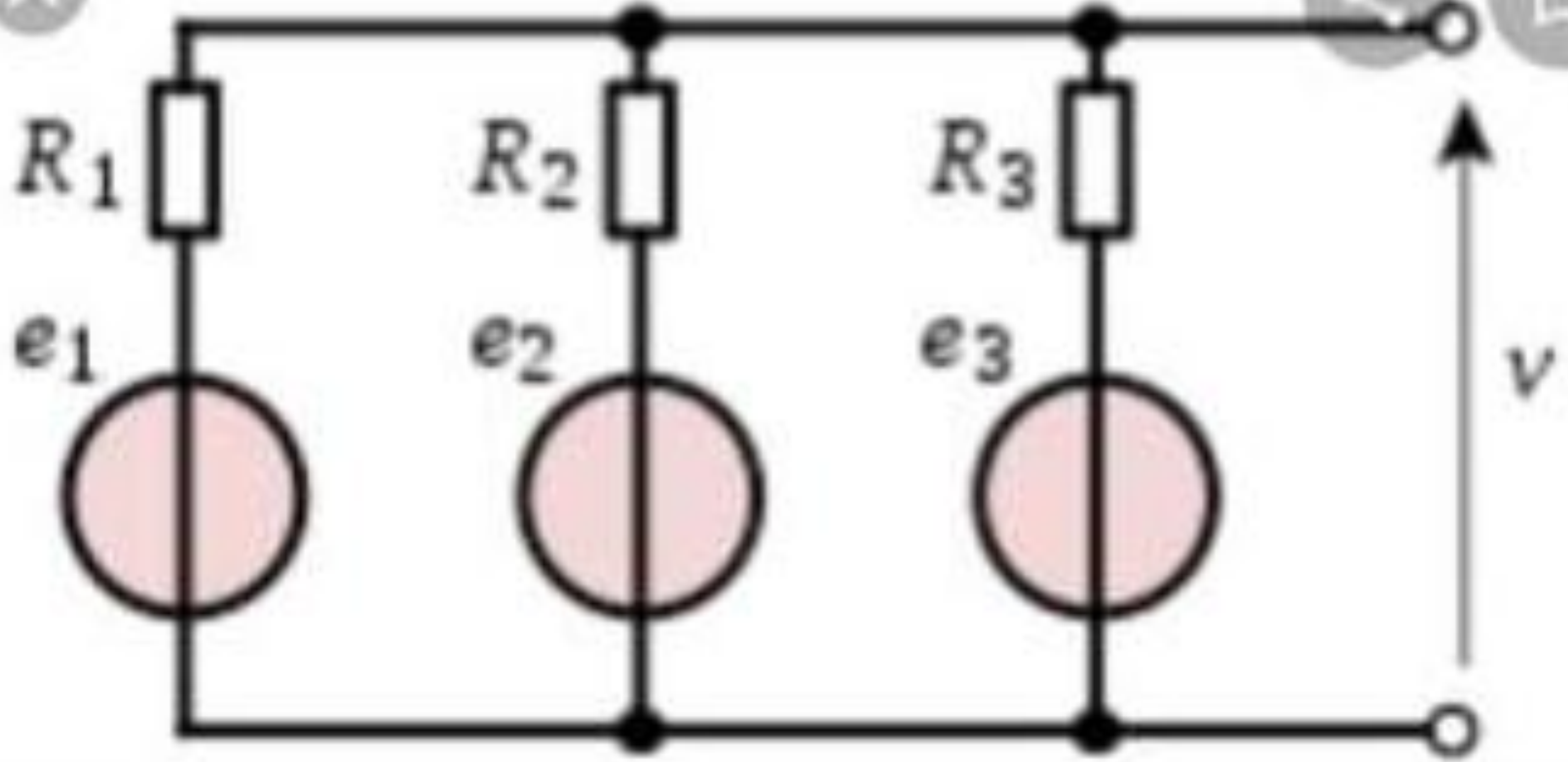
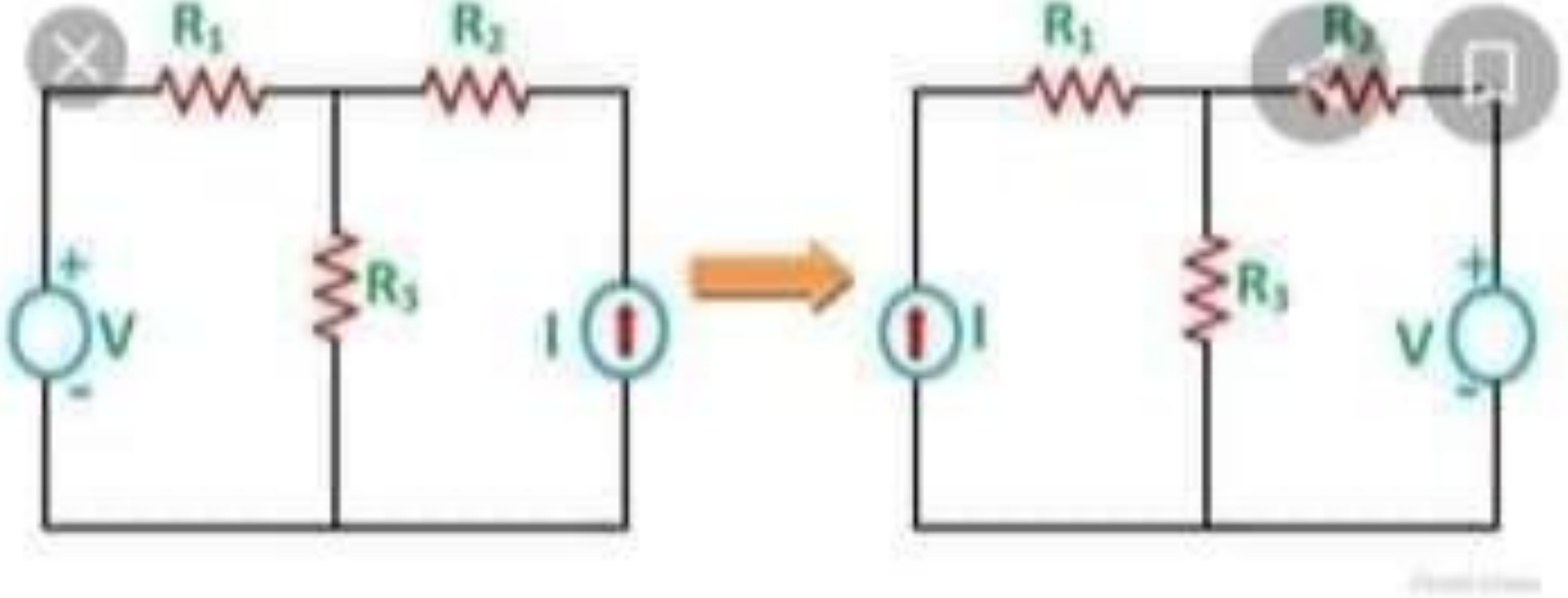
Millman's theorem states that in any circuit, if **the number of voltage sources is connected in series** along with internal resistances in the circuit which are in parallel, afterward these voltage sources may be changed through a single voltage source in series with a resistor.



