ELECTRICAL CONCEPTS

Turn on bookmarks to navigate this document

PURPOSE OF THIS GUIDE

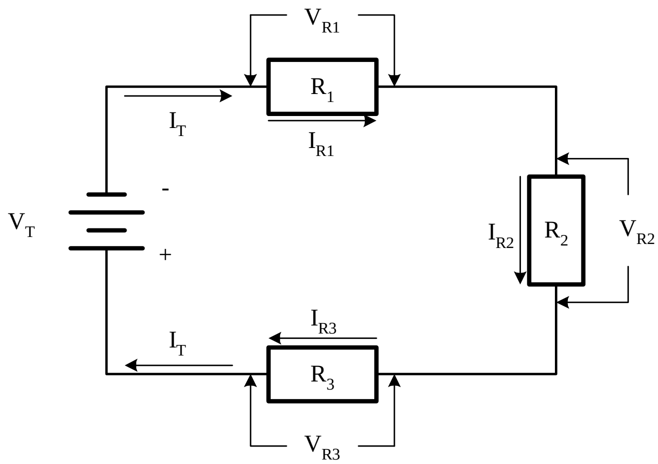
This "Study Guide" is designed to provide a review of basic electrical principles that are commonly used in industry. It includes a review of DC theory, AC theory, three phase circuits, relays and contactors. Some of the other components that are commonly found in basic electrical circuits are addressed as well

Contents

MICHELIN
A BETTER WAY FORWARD

BASIC D.C. CIRCUITS

SERIES CIRCUITS



The above circuit is classified as a **series circuit**. In this circuit there is only **one current path.** This distinguishes the series circuit from the parallel circuit. The battery is the voltage source and is usually referred to as the **applied or total voltage** of the circuit.

IMPORTANT PROPERTIES

A. The amount of current flowing in one part of the circuit is equal to the amount flowing in any other part of the circuit. In other words, the same current flows through R_1, R_2, and R_3.

$$I_T = I_{R1} = I_{R2} = I_{R3}$$

As seen from Ohm's Law, a current flowing through a resistor produces a potential difference across the terminals of the resistor. ($V = I \times R$) This potential difference is called a **Voltage drop**.

B. **Kirchhoff's Voltage Law**

The sum of the voltage drops around a circuit loop must be equal to the applied voltage.

$$V_T = V_{R1} + V_{R2} + V_{R3}$$

OHM'S LAW

$V_T = V_{R1} + V_{R2} + V_{R3}$	(Kirchhoff's Voltage Law for Series Circuits)
$I_T = I_{R1} = I_{R2} = I_{R3}$	(Current common in series circuits)

$V_{R1} = R_1 \bullet I_T$	
$V_{R2} = R_2 \bullet I_T$	(Ohm's Law)
$V_{R3} = R_3 \bullet I_T$	
$V_T = R_T \bullet I_T$	

$R_T \bullet I_T = (R_1 \bullet I_T) + (R_2 \bullet I_T) + (R_3 \bullet I_T)$ (Substitute Ohm's Law into Kirchhoff's Law)

Divide both sides of the equation by I_T

$$\frac{R_T \bullet I_T}{I_T} = \frac{R_1 \bullet I_T}{I_T} + \frac{R_2 \bullet I_T}{I_T} + \frac{R_3 \bullet I_T}{I_T}$$

I_T cancels and the following equation is the result:

RULE FOR SERIES CIRCUITS: **Total resistance for any series resistive circuit is the sum of the individual resistances.**

$$\mathbf{R_T = R_1 + R_2 + R_3}$$

UNIT OF POWER

Power is the rate of doing work, and the unit of electrical power is the watt.

$$Power = Work/Time$$

Power is expressed as VOLTS X AMPS or as an equation. **P = V X I**

Note that: I = V ÷ R and V = I X R (Ohm's Law).

By substituting Ohm's Law into the expression **P = V x I** we get:

$$P = \frac{V^2}{R}$$

$$or\ P = I^2 R$$

Example:

A device is connected across a supply of 230V. There is a current flow of 5 AMPS. What is the power dissipated by the circuit?

P = V x I
P = 230V x 5A = 1150W or 1.15KW

Power for electric motors is sometimes rated in watts or kilowatts, but more usually in Horsepower (hp).

1 hp = 746 watts

Energy and work are essentially the same and are expressed in identical units. Power is different, however, because it is the time rate of doing work. The Kilowatt-hour (KWh) is the practical commercial unit of electrical energy or work performed. If a device, as in the above example, were connected to the supply for a period of ten (10) hours, then 11.5 KWh would be used (1.15 KW x 10 Hrs.).

Work = Power x time

Find the Power P_T:

1. $V_T = 48v$

   $I_T = 2A$

   $P_T =$

2. $R_1 = 10\Omega$

   $I_T = 8A$

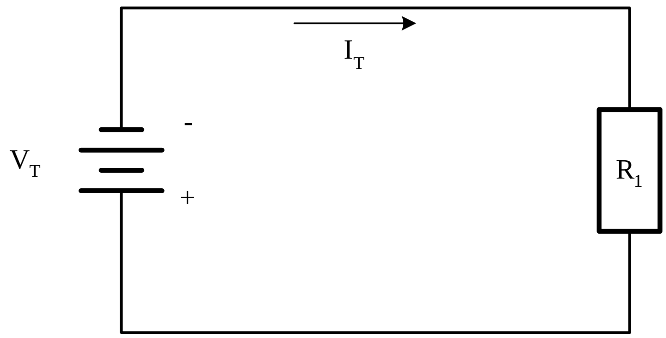
   $P_T =$

3. $V_T = 40v$

   $R_1 = 100\Omega$

   $P_T =$

Find the Power P_T:



1. $V_T = 48v$

   $I_T = 2A$

   $P_T = V_T * I_T$
   $P_T = (48v) * (2A) = 96W$

2. $R_1 = 10\Omega$

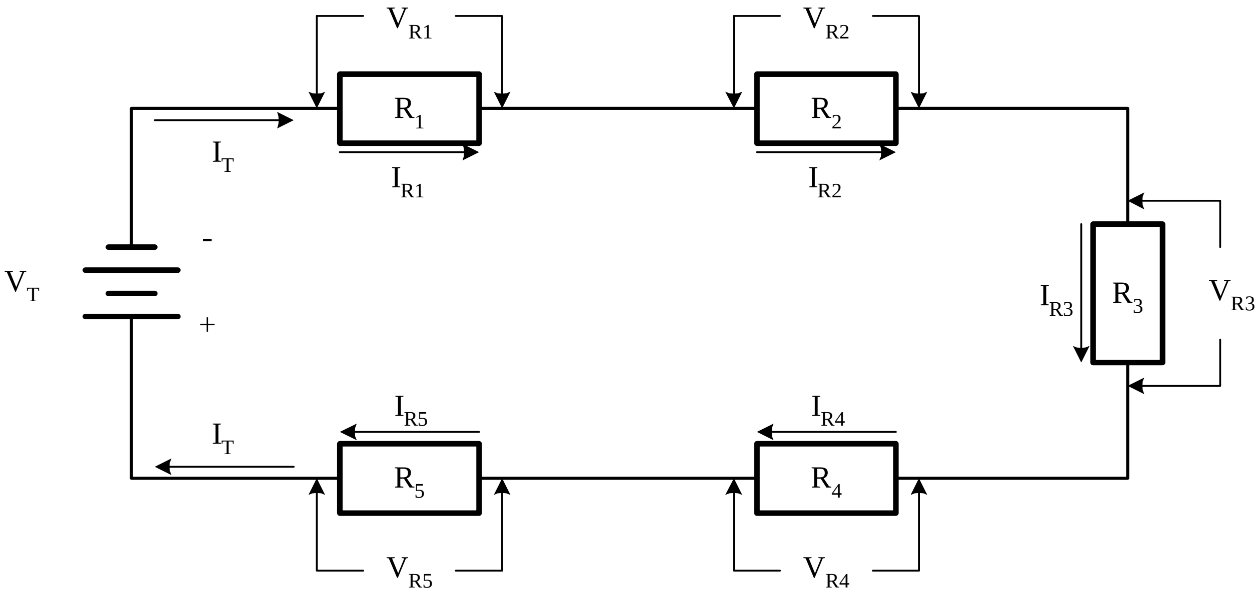
   $I_T = 8A$

   $P_T = I_T^2 * R_T$
   $R_T = R_1$
   $P_T = (8A)^2 * (10\Omega) = 640W$

3. $V_T = 40v$

   $R_1 = 100\Omega$

   $P_T = V^2 / R_T$
   $R_T = R_1$
   $P_T = (40V)^2 / (100\Omega) = 16W$



Given:

$I_T = 60$ A

$R_1 = 5\ \Omega$

$R_2 = 3\ \Omega$

$R_3 = 9\ \Omega$

$R_4 = 5\ \Omega$

$R_5 = 8\ \Omega$

Find: $V_T =$

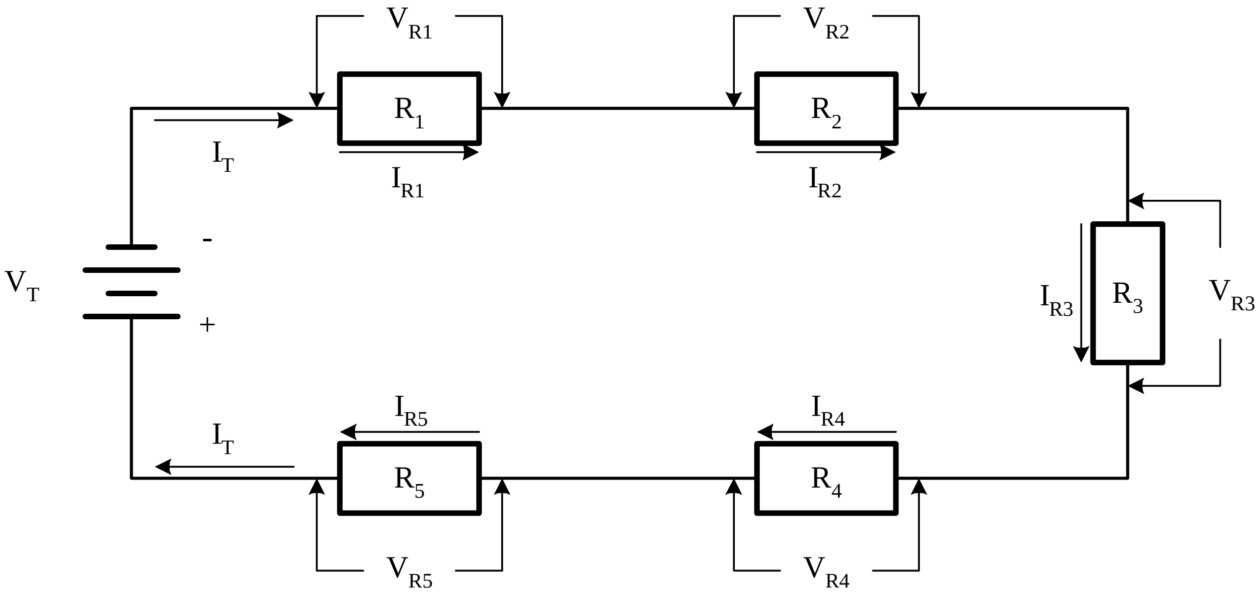
$V_{R1} =$

$V_{R2} =$

$V_{R3} =$

$V_{R4} =$

$P_T =$



Given:

$I_T = 60$ A

$R_1 = 5\ \Omega$

$R_2 = 3\ \Omega$

$R_3 = 9\ \Omega$

$R_4 = 5\ \Omega$

$R_5 = 8\ \Omega$

Find:

$V_T = I_T * R_T$

$R_T = R_1 + R_2 + R_3 + R_4 + R_5$

$R_T = (5\Omega) + (3\Omega) + (9\Omega) + (5\Omega) + (8\Omega) \quad = 30\Omega$

$V_T = (60A) * (30\Omega) \quad = 1800V$

$V_{R1} = I_{R1} * R_1$

$I_{R1} = I_T$

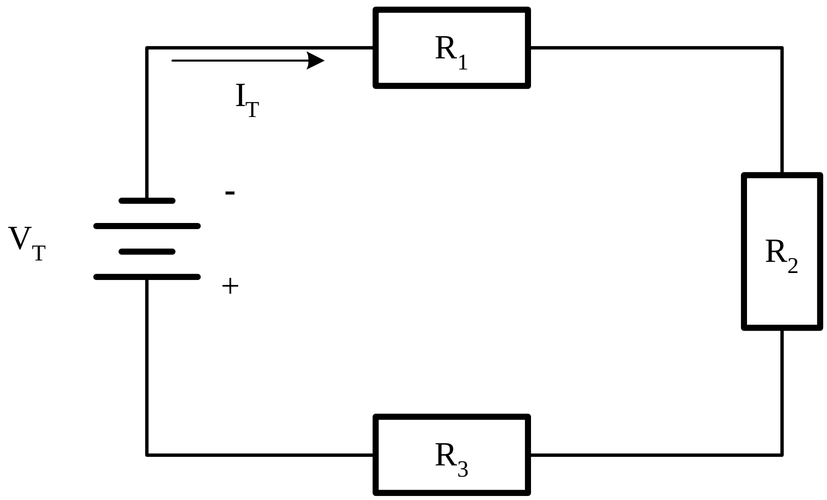
$V_{R1} = (60A) * (5\Omega) = 300V$

$V_{R2} = I_{R2} * R_2$
$I_{R2} = I_T$
$V_{R2} = (60A) * (3\Omega) = 180V$

$V_{R3} = I_{R3} * R_3$
$I_{R3} = I_T$
$V_{R3} = (60A) * (9\Omega) = 540V$

$V_{R4} = I_{R4} * R_1$
$I_{R4} = I_T$
$V_{R4} = (60A) * (5\Omega) = 300V$

$P_T = I_T^2 * R_T \quad = (60A)^2 * (30\Omega) \qquad = 108{,}000W$



Given:

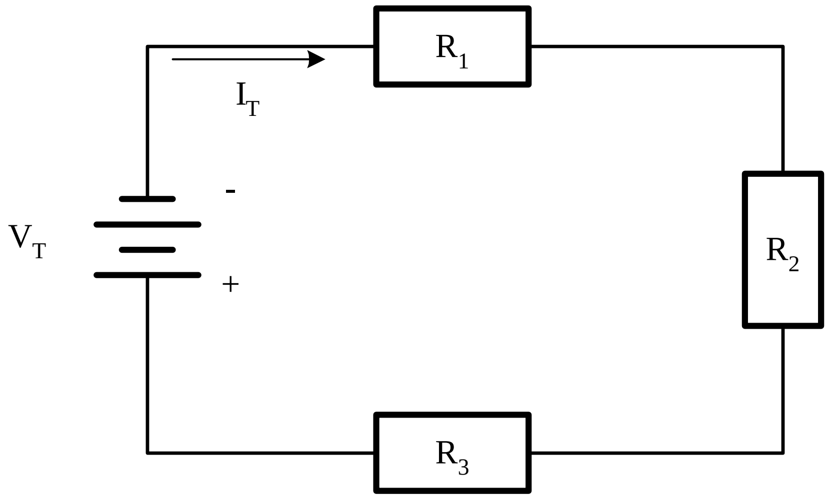
$V_T = 210$ V

$R_1 = 6\ \Omega$

$R_2 = 19\ \Omega$

$R_3 = 5\ \Omega$

Find: $I_T =$



Given:

$V_T = 210\ V$

$R_1 = 6\ \Omega$

$R_2 = 19\ \Omega$

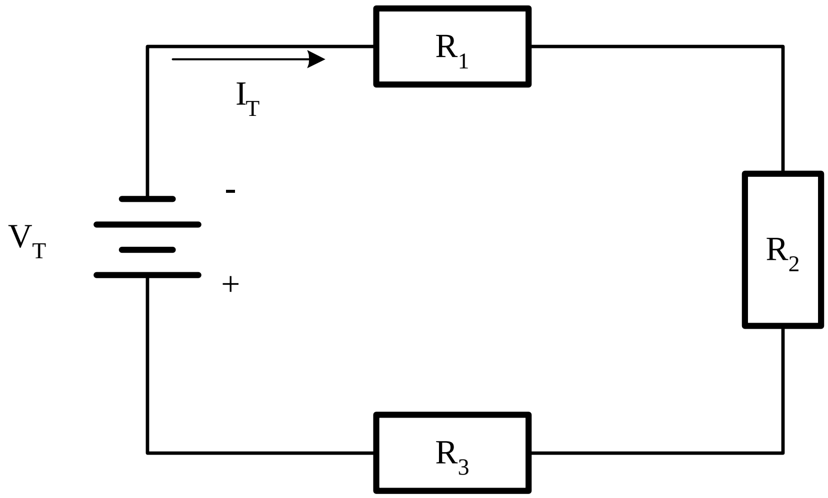
$R_3 = 5\ \Omega$

Find: $I_T = V_T / R_T$

$R_T = R_1 + R_2 + R_3$

$R_T = (6\Omega) + (19\Omega) + (5\Omega) = 30\Omega$

$I_T = V_T / R_T = (210V) / (30\Omega) = 7A$



Given:

$V_T = 250$ V

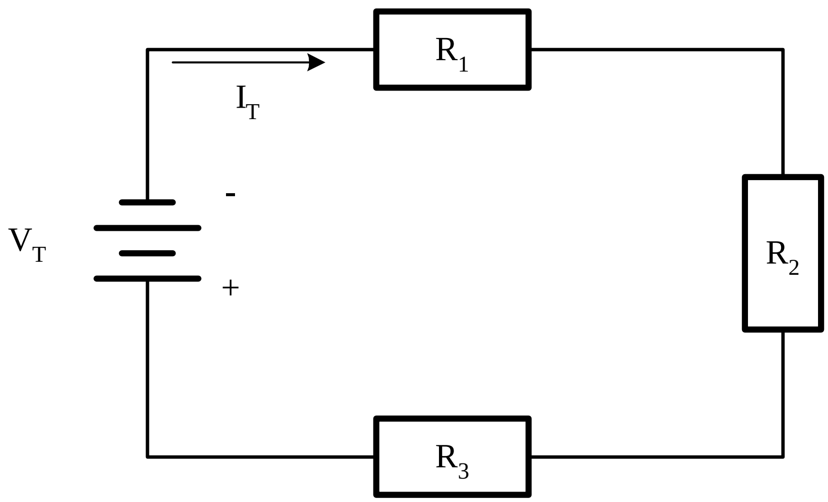
$I_T = 25$ A

$R_1 = 5\ \Omega$

$R_2 = 2.5\ \Omega$

Find: $R_T =$

$R_3 =$



Given:

$V_T = 250$ V

$I_T = 25$ A

$R_1 = 5\ \Omega$

$R_2 = 2.5\ \Omega$

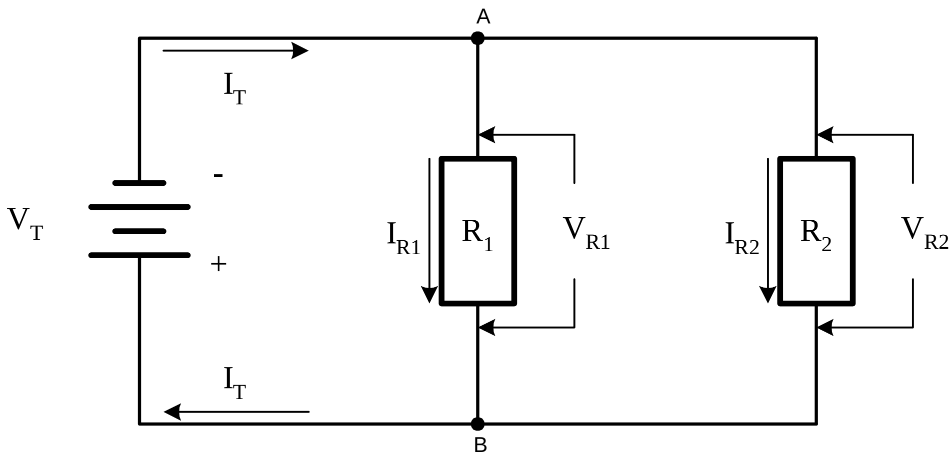
Find: $R_T =$

$R_3 =$

$R_T = V_T / I_T \quad = (250V) / (25A) \quad = 10\Omega$

$R_3 = R_T - (R_1 + R_2) \quad = (10\Omega) - (5\Omega + 2.5\Omega) \quad = 2.5\Omega$

PARALLEL CIRCUITS



The above circuit is classified as a **parallel circuit**. In this circuit a total current (**I_T**) leaves the negative terminal of the battery. When the current reaches the junction labeled (**A**), it splits into two branch currents (**I_{R1}**) and (**I_{R2}**).

When (**I_{R1}**) and (**I_{R2}**) reach the junction labeled **B**, they join back together as **I_T** and continue on to the positive side of the battery. Since no current can be lost, the sum of **I_{R1}** and **I_{R2}** must be equal to **I_T**.

IMPORTANT PROPERTIES

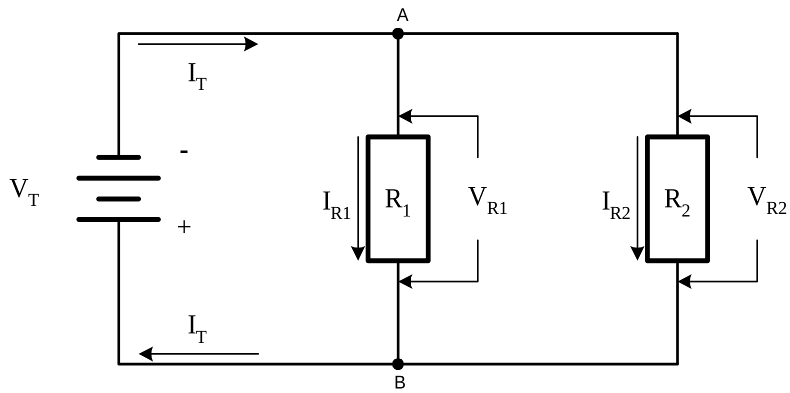
A. The voltage across one branch of a parallel circuit is equal to the voltage across any other parallel branch of the circuit.

$$V_T = V_{R1} = V_{R2}$$

B. **Kirchhoff's Current Law**

The sum of the currents entering a junction must equal the sum of currents leaving the junction.

$$I_T = I_{R1} + I_{R2}$$



When two resistors are connected in parallel, the electrons can move more easily. In a parallel circuit the electrons can move through one branch of the circuit without having to go through the other branch. The total current flowing through a parallel circuit splits up, some going one way and some going the other. The branch currents will add up.

$I_T = I_{R1} + I_{R2}$	(Kirchhoff's Current Law for Parallel Circuits)
$V_T = V_{R1} = V_{R2}$	(Voltage common in parallel circuits)

$I_{R1} = V_T \div R_1$ $I_{R2} = V_T \div R_2$ $I_T = V_T \div R_T$	(Ohm's Law)

(Substitute Ohm's Law into Kirchhoff's Current Law)

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

(Divide both sides of the equation by V_T)

$$\frac{V_T}{R_T} \bullet \left(\frac{1}{V_T}\right) = \left(\frac{V_T}{R_1} + \frac{V_T}{R_2}\right) \bullet \frac{1}{V_T}$$

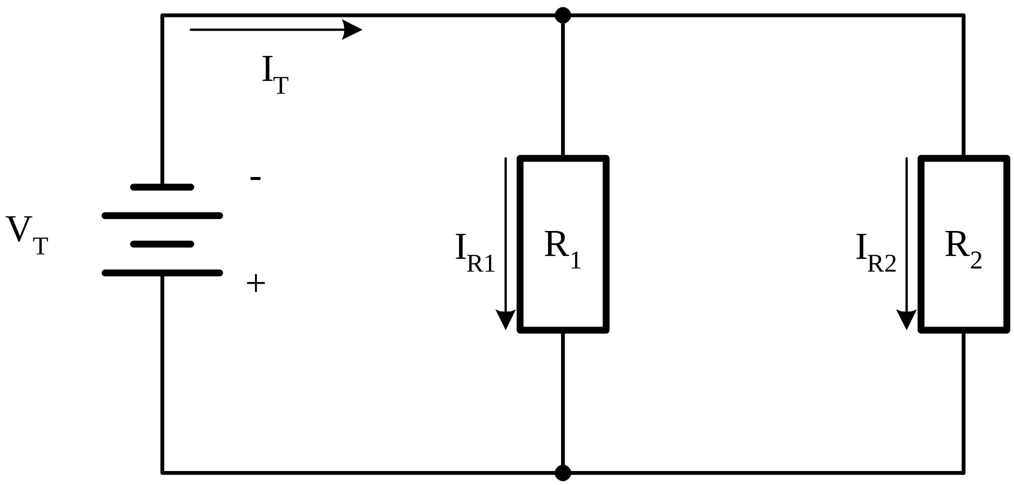
And then,

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

V_T now cancels out and the following equation is the result:

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

Use the reciprocal to get $R_T = 1/(1/R_1 + 1/R_2)$



Given:

$V_T = 120$ V

$R_1 = 15\ \Omega$

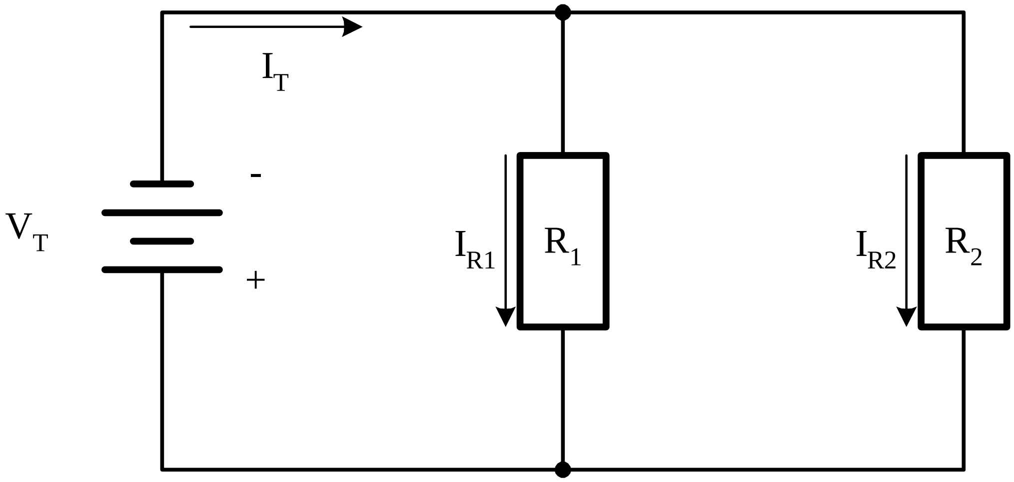
$R_2 = 10\ \Omega$

Find: $R_T =$

$I_T =$

$I_{R1} =$

$I_{R2} =$



Given:

