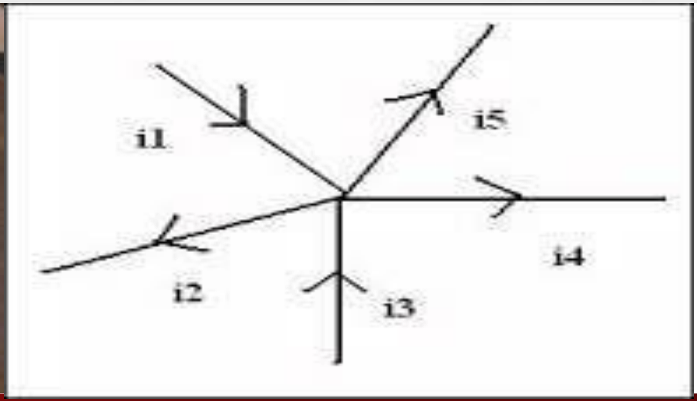
Muthayammal Engineering College

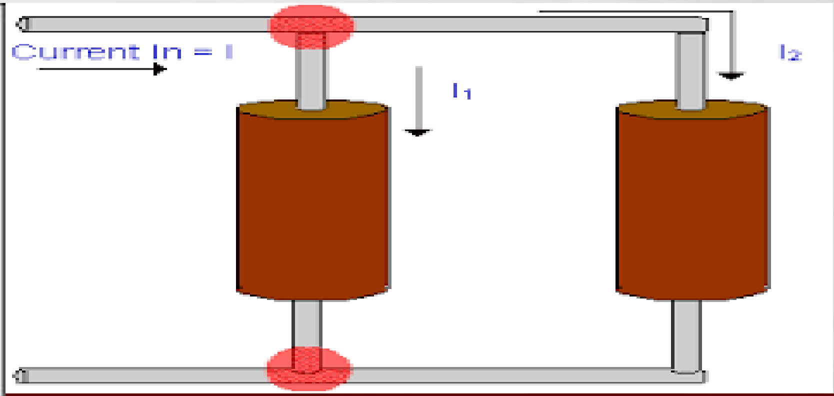
19ECC01-ELECTRIC NETWORK ANALYSIS AND MACHINES

UNIT 1:**THEOREMS AND DC TRANSIENT ANALYSIS**
UNIT 2:**SINUSOIDAL AND STEADY STATE POWER ANALYSIS**
UNIT 3:**APPLICATION OF LAPLACE TRANSFORM TO CIRCUIT ANALYSIS**
UNIT 4:**NETWORK TOPOLOGY AND TWO PORT NETWORK**
UNIT 5:**ELECTRIC MACHINES**

TOPIC NAME:

- KIRCHHOFF'S LAWS.





TYPES OF LAWS:

Kirchhoff's laws.

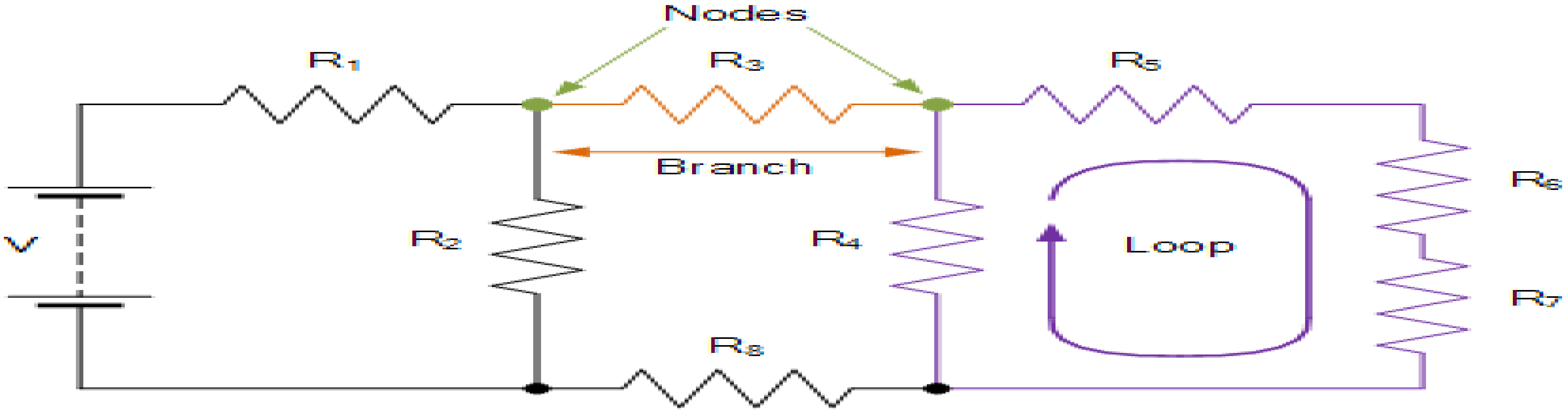
KIRCHHOFF'S CURRENT LAW(KCL)

KIRCHHOFF'S VOLTAGE LAW (KVL)

- These laws are first derived by **Guatov Robert Kirchhoff** and hence these laws are also referred as **Kirchhoff Laws**.

Circuit Definitions

- Node - any point where 2 or more circuit elements are connected together
  - Wires usually have negligible resistance
  - Each node has one voltage (w.r.t. ground)
- Branch - a circuit element between two nodes
- Loop - a collection of branches that form a closed path returning to the same node without going through any other nodes or branches twice

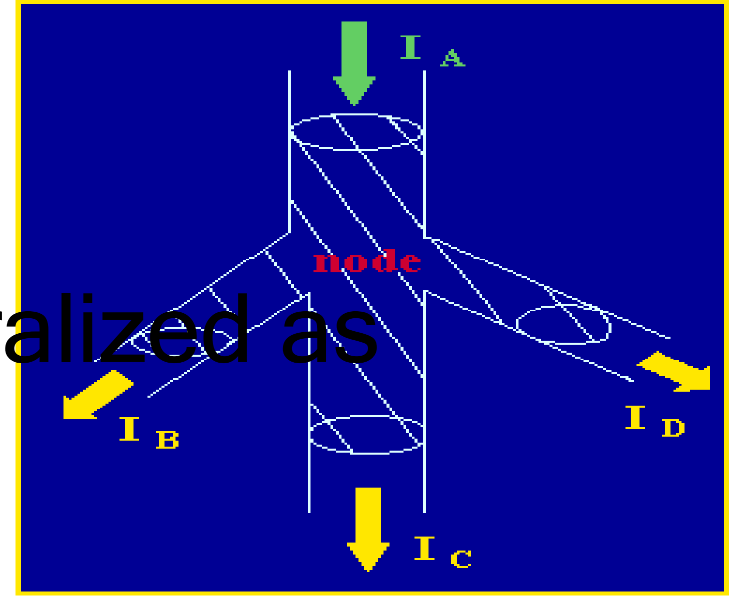


(KCL)

- The algebraic sum of currents entering a node is zero
  - Add each branch current entering the node and subtract each branch current leaving the node
- Σ currents in - Σ currents out = 0
- Or Σ currents in = Σ currents out

(IB + IC + ID) - IA = 0

Then, the sum of all the currents is zero. This can be generalized as follows, $\sum I = 0$



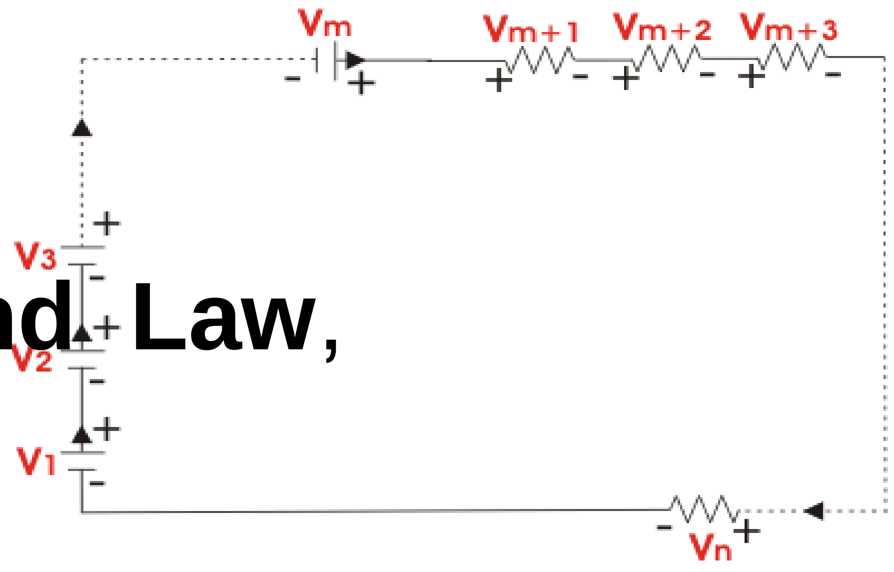
(KVL)

- **"The algebraic sum of all voltages around a closed loop must be equal to zero".**
- Σ voltage drops - Σ voltage rises = 0
- Or Σ voltage drops = Σ voltage rises

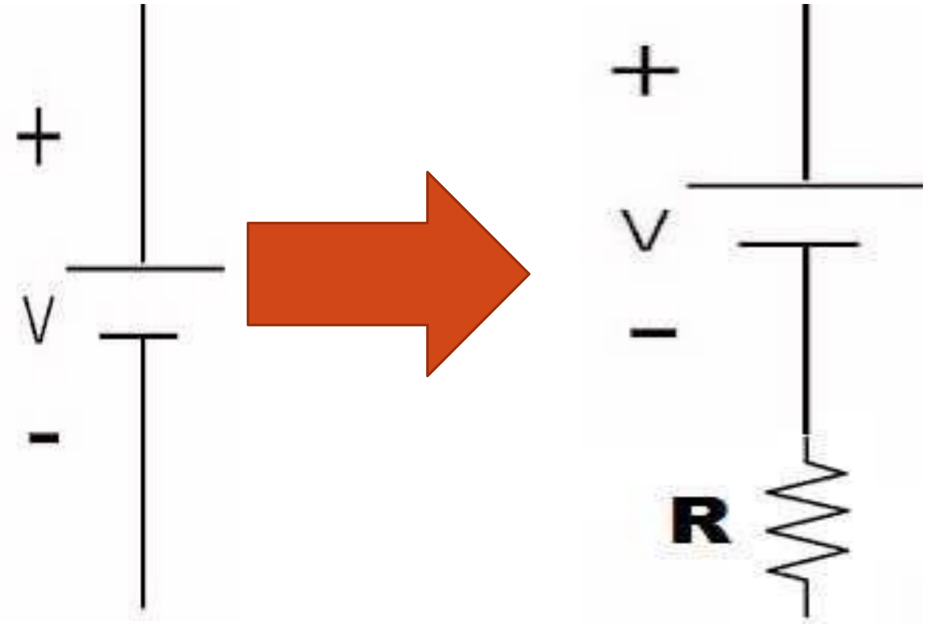
That means, $V_1 + V_2 + V_3 + \ldots\ldots\ldots\ldots\ldots\ldots + V_m - V_{m+1} - V_{m+2} - V_{m+3} + \ldots\ldots\ldots\ldots\ldots\ldots - V_n = 0$.

So accordingly **Kirchhoff Second Law,**

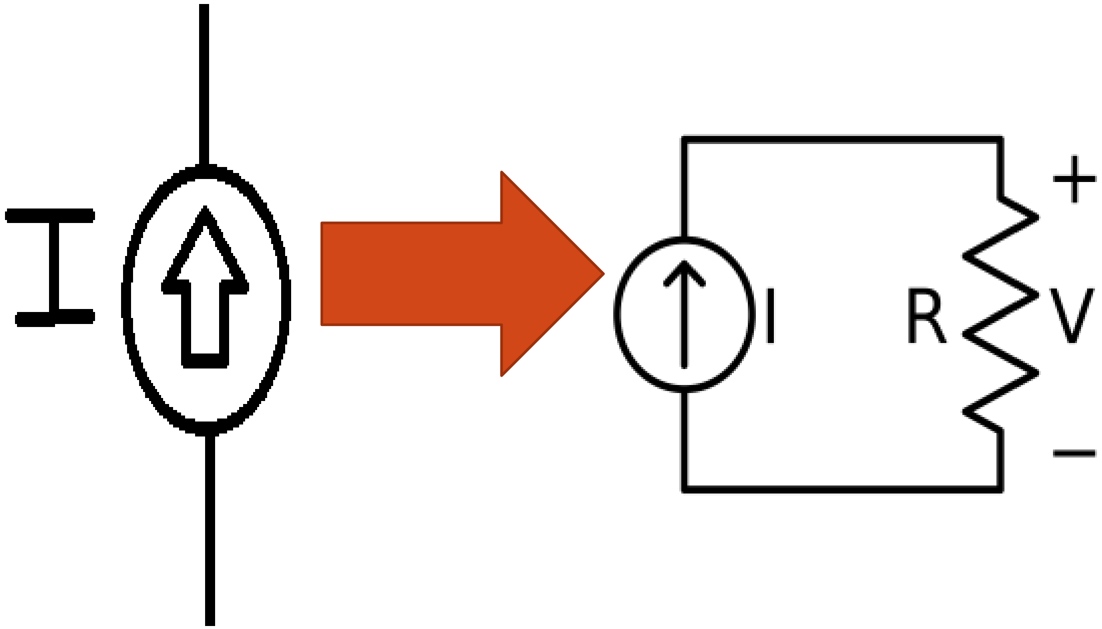
$\sum V = 0$.



Ideal voltage and current source.

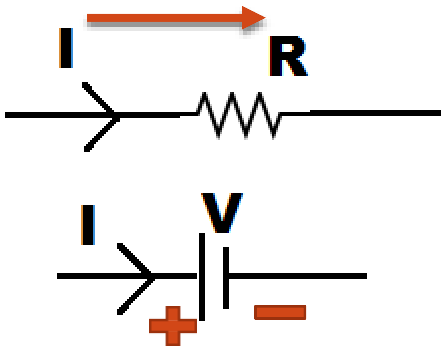


VOLTAGE SOURCE

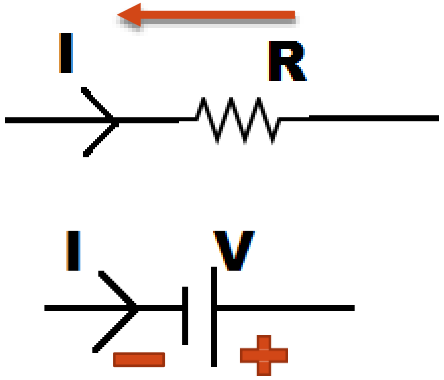


CURRENT SOURCE

Voltage rise and voltage drop:



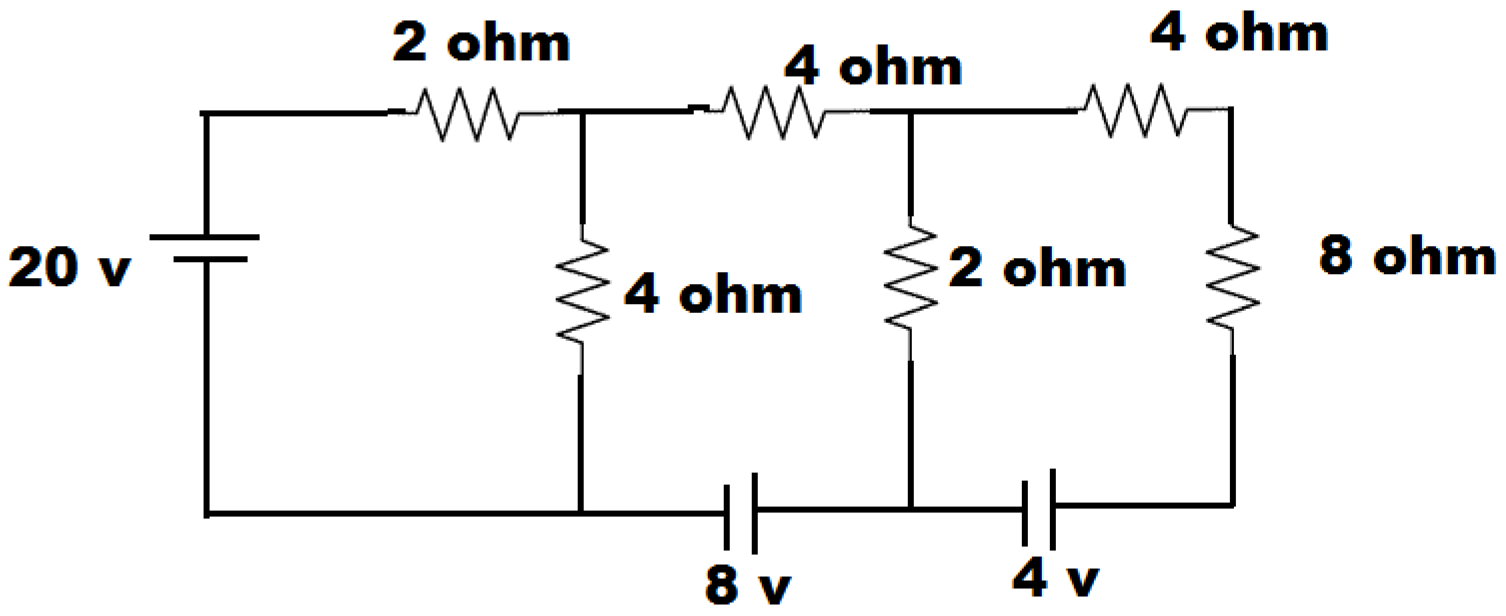
Voltage drop



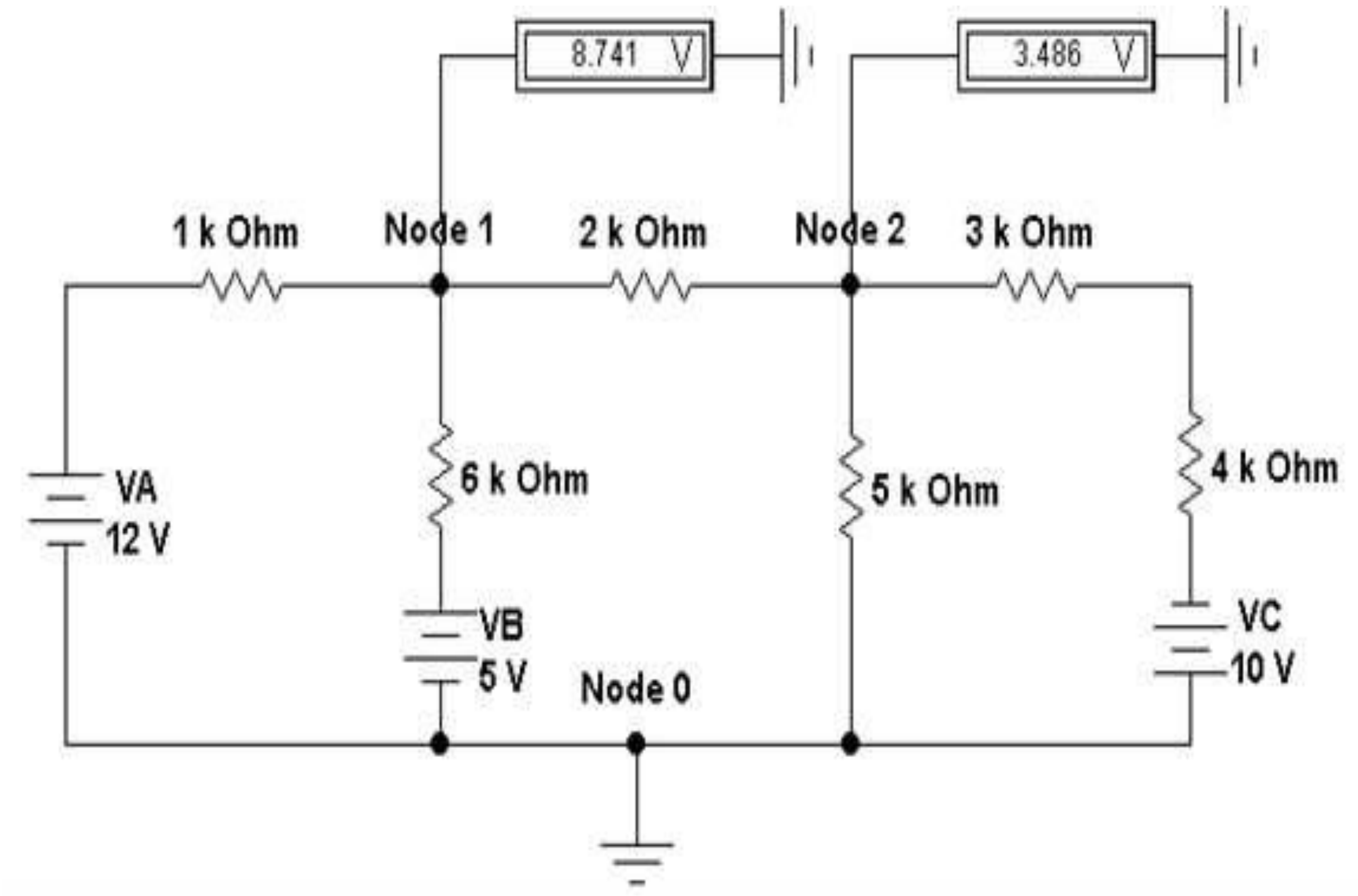
Voltage rise

Example.

- Find the current through 8Ω resistor using KIRCHHOFF'S LAWS.



EXAMPLE OF KCL



EXAMPLE OF KCL

the nodal equations (We assume all currents are leaving the node):

$$\frac{V1-12\text{v}}{1k\Omega}+\frac{V1-5\text{v}}{6k\Omega}+\frac{V1-V2}{2k\Omega}=0$$

$$\frac{V2-V1}{2k\Omega}+\frac{V2}{5k\Omega}+\frac{V2+10\text{v}}{7k\Omega}=0$$

Rearranging the terms: $10V1-3V2=77$

$$35V1-59V2=100$$

Solving the linear equations with the Cramer's Rule:

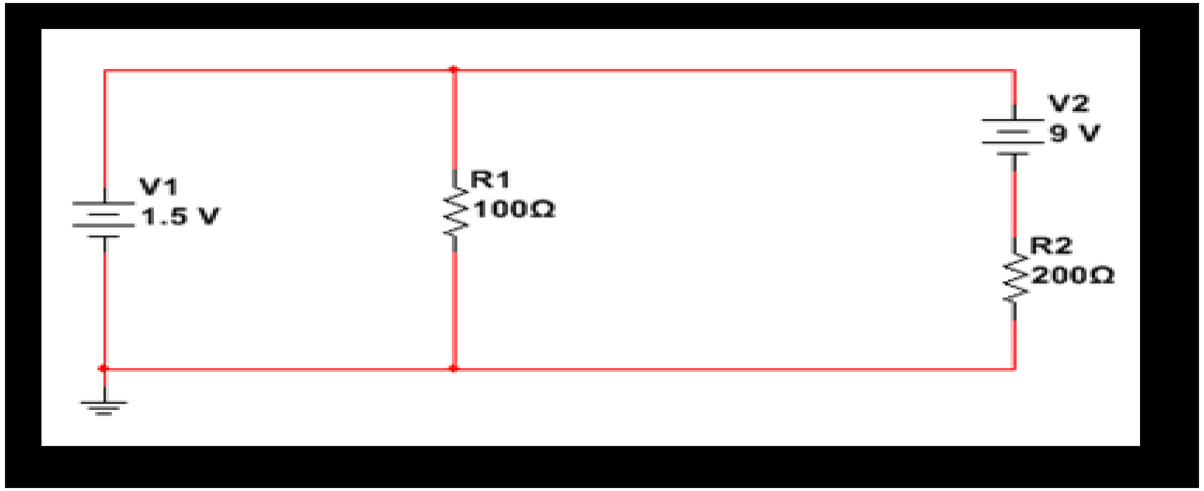
$$\begin{vmatrix}10 & -3\\ 35 & -59\end{vmatrix}=-485 \qquad \begin{vmatrix}77 & -3\\ 100 & -59\end{vmatrix}=-4243 \qquad \begin{vmatrix}10 & 77\\ 35 & 100\end{vmatrix}=-1695$$

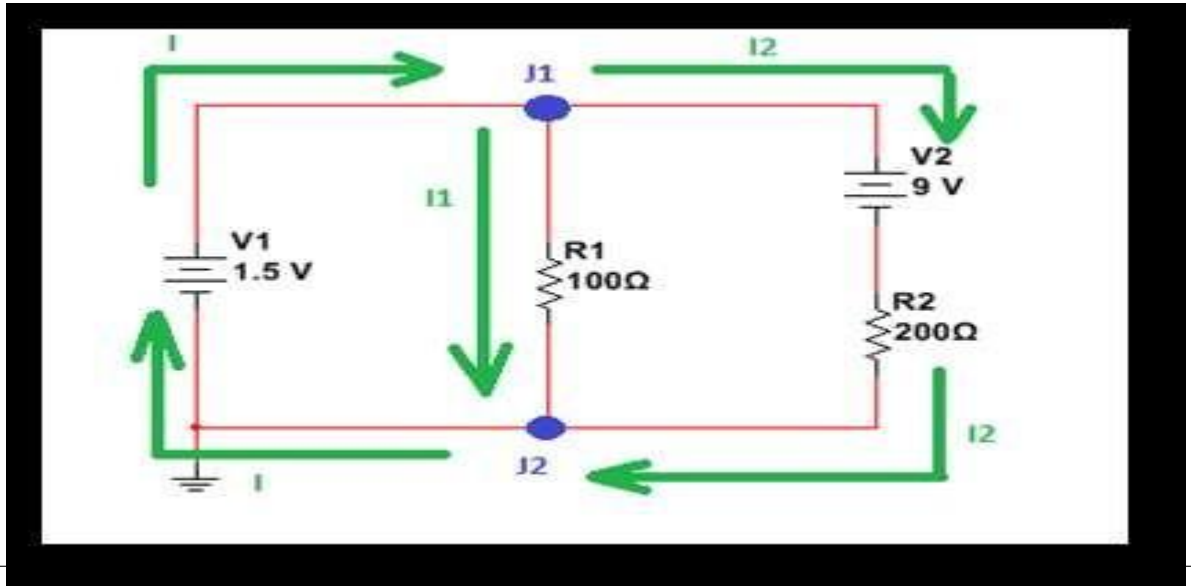
$$\Rightarrow V1=\frac{-4243}{-485}=8.748 \qquad V2=\frac{-1695}{-485}=3.495$$