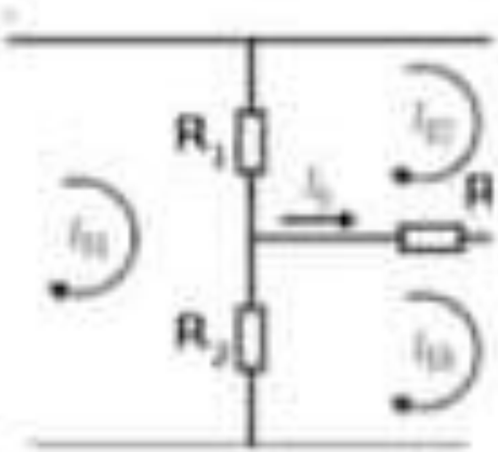
R1
R2
R3
e1
e2
e3
v

The reciprocity theorem states that **the current at one point in a circuit due to a voltage at a second point is the same as the current** at the second point due to the same voltage at the first. The reciprocity theorem is valid for almost all passive networks.



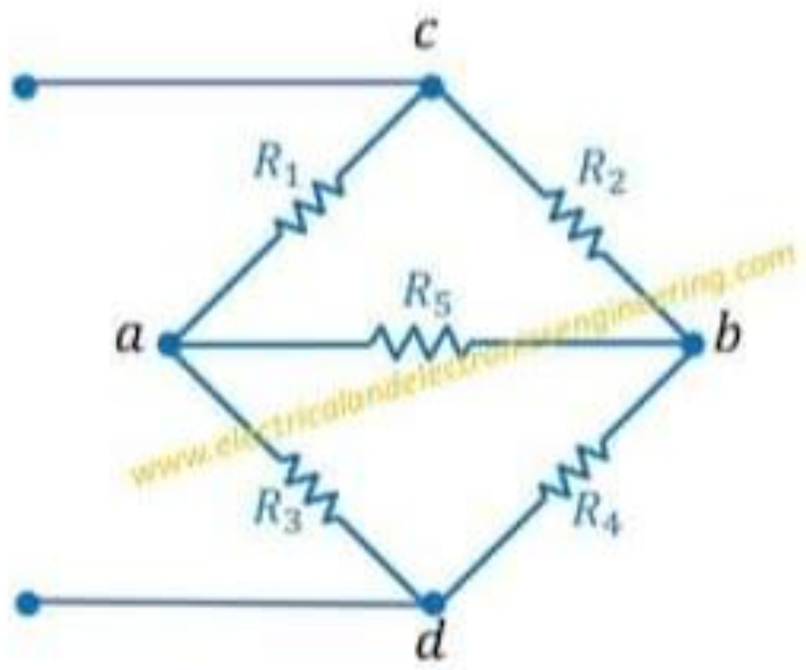
R1
R2
R3
V
I
R1
R2
R3
I
V

What is a bridge network in electronics?

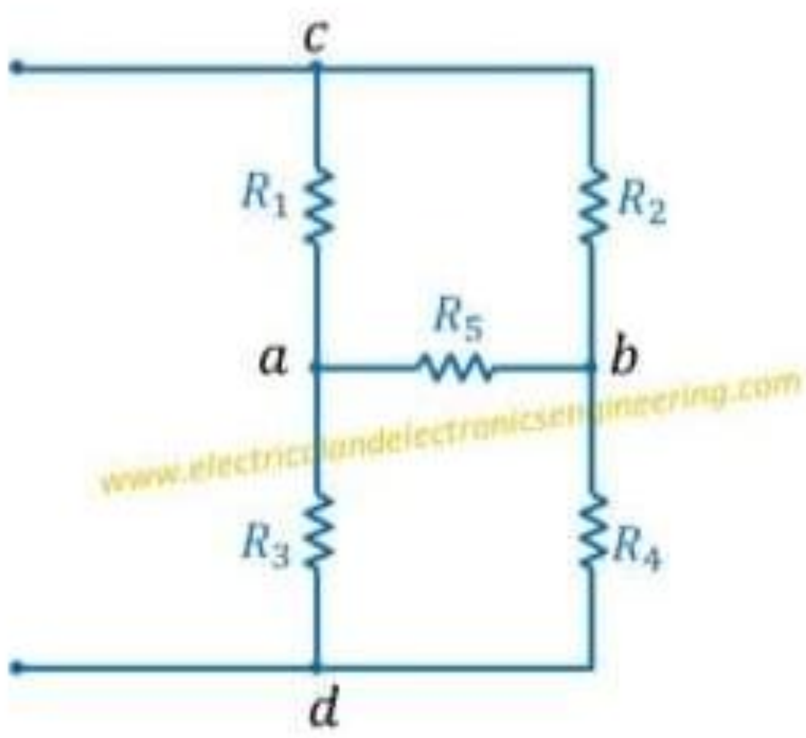


From Wikipedia, the free encyclopedia. A bridge circuit is **a topology of electrical circuitry in which two circuit branches (usually in parallel with each other)** are "bridged" by a third branch connected between the first two branches at some intermediate point along them.

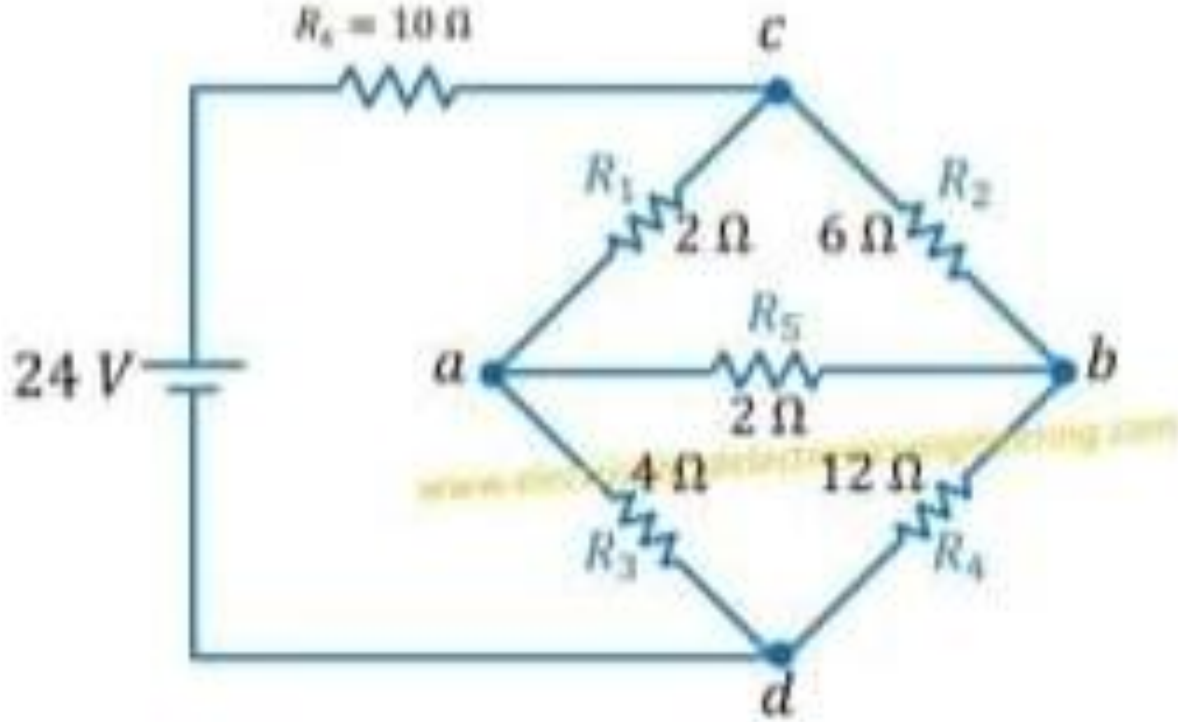
The figure below displays a 5 resistor bridge network:



