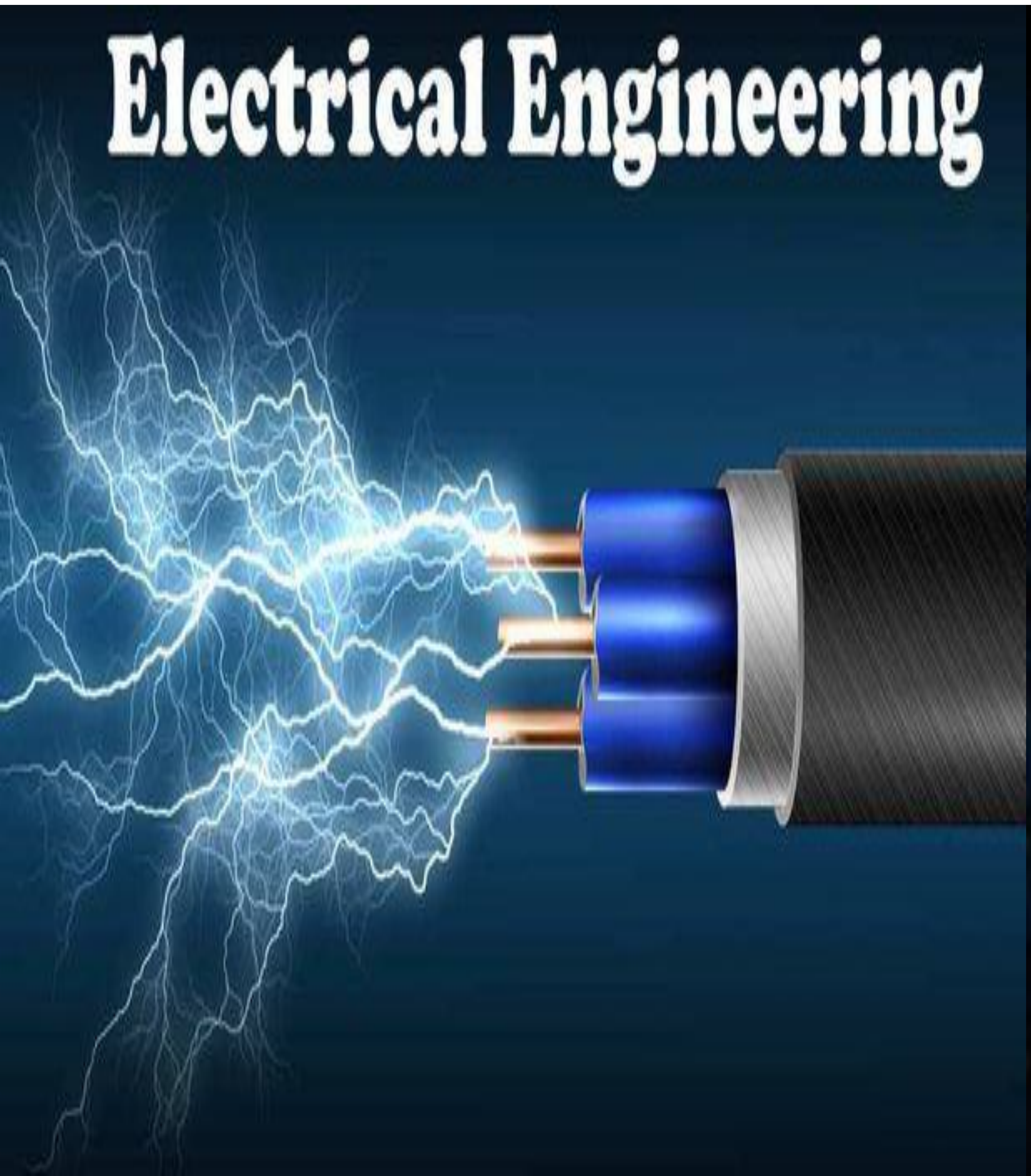
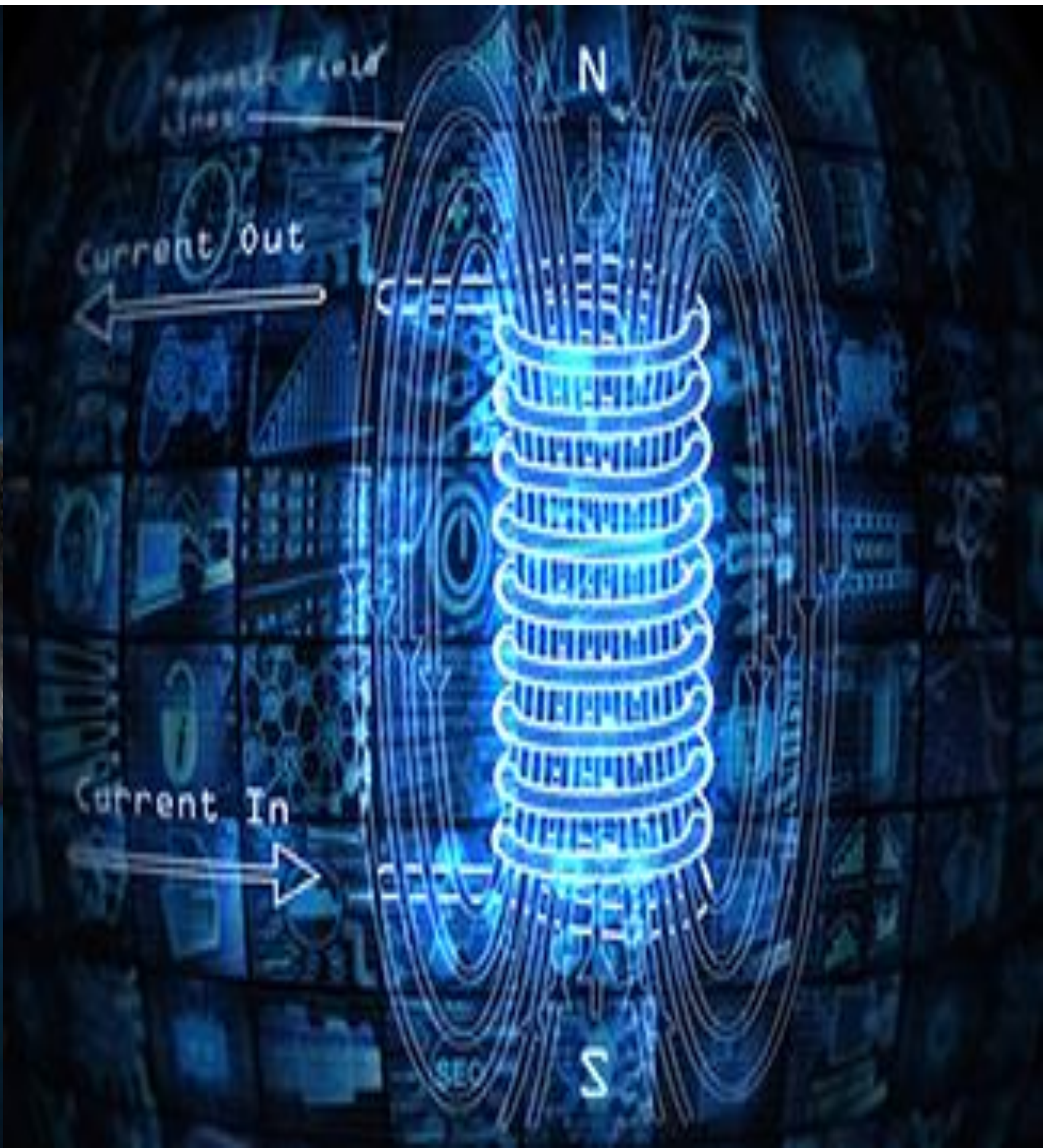

Electrical Engineering

N
Current Out
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S

# LECTURE 1

# Electrical Technology (EEC-01)

## ❖ SYLLABUS

- Fundamentals of Electric Circuits: Ohm's laws, Kirchhoff's laws, Independent and Dependent sources, Analysis of simple circuits.
- Network Theorems: Superposition theorem, Reciprocity theorem, Thevenin's and Norton's theorem, Maximum Power Transfer theorem.
- Magnetic field, Concept of magnetic circuits, Magnetomotive force, Reluctance, Ampere's circuital law and Biot-Savart law, Determination of B/H curve, Comparison of electric and magnetic circuit, Electromagnetic induction, Faraday's laws of electromagnetic induction, Direction and Magnitude of induced E.M.F.
- Self and mutual Inductance, Inductances in series and parallel, Energy stored in inductor, Capacitance, Capacitance in series and parallel, Relationship between charge, voltage and current, Energy stored in capacitor.
- Transients with D.C. excitation.

# Electrical Technology (EEC-01)

## ❖ SYLLABUS

- Generation of alternating voltage and current, E.M.F. equation, Average and R.M.S. value, Phase and phase difference, Phasor representation of alternating quantity, Behaviour of A.C. circuits, Resonance in series and parallel R-L-C circuits.
- Single-Phase Transformer, equivalent circuits, open circuit and short circuit tests.
- Poly phase system, Advantages of 3-phase system, Generation of 3-phase voltages, Voltage, current and power in a star and delta connected systems, 3-phase balanced and unbalanced circuits, Power measurement in 3-phase circuits.

**Text Books:**

1.

1. Electrical & Electronic Technology by Hughes, Pearson Education India.

**Reference Books**:

1. Advanced Electrical Technology by H. Cotton, Reem Publication Pvt. Ltd
2. Electrical Engineering fundamentals by Vincent Deltoro, Pearson Education India.

# Electrical Technology (EEC-01)

## ➢ Another Reference Books:


1. Electrical Engineering Concepts and Applications by S. A. Reza Zekavat;
2. Fundamentals of Electric Circuits by Charles K Alexander & Mathew N O Sadiku;
3. Electrical and Electronic Technology by Edward Hughes;
4. Electrical Circuits by Hyte and Kamarly;
5. Basic Electric Circuit Analysis by David E. Johnson, John L. Hilburn, Johnny R. Johnson and Peter D. Scott.
6. Engineering Circuit Analysis by J. David Irwin and Robert M. Nelms;
7. Linear Circuit Analysis by Raymond A. De Carlo and Pen-Min Lin.
8. Circuits and Networks by M.S. Sukhija and T. K. Nagsarkar;
9. Network Analysis by M.E. Van Valkenburg;
10. Networks and Systems by D. Roy Choudhury.
11. A text book of Electrical Technology by B. L. Thereja and A. K. Thereja;
12. Circuit Theory (Analysis and Synthesis) by A. Chakrabarty.

# Fundamentals of Electric Circuits

## ➢ Ohm's Law

- ✓ George Simon Ohm (1789 – 1854), a German physicist, investigated the relation between current and voltage in a resistor.

- ✓ **Difinition:** Provided the physical conditions of a normal conductor remain the same, the potential difference necessary to send a current through the conductor is proportional to the current.

$$\therefore \text{Potential difference, } V \propto \text{Current, } I$$

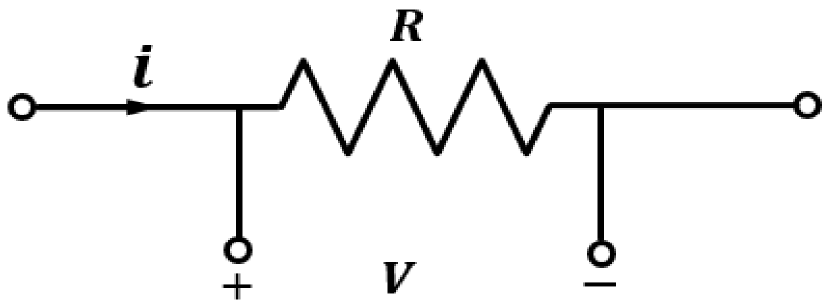



**Fig. 1.1.** Voltage-Current Relationship of a Resistor

- ✓ In **Fig. 1.1,** the potential difference $V$ across the $l$ terminal of a resistor R is directly proportional to the current $i$ flowing through it.

$$\therefore\ V = RI\ ;$$

$R$ is called the linear, time invariant, lumped resistance.

# Fundamentals of Electric Circuits

## ➢ Ohm's Law

### ✓ Resistors

- When a current flows in a material, the free electrons move through the material and collide with atoms.
- The collision cause the electrons to lose some of their energy.
- This loss of energy per unit charge is the drop in potential across the material.
- The amount of energy lost by the electrons is related to the physical property of the material.
- These collisions restrict the movement of electrons.
- The property of a material to restrict the flow of electrons is called resistance.
- The resistance is denoted by ***R***. The symbol for the resistor is shown in **Fig. 1.2**.

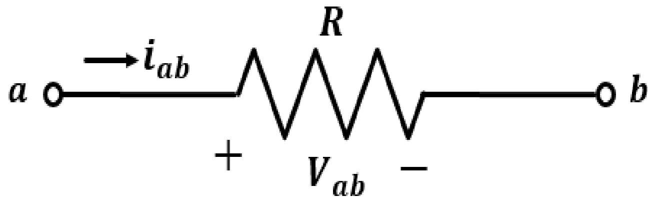



**Fig. 1.2.** Symbol of resistor

✓ **Definition:** A resistance is a two-terminal network component with terminal voltage $V_{ab}$ directly proportional to current $i_{ab}$. The constant of proportionality is also called resistance.

# Fundamentals of Electric Circuits

## ➢ Ohm's Law

### ✓ Resistors

- The unit of resistance is ohm (Ω).
- Ohm is defined as the resistance offered by the material when a current of one ampere flows between two terminals with one volt applied across it.
- The volt ampere plot of a linear resistor is a straight line and that of many devices are nonlinear such as diode.
- A resistor constructed of a semiconductor material such as silicon carbide have a characteristics of curve **b** in **Fig. 3**.
- The device which exhibits nonlinear resistance is called a nonlinear resistor.
- The resistor which is metallic conductor shows the voltage across the conductor is directly proportional to the current through it at constant temperature.
- A resistor constructed of metal would obey ohm's law and would have a characteristic that follow a straight line as given by a curve **a** of **Fig. 1.3**.