EXAMPLE OF KCL

- Currents:
  - $I_{1k} = \; = -3.252$ mA (→) $I_{2k} = \; = 2.626$ mA (→)
  - $I_{3k} = \; = 1.928$ mA (→) $I_{4k} = \; = 1.928$ mA (↓)
  - $I_{5k} = \; = 0.699$ mA (↓) $I_{6k} = \; = 0.625$ mA (↓)

EXAMPLE OF KVL



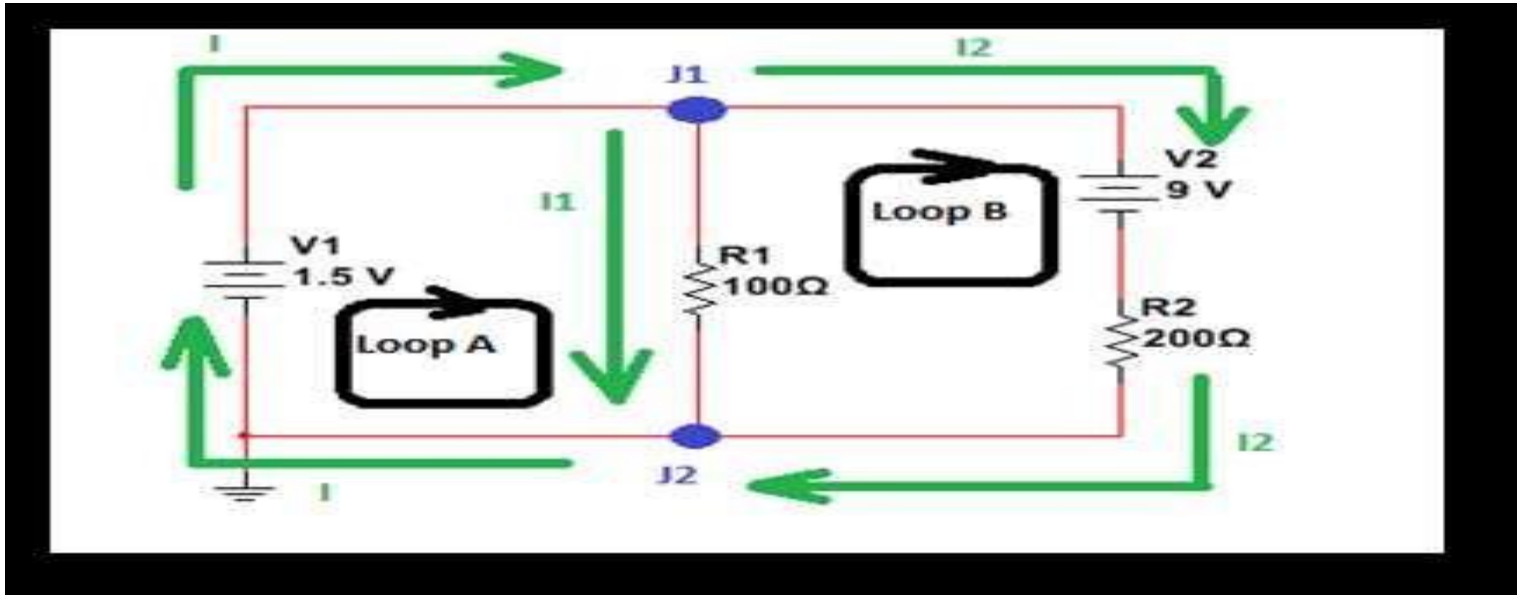


EXAMPLE OF KVL

- **Junction J_1:**

  $I = I_1 + I_2$ (equation 1)

- **Junction J_2:** $I_1 + I_2 = I$ (equation 2)



- **Loop A:** (start from the upper left corner and move clockwise)

  $-I_1 \times (100\ \Omega) + 1.5V = 0$ (equation 3)

  Therefore: **$I_1 = 0.015$ A**
- **Loop B:**

  $-9V - I_2 \times (200\ \Omega) + I_1 \times (100\ \Omega) = 0$ (equation 4)
- Substituting the value of I_1 into equation 3 yields:

  $-9 - I_2 \times (200\ \Omega) + (0.015)(100\ \Omega) = 0$

  $-7.5 = (200) \times I_2$ therefore: **$I_2 = -0.0375$ A**
- And then **$I = -0.0225$ A**
- **$V_{R1} = I_1 \times R_1$** = (0.015 A) x (100 Ω) therefore **$V_{R1} = 1.5V$**
- **$V_{R2} = I_2 \times R_2$** = (-0.0375 A) x (200 Ω) therefore **$V_{R2} = -7.5V$**

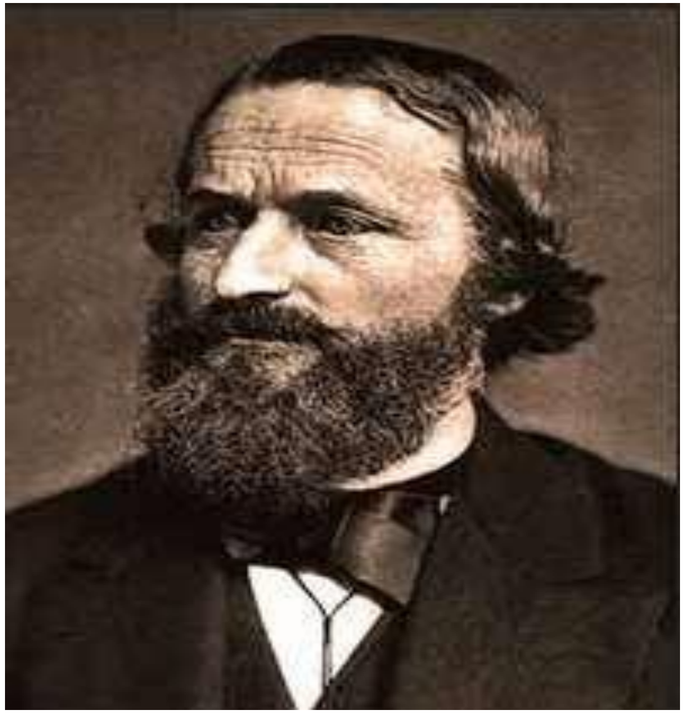
INTRODUCTION KIRCHOFF’S LAW

HISTORY OF KIRCHOFF’S LAW

INTRODUCTION

TYPES OF KIRCHOFF’S LAW

HISTORY OF KIRCHOFF'S LAW



Gustav Robert Kirchhoff (German physicist)

described two laws that became central to electrical engineering in 1845

The laws were generalized from the work of Georg Ohm

It's can also be derived from Maxwell's equations, but were developed prior to Maxwell's work

INTRODUCTION

What?

- A pair of laws stating general restrictions on the current and voltage in an electric circuit.

- The first of these states that at any given instant the sum of the voltages around any closed path, or loop, in the network is zero.
- The second states that at any junction of paths, or node, in a network the sum of the currents arriving at any instant is equal to the sum of the currents flowing away.

How?

TYPES OF KIRCHOFF'S LAW

KVL

- Kirchoff Voltage Law

KCL

- Kirchoff Current Law

KIRCHOFF'S VOLTAGE LAW

INTRODUCTION KVL

MESH ANALYSIS

EXERCISE

INTRODUCTION KVL

Kirchhoff's Voltage Law - KVL - is one of two fundamental laws in electrical engineering, the other being Kirchhoff's Current Law (KCL)

KVL is a fundamental law, as fundamental as Conservation of Energy in mechanics, for example, because KVL is really conservation of electrical energy

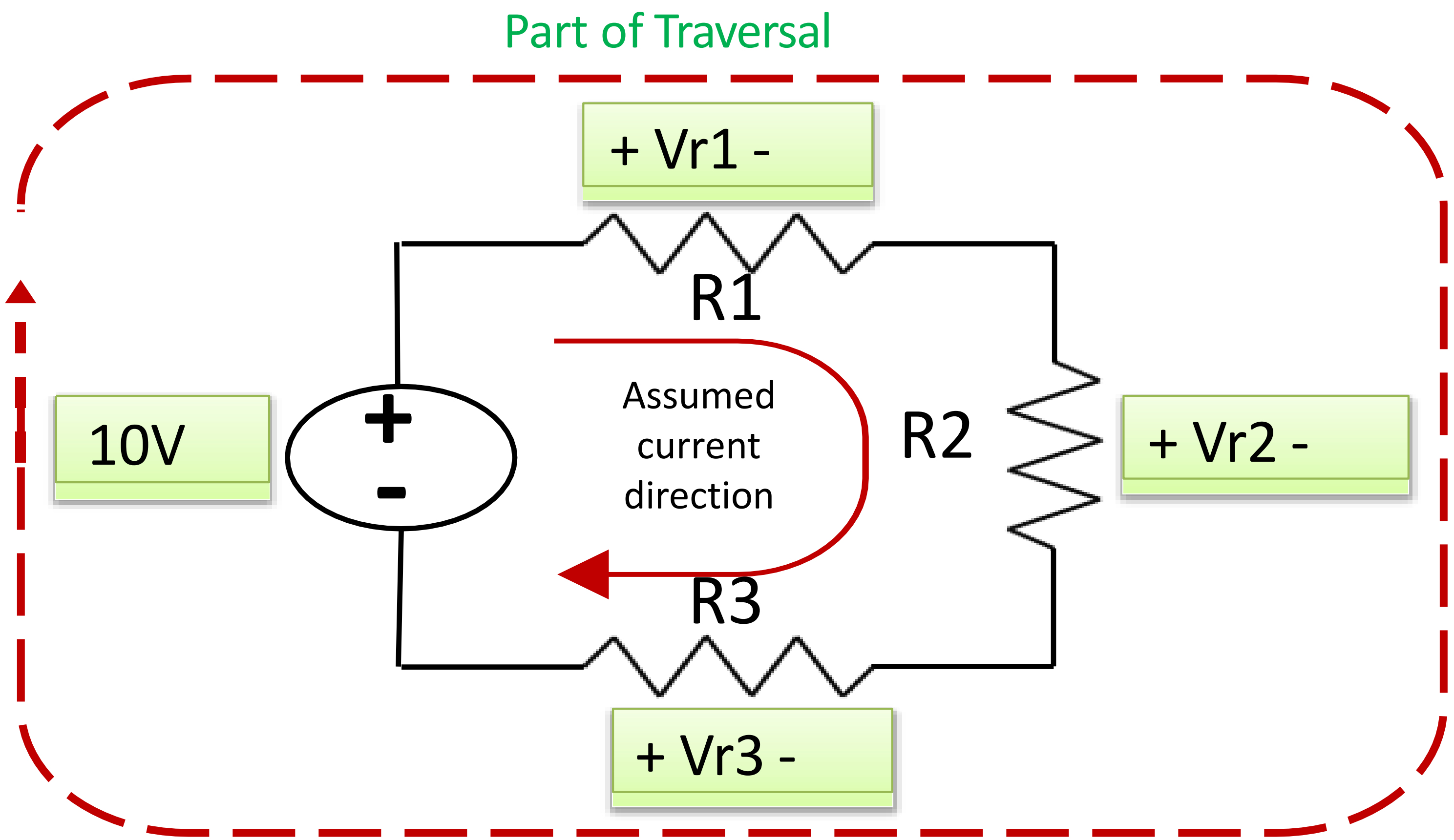
KVL and KCL are the starting point for analysis of any circuit

KCL and KVL always hold and are usually the most useful piece of information you will have about a circuit after the circuit itself

- Kirchoff’s Voltage Law (KVL) states that the algebraic sum of the voltages across any set of branches in a closed loop is zero. i.e.;

$$\sum V_{acrossbranches} = 0$$

Below is a single loop circuit. The KVL computation is expressed graphically in that voltages around a loop are summed up by traversing (figuratively walking around) the
loop.



Resulting KVL Equation: $V_{r1}+V_{r2}+V_{r3}-10=0$

- The KVL equation is obtained by traversing a circuit loop in either direction and writing down unchanged the voltage of each element whose "+" terminal is entered first and writing down the negative of every element's voltage where the minus sign is first met.

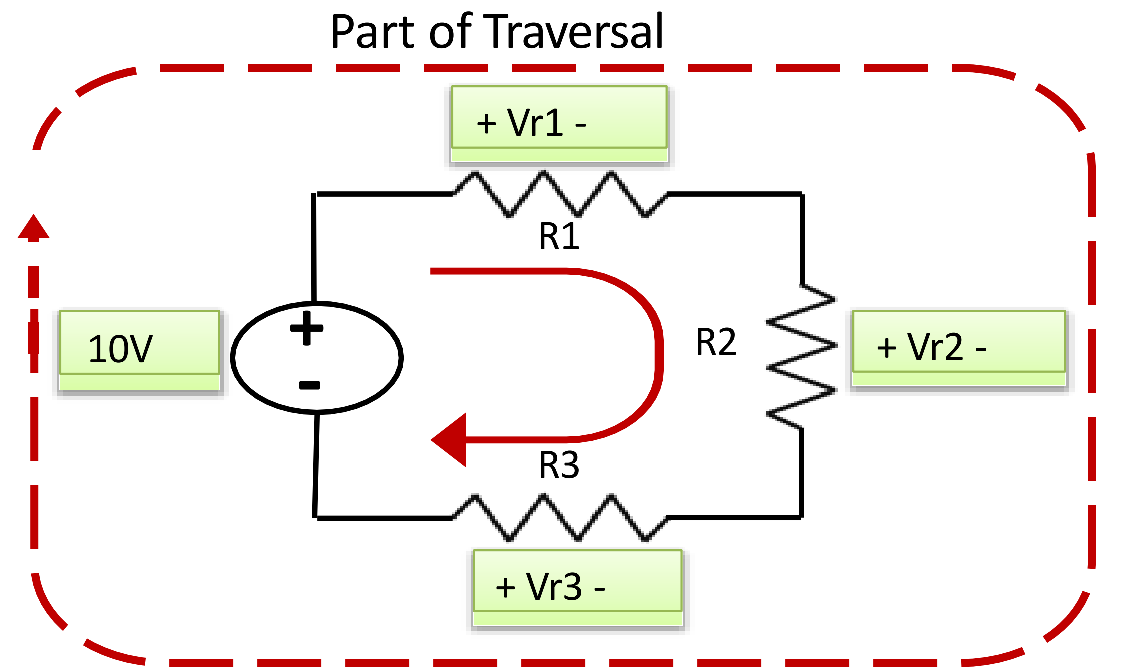
- The loop must start and end at the same point. It does not matter where you start on the loop.

- Note that a current direction must have been assumed. The assumed current creates a voltage across each resistor and fixes the position of the "+" and "-" signs so that the passive sign con-vention is obeyed.

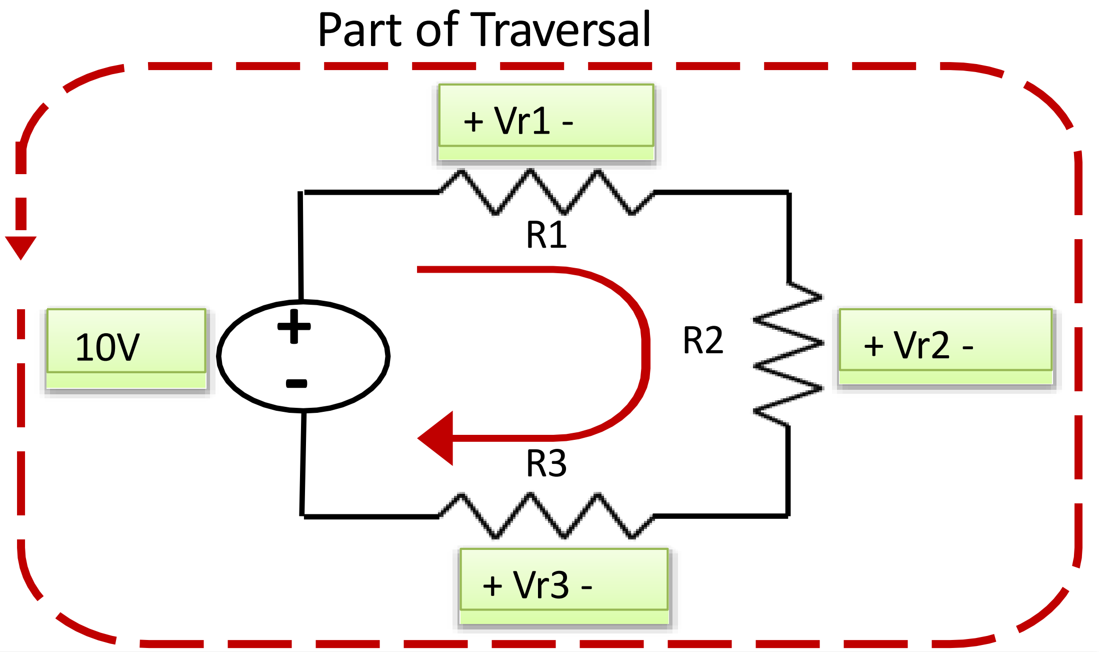
- The assumed current direction and polarity of the voltage across each resistor must be in agreement with the passive sign convention for KVL analysis to work.

- The voltages in the loop may be summed in either direction. It makes no difference except to change all the signs in the resulting equation. Mathematically speaking, its as if the KVL equation is multiplied by -1. See the illustration below.

Summation of voltage terms may be done in either direction



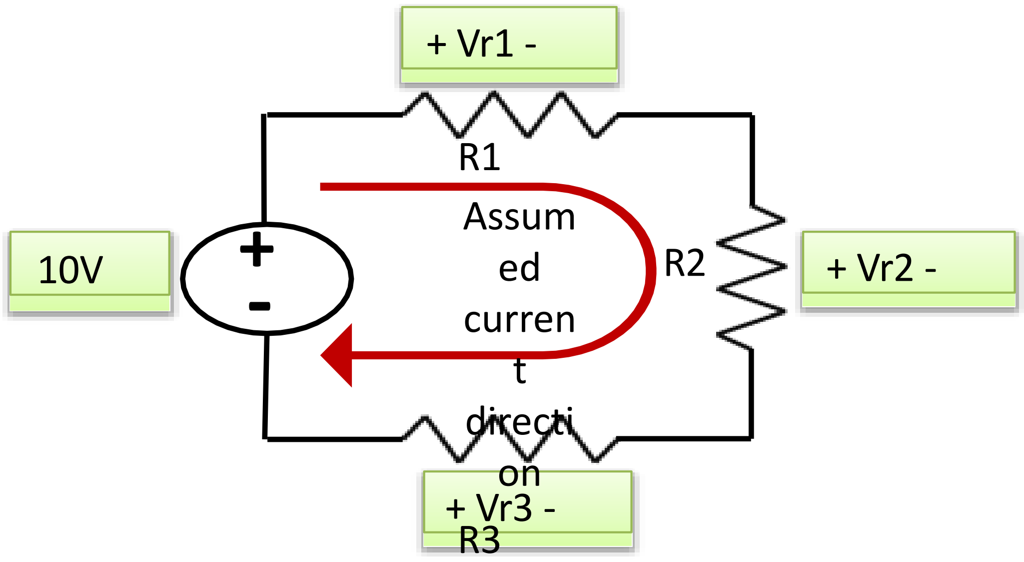
Resulting KVL Equation: $V_{r1}+V_{r2}+V_{r3}-10=0$

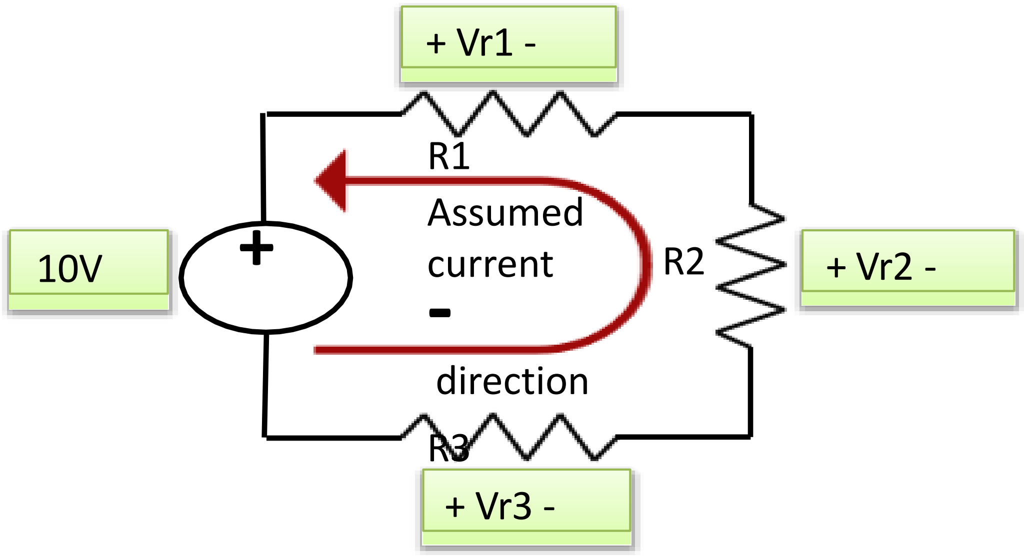


Resulting KVL Equation: $-V_{r1}-V_{r2}-V_{r3}+10=0$

For both summations, the assumed current direction was the same

Assuming the current direction fixes the voltage references





Resulting KVL Equation: $V_{r1}+V_{r2}+V_{r3}-10=0$

Resulting KVL Equation: $-V_{r1}-V_{r2}-V_{r3}-10=0$

For both cases shown, the direction of summation was the same

MESH ANALYSIS

- Analysis using KVL to solve for the currents around each closed loop of the network and hence determine the currents through and voltages across each elements of the network

- Mesh analysis procedure

STEP 1

Assign a distinct current to each closed loop of the network

STEP 2

Apply KVL around each closed loop of the network

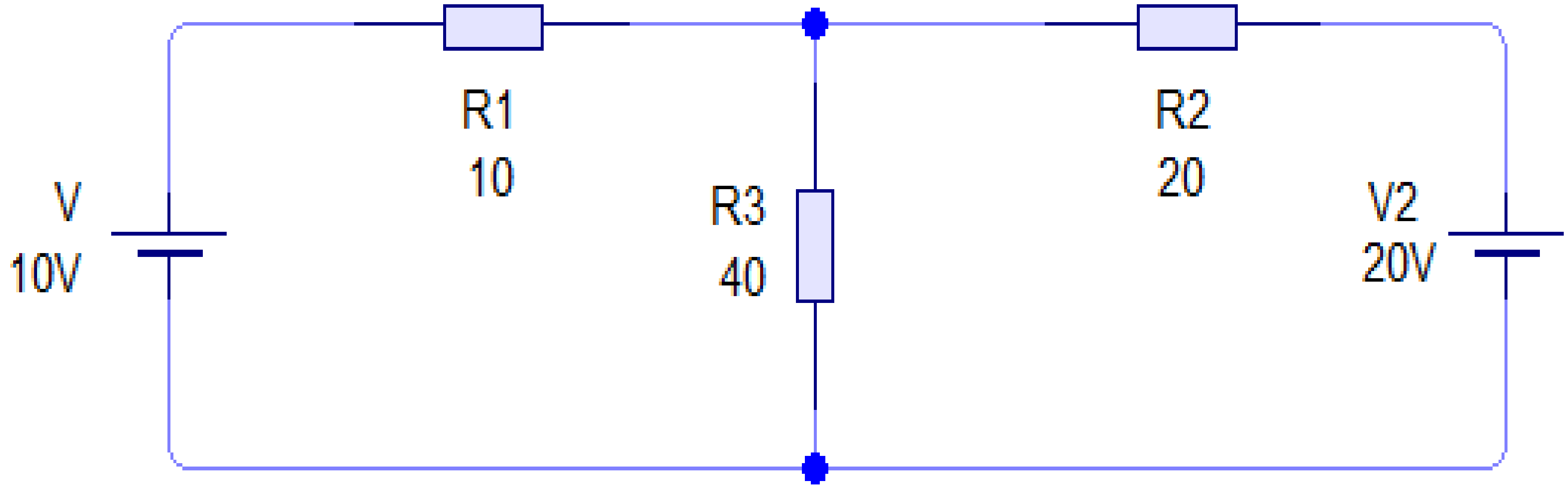
STEP 3

Solve the resulting simultaneous linear equation for the loop currents

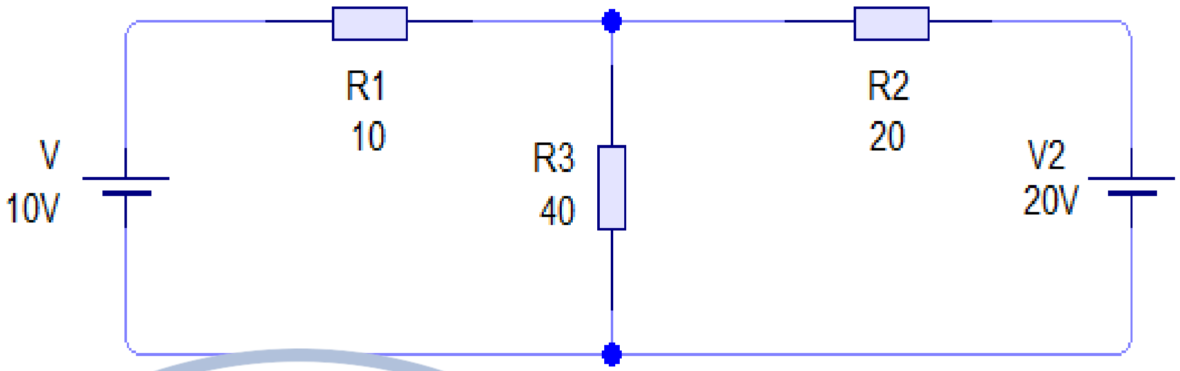
EXERCISE

- Exercise 1

Find the current flow through each resistor using mesh analysis for the circuit below



