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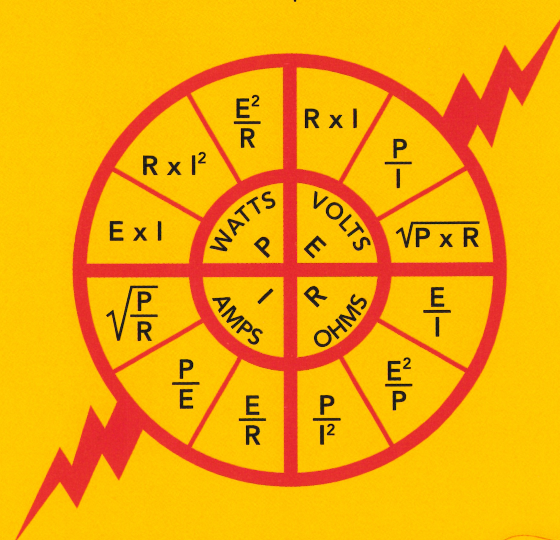
ELECTRICAL REFERENCES

Charles R. Miller | Daniel Sandefur



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Charles R. Miller and Daniel Sandefur

A Note from the Author...

Ugly's Electrical References is designed to be used as a quick on-the-job reference in the electrical industry. Used worldwide by electricians, engineers, contractors, designers, maintenance workers, instructors, and the military, Ugly's contains the most commonly required information in an easy-to-read format.

Ugly's Electrical References is not intended to be a substitute for the *National Electrical Code®*.

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JONES & BARTLETT
LEARNING

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OHM'S LAW

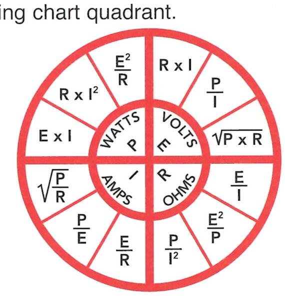
Ohm's Law is the relationship between voltage (E), current (I), and resistance (R). The rate of the current flow is equal to electromotive force divided by resistance.

I = Intensity of Current = Amperes
E = Electromotive Force = Volts
R = Resistance = Ohms
P = Power = Watts

The three basic Ohm's Law formulas are:

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

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?

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

What is the resistance of the same appliance?

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

OHM'S LAW

In the preceding example, we know the following values:

I = Amps = 10 Amps   R = Ohms = 12 Ohms

E = Volts = 120 Volts   P = Watts = 1200 Watts

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

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

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

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

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

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

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

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

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

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

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

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

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

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.**

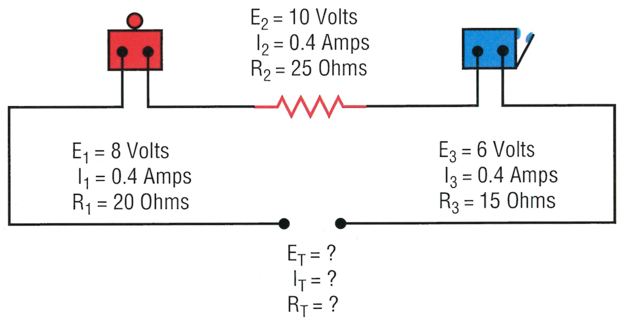
Formulas from Ohm's Law

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

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

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

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



SERIES CIRCUITS

$E_T = E_1 + E_2 + E_3$
$= 8 + 10 + 6$
$E_T = 24$ Volts

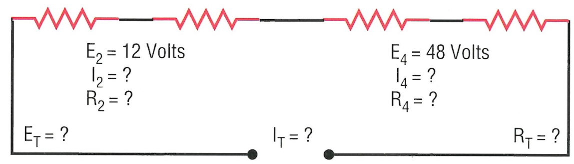
$I_T = I_1 = I_2 = I_3$
$= 0.4 = 0.4 = 0.4$
$I_T = 0.4$ Amps

$R_T = R_1 + R_2 + R_3$
$= 20 + 25 + 15$
$R_T = 60$ Ohms

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.

