the power factor to 85%.

Solution: From the table, select the multiplying factor 0.400 corresponding to the existing 70%, and the corrected 85% power factor.
 $0.400 \times 500 = 200$ kVA of capacitors required.

POWER FACTOR AND EFFICIENCY EXAMPLE

A squirrel cage induction motor is rated 10 HP, 208 volt, three-phase, and has a nameplate rating of 27.79 amps. A wattmeter reading indicates 8 kilowatts of consumed (true) power. Calculate apparent power (kVA), power factor, efficiency, internal losses, and size of the capacitor in kilovolt-amperes reactive (KVAR) needed to correct the power factor to unity (100%).

Apparent input power: kilovolt-amperes (kVA)

$$\text{KVA} = (E \times I \times 1.73)/1000 = (208 \times 27.79 \times 1.73)/1000 = \mathbf{10 \text{ kVA}}$$

Power factor (PF) = ratio of true power (kW) to apparent power (kVA)

$$\text{Kilowatts/kilovolt-amperes} = 8 \text{ kW}/10 \text{ kVA} = 0.8 = \mathbf{80\% \text{ Power Factor}}$$

80% of the 10-kVA apparent power input performs work.

Motor output in kilowatts = 10 HP x 746 watts = 7460 watts = **7.46 kW**

$$\text{Efficiency} = \text{watts out/watts in} = 7.46 \text{ kW}/8 \text{ kW} = 0.9325 = \mathbf{93.25\% \text{ efficiency}}$$

Internal losses (heat, friction, hysteresis) = 8 kW – 7.46 kW = **0.54 kW** (540 Watts)

Kilovolt-amperes reactive (KVAR) (Power stored in motor magnetic field)

$$\text{KVAR} = \sqrt{\text{kVA}^2 - \text{kW}^2} = \sqrt{10 \text{ kVA}^2 - 8 \text{ kW}^2} = \sqrt{100 - 64} = \sqrt{36} = \mathbf{6 \text{ KVAR}}$$

The size capacitor needed to equal the motor's stored reactive power is 6 KVAR. (A capacitor stores reactive power in its electrostatic field.)

The power source must supply the current to perform work and maintain the motor's magnetic field. Before power factor correction, this was 27.79 amperes. The motor magnetizing current after power factor correction is supplied by

circulation of current between the motor and the electrostatic field of the capacitor and is no longer supplied by power source after initial startup.

The motor feeder current after correction to 100% will equal the amount required by the input watts in this case $(8 \text{ kW})/(208 \text{ volts} \times 1.73) = (8 \times 1000)/(208 \text{ volts} \times 1.73) = \mathbf{22.2 \text{ amps}}$.

- Kilo = 1000. For example: 1000 Watts = 1 Kilowatt.
- Inductive loads (motors, coils) have lagging currents, and capacitive loads have leading currents.
- Inductance and capacitance have opposite effects in a circuit and can cancel each other.

TO FIND INDUCTANCE

Inductance (L)

Inductance is the production of magnetization of electrification in a body by the proximity of a magnetic field or electric charge, or of the electric current in a conductor by the variation of the magnetic field in its vicinity. The unit of measurement for inductance is the Henry (H).

A. To find the total inductance of coils connected in series:

$$L_T = L_1 + L_2 + L_3 + L_4$$

Determine the total inductance of four coils connected in series. Each coil has an inductance of 4 Henries.

$$\begin{aligned} L_T &= L_1 + L_2 + L_3 + L_4 \\ &= 4 + 4 + 4 + 4 = 16 \text{ Henries} \end{aligned}$$

B. To find the total inductance of coils connected in parallel:

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \frac{1}{L_4}$$

Determine the total inductance of four coils connected in parallel. Each coil has an inductance of 4 Henries.

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \frac{1}{L_4}$$

$$\frac{1}{L_T} = \frac{1}{4} + \frac{1}{4} + \frac{1}{4} + \frac{1}{4}$$

$$\frac{1}{L_T} = \frac{4}{4} \text{ or } L_T \times 4 = 1 \times 4 \text{ or } L_T = \frac{4}{4} = 1 \text{ Henry}$$

An induction coil is a device consisting of two concentric coils and an interrupter, which changes a low steady voltage into a high intermittent alternating voltage by electromagnetic induction. Most often used as a spark coil.

TO FIND IMPEDANCE

Impedance (Z)

Impedance is the total opposition to an alternating current presented by a circuit. Expressed in ohms.

A. When *volts* and *amperes* are known:

$$\text{Impedance} = \frac{\text{Volts}}{\text{Amperes}} \quad \text{or} \quad Z = \frac{E}{I}$$

Determine the impedance of a 120-volt ac circuit that draws a current of 4 amps.

$$Z = \frac{E}{I} = \frac{120}{4} = 30 \text{ Ohms}$$

B. When *resistance* and *reactance* are known:

$$Z = \sqrt{\text{Resistance}^2 + \text{Reactance}^2} = \sqrt{R^2 + X^2}$$

Determine the impedance of an ac circuit when the resistance is 6 ohms, and the reactance is 8 ohms.

$$Z = \sqrt{R^2 + X^2} = \sqrt{36 + 64} = \sqrt{100} = 10 \text{ Ohms}$$

C. When *resistance*, *inductive reactance*, and *capacitive reactance* are known:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Determine the impedance of an ac circuit that has a resistance of 6 ohms, an inductive reactance of 18 ohms, and a capacitive reactance of 10 ohms.

$$\begin{aligned} Z &= \sqrt{R^2 + (X_L - X_C)^2} \\ &= \sqrt{6^2 + (18 - 10)^2} = \sqrt{6^2 + (8)^2} \\ &= \sqrt{36 + 64} = \sqrt{100} = 10 \text{ Ohms} \end{aligned}$$