It can also be redrawn as:



Example: Find the current flowing Rs in bridge network shown below.



Solution:

Since R1/R3 = R2/R4, zero current passes through R5.

Here we can replace the resistance R5 by an open circuit.

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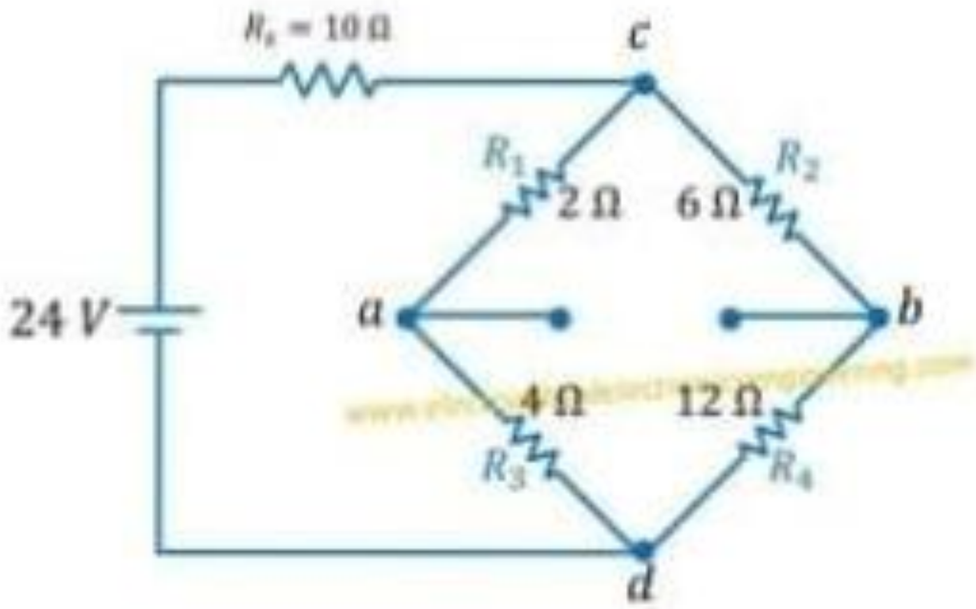


The overall resistance Rs through circuit is:

Rs = 10 Ω + {(2 Ω +4 Ω)||(6 Ω + 12 Ω)} = 10 Ω + 4.5 Ω = 14.5 Ω

I (Rs) = V/Rs = 24/14.5 Ω = 1.65 A

What Is Wye And Delta?

Chapter 1 - Voltage, Current, Energy, and Power

We learned in a previous page that resistors can be connected in series or in parallel. Sometimes, circuit analysis is easier if we convert series or parallel resistors into a single equivalent resistor. However, resistors can be configured in a way that does not result in a series connection or a parallel connection:

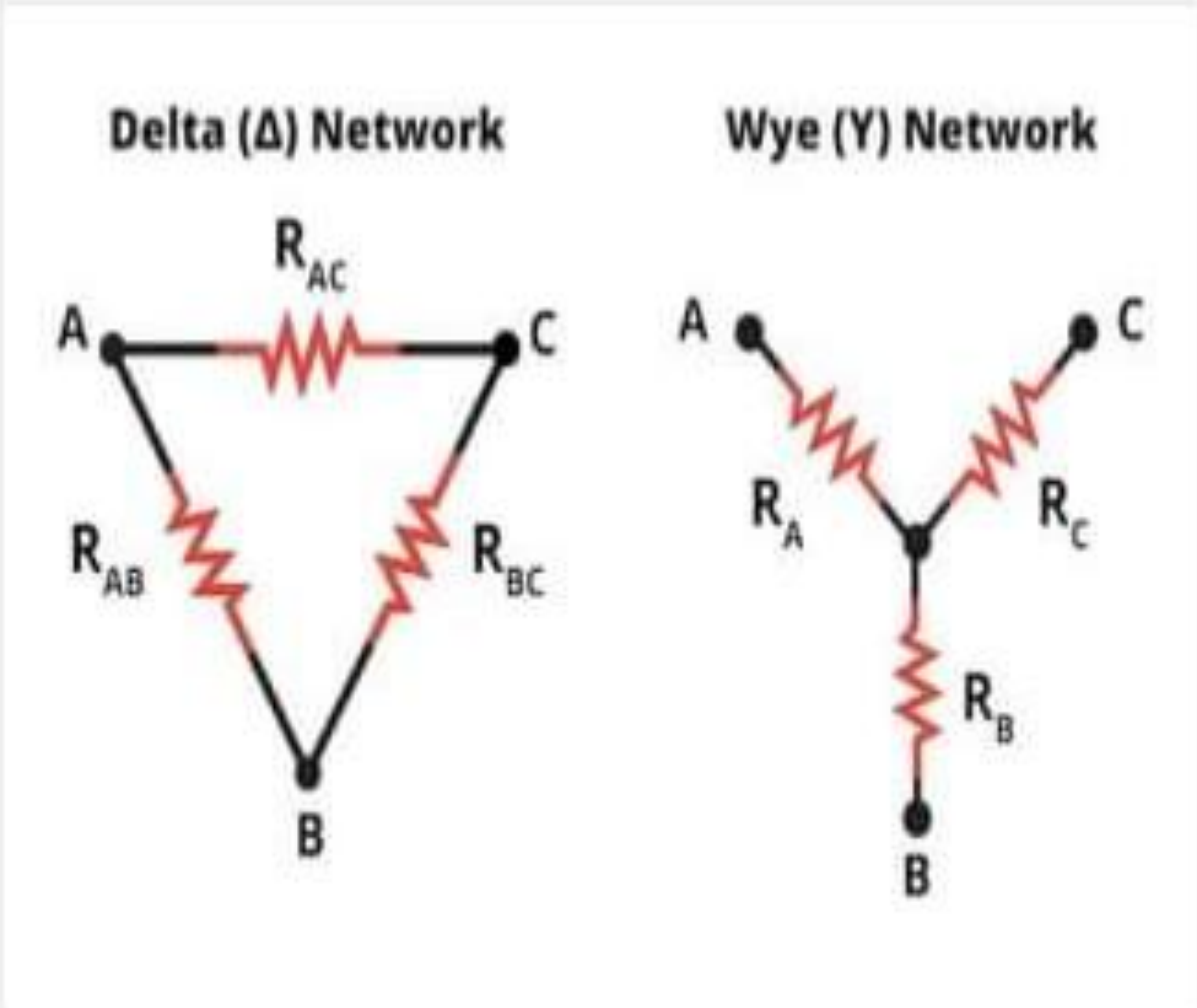


Figure 1. Delta and wye networks

These two resistor configurations cannot be reduced to a single equivalent resistance. They are called **delta** and **wye** (or Y) networks, because of their shapes. They can also be arranged as **pi** (π) and **T** networks. It's important to recognize that in terms of electrical behavior, the delta network is exactly the same as the pi network and the wye network is exactly the same as the T network; they are merely drawn differently.

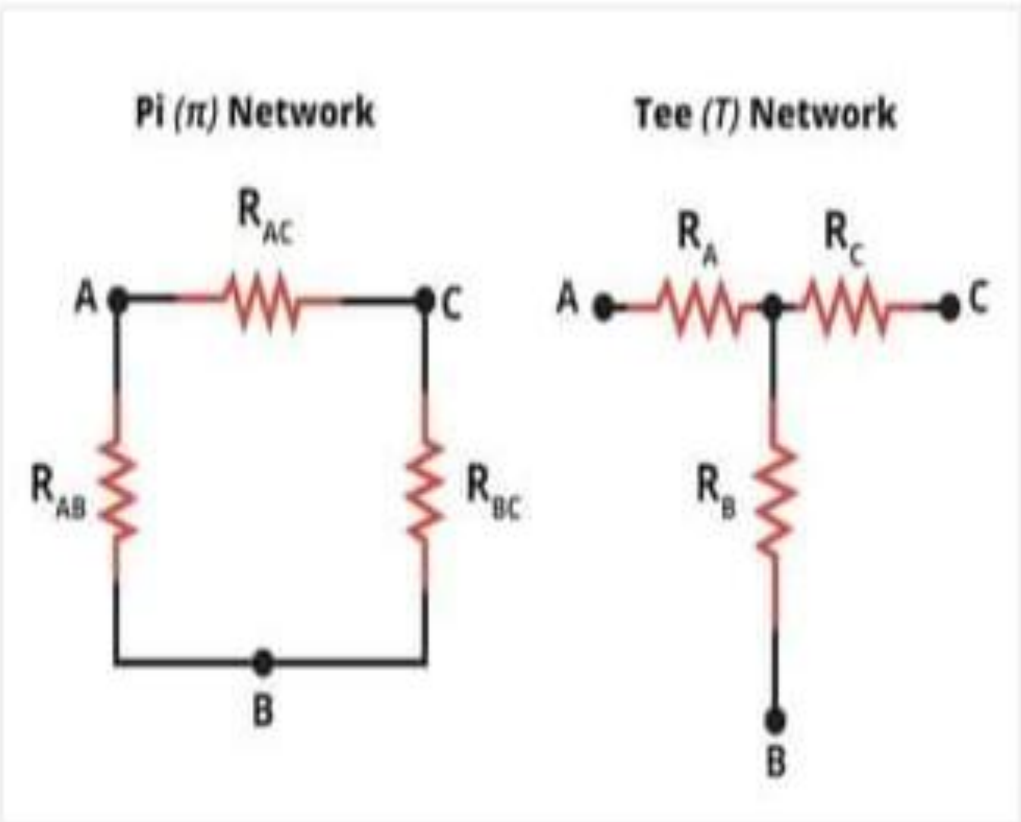


Figure 2. Pi and T networks (the names come from their appearance) are alternative ways of drawing delta and wye networks.

Delta-Wye Conversions

It is possible to convert a delta network into a functionally equivalent wye network, and it is also possible to convert a wye network into a functionally equivalent delta network. "Functionally equivalent" means that the overall electrical behavior of the converted network is identical to the overall electrical behavior of the original network. In other words, if the original network is connected to the system at terminals A, B, and C, we can remove the original network and connect the converted network to terminals A, B, and C without changing the behavior of the system.

At this point we know what a delta–wye conversion is, but we don't know why someone would want to perform these conversions. It turns out that converting a delta network to a wye network, or a wye network to a delta network, can facilitate the analysis of a larger circuit that includes a delta or wye network. In the next section we'll look at the conversion formulas, then we'll work through an example.

Delta-Wye Conversion Formulas

The following formulas allow you to calculate wye-network resistances from delta-network resistances.

$$R_A = \frac{R_{AB} R_{AC}}{R_{AB} + R_{AC} + R_{BC}}$$

$$R_B = \frac{R_{AB} R_{BC}}{R_{AB} + R_{AC} + R_{BC}}$$

$$R_C = \frac{R_{AC} R_{BC}}{R_{AB} + R_{AC} + R_{BC}}$$

To calculate delta-network resistances from wye-network resistances, we use these formulas:

$$R_{AB} = \frac{R_A R_B + R_A R_C + R_B R_C}{R_C}$$

$$R_{BC} = \frac{R_A R_B + R_A R_C + R_B R_C}{R_A}$$

$$R_{AC} = \frac{R_A R_B + R_A R_C + R_B R_C}{R_B}$$

Looks pretty tough, but the astute reader will recognize R_1, R_2, and R_3 as forming a delta configuration. Now, the fun begins!

First, let's change the resistor labels so that we can directly use the conversion formulas.