❑ EXERCISE 1



❖ SOLUTION

- Assign a distinct current to each closed loop of the network

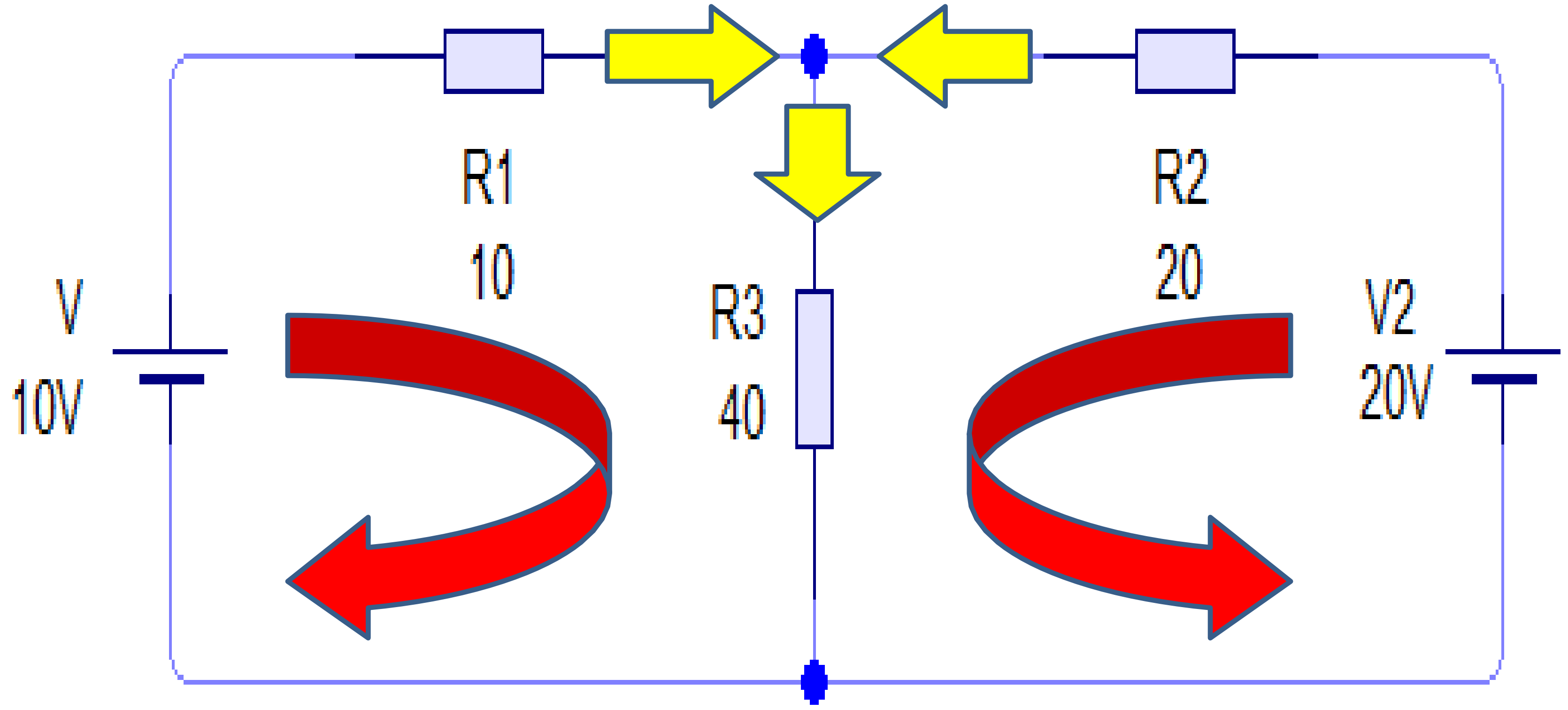
STEP 1

STEP 2

•Apply KVL around each closed loop of the network

- Solve the resulting simultaneous linear equation for the loop currents

STEP 3



S T E P 1

$$Loop1:$$

$$I_1R_1 + I_1R_3 + I_2R_3 = V_1$$

$$10I_1 + 40I_1 + 40I_2 = 10$$

$$50I_1 + 40I_2 = 10 ----equation1$$

$$Loop2:$$

$$I_2R_2 + I_2R_3 + I_1R_3 = V_2$$

$$20I_2 + 40I_2 + 40I_1 = 20$$

$$40I_1 + 60I_2 = 20 ----equation2$$

STEP 2

Solve equation 1 and equation 2 using Matrix

$$50I_1 + 40I_2 = 10$$
$$40I_1 + 60I_2 = 20$$

Matrixform :

$$\begin{bmatrix} 50 & 40 \\ 40 & 60 \end{bmatrix}\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 10 \\ 20 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 50 & 40 \\ 40 & 60 \end{vmatrix} = 3000 - 1600 = 1400$$

$$\Delta I_1 = \begin{vmatrix} 10 & 40 \\ 20 & 60 \end{vmatrix} = 600 - 800 = -200$$

$$\Delta I_2 = \begin{vmatrix} 50 & 10 \\ 40 & 20 \end{vmatrix} = 1000 - 400 = 600$$

$$I_1 = \frac{\Delta I_1}{\Delta} = \frac{-200}{1400} = -0.143A$$

$$I_2 = \frac{\Delta I_2}{\Delta} = \frac{600}{1400} = 0.429A$$

FromKCL :

$$I_3 = I_1 + I_2 = -0.143A + 0.429A = 0.286A$$

STEP 3

KIRCHOFF'S CURRENT LAW

INTRODUCTION KCL

NODES ANALYSIS

EXERCISE

INTRODUCTION OF KCL

1

Kirchhoff's Current Law is sometimes called "Kirchhoff's First Law" or "Kirchhoff's Junction Rule"

along with Kirchhoff's Voltage Law makes up the two fundamental laws of Electrical Engineering

2

In this lesson it will be shown how Kirchhoff's Current Law describes the current flow through a junction of a circuit

3

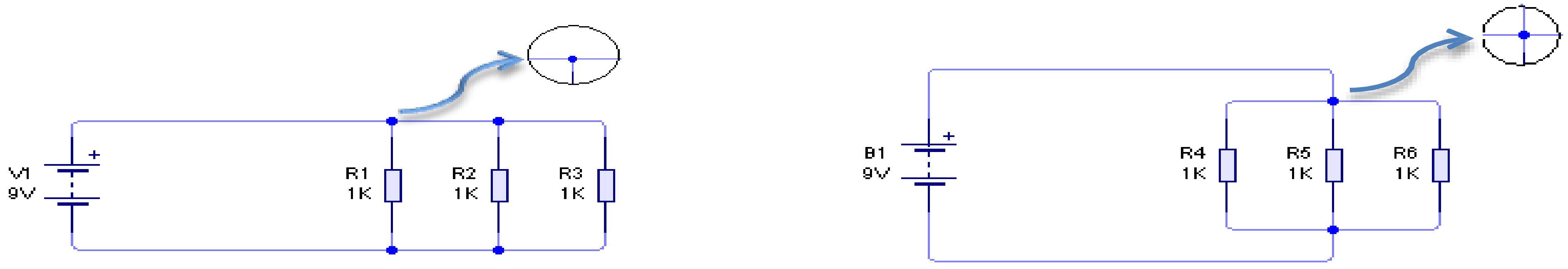
KCL helps to solve unknowns when working with electrical circuits

4

KCL with the addition of KVL and Ohm's Law will allow for the solution of complex circuits

- Definition that will help in understanding Kirchhoff's Current Law:

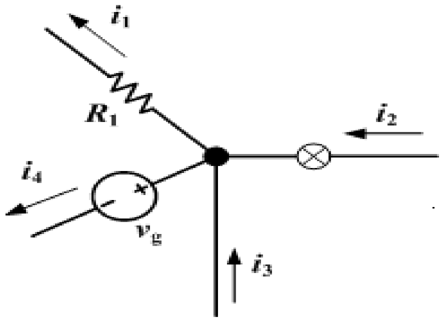
Junction - A junction is any point in a circuit where two or more circuit paths come together.



Examples of a Junction

- Kirchhoff's Current Law generally states:

The algebraic sum of all currents entering (+) and leaving (-) any point (junction) in a circuit must equal zero.

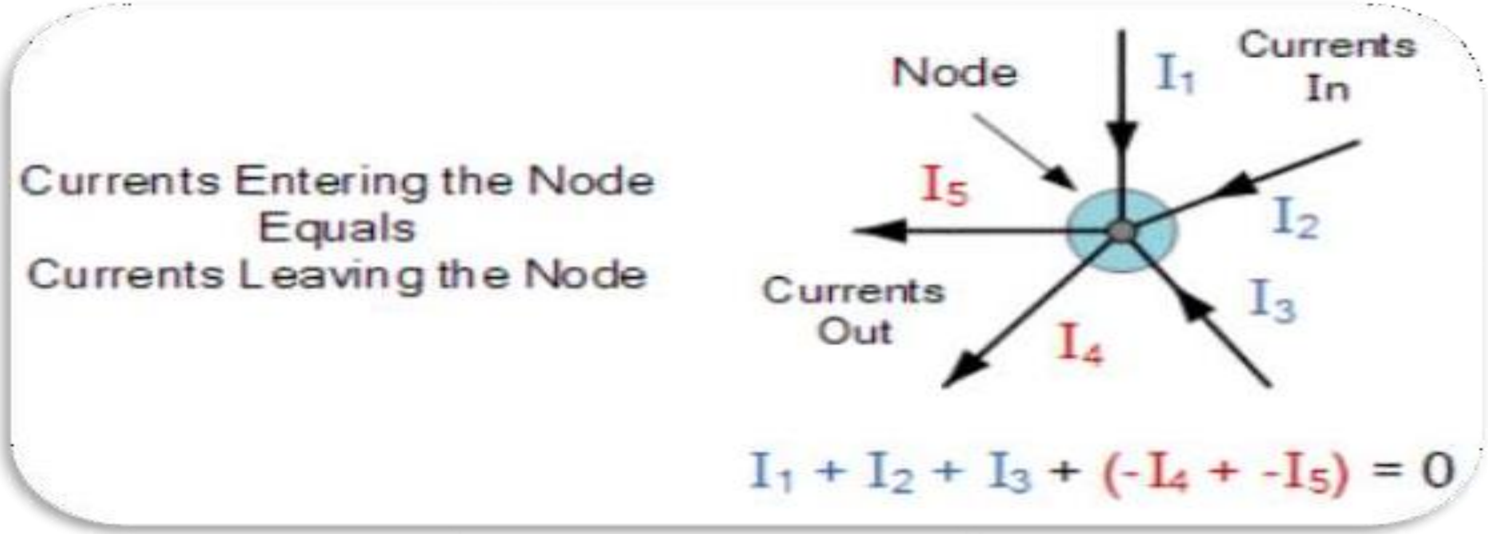


$$\sum_n i_n = i_1 + i_2 + i_3 + i_4 = 0$$

- Restated as:

The sum of the currents into a junction is equal to the sum of the currents out of that junction.

- The algebraic sum of all currents entering (+) and leaving (-) any point (junction) in a circuit must equal zero.



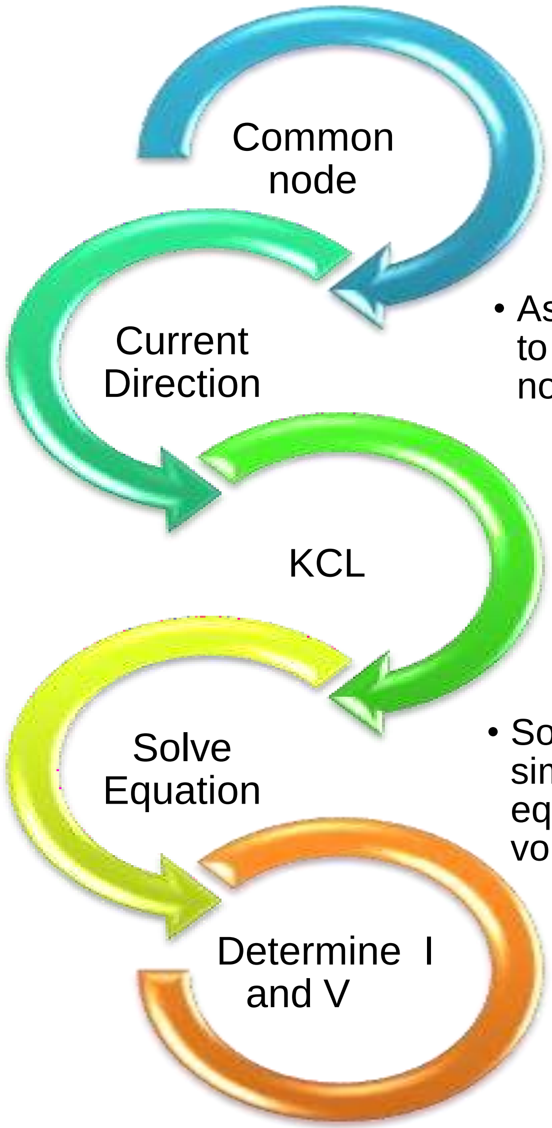
- Here, the 3 currents entering the node, I_1, I_2, I_3 are all positive in value and the 2 currents leaving the node, I_4 and I_5 are negative in value. Then this means we can also rewrite the equation as;

$$I_1 + I_2 + I_3 - I_4 - I_5 = 0$$

NODES ANALYSIS

Analysis using KCL to solve for voltages at each common node of the network and hence determine the currents though and voltages across each elements of the network.

Nodes Analysis Procedure



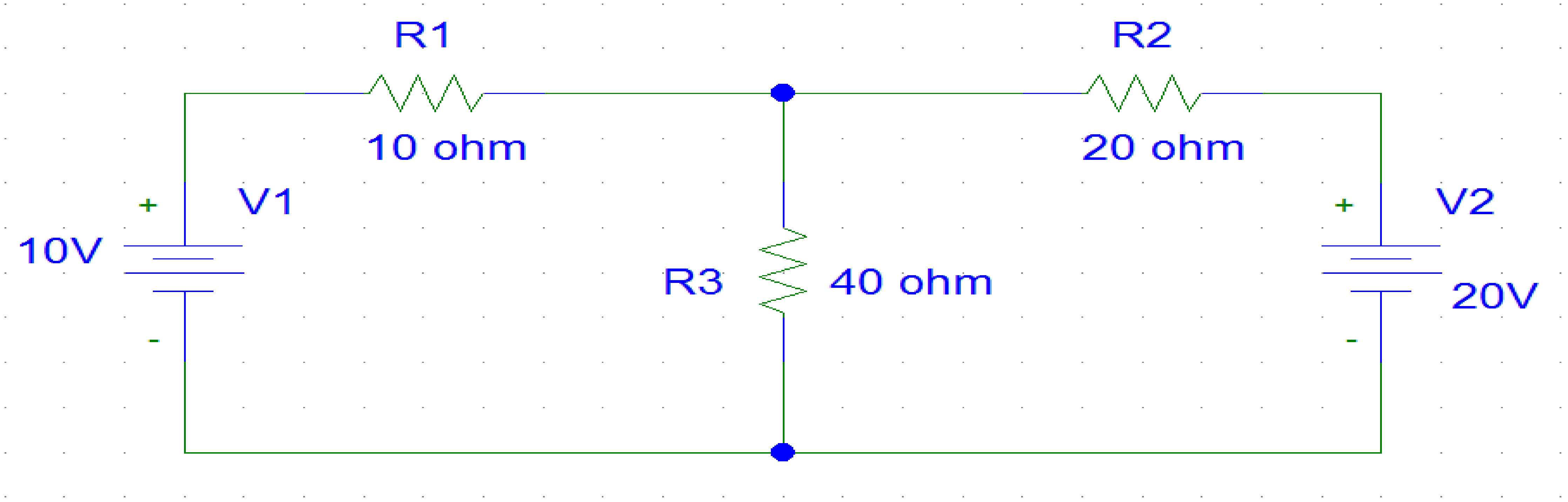
- Determine the number of common nodes and reference node within the network
- Assign current and its direction to each distinct branch of the nodes in the network
- Apply KCL at each of the common nodes in the network
- Solve the resulting simultaneous linear equation for the node voltage
- Determine the currents through and voltages across each elements in the network

EXIT

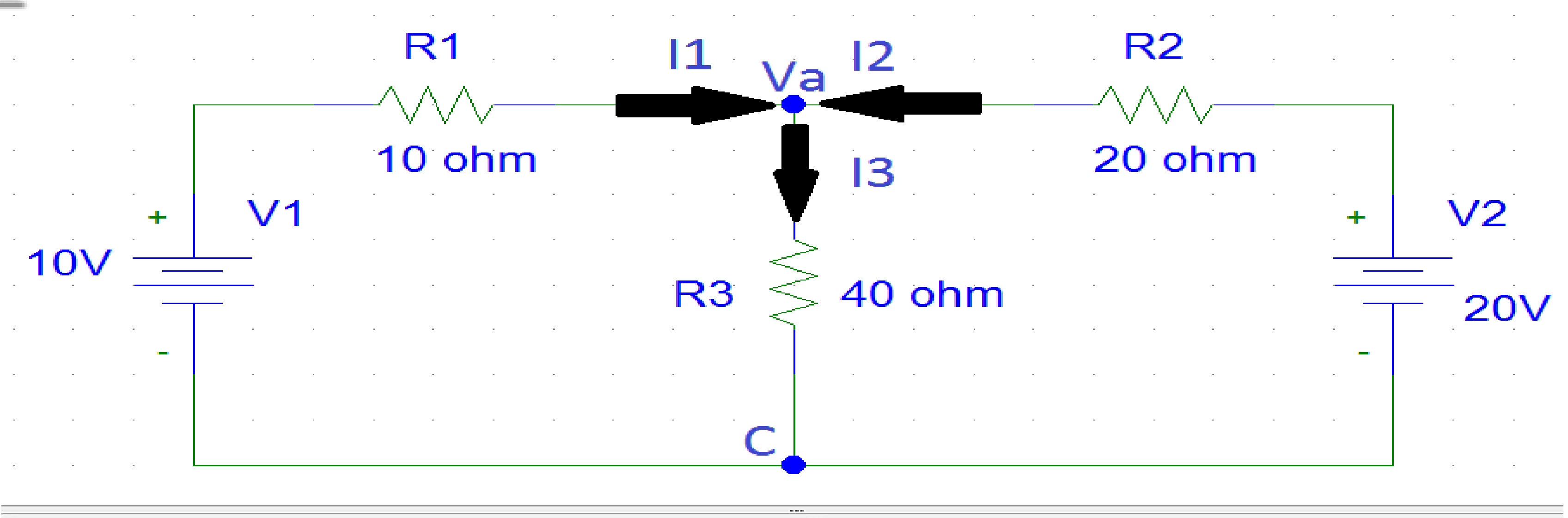
EXERCISE

Example 1:

Find the current flow through each resistor using node analysis for the circuit below.



EXERCISE



REMEMBER THE STEPS EARLIER??

Determine the number of common nodes and reference node within the network.

1 common node (Va) and 1 reference node C

Assign current and its direction to each distinct branch of the nodes in the network (refer o the figure)

Apply KCL at each of the common nodes in the network

KCL: I1 + I2 = I3

$$\frac{(10-Va)}{10} + \frac{(20-Va)}{20} = \frac{Va}{40}$$

$$1-\frac{Va}{10} + 1-\frac{Va}{20} = \frac{Va}{40}$$

$$\frac{Va}{40} + \frac{Va}{10} + \frac{Va}{20} = 2$$

$$Va\left(\frac{1}{40} + \frac{1}{10} + \frac{1}{20}\right) = 2$$

$$Va\left(\frac{7}{40}\right) = 2$$

$$Va = 11.428V$$

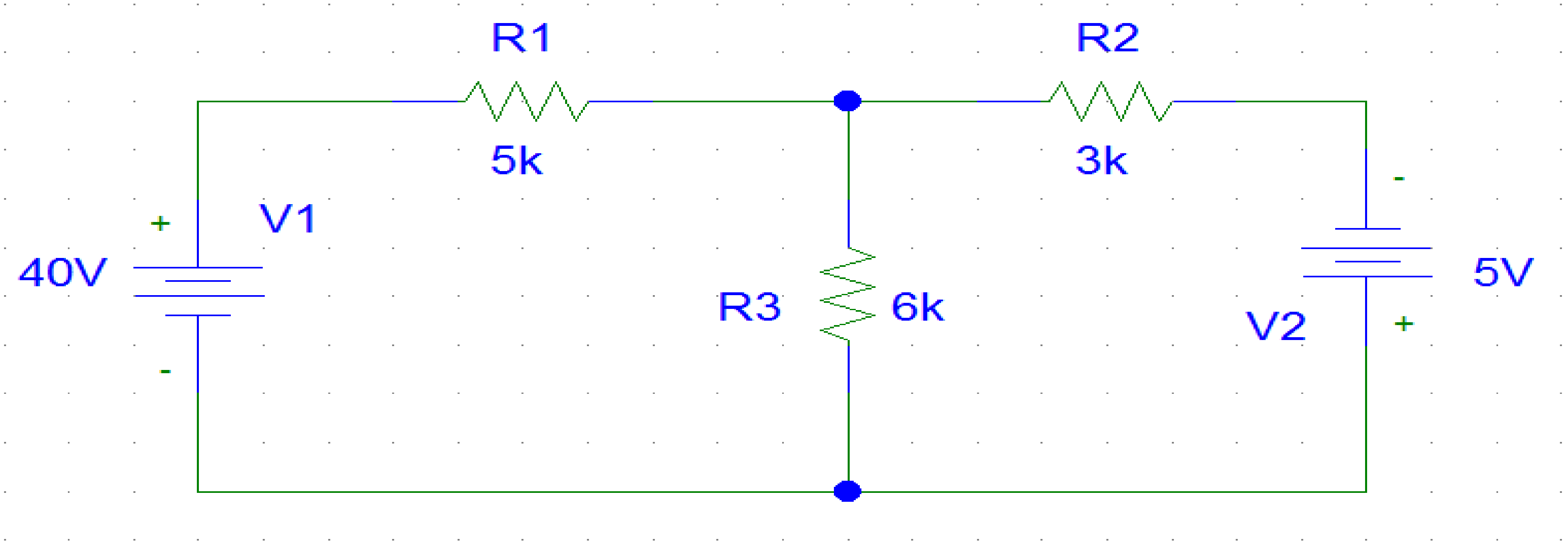
$$I_1 = \frac{(10-11.428)}{10} = -0.143A$$

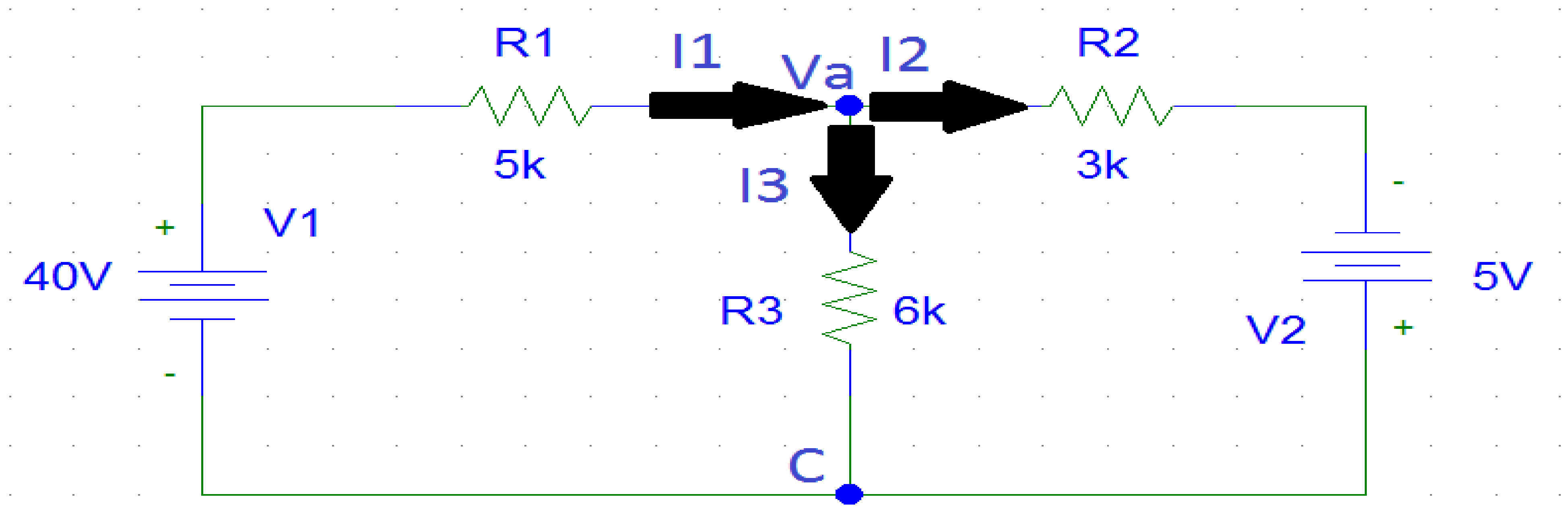
$$I_2 = \frac{(20-11.428)}{20} = 0.429A$$

$$I_3 = \frac{11.428}{40} = 0.286V$$

Example 2:

Find the current flow through each resistor using node analysis for the circuit below.





REMEMBER THE STEPS EARLIER??

