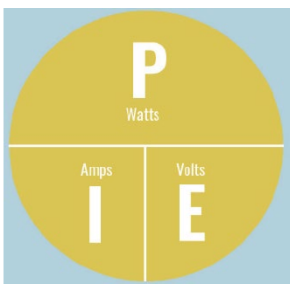
## Electrical Units

| | Symbol | Description | Unit (Abbreviation) |
|---|---|---|---|
| voltage | E | A source of energy (electromotive force), or lost, used, or stored energy (potential drop). A voltmeter measures the voltage between two points. | volt (V)<br>Example: 120 V |
| amperage | I | The volume of electrical current conducted at a given point in a circuit. | amp (A)<br>Example: 20 A |
| wattage | P | Power output as a result of voltage and amperage. For loads that have power factor below 1.0, wattage is called **true power**, which is different than **apparent power** given in volt-amperes (VA). | watt (W)<br>Example: 2000 W or 2 kW |
| resistance | R | The opposition that a circuit presents to current (applies to DC loads and purely resistive AC loads). | ohms (Ω)<br>Example: 1.4 Ω. |
| impedance | Z | The total opposition that a circuit presents to current when AC voltage is applied. It is a combination of resistance and reactance. | ohms (Ω)<br>Example: 1.4 Ω. |

## Power Formula (easy as PIE)




Place your finger over the term you want to calculate; what remains is the equation to use.

The power formula is used to determine the amperage of a load from the wattage and voltage, which is the first step of making load calculations. For example, to calculate the amperage of a load, place your finger over I and read:

$$I\ (amps) = \frac{P\ (watts)}{E\ (volts)} \qquad \text{Example, 1 kW light: } \frac{1000\ W}{120\ V} = 8.3\ A$$

## Load Calculations

For cable sizing and generator sizing, loads should be calculated as follows.

For purely **resistive loads** (i.e.: incandescent lights), use the power formula: $I\ (amps) = \frac{P\ (watts)}{E\ (volts)}$

For 208- and 240-volt loads, the amperage given by the power formula is applied to **both** phases.

Or, for 120-volt loads, use **paper loads** (divide the wattage by 100 instead of 120, which is easy arithmetic). $I\ (amps) = \frac{P\ (watts)}{100}$

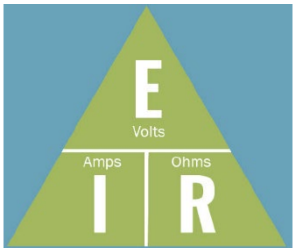
For loads that have a **power factor** of less than 1.0 (<100%), the current can be calculated:

$I\ (amps) = \frac{P\ (watts)}{E\ (volts) \times pf}$ Example, 4000 W HMI, pf = 0.7: $I\ (amps) = \frac{4000\ W}{120\ V \times 0.7} = 47.6\ amps$

For large loads comprising electronic power supplies, consideration should be given to the following:

- The power requirements of the power supply may be greater than the lamp wattage. For example, an 18 kW power supply draws 96 amps/phase. Whereas, using just the lamp wattage, you'd get $18{,}000/208 = 86$ amps/phase). Use manufacturer's rating in volt-amperes (VA)—19,968 VA in this example. Calculate *I* by dividing VA by the operating voltage.
- Phase-control dimmers and electronic power supplies that are not power factor corrected introduce triplen harmonics, which can overload the neutral. The neutral feeder must be doubled when powering such loads.

## Ohms Law

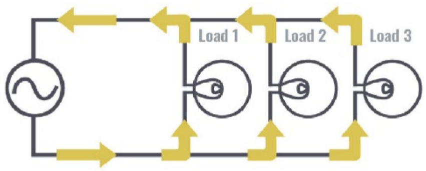



Ohms Law describes the underlying forces at work in any circuit: a given voltage can move only a certain amount of current (amps) through a given resistance.

To determine the resistance of a load: $R = \frac{E}{I}$ Example, 1 kW light: $R = \frac{120\ V}{8.3\ A} = 14.4\Omega$

To determine the amperage: $I = \frac{E}{R}$ Example, 2 kW light: $I = \frac{120\ V}{7.2\Omega} = 16.67\ A$

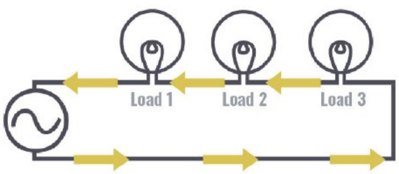
## Parallel Circuit




In a parallel circuit, each load forms a separate path. The voltage potential across each path is the same. The total amperage is the sum of the amperages in each path.

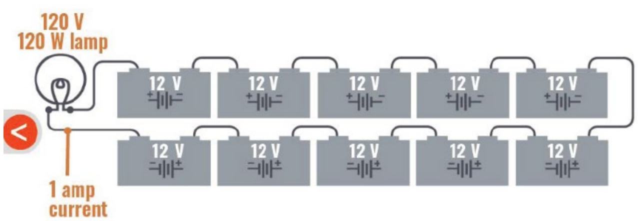
$E_T = E_1 = E_2 = E_3$ $I_T = I_1 + I_2 + I_3$ $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

## Series Circuit




In a series circuit there is only one path for current. The current is the same in all parts of the circuit. The total voltage drop is the sum of the voltage drops over each load. The voltage drop over each load depends on the resistance of the load (per Ohms Law). The total resistance is the sum of the resistances.