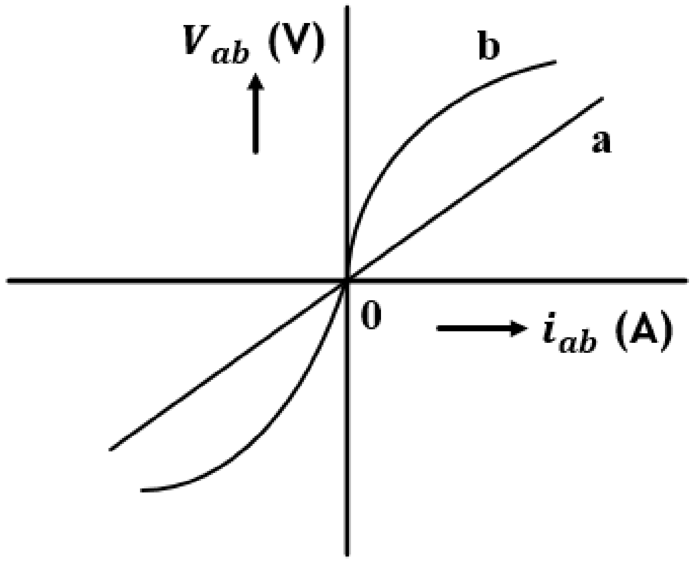



**Fig. 1.3.** Characteristics of resistor

# Fundamentals of Electric Circuits

- **Ohm's Law**

  - **Resistors**

    - Let a voltage $v(t) = V_0 \sin \omega t$ be applied across a resistance $R$ as shown in **Fig. 1.4.** The reference polarity for $v(t)$ and the reference direction for $i(t)$ are shown in the figure.

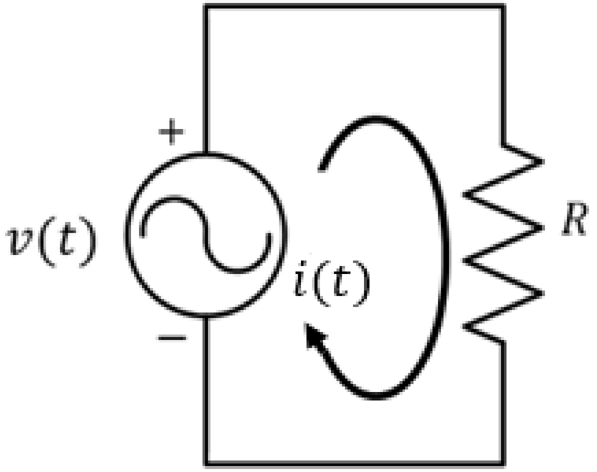



**Fig. 1.4.** Sinusoidal Voltage applied to resistor

- Ohm's law is valid at any instant. Hence, the current is given by

$$i(t) = \frac{v(t)}{R} = \frac{V_0}{R} \sin \omega t$$

- The current $i(t)$ is a sinusoidal alternating current and this is in phase with $v(t)$ and having the same frequency.

# Fundamentals of Electric Circuits

- **Ohm's Law**
  - **Resistors**
    - The peak value of $i(t)$ is

$$I_0 = \frac{V_0}{R}.$$

    - The power delivered by the source at any instant is

$$p(t) = v(t)i(t) = \frac{V_0^2}{R}(\sin\omega t)^2 = \frac{V_0^2}{2R}(1 - \cos 2\omega t)$$

    - If $T$ is the time period of the impressed voltage, the average power per cycle is given by

$$P = \int_0^T p(t)dt \Big/ \int_0^T dt$$

$$= \frac{\omega}{2\pi}\frac{V_0^2}{2R}\left[\left(t - \frac{1}{2\omega}\sin 2\omega t\right)\right]_0^{2\pi/\omega}$$

$$= \frac{V_0^2}{2R} = \frac{I_0^2 R}{2} \text{ watt}$$

# Fundamentals of Electric Circuits

- **Ohm's Law**
  - **Resistors**
    - If $w(t)$ is the instantaneous energy

$$p(t) = \frac{d}{dt}w(t)$$

- Hence, the energy input from $t = 0$ to $t = t_1$ is

$$w_{t1} = \int_0^{t_1} p(t)dt = \frac{V_0^2}{2R}\int_0^{t_1}(1 - \cos 2\omega t)dt$$

$$= \frac{V_0^2}{2R}\left(t_1 - \frac{1}{2\omega}\sin 2\omega t_1\right) \text{ joules}$$

- The energy input in n complete cycles is

$w_n = \frac{V_0^2}{2R}(nT) = \frac{nV_0^2}{2Rf}$ joule, here $f = \frac{1}{T}$ is the frequency in hertz.

- This energy is dissipated in the form of joule heat.

# Fundamentals of Electric Circuits

- **Ohm's Law**

  - When a sinusoidal current $i = I_m \sin \omega t$ is applied to the resistor $R$, the potential difference across it will be

$$V = RI_m \sin \omega t = V_m \sin \omega t$$

  - The r.m.s value of voltage

$$V = \frac{V_m}{\sqrt{2}} = \frac{I_m R}{\sqrt{2}} = RI$$

where the r.m.s. value of current $I = \frac{I_m}{\sqrt{2}}$

  - Ohm's law can also be expressed in terms of conductance $G$ (which is reciprocal of $R$) as $i = GV$

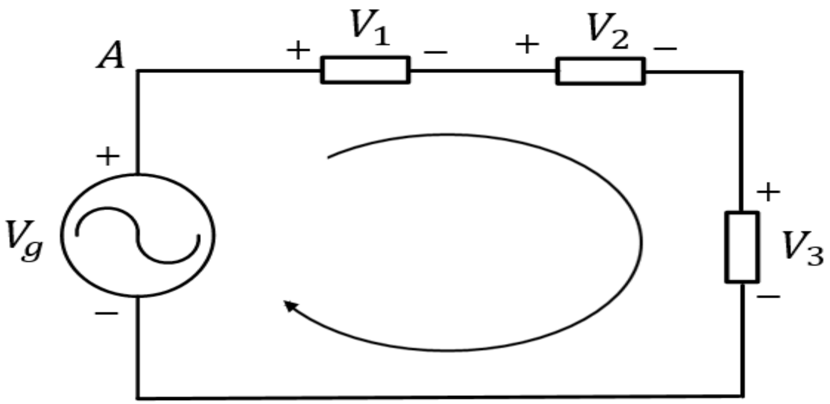
  - The r.m.s. value of current $I = VG$

  - Material whose conductivity depends not only on the value of the current flowing but also on its direction.
    - Silicon carbide possess a conductivity that varies over a wide range as the current through it is varied.
    - The well-known junction in a copper oxide rectifier has a conductivity which is high in one direction of current, low in the reverse direction and varies with current in either direction and varies with current in either case.

# Fundamentals of Electric Circuits

- **Kirchhoff's Law**
  - ✓ Electric circuit theory is based on two fundamental laws introduced by Kirchhoff.
  - ✓ These are Kirchhoff's Voltage Law (abbreviated KVL) and Kirchhoff's Current Law (abbreviated KCL)
  - ❖ **Kirchhoff's Voltage Law**
    - It states that the algebraic sum of the voltage drops around any closed path of a circuit is zero at all instants of time.

      In other words, around any closed path, at all instants of time, the sum of the voltage drops must equal the sum of the voltage rises.
    - A simple circuit is shown in **Fig. 1.5** to illustrate the application of Kirchhoff's Voltage Law.




The boxes contain the circuit elements. The reference polarities for voltages across the elements are shown.

**Fig. 1.5.** Circuit containing voltage source and circuit elements

# Fundamentals of Electric Circuits

- **Kirchhoff’s Law**
  - **Kirchhoff’s Voltage Law**
    - The law follows from the principle of conservation of energy.
    - Let us start from the point A and move a unit positive charge in the direction of the arrow around the closed path.
    - The net change of energy for the movement of charge is zero.
    - The voltage drops around the closed path of the circuit is zero as voltage difference is equal to the ratio of energy change to unit charge.
    - A voltage drop is positive when we move from a ‘+’ polarity and is negative otherwise.
    - According to Kirchhoff’s law, the algebraic sum of the voltage drops must be zero.

$$V_1 + V_2 + V_3 - V_g = 0$$

$$\therefore V_1 + V_2 + V_3 = V_g$$

- This equation shows that the sum of the voltage drops is equal to the sum of the voltage rises.

# Fundamentals of Electric Circuits

- **Kirchhoff's Law**
  - **Kirchhoff's Current Law**

    - It states that the algebraic sum of the currents entering a given point in a circuit is zero at all instants of time.
      In other words, the sum of the currents entering a given point in a circuit equals the sum of the currents leaving that point at any instant of time.

    - This law is a consequence of the conservation of charge.
      As charge can not accumulate at a point, the charge entering a point must leave it. The algebraic sum of the charge or its time derivative (which is the current) must thus be zero..

    - A simple circuit is shown in **Fig. 1.6** to illustrate the application of Kirchhoff's Current Law.

    - In **Fig. 1.6,** the currents $i_1$ and $i_2$ are entering the point $N$ and the currents $i_3$ and $i_4$ are leaving it.

    - Conventionally, the currents entering a point are taken to be positive.

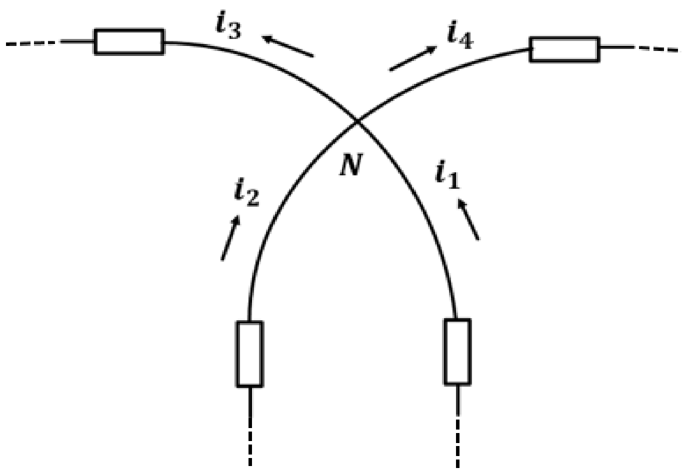



**Fig. 1.6.** Currents meeting at node $N$

# Fundamentals of Electric Circuits

- **Kirchhoff's Law**
  - **Kirchhoff's Current Law**
    - According to Kirchhoff's Current Law,

$$i_1 + i_2 - i_3 - i_4 = 0$$

$$\therefore i_1 + i_2 = i_3 + i_4$$

    - Kirchhoff's Current Law is sometimes termed Kirchhoff's Point Law.

**Example – P1.1**

obtain the branch currents in the unbalanced bridge circuit of **Fig. P1.1**. Also determine the voltage drop across AC and the equivalent resistance between terminals A and C in the bridge circuit.

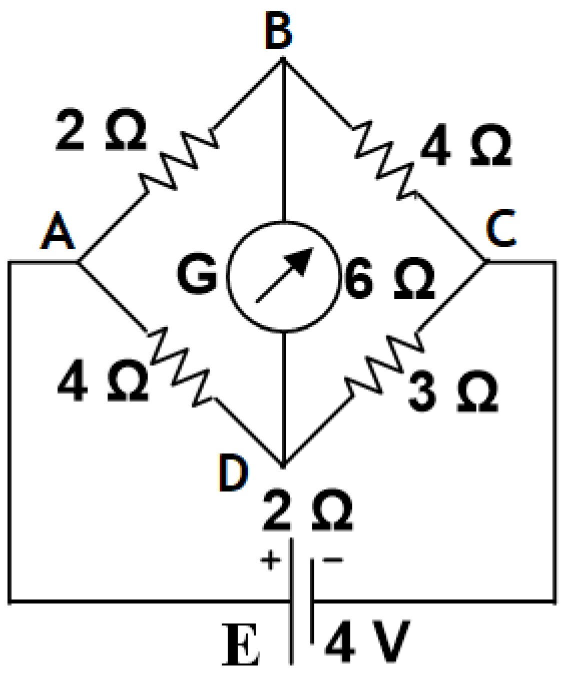



**Fig. P1.1**

## Solution of Example – P1.1

The assumed direction of currents are shown in the figure.

