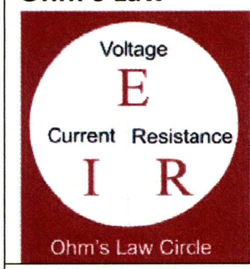
| CMGT 235 – Electrical and Mechanical Systems | | |
|---|---|---|
| Discussion No. 19 | Unit 3 - Electrical Systems | Fall 2021 |

## Electrical Fundamentals

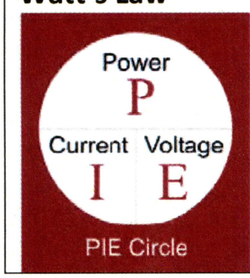
### Electrical Quantities

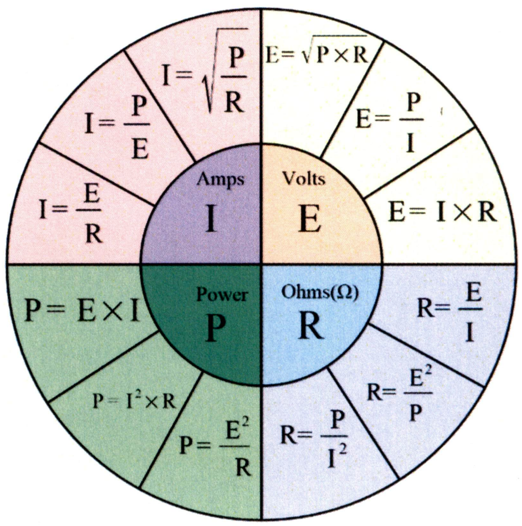
| Quantity | Symbol | Unit of Measure | Unit Abbreviation |
|---|---|---|---|
| Current | I | Amp | A |
| Voltage | V or E | Volt | V |
| Resistance | R | Ohm | Ω |
| Power | P | Watt | W or kW |

### Ohm's Law




### Watt's Law




<u>Definition of an Ohm</u>

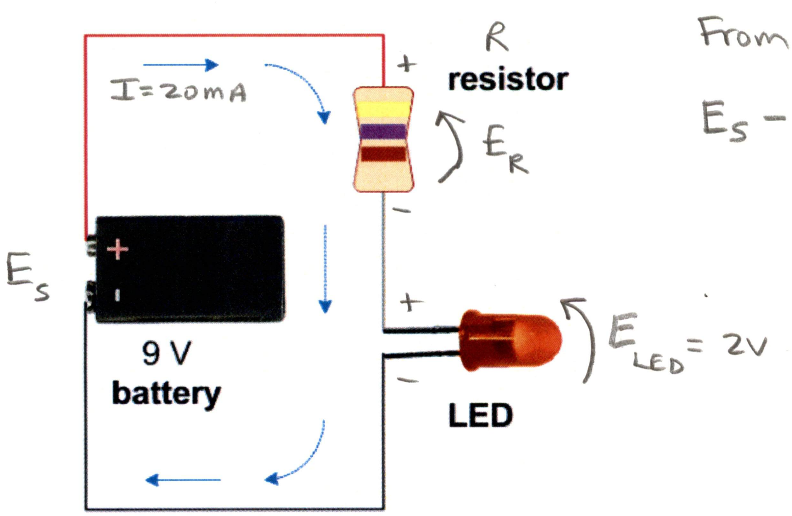
An ohm is a unit of electrical resistance seen between two points across a resistor, conductor, device or circuit. One ohm means that a potential difference (voltage) of 1V between these two points produces a current of 1A.

<u>Electric Power</u>

Electric power is the rate, per unit time, at which electrical energy is transferred by an electric circuit. The SI unit of power is the watt, one joule per second.

**Example 1.**

If a single Red LED is connected to a 9V battery and has a voltage drop of 2V and is rated for a 20mA current, how much resistance must be added to the circuit to operate the LED at its specifications?




From Kirchoff's Voltage Law $[\Sigma V_{Loop}=0]$

$E_S - E_R - E_{LED} = 0$

$E_R = 9V - 2V = 7V$

$R = \frac{E}{I} = \frac{7V}{20mA} = \frac{7V}{0.02A} = 350\,\Omega$

milli $= 10^{-3}$

20 mA = 0.02 A

**Example 2.**

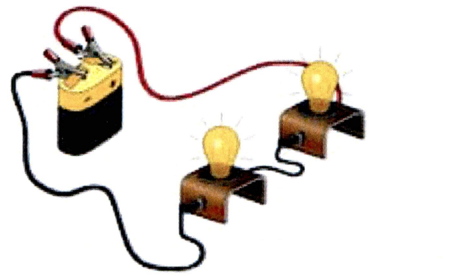
For the circuit shown each bulb is 75W and the source voltage is 120V.