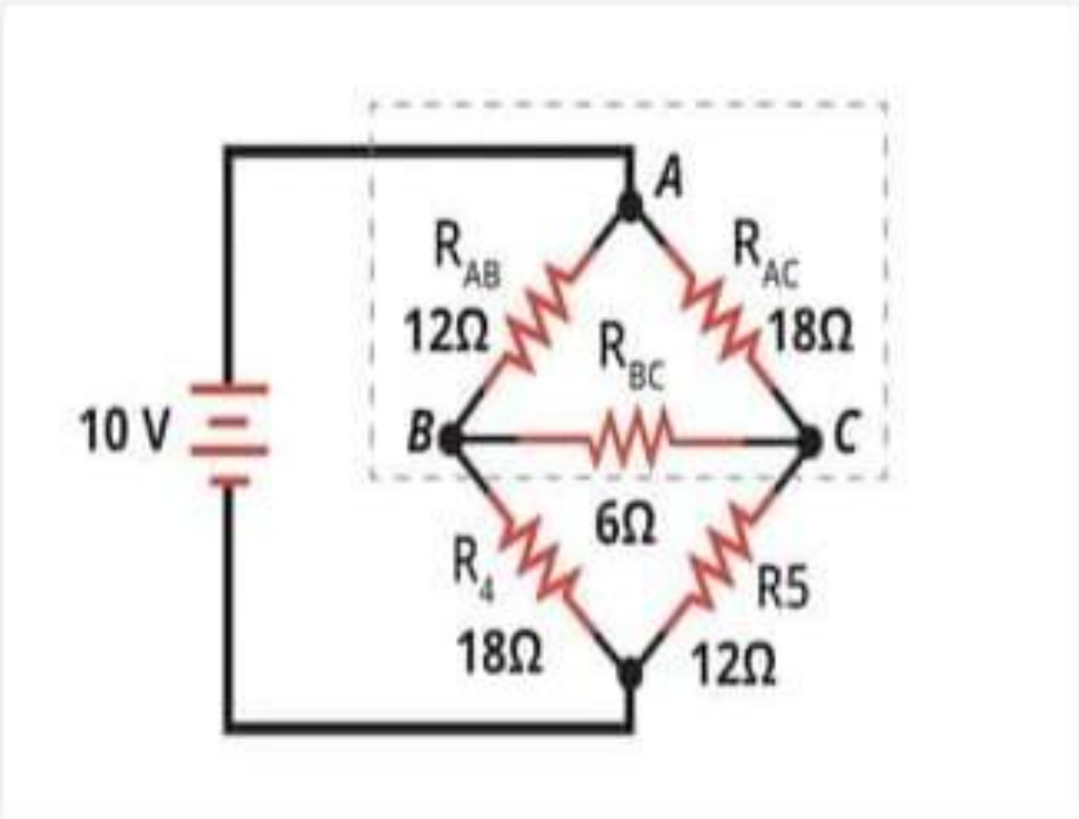


Figure 4. Updated resistor labels

Now, we can convert the delta configuration composed of R_{AB}, R_{AC}, and R_{BC} to a wye configuration.

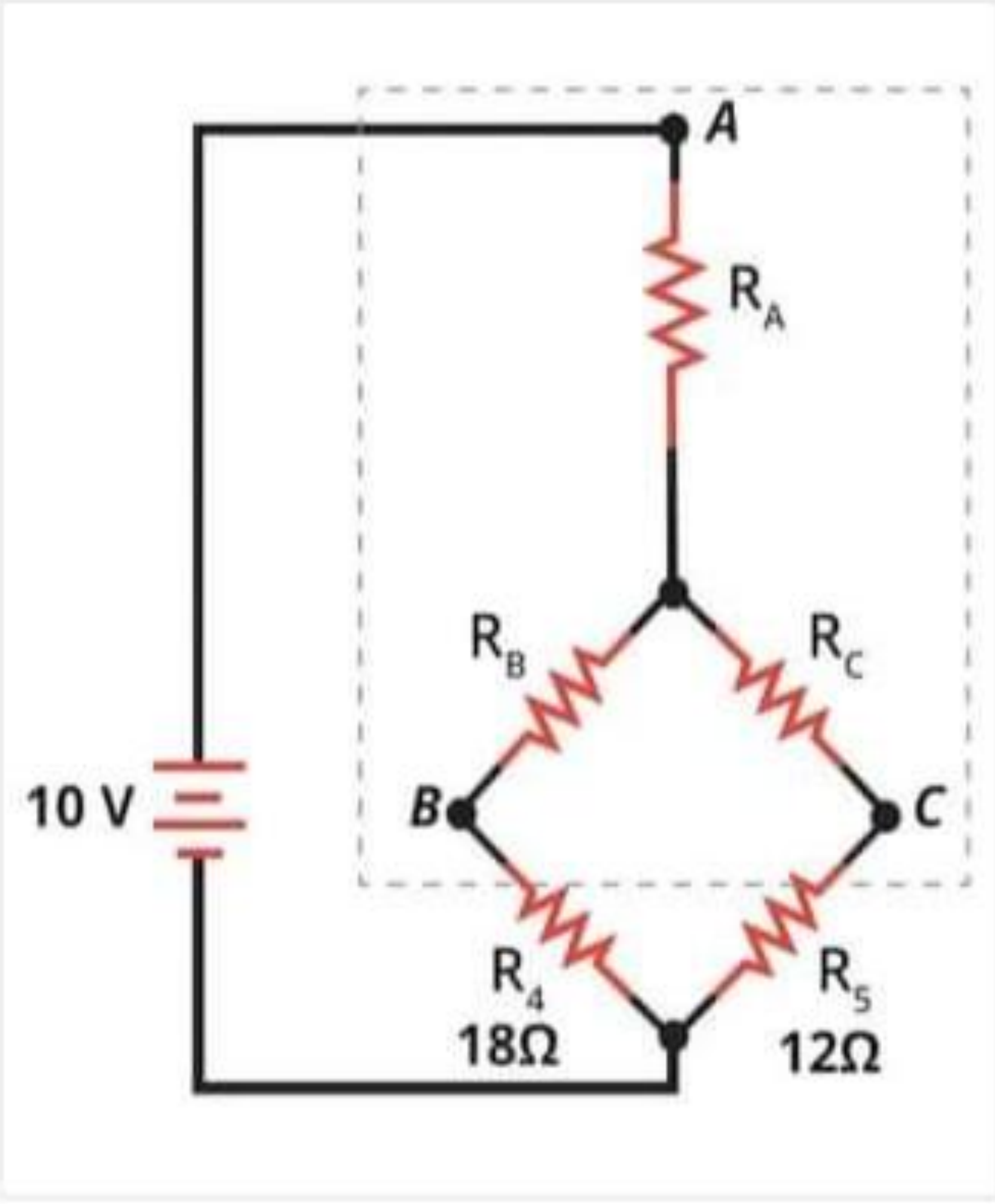
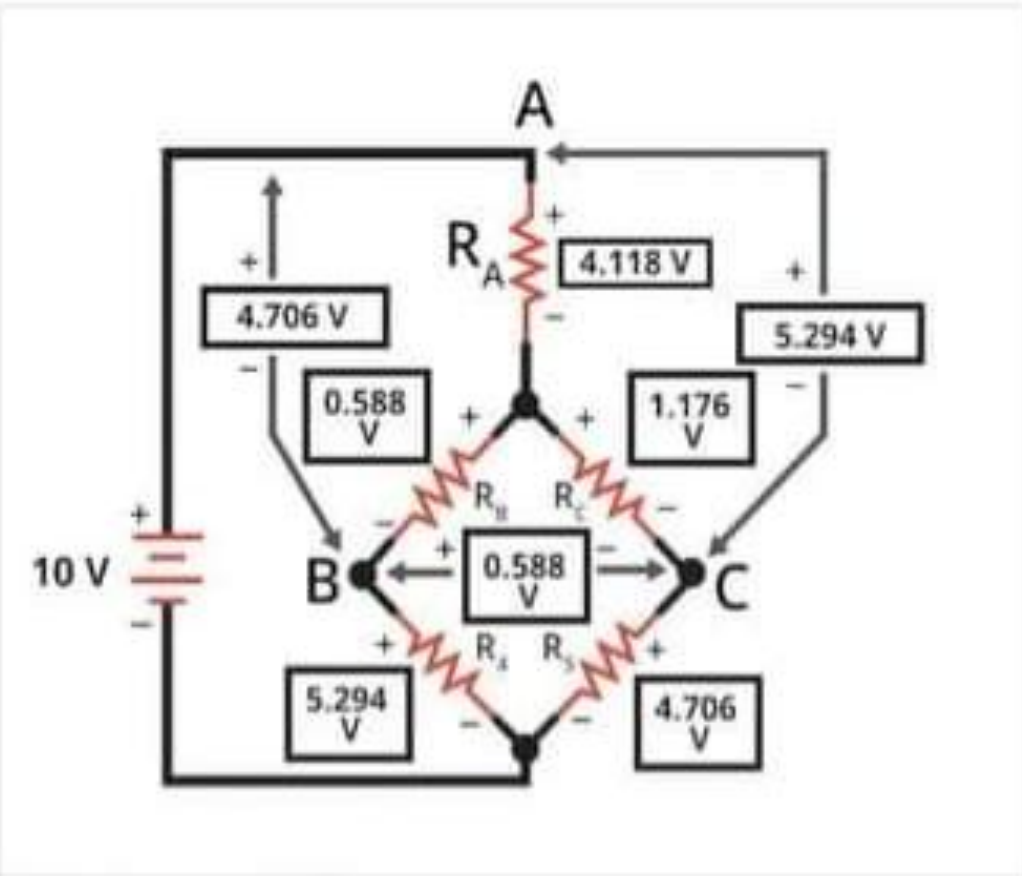