Determine the number of common nodes and reference node within the network.

1 common node (Va) and 1 reference node C

Assign current and its direction to each distinct branch of the nodes in the network (refer o the figure)

Apply KCL at each of the common nodes in the network

KCL: I1 = I2 + I3

$$\frac{(40-Va)}{5k} = \frac{(Va-(-55))}{3k} + \frac{Va}{6k}$$

$$\frac{40}{5k} - \frac{Va}{5k} = \frac{Va}{3k} + \frac{55}{3k} + \frac{Va}{6k}$$

$$\frac{(-Va)}{5k} - \frac{Va}{3k} - \frac{Va}{6k} = \frac{55}{3k} - \frac{40}{5k}$$

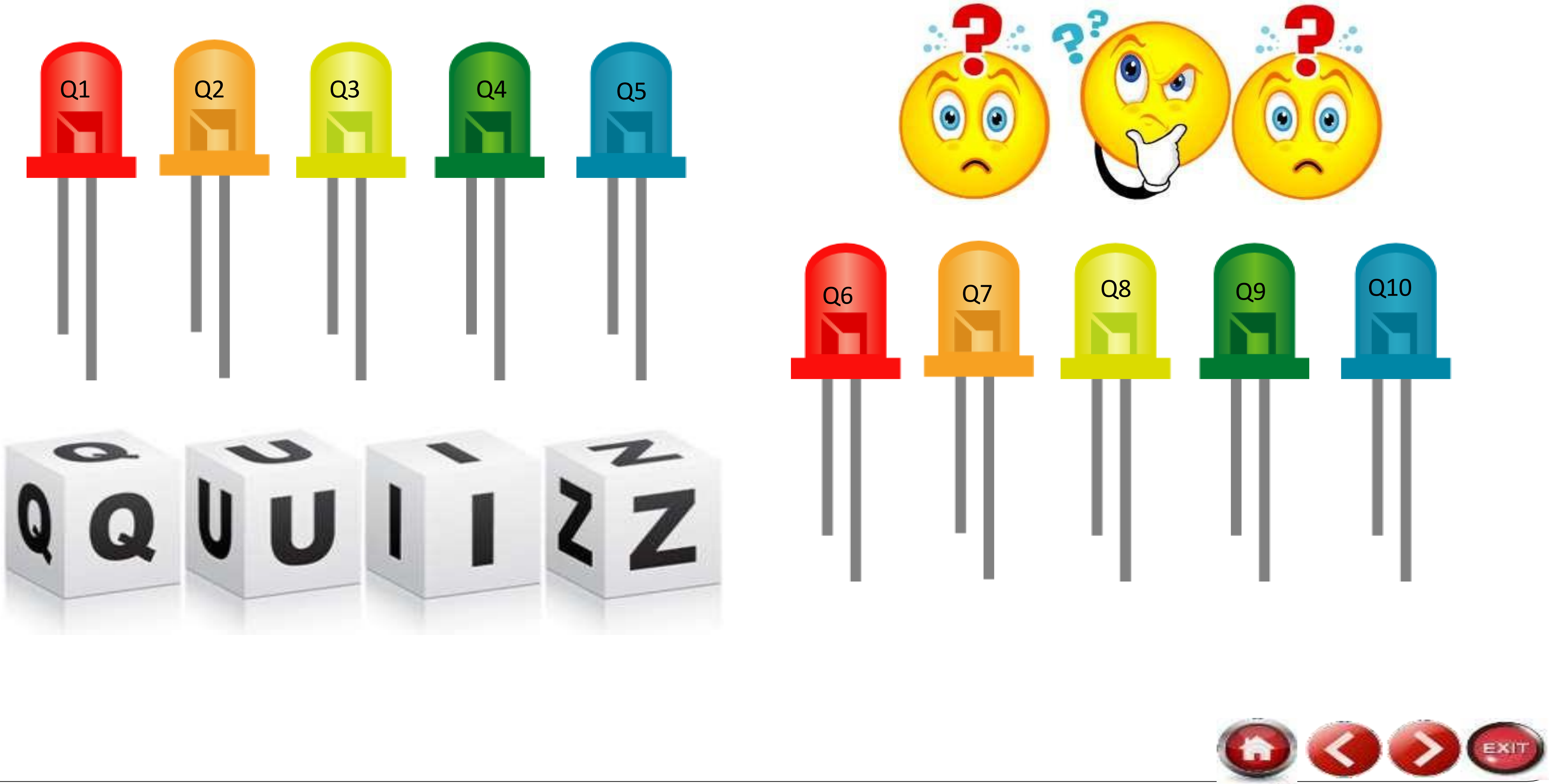
$$-Va\left(\frac{1}{5k} + \frac{1}{3k} + \frac{1}{6k}\right) = \frac{55}{3k} - \frac{40}{5k}$$

$$-Va\,(700 \times 10^{-6}) = 10.33 \times 10^{-3} \quad Va = -14.757V$$

$$I_1 = \frac{(40-(-14.757))}{5k} = 10.95mA$$

$$I_2 = \frac{(-14.757+55)}{3k} = 13.41mA$$

$$I_3 = \frac{(-14.757)}{6k} = -2.46mA$$


Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
QUIZ
EXIT

Kirchhoff's First Law says that:

A. Current loses strength as it flows about a circuit

B. Voltage loses strength as it flows about a circuit

C. Wires need insulation to stop electrons from leaking out of the wire

D. Total current flowing into a point is the same as the current flowing out of that point

Question 1

Question 2

KCL is used when solving circuits with…

Closed loops

Sufficient nodes/ junctions

Capacitors

None

Question 3

Nodal Analysis applies the following principles…

A. KVL & Ohm's Law

B. KCL & Ohm's Law

C. KVL & Superposition

D. KCL & Superposition

Question 4

Which of the following statements is true?

Mesh Analysis is easiest when a circuit has more than two nodes

Mesh Analysis is more difficult than Nodal Analysis

Mesh Analysis employs KVL to solve loop currents

All of t All of the above

Question 5

If a circuit contains three loops, how many *independent* equations can be obtained with Kirchhoff's Second laws?

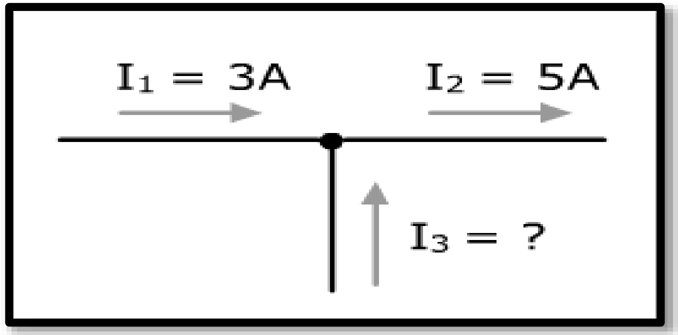
Three

Four

Five

Six

How much is current I_3 in the node shown?



Question 6

2A

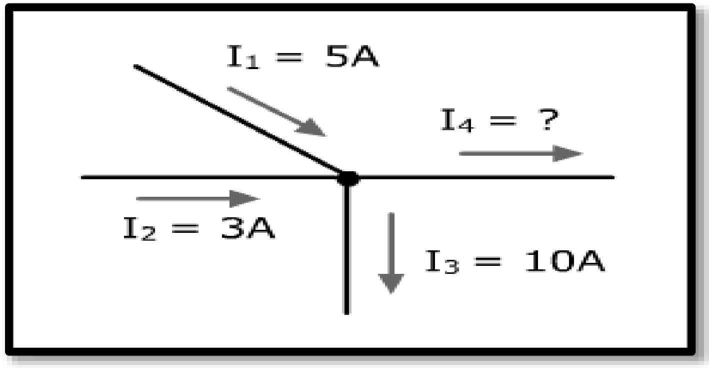
-2A

0A

8A

Question 7

How much is current I_4 in the node shown?



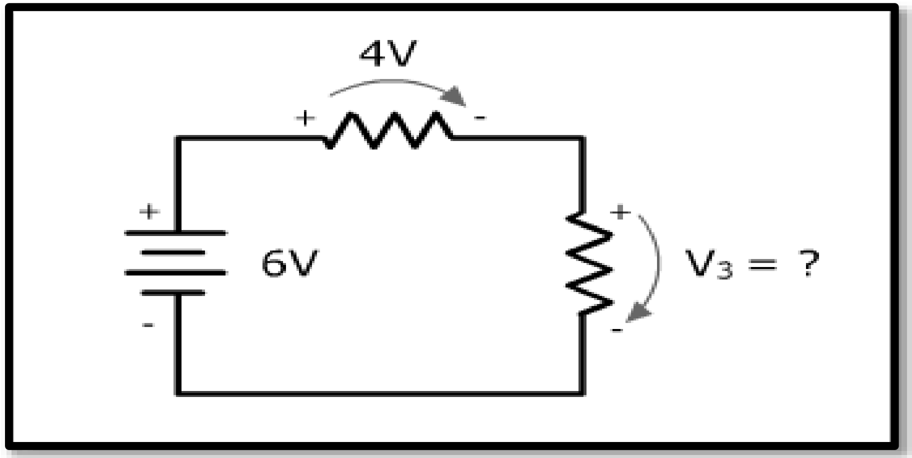
2A

-2A

18A

8A

How much is voltage V_3 in the closed loop circuit shown?



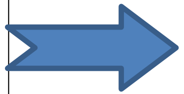
2A

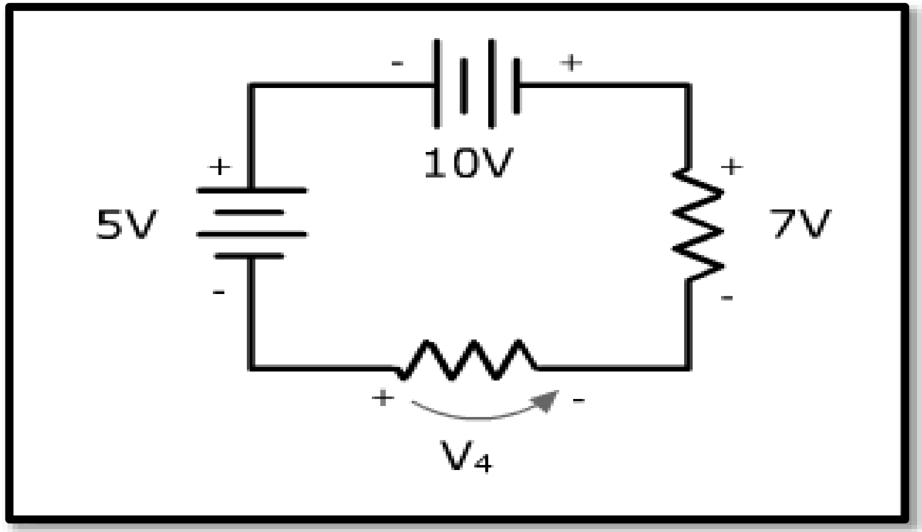
-2A

10A

-10A

How much is voltage V_4 in the closed loop circuit shown?





4A

-4A

8A

-8A

Mesh Current Method

Objectives

- To introduce the mesh – current method.
- To formulate the mesh-current equations.
- To solve electric circuits using the mesh-current method.

Mesh Analysis (Loop Analysis)

- MeshAnalysis is developed by applying KVL around meshes in the circuit.
- Loop (mesh) analysis results in a system of linear equations which must be solved for unknown currents.
- Reduces the number of required equations to the number of meshes
- Can be done systematically with little thinking
- As usual, be careful writing mesh equations – follow sign convention.

Definitions

Mesh: Loop that does not enclose other loops

Essential Branch: Path between 2 essential nodes (without crossing other essential nodes).

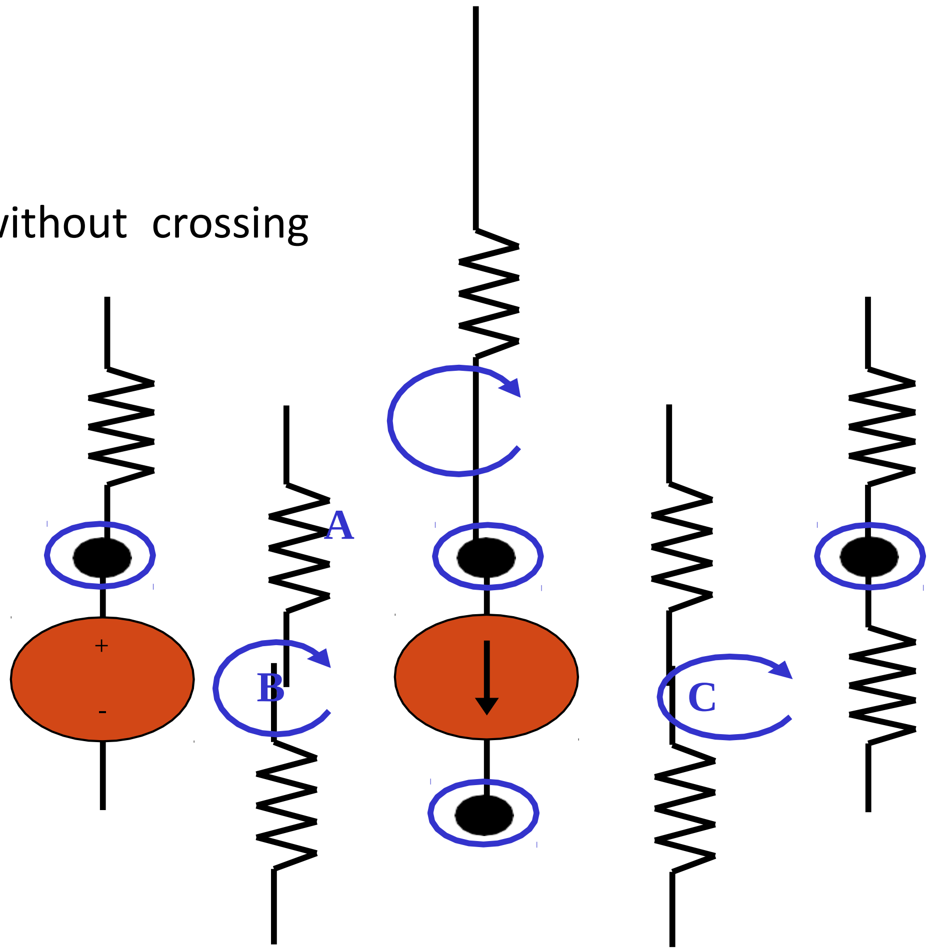
How many mesh-currents?

\# of essential nodes **Ne = 4**

\# of essential branches **Be = 6**

No. of Mesh-currents **M = Be –(Ne-1)**

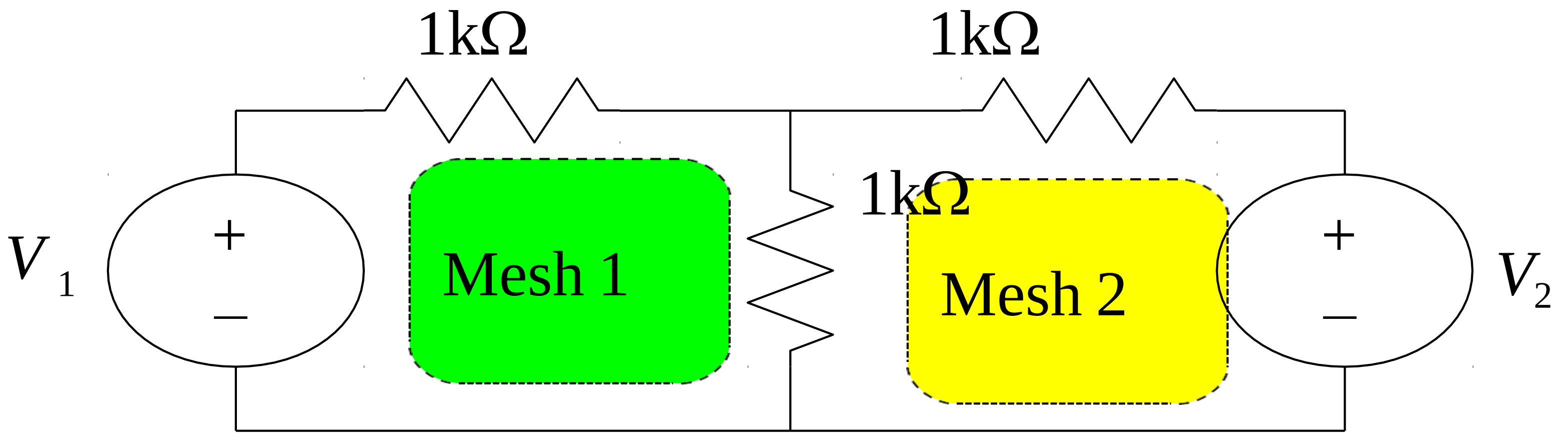
- Enough equations to get unknowns



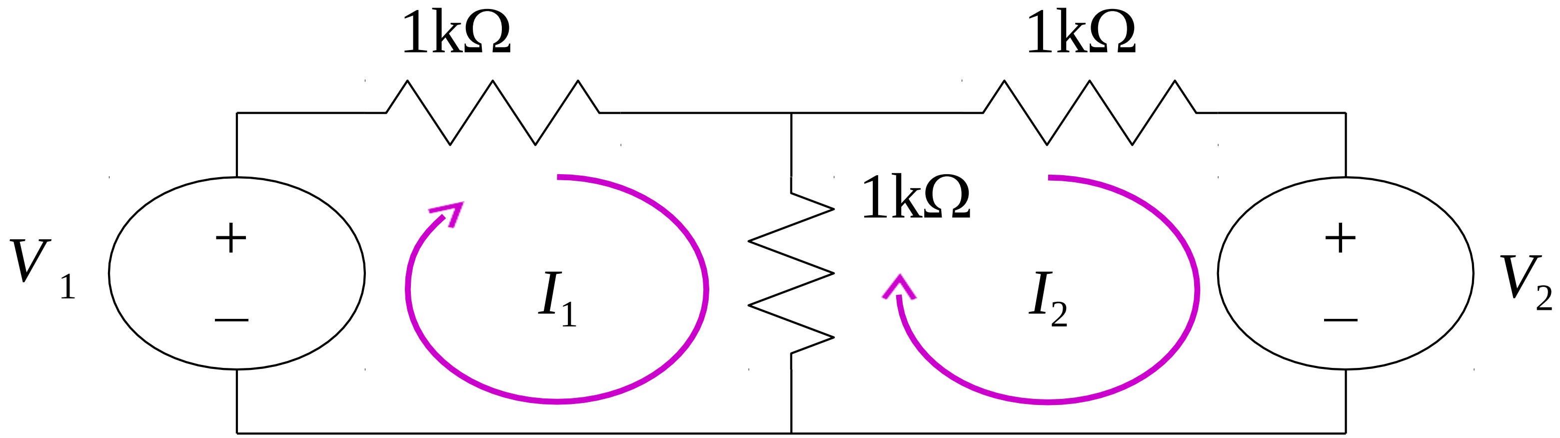
Steps of Mesh Analysis

1. Identify the number of basic meshes.
2. Assign a current to each mesh.
3. Apply KVL around each loop to get an equation in terms of the loop currents.
4. Solve the resulting system of linear equations.