Applying KVL in the loop ABDA, we get

$$2i_1 + 6i_3 - 4i_2 = 0$$

$$\text{or, } i_1 + 3i_3 - 2i_2 = 0$$

$$\text{or, } i_1 - 2i_2 + 3i_3 = 0 \longrightarrow (1)$$

Applying KVL in the loop BCDB, we get

$$4(i_1 - i_3) - 3(i_2 + i_3) - 6i_3 = 0$$

$$\text{or, } 4i_1 - 3i_2 - 13i_3 = 0 \longrightarrow (2)$$

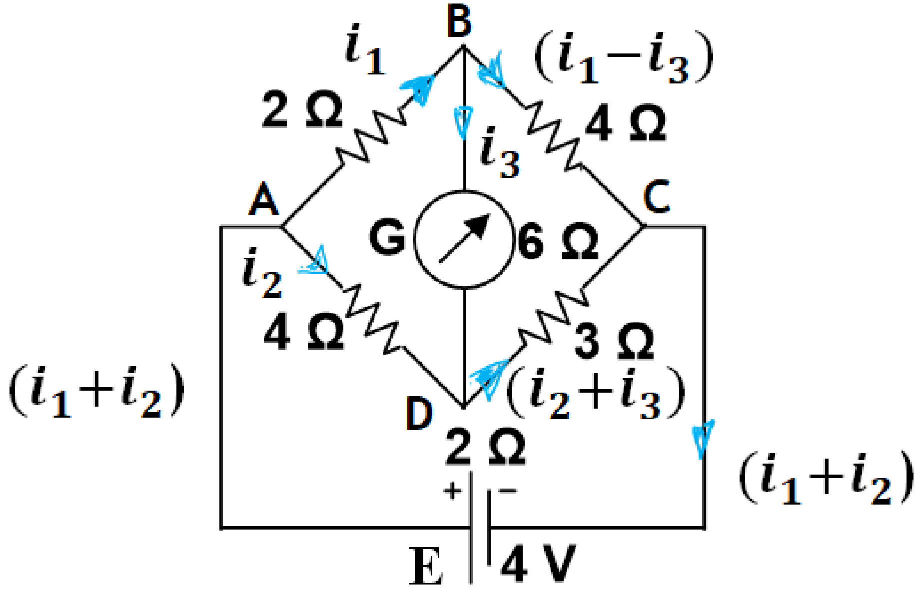



Fig. P1.1

## Solution of Example – P1.1

Applying KVL in the loop ABCEA, we get

$$2\, i_1 + 4(i_1 - i_3) + 2(i_1 + i_2) = 4$$

or, $8i_1 + 2i_2 - 4i_3 = 4$

or, $4i_1 + i_2 - 2i_3 = 2 \longrightarrow (3)$

Solving these equations $(1), (2)$ and $(3)$, we get

$$i_1 = 451.61\, mA$$

$$i_2 = 322.58\, mA \qquad \therefore\ (i_1 + i_2) = i = 774.19\, mA$$

$$i_3 = 64.51\, mA$$

## Solution of Example – P1.1

Then the branch currents are as follows:

Current in branch $AB$ $(i_1) = 451.61\ mA$

Current in branch $AD$ $(i_2) = 322.58\ mA$

Current in branch $BD$ $(i_3) = 64.51\ mA$

Current in branch $BC$ $(i_1 - i_3) = 387.1\ mA$

Current in branch $DC$ $(i_2 + i_3) = 387.09\ mA$

Current in external circuit $(i_1 + i_2) = 774.19\ mA$

## Solution of Example – P1.1

The internal voltage drop of the cell being $[r_{int}(i_1 + i_2)] = \ (2 \times 774.10) \times 10^{-3}\ V = 1.55\ V$

Equivalent resistance between points $A$ and $C$ is the ratio of p.d. between points $A$ and $C$ to the current between these two points, The numerical value of the equivalent resistance becomes

$$r_{eqiv}(AC) = \frac{2.452}{0.77419} = 3.17\ \Omega$$

[∵ The p.d. between points $A$ and $C$ = $(2 \times 0.45161) + (4 \times 0.3871)V = 2.452\ V$]

# LECTURE 2

# Fundamentals of Electric Circuits

## ➢ Analysis of simple circuits−Node Method

- The node method is based on kirchhoff’s current law (KCL).
- The advantages of node method is that a minimum number of equations need to be solved to determine the unknown quantities.
- Every junction in the network where two or more branches meet is regarded a node.
- One of these is regarded as the reference node or datum node or zero potential node.
- Hence, the number of simultaneous equations to be solved becomes (n-1) where n is the number of independent nodes.
- These node equations often become simplified if all voltage sources are converted into current sources.

# Fundamentals of Electric Circuits

## ➢ Analysis of simple circuits−Node Method

- The analysis of node method is illustrated through the circuit as shown in **Fig. 1.7**.
- There are four nodes, marked 0, 1, 2 and 3 in the network.
- The node 0 is taken as the ground node or reference.
- Let $V_1$, $V_2$ and $V_3$ be the voltages at nodes 1, 2 and 3 respectively with respect to the reference.
- Voltages $V_1$, $V_2$ and $V_3$ are assumed to be positive.
- The current entering node 1 is $I_1$.
- The current leaving this node is

$$Y_1V_1 + Y_2(V_1 - V_2) + Y_6(V_1 - V_3)$$

- Application of Kirchhoff's current law gives

$$Y_1V_1 + Y_2(V_1 - V_2) + Y_6(V_1 - V_3) = I_1 \longrightarrow (1)$$

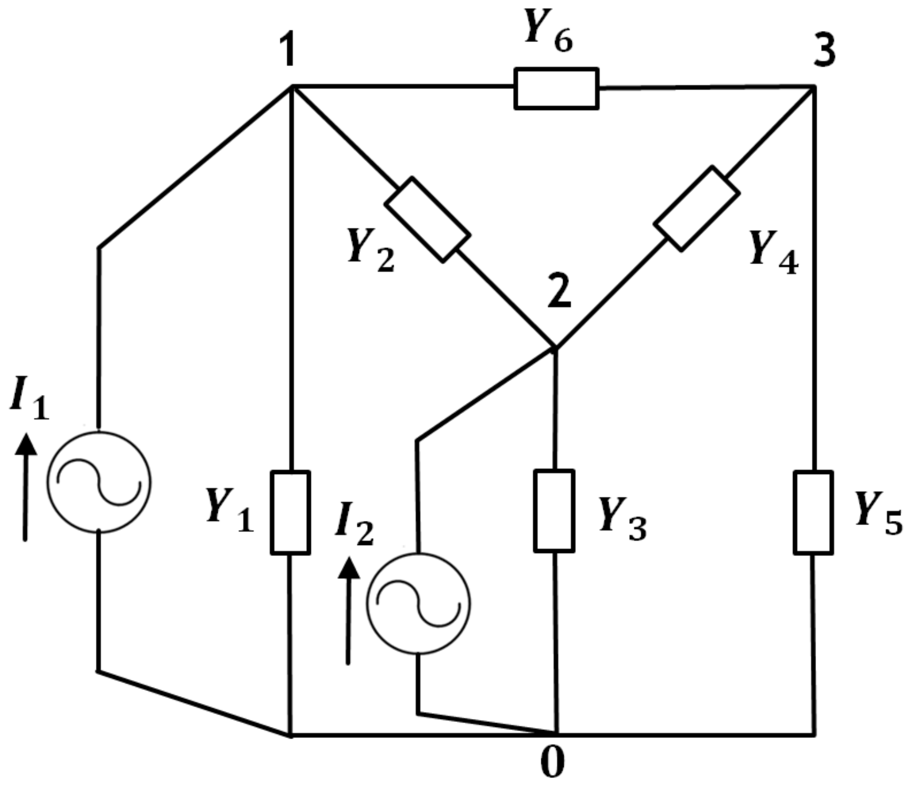



**Fig. 1.7.** Circuit used for node analysis.

## ➢ Analysis of simple circuits−Node Method

- Similarly, we get for node 2

$$Y_3V_2 + Y_2(V_2 - V_1) + Y_4(V_2 - V_3) = I_2 \longrightarrow (2)$$

- and for node 3

$$Y_5V_3 + Y_4(V_3 - V_2) + Y_6(V_3 - V_1) = 0 \longrightarrow (3)$$

- Rearranging equations (1) through (3), we obtain

$$(Y_1 + Y_2 + Y_6)\,V_1 - Y_2\,V_2 - Y_6\,V_3 = I_1 \longrightarrow (4)$$

$$-Y_2\,V_1 + (Y_2 + Y_3 + Y_4)\,V_2 - Y_4\,V_3 = I_2 \longrightarrow (5)$$

$$-Y_6\,V_1 - Y_4\,V_2 + (Y_4 + Y_5 + Y_6)\,V_3 = 0 \longrightarrow (6)$$

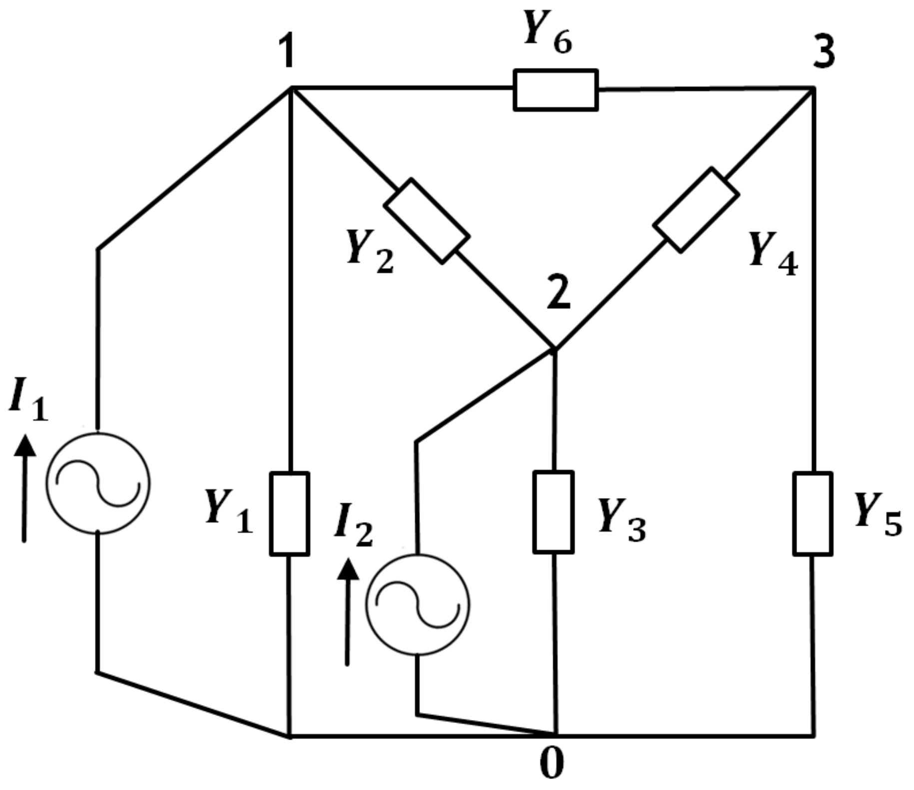



**Fig. 1.7.** Circuit used for node analysis

- The self-admittance of a node is defined as the sum of the admittances connected to that node.
- In the example, $Y_{11} = Y_1 + Y_2 + Y_6$, $Y_{22} = Y_2 + Y_3 + Y_4$ and $Y_{33} = Y_4 + Y_5 + Y_6$.

## ➢ Analysis of simple circuits−Node Method

- The coefficients of $V_1$ in Eq. (1), $V_2$ in Eq. (2) and $V_3$ in Eq.(3) are the self-admittance of nodes 1, 2 and 3 respectively.
- The coupling admittance between two nodes is the admittance connecting these two nodes.
- In the example, the coefficient of $V_2$ in Eq. (4), $-Y_2$ is the coupling admittance between nodes 1 and 2. Similarly, $-Y_6$ between nodes 1 and 3 and so on.
- It is observed that the self-admittance terms are positive while the sign of all the coupling admittance terms are negative.
- The symbol for the coupling admittance between nodes h and k is $Y_{hk}$.
- For linear bilateral elements, $Y_{hk} = Y_{kh}$ $(h \neq k)$.
- In the example, $Y_{12} = Y_{21} = Y_2$ etc.
- If there is no admittance coupling between nodes $h$ and $k$, $Y_{hk} = Y_{kh} = 0$.

# Fundamentals of Electric Circuits

## ➢ Analysis of simple circuits−Node Method

- The right-hand sides of the equation are positive when they denote current entering the nodes, and are negative when the current leave the nodes. These features follow from the reference directions and polarities chosen.
- The right hand sides of some of the above equations may be zero.
- Generalisation of these equations for a network having $(n+1)$ nodes of which one is a ground node yields

$$
\begin{array}{c}
Y_{11}V_1 - Y_{12}V_2 - Y_{13}V_3 - \cdots - Y_{1n}V_n = I_1 \\
-Y_{21}V_1 + Y_{22}V_2 - Y_{23}V_3 - \cdots - Y_{2n}V_n = I_2 \\
. \quad . \quad . \quad . \quad . \\
. \quad . \quad . \quad . \quad . \\
-Y_{n1}V_1 - Y_{n2}V_2 - Y_{n3}V_3 - \cdots + Y_{nn}V_n = I_n
\end{array}
$$

- The self-admittances of nodes 1 through n are designated by $Y_{11}$, $Y_{22}$,... $Y_{nn}$ respectively
- The coupling-admittances are $-Y_{12}$, $-Y_{13}$,…$-Y_{1n}$; $-Y_{21}$, $-Y_{23}$,…$-Y_{2n}$; .. $-Y_{n1}$, $-Y_{n2}$,…$-Y_{n(n-1)}$
- The incoming currents are $I_1$, $I_2$, $I_3$, ... $I_n$ respectively.

## ➢ Analysis of simple circuits−Node Method

- The voltages $V_1$, $V_2$, …, $V_n$ can now be determined by solving the above equations by Cramer's rule.

**Cramer's Rule**

$$a_1x + b_1y + c_1z = d_1$$

$$a_2x + b_2y + c_2z = d_2$$

$$a_3x + b_3y + c_3z = d_3$$

$$\text{or, } \begin{bmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ d_3 \end{bmatrix}$$

$$\therefore \Delta = \begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix}$$

$$\text{or, } x\Delta = \begin{vmatrix} xa_1 & b_1 & c_1 \\ xa_2 & b_2 & c_2 \\ xa_3 & b_3 & c_3 \end{vmatrix}$$

## ➢ Analysis of simple circuits−Node Method

$$\therefore x\Delta = \begin{vmatrix} a_1x + b_1y + c_1z & b_1 & c_1 \\ a_2x + b_2y + c_2z & b_2 & c_2 \\ a_3x + b_3y + c_3z & b_3 & c_3 \end{vmatrix} = \begin{vmatrix} d_1 & b_1 & c_1 \\ d_2 & b_2 & c_2 \\ d_3 & b_3 & c_3 \end{vmatrix}$$

$$\therefore\ x = \frac{\begin{vmatrix} d_1 & b_1 & c_1 \\ d_2 & b_2 & c_2 \\ d_3 & b_3 & c_3 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix}}$$

Similarly, $y = \frac{\begin{vmatrix} a_1 & d_1 & c_1 \\ a_2 & d_2 & c_2 \\ a_3 & d_3 & c_3 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix}}$ and $z = \frac{\begin{vmatrix} a_1 & b_1 & d_1 \\ a_2 & b_2 & d_2 \\ a_3 & b_3 & d_3 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix}}$

## ➢ Analysis of simple circuits−Node Method

**Example – P1.2**

Determine the output voltage, $V_{out}$ in the circuit as shown in **Fig. P1.2** by using nodal method.