$E_1 = ?$
$I_1 = ?$
$R_1 = 72$ Ohms

$E_3 = ?$
$I_3 = 0.5$ Amps
$R_3 = 48$ Ohms



$I_T = I_1 = I_2 = I_3 = I_4$
$I_T = I_1 = I_2 = 0.5 = I_4$
$0.5 = 0.5 = 0.5 = 0.5 = 0.5$
$I_T = 0.5$ Amps $\quad I_2 = 0.5$ Amps
$I_1 = 0.5$ Amps $\quad I_4 = 0.5$ Amps

$E_T = E_1 + E_2 + E_3 + E_4$
$= 36 + 12 + 24 + 48$
$E_T = 120$ Volts

$R_T = R_1 + R_2 + R_3 + R_4$
$= 72 + 24 + 48 + 96$
$R_T = 240$ Ohms

$R_2 = \frac{E_2}{I_2} = \frac{12}{0.5}$
$R_2 = 24$ Ohms

$E_1 = I_1 \times R_1$
$= 0.5 \times 72$
$E_1 = 36$ Volts

$E_3 = I_3 \times R_3$
$= 0.5 \times 48$
$E_3 = 24$ Volts

$R_4 = \frac{E_4}{I_4} = \frac{48}{0.5}$
$R_4 = 96$ Ohms

PARALLEL CIRCUITS

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

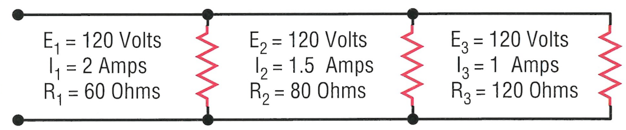
Rule 1: The total current in a parallel circuit is equal to the sum of the currents in all the branches of the circuit.
Total Current $I_T = I_1 + I_2 + I_3$, etc.

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.

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

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



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

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

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

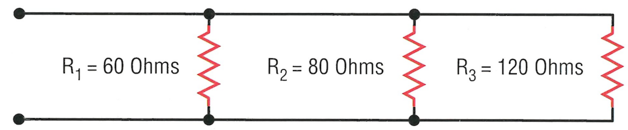
Note: In a parallel circuit, the total resistance is always less than the resistance of any branch. If the branches of a parallel circuit have the same resistance, then each will draw the same current. If the branches of a parallel circuit have different resistances, then each will draw a different current.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

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

Example 2: Find the total resistance.



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

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

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

$$\frac{1}{R_T} \times \frac{9}{240}$$ Cross multiply.

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

$9 \times R_T = 1 \times 240$ or $9R_T = 240$

Divide both sides of the equation by 9.

$R_T = 26.66$ Ohms Resistance

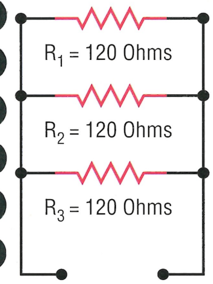
Note: The total resistance of a number of equal resistors in parallel is equal to the resistance of one resistor divided by the number of resistors.

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

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.

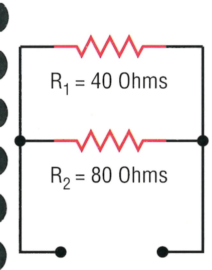
$R_T = \frac{R}{N}$ or $R_T = \frac{120}{3}$

Total Resistance = 40 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: Total Resistance $= \frac{R_1 \times R_2}{R_1 + R_2}$

Example 4: Find the total resistance.



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

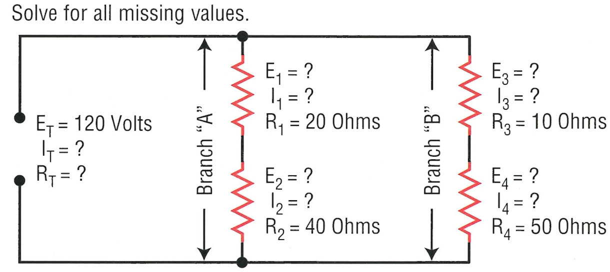
$$= \frac{40 \times 80}{40 + 80}$$

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

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.