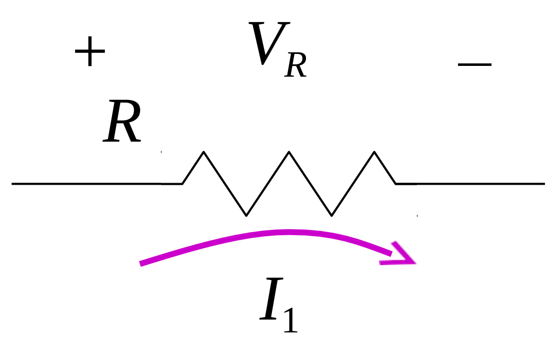
Identifying the Meshes

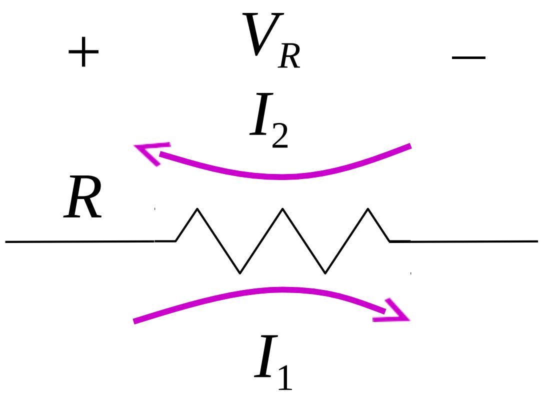


Assigning Mesh Currents



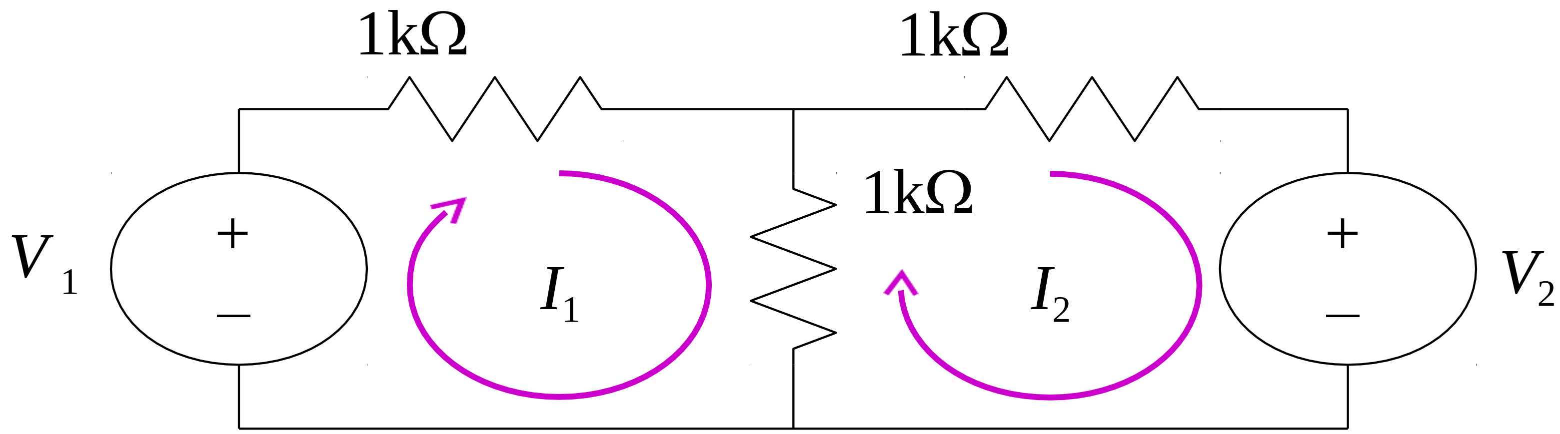
Voltages from Mesh Currents



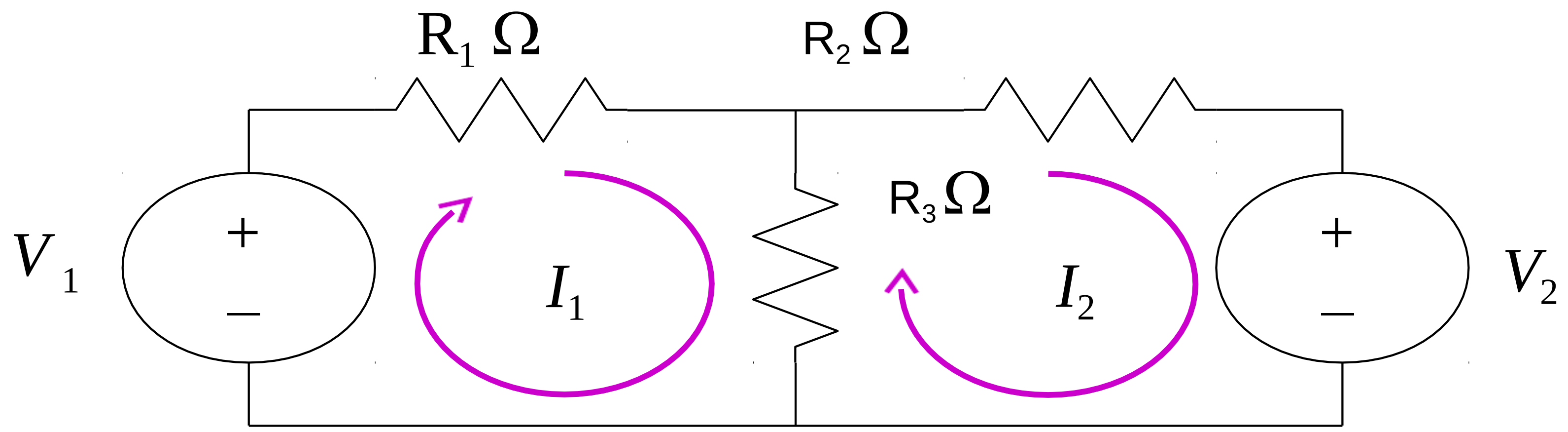


$$V_R = I_1 R$$

$$V_R = (I_1 - I_2)\, R$$



Mesh-Current Equations



$$-V_1 + I_1 R_1 + (I_1 - I_2) R_3 = 0$$

$$I_2 R_2 + V_2 + (I_2 - I_1) R_3 = 0$$

Mesh Current Method

1. Assign mesh currents
2. Write mesh equations

$i_1(20+6+4) + (i_1-i_2)(4+6) = 0$ $i_2(2+4+4) + (i_2-i_1)(4+6) - 70 = 0$

3. Solve mesh equations

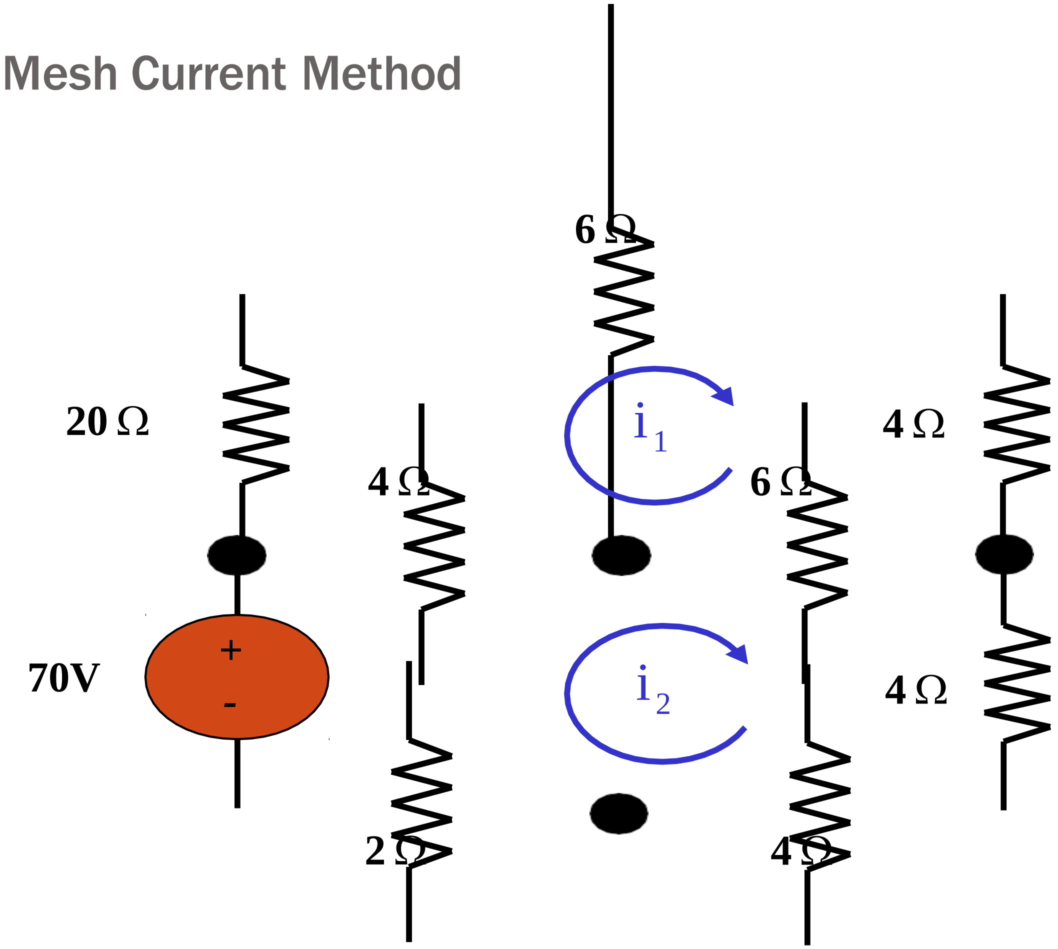
$40i_1 - 10i_2 = 0$

$-10i_1 + 20i_2 = 70$

========================= $40i_1 - 10i_2 = 0$

$70i_2 = 280$

Solution: $i_1 = 1A$; $i_2 = 4A$



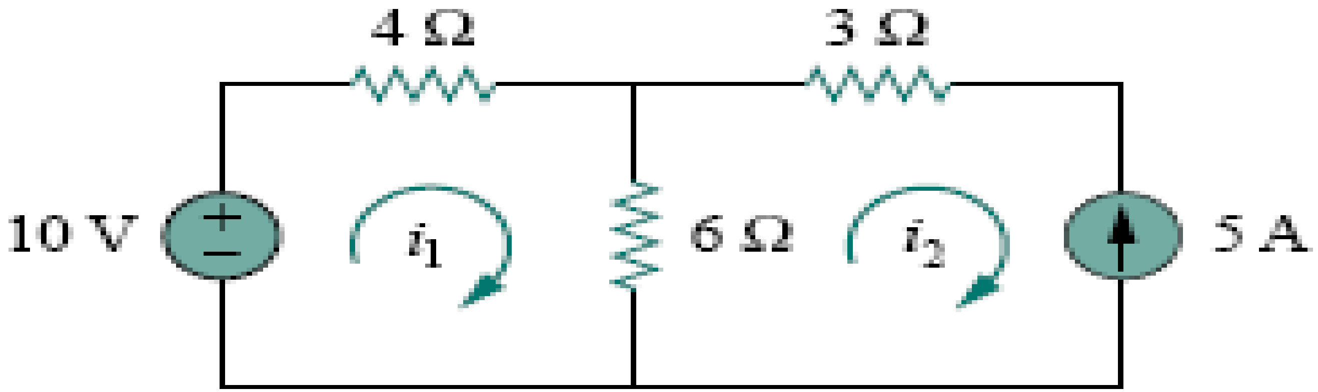
Case I: When a current source exists only in one mesh

Loop 1

$-10 + 4i_1 + 6(i_1 - i_2) = 0$

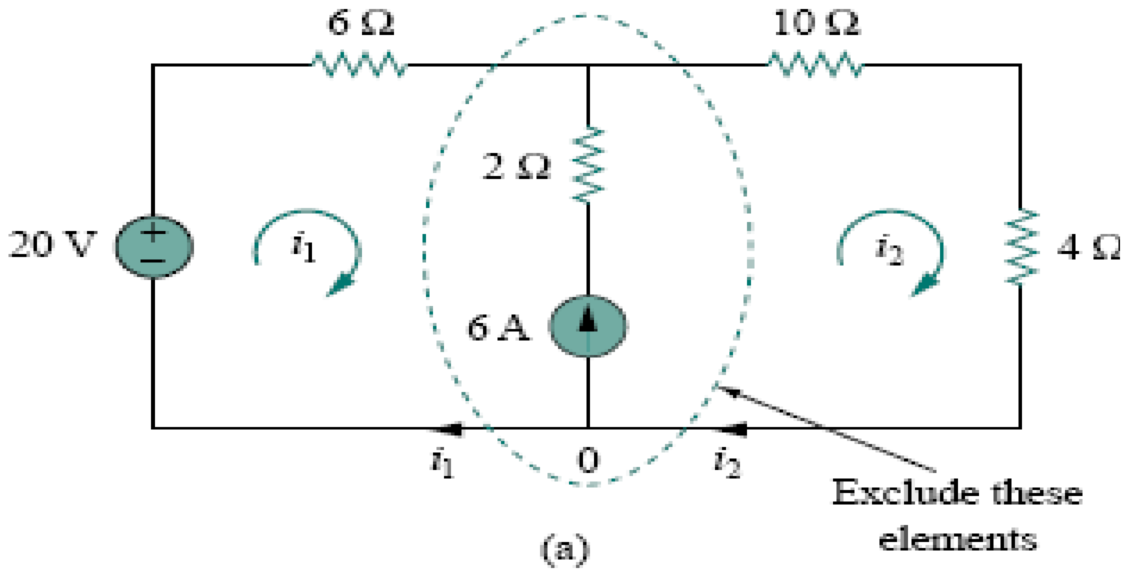
Loop 2 $i_2 = -5A$

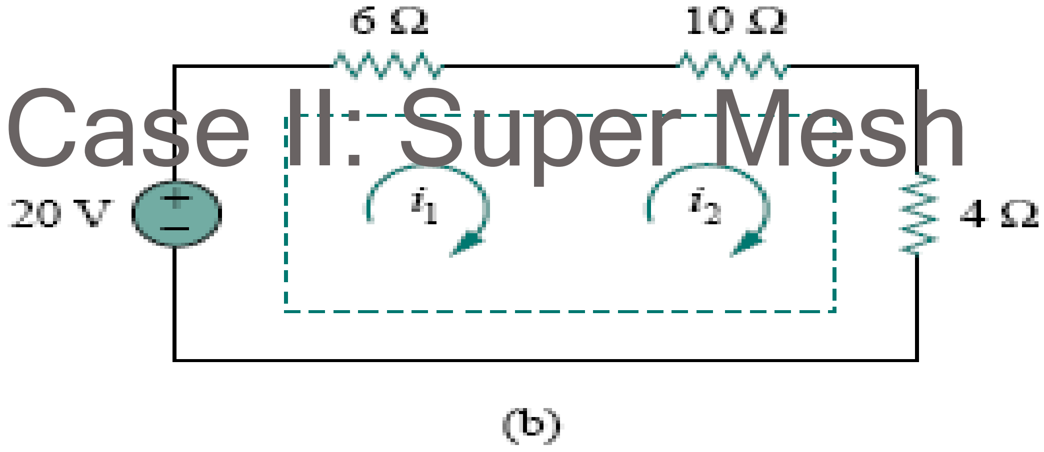
No need to write a loop equation



Case II: Super Mesh

When a current source exists between two meshes





$$-20 + 6i_1 + 10i_2 + 4i_2 = 0$$

$$i_2 = i_1 + 6$$

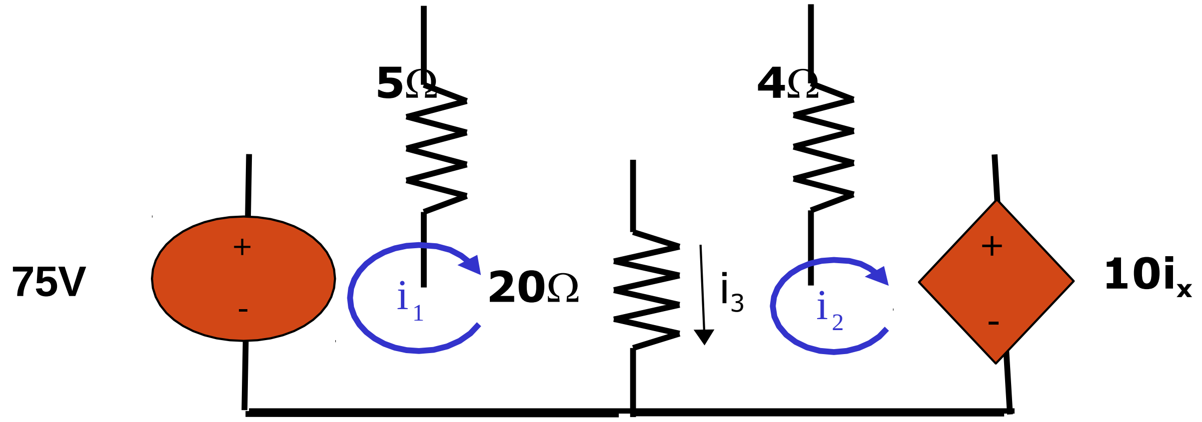
$$i_1 = -3.2 \text{ A},$$

$$i_2 = 2.8 \text{ A}$$

Case III: Mesh with Dependent Sources

$-75 + 5i_1 + 20(i_1-i_2) = 0$

$10i_x + 20(i_2-i_1) + 4i_2 = 0$



$i_x = i_1 - i_2$

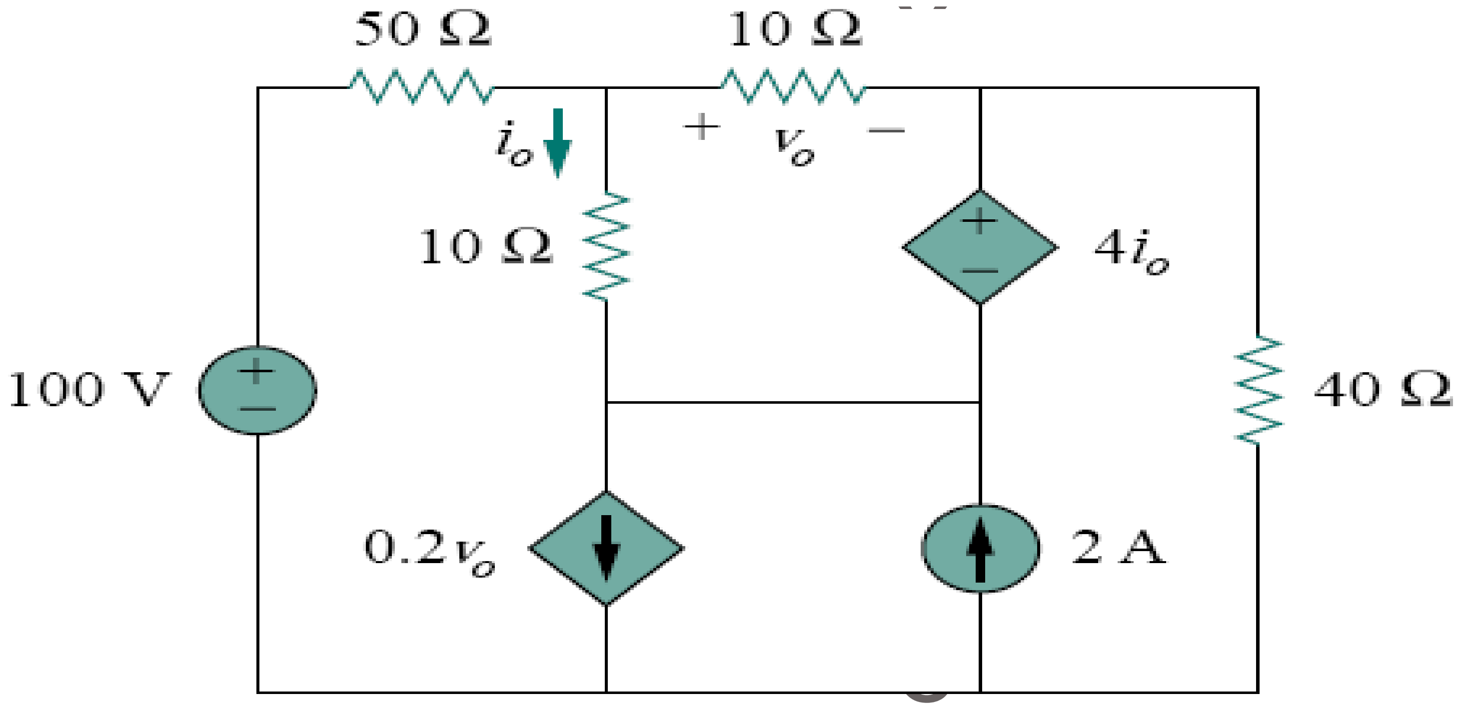
$-75 + 5i_1 + 20(i_1-i_2) = 0$

$10(i_1-i_2) + 20(i_2-i_1) + 4i_2 = 0$

$i_2 = 5A \quad i_1 = 7A$

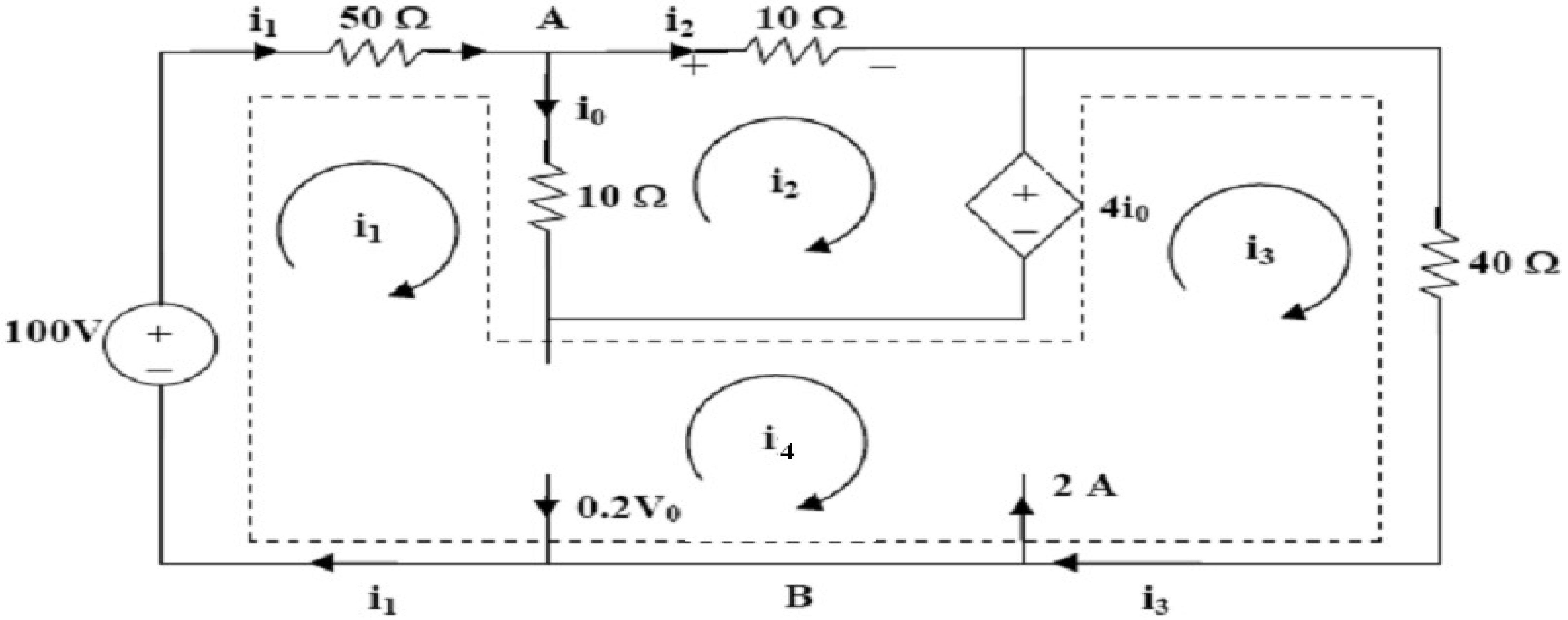
Use the mesh-current method to find *io*

E



Ans. I_o = A

Solution



Solution

For mesh 2, $20i_2 - 10i_1 + 4i_0 = 0$ (1)

But at node A, $i_o = i_1 - i_2$ so that (1) becomes $i_1 = (16/6)i_2$ (2)

For the supermesh, $-100 + 50i_1 + 10(i_1 - i_2) - 4i_0 + 40i_3 = 0$

or $50 = 28i_1 - 3i_2 + 20i_3$ (3)

$i_3 - i_4 = 2$ $i_4 - i_1 = 0.2v_0$ (4)

But, $v_0 = 10i_2$ so that (4) becomes $i_3 = 2 + (2/3)i_2$ (5)

Solving (1) to (5), $i_2 = 0.11764$,

$v_0 = 10i_2 =$ **1.1764 volts**, $i_0 = i_1 - i_2 = (5/3)i_2 =$ **196.07 mA**

UNIT :5

What is an Induction Motor?

A motor with only armortisseur windings is called an induction motor. An induction motor is the most modest electrical machine from constructional point of view, in the majority of the cases. Induction motor works on the principle of induction where electro-magnetic field is induced into the rotor when rotating magnetic field of stator cuts the stationary rotor. Induction machines are by far the most common type of motor used in industrial, commercial or residential settings. It is a three phase AC motor. Its characteristic features are:

Simple and rugged construction

Low cost and minimum maintenance

High dependability and sufficiently high proficiency

Needs no additional starting motor and necessity not be synchronized

What are the basic parts of an Induction Motor?

An induction motor has basically two parts: Stator and Rotor.

Stator:

The stator is made up of various stampings with slots to carry three phase windings. It is wound for a distinct number of poles. The windings are geometrically divided 120 degrees separated.

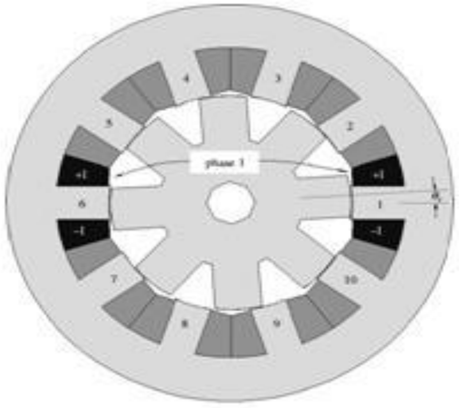
Two sorts of rotors are used in Induction motors:

Squirrel cage rotor and Wound rotor.

No DC field current is required to run the machine. Rotor voltage is induced in the rotor windings rather than being physically connected by wires.

Rotor:
The rotor is the rotating part of the electromagnetic circuit. The most common type of rotor is the squirrel cage rotor. The rotor comprises of a cylindrical laminated core with axially placed parallel slots for carrying the conductors. Each slot carries a copper, aluminum, or alloy bar. The rotor of three-phase induction motors frequently is likewise implied as an anchor. The purpose behind this name is the anchor shape of the rotors used within quite early electrical devices. In electrical equipment the anchor's winding would be induced by the magnetic field, although the rotor takes this part in three-phase induction motors.

Two Types of Induction Motors
Single phase induction motor:
Three-Phase Induction Motor:

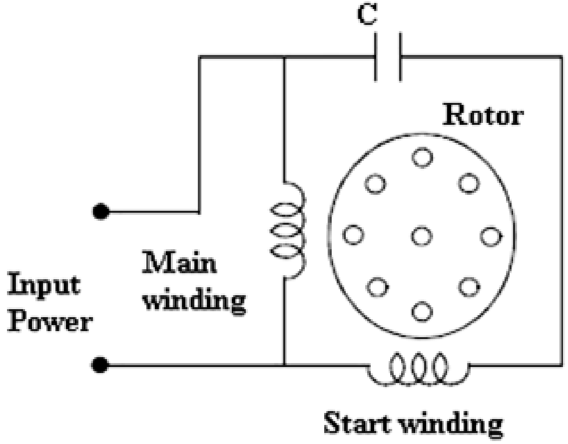


Note: Phase 1 (stator poles 1 and 6) under excitation

Single phase induction motor:

The single-phase induction motor is not self-starting. When the motor is connected to a single-phase power supply, the main winding carries an alternating current. It is logical that the least expensive, most reduced upkeep sort engine ought to be utilized most regularly. These are of different types based on their way of starting since these are of not self starting.

Those are split phase, shaded pole and capacitor motors. Again capacitor motors are capacitor start, capacitor run and permanent capacitor motors. Permanent capacitor motor is shown below.



In these types of motors the start winding can have a series capacitor and/or a centrifugal switch. When the supply voltage is applied, current in the main winding lags the supply voltage because of the main winding impedance. And current in the start winding leads/lags the supply voltage depending on the starting mechanism impedance. The angel between the two windings is sufficient phase difference to provide a rotating magnitude field to produce a starting torque. The point when the motor reaches 70% to 80% of synchronous speed, a centrifugal switch on the motor shaft opens and disconnects the starting winding.

Applications of Single Phase Induction Motor

These are used in low power applications and widely used in domestic applications as well as industrial. And some of those are mentioned below

Pumps
Compressors
Small fans
Mixers
Toys
High speed vacuum cleaners
Electric shavers
Drilling machines

Three-Phase Induction Motor:

The three phase induction motor is a preferable type of motor. It is mostly used in industrial drives because it is very reasonable and vigorous, economical and reliable. It is also called asynchronous motor because it does not run at a synchronous speed. The induction motor requires very little maintenance and also it has high overloading capacity.

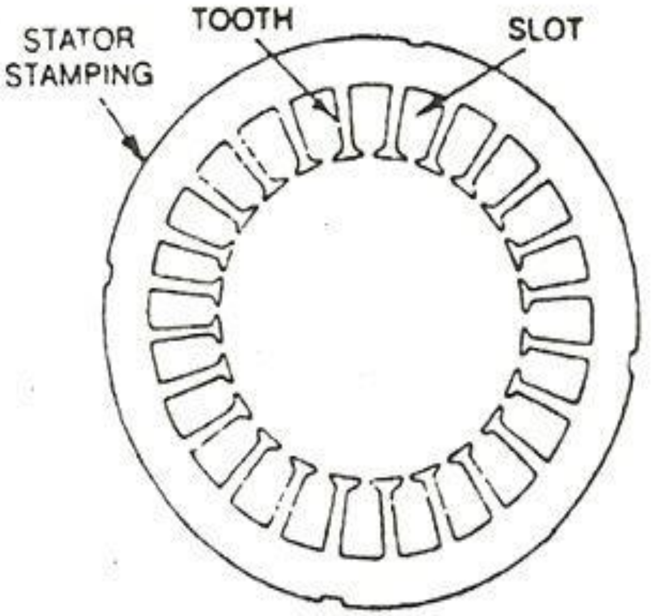
A three phase **Induction motor** mainly consists of two parts called as the **Stator** and the **Rotor**. The stator is the stationary part of the induction motor, and the rotor is the rotating part. The construction of the stator is similar to the three-phase synchronous motor, and the construction of rotor is different for the different machine. The construction of the induction motor is explained below in detail.

Construction of Stator

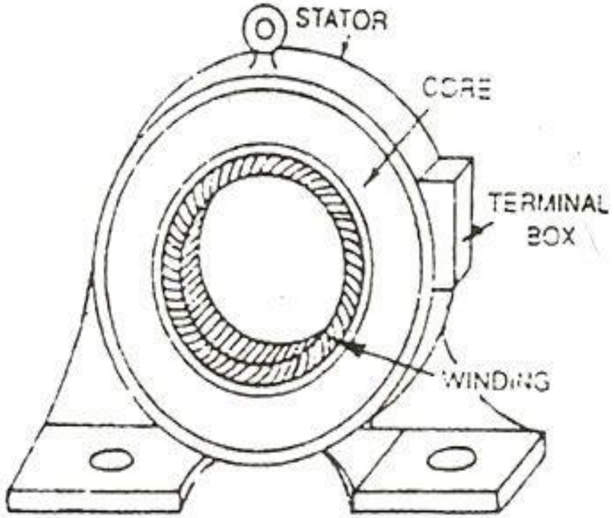
The stator is built up of high-grade alloy steel laminations to reduce eddy current losses. It has three main parts, namely outer frame, the stator core and a stator winding

Outer frame

It is the outer body of the motor. Its main function is to support the stator core and to protect the inner parts of the machine. For small machines, the outer frame is casted, but for the large machine, it is fabricated. The figure below shows the stator construction.