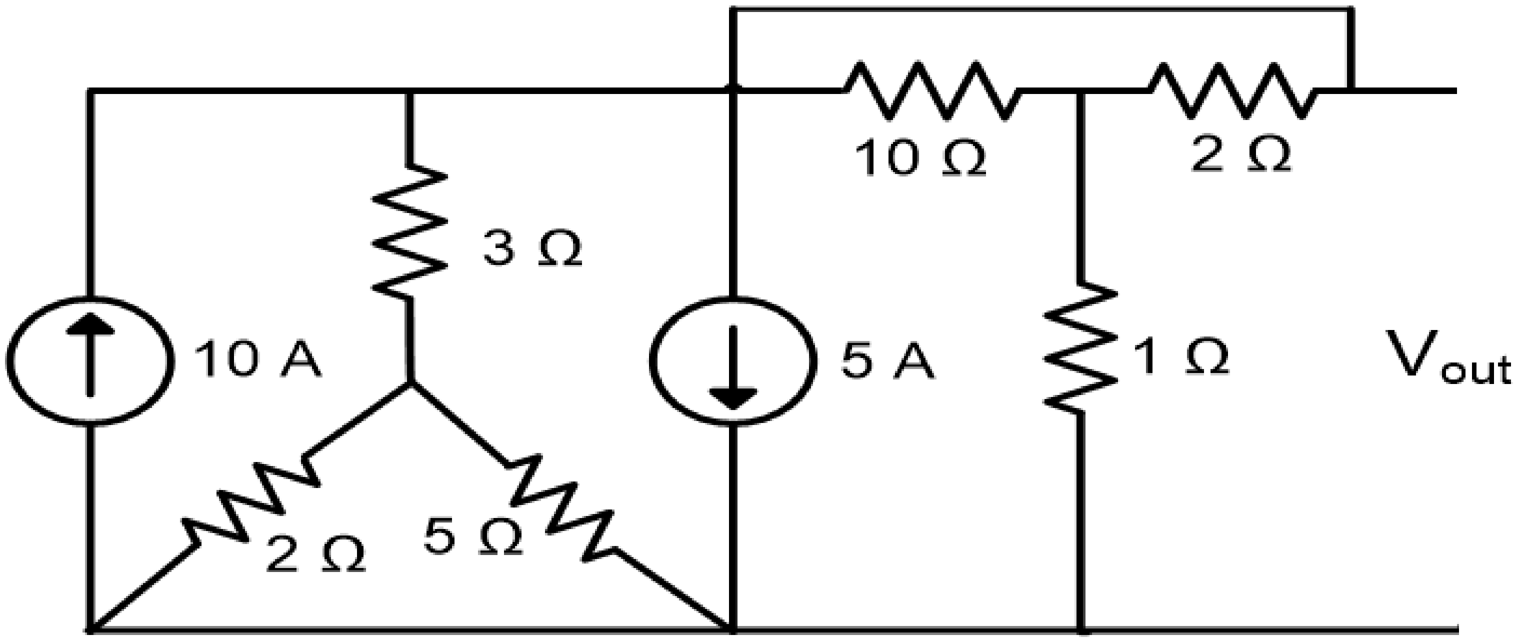



**Fig. P1.2**

# Fundamentals of Electric Circuits

## ➢ Analysis of simple circuits−Node Method

### Solution of Example – P1.2

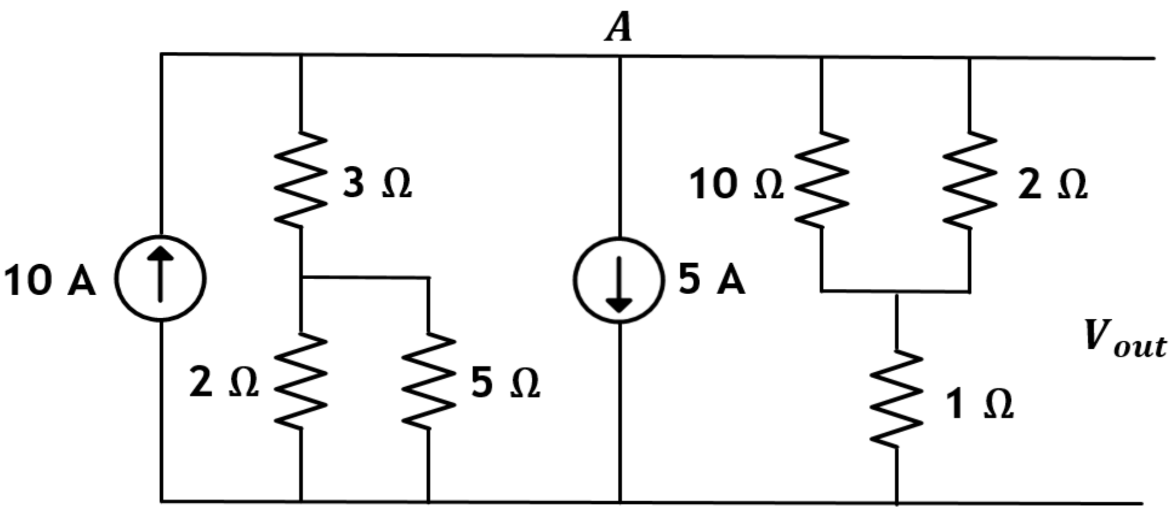



**Fig. P1.2**

In the above circuit, 2 Ω and 5 Ω are in parallel and this is connected to 3 Ω in series. So, the equivalent resistance is $3+(2 \parallel 5) = 4.43\ \Omega$

Also 10 Ω and 2 Ω are in parallel and this is connected to 1 Ω in series. So, the equivalent resistance is $1+(10 \parallel 2) = 2.67\ \Omega$.

# Fundamentals of Electric Circuits

## ➢ Analysis of simple circuits−Node Method

### Solution of Example – P1.2

Assuming voltage $V_A$ at node $A$ and applying Kirchhoff's current law in the circuit, we get

$$10 - \frac{V_A}{4.43} - 5 - \frac{V_A}{2.67} = 0$$

$$V_A\left[\frac{1}{4.43} + \frac{1}{2.67}\right] = 5$$

$$V_A = 8.33\ V$$

$$\therefore\ V_{out} = V_A = 8.33\ \text{Volt}$$

## ➢ Analysis of simple circuits−Node Method

### Example – P1.3

In the network of **Fig. P1.3**, find the current through and voltage across 5 Ω resistor.

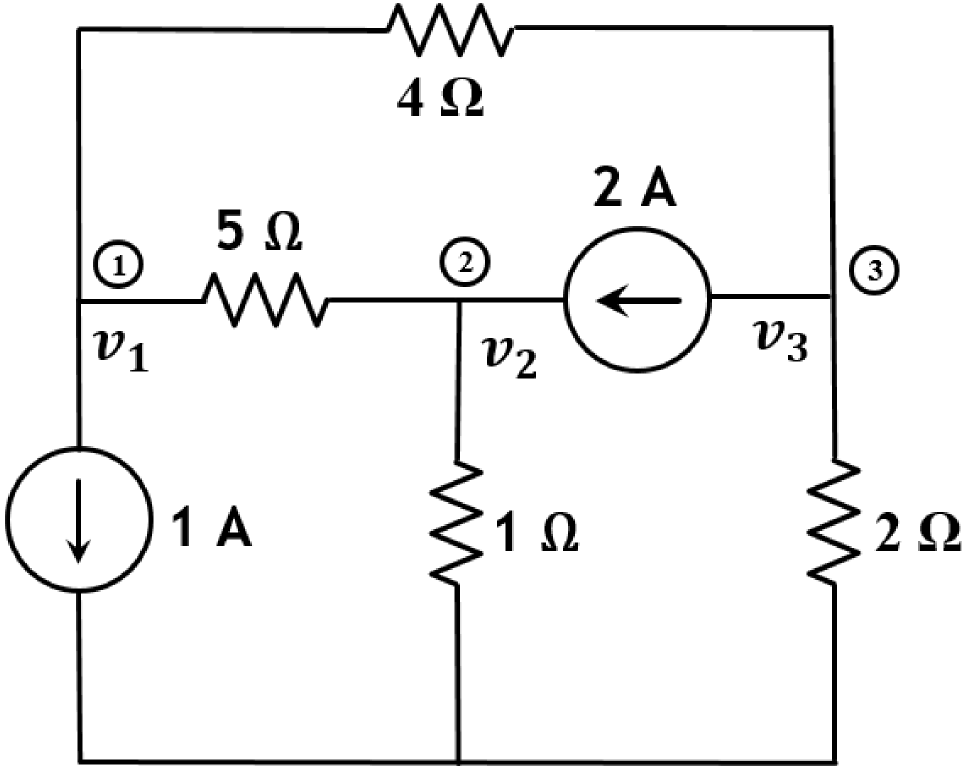



**Fig. P1.3**

## ➢ Analysis of simple circuits−Node Method

### Solution of Example – P1.3

Apply KCL at node 1 and we get

$$\frac{v_1 - v_2}{5} + \frac{v_1 - v_3}{4} + 1 = 0$$

or, $$9v_1 - 4v_2 - 5v_3 = -20 \qquad (1)$$

Apply KCL at node 2 and we get

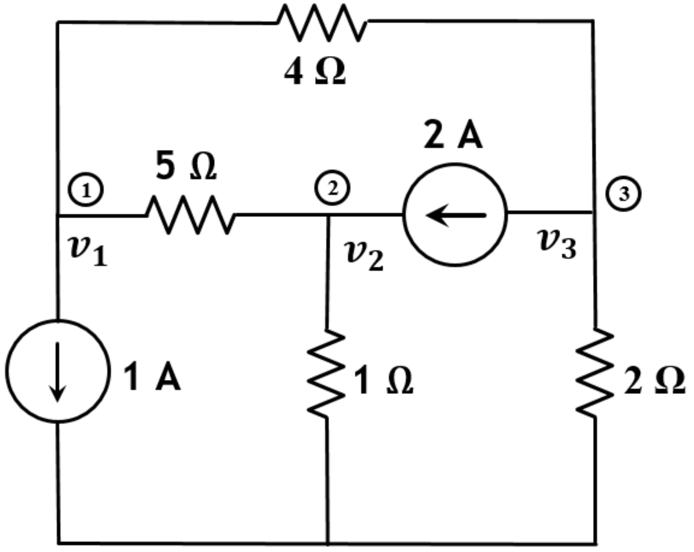
$$\frac{v_2 - v_1}{5} + \frac{v_2}{1} - 2 = 0$$

or, $$-v_1 + 6v_2 = 10 \qquad (2)$$

Apply KCL at node 3 and we get

$$\frac{v_3 - v_1}{4} + \frac{v_3}{2} + 2 = 0$$

or, $$-v_1 + 3v_3 = -8 \qquad (3)$$



# Fundamentals of Electric Circuits

## ➢ Analysis of simple circuits−Node Method

### Solution of Example – P1.3

In matrix form,

$$\begin{bmatrix} 9 & -4 & -5 \\ -1 & 6 & 0 \\ -1 & 0 & 3 \end{bmatrix}\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = \begin{bmatrix} -20 \\ 10 \\ -8 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 9 & -4 & -5 \\ -1 & 6 & 0 \\ -1 & 0 & 3 \end{vmatrix} = 9(6\times 3-0)+(-4)\big(0-(-1\times 3)\big)+(-5)\big(0-(-1\times 6)\big) = 162-12-30 = 120$$

$$\Delta_1 = \begin{vmatrix} -20 & -4 & -5 \\ 10 & 6 & 0 \\ -8 & 0 & 3 \end{vmatrix} = (-20)(6\times 3-0)+(-4)\big(0-(3\times 10)\big)+(-5)\big(0-(6\times -8)\big) = -360+120-240$$

$$= -480$$

$$\Delta_2 = \begin{vmatrix} 9 & -20 & -5 \\ -1 & 10 & 0 \\ -1 & -8 & 3 \end{vmatrix} = 9(10\times 3-0)+(-20)\big(0-(-1\times 3)\big)+(-5)\big((-1)\times(-8)-(-1\times 10)\big)$$

$$= 270-60-90 = 120$$

## ➢ Analysis of simple circuits−Node Method

**Solution of Example – P1.3**

$\therefore \quad v_1 = \frac{\Delta_1}{\Delta} = \frac{-480}{120} = -4\ V \quad ; \quad v_2 = \frac{\Delta_2}{\Delta} = \frac{120}{120} = 1\ V$

$\therefore$ The current through 5 Ω resistor is $\frac{v_1 - v_2}{5} = \frac{-4-1}{5} = -1\ A$

$\therefore$ The voltage drop across 5 Ω resistor is $(v_1 - v_2) = -5\ V$.

## ➢ Analysis of simple circuits−Mesh Method

- The analysis of mesh method is illustrated through the circuit as shown in **Fig. 1.8**.
- The current supplied by the generator of voltage $V_a$ is to find out.
- A suitable tree as shown in **Fig. 1.9** is selected in such a way that the links of the tree contain the generator $V_a$, the impedance $Z_5$, and the impedance $Z_6$.