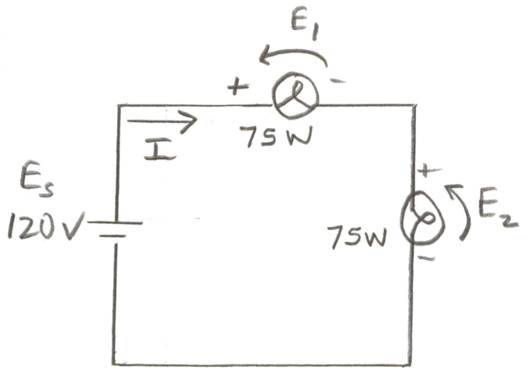
A. What type of circuit is this? Series Circuit

B. Sketch the circuit diagram.

C. Determine the total current and the voltage drop across each lamp.

D. Determine the Resistance of each of each lamp and the total Resistance.

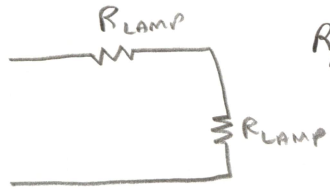





$$I = \frac{P}{E} = \frac{75W + 75W}{120V} = \frac{150W}{120V} = 1.25\ A$$

$$E_1 = \frac{P}{I} = \frac{75W}{1.25A} = 60V$$

$$E_2 = \frac{75W}{1.25A} = 60V \quad \text{or} \quad E_2 = E_S - E_1 = 120 - 60 = 60V \quad (\Sigma V_{LOOP} = 0)$$




$$R_{LAMP} = \frac{E}{I} = \frac{60V}{1.25A} = 48\Omega \text{ (each Lamp)}$$

$$R_{Total} = 48\Omega + 48\Omega = 96\Omega$$

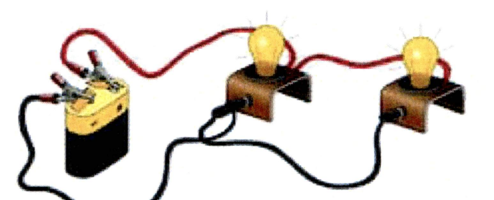
For the circuit shown each bulb is 75W and the source voltage is 120V.

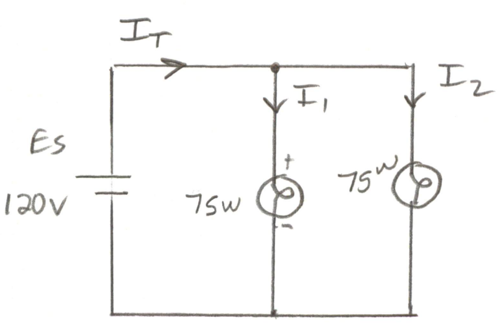
A. What type of circuit is this? Parallel Circuit

B. Sketch the circuit diagram.

C. Determine the current in each lamp and the total current.

D. Determine the Resistance of each of each lamp and the total Resistance.



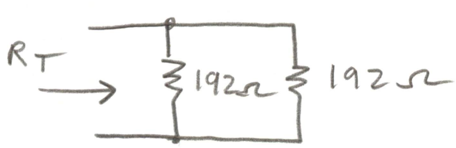



$$I_1 = \frac{P}{E} = \frac{75W}{120V} = 0.625\ A$$

$$I_2 = \frac{P}{E} = \frac{75W}{120V} = 0.625\ A$$

$$I_T = I_1 + I_2 = 0.625A + 0.625A = 1.25\ A$$

$$R_{LAMP} = \frac{E}{I} = \frac{120V}{0.625A} = 192\Omega \text{ (each lamp)}$$




$$R_T = \frac{1}{\frac{1}{192} + \frac{1}{192}} = \frac{192(192)}{192+192} = 96\Omega$$

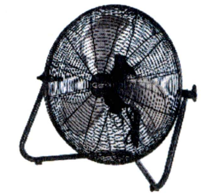
***Which circuit dissipates the most heat?*** SAME. They both use the same amount of Power.

## Electric Power

Electricity is useful because it changes easily into other forms of energy.

The elements in a toaster changes electrical energy into ___Heat___ energy.

An electric mixer changes electrical energy into ___Mechanical___ energy.



An electric fan transforms electrical energy into ___Kinetic___ energy.