STATOR
STAMPING
TOOTH
SLOT



STATOR
CORE
TERMINAL
BOX

Stator Core

The stator core is built of high-grade silicon steel stampings. Its main function is to carry the alternating magnetic field which produces hysteresis and eddy current losses. The stampings are fixed to the stator frame. Each stamping are insulated from the other with a thin varnish layer. The thickness of the stamping usually varies from 0.3 to 0.5 mm. Slots are punched on the inner side of the stampings as shown in the figure below.

Stator windings

The core of the stator carries three phase windings which are usually supplied from a three-phase supply system. The six terminals of the windings (two of each phase) are connected in the terminal box of the machine. The stator of the motor is wound for a definite number of poles, depending on the speed of the motor. If the number of poles is greater, the speed of the motor will be less and if the number of poles is less than the speed will be high.

As the relationship between the speed and the pole of the motor is given as

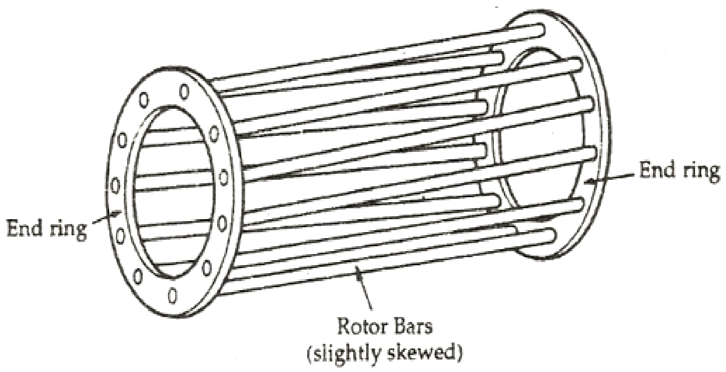
$$N_S \propto \frac{1}{P} \quad \text{or} \quad N_S = \frac{120f}{P}$$

Construction of Rotor

The rotor is also built of thin laminations of the same material as the stator. The laminated cylindrical core is mounted directly on the shaft. These laminations are slotted on the outer side to receive the conductors. There are two types of rotor.

Squirrel Cage Rotor

A squirrel cage rotor consists of a laminated cylindrical core. The circular slots at the outer periphery are semi-closed. Each slot contains uninsulated bar conductor of aluminium or copper. At the end of the rotor the conductors the short-circuited by a heavy ring of copper or aluminium. The diagram of the cage rotor is shown below.



The rotor slots are usually not parallel to the shaft but are skewed. The skewing of the rotor conductors has the following advantages given below.

It reduces humming and provide smooth and noise free operation.

It results in a uniform torque curve for different positions of the rotor.

The locking tendency of the rotor is reduced. As the teeth of the rotor and the stator attract each other and lock.

It increases the rotor resistance due to the increased length of the rotor bar conductors.

Advantages of Squirrel Cage Rotor

The following advantages of the cage rotor are given below.

The cage rotor is cheaper, and the construction is robust.

The absence of the brushes reduces the risk of sparking.

Its Maintenance is less.

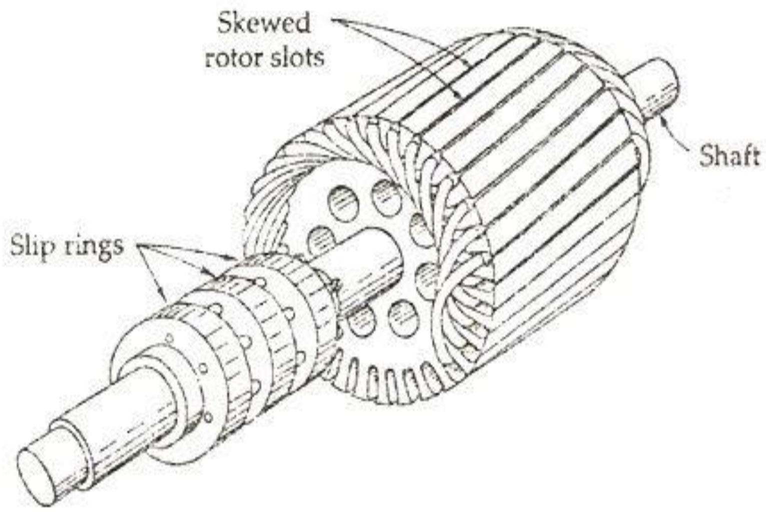
The power factor is higher

The efficiency of the cage rotor is higher.

Phase Wound Rotor

The Phase wound rotor is also called as Slip Ring Rotor. It consists of a cylindrical core which is laminated. The outer periphery of the rotor has a semi-closed slot which carries a 3 phase insulated windings. The rotor windings are connected in star.

The **slip ring induction motor** is shown in the figure below.



The slip rings are mounted on the shaft with brushes resting on them. The brushes are connected to the variable resistor. The function of the slip rings and the brushes is to provide a means of connecting external resistors in the rotor circuit. The resistor enables the variation of each rotor phase resistance to serve the following purposes given below.

It increases the starting torque and decreases the starting current.

It is used to control the speed of the motor.

In this type also, the rotor is skewed. A mild steel shaft is passed through the center of the rotor and is fixed to it. The purpose of the shaft is to transfer mechanical power.

Advantages of Phase Wound Rotor

High starting torque and low starting current.

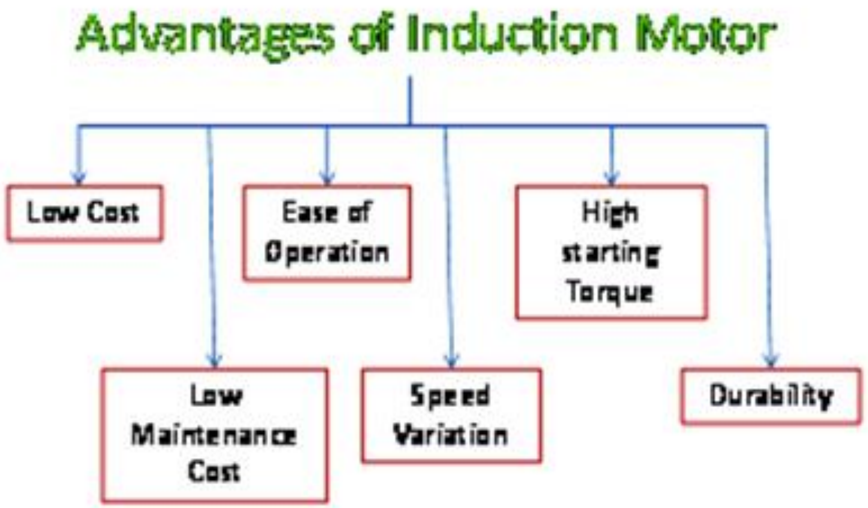
For controlling the speed of the motor, an external resistance can be added in the circuit.

Applications of Three Phase Induction Motor

Lifts
Cranes
Hoists
Large capacity exhaust fans
Driving lathe machines
Crushers
Oil extracting mills
Textile and etc.

Advantages of Induction Motor

The motor construction and the way electric power is supplied all give the induction motor several advantages is shown in figure below. And let’s see of them in brief.



Low cost: Induction machines are very cheap when compared to synchronous and DC motors. This is due to the modest design of induction motor. Therefore, these motors are overwhelmingly preferred for fixed speed applications in industrial applications and for commercial and domestic applications where AC line power can be easily attached.

Low maintenance cost: Induction motors are maintenance free motors unlike dc motors and synchronous motors. The construction of induction motor is very simple and hence maintenance is also easy, resulting in low maintenance cost.

Ease of operation: Operation of induction motor is very simple because there is no electrical connector to the rotor that supply power and current is induced by the movement of the transformer performs on the rotor due to the low resistance of the rotating coils. Induction motors are self start motors. This can result in reducing the effort needed for maintenance.

Speed Variation: The speed variation of induction motor is nearly constant. The speed typically varies only by a few percent going from no load to rated load.

High starting torque: The staring torque of induction motor is very high which makes motor useful for operations where load is applied before the starting of the motor.3 phase induction motors will have self starting torque unlike synchronous motors. However, single-phase induction motors does not have self starting torque and are made to rotate using some auxiliaries.
Durability: Another major advantage an induction motor is that it is durability. This makes it the ideal machine for many uses. This results the motor to run for many years with no cost and maintenance.
All these advantages make induction motor to use in many applications such as industrial, domestic and in many applications.

Introduction of machine

The DC machine can be classified into two types namely DC motors **as well as DC** generators.
Most of the DC machines are equivalent to AC machines because they include AC currents as well as AC voltages in them.
The output of the DC machine is DC output because they convert AC voltage to DC voltage. The conversion of this mechanism is known as the commutator, thus these machines are also named as commutating machines.
DC machine is most frequently used for a motor. The main benefits of this machine include torque regulation as well as easy speed.
The **applications of the DC machine** is limited to trains, mills, and mines. For example, underground subway cars, as well as trolleys, may utilize DC motors. In the past, automobiles were designed with DC dynamos for charging their batteries.

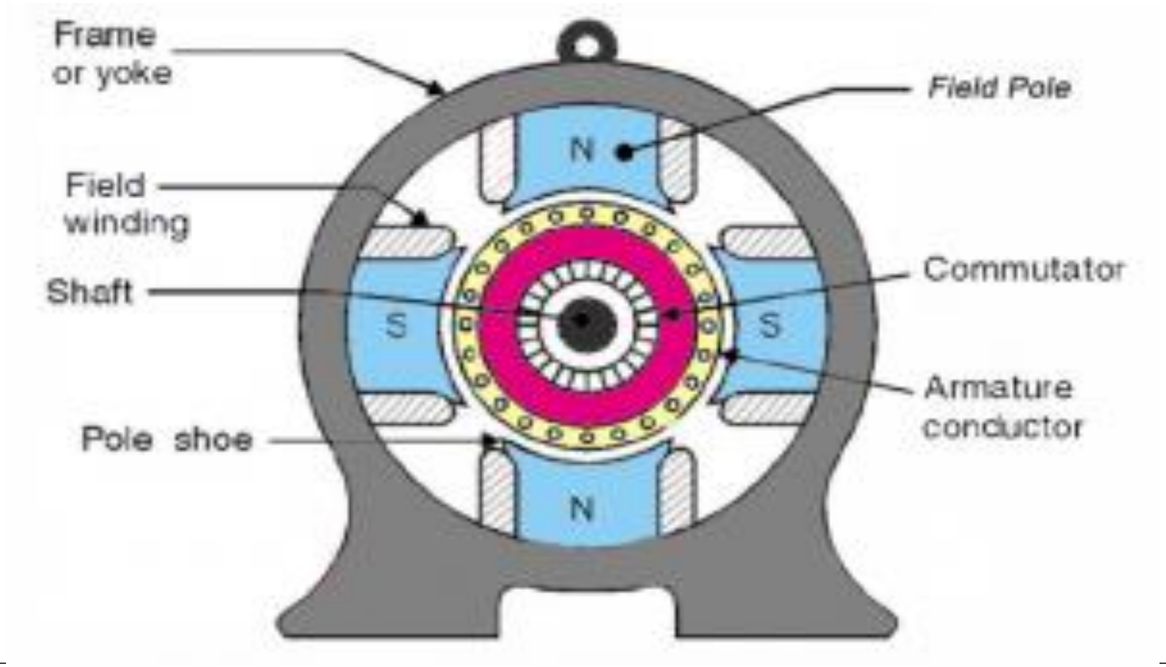
What is a DC Machine?

A DC machine is an electromechanical energy alteration device. The **working principle of a DC machine** is when electric current flows through a coil within a magnetic field, and then the magnetic force generates a torque that rotates the dc motor. The DC machines are classified into two types such as DC generator as well as DC motor.

The main function of the DC generator is to convert mechanical power to DC electrical power, whereas a DC motor converts DC power to mechanical power. The **AC motor** is frequently used in industrial applications for altering electrical energy to mechanical energy. However, a DC motor is applicable where good speed regulation & an ample range of speeds are necessary like in electric-transaction systems.

Construction of DC Machine

The construction of the DC machine can be done using some of the essential parts like Yoke, Pole core & pole shoes, Pole coil & field coil, Armature core, Armature winding otherwise conductor, commutator, brushes & bearings. Some of the **parts of the DC machine** is discussed below.



Yoke

Another name of a yoke is the frame. The main function of the yoke in the machine is to offer mechanical support intended for poles and protects the entire machine from moisture, dust, etc. The materials used in the yoke are designed with cast iron, cast steel otherwise rolled steel.

Pole and Pole Core

The pole of the DC machine is an electromagnet and the field winding is winding among pole. Whenever field winding is energized then the pole gives magnetic flux. The materials used for this are cast steel, cast iron otherwise pole core. It can be built with the annealed steel laminations for reducing the power drop because of the eddy currents.

Pole Shoe

Pole shoe in the DC machine is an extensive part as well as to enlarge the region of the pole. Because of this region, flux can be spread out within the air-gap as well as extra flux can be passed through the air space toward armature. The materials used to build pole shoe is cast iron otherwise cast steed, and also used annealed steel lamination to reduce the loss of power because of eddy currents.

Field Windings

In this, the windings are wounded in the region of pole core & named as field coil. Whenever current is supplied through field winding than it electromagnetics the poles which generate required flux. The material used for field windings is copper.

Armature Core

Armature core includes a huge number of slots within its edge. The armature conductor is located in these slots. It provides the low-reluctance path toward the flux generated with field winding. The materials used in this core are permeability low-reluctance materials like iron otherwise cast. The lamination is used to decrease the loss because of the eddy current.

Armature Winding

The armature winding can be formed by interconnecting the armature conductor. Whenever an armature winding is turned with the help of prime mover then the voltage, as well as magnetic flux, gets induced within it. This winding is allied to an exterior circuit. The materials used for this winding are conducting material like copper.

Commutator

The main function of the commutator in the DC machine is to collect the current from the armature conductor as well as supplies the current to the load using brushes. And also provides uni-directional torque for DC-motor. The commutator can be built with a huge number of segments in the edge form of hard drawn copper. The Segments in the commutator are protected from the thin mica layer.

Brushes

Brushes in the DC machine gather the current from the commutator and supply it to the exterior load. Brushes wear with time to inspect frequently. The materials used in brushes are graphite otherwise carbon which is in rectangular form.

EMF Equation of DC Machine

The **DC machine e.m.f** can be defined as when the armature in the dc machine rotates, the voltage can be generated within the coils. In a generator, the e.m.f of rotation can be called the generated emf, and Er=Eg. In the motor, the emf of rotation can be called as counter or back emf, and Er=Eb.

Let Φ is the useful flux for every pole within webers

P is the total number of poles

z is the total number of conductors within the armature

n is the rotation speed for an armature in the revolution for each second

A is the no. of parallel lane throughout the armature among the opposite polarity brushes.

Z/A is the no. of armature conductor within series for each parallel lane

As the flux for each pole is ‘Φ’, every conductor slashes a flux ‘PΦ’ within a single revolution.

The voltage produced for each conductor = flux slash for each revolution in WB / Time taken for a single revolution within seconds.

As ‘n’ revolutions are completed within a single second and 1 revolution will be completed within a 1/n second. Thus the time for a single armature revolution is a 1/n sec.

The standard value of produced voltage for each conductor

$$\mathbf{p\,\Phi/1/n = np\,\Phi\ volts}$$

The voltage produced (E) can be decided with the no.of armature conductors within series I any single lane among the brushes thus, the whole voltage produced

E = standard voltage for each conductor x no. of conductors within series for each lane

$$\mathbf{E = n.P.\Phi \times Z/A}$$

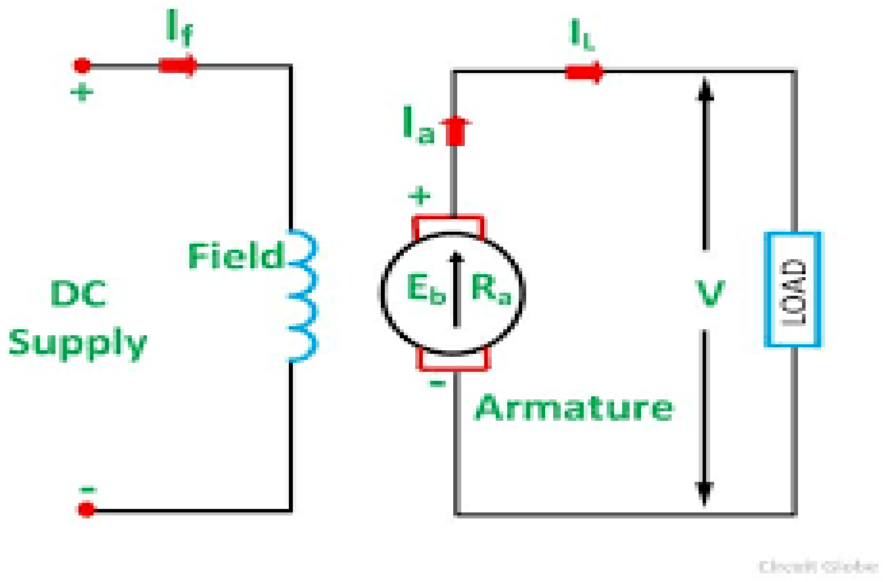
The above equation is the e.m.f. the equation of the DC machine.

Types of DC Machines

The excitation of the DC machine is classified into two types namely separate excitation, as well as self-excitation. In a separate excitation type of dc machine, the field coils are activated with a separate DC source. In the self-excitation type of dc machine, the flow of current throughout the field-winding is supplied with the machine. The principal kinds of DC machines are classified into four types which include the following.
Separately excited DC machine
Shunt-wound/shunt machine.
Series wound/series machine.
Compound wound / compound machine.

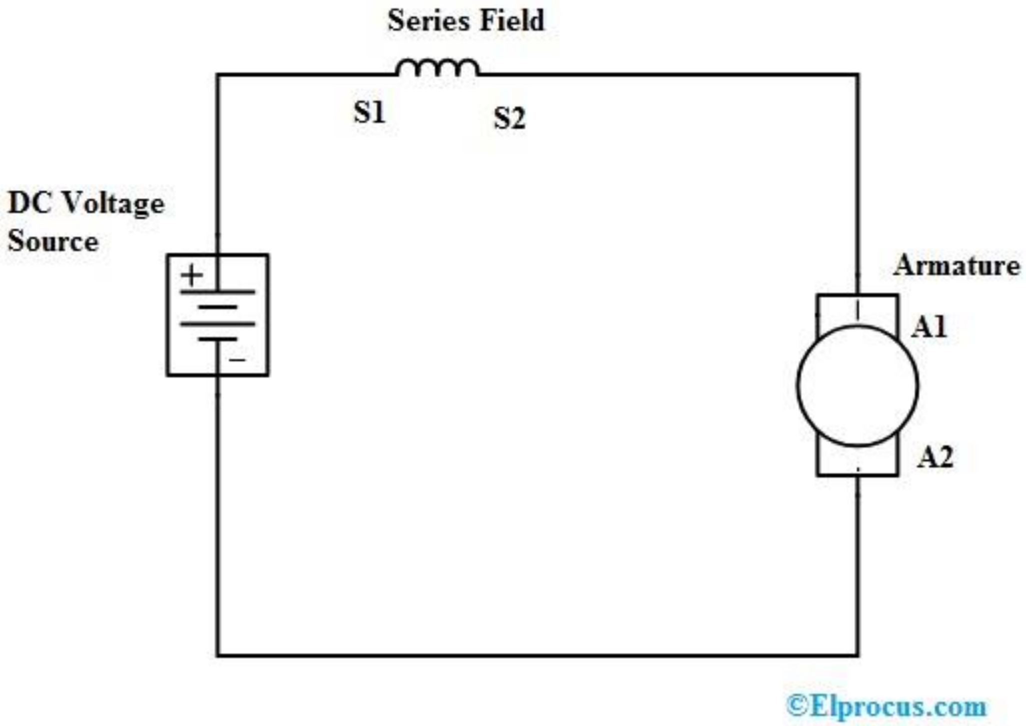
Separately Excited

In Separately Excited DC Machine, a separate DC source is utilized for activating the field coils.



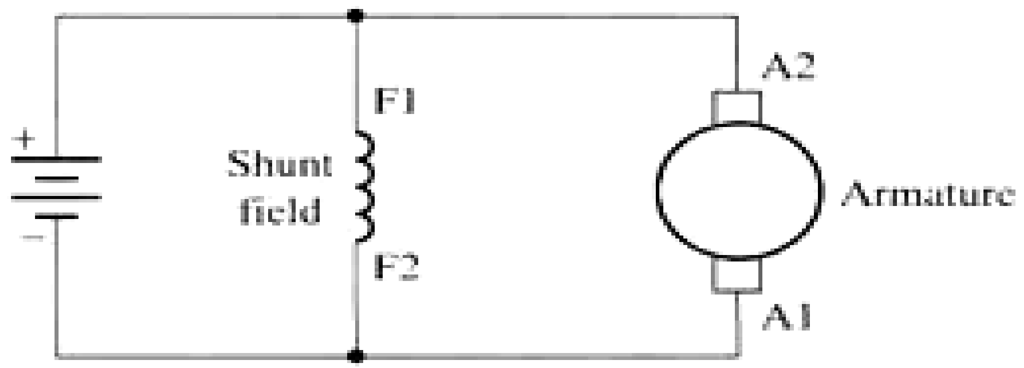
Series Wound

In series-wound D.C. Machines, the field coils are allied in series through the armature. As series field winding gets the armature current, as well as the armature current is huge, due to this the series field winding includes few twists of wire of big cross-sectional region.



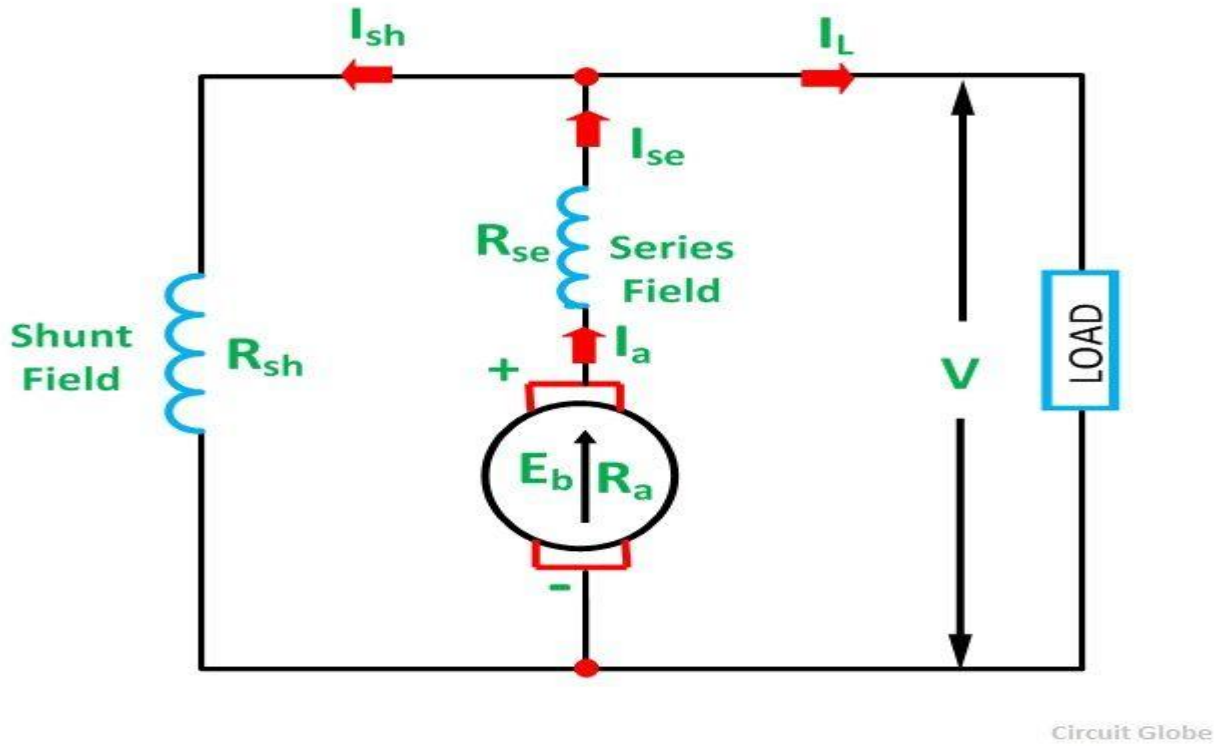
Shunt Wound

In Shunt wound DC Machines, the field coils are allied in parallel through **the armature**. As the shunt field gets the complete o/p voltage of a generator otherwise a motor supply voltage, it is normally made of a huge number of twists of fine wire with a small field current carrying.



Compound Wound

A compound machine includes both the series as well as shunt fields. The two windings are carried-out with every machine pole. The series winding of the machine includes few twists of a huge cross-sectional region, as well as the shunt windings, include several fine wire twists. The connection of the compound machine can be done in two ways. If the shunt-field is allied in parallel by the armature only, then the machine can be named as the ‘short shunt compound machine’ & if the shunt-field is allied in parallel by both the armature as well as series field, then the machine is named as the ‘long shunt compound machine’.



Losses in DC Machine

We know that **the main function of a DC machine** is to convert mechanical energy to electrical energy. Throughout this conversion method, the whole input power cannot be changed into output power because of the power loss in different forms. The type of loss may change from one apparatus to another. These losses will decrease the apparatus efficiency as well as the temperature will be increased. The DC machine energy losses can be classified into Electrical otherwise Copper losses, Core losses otherwise Iron losses, Mechanical losses, Brush losses, and Stray load losses.

DC Machine Advantages

DC machines like dc motors have various advantages like starting torque is high, reversing, fast-starting & stopping, changeable speeds through voltage input

These are very easily controlled as well as cheaper when compared with AC

Speed control is good

Torque is high

Operation is Seamless

Free from harmonics

Installation and maintenance is easy

Applications of DC Machine

At present, the generation of electrical energy can be done in bulk in the form of AC (an alternating current). Therefore, the utilization of DC machines like motors and generators DC generators are extremely limited because they are utilized mainly for providing excitation of tiny & middle range of alternators. In industries, DC machines are used for different processes like welding, electrolytic, etc.