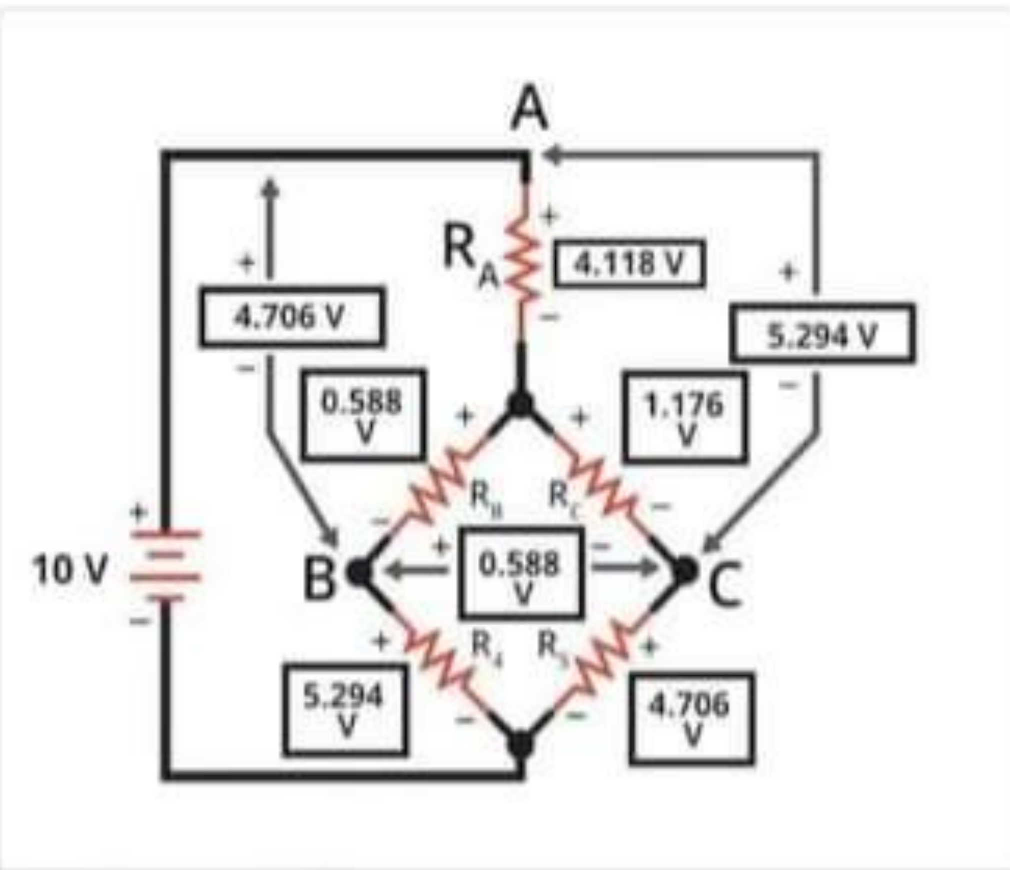
Figure 5. Convert the delta configuration to a wye configuration

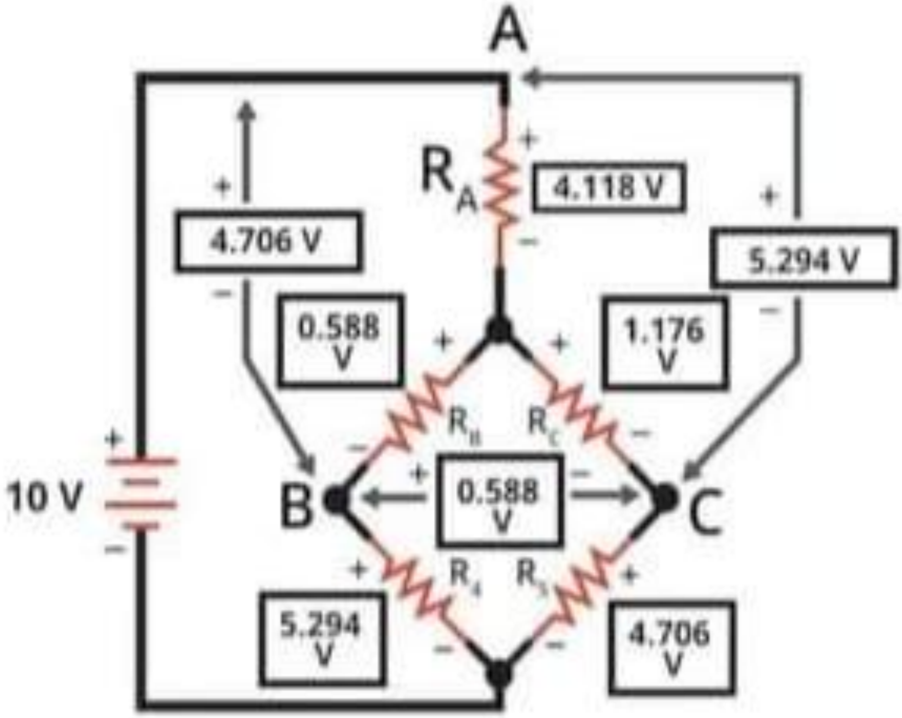
Using the formulas from the previous section, we can find R_A, R_B, and R_C for our wye network.