**Can you think of another form of energy electricity is commonly changed into?** Light

### Convenience Receptacles

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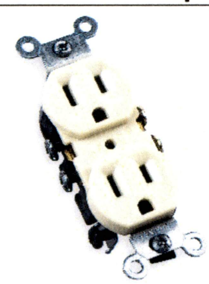
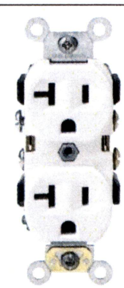
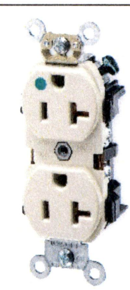
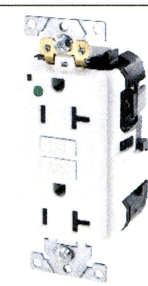
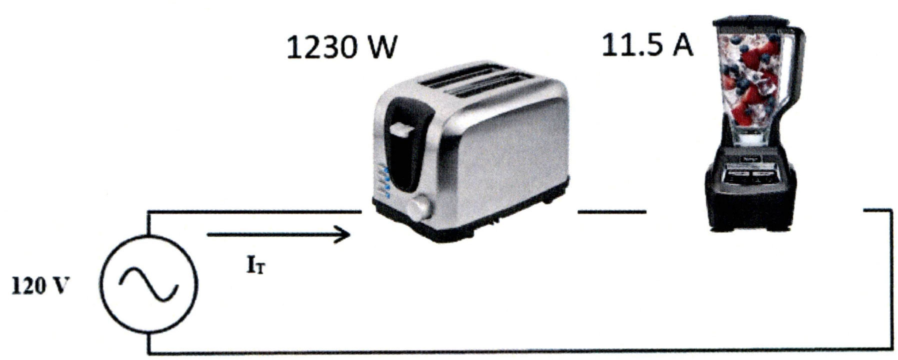
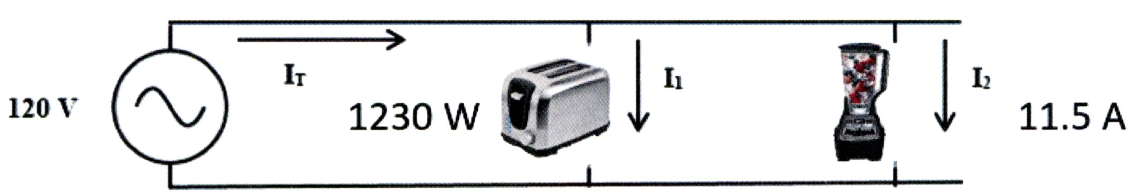
|  |  |  |  |
| 15A, 125V<br>Residential | 20A, 125V<br>Commercial | 20A, 125V<br>Hospital | 20A, 125V, GFCI<br>NEMA 5-20R |

### How are receptacles wired?

***Series Circuit?***




***Parallel Circuit?***




What is the current in the toaster? $I = \frac{P}{E} = \frac{1230W}{120V} = 10.25\ A$

What is the power of the blender? $P = I \times E = 11.5A \times 120V = 1380\ W$

**What is a UL Approved Label?**

Many products must be permanently marked or labeled with specific safety-related information such as hazards, warnings, cautions, installation instructions and electrical ratings.

**Where are UL Labels Typically Found?**

UL labels are typically used in electronic applications, including household appliances and other consumer goods. Other industries that use UL labels include medical, industrial, and outdoor applications. Labels are often referred to as a nameplate.

<table>
<tr><th>How much current?</th><th>How much power?</th></tr>
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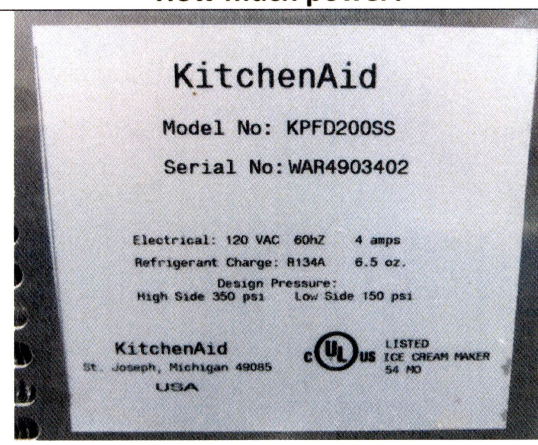

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<tr><td>

$I = \frac{P}{E} = \frac{900W}{120V} = 7.5A$

</td><td>

$P = I \times E = 4A \times 120V = 480W$

**What is the HP of the motor?**

$HP = 480W \times 0.001341 \frac{HP}{W} = 0.64\ HP$

$(< 1 HP)$

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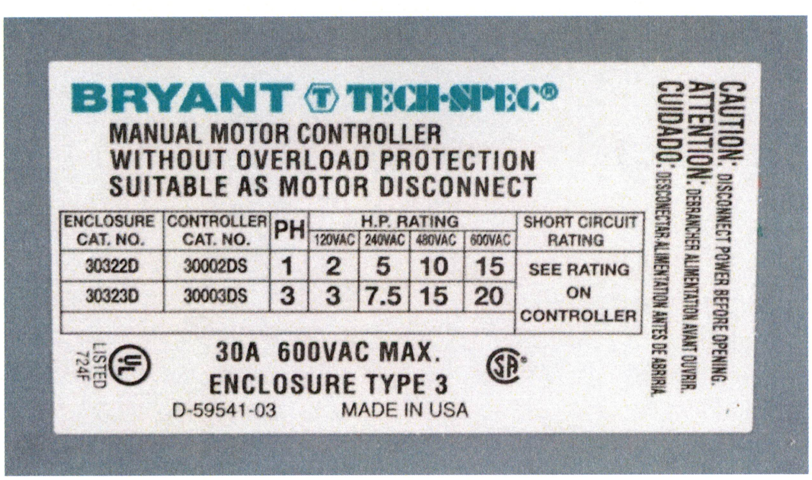
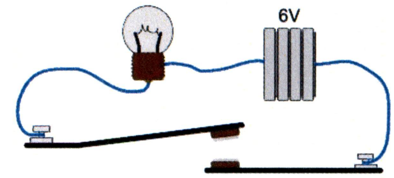