$V_T = 120$ V

$R_1 = 15\ \Omega$

$R_2 = 10\ \Omega$

Find:

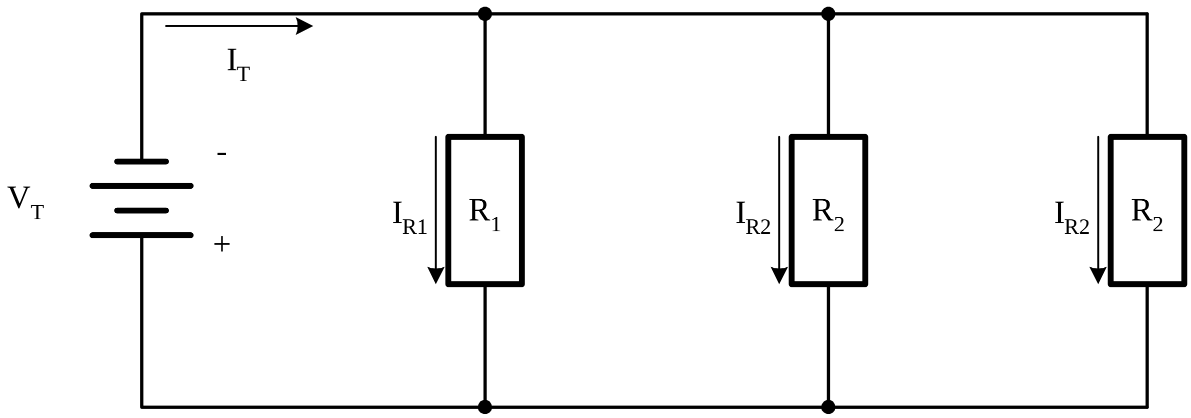
$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$$

$R\_T = \mathbf{1/(1/15\Omega + 1/10\Omega)}$ **= 6** Ω

$I_T = V_T / R_T$ = (120V) / **6** Ω = 20A

$I_{R1} = V_{R1} / R_1$ $V_{R1} = V_T$ I_{R1} = (120V) / (15Ω) = 8A

$I_{R2} = V_{R2} / R_2$ $V_{R2} = V_T$ I_{R2} = (120V) / (10Ω) = 12A



Given:

$I_T = 3\ A$

$R_1 = 12\ \Omega$

$R_2 = 15\ \Omega$

$R_3 = 10\ \Omega$

Find:

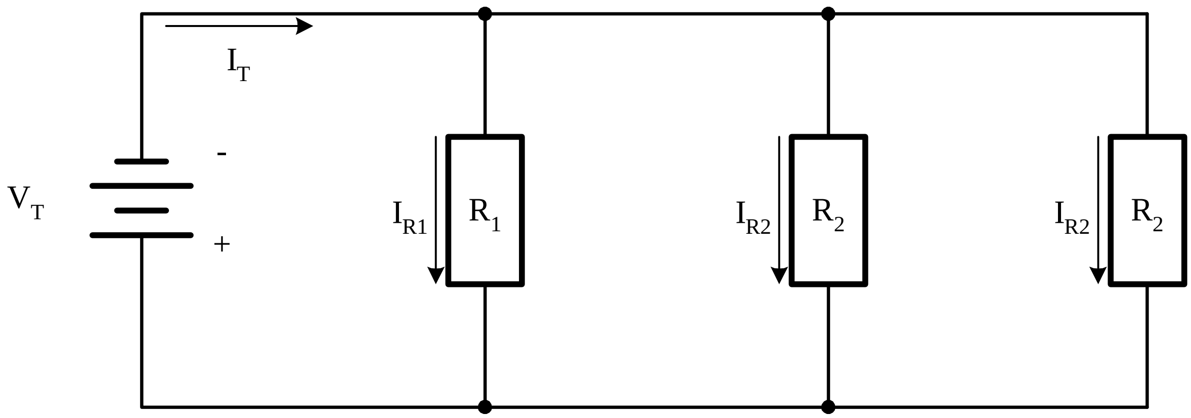
$R_T =$

$V_T =$

$I_{R1} =$

$I_{R2} =$

$I_{R3} =$



Given:

$I_T = 3\ A$

$R_1 = 12\ \Omega$

$R_2 = 15\ \Omega$

$R_3 = 10\ \Omega$

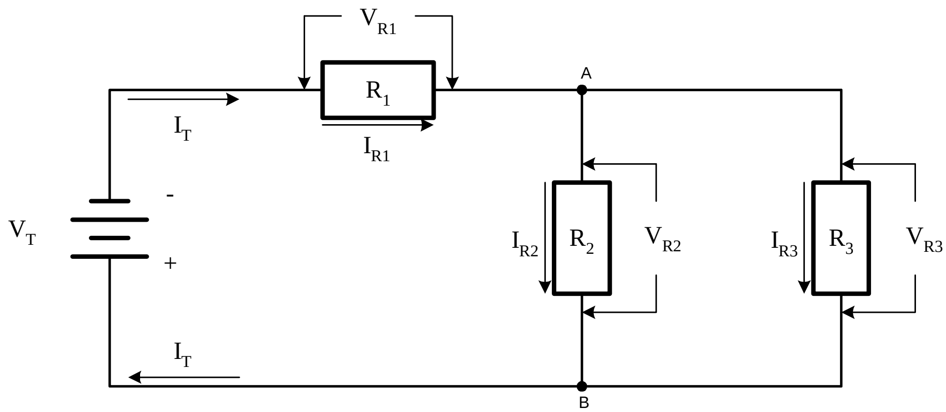
Find: R_T = $R\_T = 1/(1/R\_1 + 1/R\_2 + 1/R\_3) = 1/(1/12\Omega + 1/15\Omega + 1/10\Omega) = 4\ \Omega$

$V_T = I_T * R_T = (3A) * (4\Omega) = 12V$

$I_{R1} = V_{R1} / R_1$
$V_{R1} = V_T = 12V$
$I_{R1} = (12V) / (12\Omega) = 1A$

$I_{R2} = V_{R2} / R_2$
$V_{R2} = V_T = 12V$
$I_{R2} = (12V) / (15\Omega) = 0.8A$

$I_{R3} = V_{R3} / R_3$
$V_{R3} = V_T = 12V$
$I_{R3} = (12V) / (10\Omega) = 1.2A$

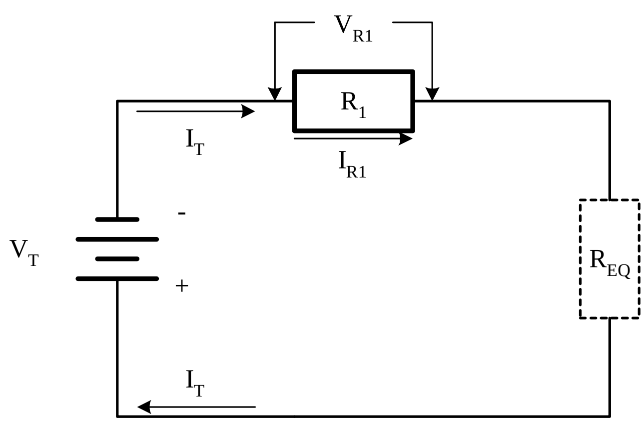


SERIES AND PARALLEL CIRCUITS

If resistors are arranged in both series and parallel in the same circuit, then solving the parallel section first and then the entire circuit is the simplest solution. In the circuit shown, R_2 and R_3 are in parallel and this combination is in series with R_1. We may call the resistance of the parallel section R_{EQ} and find it by the reciprocal method:

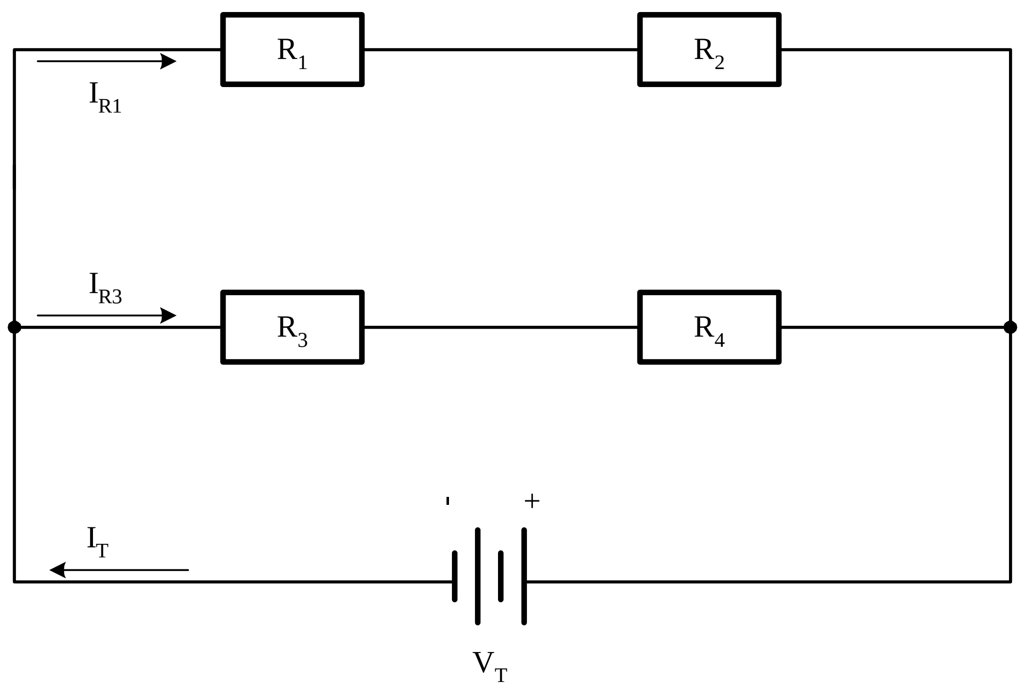
$$R\_EQ = 1/(1/R\_2 + 1/R\_3)$$

We may then redraw the circuit as shown below, where the branch with resistance R_{EQ} has replaced the parallel section R_2 and R_3.



Now the resistance of the entire circuit is simply: $R_T = R_1 + R_{EQ}$.

Note: R_{EQ} = Equivalent resistance for R_2 in parallel with R_3 and is shown as a broken line.



Given:

$V_T = 150$ V

$R_1 = 6\ \Omega$

$R_2 = 4\ \Omega$

$R_3 = 14\ \Omega$

$R_4 = 16\ \Omega$

Find:

$I_T =$

$I_{R1} =$

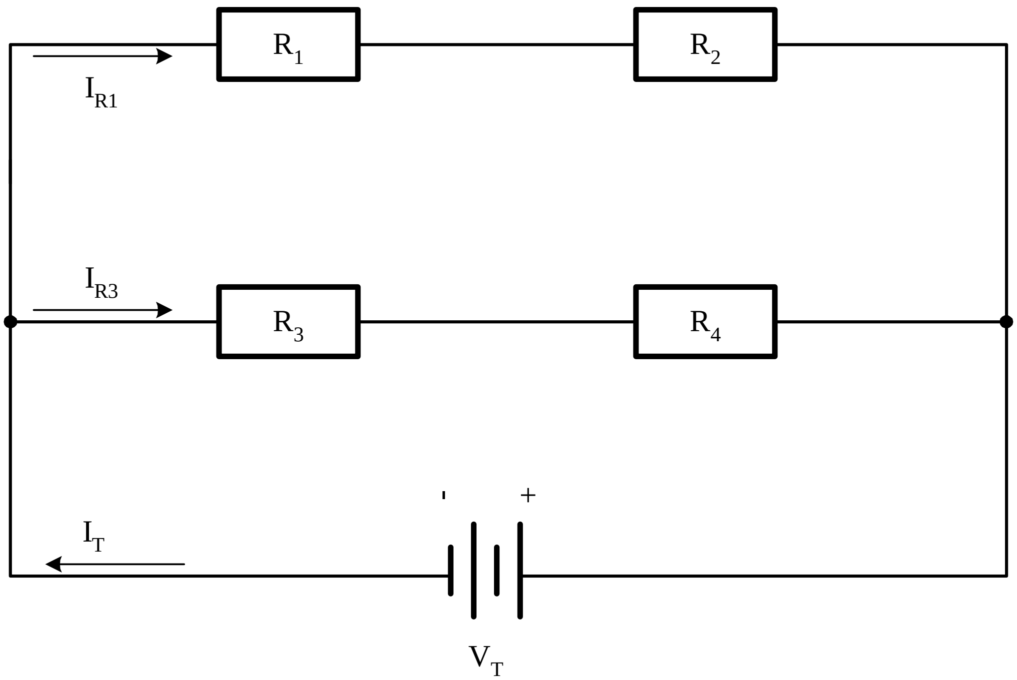
$I_{R3} =$

$V_{R4} =$

$P_{R1} =$

MICHELIN

A BETTER WAY FORWARD



Given:

$V_T = 150\ V$

$R_1 = 6\ \Omega$

$R_2 = 4\ \Omega$

$R_3 = 14\ \Omega$

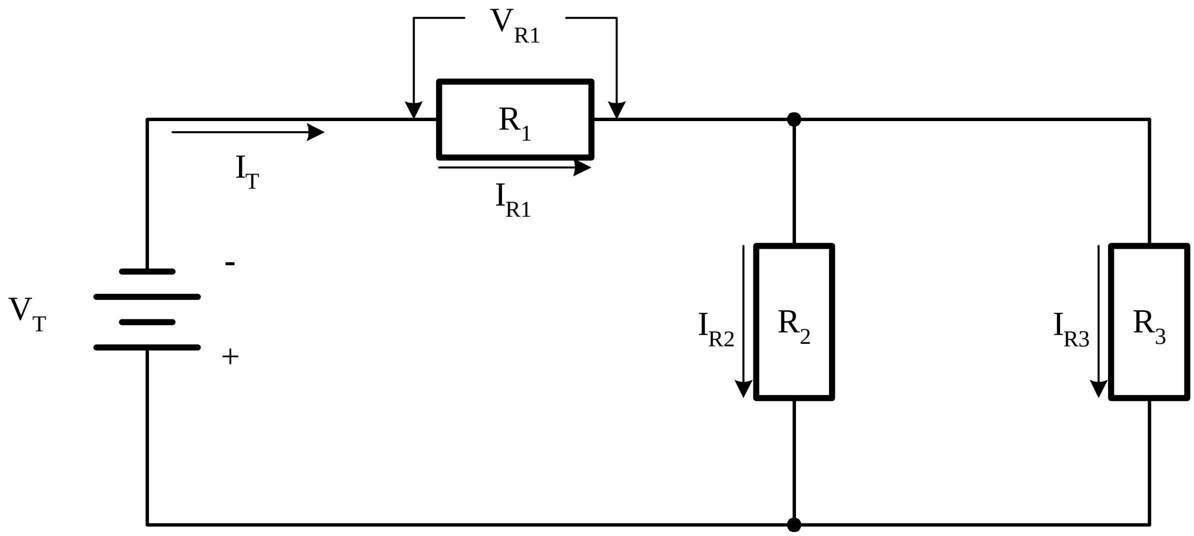
$R_4 = 16\ \Omega$

Find:

$R_{EQ1} = R_1 + R_2$	$= (6\ \Omega) + (4\ \Omega)$	$= 10\ \Omega$
$R_{EQ2} = R_3 + R_4$	$= (14\ \Omega) + (16\ \Omega)$	$= 30\ \Omega$
$I_{R1} = V_T / R_{EQ1}$	$= (150V) / (10\ \Omega)$	$= 15A$
$I_{R3} = V_T / R_{EQ2}$	$= (150V) / (30\ \Omega)$	$= 5A$
$I_T = I_{R1} + I_{R3}$	$= (15A) + (5A)$	$= 20A$

$I_{R4} = I_{R3} = 5A$

$V_{R4} = I_{R4} * R_4$	$= (5A) * (16\ \Omega)$	$= 80V$
$P_{R1} = (I_{R1})^2 * R_1$	$= (15A)^2 * (6\ \Omega)$	$= 1,350W$



Given:

$V_T = 30$ V

$R_1 = 10\ \Omega$

$R_2 = 15\ \Omega$

$R_3 = 20\ \Omega$

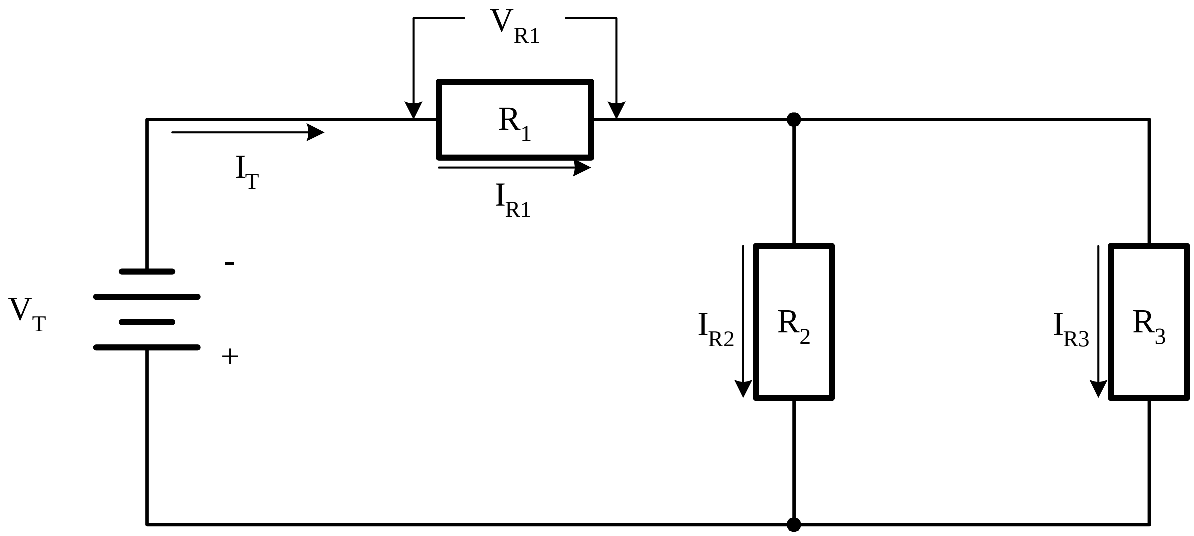
Find:

$R_T =$

$I_T =$

$V_{R1} =$

$I_{R3} =$



Given:

$V_T = 30$ V

$R_1 = 10\ \Omega$

$R_2 = 15\ \Omega$

$R_3 = 20\ \Omega$

Find:

$R_T = R_1 + 1/(1/R2 + 1/R3)$ $= 10\ \Omega + 1/(1/(15\ \Omega) + 1/(20\ \Omega))$ $= 18.57\ \Omega$

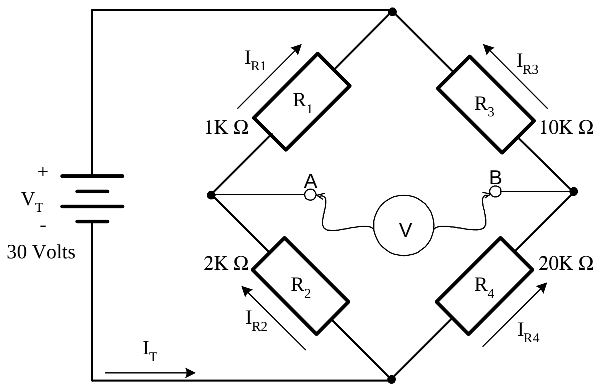
$I_T = V_T / R_T$ $= 30\text{ V} / 18.57\ \Omega$ $= 1.615$ A

$V_{R1} = I_{R1} * R_1$ $= 1.615\text{A} * 10\ \Omega$ $= 16.15$ V

$V_{R3} = V_T - V_{R1}$ $= 30\text{ V} - 16.15\text{V}$ $= 13.85$ V

$I_{R3} = V_{R3} / R_3$ $= 13.85\text{ V} / 20\ \Omega$ $= 0.692$ A

WHEATSTONE BRIDGE CIRCUIT

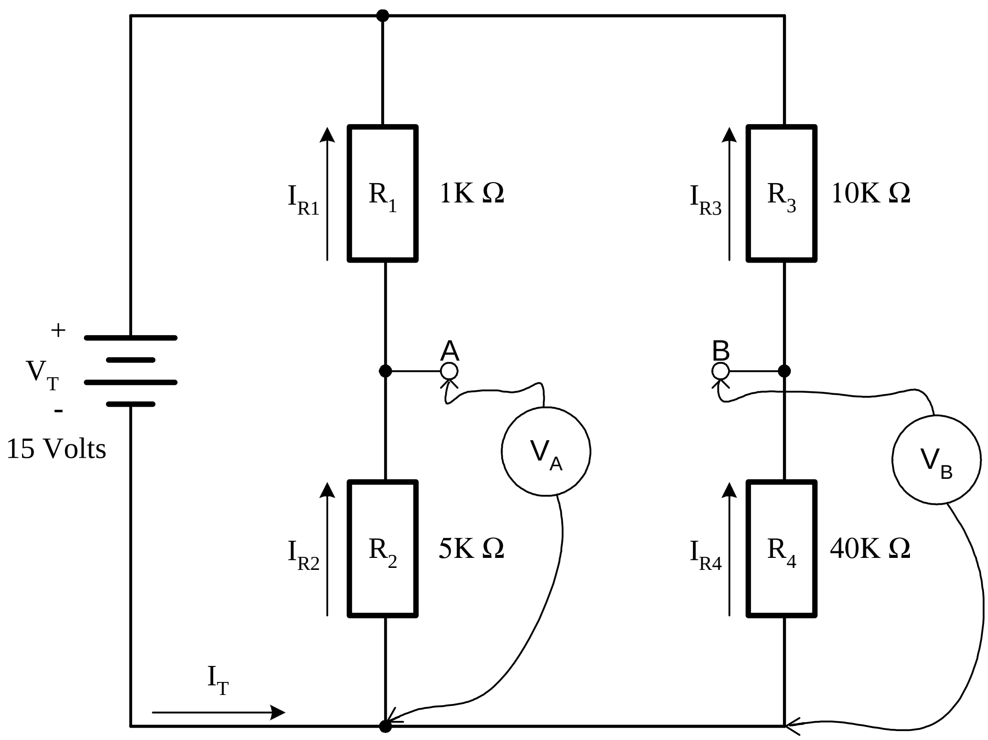


A type of circuit that is widely used for precision measurements of resistance is the Wheatstone bridge. The circuit diagram, as shown above, is the standard drawing configuration. This type circuit can be drawn and evaluated as a basic D.C. combination circuit. Before we redraw and look at some applications of Wheatstone bridges, let's look at the characteristics of this circuit.

A bridge circuit may be either **balanced** or **unbalanced**. A balanced bridge is one where the voltage across terminals A and B will equal zero **($V_{A\ to\ B} = 0$)**. There would be a difference in potential across terminals A and B if the circuit were unbalanced. First, let's evaluate a balanced circuit.

If $V_{A\ to\ B} = 0$ then:

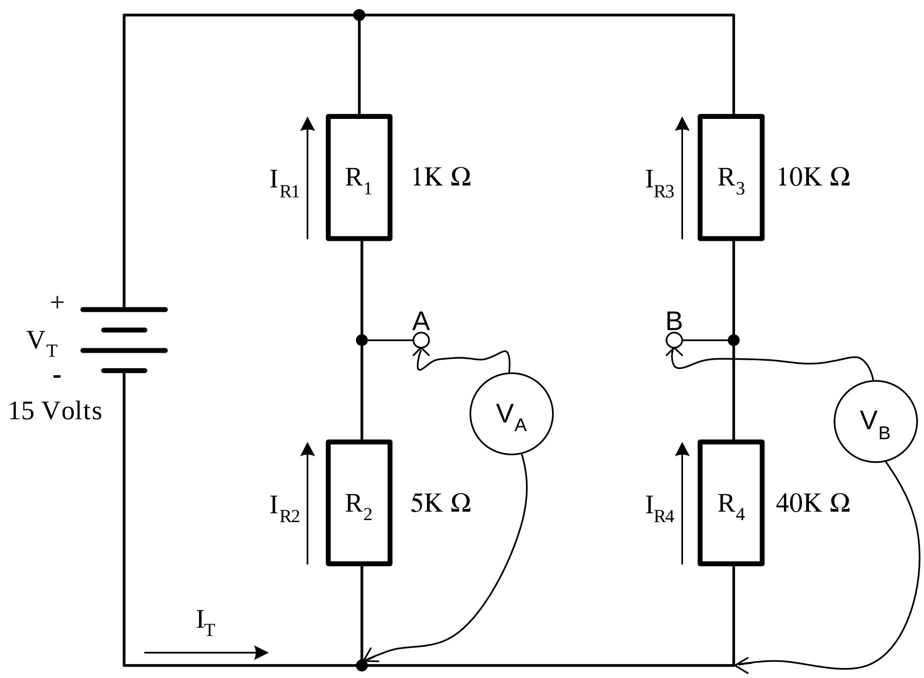
$$I\_R1 = I\_R2 = V\_T/(R\_1 + R\_2) = 30v/3K\Omega = 10mA$$
$$V\_R1 = I\_R1 \times R\_1 = 10mA \times 1K\Omega = 10volts$$
$$V\_R2 = I\_R2 \times R\_2 = 10mA \times 2K\Omega = 20volts$$
$$I\_R3 = I\_R4 = V\_T/(R\_3 + R\_4) = 30v/30K\Omega = 1mA$$
$$V\_R3 = I\_R3 \times R\_3 = 1mA \times 10K\Omega = 10volts$$
$$V\_R4 = I\_R4 \times R\_4 = 1mA \times 20K\Omega = 20volts$$



The calculations from the previous page determined that $\mathbf{V_{R2} = 20}$ **volts** and $\mathbf{V_{R4} = 20}$ **volts**.
Let's measure the voltage at terminal **A** and **B** using the negative side of the battery as a reference
(- lead of meter) and reading the voltage with the (+) positive lead of the meter. Since $\mathbf{V_{R2}} = \mathbf{V_A}$ and $\mathbf{V_{R4}} = \mathbf{V_B}$, we can state that $\mathbf{V_A = +20}$ **volts** and $\mathbf{V_B = +20}$ **volts** There is no potential difference across terminals A and B and therefore $\mathbf{V_{A\ to\ B} = 0}$ **volts**. This bridge circuit is **balanced** and a relationship between the resistances can be written as follows.

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

Note: For this relationship to be true the branch circuits must remain the same.



Now, let's evaluate another circuit to see if it is balanced or unbalanced. For the circuit to be balanced, V_{AB} = 0v as we saw from the previous example. For the circuit to be unbalanced, $V_{AB} \neq$ 0v. Let's use the resistance relationship from the previous example.