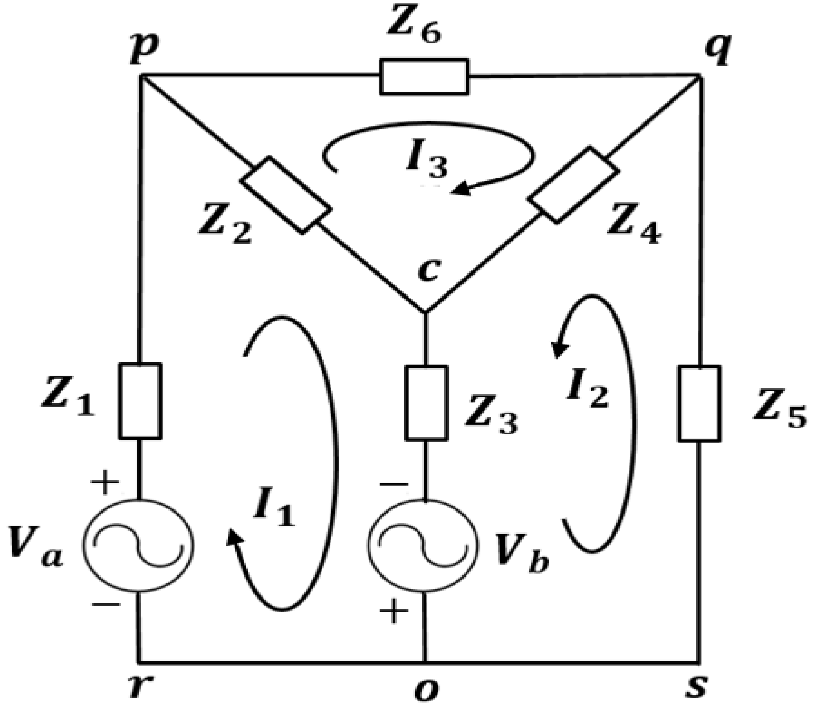



**Fig. 1.8.** Circuit used for mesh analysis

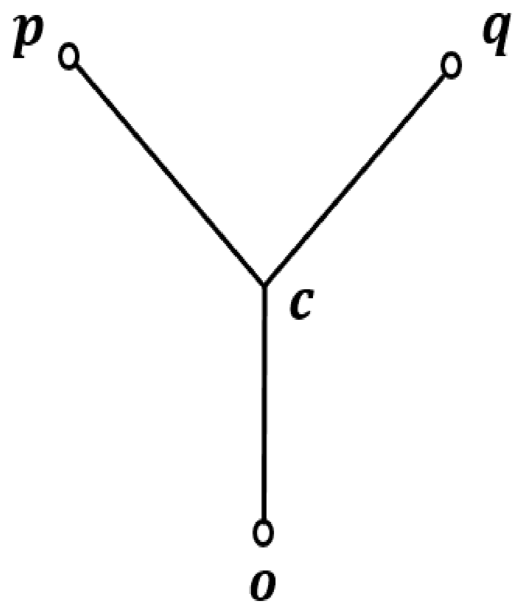



**Fig. 1.9.** A tree of the circuit of Fig. 1.8

## Analysis of simple circuits−Mesh Method

- The network contains six branches and four nodes marked $p$, $q$, $c$ and $o$.
- The number of links or independent meshes is $(b - n + 1) = (6 - 4 + 1) = 3$.
- These three links placed one at a time, form the meshes $pcorp, osqco$ and $pqcp$ respectively.
- The link currents or the mesh currents in **Fig. 1.8** are denoted by $I_1$, $I_2$ and $I_3$ respectively.
- Kirchhoff's voltage law equation is to be written for each mesh. These equations are called mesh equations or loop equations.
- These equations are to be solved to yield the link currents or the mesh currents.
- The current in a tree branch which is common to two or more meshes is obtained by algebraically summing the associated mesh currents.

## ➢ Analysis of simple circuits−Mesh Method

- Application of Kirchhoff's Voltage Law to the three meshes gives the following three simultaneous equations.

$$Z_1\, I_1 + Z_2\,(I_1 - I_3) + Z_3\,(I_1 + I_2) = V_b + V_a = V_1 \quad (say) \longrightarrow (1)$$

$$Z_3\,(I_2 + I_1) + Z_4\,(I_2 + I_3) + Z_5\, I_2 = V_b = V_2 \quad (say) \longrightarrow (2)$$

$$Z_2\,(I_3 - I_1) + Z_4\,(I_3 + I_2) + Z_6\, I_3 = 0 \longrightarrow (3)$$

- Rearranging equations (1) through (3), we obtain

$$(Z_1 + Z_2 + Z_3)\, I_1 + Z_3\, I_2 - Z_2\, I_3 = V_1 \longrightarrow (4)$$

$$Z_3\, I_1 + (Z_3 + Z_4 + Z_5)\, I_2 + Z_4\, I_3 = V_2 \longrightarrow (5)$$

$$-Z_2\, I_1 + Z_4\, I_2 + (Z_2 + Z_4 + Z_6)\, I_3 = 0 \longrightarrow (6)$$

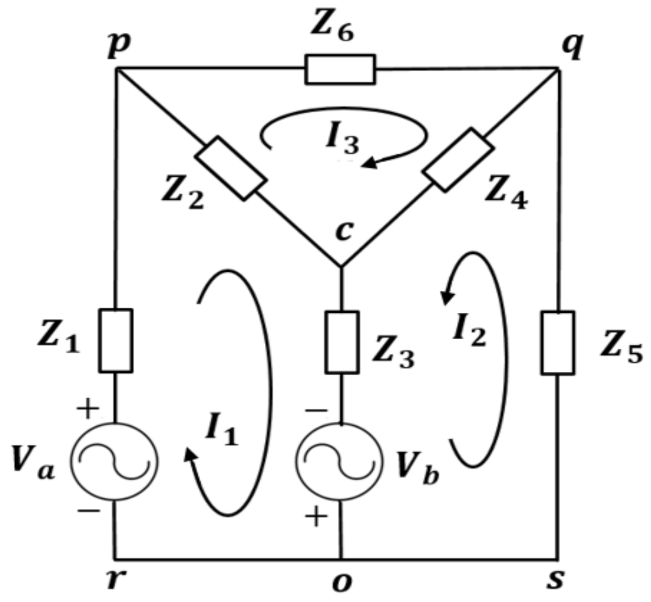



**Fig. 1.8.** Circuit used for mesh analysis

## Analysis of simple circuits−Mesh Method

- Solving these equations, we get the desired current $I_1$. The solution for $I_2$ and $I_3$ give the currents in impedances $Z_5$ and $Z_6$ respectively.
- The current through $Z_2$ is $(I_1 - I_3)$, that through $Z_4$ is $(I_2 + I_3)$ and that through $Z_3$ is $(I_1 + I_2)$.
- If any current turns out to be negative, it simply means that its actual reference direction is opposite to that chosen.
- Since the current through any impedance is known, the voltages at the nodes are readily determined.
- The sum of the impedances in going completely round a mesh is referred to as the self-impedance of the mesh.
- The self-impedances of meshes 1 through $n$ are denoted by $Z_{11}$, $Z_{22}$, $Z_{33}$, …, $Z_{nn}$ respectively.
- In the example, $Z_{11} = (Z_1 + Z_2 + Z_3)$, $Z_{22} = (Z_3 + Z_4 + Z_5)$ and $Z_{33} = (Z_2 + Z_4 + Z_6)$.
- The impedances that is common to two meshes is called the coupling impedance between the meshes.
- The coupling impedance between meshes $h$ and $k$ is denoted by $Z_{hk}$

## Analysis of simple circuits−Mesh Method

- The coupling impedance between meshes $h$ and $k$ is denoted by $Z_{hk}$.
- Since, only linear bilateral elements are considered, hence $Z_{hk} = Z_{kh} (k \neq h)$.
- In the example, $Z_{12} = Z_{21} = Z_3$, $Z_{13} = Z_{31} = Z_2$ and $Z_{23} = Z_{32} = Z_4$.
- Generalisation of these equations for a network having $n$ meshes yields.

$$
\begin{array}{c}
Z_{11}I_1 + Z_{12}I_2 + Z_{13}I_3 + \cdots + Z_{1n}I_n = V_1 \\
Z_{21}I_1 + Z_{22}I_2 + Z_{23}I_3 + \cdots + Z_{2n}I_n = V_2 \\
\cdot \qquad\quad \cdot \qquad\quad \cdot \qquad\qquad\quad \cdot \qquad\quad \cdot \\
\cdot \qquad\quad \cdot \qquad\quad \cdot \qquad\qquad\quad \cdot \qquad\quad \cdot \\
\cdot \qquad\quad \cdot \qquad\quad \cdot \qquad\qquad\quad \cdot \qquad\quad \cdot \\
Z_{n1}I_1 + Z_{n2}I_2 + Z_{n3}I_3 + \cdots + Z_{nn}I_n = V_n
\end{array}
$$

- Here, the signs of the self-impedance terms are all positive.
- The signs of some of the coupling impedance terms may be negative depending on the chosen reference directions of currents.

# Fundamentals of Electric Circuits

## ➢ Analysis of simple circuits−Mesh Method

- The coupling impedance between meshes $h$ and $k$ is denoted by $Z_{hk}$.
- The sign before $Z_{hk}$ will be positive if the currents in the adjacent meshes $h$ and $k$ flow in the same direction through $Z_{hk}$.
- If they flow in the opposite direction through $Z_{hk}$, the sign before $Z_{hk}$ is negative.
- If there is no impedance common to meshes $h$ and $k$, $Z_{hk} = Z_{kh}$ will be zero.
- $V_1$, $V_2$,…..$V_n$ are respectively the resultant voltages applied to meshes 1, 2,…n. If there is no resultant applied voltage in a particular, say $h$, $V_h$ will be zero.

- The currents $I_1$, $\mathrm{I}_2$, …, $I_n$ can now be determined by solving the above equations by Cramer's rule.

# Fundamentals of Electric Circuits

➢ **Analysis of simple circuits−Mesh Method**

**Example – P1.4**

Find the current in the 3 Ω resistor of the circuit as shown in **Fig. P1.4** by mesh method