**Direct Current (DC)**

Direct current (DC) is the constant flow of electricity through a conductor in one direction. A dry-cell battery connected to a light bulb is an example of a simple dc circuit.

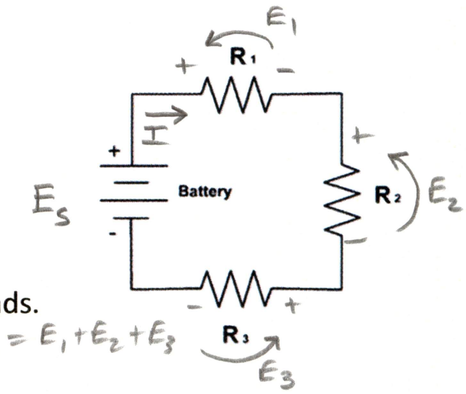



**Four rules apply to DC series circuits:**

(1) The total voltage is the sum of the voltages across each load.
(2) The current is the same in all parts of the circuit.
(3) The total resistance is the sum of the individual load resistances.

$$R_{total} = R_1 + R_2 + R_3 \ldots\ldots$$

(4) The total power is the sum of the powers used by the individual loads.

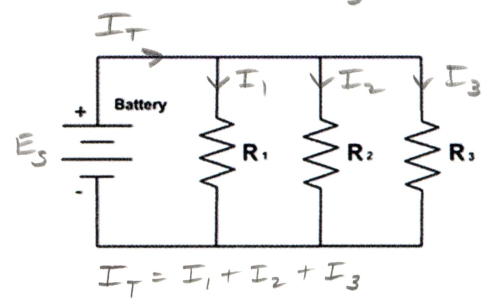



**The rules for DC parallel circuits are:**

(1) The voltage across each load is the same.
(2) The total current is the sum of the currents in each load.
(3) The total resistance is always lower than the smallest load resistance. The formula for calculating total resistance (RT) is:

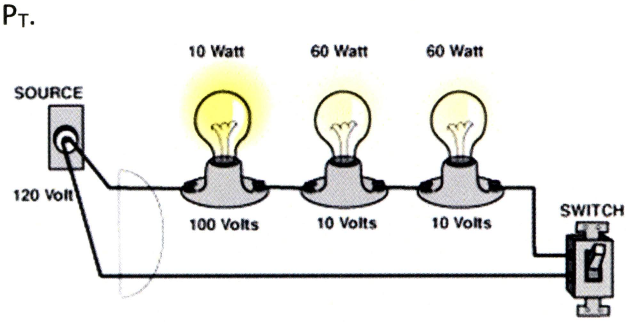
$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots\ldots$$

(4) The total power is the sum of the powers used by the individual loads.




**Example 3.**

For the series circuit shown determine $I_T$, $R_T$, and $P_T$.




$P_T = 10W + 60W + 60W = 130W$

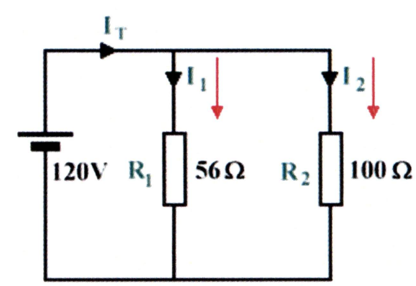
$I_T = \frac{P_T}{E_S} = \frac{130W}{120V} = 1.083\ A$

$R_T = \frac{E_T}{I_T} = \frac{120V}{1.083A} = 110.8\ \Omega$

Check,

$I_T = \frac{E_T}{R_T} = \frac{120V}{110.8\Omega} = 1.083\ A$ ✓

For the parallel circuit shown determine $R_T$, $I_1$, $I_2$, $I_T$ and $P_T$.