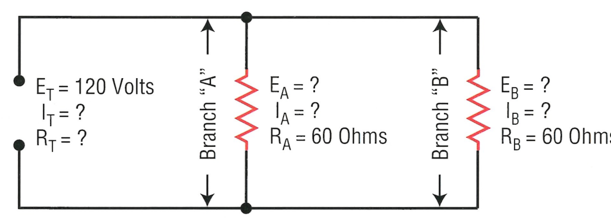


To solve:

1. Find the total resistance of each branch. Both branches are simple series circuits, so:
   R_1 + R_2 = R_A
   20 + 40 = 60 Ohms total resistance of branch "A"

   R_3 + R_4 = R_B
   10 + 50 = 60 Ohms total resistance of branch "B"

2. 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,

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

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

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

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.

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

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

$I_A = I_1 = I_2$ or $2 = 2 = 2$ $\quad I_1 = 2$ Amps, $I_2 = 2$ Amps

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

$I_B = I_3 = I_4$ or $2 = 2 = 2$ $\quad I_3 = 2$ Amps, $I_4 = 2$ 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"
$\mathbf{I_A = I_1 = I_2}$	$\mathbf{I_B = I_3 = I_4}$
$2 = 2 = 2$	$2 = 2 = 2$
I_1 = 2 Amps	I_3 = 2 Amps
I_2 = 2 Amps	I_4 = 2 Amps

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

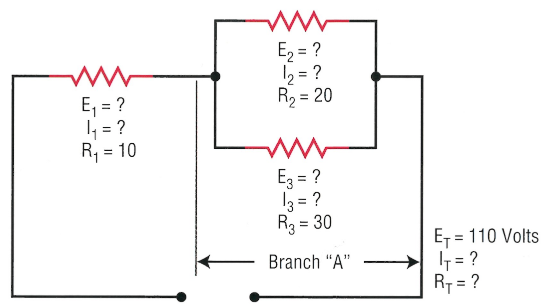
$\mathbf{E_1 = R_1 \times I_1}$
$= 20 \times 2$
E_1 = 40 Volts

$\mathbf{E_3 = R_3 \times I_3}$
$= 10 \times 2$
E_3 = 20 Volts

$\mathbf{E_2 = R_2 \times I_2}$
$= 40 \times 2$
E_2 = 80 Volts

$\mathbf{E_4 = R_4 \times I_4}$
$= 50 \times 2$
E_4 = 100 Volts

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



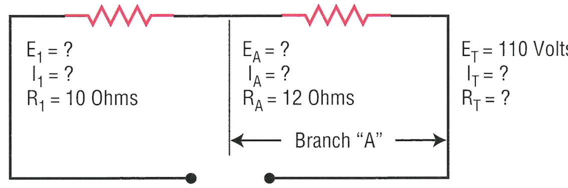
COMBINATION CIRCUITS

To solve:

1. 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:

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

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



3. In a series circuit,

$\mathbf{R_T = R_1 + R_A}$ 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,

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

By using Ohm's Law,

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

$E_T - E_1 = E_A$ or $110 - 50 = 60$ Volts $= E_A$

In a parallel circuit,

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

$E_2 = 60$ Volts, and $E_3 = 60$ Volts

By using Ohm's Law,

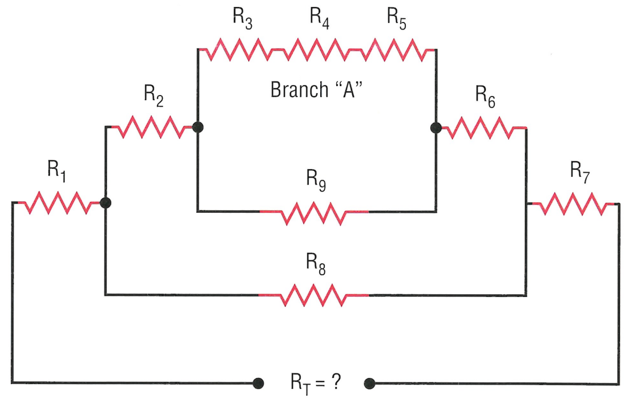
$$I_2 = \frac{E_2}{R_2} = \frac{60}{20} = 3 \text{ Amps}$$

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

COMBINATION CIRCUITS

Problem:

Find the total resistance.
Redraw circuit as many times as necessary.
Correct answer is 100 Ohms.