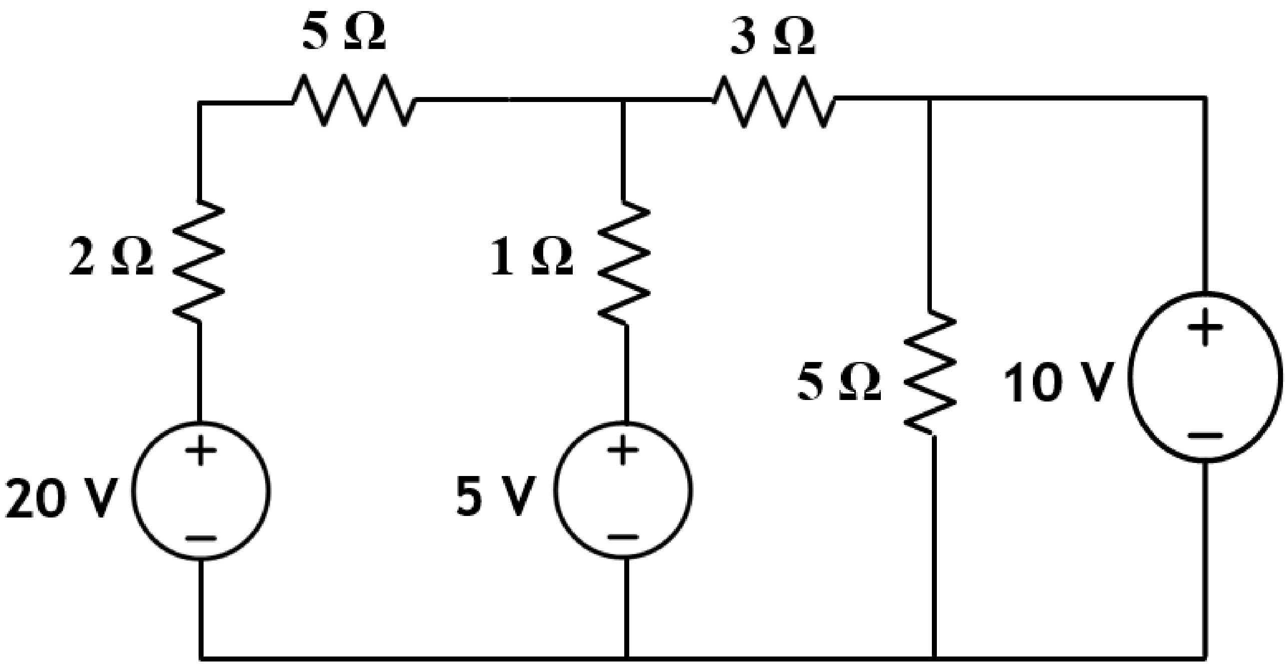



**Fig. P1.4**

# Fundamentals of Electric Circuits

➢ **Analysis of simple circuits−Mesh Method**

**Solution of Example – P1.4**

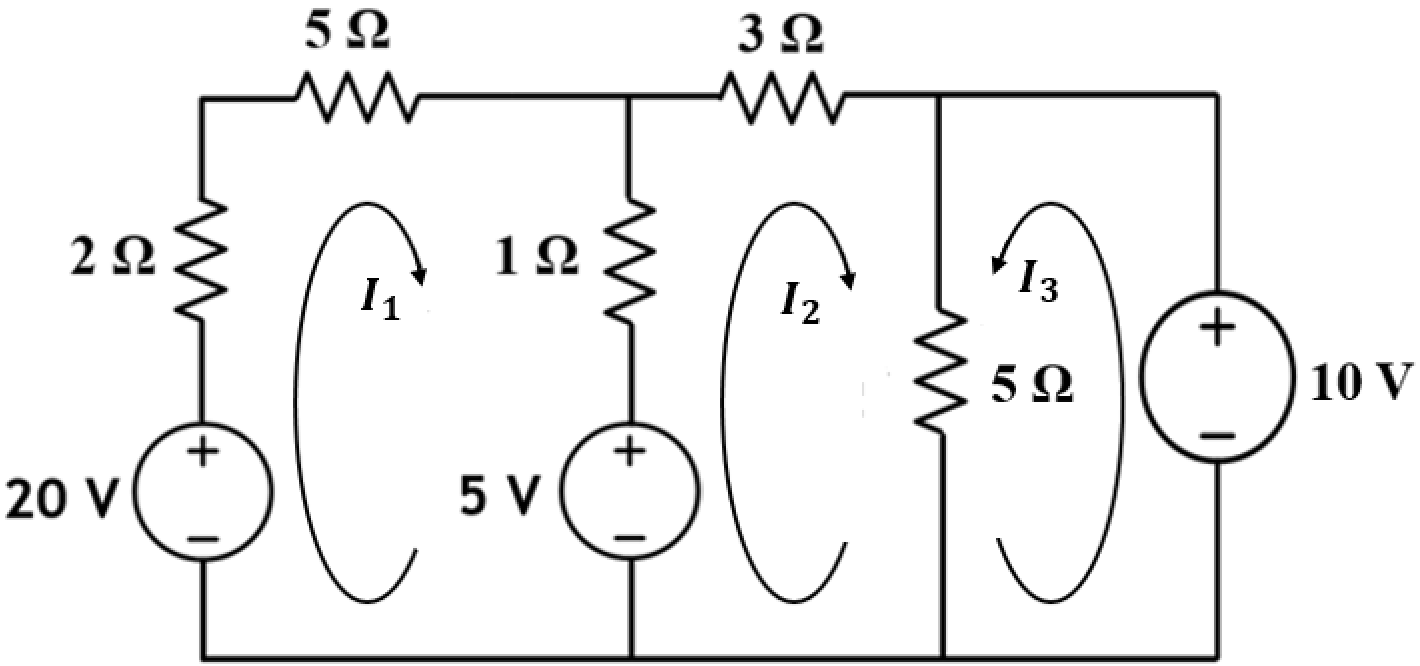



**Fig. P1.4.1**

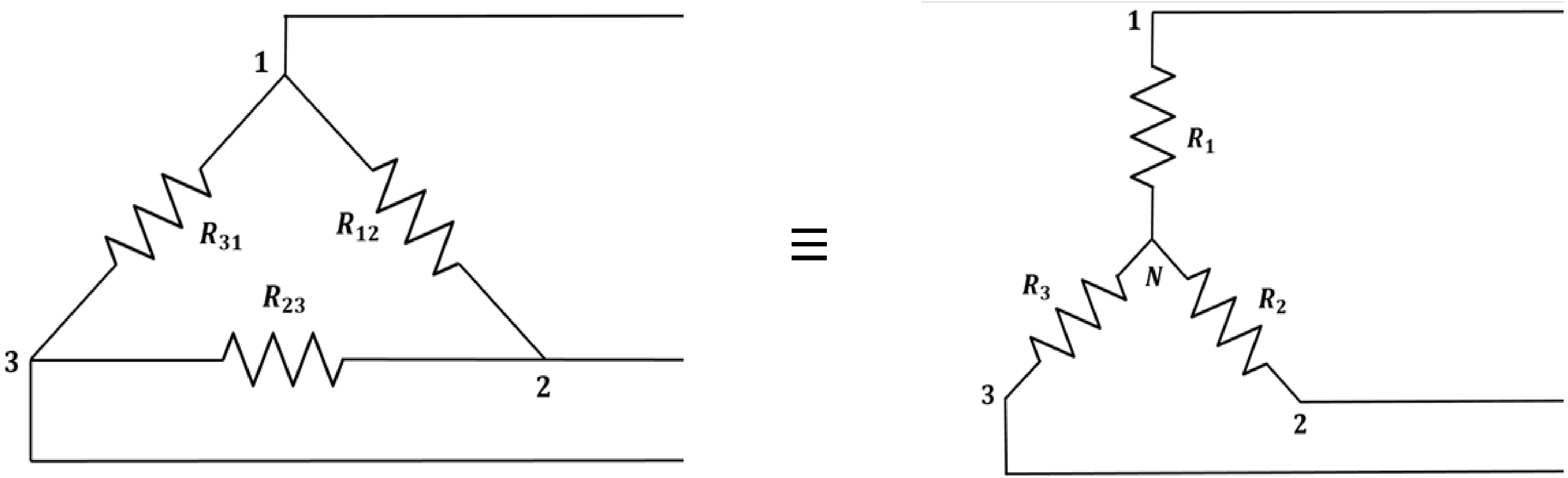
The current through 3 Ω resistor is given by $I_L = 0.806\ A$

# LECTURE 3

# Fundamentals of Electric Circuits

## ➢ Delta/Star and Star/Delta Transformation

- The complicated networks can be simplified by successfully replacing delta meshes by equivalent star systems and vice versa.
- The analysis of ‘delta/star and star/delta transformation’ is illustrated through the circuit as shown in **Fig. 1.9**.




**(a)** **(b)**

**Fig. 1.9.** Circuit for delta/star and star/delta transformation

# Fundamentals of Electric Circuits

## ➢ Delta/Star and Star/Delta Transformation

- Three resistances $R_{12}$, $R_{23}$ and $R_{31}$ are connected in delta fashion between terminals 1, 2 and 3 as shown in **Fig. 12 (a).**
- These three resistances are replaced by the resistances $R_1$, $R_2$ and $R_3$, connected in star as shown in **Fig. 12(b).**
- These two arrangements will be electrically equivalent if the resistance as measured between any pair of terminals is the same in both the arrangements.
- First, consider the terminals of 1 and 2 in delta connection. There are two parallel paths. One having a resistance of $R_{12}$ and the other having a resistance of $(R_{23} + R_{31})$.

∴ Resistance between terminals 1 and 2 is

$$\frac{R_{12} \times (R_{23} + R_{31})}{R_{12} + R_{23} + R_{31}}$$

- Now, consider star connection. The resistance between the same terminals 1 and 2 is $(R_1 + R_2)$.

# Fundamentals of Electric Circuits

## ➢ Delta/Star and Star/Delta Transformation

- As terminal resistance have to be the same

$$R_1 + R_2 = \frac{R_{12}(R_{23} + R_{31})}{R_{12} + R_{23} + R_{31}} \longrightarrow (1)$$

- Similarly, for terminals 2 and 3 and terminals 3 and 1, we get

$$R_2 + R_3 = \frac{R_{23}(R_{31} + R_{12})}{R_{12} + R_{23} + R_{31}} \longrightarrow (2)$$

and $$R_3 + R_1 = \frac{R_{31}(R_{12} + R_{23})}{R_{12} + R_{23} + R_{31}} \longrightarrow (3)$$

## ➢ Delta/Star and Star/Delta Transformation

- Now, subtracting (2) from (1) and adding the result to (3), we get

$$R_1 = \frac{R_{12}R_{31}}{R_{12} + R_{23} + R_{31}} \longrightarrow \quad (4)$$

- Putting the value of $R_1$ in Eq. (1), we get

$$R_2 = \frac{R_{23}R_{12}}{R_{12} + R_{23} + R_{31}} \longrightarrow \quad (5)$$

- Putting the value of $R_1$ in Eq. (3), we get

$$R_3 = \frac{R_{31}R_{23}}{R_{12} + R_{23} + R_{31}} \longrightarrow \quad (6)$$

- So, resistance of each arm of the star is given by the product of the resistances of the two delta sides that meet at its end divided by the sum of the three delta resistances.

# Fundamentals of Electric Circuits

## ➢ Delta/Star and Star/Delta Transformation

- Dividing Eq. (4) by Eq. (5), we get

$$\frac{R_1}{R_2} = \frac{R_{31}}{R_{23}} \longrightarrow (7)$$

- Similarly, dividing Eq. (5) by Eq. (6), we get

$$\frac{R_2}{R_3} = \frac{R_{12}}{R_{31}} \longrightarrow (8)$$

- From Eqs. (7) and (8), we get

$$R_{23} = \frac{R_2}{R_1} R_{31} \quad \text{and} \quad R_{12} = \frac{R_2}{R_3} R_{31}$$

## ➢ Delta/Star and Star/Delta Transformation

- Putting values of $R_{23}$ and $R_{12}$ in Eq. (1), we get

$$R_1 + R_2 = \frac{R_{12}(R_{23} + R_{31})}{R_{12} + R_{23} + R_{31}}$$

$$= \frac{\frac{R_2}{R_3} R_{31} \left( \frac{R_2}{R_1} R_{31} + R_{31} \right)}{\frac{R_2}{R_3} R_{31} + \frac{R_2}{R_1} R_{31} + R_{31}}$$

$$= \frac{\frac{R_2}{R_3} R_{31} \left( 1 + \frac{R_2}{R_1} \right) R_{31}}{R_{31} \left( 1 + \frac{R_2}{R_3} + \frac{R_2}{R_1} \right)}$$

# Fundamentals of Electric Circuits

## ➢ Delta/Star and Star/Delta Transformation

or, $$R_1+R_2 = \frac{(R_1+R_2)R_2R_{31}}{R_1R_3} \times \frac{R_1R_3}{R_1R_2+R_2R_3+R_3R_1}$$

or, $$R_{31} = \frac{R_1R_2+R_2R_3+R_3R_1}{R_2}$$

$$\therefore \quad R_{31} = R_3 + R_1 + \frac{R_3R_1}{R_2}$$

Similarly,

$$R_{23} = R_2 + R_3 + \frac{R_2R_3}{R_1}$$

$$R_{12} = R_1 + R_2 + \frac{R_1R_2}{R_3}$$

## ➢ Delta/Star and Star/Delta Transformation

### Example – P1.5

Determine the equivalent resistance across X-Y of the circuit as shown in **Fig. P1.5** by using star-delta transformation.

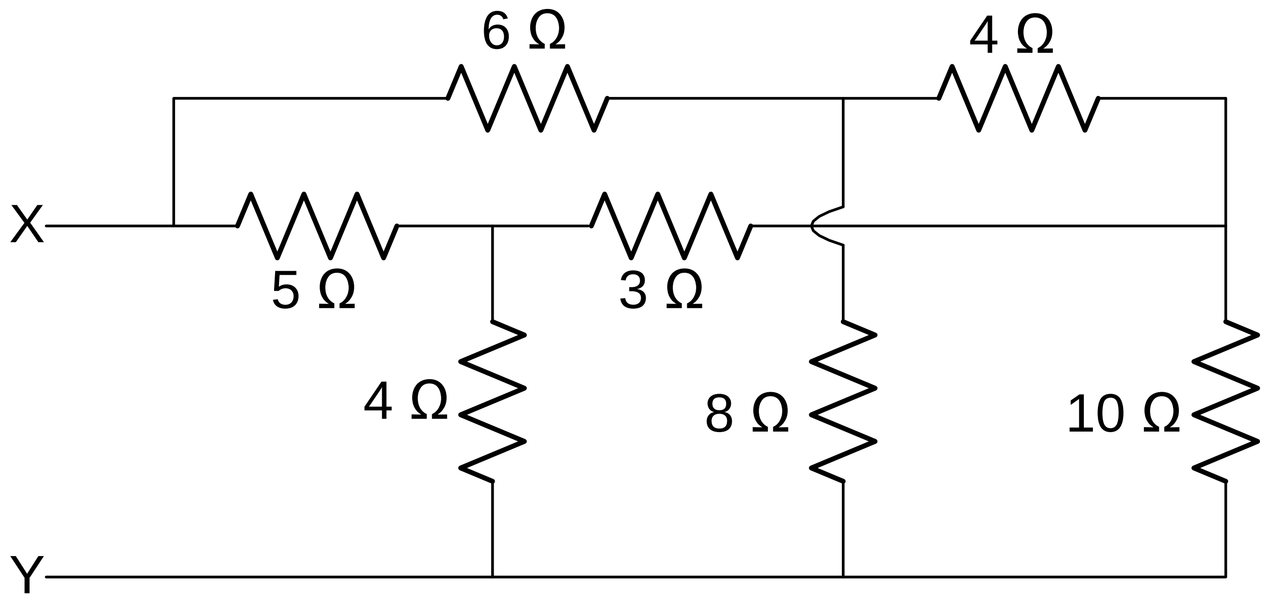



**Fig. P1.5**

## ➢ Delta/Star and Star/Delta Transformation

### Solution of Example – P1.5

There are two star circuits in **Fig. P1.5.** One consisting of 5 Ω, 3 Ω and 4 Ω resistors and other one consisting of 6 Ω, 4 Ω and 8 Ω resistors.

Convert the star circuits into delta circuits so that the two delta circuits are in parallel.

The two star circuits and their equivalent circuits are shown below:

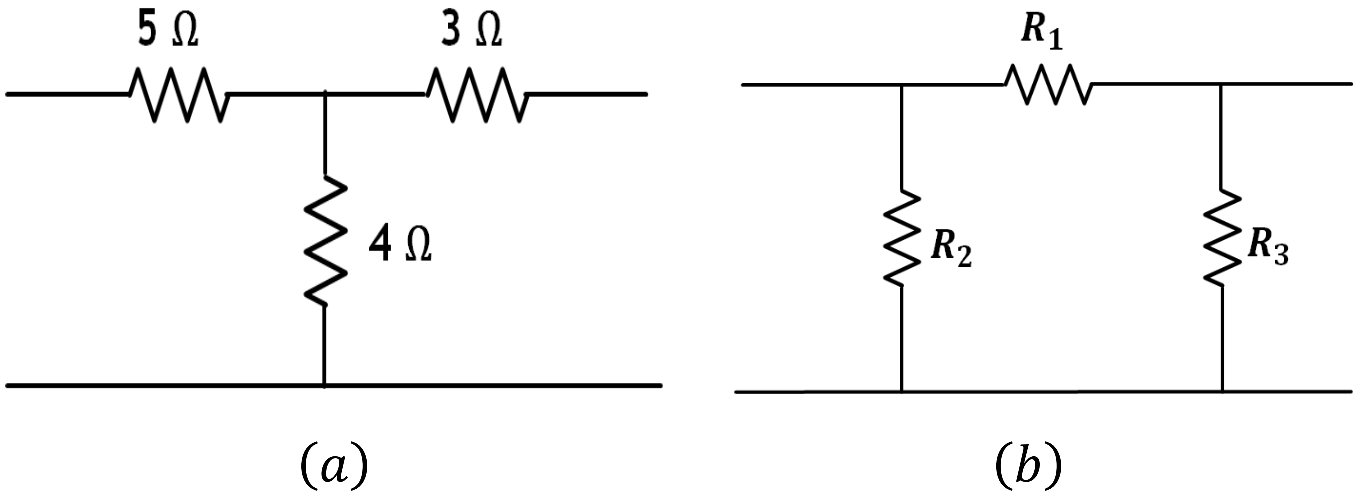



**Fig. P1.5.1**

$$R_1 = \frac{5\times3+4\times3+5\times4}{4} = 11.75\ \Omega$$

$$R_2 = \frac{5\times3+4\times3+5\times4}{3} = 15.67\ \Omega$$

$$R_3 = \frac{5\times3+4\times3+5\times4}{5} = 9.4\ \Omega$$

## ➢ Delta/Star and Star/Delta Transformation

### Solution of Example – P1.5

The two star circuits and their equivalent circuits are shown below:

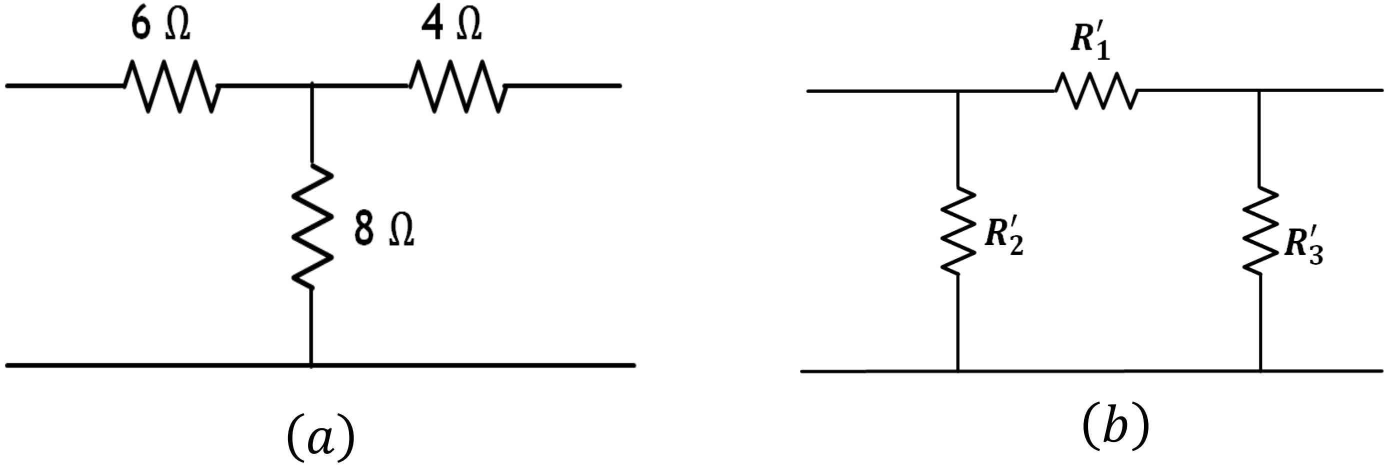



**Fig. P1.5.2**

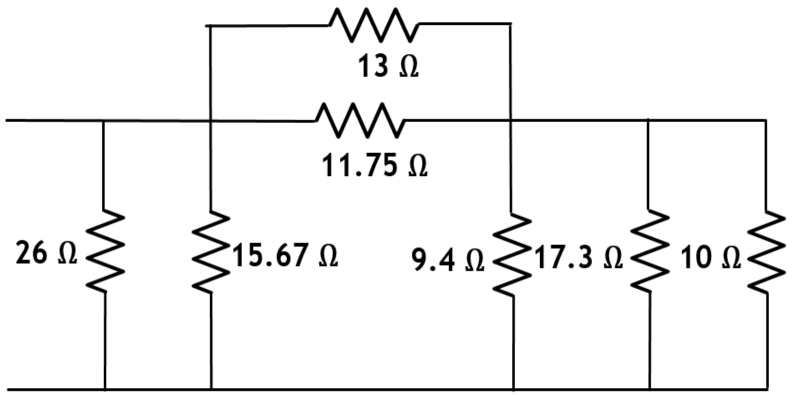
$$R_1' = \frac{6\times 4 + 4\times 8 + 8\times 6}{8} = 13\ \Omega \qquad R_2' = \frac{6\times 4 + 4\times 8 + 8\times 6}{4} = 26\ \Omega$$

$$R_3' = \frac{6\times 4 + 4\times 8 + 8\times 6}{6} = 17.3\ \Omega$$

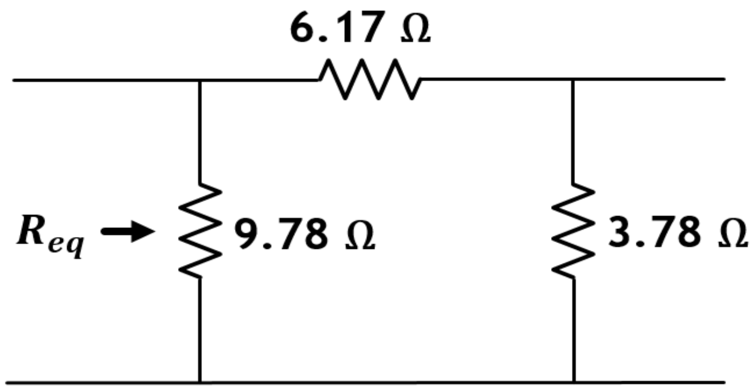
## ➢ Delta/Star and Star/Delta Transformation

### Solution of Example – P1.5

The simplified circuit is shown in figure below




The simplified circuit is shown in Fig. below




In the circuit, three resistors 10 Ω, 9.4 Ω and 17.3 Ω are in parallel.

Equivalent resistance = (10 ∥ 9.4 ∥ 17.3) = 3.78 Ω.

Resistors 13 Ω and 11.75 Ω are in parallel.

Equivalent resistance = (13 ∥ 11.75) = 6.17 Ω.

Resistors 26 Ω and 15.67 Ω are in parallel.

Equivalent resistance = (26 ∥ 15.67) = 9.78 Ω.

$$\therefore \text{The equivalent resistance } R_{eq} = \big(9.78 \parallel (6.17 + 5.78)\big)$$

$$= (9.78 \parallel 9.95) = 4.93\ \Omega$$

# LECTURE 4

# Fundamentals of Electric Circuits

## ➢ Sources

✓ **Definition**: The availability of electrical energy with network components called sources.

**Example:** Generators or alternators, that convert mechanical energy into electrical energy.
A battery that convert chemical energy into electrical energy.

**Sources**

**Independent Sources**

**1. Independent Voltage Source**

**2. Independent Current Source**

**Dependent Sources**

**1. Voltage- Controlled Voltage Source (VCVS)**

**2. Voltage- Controlled Current Source (VCVS)**

**3. Current- Controlled Voltage Source (CCVS)**

**4. Current- Controlled Current Source (CCCS)**

# Fundamentals of Electric Circuits

## ➢ Sources

- **Independent Source:** The sources which do not depend on any other quantity in the circuit are called independent sources.
  - ✓ **Independent Voltage Source**
    - A practical energy source such as battery in an automobile can maintain a voltage across its terminals which is relatively independent of the current required by the accessories under practical operating conditions.
    - The idealization of the device with a network component called an independent voltage source or more simply a voltage source.
    - The network symbol for the representation of an independent voltage source is shown in **Fig. 1.10.**

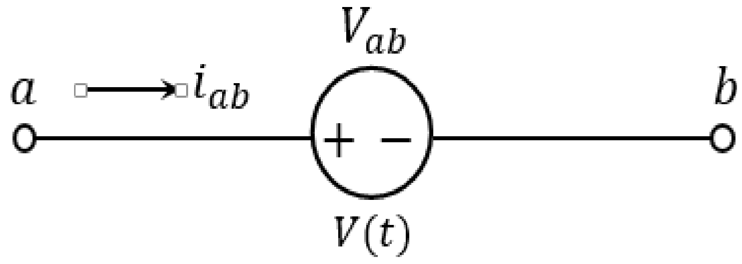



**Fig. 1.10.** Independent Voltage Source

The $(+)$ and $(-)$ marks inside the circle of the voltage source symbol identify the component as a voltage source.

# Fundamentals of Electric Circuits

## ➢ Sources

### ❖ Independent Source

#### ✓ Independent Voltage Source

- Independent voltage source equation or source equation is $V_{ab} = V(t)$
- The component equation is graphically depicted in **Fig. 1.11** for an independent voltage source with voltage $V_{ab} = 12\,V$ to emphasize that the terminal voltage is independent of the terminal current.

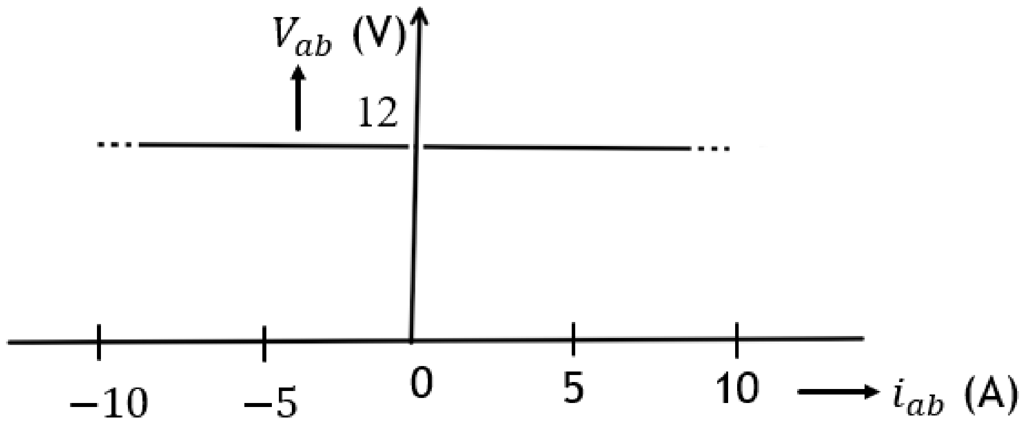



**Fig. 1.11.** Graphical representation of Independent Voltage Source

- It is observed from **Fig. 1.11** that current $i_{ab}$ has no effect on voltage $V_{ab}$.

# Fundamentals of Electric Circuits

- **Sources**
  - **Independent Source**
    - **Independent Voltage Source**
      - **<u>Definition</u>:** An independent voltage source is a two terminal network component with terminal voltage $V_{ab}$ specified by a time function $v(t)$ that is independent of the terminal current $i_{ab}$.
      - The definition of a voltage source represent that a short circuit can be considered to be a voltage source of value zero.
      - An independent voltage source can also be known as  an ideal voltage source.

# Fundamentals of Electric Circuits

## ➢ Sources

### ❖ Independent Source

#### ✓ Independent Current Source

- A few practical devices generate a current that is relatively independent of the terminal voltage over the normal range of operating voltage. The examples are as follows:
  1. A constant current transformer used to supply power to incandescent street light.
  2. An automobile alternator which provides relatively constant current under certain operating conditions.
- We idealize such a device with a network component called an independent current source, or more simply a current source.
- The network symbol used to represent an independent current source is shown in **Fig. 1.12**.

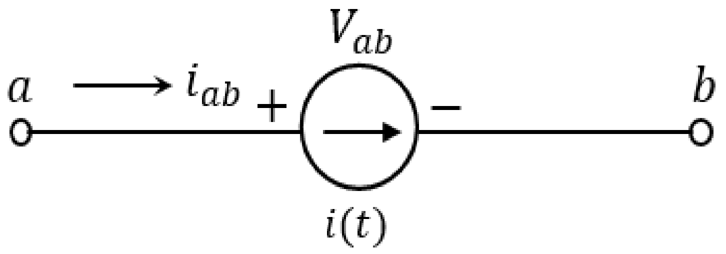



**Fig. 1.12.** Independent Current Source

The arrow inside the circle of the current source symbol identifies the component as a current source.

## ➢ Sources

### ❖ Independent Source

#### ✓ Independent Current Source

- An Independent current source equation or source equation is $i_{ab} = i(t)$
- The component equation is graphically depicted in **Fig. 1.13** for an independent current source with current $i_{ab} = 50\ A$ to emphasize that the terminal current is independent of the terminal voltage.

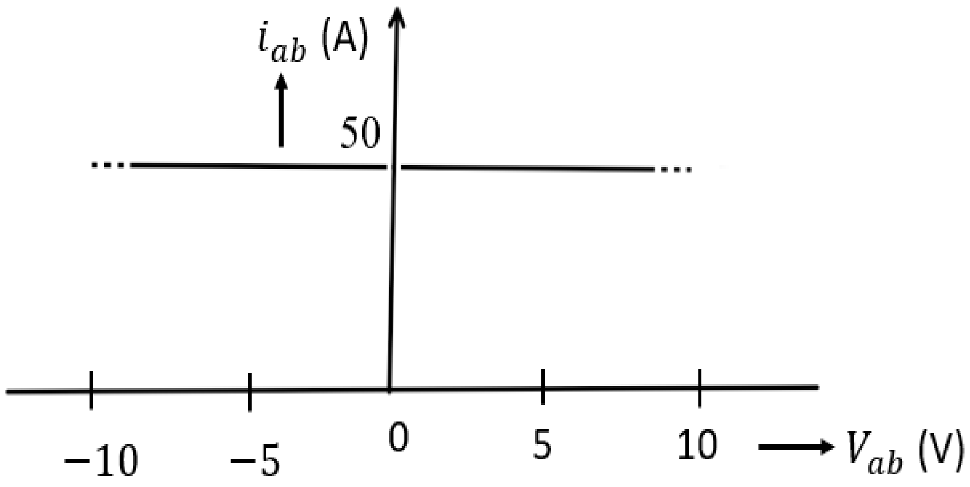



**Fig. 1.13.** Graphical representation of Independent Current Source

- It is observed from **Fig. 1.13** that voltage $V_{ab}$ has no effect on current $i_{ab}$.

# Fundamentals of Electric Circuits

## ➢ Sources

### ❖ Independent Source

#### ✓ Independent Current Source

- **Definition:** An independent current source is a two terminal network component with terminal current $i_{ab}$ specified by a time function $i(t)$ that is independent of the terminal voltage $V_{ab}$.
- The definition of a current source represent that an open circuit can be considered to be a current source of value zero
- An independent current source can also be known as  an ideal current source.

# Fundamentals of Electric Circuits

## ➢ Sources

### ❖ Dependent Source

- Many electrical systems take a small amount of electric power from one source and use this to control the delivery of a large amount of electric power from another source.
- The example of dependent source is an amplifier used in a tape player. The working principle of the amplifier is given below:

  i. The magnetized tape moving past the tape ahead, which consists of magnetic material and a small coil of wire, generates a very small voltage signal that delivers a small fraction of a watt to the amplifier.

  ii. This low power signal ultimately controls the delivery of tens of watts to the speaker system.

  iii. The power to the speaker is obtained from the amplifier power source: a car battery or an electrical outlet.

- The ability to control the delivery of power is modelled by the introduction of four terminal network components called dependent sources or controlled sources.

# Fundamentals of Electric Circuits

## ➢ Sources

### ❖ Dependent Source

#### ✓ Voltage- Controlled Voltage Source (VCVS)

- A tape player amplifier is an example of voltage-controlled voltage source. The amplifier generate a large voltage across two terminals that is intended to be proportional to a smaller voltage established across other two terminals.
- A practical voltage amplifier is idealized with a four terminal network component called a voltage controlled voltage source (VCVS).
- The network symbol as shown in **Fig. 1.14** is used to represent a VCVS.