$I_1 = \frac{120V}{56\Omega} = 2.1\ A$

$I_2 = \frac{120V}{100\Omega} = 1.2\ A$

$I_T = I_1 + I_2 = 2.1A + 1.2A = 3.3A$

$R_T = \frac{120V}{3.3A} = 36\ \Omega$

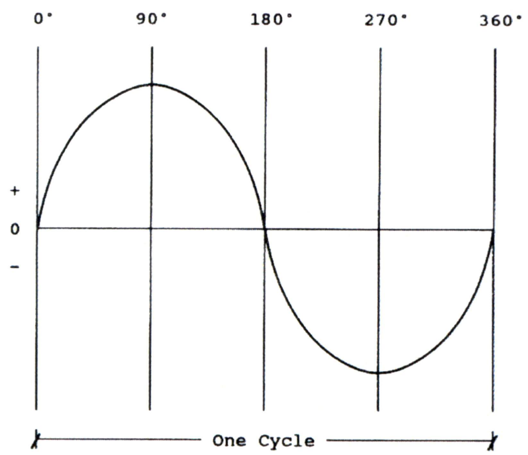
or $R_T = \frac{56(100)}{56+100} = 36\ \Omega$

## Alternating Current (AC)

Alternating current (AC) is the flow of electric charge that periodically reverses direction. If the source varies periodically, particularly sinusoidally, the circuit is known as an alternating current circuit.

Examples include the commercial and residential power supplied by the electric power grid.

### Single-Phase AC



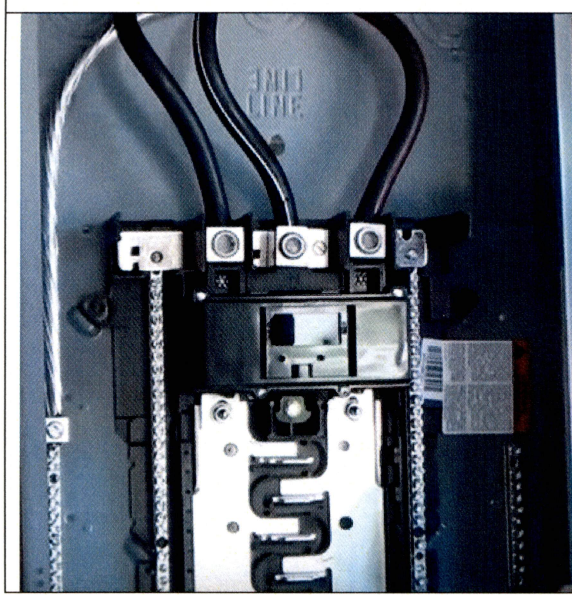

Single-phase ac

Throughout North America, homes are powered by 120-volt single-phase electricity.

At what frequency? 60 Hz U.S.

At that frequency, the alternating current sine wave crosses the zero point 120 times each second.

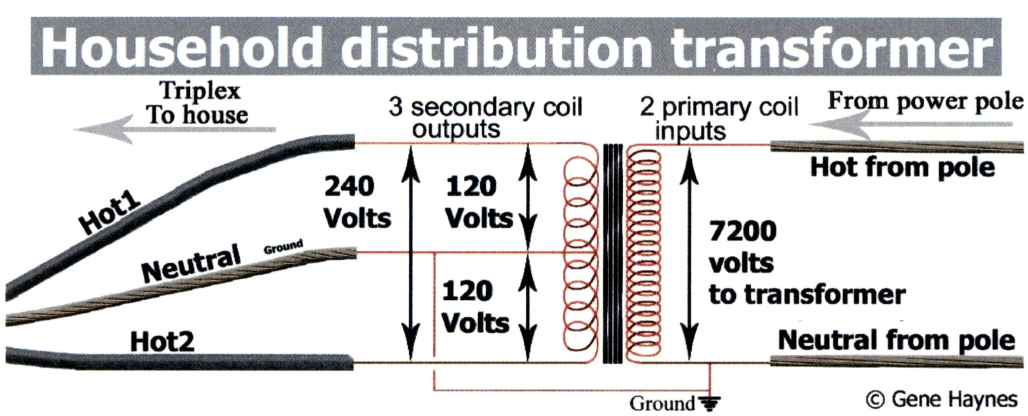
When either voltage or current crosses the zero point, the electrical power being delivered falls to zero. Does that matter to electronic equipment? Yes. Motors



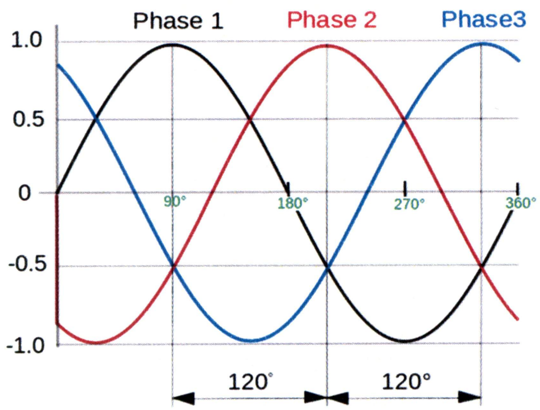
A typical residential circuit breaker box reveals four wires coming into our homes main panel: two "hot" wires, a neutral wire and ground.