Generally, the AC is generated and after that, it is changed into DC with the help of rectifiers. Therefore DC generator is suppressed through an AC supply which is rectified to use in several applications. DC motors are frequently used like variable speed drives & where changes in the severe torque occur.

The application of DC machine as a motor is used by dividing into three types like Series, Shunt &Compound whereas the application of dc machine as a generator is classified into separately excited, series, and shunt-wound generators.

Thus, this is all about DC machines. From the above information, finally, we can conclude that DC machines are dc generator & dc motor. The DC generator is mainly useful for supplying DC sources toward the DC machine in power stations. Whereas DC motor drives some devices like lathes, fans, centrifugal pumps, printing presses, electric locomotives, hoists, cranes, conveyors, rolling mills, auto-rickshaw, ice machines, etc.

Characteristics Of DC Motors

Generally, three characteristic curves are considered important for DC motors which are, (i) Torque vs. armature current, (ii) Speed vs. armature current and (iii) Speed vs. torque. These are explained below for each type of DC motor. These characteristics are determined by two relations.

$\mathbf{T_a \propto \phi . I_a}$ and $\mathbf{N \propto E_b/\phi}$

These above equations can be studied at - emf and torque equation of dc machine. For a DC motor, magnitude of the back emf is given by the same emf equation of a dc generator i.e. $E_b = P\phi NZ / 60A$. For a machine, P, Z and A are constant, therefore, $N \propto E_b/\phi$

Characteristics Of DC Series Motors

Torque Vs. Armature Current (T_a-I_a)

This characteristic is also known as **electrical characteristic**. We know that torque is directly proportional to the product of armature current and field flux, $T_a \propto \phi.I_a$. In DC series motors, field winding is connected in series with the armature, i.e. $I_a = I_f$. Therefore, before magnetic saturation of the field, flux ϕ is directly proportional to Ia. Hence, before magnetic saturation Ta α Ia^2. Therefore, the Ta-Ia curve is parabola for smaller values of Ia.

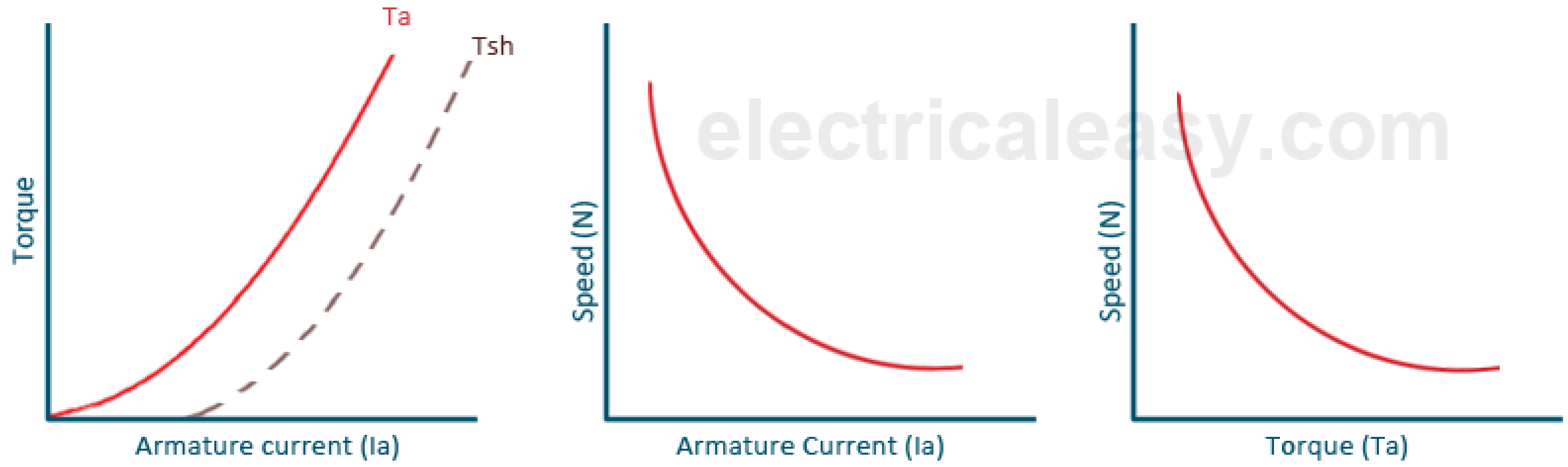
After magnetic saturation of the field poles, flux ϕ is independent of armature current Ia. Therefore, the torque varies proportionally to Ia only, T ∝ Ia.Therefore, after magnetic saturation, Ta-Ia curve becomes a straight line.
The shaft torque (Tsh) is less than armature torque (Ta) due to stray losses.
Hence, the curve Tsh vs Ia lies slightly lower.
In DC series motors, (prior to magnetic saturation) torque increases as the square of armature current, these motors are used where high starting torque is required.

Speed Vs. Armature Current (N-Ia)

We know the relation, N ∝ E_b/ϕ
For small load current (and hence for small armature current) change in back emf Eb is small and it may be neglected. Hence, for small currents speed is inversely proportional to ϕ. As we know, flux is directly proportional to Ia, speed is inversely proportional to Ia. Therefore, when armature current is very small the speed becomes dangerously high. That is **why a series motor should never be started without some mechanical load**.
But, at heavy loads, armature current Ia is large. And hence, speed is low which results in decreased back emf Eb. Due to decreased Eb, more armature current is allowed.

Speed Vs. Torque (N-Ta)

This characteristic is also called as **mechanical characteristic**. From the above two **characteristics of DC series motor**, it can be found that when speed is high, torque is low and vice versa.



Characteristics of DC series motor

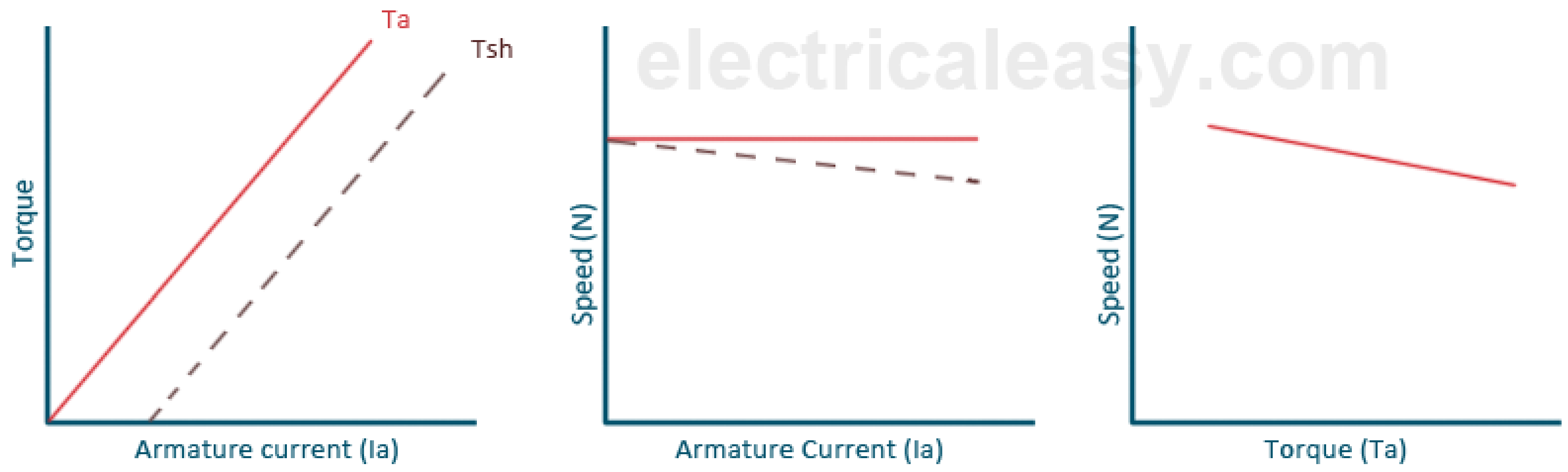
Characteristics Of DC Shunt Motors

Torque Vs. Armature Current (Ta-Ia)

In case of DC shunt motors, we can assume the field flux ϕ to be constant. Though at heavy loads, ϕ decreases in a small amount due to increased armature reaction. As we are neglecting the change in the flux ϕ, we can say that torque is proportional to armature current. Hence, the Ta-Ia characteristic for a dc shunt motor will be a straight line through the origin.

Since heavy starting load needs heavy starting current, **shunt motor should never be started on a heavy load**.

Speed Vs. Armature Current (N-Ia)
As flux ϕ is assumed to be constant, we can say $N \propto E_b$. But, as back emf is also almost constant, the speed should remain constant. But practically, ϕ as well as Eb decreases with increase in load. Back emf Eb decreases slightly more than ϕ, therefore, the speed decreases slightly. Generally, the speed decreases only by 5 to 15% of full load speed. Therefore, **a shunt motor can be assumed as a constant speed motor**. In speed vs. armature current characteristic in the following figure, the straight horizontal line represents the ideal characteristic and the actual characteristic is shown by the dotted line.



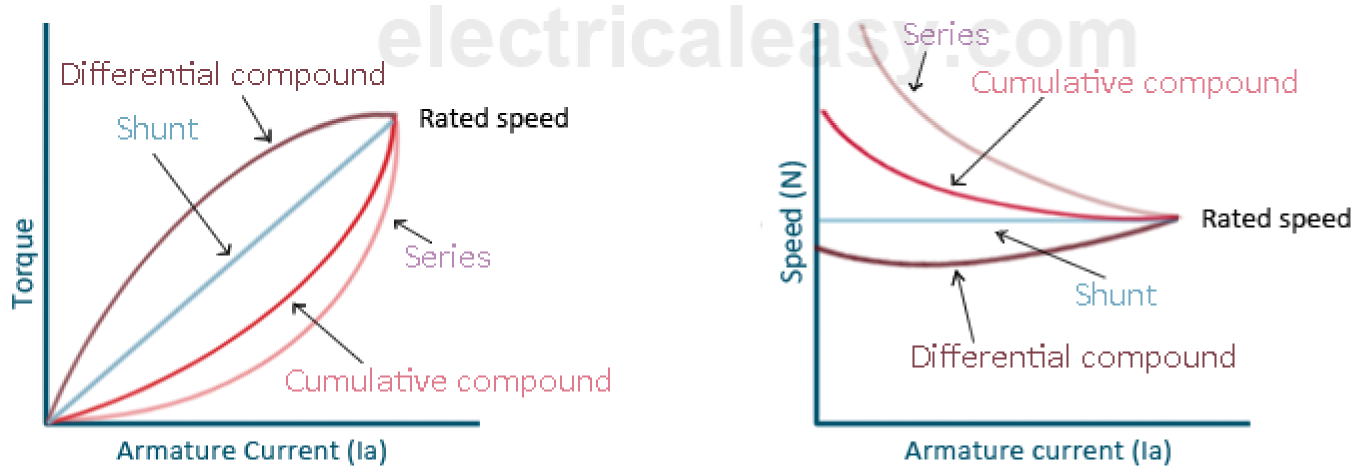
Characteristics of DC shunt motor

Characteristics Of DC Compound Motor

DC compound motors have both series as well as shunt winding. In a compound motor, if series and shunt windings are connected such that series flux is in direction as that of the shunt flux then the motor is said to be cumulatively compounded. And if the series flux is opposite to the direction of the shunt flux, then the motor is said to be differentially compounded. Characteristics of both these compound motors are explained below.

(a) Cumulative compound motor
Cumulative compound motors are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors have generally employed a flywheel, where sudden and temporary loads are applied like in rolling mills.

(b) Differential compound motor
Since in differential field motors, series flux opposes shunt flux, the total flux decreases with increase in load. Due to this, the speed remains almost constant or even it may increase slightly with increase in load ($N \propto E_b/\phi$). Differential compound motors are not commonly used, but they find limited applications in experimental and research work.



Characteristics of DC compound motor

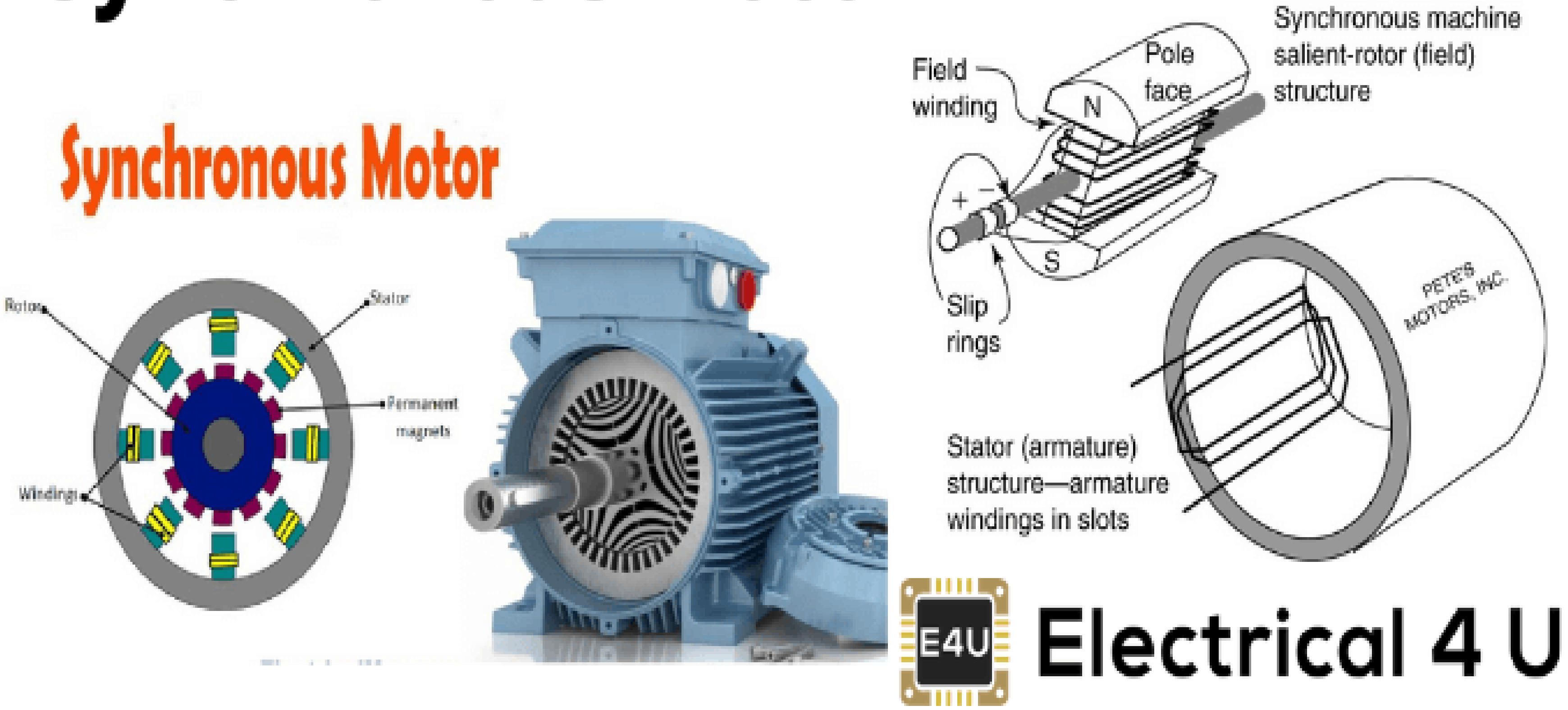
Synchronous Motor

Definition: The motor which runs at synchronous speed is known as the synchronous motor. The synchronous speed is the constant speed at which motor generates the electromotive force. The synchronous motor is used for converting the electrical energy into mechanical energy.

Where, N_s = synchronous speed, f = supply frequency and p = number of poles. As we can see from the equation, the synchronous speed depends on the frequency of the supply and the number of poles.

$$N_s = \frac{120f}{p}$$

Construction of a Synchronous Motor



Construction of Synchronous Motor

The stator and the rotor are the two main parts of the synchronous motor. The stator becomes stationary, and it carries the armature winding of the motor. **The armature winding is the main winding because of which the EMF induces in the motor**. The rotator carry the field windings. The main field flux induces in the rotor. The rotor is designed in two ways, i.e., the salient pole rotor and the non-salient pole rotor.

The synchronous motor uses the salient pole rotor. **The word salient means the poles of the rotor projected towards the armature windings**. The rotor of the synchronous motor is made with the laminations of the steel. The laminations reduce the eddy current loss occurs on the winding of the transformer. The salient pole rotor is mostly used for designing the medium and low-speed motor. For obtaining the high-speed cylindrical rotor is used in the motor.

The **construction of a synchronous motor** is very similar to the construction of an alternator. Both are synchronous machines where one we use as a motor and the other as a generator. Just like any other motor, the synchronous motor also has a stator and a rotor. We will look into the construction details of the various parts one by one in detail.

Stator of Synchronous Motor

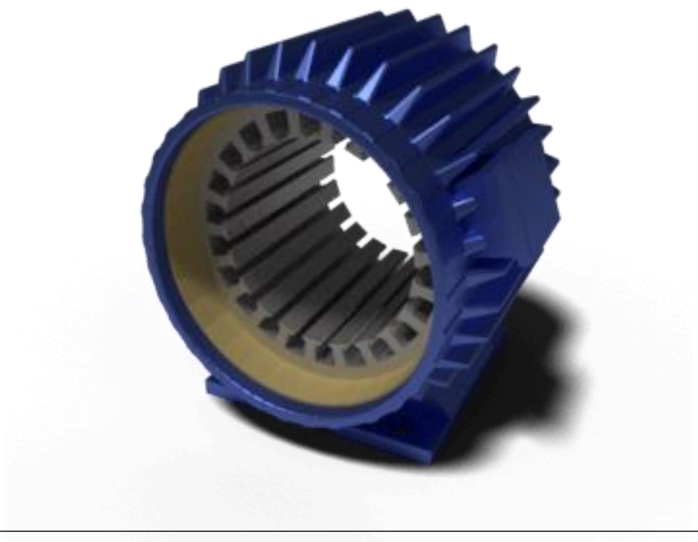
The main stationary part of the machine is stator. The stator consists of the following parts.

Stator Frame

The stator frame is the outer part of the machine and is made up of cast iron. It protects the enter inner parts of the machine.

Stator Core

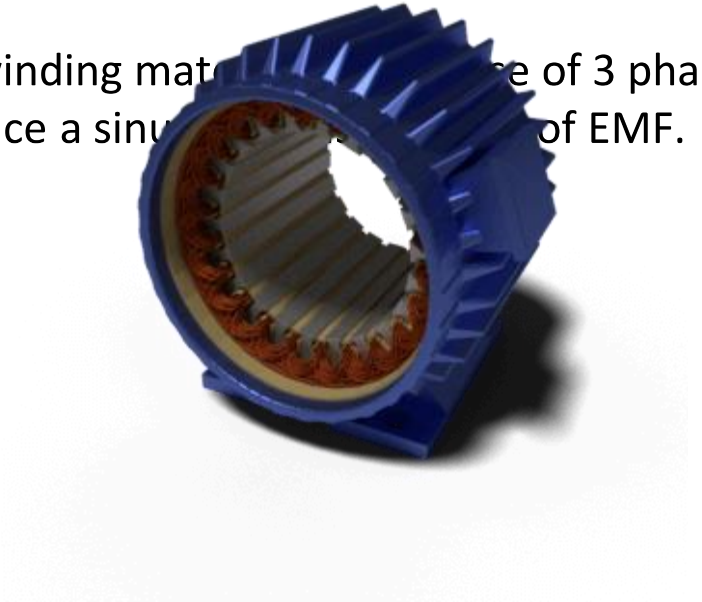
The stator core is made up of thin silicon laminations. It is insulated by a surface coating to minimize hysteresis and eddy current losses. Its main purpose is to provide a path of low reluctance for the magnetic lines of force and accommodate the stator windings.



Stator Winding

The stator core has cuts on the inner periphery to accommodate the stator windings. The stator windings could be either three-phase windings or single phase windings.

Enamelled copper is used as the winding mat[illegible]e of 3 phase windings, the windings are distributed over several slots. This is done to produce a sin[illegible] of EMF.



Rotor of Synchronous Motor

The rotor is the moving part of the machine. Rotors are available in two types:

Salient Pole Type

Cylindrical Rotor Type

The salient pole type rotor consists of poles projecting out from the rotor surface.

It is made up of steel laminations to reduce eddy current losses.

A salient pole machine has a non-uniform air gap. The gap is maximum between the poles and is minimum at the pole centres. They are generally used for medium and low-speed operations as they have a large number of poles. They contain damper windings which are used for starting the motor.

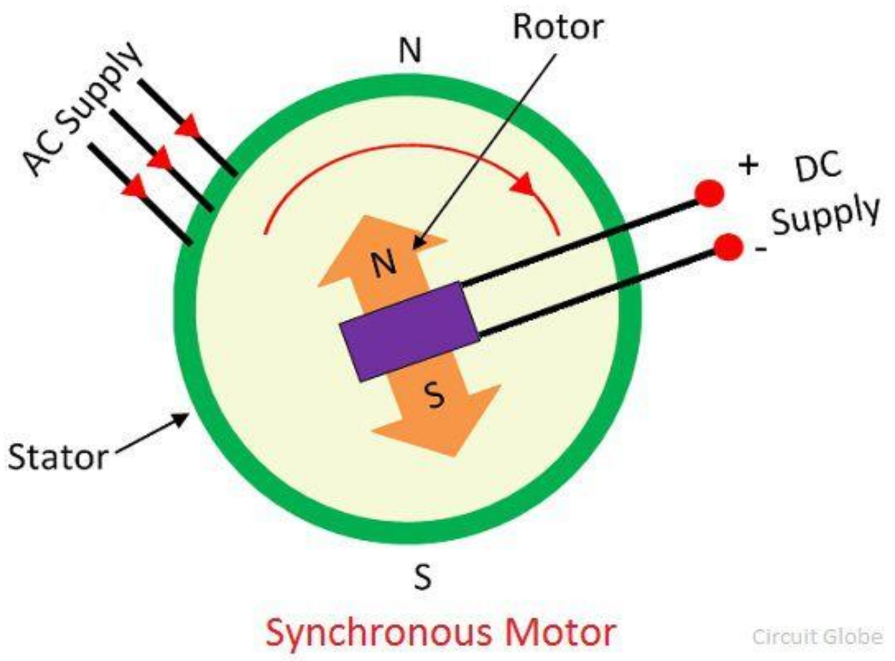
A cylindrical rotor is made from solid forgings of high-grade nickel chrome molybdenum steel forgings of high-grade nickel chrome molybdenum steel. The poles are created by the current flowing through the windings. They are used for high-speed applications as they have less number of poles. They also produce less noise and windage losses as they have a uniform air gap. DC supply is given to the rotor windings via slip-rings. Once the rotor windings are excited, they act like poles.

Synchronous Motor Working

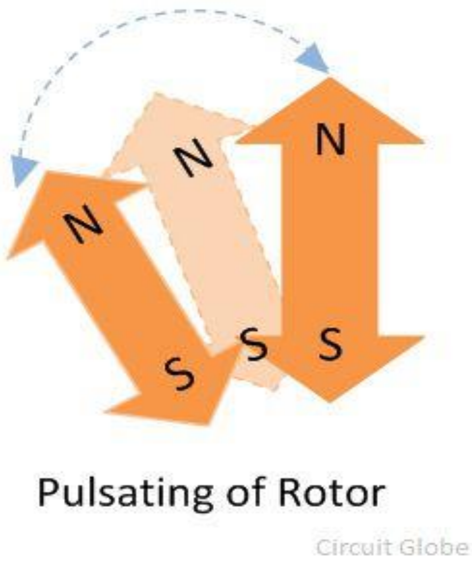
The stator and rotor are the two main parts of the synchronous motor. The stator is the stationary part, and the rotor is the rotating part of the machine. The three-phase AC supply is given to the stator of the motor.
The stator and rotor both are excited separately. **The excitation is the process of inducing the magnetic field on the parts of the motor with the help of an electric current.**
When the three phase supply is given to the stator, the rotating magnetic field developed between the stator and rotor gap. **The field having moving polarities is known as the rotating magnetic field.** The rotating magnetic field develops only in the polyphase system. Because of the rotating magnetic field, the north and south poles develop on the stator.

The rotor is excited by the DC supply. The DC supply induces the north and south poles on the rotor. As the DC supply remains constant, the flux induces on the rotor remains same. Thus, the flux has fixed polarity. The north pole develops on one end of the rotor, and the south pole develops on another end.
The AC is sinusoidal. The polarity of the wave changes in every half cycle, i.e., the wave remains positive in the first half cycle and becomes negative in the second half cycle. The positive and negative half cycle of the wave develops the north and south pole on the stator respectively.

When the rotor and stator both have the same pole on the same side, they repel each other. If they have opposite poles, they attract each other. This can easily be understood with the help of the figure shown below.



The rotor attracts towards the pole of the stator for the first half cycle of the supply and repulse for the second half cycle. Thus the rotor becomes pulsated only at one place. This is the reason because of which the synchronous motor is not self-starting.



Pulsating of Rotor

The prime mover is used for rotating the motor. The prime mover rotates the rotor at their synchronous speed. The synchronous speed is the constant speed of the machine whose value depends on the frequency and the numbers of the pole of the machine.

When the rotor starts rotating at their synchronous speed, the prime mover is disconnected to the motor. And the DC supply is provided to the rotor because of which the north and south pole develops at their ends

The north and south poles of the rotor and the stator interlock each other. Thus, the rotor starts rotating at the speed of the rotating magnetic field. And the motor runs at the synchronous speed. The speed of the motor can only be changed by changing the frequency of the supply.