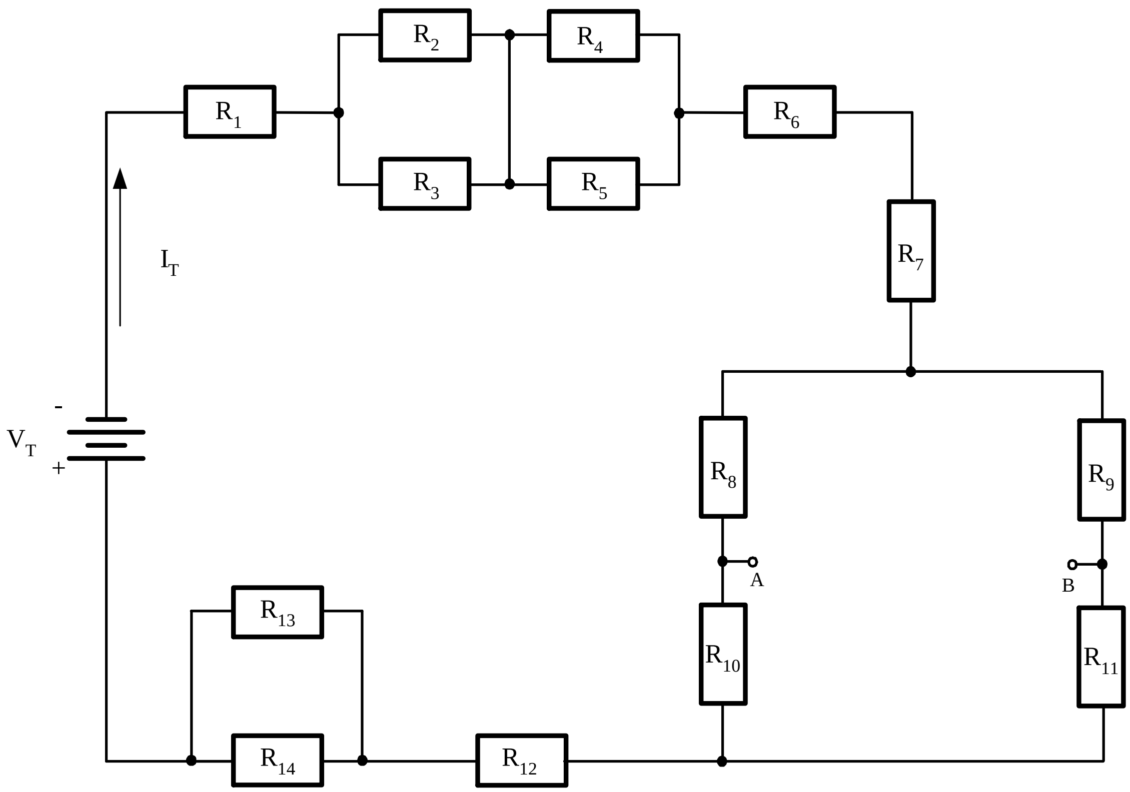
$\frac{R_1}{R_2} = \frac{R_3}{R_4}, \quad \frac{1K\Omega}{5K\Omega} = \frac{10K\Omega}{40K\Omega}, \quad \frac{1}{5} \neq \frac{1}{4}$ The bridge is unbalanced. Now let's find $V_{A\text{ to }B}$.

$$I_{R1} = I_{R2} = V_T/(R_1 + R_2) = 15v/6K\Omega = 2.5mA$$
$$V_{R1} = I_{R1} \times R_1 = 2.5mA \times 1K\Omega = 2.5volts$$
$$V_{R2} = I_{R2} \times R_2 = 2.5mA \times 5K\Omega = 12.5volts$$
$$I_{R3} = I_{R4} = V_T/(R_3 + R_4) = 15v/50K\Omega = 0.3mA$$
$$V_{R3} = I_{R3} \times R_3 = 0.3mA \times 10K\Omega = 3volts$$
$$V_{R4} = I_{R4} \times R_4 = 0.3mA \times 40K\Omega = 12volts$$

Using the negative side of the battery as reference again, measure the voltage:

V_A – 12.5 volts, **V_B = 12 volts,** **$V_{A\text{ to }B}$ = 0.5 volts**

If a voltmeter were connected across terminal **A** and **B**, there would be a potential difference of **0.5 volts** and the bridge is **unbalanced.**



Given:

$V_T = 150$ V

$R_1, R_2, R_3 = 10\Omega$

$R_4 = 7\Omega$

$R_5 = 13\Omega$

$R_6 = 15\Omega$

$R_7 = 3\Omega$

$R_8 = 12\Omega$

$R_9 = 5\Omega$

$R_{10} = 8\Omega$

$R_{11} = 15\Omega$

$R_{12} = 3\Omega$

$R_{13} = 20\Omega$

$R_{14} = 10\Omega$

Find:

$R_T =$

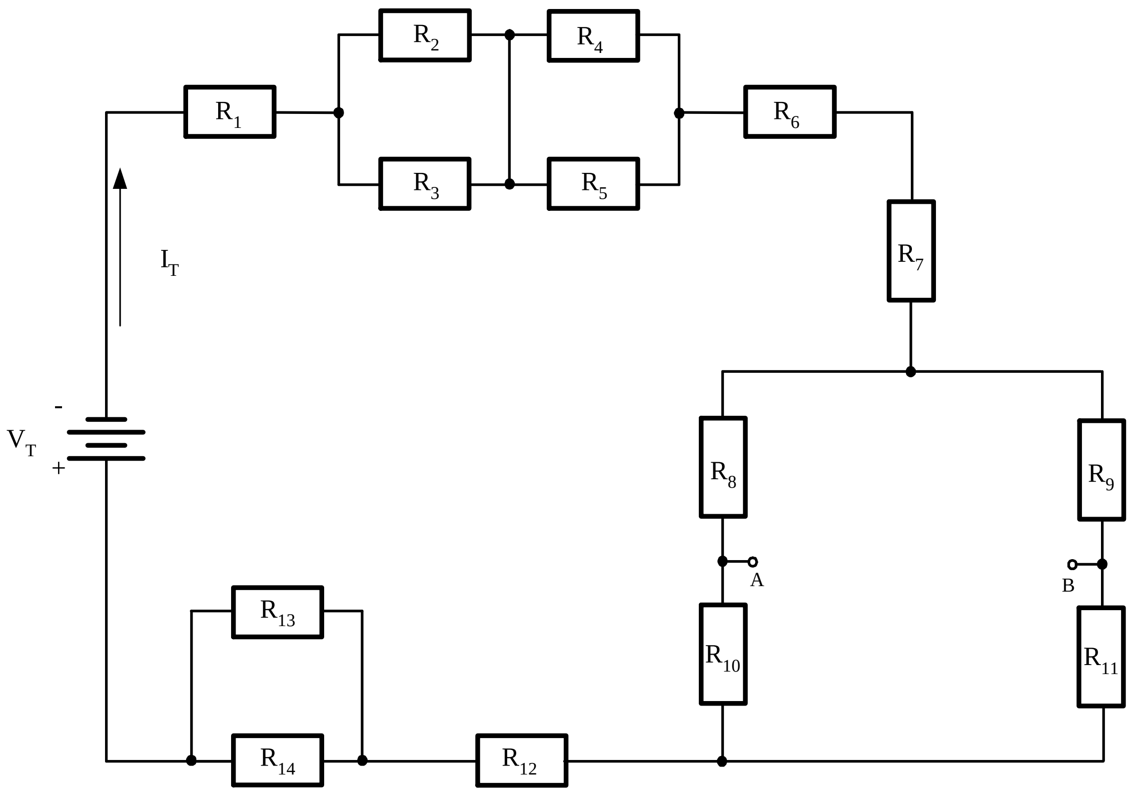
$I_T =$

$I_{R9} =$

$V_{R6} =$

$P_{R12} =$

$V_{A-B} =$



Given:

$V_T = 150$ V

$R_1, R_2, R_3 = 10\Omega$

$R_4 = 7\Omega$

$R_5 = 13\Omega$

$R_6 = 15\Omega$

$R_7 = 3\Omega$

$R_8 = 12\Omega$

$R_9 = 5\Omega$

$R_{10} = 8\Omega$

$R_{11} = 15\Omega$

$R_{12} = 3\Omega$

$R_{13} = 20\Omega$

$R_{14} = 10\Omega$

Find:

$R_T = 57.217\ \Omega$

$I_T = 2.622$ A

$I_{R9} = 1.31$ A

$V_{R6} = 39.324$ A

$P_{R12} = 20.619$ W

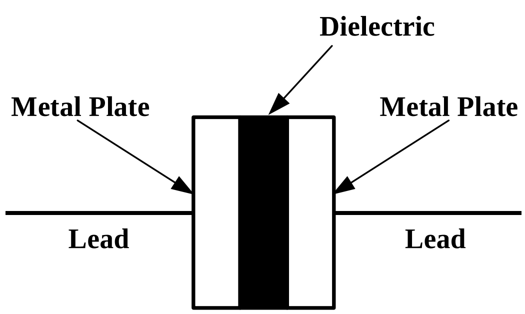
$V_{A\text{-}B} = 9.17$ V

CAPACITANCE IN DC

Introduction

It will be recalled that electrons are loosely held in the rings of each atom of a good conductor such as copper, and only a small force is required to dislodge these electrons. Good conductive materials have an abundance of free electrons in their structure. On the other hand, it is a characteristic of insulating materials to have the electrons firmly held in the rings of each atom of the material, and considerable force is required to remove these electrons. Insulating materials have practically no free electrons in their structure.

If an insulating material, sometimes called a dielectric, is placed between two plates of a good conducting material, an elementary form of a capacitor has been developed.



Elementary Capacitor

The diagram in Fig. 1 represents an elementary capacitor consisting of two metal plates separated from each other by a thickness of dielectric. Under normal conditions with the capacitor de-energized, the electrons in the dielectric revolve around the positive center of each atom in circular orbits.

Capacitance
A capacitor can store electrical energy and also return this energy back into an electric circuit. It is important at this point to understand what the term capacitance actually means. **Capacitance is really the property of a circuit or circuit component which allows it to store electrical energy in electrostatic form.**

Capacitors store energy, but other components also create capacitance effect. For example, the two wires of a circuit separated by air will act as a capacitor, or adjacent turns of a coil winding separated only by the insulation of the wire will have some capacitance effect. The standard unit of measurement for capacitance is the **FARAD** and may be defined as follows:

> A capacitor has a capacitance of one farad when a change of one volt across its plates results in the charge of one coulomb.

The farad is too large of a unit of measure for the typical capacitor. Therefore a smaller unit is used called the microfarad (μF).

Microfarad (μF)	=	10^{-6}
Nanofarad (ηF)	=	10^{-9}
Picofarads (ρF)	=	10^{-12}

The capacitance of a capacitor can be increased by:

1. Increasing the plate area and, therefore, the area of the dielectric under stress.

2. Having the metal plates as close as possible with a resultant decrease in the thickness of its dielectric.

3. Using a dielectric with as high a dielectric constant as practical.

Capacitors in Parallel

An increase in the capacitance can also be obtained by increasing the number of plates, which make up the capacitor. This is the same as increasing the plate area.

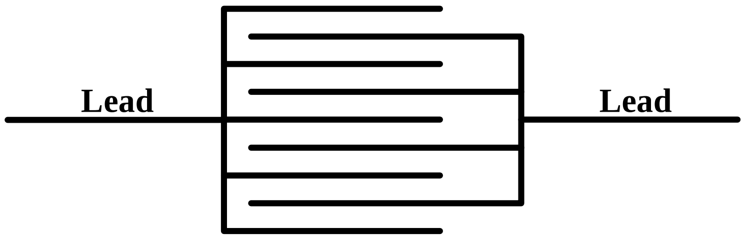


Fig. 6

Fig. 6 shows a multi-plate capacitor with the plates in such a way as to have a maximum in plate area. It will be noted that alternate plates are common or paralleled.

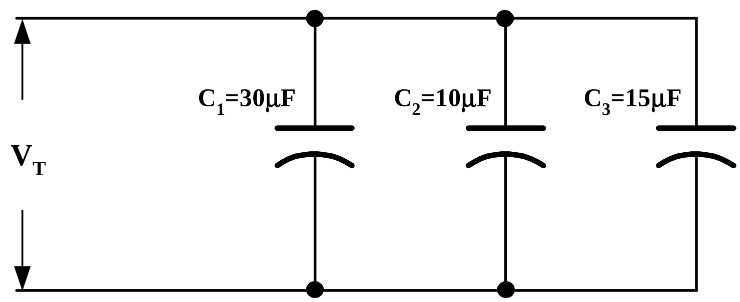


Fig. 7 Capacitors in Parallel

When capacitors are connected in parallel, the effect is the same as increasing the number of plates. This means that the total capacitance is equal to the sum of the capacitance of the individual capacitors. For example, in Fig. 7, three capacitors of 30, 10, and 15 microfarads are connected in parallel across the line voltage, designated as V. The charge on each capacitor in coulombs is:

$\mathbf{Q_{C1} = V_{C1} \times C_1}$ $\mathbf{Q_{C2} = V_{C2} \times C_2}$ $\mathbf{Q_{C3} = V_{C3} \times C_3}$

The total charge of the three capacitors in parallel is:

$\mathbf{Q_{Total} = V_T \times C_T}$ $\mathbf{Q_{Total} = Q_{C1} + Q_{C2} + Q_{C3}}$

The total capacitance for the three capacitors in parallel is:

$$\mathbf{C_T = C_1 + C_2 + C_3}$$
$$\mathbf{C_T = 30\mu F + 10\mu F + 15\mu F = 55\mu F}$$

The voltage across the parallel circuit is:

$$\mathbf{V_T = V_{C1} = V_{C2} = V_{C3}}$$

Capacitors in Series

When capacitors are in series, there is a single circuit path with all the dielectrics of the individual capacitors connected in succession. This is equivalent to increasing the thickness of the dielectric of one capacitor. As a result the total capacitance of the circuit is less than the capacitance of any individual capacitor.

When capacitors are charged in a series circuit, the same numbers of electrons flow to each capacitor. Hence, each capacitor has the same charge in coulombs or each has the same value of charge (Q).

In Fig. 8, three capacitors are connected in series across a line voltage (V). The microfarad rating of each capacitor is the same as in the parallel circuit example. The following computations show that the total capacitance of this series bank of capacitors is less than the capacitance of any one capacitor.

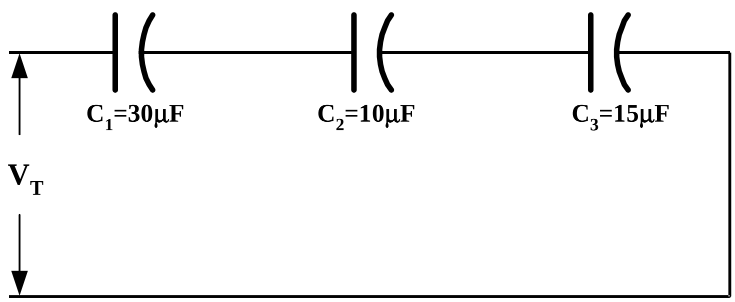


Fig. 8 Capacitors in Series

The charge on each capacitor is the same:

$$Q_T = Q_{C1} = Q_{C2} = Q_{C3}$$

The voltage across the total series circuit is:

$$V_T = V_{C1} + V_{C2} + V_{C3}$$

The voltage can also be expressed with charge and capacitance:

$$V_T = \frac{Q_T}{C_T}, \ldots and \ldots V_{C1} = \frac{Q_{C1}}{C_1}, \ldots and \ldots V_{C2} = \frac{Q_{C2}}{C_2}, \ldots and \ldots V_{C3} = \frac{Q_{C3}}{C_3}$$

To find the equation to calculate the total capacitance in a series capacitive circuit, let's substitute the previous equation for charge into the voltage relationship.

$$\frac{Q_T}{C_T} = \frac{Q_{C1}}{C_1} + \frac{Q_{C2}}{C_2} + \frac{Q_{C3}}{C_3}$$

Since (**$Q_T = Q_{C1} = Q_{C2} = Q_{C3}$**) then the following equation is true:

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}, \ldots and \ldots C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

Using the microfarad ratings of the three capacitors given in Fig. 8, the total capacitance of the series capacitor bank is:

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} = \frac{1}{\frac{1}{30\mu F} + \frac{1}{10\mu F} + \frac{1}{15\mu F}} = 5\mu F$$

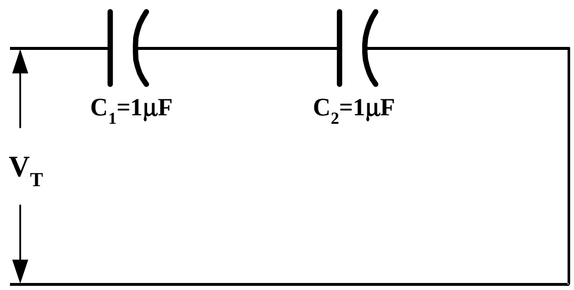
You must use the reciprocal equation for total capacitance in a series circuit.

We saw previously that in a parallel capacitive circuit the total capacitance is:

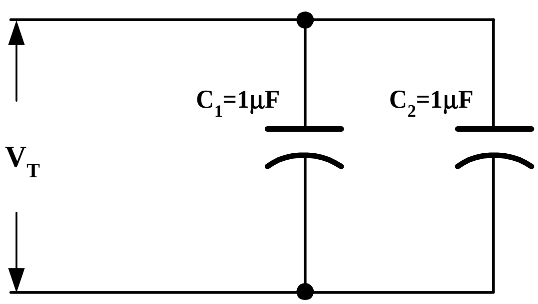
$C_T = C_1 + C_2 + C_3$

Exercises:

1. Calculate C_T.

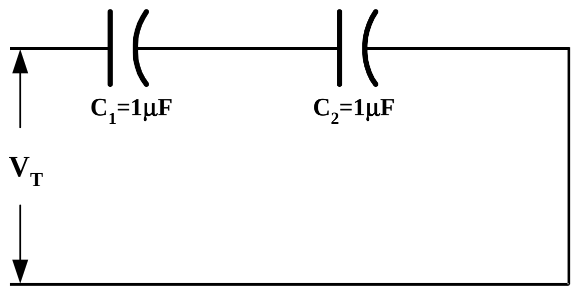


2. Calculate C_T.



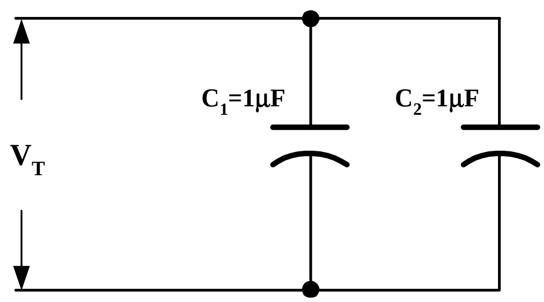
Exercises:

1. Calculate C_T.



$C_T = 1/(1/C1 + 1/C2) = 1/(1/(1\mu F) + 1/(1\mu F)) = 0.5\mu F$

2. Calculate C_T.



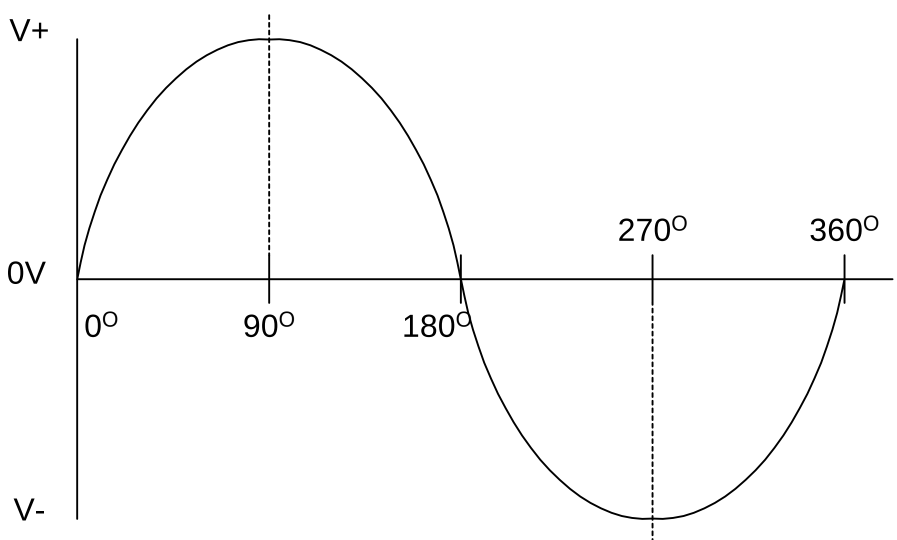
$C_T = C_1 + C_2 = 1\mu F + 1\mu F = 2\mu F$

INTRODUCTION TO AC

The majority of electrical energy is produced in large power stations and is transmitted throughout the country on long distribution lines. Using a D.C. voltage source would be difficult and costly. The batteries and the conductors would have to be very big. All voltages would have to be essentially the same. However, by using an Alternating Current (A.C.), power may be transmitted much more simply and efficiently. Therefore, A.C. generation and transmission has become a standard practice throughout the world.

Generating an Alternating Voltage

An A.C. voltage is one that continually changes in magnitude and periodically reverses in polarity. The time axis or line is a horizontal line across the center. The vertical axis shows the changes in magnitude by the variations of the voltage.



DEFINITIONS

Single Phase System - System energized by a single alternating voltage.

Poly Phase System - System energized by two, three or more alternating voltages.

Three Phase System - System energized by three **equal** alternating voltages 120 apart.

Line Voltage (V_L) - The voltage measured between terminals of an alternator, motor or branch circuit feeder wires.

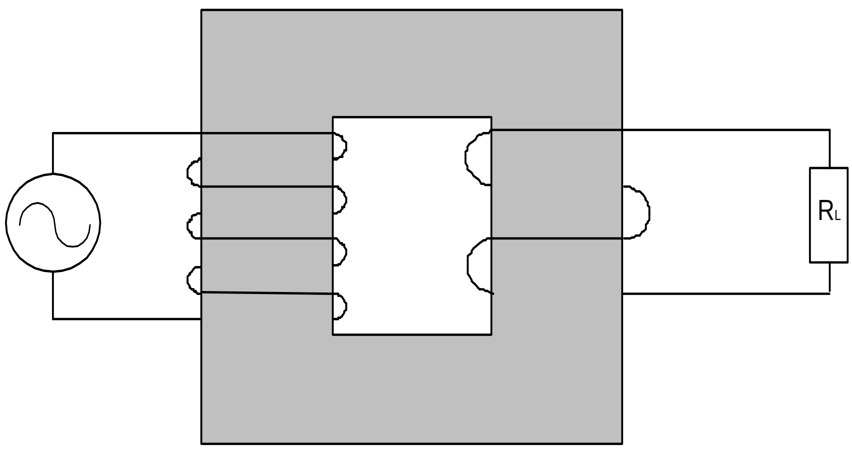
Phase - Each winding of an alternator, of a motor, or of a branch circuit forming part of a load.

Phase Voltage (V_{ph}) - The voltage measured across a phase of an alternator, motor or load.

SINGLE PHASE TRANSFORMERS

IDEAL TRANSFORMER CHARACTERISTICS

The basic transformer consists of two coils electrically insulated from each other and wound upon a common core. Magnetic coupling is used to transfer electric energy from one coil to another. The coil, which receives energy from the AC source, is called the **primary**. The coil, which delivers energy to the AC load, is called the **secondary**. The core of transformers used at low frequencies is generally made of magnetic material, usually sheet steel. Cores of transformers used at higher frequencies are made of powdered iron and ceramics, or nonmagnetic materials. Some coils are simply wound on nonmagnetic hollow forms such as cardboard or plastic so that the core material is actually air.



If a transformer is assumed to be operating under an ideal or perfect condition, the transfer of energy from one voltage to another is accompanied by **no losses**.

VOLTAGE RELATIONSHIP

The voltage (**V**) on the coils of a transformer is directly proportional to the number (**N**) of turns on the coils. This voltage relationship is expressed by the formula:

$$\frac{V_{pri}}{V_{\sec}} = \frac{N_{pri}}{N_{\sec}}$$

where V_{pri} = voltage on primary coil, **V**
V_{sec} = voltage on secondary coil, **V**
N_{pri} = number of turns on primary coil
N_{sec} = number of turns on secondary coil

Step-up and Step-down transformers

A voltage ratio of 1:4 (read as 1 to 4) means that for each volt on the transformer primary, there is 4 volts on the secondary. When the secondary voltage is greater than the primary voltage, the transformer is a **step-up** transformer. A voltage ratio of 4:1 means that for every 4 volts on the primary, there is only 1 volt on the secondary. When the secondary voltage is less than the primary voltage, the transformer is called a **step-down** transformer. The voltage relationship discussed previously will apply to both step-up and step-down transformers.

CURRENT RELATIONSHIP

The current (**I**) in the coils of a transformer is inversely proportional to the voltage (**V**) on the coils. This current relationship is expressed by the formula:

$$\frac{V_{pri}}{V_{\sec}} = \frac{I_{\sec}}{I_{pri}}$$

Where
- V_{pri} = voltage on primary coil, **V**
- V_{sec} = voltage on secondary coil, **V**
- I_{pri} = current in the primary coil, **A**
- I_{sec} = current in the secondary coil, **A**

EFFICIENCY

The efficiency of a transformer is equal to the ratio of the power output of the secondary winding to power input of the primary winding. An ideal transformer is 100% efficient because it delivers all the energy it receives. Because of core and copper losses, the efficiency of even the best practical transformer is less than 100%. Efficiency expressed as an equation is:

$$Eff = \frac{output\ power}{input\ power} = \frac{P_{\sec}}{P_{pri}}$$

Where
- Eff = efficiency
- P_{sec} = power output from the secondary coil, **W**
- P_{pri} = power input to the primary coil, **W**

TRANSFORMER RATINGS

Transformer capacity is rated in kilo-volt-amperes (**KVA**). This transformer rating is sometimes represented by the letter **S.** Since power in an AC circuit depends on the power factor of the load and the current in the load, an output rating in kilowatts must specify the power factor.