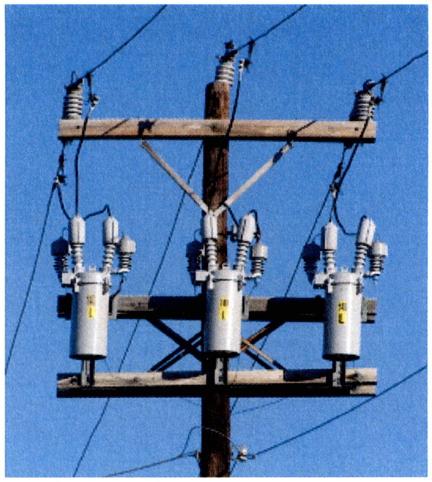
For the panel shown which conductor is the neutral? Black w/ white stripe

The two "hot" wires carry 240 VAC, which is used for heavy appliances like electric ranges and dryers. The voltage between both hot wire and the neutral wire is 120 VAC, which powers everything else in our homes.



### Three-Phase AC

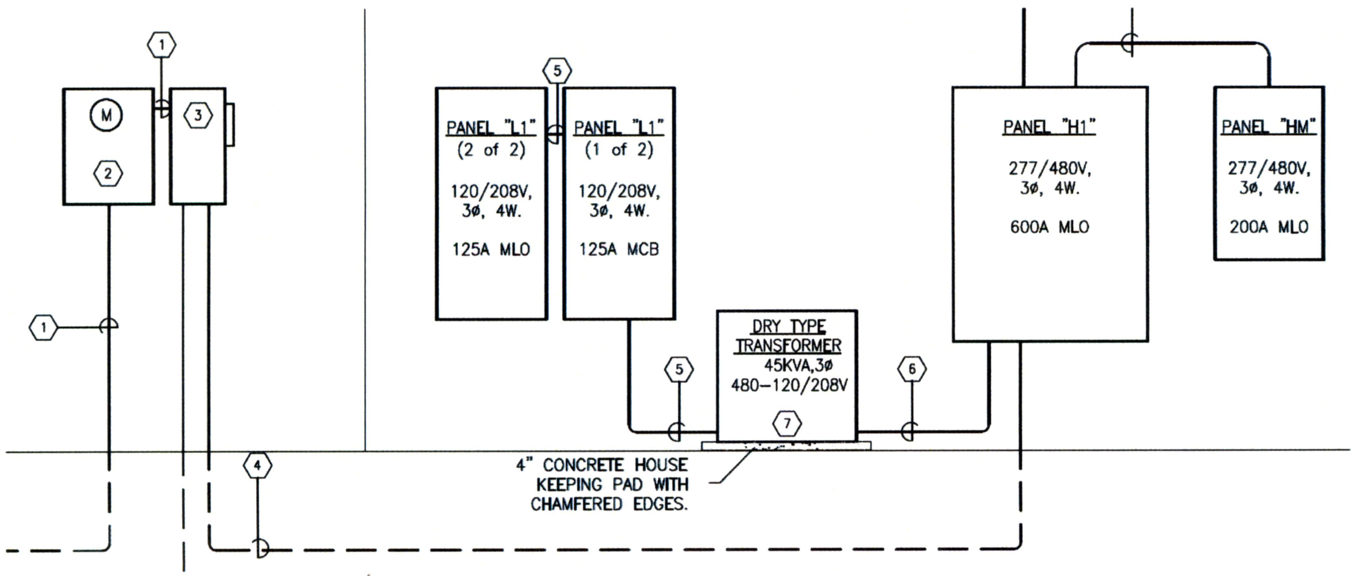


- Three-phase power consists of three sine waves separated by 120 degrees that overlap.
- This form of power is created by an AC generator with three independent windings, each exactly 120 degrees apart. Each current (phase) is carried on a separate conductor.
- Due to the phase relationship, neither voltage nor current flow applied to a load ever drops to zero.
  - This means three-phase power at a given voltage can deliver more power. In fact, about 1.7 times the power of a single-phase supply ($\sqrt{3} = 1.732$).
- Three-phase allows for smaller, less expensive wiring and lower voltages, making it safer and less expensive to run.

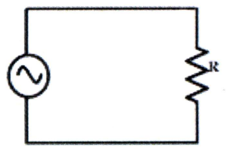
### Why do Commercial Buildings Use Three-Phase Power?

- Used to power large motors and other heavy loads.
- Motors perform better running on three-phase power.
- It is more efficient for larger loads, less costly to install, and the industry norm for medium to large sized facilities.
- Purchasing power at 13.8KV from the local utility is less costly. The owner will provide and maintain their own step-down transformer, which lowers the voltage to a more usable level (in the US, 480/277 volts). This transformer can be mounted on a pad outside the building or in a transformer room inside the building.