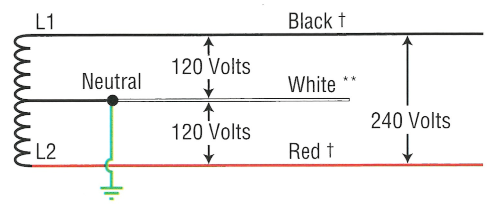


Given Values:

R_1	=	15 Ohms
R_2	=	35 Ohms
R_3	=	50 Ohms
R_4	=	40 Ohms
R_5	=	30 Ohms
R_6	=	25 Ohms
R_7	=	10 Ohms
R_8	=	300 Ohms
R_9	=	60 Ohms

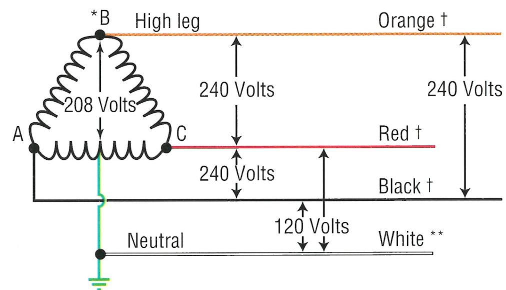
COMMON ELECTRICAL DISTRIBUTION SYSTEMS

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)

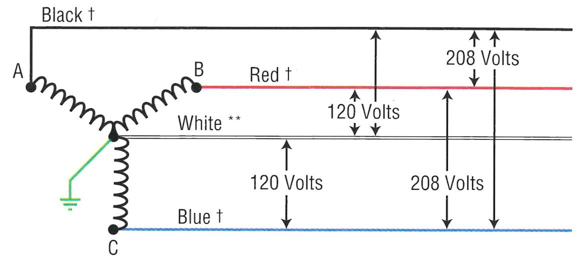


† · **A** phase ungrounded conductor colored **black**
†* · **B** phase ungrounded conductor colored **orange** or tagged (high leg). (Caution: 208 volts orange to white)
† · **C** phase ungrounded conductor colored **red**
** · Grounded conductor colored **white** or gray (center tap)

** 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.

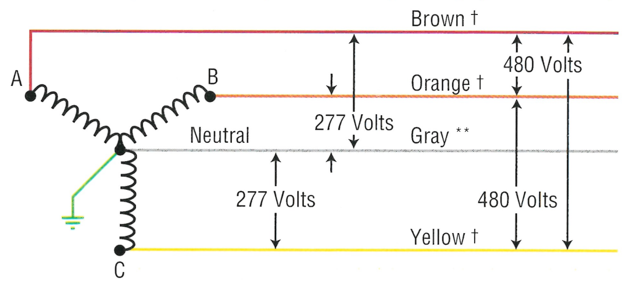
COMMON ELECTRICAL DISTRIBUTION SYSTEMS

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	Direct Current	Alternating 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 = % EFF = $\frac{\text{Output (Watts)}}{\text{Input (Watts)}}$ Power Factor = PF = $\frac{\text{Power Used (Watts)}}{\text{Apparent Power}} = \frac{KW}{KVA}$

Note: Direct-current formulas do not use (PF, 2 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:

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

What current will a travel-trailer toilet draw when equipped with a 12-volt direct-current, ⅛-HP motor that has a 96% efficiency rating?

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

B. When *kilowatts* are known:

$$\textbf{Amperes} = \frac{\textbf{Kilowatts x 1000}}{\textbf{Volts}} \quad \textbf{or} \quad I = \frac{\textbf{KW x 1000}}{\textbf{E}}$$

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.

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

Single Phase

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

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

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:

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

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%.