$E_T = E_1 + E_2 + E_3$ $I_T = I_1 = I_2 = I_3$ $R_T = R_1 + R_2 + R_3$

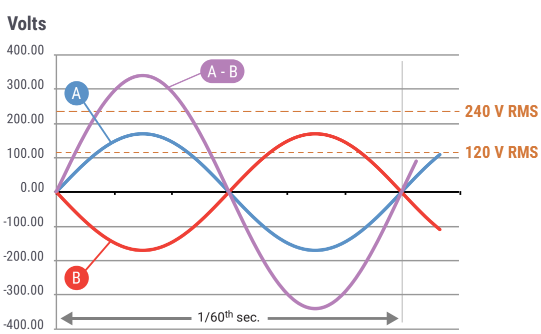



Example: Ten 12-volt batteries connected in series to a 120 W lamp.

Total voltage: $E_T = 12\ V + 12\ V + 12\ V + 12\ V + 12\ V + 12\ V + 12\ V + 12\ V + 12\ V + 12\ V = 120V$

Current in circuit: $I_T = \frac{P_T}{E_T}$ so $I_T = \frac{120\ W}{120\ V} = 1$ A

## Single-Phase System




A single-phase 240/120 V system is a three-wire system plus ground (A, B, N and G). The voltage sine wave of phases A and B pass through zero at the same moment in time, but they are opposite in polarity.

A single-phase system can power single-phase loads:

Phase to neutral @ 120 V

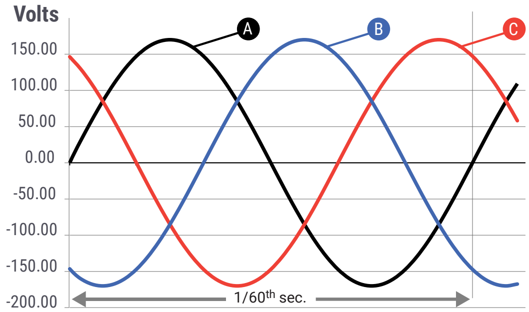
Phase to phase @ 240 V

The current on the neutral is the difference in current between phases A and B.

Example: A = 200 amps, B = 250 amps

Neutral current = 250 – 200 = 50 amps

## Three-Phase System




A three-phase 208/120 V system is a four-wire system plus ground (A, B, C, N and G). The voltage sine waves of the phases cross zero volts 1/3rd of a cycle after one another. They are 120 degrees out of phase.

A three-phase 208/120 V system can power single-phase loads: phase to neutral @ 120 V, or phase to phase @ 208 V, and three-phase loads @ 208 V.

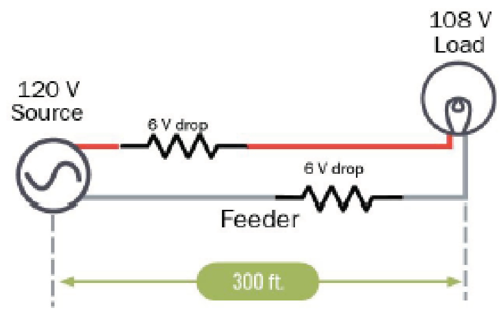
An effort should be made to balance the load between the three phases by planning the distribution of large loads and, during use, adding loads to the phase with the least current.

The current on the neutral is the three-way difference between the phases (which involves vector math). It can be estimated by subtracting the smallest phase current from the largest one.

Example: A = 200 amps, B = 250 amps, C = 270 amps

Neutral current = 270 – 200 = 70 amps

## Voltage Drop




Voltage drop ($V_d$) is the reduction of voltage along a circuit. In feeder cables, voltage drop is due to the resistance of the conductors themselves.

The amount of voltage drop that is acceptable depends on the ability of the loads to tolerate low voltage. Generally, it is recommended not to exceed a total voltage drop of 5% (6 volts for 120 V circuits, 10.4 volts for 208 V circuits).

| **Voltage Drop in Three-Phase Feeders**† (powering single-phase or three-phase loads) | |
|---|---|
| 4/0 cable | **1.06 volts** per 100 amps per 100 ft. |
| 2/0 cable | **1.68 volts** per 100 amps per 100 ft. |
| #2 cable | **3.37 volts** per 100 amps per 100 ft. |

Example: 4/0 cable, 360 amps, 300 feet.

$V_d = 1.06 \times \frac{I}{100} \times \frac{L}{100}$ $\qquad$ $V_d = 1.06 \times 3.6 \times 3 = 11.4\ V$

$L$ = one-way length in feet. $I$ = current in amps.*

| | | | |
|---|---|---|---|
| Operating voltage: | Phase to phase | 208 V – 11.4 V = 196.6 V | (5.4% drop) |
| | Phase to neutral | 120 V – 11.4 V = 108.6 V | (9.5% drop)** |

* For loads that have poor power factor, $I = \frac{P\ (watts)}{E\ (volts) \times pf}$. Check manufacturer's documentation for power factor or rating in volt-amps (VA). Use the highest phase current for calculations. If the exact load is not known, it is recommended use I = 75% of the cable ampacity for planning purposes.

** Balancing the load between phases, reduces the voltage drop for 120-volt loads by as much as half. This is because voltage drop is proportional to current, and the neutral current is close to zero when the phases are balanced. In the example above, the phase-to-neutral voltage could be anywhere from 108 V (with 360 amps carried on the neutral) to 114 V, (with zero amps carried on the neutral).

†$V_d$ for single-phase feeders and branch circuits: 4/0 cable $V_d$ = 1.22 V per 100 amps per 100 ft.; 2/0 cable $V_d$ = 1.94 V per 100 amps per 100 ft.; #2 cable $V_d$ = 3.89 V per 100 amps per 100 ft.

**Line loss** is distinct from voltage drop. Line loss is the **power** loss (in watts) due to the resistance of the conductors: $P = I^2 R$.