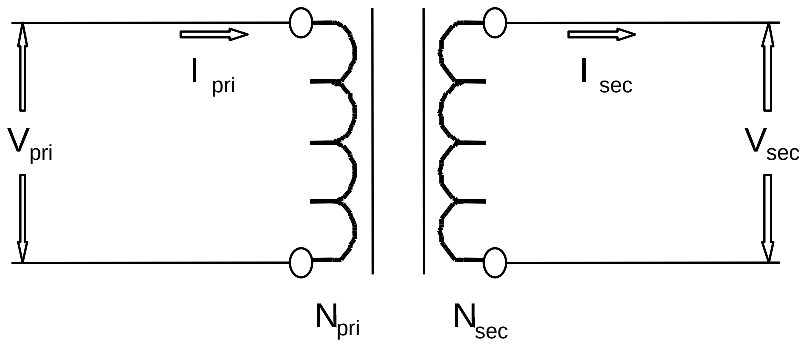
For an ideal transformer we would assume efficiency to be 100%. Since our calculations will deal with ideal transformers, we can state the following relationships:

$$VA_{pri} = V_{pri} \bullet I_{pri}$$

$$VA_{\sec} = V_{\sec} \bullet I_{\sec}$$

$$VA_{pri} = VA_{\sec}$$

Where
- VA_{pri} = power input to the primary coil, **VA**
- VA_{sec} = power output from the secondary coil, **VA**
- V_{pri} = primary voltage
- I_{pri} = primary current
- V_{sec} = secondary voltage
- I_{sec} = secondary current



EXERCISES

1. Given: N_{pri} = 1500 turns
N_{sec} = 1000 turns
V_{pri} = 100 V

Find: V_{sec} =

2. Given: N_{pri} = 4000 turns
N_{sec} = 400 turns
I_{sec} = 6 A

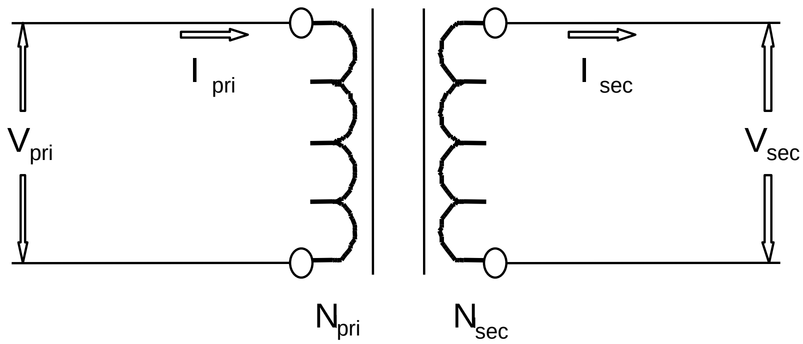
Find: I_{pri} =
What is the turn's ratio?

3. Given: V_{pri} = 300 V
V_{sec} = 24 V
I_{sec} = 1 A
N_{pri} = 1000 turns

Find: N_{sec} =
I_{pri} =

4. Given: VA_{pri} = 100
V_{pri} = 460 V
V_{sec} = 110 V

Find: I_{pri} =
I_{sec} =



EXERCISES

1. Given: N_{pri} = 1500 turns
N_{sec} = 1000 turns
V_{pri} = 100 V

Find: $V_{sec} = V_{pri} * N_{sec} / N_{pri}$ = 100 V * 1000 turns / 1500 turns = 66.667 V

2. Given: N_{pri} = 4000 turns
N_{sec} = 400 turns
I_{sec} = 6 A

Find: $I_{pri} = I_{sec} * N_{sec} / N_{pri}$ = 6 A * 400 turns / 4000 turns = 0.6 A
What is the turn's ratio? 4000 turns / 400 turns = 10:1

3. Given: V_{pri} = 300 V
V_{sec} = 24 V
I_{sec} = 1 A
N_{pri} = 1000 turns

Find: $N_{sec} = N_{pri} * V_{sec} / V_{pri}$ = 1000 turns * 24 V / 300 V = 80 turns
$I_{pri} = I_{sec} * V_{sec} / V_{pri}$ = 1 A * 24 V / 300 V = 0.08 A

4. Given: VA_{pri} = 100
V_{pri} = 460 V
V_{sec} = 110 V

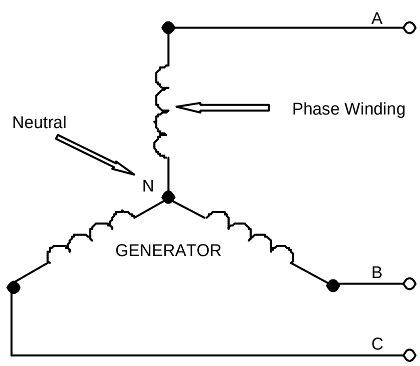
Find: $I_{pri} = VA_{pri} / V_{pri}$ = 100 VA / 460 V = 0.217 A
$I_{sec} = VA_{sec} / V_{sec}$ = 100 VA / 110 V = 0.909 A

Advantages of 3ϕ versus 1ϕ

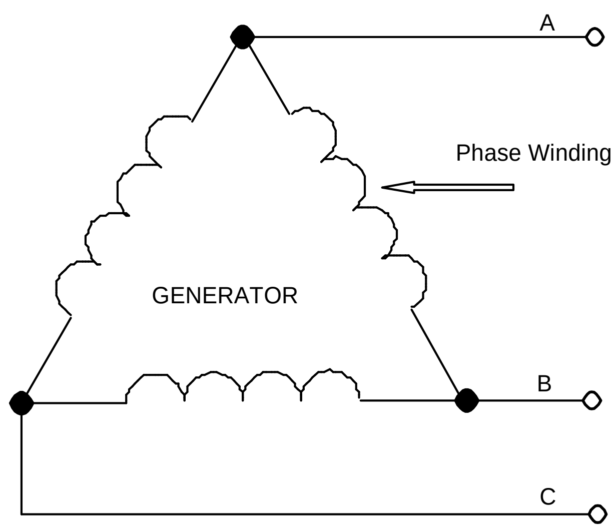
- 3ϕ circuits require **less weight of conductors** than 1ϕ circuits of the same power rating.
- 3ϕ circuits permit flexibility in the **choice of voltages**.
- 3ϕ circuits can be used for 1ϕ loads.
- 3ϕ equipment is **smaller in size**, **lighter in weight**, and **more efficient** than 1ϕ machinery of the same rated capacity.

The three phases of a 3ϕ system may be connected in two ways.

1. If the three common ends of each phase are connected together at a common terminal marked N for neutral, and the other three ends are connected to the 3ϕ line, the system is *Wye* or Y-connected. This configuration can be related as being connected in series. Sometimes the neutral connection is brought out to form a 3ϕ, 4-wire system.



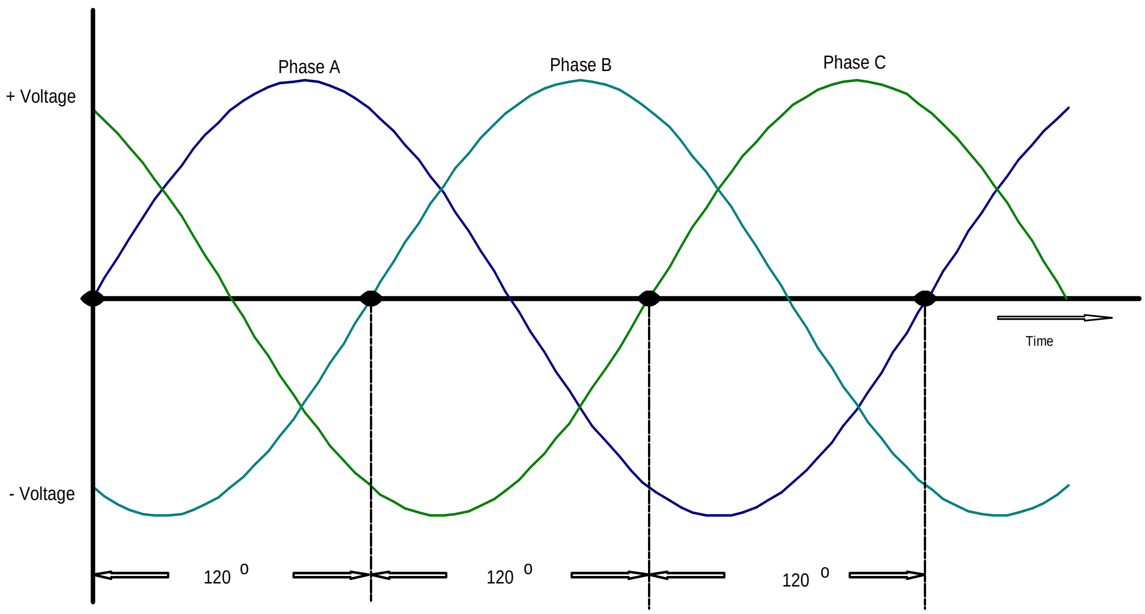
2. If the three phases are connected to form a closed loop, the system is *delta* or Δ-connected. This configuration can be related as being connected in parallel.



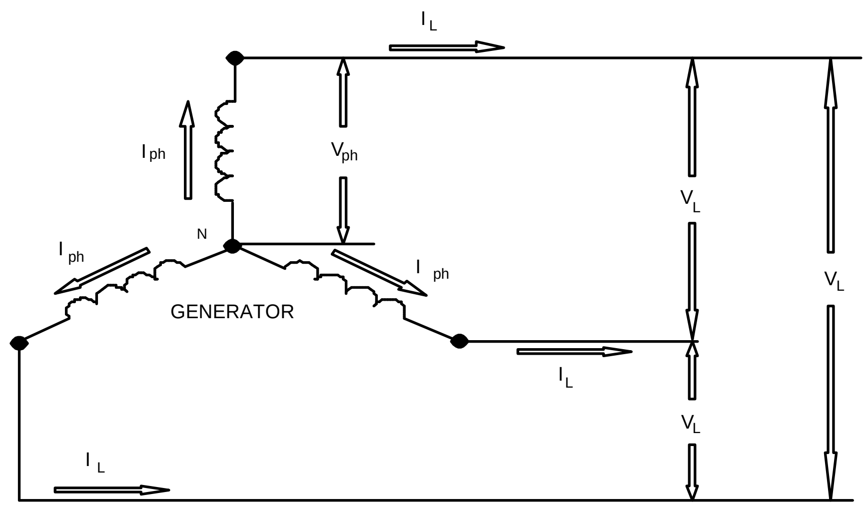
THREE PHASE SYSTEMS

CHARACTERISTICS OF THREE PHASE SYSTEMS

A three phase (3ϕ) system is a combination of three single phase (1ϕ) systems. In a 3ϕ balanced system, the power comes from an AC generator that produces three separate but equal voltages, each of which is out of phase with the other voltages by 120° (illustrated below). When any of the three voltages is at its maximum value (negative or positive), each of the other two voltages will be at 50 percent of their maximum value in the opposite direction. Although 1ϕ circuits are widely used in electrical systems, most generation and distribution of alternating current is 3ϕ



THREE PHASE RELATIONSHIPS



Voltage Relationship in a Wye Configuration - Since the line voltage is connected across two windings and the phase voltage is only connected across one winding, the line voltage (**V_L**) is much larger than the phase voltage (**V_{ph}**). At first, you would think that the line voltage is twice as large as the phase voltage, this is not the case. The actual relationship is as follows:

$$V_L = \sqrt{3} \bullet V_{ph}$$

$$\text{or } V_{ph} = \frac{V_L}{\sqrt{3}}$$

Current Relationship in a Wye Configuration **- Since the line current does not split as it enters the phase winding, the line current (I_L) is equal to the phase current (I_{ph}). The relationship is as follows:**

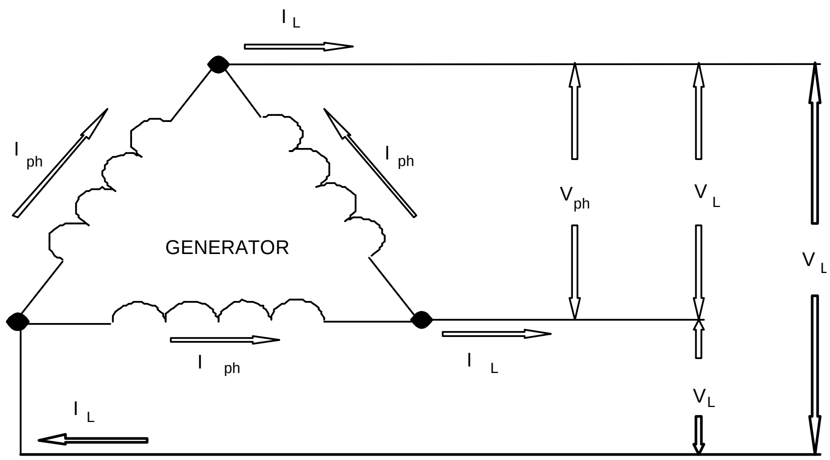
$$I_L = I_{ph}$$

Power Relationship in a Wye Configuration - As discussed in AC concepts, there are three different power relationships for AC circuits. **Real, reactive and apparent power** still applies for three phase circuits. There are some minor differences as shown with the relationships below:

$$P_{Real} = \sqrt{3} \bullet V_L \bullet I_L \bullet \cos\theta$$

$$Q_{Reactive} = \sqrt{3} \bullet V_L \bullet I_L \bullet \sin\theta$$

$$S_{Apparent} = \sqrt{3} \bullet V_L \bullet I_L$$



Voltage Relationship in a Delta Configuration **- Since the line voltage is connected across one winding just as is the phase voltage, the line voltage (V_L) is equal to the phase voltage (V_{ph}). The actual relationship is as follows:**

$$V_L = V_{ph}$$

Current Relationship in a Delta Configuration **- Since the line current is a combination of current from two windings and the phase current only comes from one winding, the line current (I_L) is much larger than the phase current (I_{ph}). At first, you would think that the line current is twice as large as the phase current, this is not the case. The actual relationship is as follows:**

$$I_L = \sqrt{3} \bullet I_{ph}$$

$$or \; I_{ph} = \frac{I_L}{\sqrt{3}}$$

Power Relationship in a Delta Configuration **- As discussed in AC concepts, there are three different power relationships for AC circuits.** Real, reactive and apparent power **still applies for three phase circuits. There are some minor differences as shown with the relationships below:**

$$P_{Real} = \sqrt{3} \bullet V_L \bullet I_L \bullet \cos\theta$$

$$Q_{Reactive} = \sqrt{3} \bullet V_L \bullet I_L \bullet \sin\theta$$

$$S_{Apparent} = \sqrt{3} \bullet V_L \bullet I_L$$

AC MOTORS

INTRODUCTION

Since alternating voltage can be easily transformed from high voltages to low voltages or vice versa, it can be transmitted over a much greater distance without too much loss in efficiency. Therefore, power generating systems today produce alternating current usually. Thus, it follows that a great majority of the electrical motors utilized today are designed to operate on alternating current. However, there are other advantages in the use of AC motors besides the wide availability of AC power.

Advantages of AC Motors versus DC Motors

- **A readily available power supply**
- **Cheaper**
- **Maintenance cost**
- **Less weight**

DC motors are best suited for applications that require variable-speed motors. However, AC motors along with variable speed AC drives are becoming more widely used.

AC motors are manufactured in **many** different sizes, shapes, and ratings, for use on an even greater number of applications. They are designed for use with either **single-phase** or **polyphase** power systems. This unit cannot possibly discuss all aspects of the subject of AC motors. Consequently, it will deal with the most common type, which is the **three phase induction motor**.

Three Phase AC Motors

There are two classes of Three Phase AC Motors: Synchronous and **Asynchronous**.

The main difference between these two classes of AC motors is their physical construction. While both have the **same stator construction**, their **rotors vary greatly**.
The purpose of the stator in both class motors is to create a rotating magnetic field.

A synchronous motor is one whose **rotor speed (N_r)** is equal to the speed of the **stator rotating magnetic field (N_s)**. In other words the speed of the shaft is rotating at the same speed as the rotating magnetic field.

$$N_s = N_r$$

An asynchronous motor is one whose rotor speed **(N_r)** is not equal to the speed of the rotating magnetic field **(N_s)**. The asynchronous motor is more commonly called an **induction motor.**

$$N_s > N_r$$

Three Phase AC Induction Motors
There are two main types of induction motors:
Squirrel-Cage
Wound Rotor

Both motors operate on induction and the principles are very similar. Let's first discuss the squirrel-cage motor and its construction since it is the simplest form. We will then look at the differences and applications of the wound rotor induction motor.

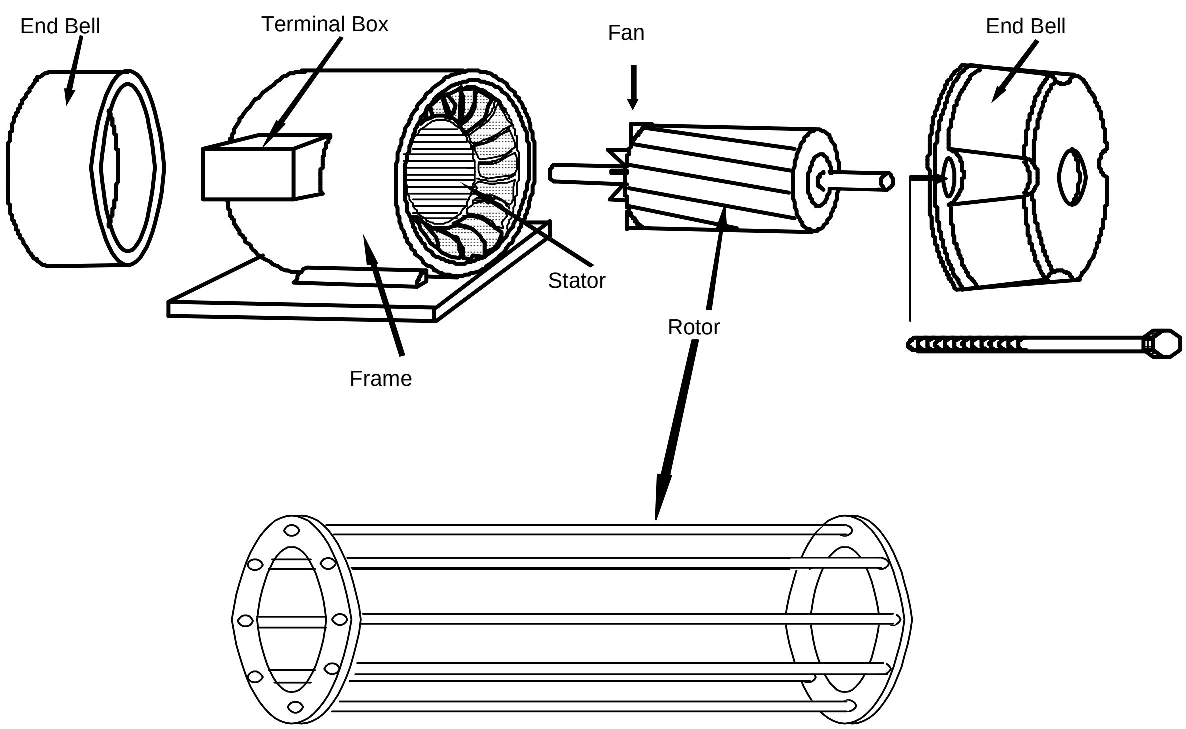
SQUIRREL-CAGE INDUCTION MOTOR

Construction

Stator - The stationary winding of the motor and it provides the rotating magnetic field. The stator windings are wound around the laminated pole pieces, which are mounted to the outside housing of the motor. It is also connected to the AC supply.

Rotor - The rotating member of the motor and it provides the torque or power to do the mechanical work. The rotor is made of circular laminations with copper or aluminum bars imbedded around the outside edge. It is connected to the shaft of the motor.

End Bells - Support the shaft of the motor and house the bearings.



Rotating Magnetic Field

The speed of the rotating magnetic field is called the ***synchronous*** speed of the motor. The following formula can be used to determine the speed of the rotating magnetic field created by the stator:

$$N_s = \frac{60 \bullet f}{P}$$

Where **N_s** is the speed of the stator rotating magnetic field in RPMs
f is the frequency of the applied voltage in hertz (H_z)
P is the number of pair of poles per phase in the stator winding

When motor manufacturers describe a 2-pole motor, they are talking about the numbers of poles that are **created in the rotor** due to the rotating magnetic field.

For a 2-pole motor which has only 1 pair of poles per phase:
N_s = 3600 rpm (assuming 60 Hz)

For a 4-pole motor which has 2 pair of poles per phase:
N_s = 1800 rpm (assuming 60 Hz)

For a 6-pole motor which has 3 pair of poles per phase:
N_s = 1200 rpm (assuming 60 Hz)

For a 8-pole motor which has 4 pair of poles per phase:
N_s = 900 rpm (assuming 60 Hz)

In AC theory we learned the left-hand rule for conductors, the left-hand rule for coils, and the left-hand rule for generators. We now can use those rules to show how the rotating magnetic field is created in the stator. The following diagrams can be used to illustrate the creation of the stator rotating magnetic field and explain why the rotor rotates:

Induction Motor Slip

An induction motor cannot run at synchronous speed since the rotor would be standing still with respect to the rotating field and no current would be induced in the rotor. The rotor speed must be slightly less than synchronous speed in order that current be induced in the rotor to permit rotor rotation. The difference between rotor speed and synchronous speed is called ***slip***:

$$slip = N_S - N_r$$

Where N_S = synchronous speed, in rpm
N_r = rotor speed, in rpm

Slip can also be expressed as a percent of synchronous speed:

$$\% \; slip = \frac{N_S - N_r}{N_S} \times 100$$

Where N_S = synchronous speed, in rpm
N_r = rotor speed, in rpm

To calculate the actual shaft speed of an induction motor this relationship will be used:

$$N_r = \frac{60 \bullet f}{P} - slip$$

Where N_r = is the actual shaft speed in RPMs
f = is the frequency of the applied voltage in hertz (H_z)
P = is the number of pair of poles per phase in the stator winding

Induction Motor Efficiency

The three-phase, squirrel-cage induction motor operates at a relatively constant speed from no-load to full-load. Because of the extremely low impedance of the rotor, only a slight decrease is speed is necessary to cause a large increase in rotor current to develop the necessary torque to turn the increased load. The percent slip at no-load is less than 1% while at full-load it is usually between 3-5%. This small change in percent slip from no-load to full-load likewise indicates why a squirrel-cage induction motor is considered a fairly constant speed motor. As the slip increases in a straight line characteristic, the rotor current will likewise increase in practically a direct proportion and cause the torque to increase as a straight line characteristic.

The losses in an induction motor consist of the stray power losses and the copper losses. The stray power losses include mechanical friction losses, windage losses, and iron losses. These remain relatively constant at all load points and are often called fixed losses. The second group of losses, called copper losses, is the I^2R losses in the windings of the motor. As the current increases in the motor windings with an increase in load, the I^2R losses increase. At light loads the percent efficiency (η) is low because the fixed losses become a smaller part of the input and the efficiency increases to its maximum value. However, when the rated capacity of the motor is exceeded, the copper losses become excessive and the efficiency decreases.

The efficiency of an AC induction motor can be determined by:

$$\eta = \frac{P_{out}}{P_{in}} x\ 100$$

Where η = Greek letter **eta**, percent efficiency
P_{out} = the output power produced by the shaft in watts
P_{in} = the input power required in watts

Example:

Given: P_{in} = 8500 watts
P_{out} = 10 hp

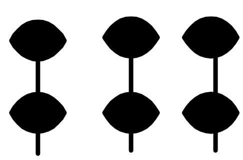
Find: η =

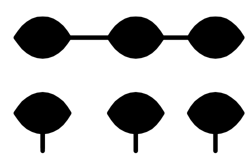
MOTOR NAMEPLATES

MODEL 5K143AL234E	NO CRF	
HP 1	SERVICE FACTOR 115	
VOLTS 230/460	PHASE 3	HERTZ 60
AMP 3.7/1.85	EFFICIENCY	
RPM 1745	TIME RATING CONT	
40 DEG. C MAX. AMB	INS CLASS A	NEMA DESIGN B
FRAME 143T		
TYPE K CODE M		
STOCK NO. K-137		
GENERAL ELECTRIC INDUCTION MOTOR		

TYPICAL AMERICAN

MOTEURS PATAY LYON		
Type BCVL38B2	No. 592320	
ch 1.7	tr/mn 1000	
kw 1.25	Hz 50	Sce SI
V 220 △		V 380 Y
A 4.1		A 2.4
FREIN-Type FM138-2 Couple 1 m kg		



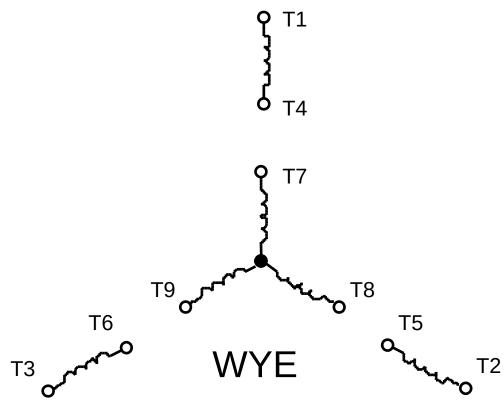


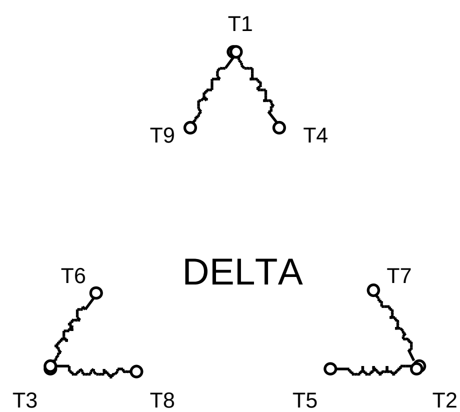
TYPICAL EUROPEAN

DUAL VOLTAGE MOTOR CONNECTIONS

It is common for electric motor manufacturers to build motors for connection to many different voltage sources. Manufacturing motors for dual voltages, such as 480/240 volt, enables the same motor to be used in applications where the line voltages are different. These motors have the same characteristics on either voltage. The speed and horsepower remain the same if the motor is operated on either the higher or lower voltage.

Dual-voltage connections are either wye-connected or delta-connected. Each phase is divided into two sections with the same number of pole-phase groups in each section and nine external connections are brought out from these sections when the motor is wound. Each external lead or connection is stamped at the terminal block with a number from one to nine.