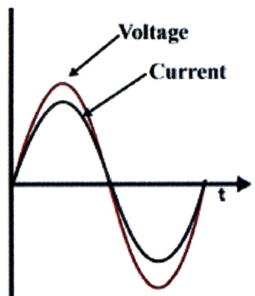


## Types of Loads

### Purely Resistive Load

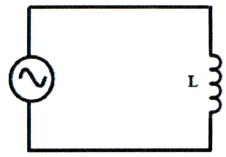



- Resistance is a measure of the opposition to current flow in an electrical circuit.
- Voltage and current sine waves are in-phase when they peak and cross the zero axis at the same time. This occurs when the AC circuit is purely resistive.

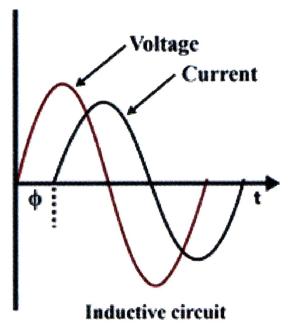



**Resistive circuit**
**ϕ = 0, Unity Power factor**

### Purely Inductive Load

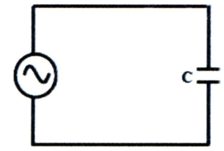



- Inductive reactance is associated with the magnetic field that surrounds a wire or a coil carrying a current.
- The current lags voltage by $90^0$. This is because an inductor does not allow a sudden change in current.

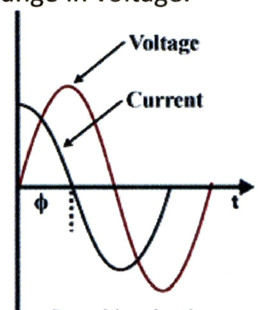



**Inductive circuit**
**Lagging Power factor**

### Purely Capacitive Load




- Capacitive reactance is associated with the changing electric field between two conducting surfaces (plates) separated from each other by an insulating medium.
- The current leads voltage by $90^0$. This is because a capacitor does not allow a sudden change in voltage.



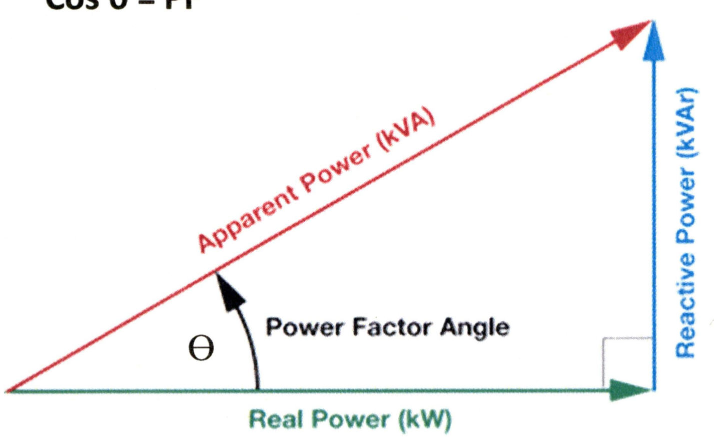

**Capacitive circuit**
**Leading Power factor**

## Power Factor

- Power factor is the ratio of real power (kW) to apparent power (kVA).
- This ratio can be a value from 0 to 1, and it indicates how efficiently an AC circuit is using electricity, with a value of 1 representing high efficiency.
- In AC circuits, inductive components (capacitors, motors, compressors, etc…) increases the reactive power and increases the difference between real and apparent power.
- A greater difference between real and apparent power produces a lower power factor.

$$PF = \frac{\text{Real Power (KW)}}{\text{Apparent Power (kVA)}}$$

$$\cos \theta = PF$$




**kW** is Working Power (also called Actual Power or Active Power or Real Power). It is the power that actually powers the equipment and performs useful work.

**kVAR** is Reactive Power. It is the power that magnetic equipment (transformer, motor, relay etc.) needs to produce the magnetizing flux.

**kVA** is Apparent Power. It is the "vectoral summation" of KVAR and KW.

**Example 4.**

The power bill for a commercial building is 600KWh, 216 hours of usage per month and a power factor of 0.75. Calculate the total Real Power (KW), Reactive Power (KVAR), and the Apparent Power (kVA).

Solution.

$$\text{Real Power (KW)} = \frac{600 \text{ KWh}}{216 \text{ h}} = 2.77 \text{ KW}$$