R_B and R_4 are series resistors with an equivalent resistance of 20Ω, and R_C and R_5 have an equivalent resistance of 15Ω. These two equivalent resistances are in parallel, so the overall equivalent resistance of R_B, R_C, R_4, and R_5 can be calculated and added to R_A. We now have an equivalent resistance for the entire group of resistors, and since we know the voltage across this equivalent resistance, we can use Ohm's law to find the current through R_A. This current allows us to determine, through simple but lengthy calculations, the voltages shown in Figure 7.



R_B and R_4 are series resistors with an equivalent resistance of 20Ω, and R_C and R_5 have an equivalent resistance of 15Ω. These two equivalent resistances are in parallel, so the overall equivalent resistance of R_B, R_C, R_4, and R_5 can be calculated and added to R_A. We now have an equivalent resistance for the entire group of resistors, and since we know the voltage across this equivalent resistance, we can use Ohm's law to find the current through R_A. This current allows us to determine, through simple but lengthy calculations, the voltages shown in Figure 7.





$E_{A\text{-}B} = 4.706$ V

$E_{A\text{-}C} = 5.294$ V

$E_{B\text{-}C} = 588.24$ mV

Figure 7. Calculated voltages

Now we can transfer these results to our original delta network, keeping in mind that equivalent networks will produce the same voltages at terminals A, B, and C.

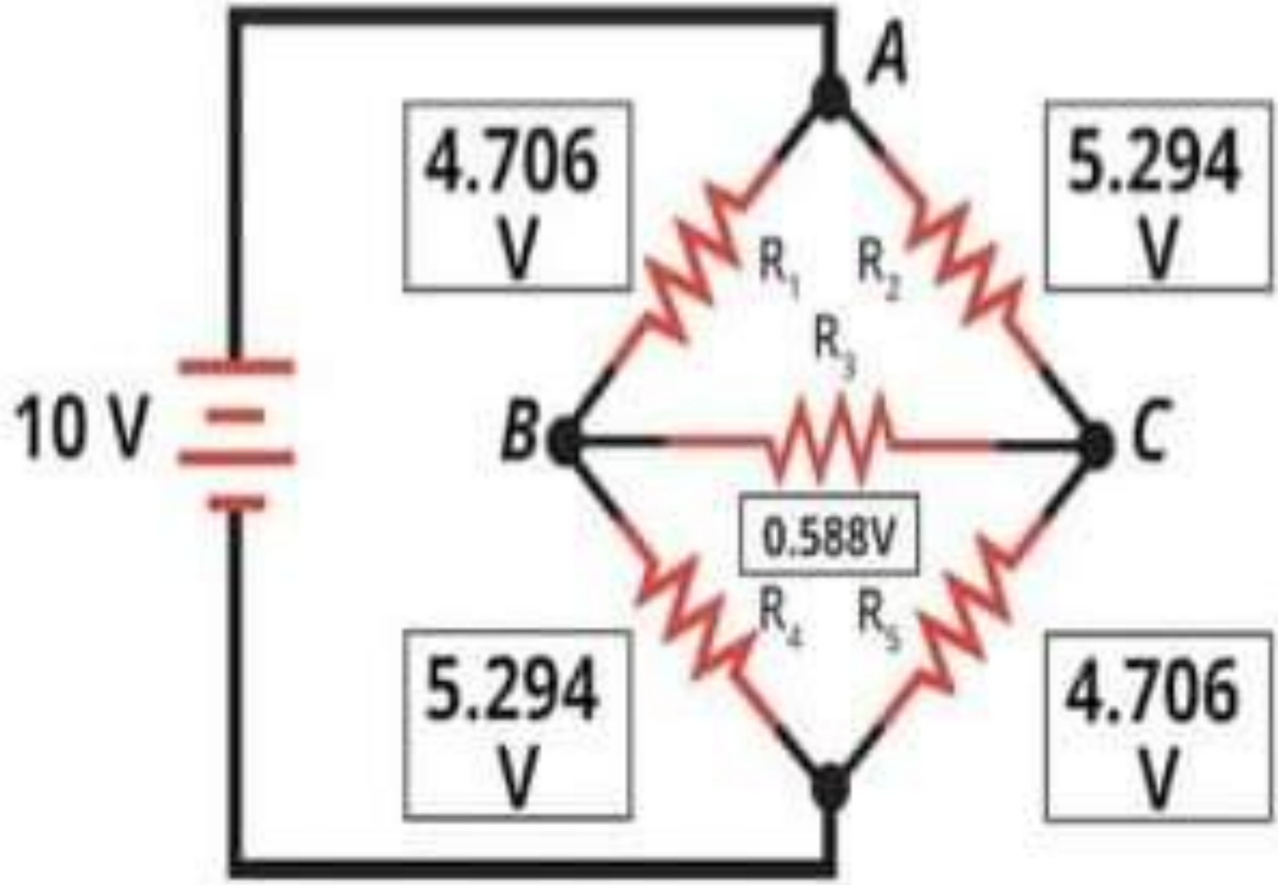


Figure 8. The voltage across each resistor

Figure 8 shows the voltage across each resistor, and now we can use Ohm's law to find the current flowing through each resistor.

7. Maxwell's Mesh Current Method

In this method, Kirchhoff's voltage law is applied to a network to write mesh equations in terms of mesh currents instead of branch currents. Each mesh is assigned a separate mesh current. This mesh current is assumed to flow clockwise around the perimeter of the mesh without splitting at a junction into branch currents. Kirchhoff's voltage law is then applied to write equations in terms of unknown mesh currents. The branch currents are then found by taking the algebraic sum of the mesh currents which are common to that branch.

Explanation. Maxwell's mesh current method consists of following steps :

(*i*) Each mesh is assigned a separate mesh current. For convenience, all mesh currents are assumed to flow in *clockwise direction. For example, in Fig. 3.6, meshes *ABDA* and *BCDB* have been assigned mesh currents I_1 and I_2 respectively.

(*ii*) If two mesh currents are flowing through a circuit element, the actual current in the circuit element is the algebraic sum of the two. Thus in Fig. 3.6, there are two mesh currents I_1 and I_2 flowing in R_2. If we go from *B* to *D*, current is $I_1 - I_2$ and if we go in the other direction (*i.e.*, from *D* to *B*), current is $I_2 - I_1$.