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

I = 4.4 Amps

C. When *kilowatts* are known:

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

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

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

D. When *kilovolt-amperes* are known:

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

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:

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

or

$$I = \frac{P}{E \text{ x } PF \text{ x } 1.73}$$

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.

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

I = 4.4 Amps

B. When *horsepower* is known:

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

or

$$I = \frac{HP \text{ x } 746}{E \text{ x } \%EFF \text{ x } PF \text{ x } 1.73}$$

Determine the current draw of a three-phase, ½-HP, 230-volt motor. The motor has an efficiency rating of 92% and a power factor of 80%.

$$I = \frac{HP \text{ x } 746}{E \text{ x } \%EFF \text{ x } PF \text{ x } 1.73} = \frac{\frac{1}{2} \text{ x } 746}{230 \text{ x } 0.92 \text{ x } 0.80 \text{ x } 1.73}$$

$$= \frac{373}{293} = 1.27 \text{ Amps}$$

TO FIND AMPERES

Three Phase (continued)

C. When *kilowatts* are known:

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

or

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

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

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

$I = 35.9$ Amps

D. When *kilovolt-amperes* are known:

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

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

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

$I = 10$ Amps

TO FIND HORSEPOWER

Direct Current

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

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

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

$$HP = 0.125 = \tfrac{1}{8}\ HP\ (\tfrac{1}{8} = 1 \div 8 = 0.125)$$

Single Phase

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

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.

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

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

Three Phase

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

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.

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

$$HP = 41.7\ HP$$

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 amps 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.

$P = E \times I = 120 \times 5 = 600$ 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

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

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

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

TO FIND KILOWATTS

Direct Current

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

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

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

Single Phase

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

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

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

Three Phase

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

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

$$KW = \frac{E \times I \times PF \times 1.73}{1000} = \frac{460 \times 52 \times 0.80 \times 1.73}{1000}$$

$$= \frac{33105}{1000} = 33.105 = 33 \text{ kW}$$

TO FIND KILOVOLT-AMPERES

Single Phase

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

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

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

Three Phase

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

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

$$KVA = \frac{E \times I \times 1.73}{1000} = \frac{460 \times 52 \times 1.73}{1000} = \frac{41382}{1000}$$

$$= 41.382 = 41 \text{ kVA}$$

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)

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

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.

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

$$= \frac{1}{12} + \frac{1}{12} + \frac{1}{12} + \frac{1}{12} = \frac{4}{12}$$

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

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:

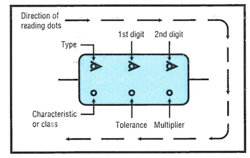
$$C_T = C_1 + C_2 + C_3 + C_4$$

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

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

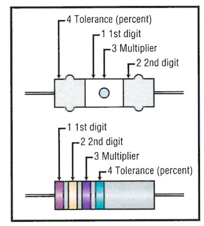
1 Farad = 1000000 Microfarads

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		
	Gold			0.1	± 10	
Molded Paper	Silver			0.01	± 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

	3600 RPM		1800 RPM		1200 RPM	
Motor Rating (HP)	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

	900 RPM		720 RPM		600 RPM	
Motor Rating (HP)	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 x 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)
KVA = (E x I x 1.73)/1000 = (208 x 27.79 x 1.73)/1000 = **10 kVA**

Power factor (PF) = ratio of true power (kW) to apparent power (kVA)
Kilowatts/kilovolt-amperes = 8 kW/10 kVA = 0.8 = **80% 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**
Efficiency = watts out/watts in = 7.46 kW/8 kW = 0.9325 = **93.25% 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)
$KVAR = \sqrt{kVA^2 - kW^2} = \sqrt{10\ kVA^2 - 8\ kW^2} = \sqrt{100 - 64} = \sqrt{36} =$ **6 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 kW)/(208 volts x 1.73) = (8 x 1000)/(208 volts x 1.73) = **22.2 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.

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

$$= 4 + 4 + 4 + 4 = 16 \text{ Henries}$$

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:

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

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.

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