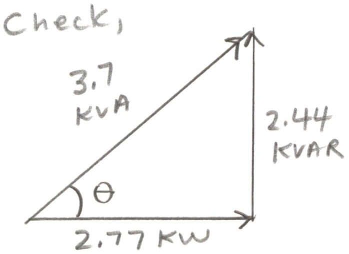
$$\text{Apparent Power (KVA)} = \frac{\text{Real Power (KW)}}{\text{PF}} = \frac{2.77 \text{ KW}}{0.75} = 3.7 \text{ KVA}$$

$$\text{Reactive Power (KVAR)} = \text{KW} \times \text{Tan}\left[\cos^{-1}(\text{PF})\right]$$

$$= 2.77 \text{ KW} \times \text{Tan}\left[\cos^{-1}(0.75)\right]$$

$$= 2.44 \text{ KVAR}$$

Check,




Right Triangle,

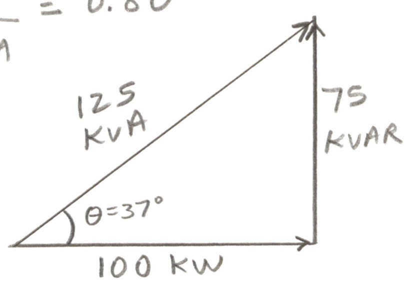
$$A^2 + B^2 = C^2 \qquad \sqrt{2.77^2 + 2.44^2} = 3.7 \text{ KVA} \checkmark$$

**Example 5.**

A boring mill was operating at 100 kW and the apparent power consumed was 125 kVA, what is the power factor? Sketch the power triangle.

Solution.

$$\text{PF} = \frac{\text{KW}}{\text{KVA}} = \frac{100 \text{ KW}}{125 \text{ KVA}} = 0.80$$




$$\text{KVAR} = \sqrt{125^2 - 100^2} = 75 \text{ KVAR}$$

or

$$\theta = \cos^{-1}(0.8) = 37^\circ$$

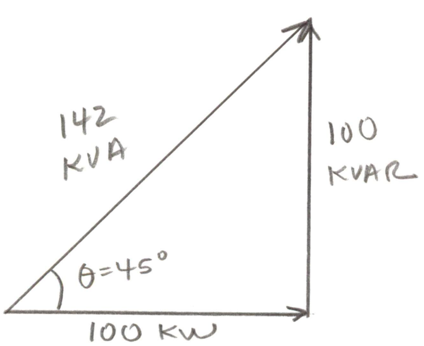
$$\sin 37^\circ = \frac{\text{KVAR}}{125 \text{ KVA}}$$

$$\text{Reactive PWR} = 75 \text{ KVAR}$$

Sketch the power triangles for a PF = 70% and PF = 95%

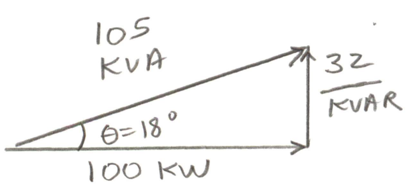
PF = 0.7

$$P_{\text{Apparent}} = \frac{100 \text{ KW}}{0.7} = 142 \text{ KVA}$$



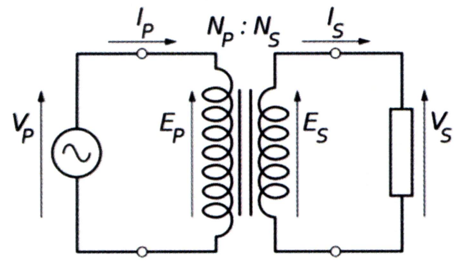

PF = 0.95

$$P_{\text{Apparent}} = \frac{100 \text{ KW}}{0.95} = 105 \text{ KVA}$$



**Transformers**

- Transformers are electrical devices consisting of two or more coils of wire used to transfer electrical energy by means of a changing magnetic field.
- Transformers are capable of either increasing or decreasing the voltage and current levels of their supply, without modifying its frequency, or the amount of electrical power being transferred from one winding to another via the magnetic circuit.

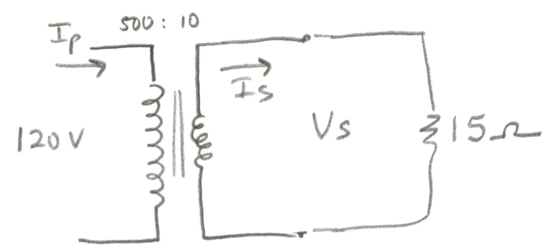



$$\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S}$$

**Example 6.**

A transformer has 500 turns of the primary winding and 10 turns of the secondary winding.

A. Determine the secondary voltage if the secondary circuit is open and the primary voltage is 120 V.
B. Determine the current in the primary and secondary winding, given that the secondary winding is connected to a resistance load 15 Ω?
C. Determine the power of the primary and the power of the secondary.
D. Is this a step-up or step-down transformer?




Solution.

A. $E_S = \frac{N_S}{N_P} \times E_P = \frac{10}{500} \times 120V = 2.4V$

B. $I_S = \frac{E_S}{R_S} = \frac{2.4V}{15\Omega} = 0.16A$

$I_P = \frac{N_S}{N_P} I_S = \frac{10}{500}(0.16A) = 0.0032A$

C. $P_{Primary} = 0.0032A \times 120V = 0.384W$

$P_{Sec} = 0.16A \times 2.4V = 0.384W$

D. Step-Down XFMR