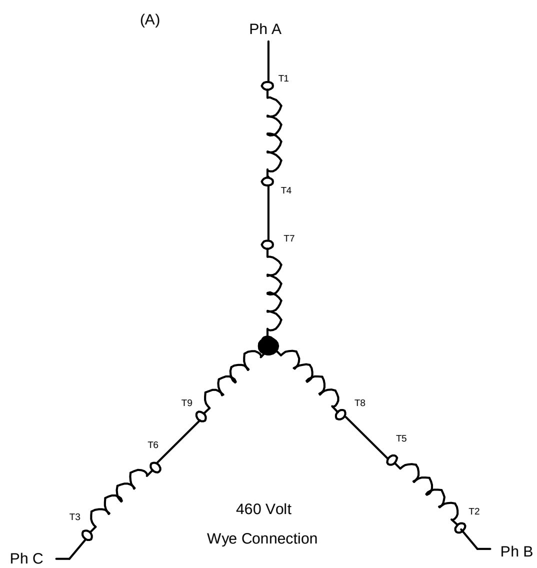

T1
T4
T7
T9
T8
T6
T5
T3
WYE
T2

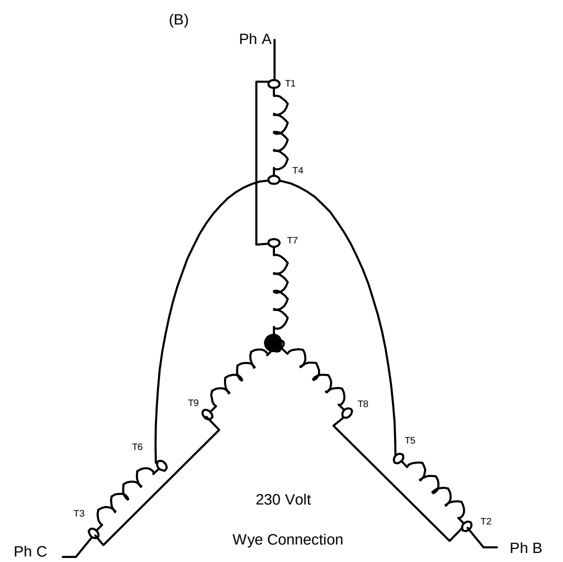

T1
T9
T4
T6
DELTA
T7
T3
T8
T5
T2

Wye-Connected Motors

Below illustrates the connections and terminal markings for a wye-connected, dual-voltage induction motor. In the series-wye connection illustrated on the left, the ascending numbers go in succession in a clockwise direction to the three points of the wye. Then starting at the end of the T1 winding, go around clockwise again, completing the three outside groups. The third start is on the inside wye just below T4 and go around clockwise again. This makes the nine external terminals of the six windings. The other three terminals of the internal wye are connected inside the motor for a nine-lead motor.

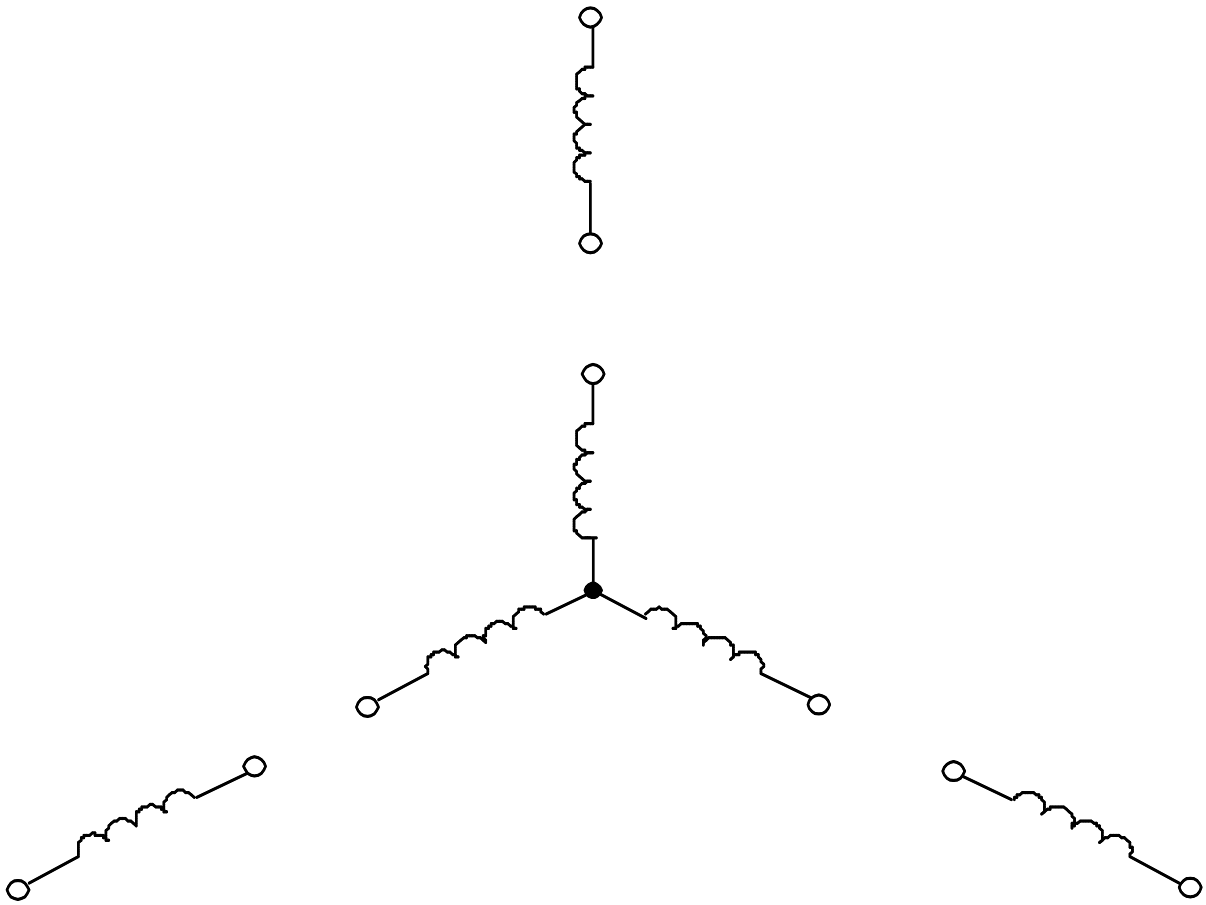
Note on the diagram on the left that this connection has two windings for each phase connected in **series.** This is known as a series-wye connection and is always the **higher voltage connection** in a dual-voltage, wye-connected motor.



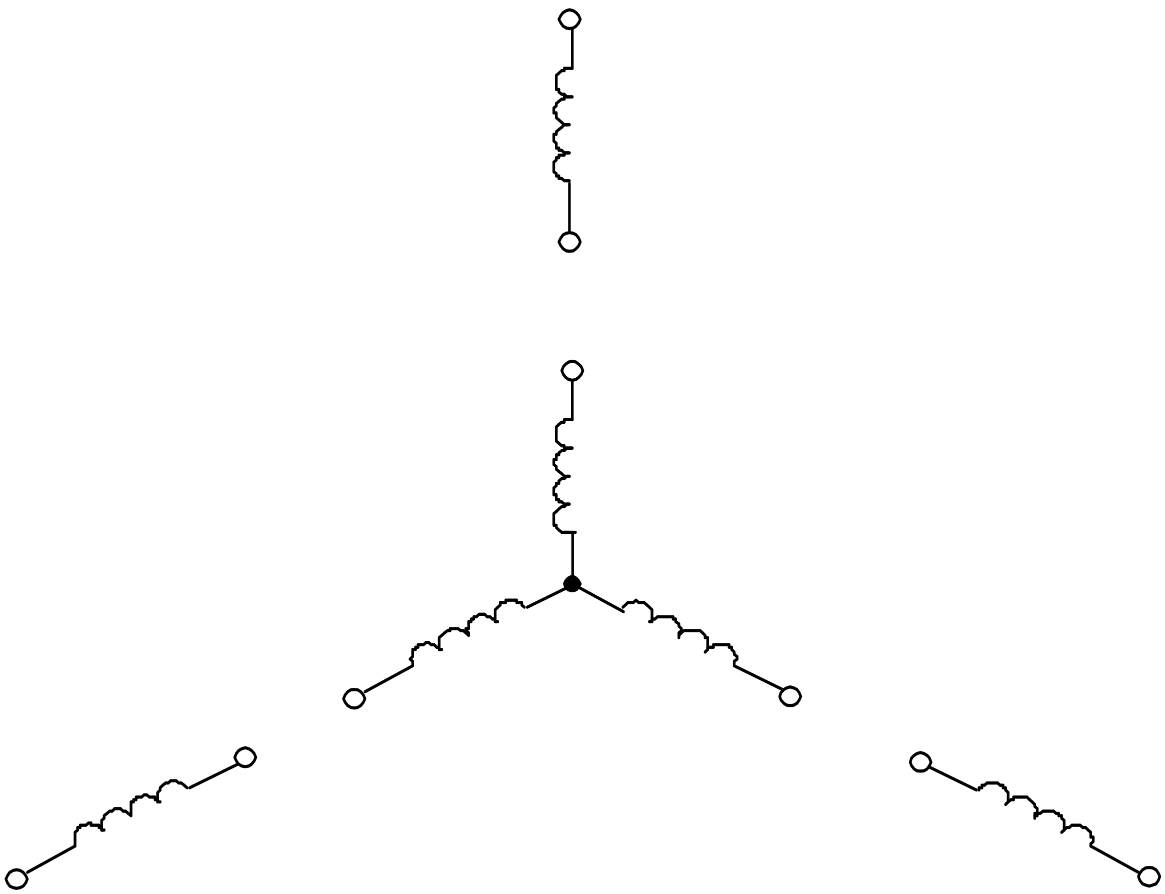


The drawing on the right illustrates how the same nine external leads are connected for the lower voltage operation. The two windings of each phase are now connected in parallel and have the same voltage drop across each winding. This is known as a parallel-wye connection and is always the **lower voltage connection** for any dual-voltage, wye-connected motor. In this connection there are two wye center points. The original internal wye and an external wye formed by connecting leads T4, T5, and T6 together as illustrated.

Use the diagram below to practice the connections for a high voltage wye-connected, 9-lead American motor.



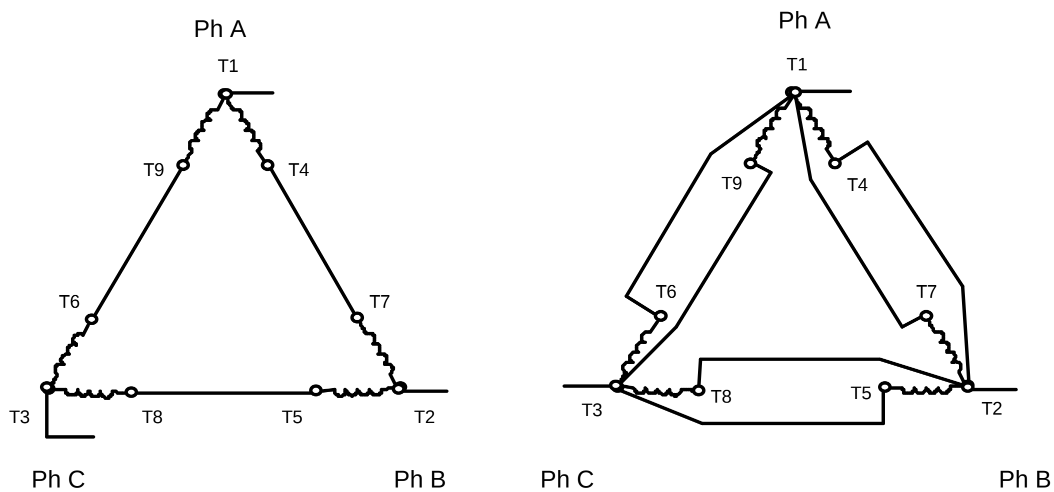
Use the diagram below to practice the connections for a low voltage wye-connected, 9-lead American motor.



Delta-Connected Motors

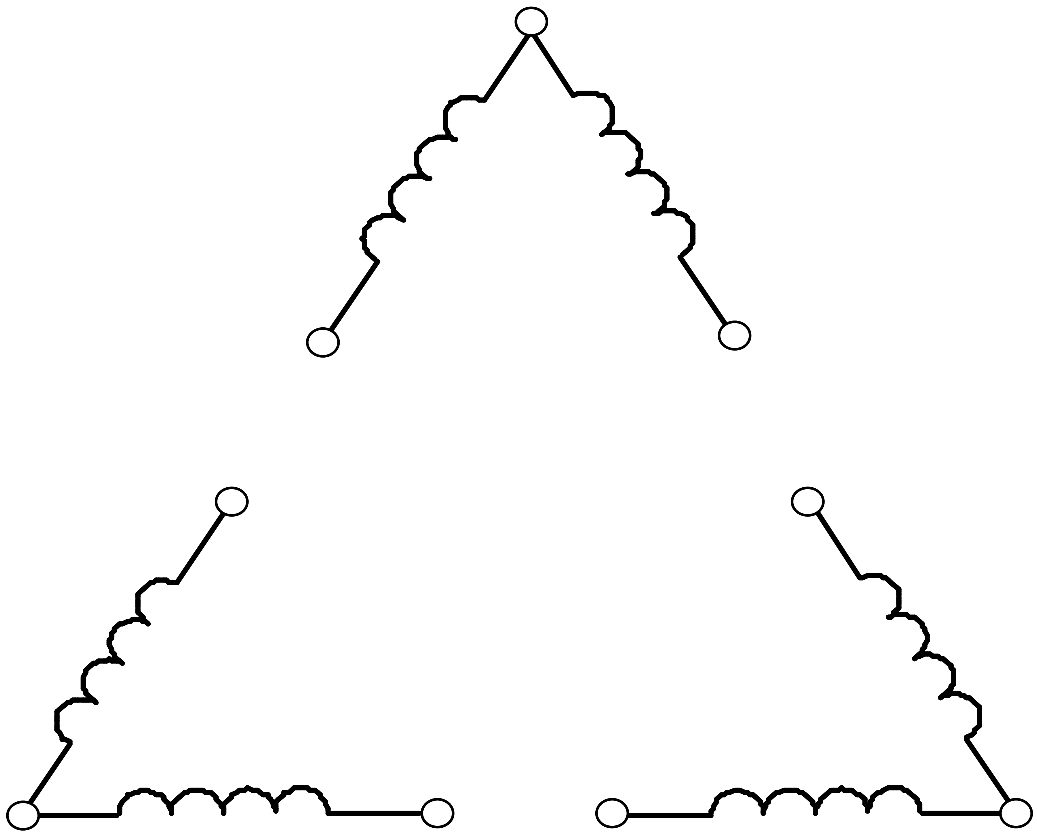
The diagrams below illustrate the connections and terminal markings for a delta-connected, dual-voltage induction motor. The diagram on the left shows the method of numbering and connecting the nine external leads for high voltage operation. The method of numbering for the delta is much the same as the wye. Starting at the top corner of the delta, number the three corners T1, T2, T3. Then start at the end of the T1 winding and go clockwise to number for T4, T2 toT5, and T3 to T6. For the next terminal, start at the T4 winding and go clockwise to the next terminal for T7, then go to clockwise of T5 and label T8, and finally label T9.

Note the diagram on the left, that the two sections of each phase are connected in series for the **high voltage connection**.

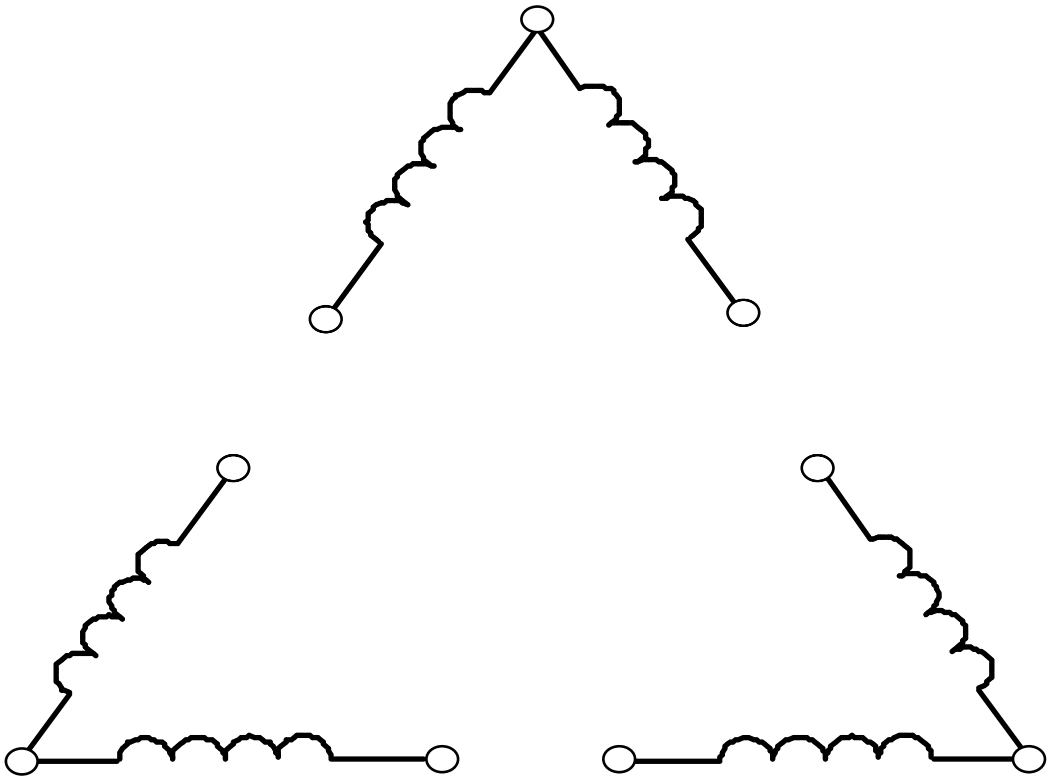


The drawing on the right illustrates the nine external lead connections for lower voltage operation. The two sections of each phase are connected in parallel. This is a parallel-delta connection and always the **lower voltage connection** in a dual-voltage, delta-connected motor.

Use the diagram below to practice the connections for a high voltage delta-connected, 9-lead American motor.

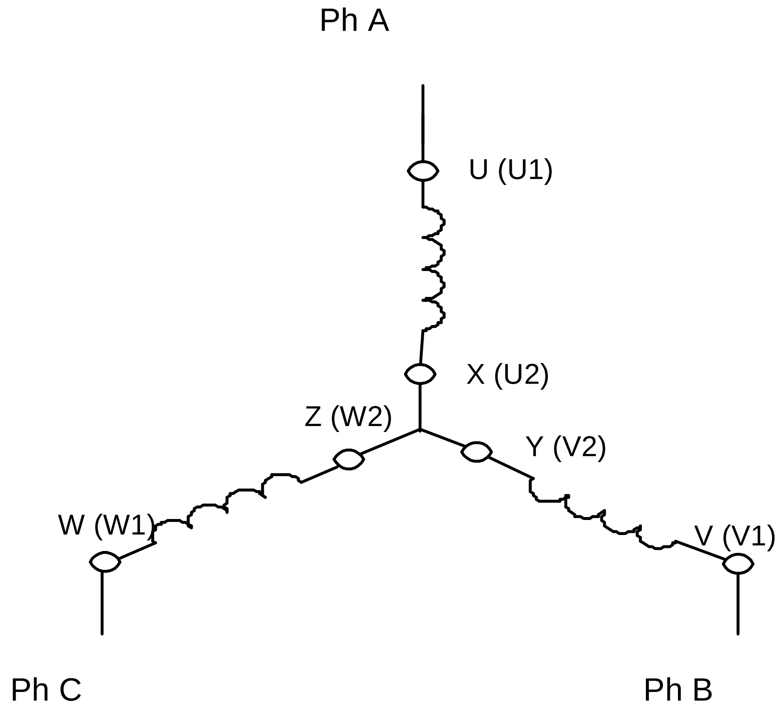


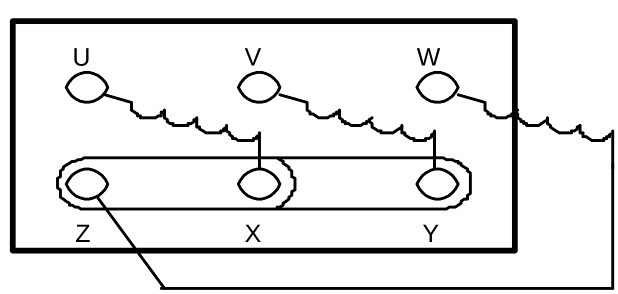
Use the diagram below to practice the connections for a low voltage delta-connected, 9-lead American motor.

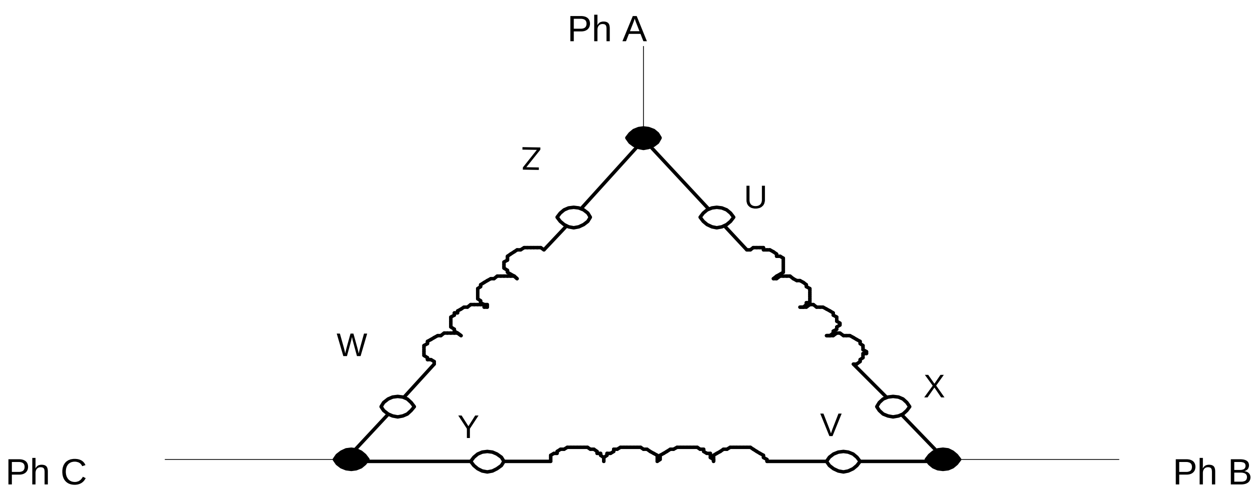


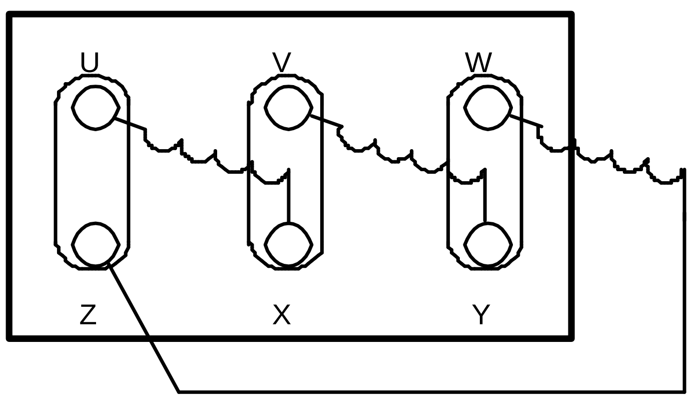
EUROPEAN MOTORS

These motors have six leads, three coils, and have the capability of being connected either wye or delta. The wye connection is used for high voltage, and the delta connection is used for low voltage. Another point to consider is that these motors were designed for 380V or 220V. Normally in the plant, 480 volts will be used; and as you might expect, the motor does not last as long. When they are burned out, they are rewound for 480 volts (wye connected) and will have only three terminal wires. They then are no longer dual voltage motors. One additional factor is the European motor is designed to operate on 50 Hertz. In the U.S., we have 60 Hertz and therefore, the nameplate rpms will not be correct.






Ph A
Z
U
W
X
Y
V
Ph C
Ph B


U
V
W
Z
X
Y

CONTROL DEVICES

PUSH BUTTON CONTROL STATIONS

A push button station is a device that can provide control of a motor with the pressing of the appropriate push button. With push button stations a motor can be controlled from any one of several locations while only using one magnetic starter. The start, forward, reverse, fast, slow and stop operations of a motor may be controlled by push buttons. Auxiliary push buttons are used to control the motor from remote points. The auxiliary control may be a simple stop or start button, or the same controls as the main station. Industrial push buttons are used in control circuits to actuate magnetic contactors or remote-operated controllers which handle power circuits.

Push buttons are pilot devices and must be ruggedly constructed to withstand operator and mechanical abuse. They are frequently exposed to oils, coolants, chemicals, dusts, and various foreign elements. Heavy electrical loads are sometimes carried by the contacts of the push button because of the high inrush current drawn by larger contactors. Push buttons are classified as standard-duty or heavy-duty, according to their current handling capabilities. Heavy-duty oil tight, and multi-light-control oil-tight are classified according to their ability to withstand these conditions. The terms standard-duty and heavy-duty describe only the contact capacity of the push button in its making and breaking ability. These designations have no reference to the service conditions or frequency of operation.

STANDARD DUTY PUSH BUTTONS

Most systems use standard duty push button stations to control A-C or D-C starters. General-purpose push button stations are designed for operating flexibility and ease of wiring. Padlocking attachments are sometimes added to the push button stations. These padlocking attachments are added to lock the "stop" button in the depressed position.

SINGLE CONTACT RATINGS

Standard-duty units have contacts rated for pilot duty, typically as follows:

A-C

3.0 Amperes, 120 volts
1.5 Amperes, 240 volts
0.75 Ampere, 480 volts
0.6 Ampere, 600 volts

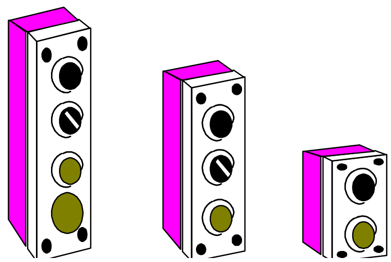
HEAVY DUTY PUSH BUTTONS

Heavy-duty push button stations are found in many industrial applications. They have approximately twice the current rating of the standard-duty station. They come with any combination of push buttons, selector switches, jogging buttons, and pilot lights. Push buttons are available with flush, extended, or mushroom heads. They may have either momentary or maintained contacts. Heavy-duty push button units have double-break contacts rated for pilot duty, typically as follows:

A-C	D-C
6 Amps, 120 Volts	**1.1 Amps, 120 Volts**
3 Amps, 240 Volts	0.55 Amps, 230 Volts
1.5 Amps, 480 Volts	0.2 Amps, 550 Volts
1.2 Amps, 600 Volts	

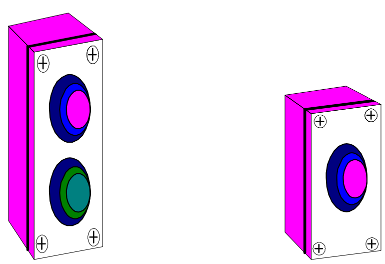
PUSH BUTTON STATION DESCRIPTIONS

General-purpose stations have steel bases and steel wraparound covers that fit tightly to exclude dirt and dust, as illustrated below.



Watertight and **dust tight** stations have a stainless steel enclosure with a gasket between the cover and base.

Water tight, **corrosion-resistant** stations are intended for applications where they are subject to corrosive fumes or liquids. The enclosure is made of nonmetallic material, and synthetic rubber boots protects the push buttons. This is illustrated below.

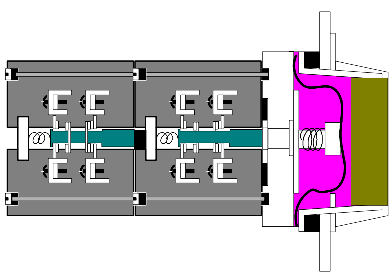


Push button stations for hazardous locations are suitable for hazardous gas and hazardous dust locations. A machined surface is provided between the cover and base.