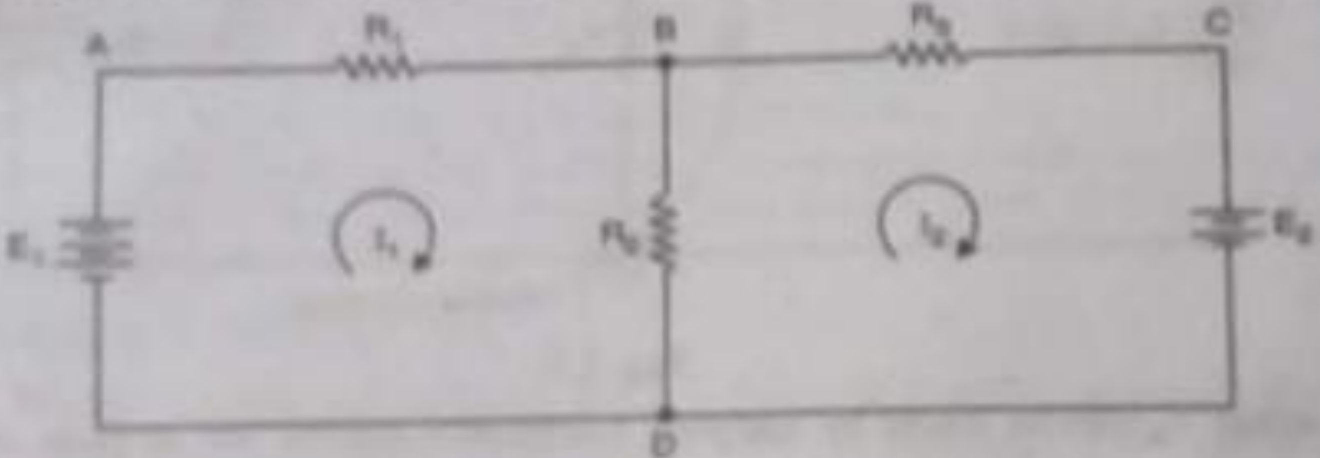


Fig. 3.6

(*iii*) Kirchhoff's voltage law is applied to write equation for each mesh in terms of mesh currents. Remember, while writing mesh equations, rise in potential is assigned positive sign and fall in potential negative sign.

(iv) If the value of any mesh current comes out to be negative in the solution, it means that true direction of that mesh current is anticlockwise *i.e.*, opposite to the assumed clockwise direction.

Applying Kirchhoff's voltage law to Fig. 3.6, we have,

Mesh ABDA. $-I_1R_1 - (I_1 - I_2) R_2 + E_1 = 0$

or $I_1 (R_1 + R_2) - I_2R_2 = E_1$ ...(i)

Mesh BCDB. $-I_2R_3 - E_2 - (I_2 - I_1) R_2 = 0$

or $-I_1R_2 + (R_2 + R_3) I_2 = -E_2$ ...(ii)

Solving eq. (i) and eq. (ii) simultaneously, mesh currents I_1 and I_2 can be found out. Once the mesh currents are known, the branch currents can be readily obtained. The advantage of this method is that it usually reduces the number of equations to solve a network problem.

8. Nodal Analysis

Consider the circuit shown in Fig. 3.7. The branch currents in the circuit can be found by Kirchhoff's laws or Maxwell's mesh current method. There is another method, called *nodal analysis*, for determining the branch currents in the circuit. In this method, one of the nodes (Remember a node is a point in a network where two or more circuit elements meet) is taken as the *reference node*. The potentials of all the points in the circuit are measured w.r.t. this reference node. In Fig. 3.7, *A*, *B*, *C* and *D* are four nodes and node *D* has been taken as the *reference node. A glance at the circuit shows that voltages at nodes *A* and *C* w.r.t. reference node *D* are known. These are $E_1 = 120$ V and $E_2 = 65$ V respectively. The only potential of node *B* w.r.t. *D* (call it V_B) is unknown. If this potential V_B can be found, each branch current can be determined because the voltage across each resistor will then be known.

Hence **nodal analysis** *essentially aims at choosing a reference node in the network and then finding the unknown voltages at the nodes w.r.t. reference node.*

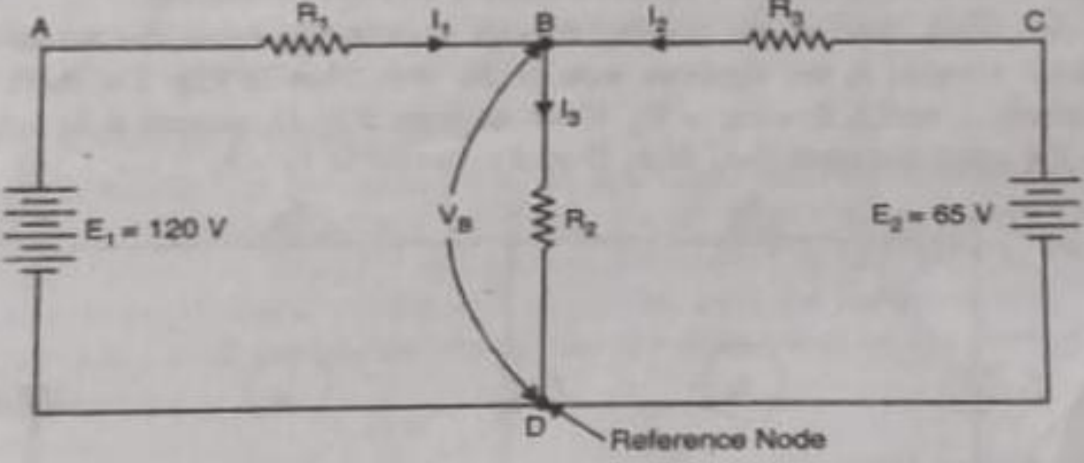


Fig. 3.7

The voltage V_B can be found by applying Kirchhoff's current law at point *B*.

$$I_1 + I_2 = I_3$$ ...(i)

In mesh *ABDA*, the voltage drop across R_1 is $E_1 - V_B$.

$$\therefore \quad I_1 = \frac{E_1 - V_B}{R_1}$$

In mesh *CBDC*, the voltage drop across R_3 is $E_2 - V_B$

$$I_2 = \frac{E_2 - V_B}{R_3}$$

Also current $I_3 = V_B/R_2$. Putting the values of I_1, I_2 and I_3 in eq. (*i*), we get,

$$\frac{E_1 - V_B}{R_1} + \frac{E_2 - V_B}{R_3} = \frac{V_B}{R_2} \qquad ...(ii)$$

All quantities except V_B are known. Hence V_B can be found out. Once V_B is known, all branch currents can be calculated. It may be seen that nodal analysis requires only one equation [eq. (*ii*)] for determining the branch currents in this circuit. However, Kirchhoff's or Maxwell's solution would have needed two equations.