Main Features of Synchronous Motor

The speed of the synchronous motor is independent of the load, i.e., the variation of the load does not affect the speed of the motor.
The synchronous motor is not self-starting. The prime mover is used for rotating the motor at their synchronous speed.
The synchronous motor operates both for leading and lagging power factor.
The synchronous motor can also be started with the help of the damper windings.

Introduction of transformers

Transformer in the simplest way can be described as a thing that converts. However, when we study more about it in-depth and in connection to electric current it is defined as a static device that changes the level of voltage between circuits. The transformer is basically a voltage control device that is used widely in the distribution and transmission of alternating current power.

The idea of a transformer was first discussed by Michael Faraday in the year 1831 and was carried forward by many other prominent scientific scholars. However, the general purpose of using transformers was to maintain a balance between the electricity that was generated at very high voltages and consumption which was done at very low voltages.

Table of Content

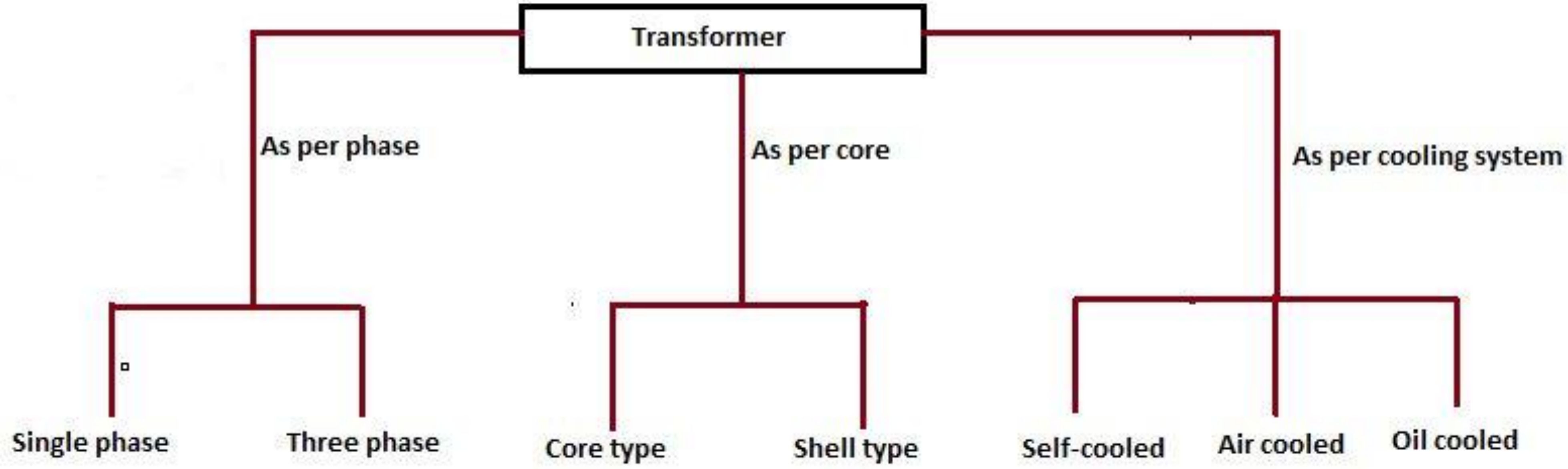
What is a Transformer?

A transformer is a device used in the power transmission of electric energy. The transmission current is AC. It is commonly used to increase or decrease the supply voltage without a change in the frequency of AC between circuits. The transformer works on basic principles of electromagnetic induction and mutual induction

Transformer Types

Transformers are used in various fields like power generation grid, distribution sector, transmission and electric energy consumption. There are various types of transformers which are classified based on the following factors;

- Working voltage range.
- The medium used in the core.
- Winding arrangement.
- Installation location.


Transformer
As per phase
As per core
As per cooling system
Single phase
Three phase
Core type
Shell type
Self-cooled
Air cooled
Oil cooled

Based on Voltage Levels

Commonly used transformer type, depending upon voltage they are classified as:

- **Step-up Transformer:** They are used between the power generator and the power grid. The secondary output voltage is higher than the input voltage.
- **Step down Transformer:** These transformers are used to convert high voltage primary supply to low voltage secondary output.

Based on the Medium of Core Used

In a transformer, we will find different types of cores that are used.

- **Air core Transformer:** The flux linkage between primary and secondary winding is through the air. The coil or windings wound on the non-magnetic strip.
- **Iron core Transformer:** Windings are wound on multiple iron plates stacked together, which provides a perfect linkage path to generate flux.

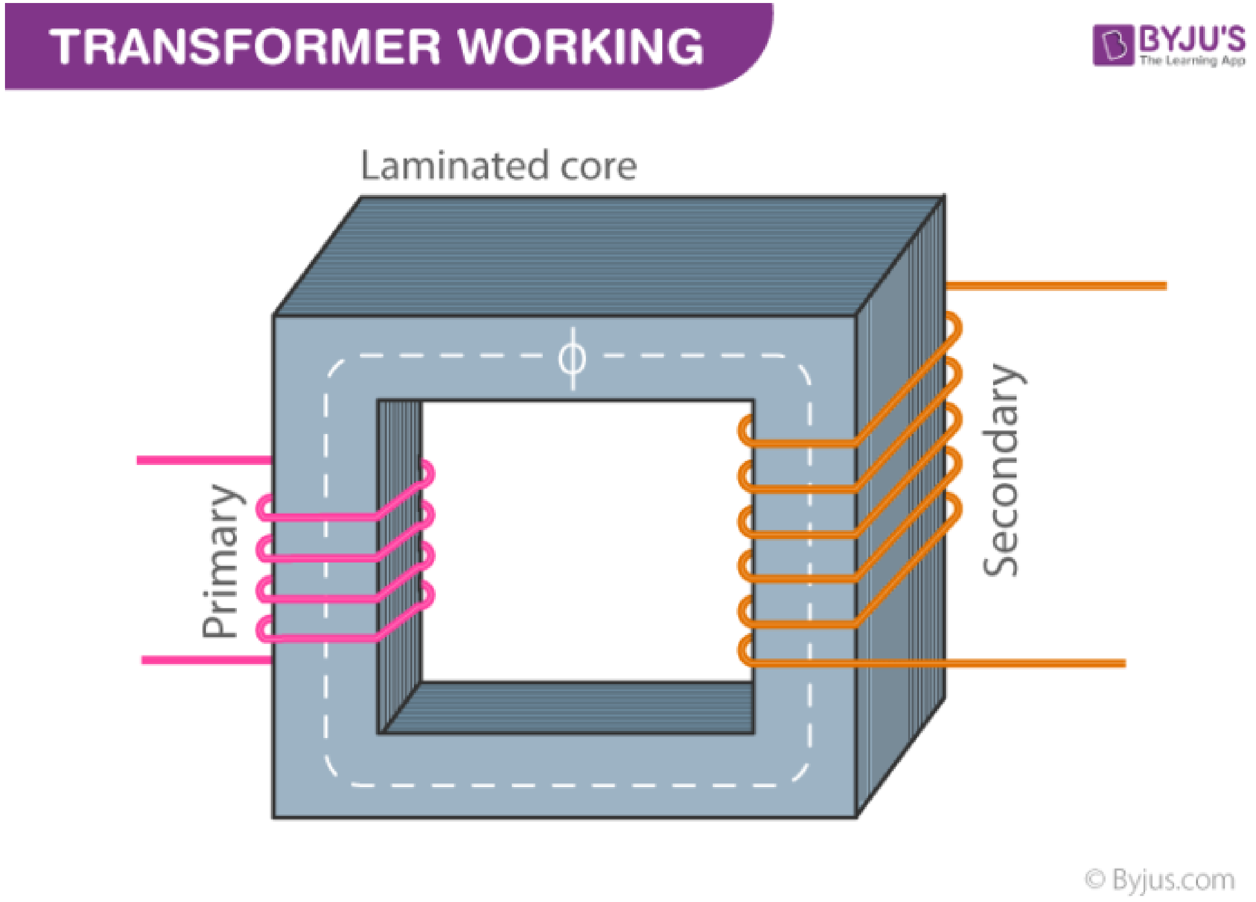
Based on the Winding Arrangement

Autotransformer: It will have only one winding wound over a laminated core. The primary and secondary share the same coil. Auto also means “self” in language Greek.

Based on Install Location

- **Power Transformer:** It is used at power generation stations as they are suitable for high voltage application
- **Distribution Transformer:** Mostly used at distribution lanes in domestic purposes. They are designed for carrying low voltages. It is very easy to install and characterized by low magnetic losses.
- **Measurement Transformers:** These are further classified. They are mainly used for measuring voltage, current, power.
- **Protection Transformers:** They are used for component protection purposes. In circuits some components must be protected from voltage fluctuation etc. protection transformers ensure component protection.

Working Principle of a Transformer



The transformer works on the principle of Faraday’s law of electromagnetic induction and mutual induction.

Lets us explain. There are usually two coils, primary coil and secondary coil on the transformer core. The core laminations are joined in the form of strips. The two coils have high mutual inductance. When an alternating current pass through the primary coil, forms a varying magnetic flux as per faraday’s law of electromagnetic induction and this change in magnetic flux induces an emf (electromotive force) in the secondary coil which is linked to the core having a primary coil. This is mutual induction.

Overall, a transformer carries the below operations:

1. Transfer of electrical energy from circuit to another
2. Transfer of electrical power through electromagnetic induction
3. Electric power transfer without any change in frequency
4. Two circuits are linked with mutual induction

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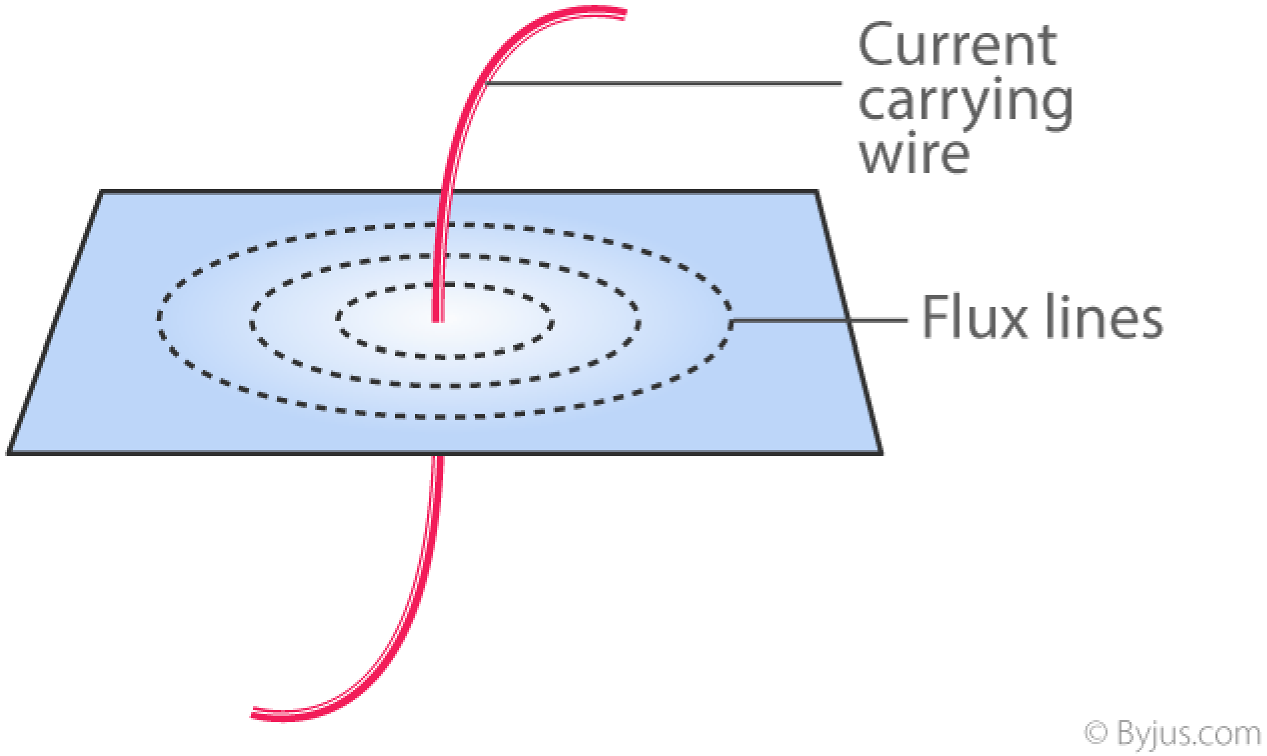
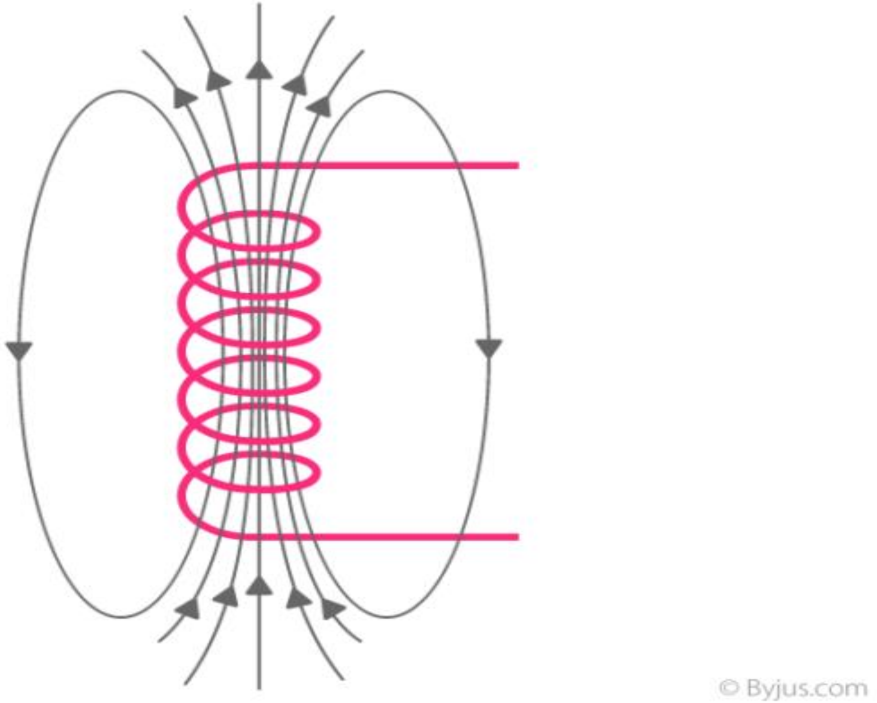




The figure shows the for … rue,
when a magnetic flux lin … d in
1831 which is the fundam

No Leakage:

$$v_P = \varepsilon_P = -N_P \frac{d\phi_B}{dt} \rightarrow (1)$$

frequency of applied voltage is same as freq of emf / magnetic flux.

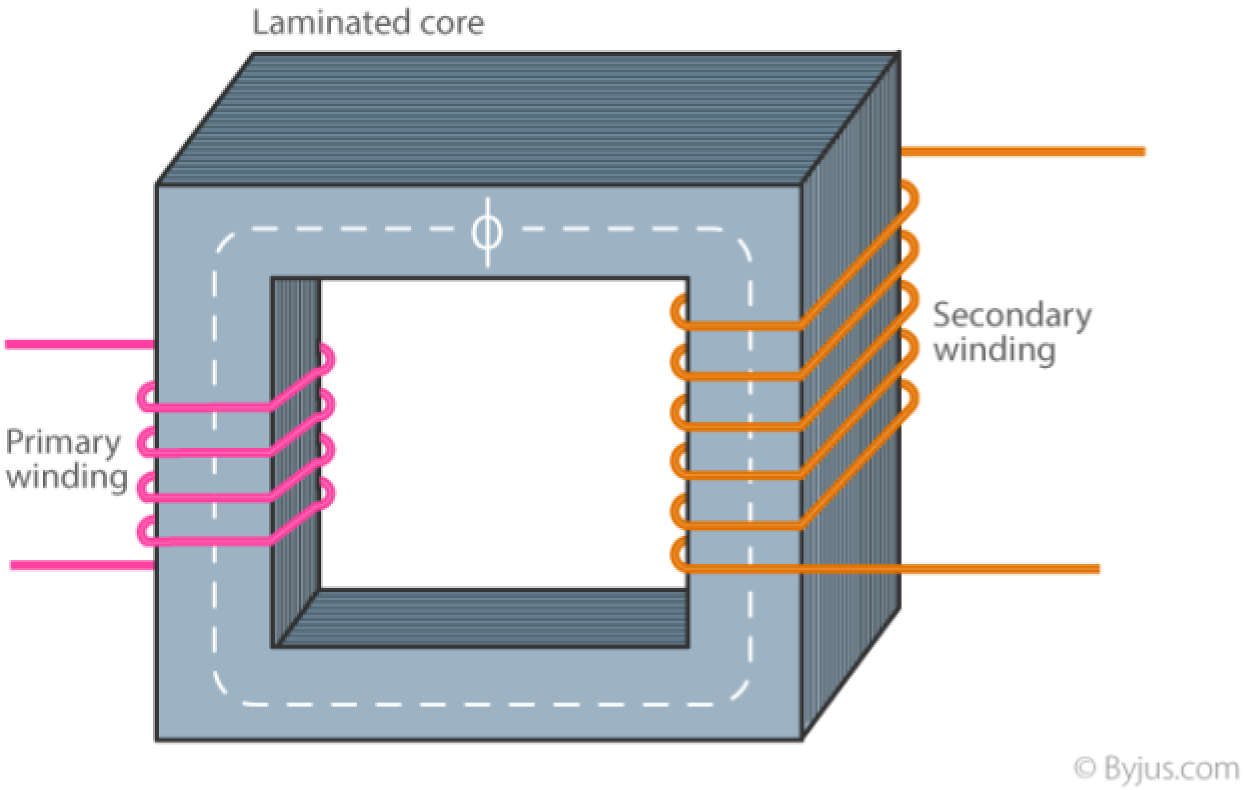
$$v_S = \varepsilon_S = -N_S \frac{d\phi_B}{dt} \rightarrow (2)$$

Eq (2) ÷ (1)

$$\frac{v_S}{v_P} = \frac{\varepsilon_S}{\varepsilon_P} = \frac{-N_S\, d\phi_B/dt}{-N_P\, d\phi_B/dt}$$

$$\frac{v_S}{v_P} = \frac{\varepsilon_S}{\varepsilon_P} = \frac{N_S}{N_P} = K$$ (Transformer ratio)

Parts of a Single-phase



The major parts of a single-phase transformer consist of:

1. Core

The core acts as a support to the winding in the transformer. It also provides a low reluctance path to the flow of magnetic flux. The winding is wound on the core as shown in the picture. It is made up of a laminated soft iron core in order to reduce the losses in a transformer. The factors such as operating voltage, current, power etc. decide core composition. The core diameter is directly proportional to copper losses and inversely proportional to iron losses.

2. Windings

Windings are the set of copper wires wound over the transformer core. Copper wires are used due to:

- High conductivity of copper. This minimizes the loss in a transformer. since conductivity increases, resistance to current flow decreases.
- High ductility of copper. Ductility is the property of metals that they can be made into very thin wires.

There are mainly two types of windings. Primary windings and secondary windings.

- Primary winding: The set of turns of windings to which supply current is feed.
- Secondary winding: the set of turns of winding from which output is taken.

The primary and secondary windings are insulated from each other using insulation coating agents.

3. Insulation Agents

Insulation is necessary for transformers to separate windings from shorting the circuit and thus facilitating the mutual induction. Insulation agents have influence in durability and the stability of a transformer.

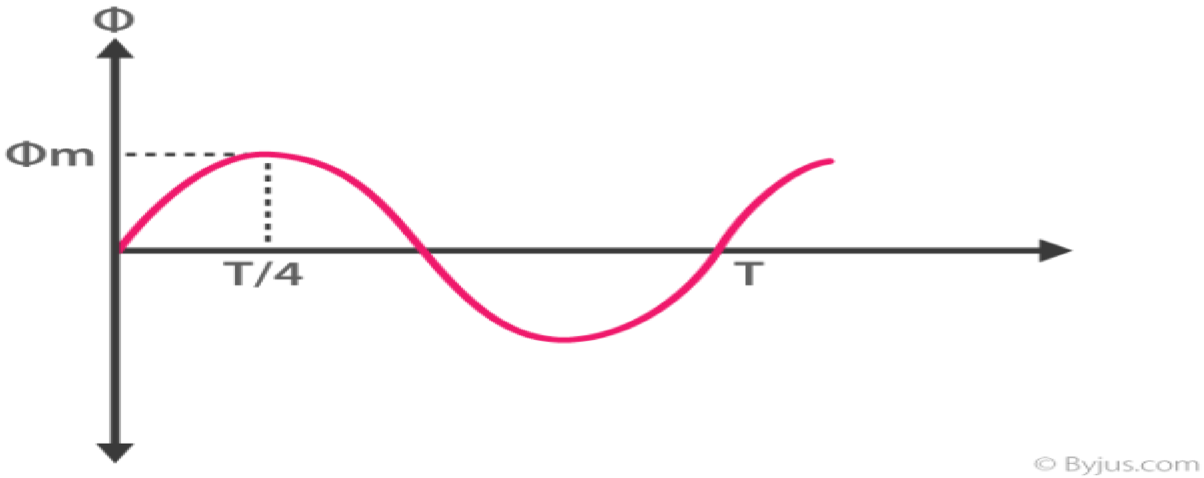
Following are used as an insulation medium in a transformer:

- Insulating oil
- Insulating tape
- Insulating paper
- Wood-based lamination

Ideal Transformer

The ideal transformer has no loses that is there is no magnetic leakage and ohmic resistance in its windings. There won’t be any core losses or I^2R.

EMF Equation of Tra



N_1 – number of turns in pr
N_2 – number of turns in se
Φ_m – maximum flux in we
T – time period. Time is ta

The flux formed is a sinusoidal wave. It rises to a maximum value Φ_m and decreases to negative maximum Φ_m. So, flux reaches a maximum in one-quarter of a cycle. The time taken is equal to T/4.
Average rate of change of flux = $\Phi_m/(T/4) = 4*f\Phi_m$
Where f = frequency
T = 1/f
Induced emf per turn = rate of change of flux per turn
Form factor = rms value / average value
Rms value = $1.11 * (4*f\Phi_m) = 4.44\, f\Phi_m$ [form factor of sine wave is 1.11]
RMS value of emf induced in winding = RMS value of emf per turn * no of turns

Ideal Transformer:

Input power = output power

$$P = VI$$

$$V_P I_P = V_S I_S$$

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

→ Current is primary
Current is secondary.

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} = \frac{i_P}{i_S}$$

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

→ Step up

i) $N_S > N_P \Rightarrow V_S > V_P \quad \therefore I_S < I_P$

ii) $N_P > N_S \Rightarrow V_P > V_S \quad \therefore I_P < I_S$

→ step down

Primary Winding

Rms value of induced emf = $E_1 = 4.44\, f\Phi m * N_1$

Secondary winding:

Rms value of induced emf = $E_2 = 4.44\, f\Phi m * N_2$

This is the emf equation of the transformer.

For a[illegible]oad condition,

E_1 = [illegible]ary winding.

E_2 = [illegible]al or calculated) on the secondary winding.

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44 f\, \Phi m$$

Voltage Transformation Rat

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = k$$

K is called the voltage transformation ratio, which is a constant.

Case1: if $N_2 > N_1$, $K>1$ it is called a step-up transformer.

Case 2: if $N_2 < N_1$, $K<1$ it is called a step-down transformer.

Transformer Efficiency

Comparing system output with input will confirm transformer efficiency. The system is called better when its efficiency is high.

$$Efficiency\,(\eta) = \frac{Outputpower}{Inputpower} \times 100$$

$$Efficiency\,(\eta) = \frac{P_{out}}{P_{out} + P_{loses}} \times 100$$

$$Efficiency\,(\eta) = \frac{V_2 I_2 cos\theta}{V_2 I_2 cos\theta + P_c + P_{cm}} \times 100$$

Where $P_{cu} = P_{sc}$

$P_c = P_{oc}$

$$\eta(_{fullload}) = \frac{V\,Acos\theta}{V\,Acos\theta + P_c + P_{cm}} \times 100$$

$$\eta(_{loadn}) = \frac{nV\,Acos\theta}{nV\,Acos\theta + P_c + n^2 P_{cm}} \times 100$$

Applications Of Transformer

- Transformer transmits electrical energy through wires over long distances.
- Transformers with multiple secondary's are used in radio and TV receivers which require several different voltages.
- Transformers are used as voltage regulators.

Transformer Related Solved Examples

1. A transformer has 600 turns of the primary winding and 20 turns of the secondary winding. Determine the secondary voltage if the secondary circuit is open and the primary voltage is 140 V.

Given

Total number of turns of the primary coil (N_1) = 600 turns

Total number of turns of the secondary coil (N_2) = 20 turns

Primary voltage (V_1) = 140 V

Solution:

The voltage on the primary coil = N_1V_1

The voltage on the secondary coil = N_2V_2

The voltage on one turn

$$V_t = \frac{V_2}{N_2} = \frac{V_1}{N_1}$$

$$k = \frac{V_2}{N_2} = \frac{V_1}{N_1}$$

k is a transformation ratio

$$V_2 = \frac{N_2}{N_1} \times V_1$$

$$V_2 = \frac{20}{600} \times \times 140$$

V_2 = 4.6 V

2. A transformer has a primary coil with 1600 loops and a secondary coil with 1000 loops. If the current in the primary coil is 6 Ampere, then what is the current in the secondary coil.

Given:

Primary coil (N_1) = 1600 loops

Secondary coil (N_2) = 1000 loops

The current in the primary coil (I_1) = 4 A

Solution :

$$\frac{I_2}{I_1} = \frac{N_1}{N_2}$$

$$\frac{I_2}{4} = \frac{1600}{1000}$$

I_2 = 6.4 A

Current on the secondary coil is 6.4 Ampere