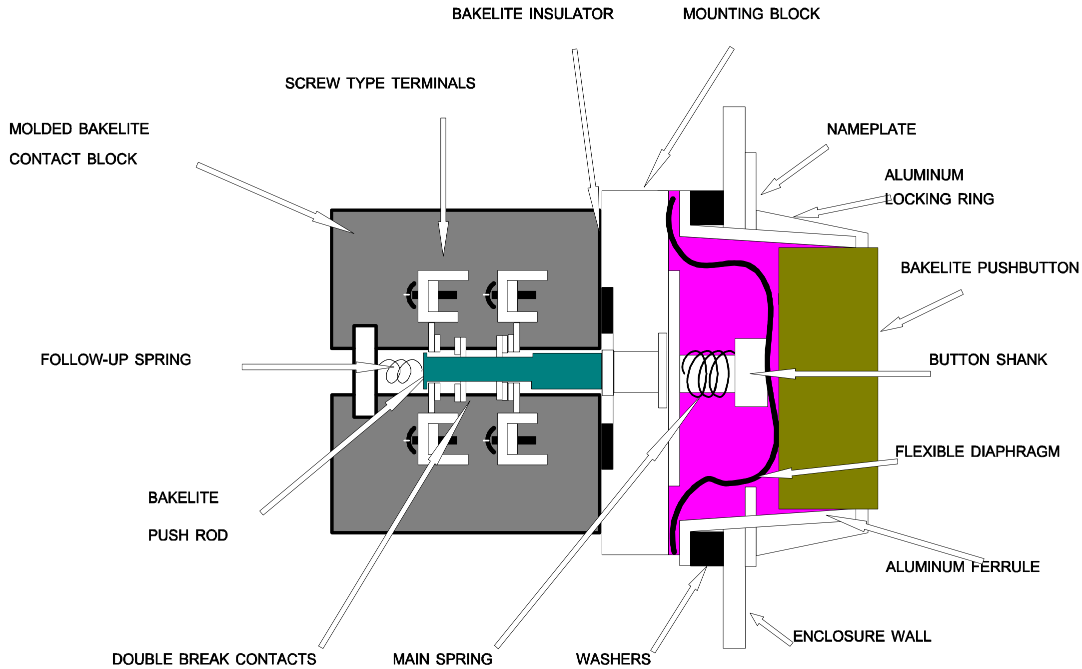
Oil tight push button control stations are used wherever there is presence of oil, coolant, and other noncorrosive industrial liquids. These control stations may be the surface mounted, flush mounted or pendant types. These stations have an enclosure that is sealed with a neoprene gasket. One or more neoprene washers tightly seal individual oil tight units.

All these control units may include momentary or maintained contact push buttons. The contacts are usually the double-break type. These contact blocks can be assembled in numerous contact arrangements.

Single and double circuit constructed contact blocks are frequently used in any combination of "normally open" or "normally closed" circuits. Double circuit blocks have an individually operated contact plunger for each circuit made from high strength phenolic to resist cracking and warping. Several contact blocks can be stacked behind the push button operator, as illustrated below.



Each unit usually consists of two parts, the operator and the contact block. The bodies of the operators are die-castings, the operating buttons are molded plastic, and the locking rings are usually aluminum. One or more synthetic rubber washers provide the oil tight seal between the panel and operator.



ACCESSORIES

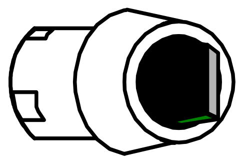
Some types of push button stations may be supplied with a padlocking attachment that locks the **stop** button in the depressed position. Some push button stations may have pilot lights on them that indicate their particular function. Push button stations usually use mushroom heads as an **E-stop** button.

PUSH BUTTON OPERATORS

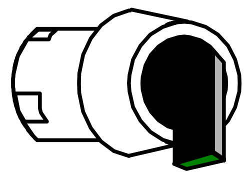
Different types of push button and cylinder lock operators are used. Some of these are flush button, extended button, mushroom head, and jumbo mushroom head. The buttons are a solid color usually made of molded plastic. The cylinder lock type push button can be locked in various positions and the key can be removed from the lock. A keyhole "dust cover" prevents dirt and other foreign matter from entering. Key operators may be used with identical locks, dissimilar locks, or with dissimilar locks having a master key system.

SELECTOR SWITCH OPERATORS

Selector Switches can be obtained in two, three, four, and etc. position types. Cams in the operator sleeve actuate the contact blocks. These selector switches can provide *maintained* or *spring return* contact operation. Many circuit combinations can be made since there is a number of different operating cams available and a variety of contact blocks.



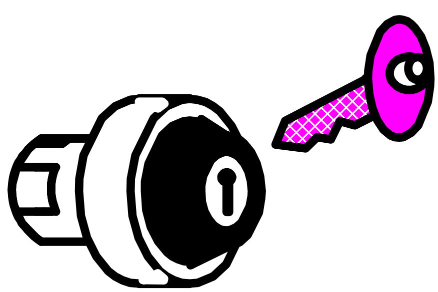
Standard Lever



Extended Lever

KEY OPERATED SELECTOR SWITCH

Key operated selector switches work just like normal selector switches plus a key locking feature to prevent unauthorized change or accidental tripping from a selected position. These switches also provide maintained or spring return momentary cam action on the contact plungers.



Key Operator

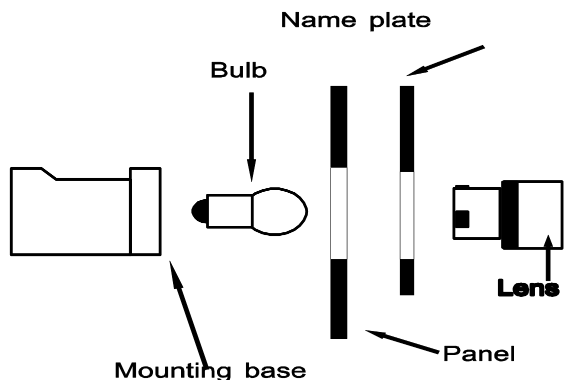
ILLUMINATED PUSH BUTTONS

These devices combine the functions of both a push button operator and an indicating light in a single unit and require only half the space of two separate units. The light unit may be either a resistor type or an encapsulated transformer. These units are usually designed to give illumination from all angles. The contact blocks can still be used for circuit control as before. A rubber diaphragm in the operator, a rubber lens gasket, and a rubber panel gasket can provide oil tight assembly.

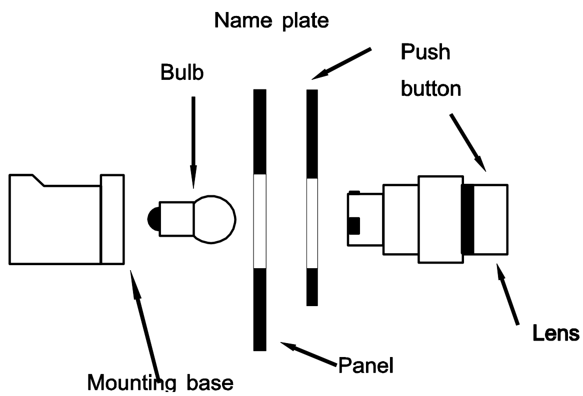
INDICATING LIGHTS

Indicating lights can tell you at a glance what is happening. They indicate if everything is ready for operation or operating smoothly. They also can warn of possible trouble and malfunction. Indicating lights also alert the attendant of the next operation for their machine. Therefore, it is important that indicating lights function accurately.

Standard indicating lights can have either a transformer built in to change the voltage or the lamps are rated for the exact voltage. Indicating lights are available for both AC and DC voltages. They are also available in color with plastic or glass lenses.



The press-to-test type indicating lights can test to see if the lamp is burned out.



LIMIT SWITCHES

Limit switches are devices used for interlocking a mechanical motion or position with an electrical circuit. The selection of a limit switch involves both electrical application requirements and mechanical placement.

Limit switches are normally in the control circuit and can start a machine in motion or stop its motion. They can also restrict the travel of a machine between two points or possibly initiate a separate action at a pre-determined point of machine travel.

Limit switches are also often used in safety devices for the protection of both personnel and equipment.

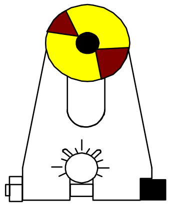
TYPES OF LIMIT SWITCHES

The function performed by limit switches is similar no matter how complex the design of the electrical circuit. The main differences are the mechanical design and the means by which the switch is actuated.

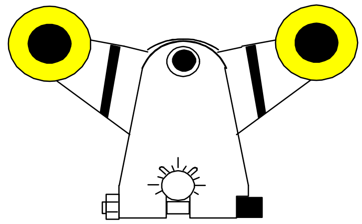
ACTUATORS

An actuator is the external linkage that detects the mechanical movement of the machine. This actuates an internal mechanism that results in contacts opening or closing.

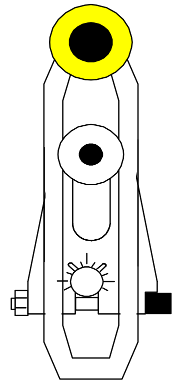
EXAMPLES OF ACTUATORS



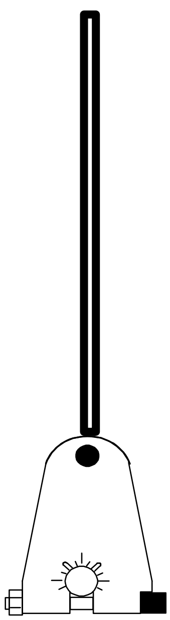
ROLLER LEVER



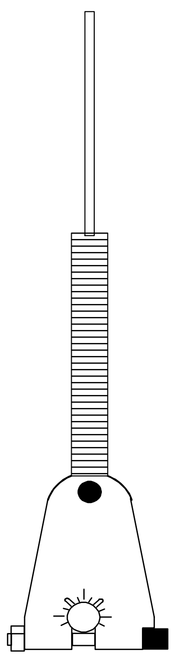
FORKED ARM



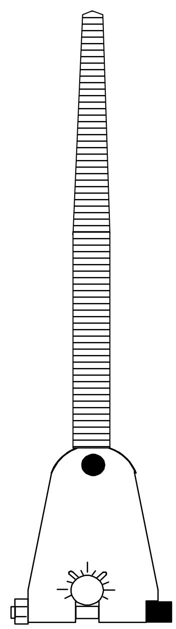
ADJUSTABLE LENGTH ROLLER LEVER



ROD



SPRING ROD LEVER



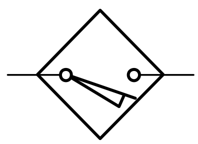
SPRING LEVER

PROXIMITY SENSORS

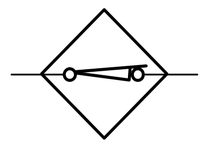
Introduction to Proximity Sensors
These devices can fulfill the same functions as the mechanical limit switch contacts, and have the following advantages:

- Rapid speed of operation
- Insensitive to humid or damp surroundings.

Proximity Sensor Symbols:



N.O.

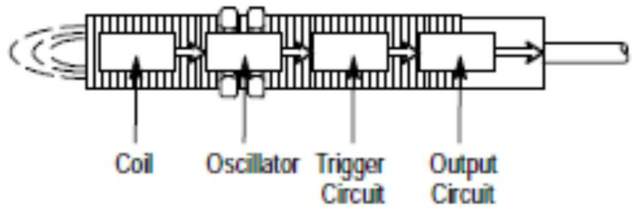


N.C.

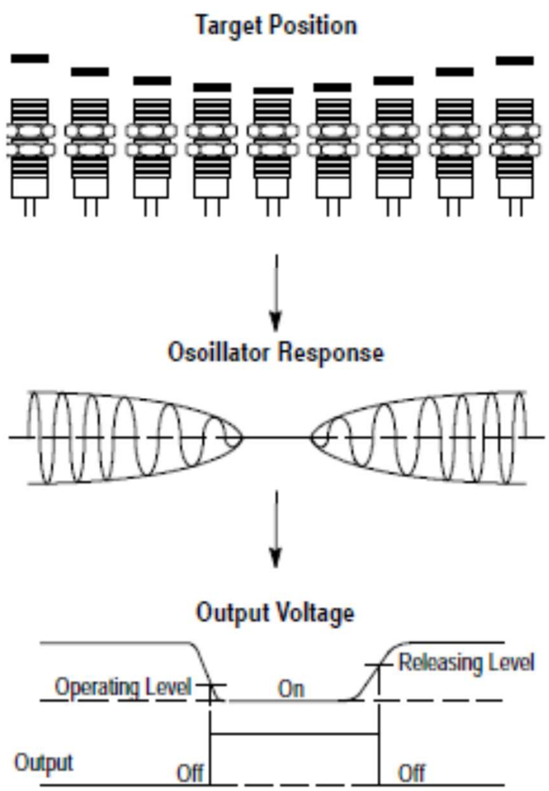
There are three types:

-Inductive
-Capacitive
-Ultrasonic

Principles of Operation for Inductive Proximity Sensors

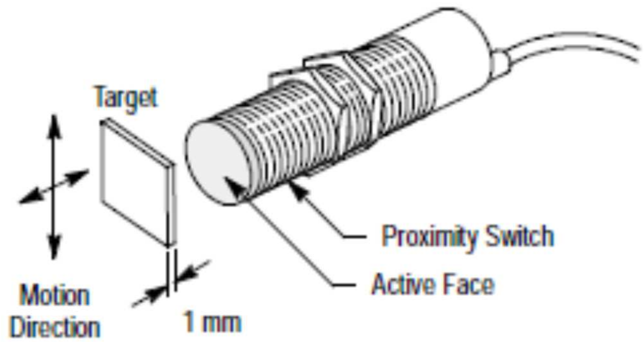


Inductive proximity sensors are designed to operate by generating an electromagnetic field and detecting the eddy current losses generated when ferrous and nonferrous metal target objects enter the field. The sensor consists of a coil on a ferrite core, an oscillator, a trigger-signal level detector and an output circuit. As a metal object advances into the field, eddy currents are induced in the target. The result is a loss of energy and lower amplitudes of oscillation. The detector circuit then recognizes a specific change in amplitude and generates a signal which will turn the solid-state output "**ON**" or "**OFF**."



A metal target approaching an inductive proximity sensor (above) absorbs energy generated by the oscillator. When the target is in close range, the energy drain stops the oscillator and changes the output state.

Standard Target for Inductive Proximity Sensors



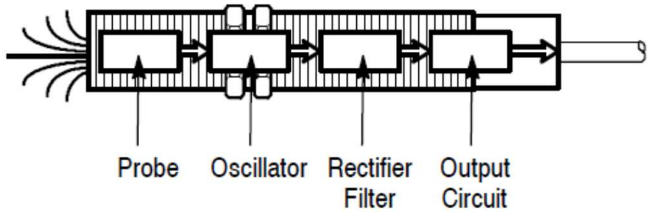
The active face of an inductive proximity switch is the surface where a high-frequency electro-magnetic field emerges.

A standard target is a mild steel square, one mm thick, with side lengths equal to the diameter of the active face or three times the nominal switching distance, whichever is greater.

The size and shape of the target may also affect the sensing distance. The following should be used as a general guideline when correcting for the size and shape of a target:

- Flat targets are preferable
- Rounded targets may reduce the sensing distance
- Nonferrous materials usually reduce the sensing distance for all-metal sensing models
- Targets smaller than the sensing face typically reduce the sensing distance
- Targets larger than the sensing face may increase the sensing distance
- Foils may increase the sensing distance

Principles of Operation for Capacitive Proximity Sensors



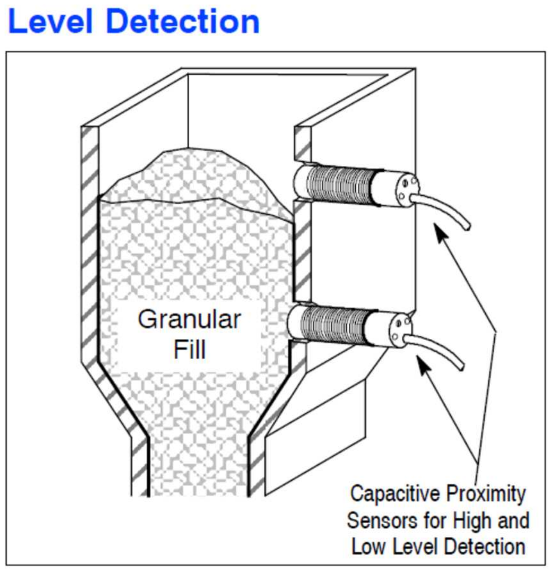
Capacitive proximity sensors are designed to operate by generating an electrostatic field and detecting changes in this field caused when a target approaches the sensing face. The sensor's internal workings consist of a capacitive probe, an oscillator, a signal rectifier, a filter circuit and an output circuit.

In the absence of a target, the oscillator is inactive. As a target approaches, it raises the capacitance of the probe system. When the capacitance reaches a specified threshold, the oscillator is activated which triggers the output circuit to change between "on" and "off."

The capacitance of the probe system is determined by the target's size, dielectric constant and distance from the probe. The larger the size and dielectric constant of a target, the more it increases capacitance. The shorter the distance between target and probe, the more the target increases capacitance.

Standard Target and Grounding for Capacitive Proximity Sensors
The standard target for capacitive sensors is the same as for inductive proximity sensors. The target is grounded per IEC test standards. However, a target in a typical application does not need to be grounded to achieve reliable sensing.

Use of a Capacitive Proximity Sensor

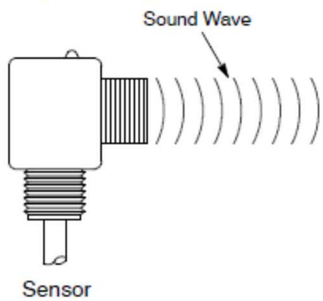


Ultrasonic Proximity Sensors

Ultrasonic Proximity Sensors

Technical Definitions and Terminology

Principles of Operation

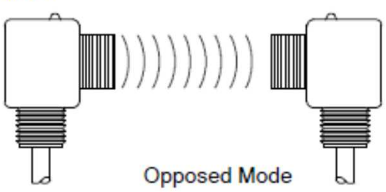


Ultrasonic sensors operate by emitting and receiving high-frequency sound waves. The frequency is usually in the order of 200 kHz, which is too high for the human ear to hear.

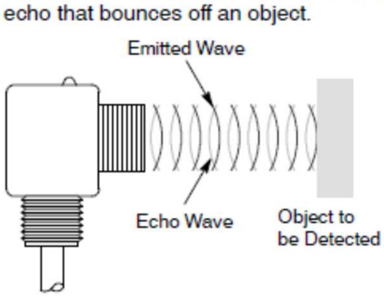
Modes of Operation

There are two basic modes of operation: opposed mode and diffuse (echo) mode.

In opposed mode, one sensor emits the sound wave and another, mounted opposite the emitter, receives the sound wave.

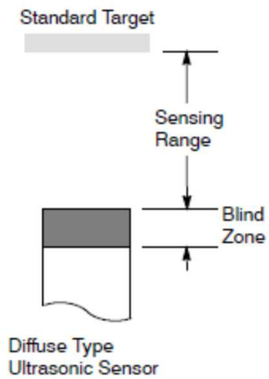


In diffuse mode, the same sensor emits the sound wave and then listens for the echo that bounces off an object.



Sensing Range

The sensing range is the distance within which the ultrasonic sensor will detect a target under fluctuations of temperature and voltage.



Blind Zone

Ultrasonic sensors have an inherent blind zone located at the sensing face. The size of the blind zone depends on the frequency of the transducer. Objects located within the blind spot can not be reliably detected.

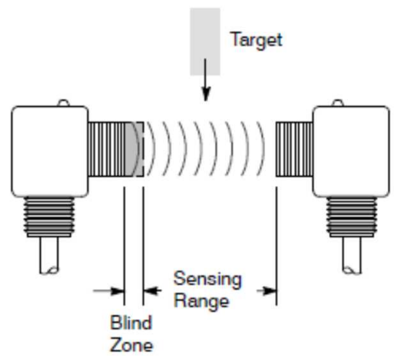
Target Considerations

Certain characteristic of targets must be considered when using ultrasonic sensors. These include target shape, material, temperature, size and positioning.

Soft materials such as fabric or foam rubber are difficult to detect by diffuse ultrasonic technology because they are not sound-reflective.

The standard target for a diffuse type ultrasonic sensor is established by the International Electrotechnical Commission standard IEC 60947-5-2. The standard target is a square shape, having a thickness of 1mm and made from metal with a rolled finish. The size of the target is dependent upon the sensing range.

For opposed mode ultrasonic sensors, there is no established standard.

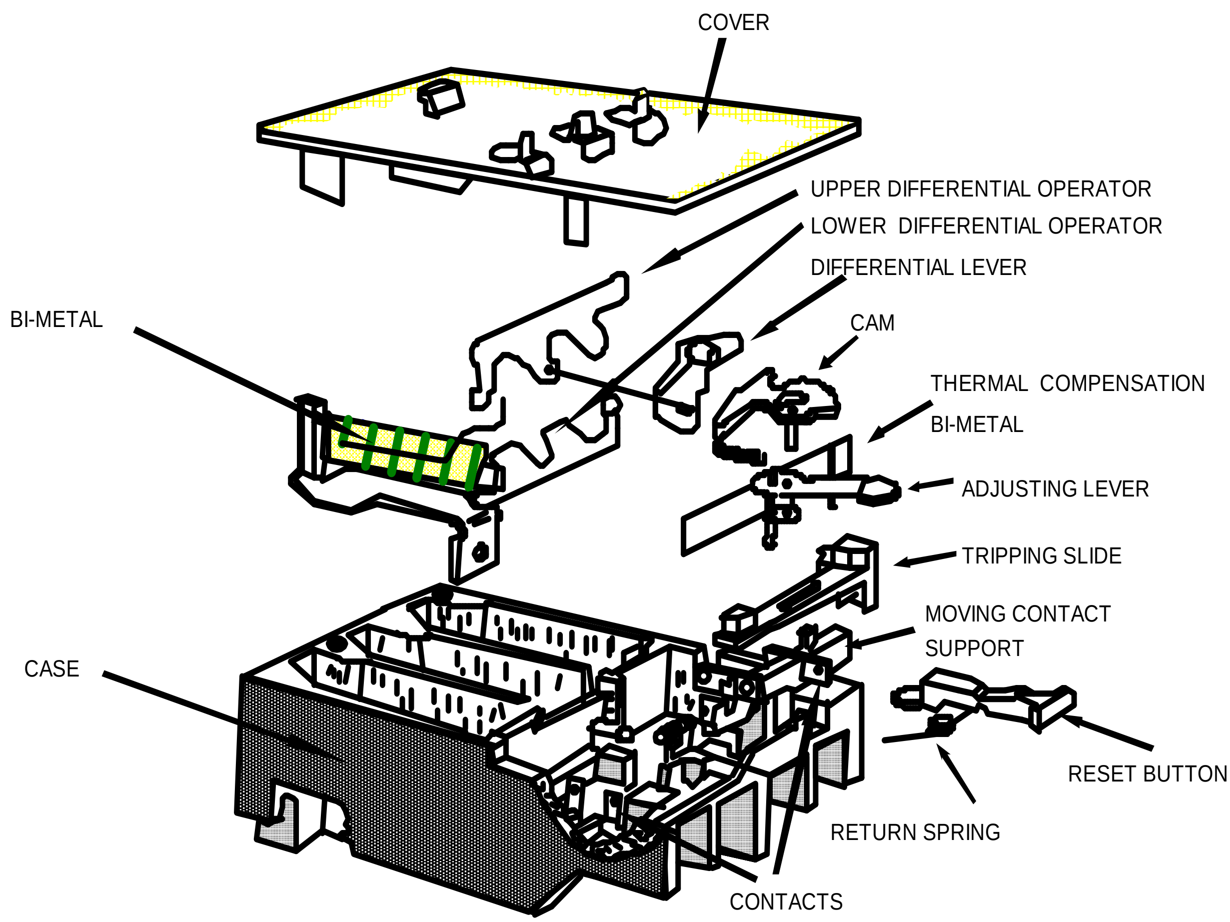


Standard targets are used to establish the performance parameters of the sensors. The user must take into consideration differences in performance due to nonstandard targets.

OVERCURRENT RELAY

CONSTRUCTION

TELEMECANIQUE
LR1-D



O/L SPECIFICATIONS

OPERATING RANGES

LR1-DO9		LR1-D12	LR1-D16	LR1-D25	LR1-D40	LR1-D63
0.1-0.16A 0.16-0.25A 0.25-0.4A 0.4-0.63A 0.63-1.0A	1-1.6A 1.6-2.5A 2.5-4A 4-6A 5.5-8A 7-10A	10-13A	13-18A	18-25A	23-32A 30-40A	38-50A 48-57A 57-66A

Maximum Voltage: 600V AC or DC

Frequency Range: up to 400 Hz

CONTACTS

1 Normally Open and 1 Normally Closed

AMBIENT TEMPERATURE COMPENSATION

From - 4 to 140 °F
-20 to 60 °C

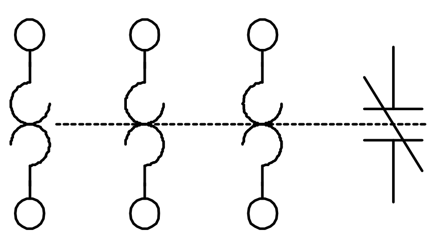
DIFFERENTIAL

Phase loss and phase unbalance detection

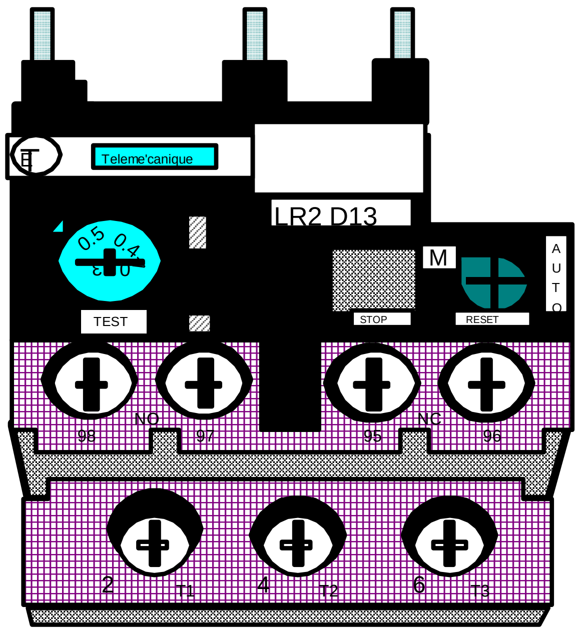
FUNCTION - The overcurrent relay is used to protect motors in case of:

- Prolonged Overcurrent (**105 to 125% Full Load Current**)
- Phase Unbalance
- Phase Loss

SYMBOL

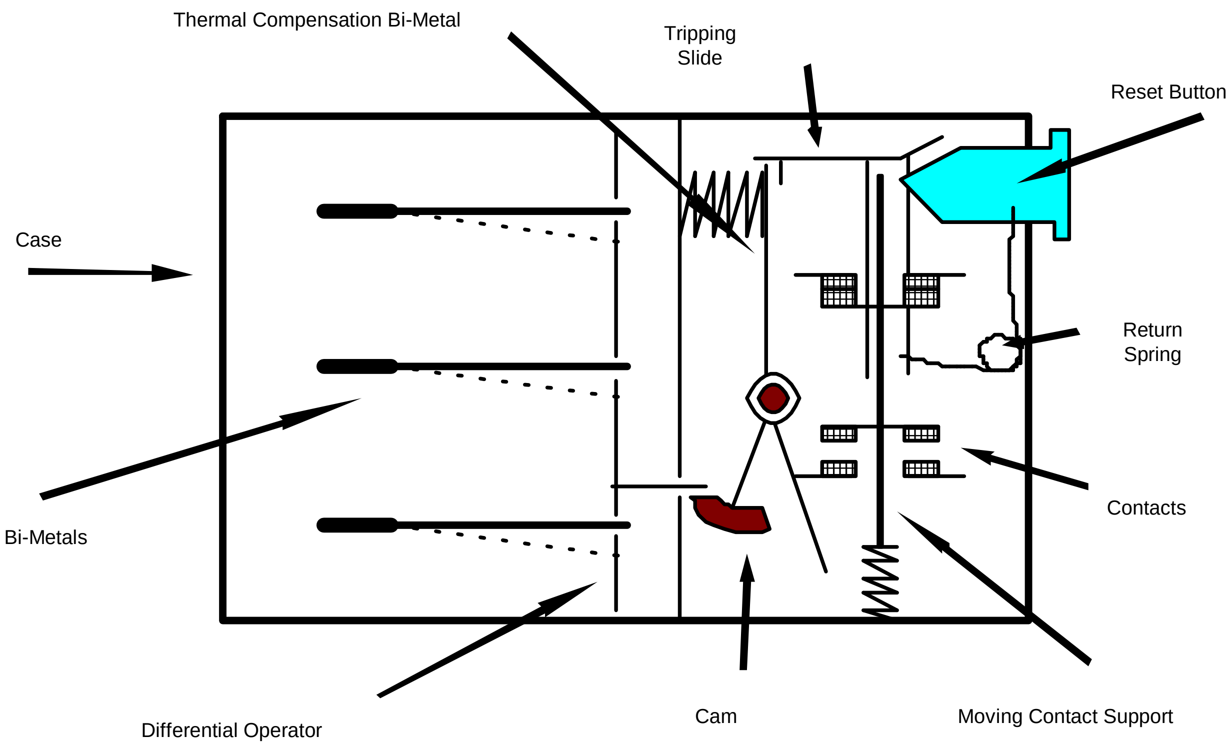


ADJUSTMENT and RESETTING

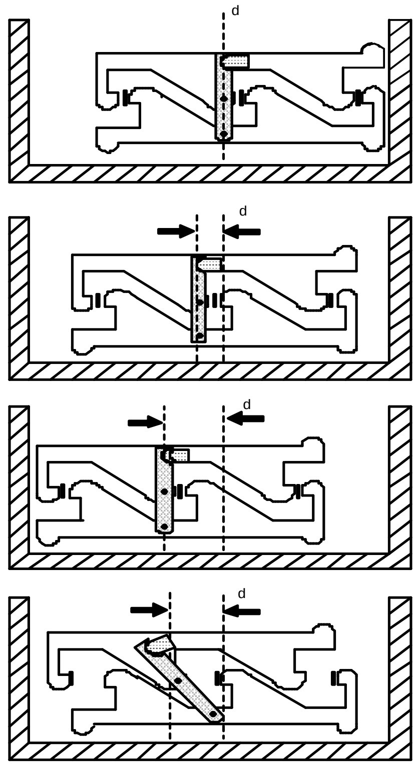


ADJUSTMENT	-	**Adjusting dial must be set to read the full load current of the motor (FLC).**
RESETTING	-	Resetting is done by pressing the blue reset button after the bi-metal elements have been allowed to cool down.

MECHANICAL OPERATION



DIFFERENTIAL OPERATION



COLD POSITION	-	The differential operators are hard over to the right.
WARM POSITION	-	**NORMAL BALANCED CURRENT** - The 3 bi-metals and the operators move to the left the same distance **d.**
WARM POSITION	-	**BALANCED OVERCURRENT** - The 3 bi-metals and the operators move over to the left the same distance which trips the overcurrent relay. Tripping current is 125% of the actual adjusting dial value.
WARM POSITION	-	**UNBALANCED CURRENT** - The unbalanced current causes unequal deflection of the 3 bi-metal strips. The differential lever amplifies this unequal deflection. The distance **d** is also amplified and causes the mechanism to trip. **The tripping current for an unbalanced current is equal to 80% of the current for 3 balanced phases.**

FUSES AND CIRCUIT BREAKERS

INTRODUCTION TO FUSES

I. **Purpose** - A fuse is intended to safely isolate a fault preventing damage to equipment. Current resulting from an overload or short circuit fault will damage or completely destroy system components if not quickly interrupted. A fuse provides reliable circuit protection preventing or minimizing damage to components such as conductors, transformers, motors, motor starters, etc. Without adequate protection of electrical distribution systems, a fault can result in severe damage to equipment and significant monetary loss due to machine or manufacturing plant downtime.

II. **Definitions**

A. **Overcurrent** - An overcurrent is excess current resulting from either a short circuit or an overload.

B. **Overload** - An overload is a current that is in excess of normal current but confined to normal conducting paths. An overload current is typically **one to six times the normal current**. It is usually associated with the normal start up of motors or inrush current to a transformer. Provided that the overload current is not continuous, any temperature rise of components will be small and have no harmful effects. An overload current becomes harmful only when it is **sustained**.

An example of a sustained overload is a defective or overloaded motor. If an overload is sustained beyond several seconds, components will begin to overheat due to the excess current that they are required to pass. This excess heat will damage or degrade the components and could lead to further problems such as short circuits due to melting insulation.

C. **Short Circuit** - Unlike an overload current, a short circuit current is not confined to normal conducting paths. Also, an overload current is relatively small being only one to six times that of the normal level. A short circuit current can be **several hundred times greater than normal current levels**.

A short circuit current can have very destructive effects totally destroying distribution equipment and causing fires. The heat energy produced by a short circuit current can be great enough to vaporize metal, melt conductors, and cause severe insulation damage. Arcing produces ionized gases that result in other conductive paths and additional short circuits.

Short circuit currents can result in destroying cable trays, warping bus bars and completely disconnecting the bus bars from their retaining supports. Any conductor that carries current will have a magnetic field around the conductor. When conductors are subjected to short circuit currents, the forces produced by the interaction of conductor magnetic fields are very destructive. The forces can typically be several hundred pounds per linear foot of the conductor.

D. **Voltage Rating** - The voltage rating of a fuse is the **maximum circuit voltage in which the fuse can be safely applied**. If the voltage rating is exceeded, re-strike is possible across the open fuse element. The fuse also may not safely clear the fault. For instance, a 250volt fuse could safely be used in a 208volt system but not in a 480volt system. The voltage rating is marked on the fuse and is usually related to its physical length within the manufacturer's specifications. This is not to say that all 600volt fuses are all the same length, but that most manufacturers have length specifications for their 600 volt fuses within its applications.

E. **Continuous Current Rating** - The continuous current rating on the fuse is the current that the fuse is intended to normally carry. The fuse will carry this current indefinitely. In selecting the continuous current rating, consideration must be given to the type of load, application and code requirements. The continuous current rating is marked on the fuse and is usually related to its physical diameter. This is not to say that all 30 ampere fuses are the same diameter, but that most manufacturers have diameter specifications for their 30 ampere fuses within its applications.

F. **Interrupting Rating** - A fuse must be able to withstand the destructive energy of a short circuit current and be able to interrupt the current without **rupture**. **The interrupting rating is the maximum short circuit current that a fuse can safely interrupt without rupturing**. The National Electric Code, Section 110-9, requires equipment intended to break current at fault levels to have an interrupting rating sufficient for the current that must be interrupted.
Analysis of a distribution system must be made to estimate available short circuit fault currents. Upon completed analysis, fuses with an adequate interrupting rating can be selected. A typical short circuit current available from a 500KVA, 480 Volt transformer is approximately 50,000 amperes.

G. **Current Limitation** - The term current limitation is associated with short circuit conditions, not overloads. **A fuse is said to be current limiting if it operates quickly under short circuit conditions, typically in less than one half of a cycle**. By opening quickly, the instantaneous peak short circuit current is **limited** to a value much less than the peak that would otherwise occur. This greatly reduces the heat energy that would otherwise be let-through to circuit conductors and components. The total energy let-through by a fuse is a function of the product of the current squared and time in seconds (I^2t).
A circuit breaker being an inherently slow device will subject a circuit to the full peak short circuit current for several cycles before opening. During this period of time, circuit conductors and components are being subjected to an enormous amount of heat energy. A fuse being a fast acting current limiting device can be used in combination with a breaker to overcome the breaker's limitation.

H. **Selective Coordination** - Selective coordination concerns the need to prevent facility blackouts. **If distribution systems protective devices are selective, only the protective device nearest the faulted circuit will open**. Devices upstream remain intact, supplying other feeders. For a system to be selective, a minimum ratio must be maintained between upstream and downstream continuous current ratings. The ratio is specified by the fuse manufacturer and depends on the type of fuse.

III.**Fuse Classification**

A. **Safety/Standards Organizations** - Various safety and standard organizations exist which assign classifications to fuses based on the criteria of safety and performance. The most predominant of these organizations is Underwriter's Laboratories, Inc. Underwriter's Laboratories evaluates fuses under specific conditions, regulatory codes and other standards including international standards. Based upon the results, U.L. may "list" the fuse and assign the fuse a class such as RK1, H, or J. There are U.L. standards that define the criteria that a fuse must meet to be considered belonging to a particular class.

B. **U.L. Classifications for Low Voltage Fuses** - A low voltage fuse is a fuse with a voltage rating of 600 volts or less. Illustrated on the following pages are charts. These charts list fuses by U.L. classification and their corresponding characteristics.

C. **Class Types** - Fuses are available with different interrupting ratings which makes misapplication possible. For instance, UL class K5 and class H fuses are both available with the same physical dimensions. Although each fuse has the same physical dimensions, voltage rating and continuous current rating, their interrupting ratings are significantly different. **The class K5 fuse has an interrupting rating of 50,000 to 200,000 amperes** where **the class H fuse has a rating of 10,000 amperes**. If the class H fuse is used in place of the class K5 fuse and a short circuit occurs resulting in a fault current in excess of 10,000 amperes, the class H fuse will rupture possibly injuring nearby personnel.
To overcome this problem a **rejection feature** is built into the end ferrules of class RK1 and RK5 fuses. The **"R"** in the class designation indicates a rejection type fuse with a minimum **interrupting rating of 200,000 amperes**. Rejection type fuses will fit only into fuse blocks intended to receive the modified end ferrule. The fuse block rejects a class H fuse, as it will not fit, since it is missing the special end ferrule.

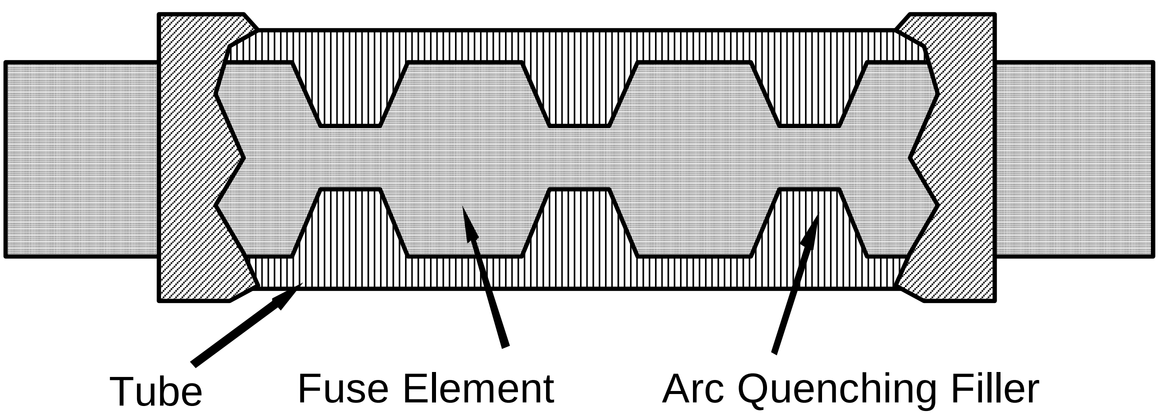
OPERATING PRINCIPLES OF FUSES

High interrupting rated; current-limiting fuses provide safe and reliable protection for electrical distribution systems. They can be used with complete confidence in their performance. Fuses operate from increased fuse element temperature caused by an overcurrent flowing through them. Since the functioning of fuses does not depend on the operation of intricate moving mechanical parts, fuse performance characteristics are reliable. Fuses remain safe and accurate since age does not increase their current carrying capacity nor lengthen their opening time. After a fuse has been used to clear a short-circuit or overload, it is replaced by a new safe, factory calibrated unit, as accurate and dependable as the original. The two basic types of current-limiting fuses are **single element** and **dual element** fuses. Each type has a simple, reliable operation principle.

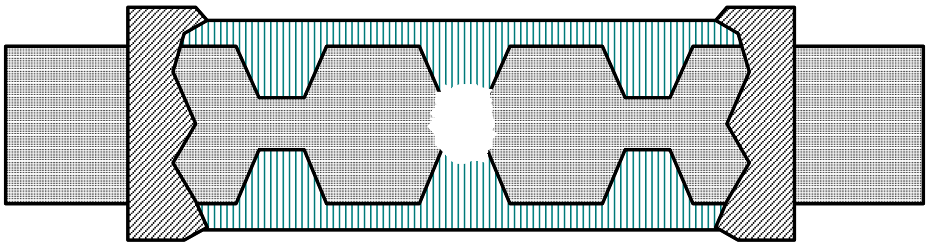
Semiconductor or Rectifier type fuses are used for special applications on electronic equipment such as power supplies. These fuses are very fast acting and are sized just like the single element type used for a control transformer secondary.

SINGLE ELEMENT FUSES

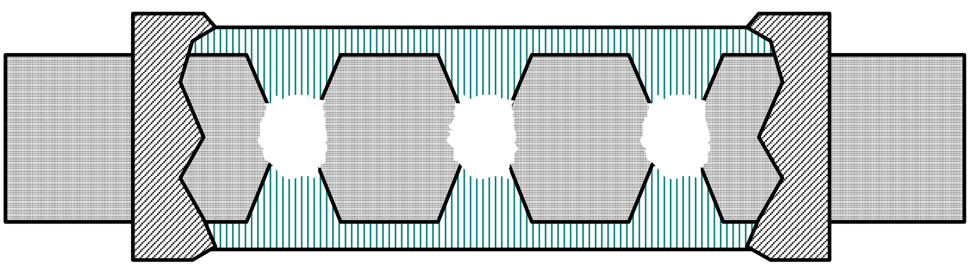
A single-element fuse consists of a link or several links contained in a tube filled with arc-quenching filler.

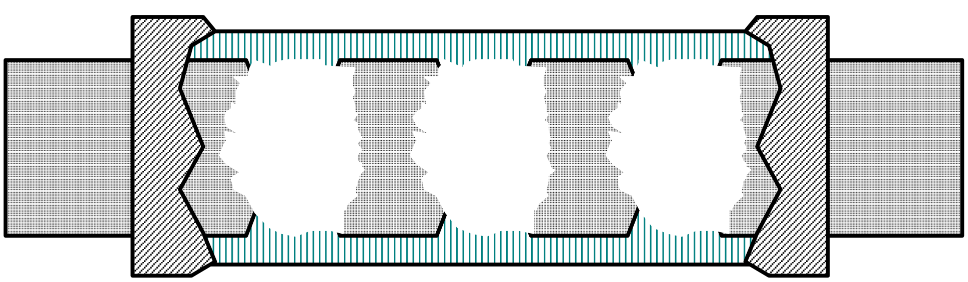


Overload Operation - If an overload current of more than rated current is continued for a sufficiently long period of time, the fuse link melts. An arc across the resulting gap burns back the metal, lengthening the gap. The arc is quenched and the circuit interrupted when the break is of sufficient length. The surrounding filler aids the arc quenching process.

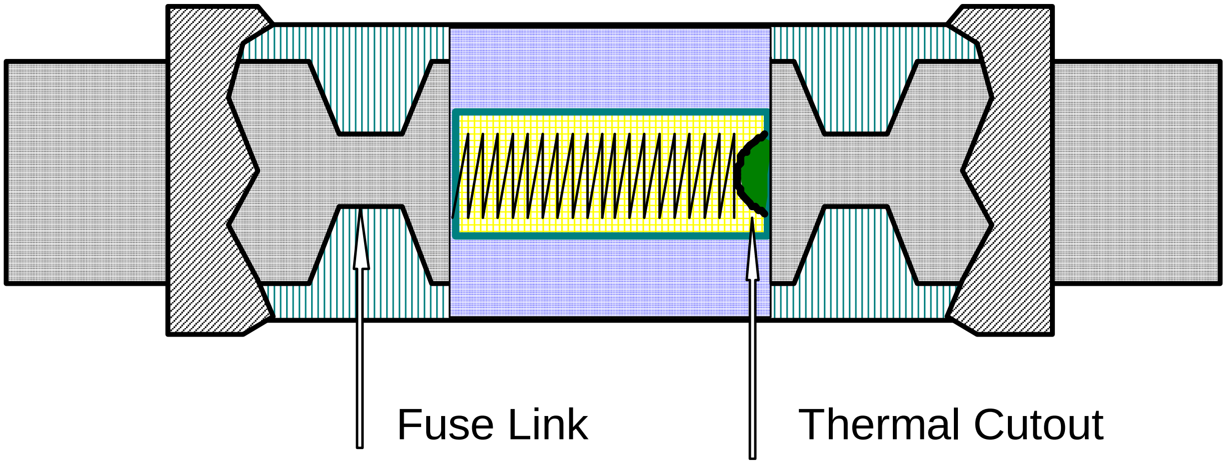


Short Circuit Operation - On a short circuit several sections of the link melt instantly. Arcing across the vaporized portions of the link commences, and the arc extinguishing filler quickly aids in quenching these arcs, and thus clearing the circuit. Although the fuse opening operation is caused by an increase in the link temperature, the fusing opening operation is safely contained in the fuse casing and the circuit is interrupted in a fraction of a second. The total operating time of current limiting fuses during short circuit conditions can be less than a half cycle (less than 8/1000 of a second). For high short circuit currents the total clearing time can be less than a quarter cycle. It is this fast clearing speed which enables current limiting fuses to protect system components from damage due to high short circuit currents that may occur.





DUAL ELEMENT FUSES



The thermal cutout gives dual element fuses a time delay on overloads, such as motor starting current. This delay allows the motor starting current to be disregarded during that time as long as the current is within five to six times normal running current. The fuse link in dual element fuses provides current limiting, short circuit protection just as single element fuses.

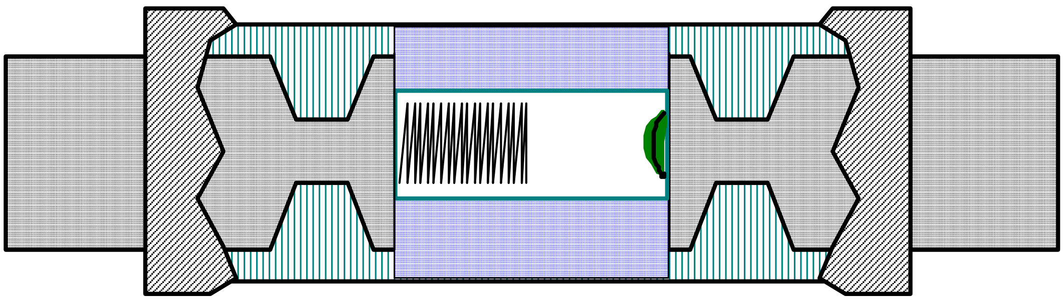
Dual element, time delay fuses utilize this time delay in the low overload range to eliminate needless opening on harmless overloads and transient conditions. These fuses are extremely fast opening and current limiting on short circuit currents. This beneficial time current characteristic is obtained by using two fusible elements (thus the name dual element) connected in series and contained in one tube:

(1) The thermal cutout element and,
(2) The fuse link element surrounded with arc extinguishing filler.

The magnitude of the overcurrent determines which element functions. The thermal cutout element is designed to open on overcurrents of up to approximately 500% of the fuse ampere rating. The fuse link or short circuit element is designed to open on heavier overloads and short circuit currents. Typical dual element, time delay fuses by manufacture.

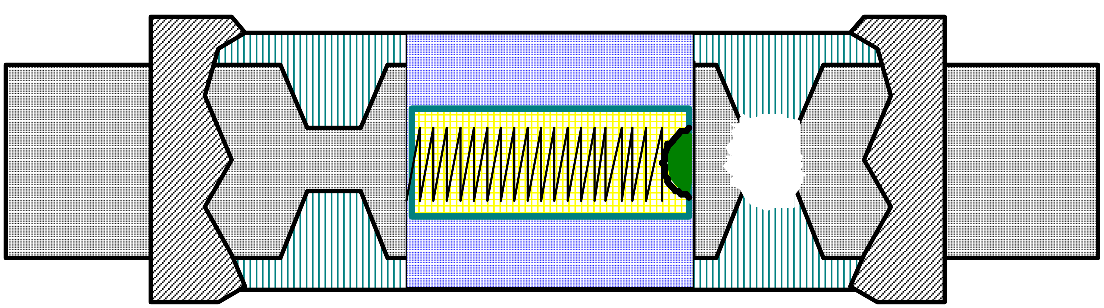
Manufacture	Name	Class
Bussman	KTS-R	RK1
Bussman	DLS-R	RK5
Bussman (*Fusetron*)	FRS-R	RK5
Gould Shawmut	TRS1R	RK5
Gould. Shawmut (*Amp-Trap*)	A6D1R	RK1

Overload Operation - On a low overload current the short circuit fuse link remains entirely inactive. The overload element consists of a center mass of copper on which is mounted a spring and a short connector. This connector is held in place by a low melting point solder joint, which connects the center mass of copper to the fuse link. When overload current flows long enough to raise the temperature of the center mass to the melting point of the solder, this connector is pulled out of place by the spring, thereby opening the circuit.



The thermal cutout element has a built-in time delay which permits momentary harmless surge currents such as motor starting current to flow without opening the fuse. If the overload current persists too long, the thermal cutout element clears the circuit, thus protecting the components and equipment. These fuses are ideal for motor, transformer and other circuits with harmless start-up current.

Short Circuit Operation - During a short circuit condition the fuse link acts as described for a single element fuse. A portion of the link vaporizes and the surrounding filler aids in extinguishing the arc. This fuse element has current-limiting ability for short circuit currents thereby reducing the mechanical, thermal, and arcing stress which system components would have to withstand.



CIRCUIT BREAKERS

The function of the circuit breaker corresponds basically to that of a switch in combination with a fuse. When the current is above the normal rating, either on overload or short circuit current, the circuit breaker is an automatic overcurrent protective device.

A circuit breaker (CB) will automatically interrupt current flow when the conditions are abnormal without damage to itself. The circuit breaker mechanism is set to interrupt the current at a particular overload value and it can interrupt a short circuit current.

The automatic circuit opening action of a circuit breaker is accomplished in several ways. Some of these are by thermal release, magnetic action, the combination of thermal release and magnetic actions, hydraulic means, and pneumatic means.

Advantages and Disadvantages - Comparison to Fuse Protection

A. **Advantages**
- Breakers can be reset after trip and need not be replaced normally.
- Breakers can be used as a switching device.
- In the case of air circuit breakers (ACB's) trip elements are adjustable (current and time)

B. **Disadvantages**
- Cost
- Size
- Handling and Weight

Circuit Breakers would be used in preference to fuses when a disconnect means is required. An example of this is motor control systems. Circuit breakers would also be used if sufficient space is available and if standard current ratings are required, such as, 20 A, 30A etc.

Fuses would be used in preference to circuit breakers where accurate current values are required, such as, 1.6A, 10.4A. Fuses (Rectifier/semi-conductor) would also be used in rapid response situations such as electronic circuits or Silicon Controlled Rectifier (SCR) Circuits found in D.C. Drives and other precise control circuits. Fuses are normally used when no disconnect means is required.

Thermal Circuit Breakers

Thermal (heat) type air circuit breakers are used primarily for protection against overcurrent. A typical thermal circuit breaker operates on the principle of metal expanding when heated. In Figure A, a mechanism holds the contacts closed with a latch. The thermal element is a bimetallic strip made of two different metals bonded together as illustrated in Figure B. The bimetallic strip, having resistance, heats in proportion to the line current. If the current becomes excessive for a prolonged period of time, the bimetallic strip becomes hot and bends because of different expansion rates of the two metals as illustrated in Figure B. When the strip bends sufficiently, it trips the latch and opens the contacts as illustrated in Figure C.

Thermal circuit breakers provide overload protection at voltages up to 600 volts A-C and 250 volts D-C, from 10 to 60 amperes.

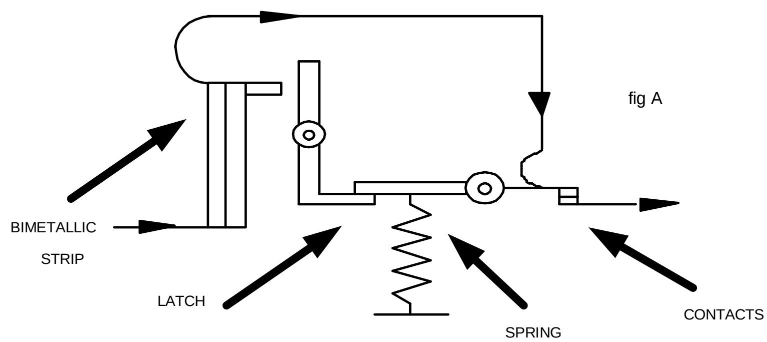


fig A

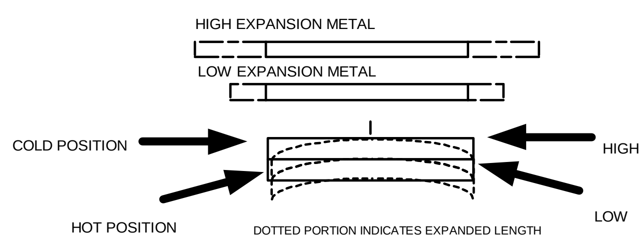


fig B

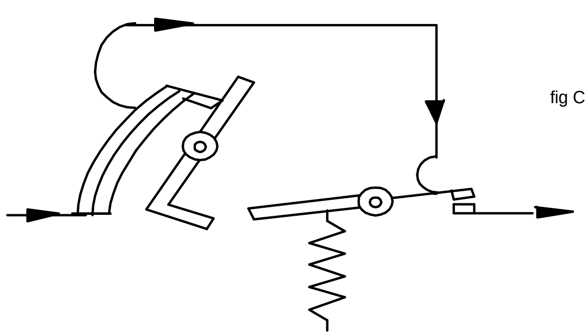


fig C

Magnetic Circuit Breaker

A magnetic circuit breaker has no thermal device. It is used whenever instantaneous action is required to open a faulted circuit. Figure A illustrates a magnetic circuit breaker under normal conditions. Figure B shows the circuit breaker in a tripped position.

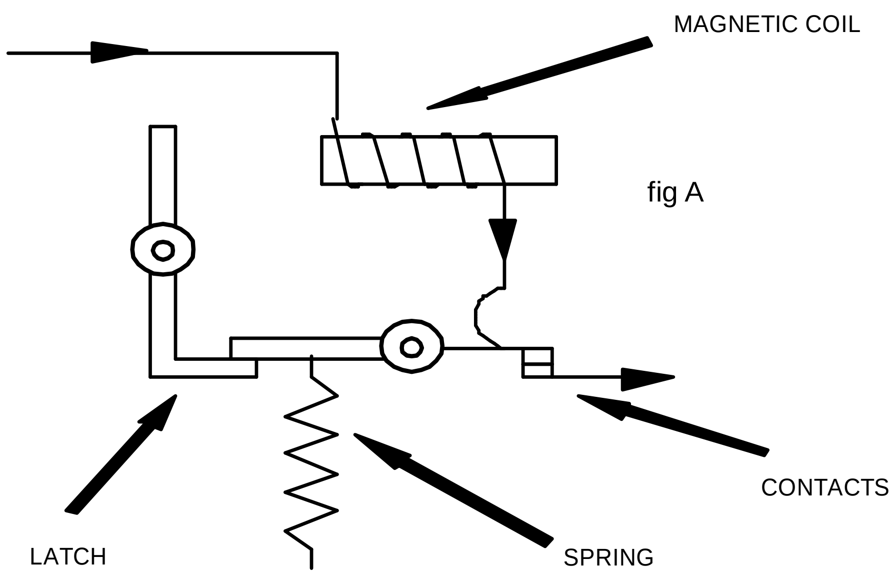


fig A

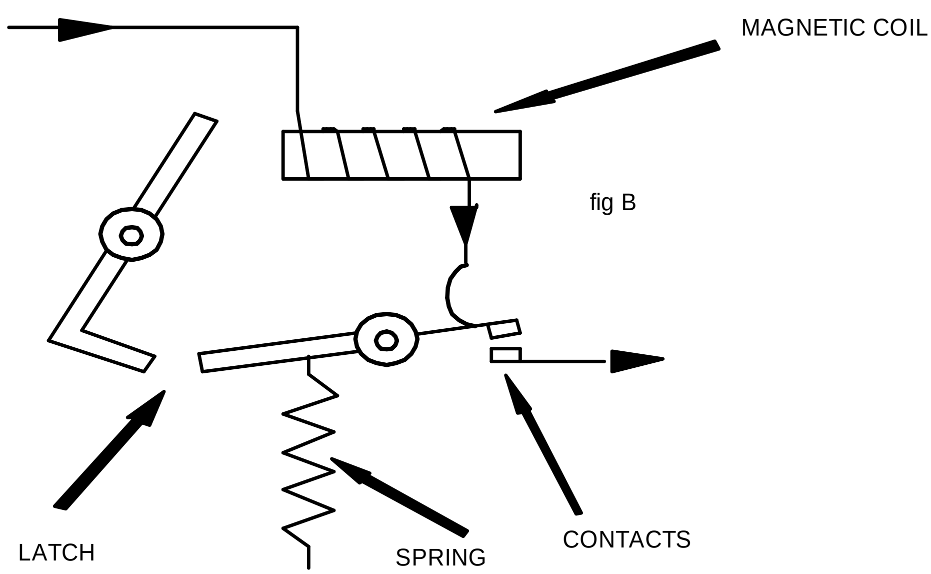
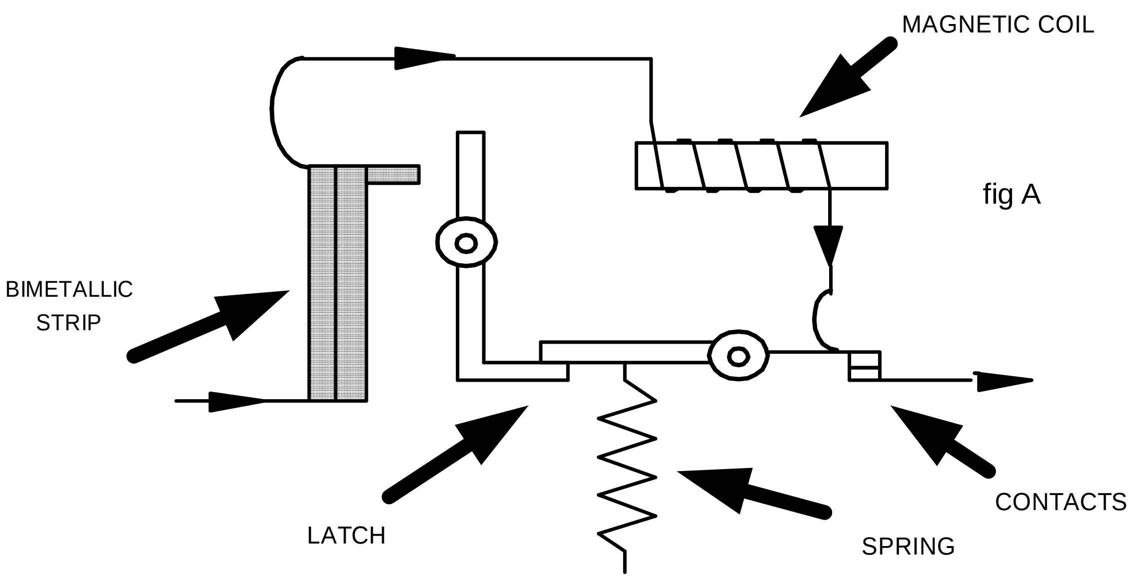
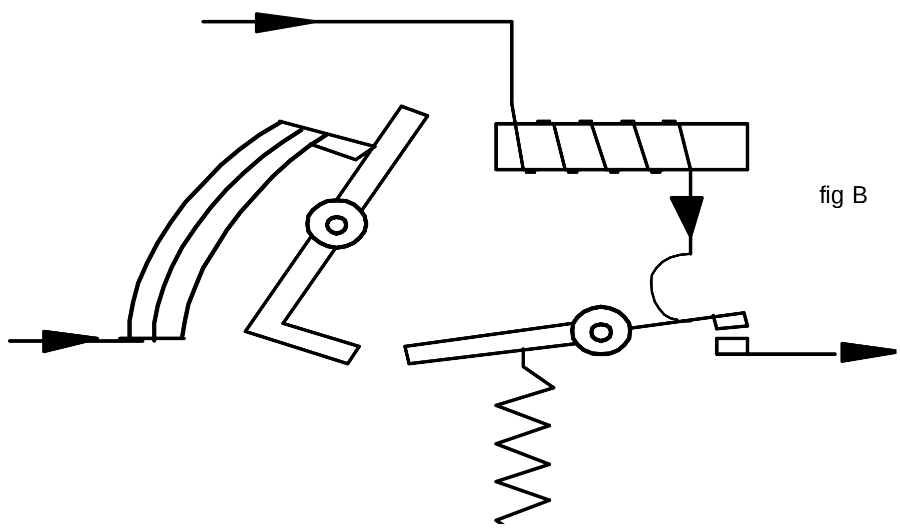


fig B

Thermal-Magnetic Circuit Breaker

A thermal-magnetic circuit breaker incorporates both a thermal strip and a magnetic coil. The thermal strip provides a time delay for momentary overloads. The magnetic coil provides instantaneous trip on high or short circuit currents. The magnetic trip also protects the bimetallic strip from excessive overheating that can destroy it. Figure A illustrates normal operation and Figure B illustrates





the tripped position of a thermal-magnetic circuit breaker.

Ambient Compensating Circuit Breaker

The ambient-compensated circuit breaker has an overload bimetallic strip, and a compensating bimetallic strip.

Both elements bend with an increase in ambient heat but only the overload element responds to the current. Figure A illustrates the ambient compensating circuit breaker in a normal ambient temperature of 18 to 21 degrees C. Figure B illustrates the two bimetallic strips bending because of an increase of ambient temperature. This does not trip the breaker. The breaker trips only when the excessive current through the overload strip causes it to bend more than the compensating strip.

The ambient-compensated circuit breaker is used in areas where high temperatures are encountered.

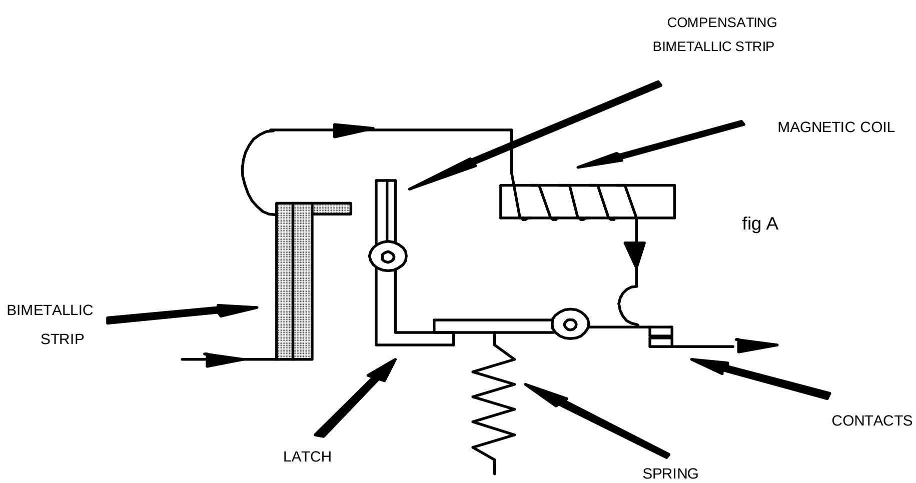


fig A

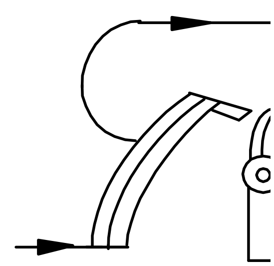


fig B

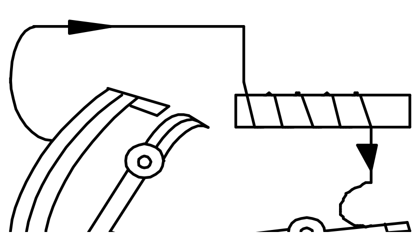
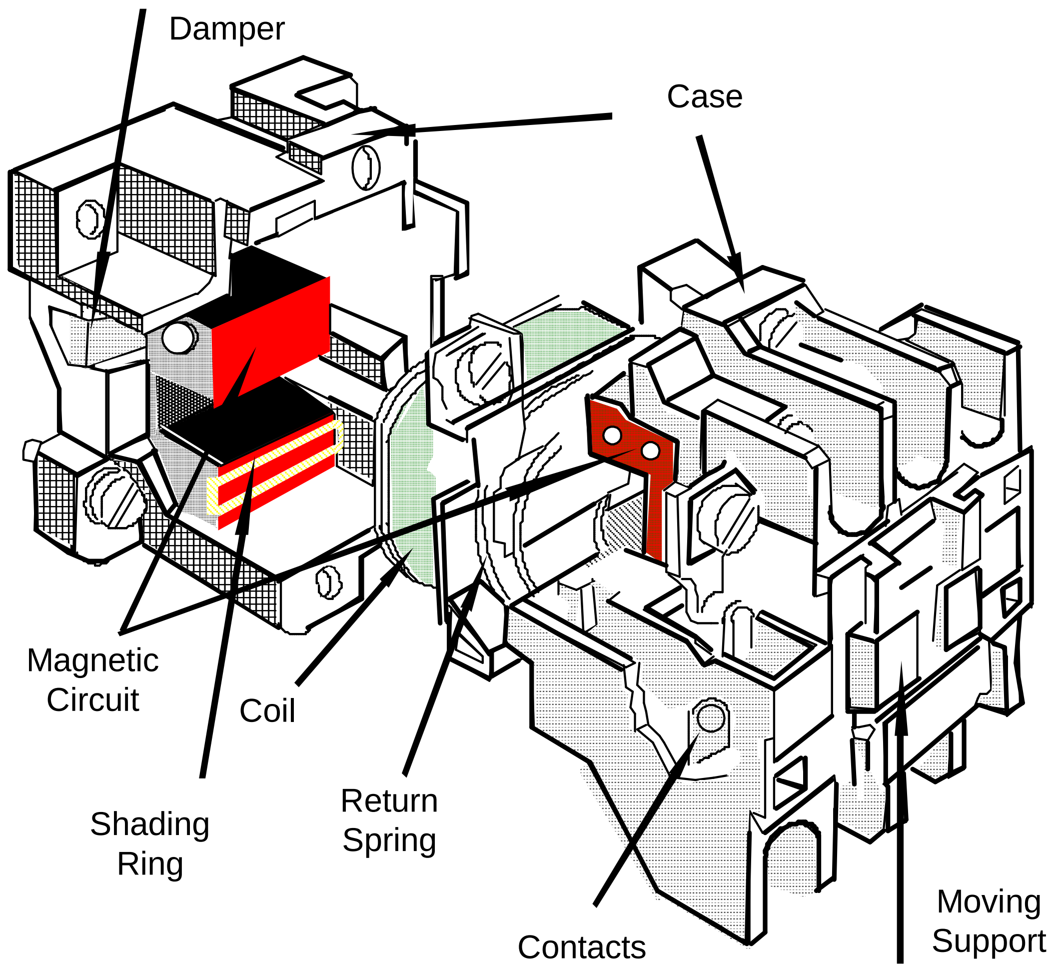


fig C

CONTACTORS AND RELAYS


Damper
Case
Magnetic
Circuit
Coil
Shading
Ring
Return
Spring
Contacts
Moving
Support

PURPOSE: Both relays and contactors provide a means of automatic operation of a machine from a remote location.

A contactor belongs to both the control circuit and the power circuit. The contactor coil and auxiliary contacts such as those required to seal-in or provide electrical interlock are found in the control circuit. The remaining main contacts are used to switch loads in the power circuit.

A relay is <u>always</u> used in the control circuit. It is used to remember machine events such as the momentary closure of a limit switch contact. It is also used to overcome contact constraints, such as, incorrect type or not enough normally open or normally closed contacts available on a particular device.

OPERATION AND CONSTRUCTION

CASE or HOUSING - Contains all the parts and provides the insulation necessary to isolate individual contacts.

CONTACTS

Main contacts, usually three and each of them having

- Fixed contact
- Movable contact
- Sometimes an arc blow-out device

Auxiliary contacts, usually on the device or added and having

- Fixed contact
- Movable contact

Different types

- Normally open contact
- Normally closed contact

These contacts should open and close at the same time as the main contacts and can be used to control various other circuits.

RETURN SPRING

This spring insures that the moveable core rapidly moves away for the stationary core when the coil is de-energized. This rapid opening insures that the contacts, both main and auxiliary open as quickly as possible.

ELECTROMAGNET

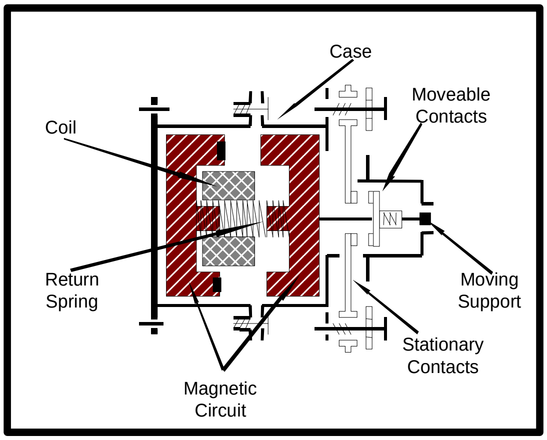
The main feature of a contactor that distinguishes it from a manual starter is the use of an **electromagnet**. The electromagnet is ultimately responsible for switching the state of the contacts. The electromagnet consists of the following:

Coil: The coil produces magnetic flux as the result of current flow. The **impedance of the coil limits the current in an AC circuit**. The coil's impedance is mainly inductive reactance since the coil usually has a very low internal resistance. **Only the DC resistance of the coil limits the current in a DC circuit**.

Stationary Core: The stationary core concentrates magnetic flux. In doing so, this core's surface, which mates with the moveable core, is polarized and attracts the moveable core. This core is constructed of laminated steel to reduce Eddy currents.

Movable Core: The moveable core also concentrates magnetic flux. The moveable core concentrates magnetic flux radiating from the mating surfaces of the stationary core. As a result, the mating surfaces of the moveable core are attracted to the stationary core resulting in the movement of the moveable core against the stationary core. The moveable core is attached through a plastic or insulated assembly to the contacts. As the moveable core is pulled against the stationary core, the contacts change state. Since the moveable core is made to move, it is often referred to as the armature. This core is also constructed of laminated steel to reduce Eddy currents.

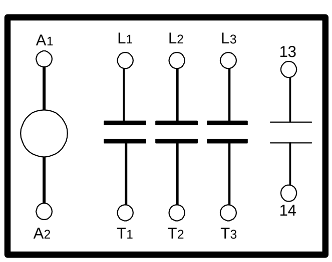
The contactor and relay functions are mechanically the same. The cross-section



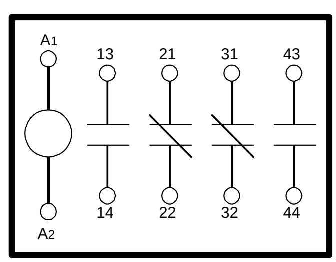
Mechanical Drawing Cross-Section

drawing above shows how the moveable contacts are mechanically connected to the moveable part of the magnetic circuit. When the moveable part of the magnetic circuit is pulled against the return spring, the moveable part of the contacts either closes or opens relative to the stationary set of corresponding contacts. This is a mechanical representation of the contactor. The moveable and stationary contacts must be electrically insulated and isolated from each other, the magnetic circuit and the coil. There are many different variations of contact configurations.

There is not just one symbol for a contactor or a relay. These devices are a combination of many symbols, such as contacts and coils. Below is an electrical representation for a contactor and a relay. Both contain a coil that has terminal numbers A1 and A2. The contactor has three main contacts numbered L1 –T1, L2 – T2, L3 – T3, which are designed to carry heavy loads to motors, heaters, etc. The darker lines show these main contacts. The contactors auxiliary contacts are shown with smaller lines and numbered 13 – 14. The relay has all smaller auxiliary type contacts with different numbers. The numbers will be different for different configurations of contacts. The one shown is two normally open and two normally closed.



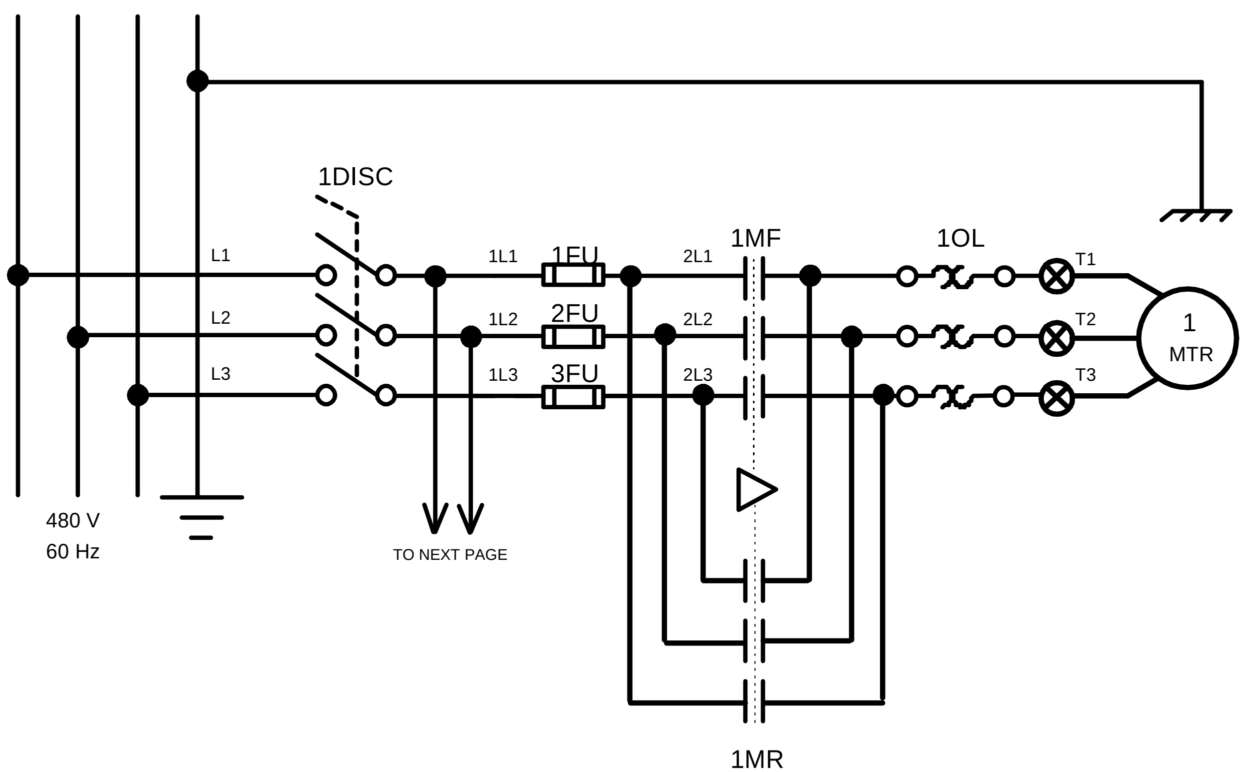
Electrical Representation for a Contactor



Electrical Representation for a Relay

Direct-On-Line Reversing

Motor starters are used when it is desired to reverse the direction of rotation of a three-phase squirrel-cage motor. The standard arrangement consists of a set of two, three pole; contactors operated electro-magnetically and mechanically linked together. They are usually controlled by three push buttons: **Forward**, **Reverse**, and **Emergency Stop**. The connections of one contactor reverse the supply voltage to two of the three motor terminals.



Forward-Reverse Contactor with Limit Switches to Control Stopping of the Opposing Motions

THE DIGITAL MULTI-METER (DMM)

Fig. 1

Digital multimeters (DMM) have generally replaced the analog-type multimeter (VOM) as the test device of choice for maintainers because they are easier to read, are often more compact and have greater accuracy. The DMM performs all standard VOM measurement functions of a-c and d-c. Some offer frequency and temperature measurement. Many have such features as peak-hold display that provides short-term memory for capturing the peak value of transient signals as well as audible and visual indications for continuity testing and level detection.

Measuring resistance – Fig. 4 shows the steps that should be followed when measuring resistance. Remember that resistance measurements are carried out without the power being applied to the component under test, and resistance values can vary by as much as 20% due to the tolerance of certain resistors. Do not be misled if your meter reading is slightly different from the color band on the resistor. If a resistor's value is off and exceeds the tolerance, the resistor should be replaced. A resistor will rarely short, but typically will open. If a resistor does open, the DMM display will flash on and off or display OL (open line) because the resistor has an infinite resistance.

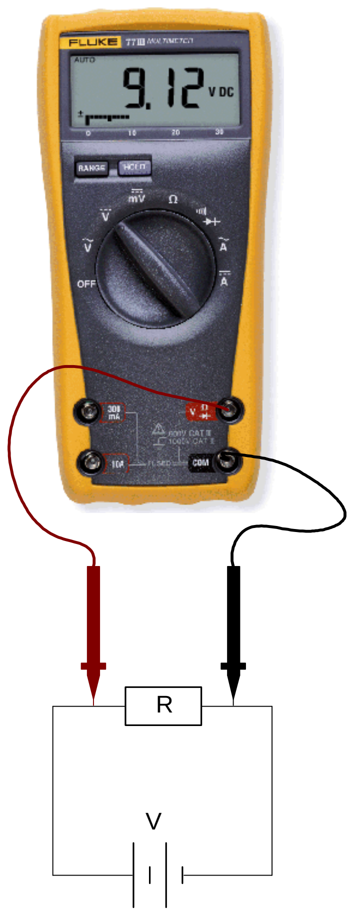
1. Turn off power to the circuit
2. Select resistance Ω
3. Plug the black test lead into the COM jack and the red test lead into the Ω jack
4. Connect the probe tips across the component or portion of the circuit for which you want to determine the resistance
5. View the reading and be sure to note the unit of measure, Ω, KΩ, MΩ, etc.

Fig. 4

Measuring voltage **– Fig. 5 shows the steps that should be followed when measuring voltage. The measurement of both voltage and resistance is where the DMM finds its greatest utilization. For voltage and resistance measurement, the red lead is inserted into the V – Ω (volt or ohm) meter jack.**

1. Select volts AC (V~), volts DC (V---), mvolts (V---) as desired
2. Plug the black test lead into the COM jack and the red test lead into the V jack
3. Touch the probe tips to the circuit across a load or power source as shown (parallel to the circuit to be tested)
4. View the reading being sure to note the unit of measure

Note: For DC readings of the correct polarity (+ or -), touch the red test probe to the positive side of the circuit, and the black test probe to the negative side of the circuit ground. If you reverse the connections, a DMM with auto-polarity will merely display a minus sign indicating negative polarity. With an analog meter you risk damaging the meter.



Measuring current – **Fig. 6 shows the steps that should be followed when measuring current. The measurement of current is rarely performed when troubleshooting, as the circuit path has to be opened to insert the DMM in series with the current flow. However, if current is to be measured, the red lead is inserted into one of the ampere jacks, 10 amp (10A) or 300 milliamp (300 mA) input jack depending on the expected value of the reading.**

1. Turn off the power to the circuit
2. Disconnect, cut or unsolder the circuit, creating a place where the meter probes can be inserted
3. Select amps AC (A~), or amps DC (A---) as desired
4. Plug the black test lead into the COM jack and the red test lead into 10 amp (10A) or 300 milliamp (300mA) jack depending on the expected value of the reading
5. Connect the probe tips to the circuit across the bread as shown so that all current will flow through the meter (a series connection)
6. Turn the circuit power back on
7. View the reading being sure to note the unit of measure

Note: If test leads are reversed a negative (-) sign will be displayed