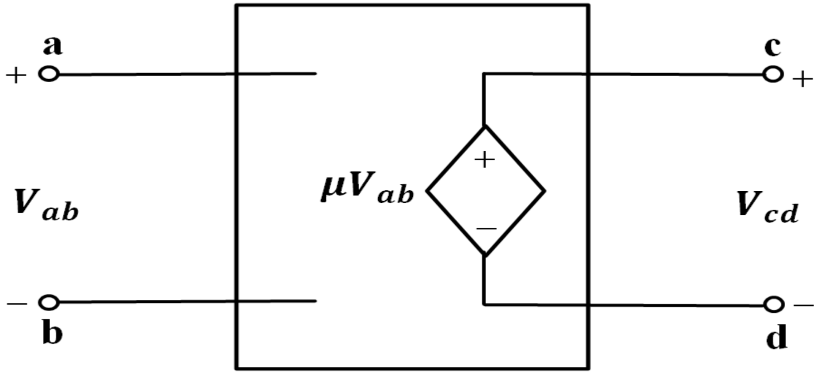



**Fig. 1.14.** Voltage- Controlled Voltage Source

The (+) and (−) marks inside the diamond of the component symbol identify the component as a voltage source.

# Fundamentals of Electric Circuits

## ➢ Sources

### ❖ Dependent Source

#### ✓ Voltage- Controlled Voltage Source (VCVS)

- An equivalent definition is given by the following component equation or control equation.

  **Control Equation:** $V_{cd} = \mu V_{ab}$

- It is observed that voltage $V_{cd}$ depends only on the constant $\mu$, a dimensionless constant called the voltage gain and the control voltage $V_{ab}$.
- Current $i_{cd}$ can affect voltage $V_{cd}$ only if it affects $V_{ab}$voltage.
- **Definition:** A voltage controlled voltage source is a four-terminal network component that establishes a voltage $V_{cd}$ between two points $c$ and $d$ in the circuit that is proportional to a voltage $V_{ab}$ between two points $a$ and $b$.

# Fundamentals of Electric Circuits

- **Sources**

  - **Dependent Source**

    - ✓ **Voltage- Controlled Voltage Source (VCVS)**

## Example of VCVS

Determine voltage $V_2$ in the circuit as shown in **Fig. 1.15**

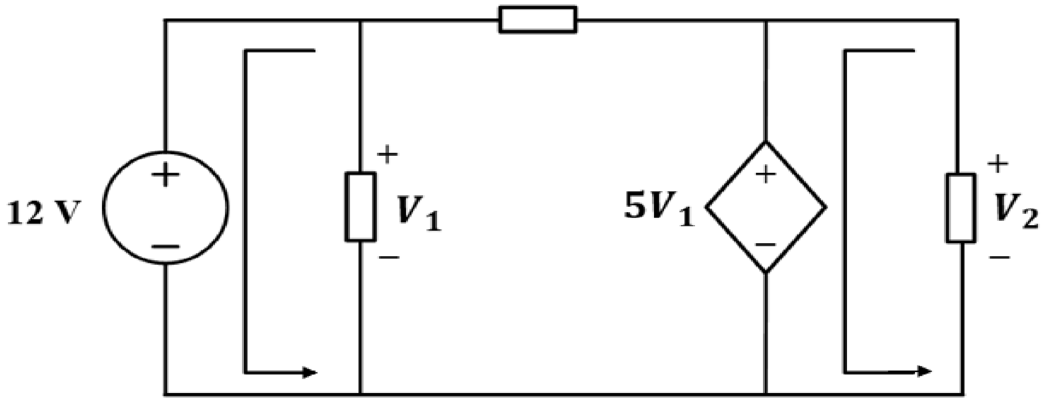



**Fig. 1.15.** Test figure of Voltage- Controlled Voltage Source

## Solution for Example of VCVS

Kirchhoff's voltage law easily established that $V_1 = 12\ V$

$$\therefore\ V_2 = 5\ V_1 = 5 \times 12\ V = 60\ V$$

# Fundamentals of Electric Circuits

## ➢ Sources

### ❖ Dependent Source

#### ✓ Voltage- Controlled Current Source (VCCS)

- The field-effect transistor is an example of voltage-controlled current source. This electronic device permit the control of a current directly with a voltage.
- The device is idealized with a four terminal network component called a voltage-controlled current source (VCCS).
- The network symbol as shown in **Fig. 1.16** is used to represent a VCCS.

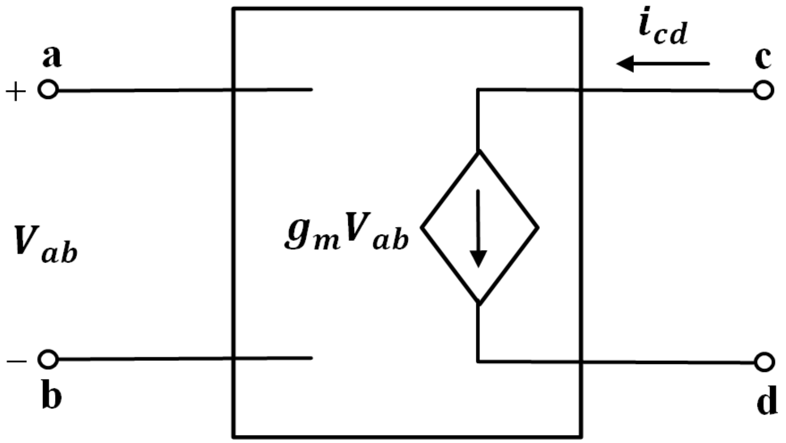



**Fig. 1.16.** Voltage- Controlled Current Source

The arrow inside the diamond of the component symbol identifies the component as a current source.

# Fundamentals of Electric Circuits

- **Sources**

  - **Dependent Source**

    - ✓ **Voltage- Controlled Current Source (VCCS)**

      - An equivalent definition is given by the following component equation or control equation.

        **Control Equation:** $i_{cd} = g_m V_{ab}$

      - It is observed that current $i_{cd}$ depends only on the control voltage $V_{ab}$ and the constant $g_m$, called the transconductance or mutual conductance.

      - Constant $g_m$ has dimension of ampere per volt or Siemens (S).

      - **Definition:** A voltage-controlled current source is a four-terminal network component that establishes a current $i_{cd}$ in a branch of the circuit that is proportional to the voltage $V_{ab}$ between two points $a$ and $b$.

# Fundamentals of Electric Circuits

## ➢ Sources

### ❖ Dependent Source

#### ✓ Voltage- Controlled Current Source (VCCS)

#### ❑ Example of VCCS

Determine the current $i_x$ in the circuit as shown in **Fig. 1.17**

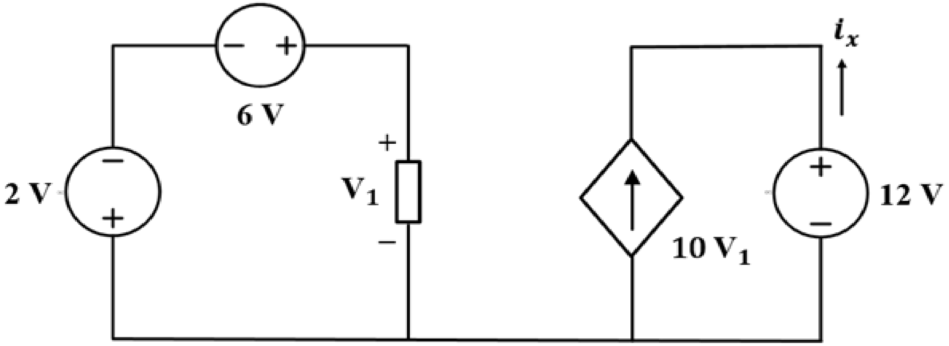



**Fig. 1.17.** Test figure of Voltage- Controlled Current Source

### Solution for Example of VCCS

$$V_1 = 6 - 2 = 4\ V$$

$$\therefore i_x = -10V_1 = -(10 \times 4) = -40\ A$$

# Fundamentals of Electric Circuits

## ➢ Sources

### ❖ Dependent Source

#### ✓ Current- Controlled Voltage Source (CCVS)

- The resistor is an example of current-controlled voltage source. This device permits the control of voltage across one branch with current through another branch in the circuit.
- The device is idealized with a four terminal network component called a current-controlled voltage source (CCVS).
- The network symbol as shown in **Fig. 1.18** is used to represent a CCVS.

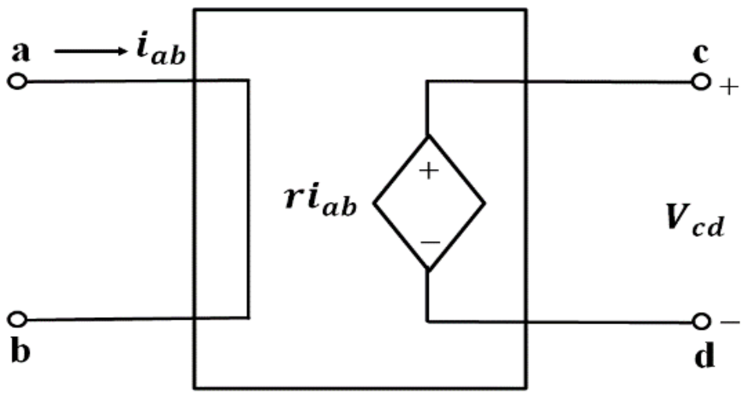



**Fig. 1.18.** Current- Controlled Voltage Source

The (+) and (−) marks inside the diamond of the component symbol identify the component as a voltage source.

# Fundamentals of Electric Circuits

- **Sources**

  - **Dependent Source**

    - ✓ **Current-Controlled Voltage Source (VCCS)**

      - An equivalent definition is given by the following component equation or control equation.

        **Control Equation:** $V_{cd} = r\, i_{ab}$

      - It is observed that voltage $V_{cd}$ depends only on the control current $i_{ab}$ and the constant $r$, called the transresistance or mutual resistance.

      - Constant $r$ has the dimension of volt per ampere or ohm (Ω).

      - **Definition**: A current-controlled voltage source is a four-terminal network component that establishes a voltage $V_{cd}$ between two points $c$ and $d$ in the circuit that is proportional to current $i_{ab}$ in some branch of the circuit.

# Fundamentals of Electric Circuits

## ➢ Sources

### ❖ Dependent Source

#### ✓ Current- Controlled Voltage Source (CCVS)

#### ❑ Example of CCVS

Determine voltage $V_2$ in the circuit as shown in **Fig. 1.19.**

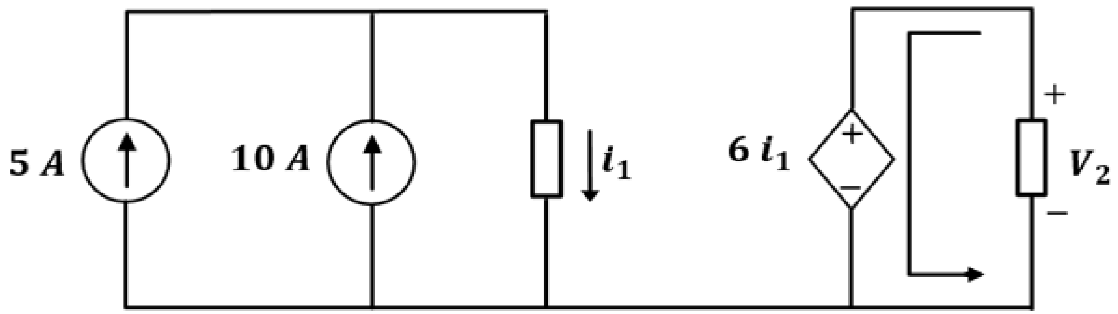



**Fig. 1.19.** Test figure of Current-Controlled Voltage Source

#### Solution for Example of CCVS

$$i_1 = 15\ A$$

$$\therefore V_2 = 6\ i_1 = (6 \times 15)\ V = 90\ V$$

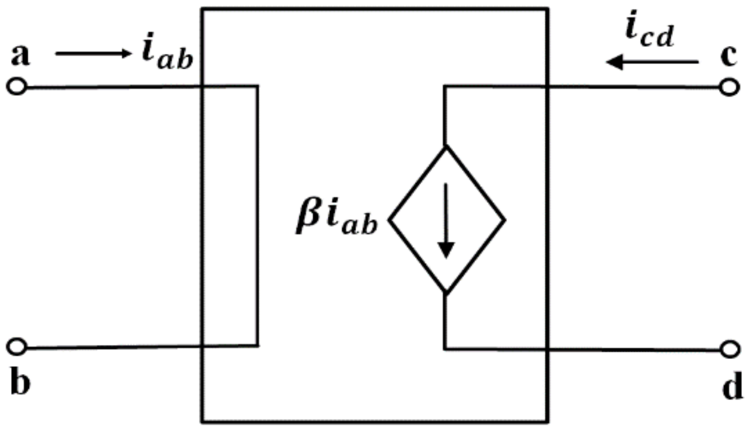
# Fundamentals of Electric Circuits

## ➢ Sources

### ❖ Dependent Source

#### ✓ Current- Controlled Current Source (CCCS)

- The bipolar junction transistor is an example of current-controlled current source. This device permits the control of one current with another
- The device is idealized with a four terminal network component called a current-controlled current source (CCCS).
- The network symbol as shown in **Fig. 1.20** is used to represent a CCCS.




The arrow inside the diamond of the component equation identifies the component as a current source.

**Fig. 1.20.** Current- Controlled Current Source

# Fundamentals of Electric Circuits

- **Sources**

  - **Dependent Source**

    - **Current-Controlled Current Source (CCCS)**

      - An equivalent definition is given by the following component equation or control equation.

        **Control Equation:** $i_{cd} = \beta \, i_{ab}$

      - It is observed that current $i_{cd}$ depends only on the control current $i_{ab}$ and the dimensionless $\beta$, called the current gain.

      - **Definition:** A current-controlled current source is a four-terminal network component that establishes a current $i_{cd}$ in one branch of a circuit that is proportional to current $i_{ab}$ in some branch of the network.

- **Sources**
  - **Dependent Source**
    - ✓ **Current- Controlled Current Source (CCCS)**

## ❑ Example of CCCS

Determine current $i_2$ in the circuit as shown in **Fig. 1.21.**

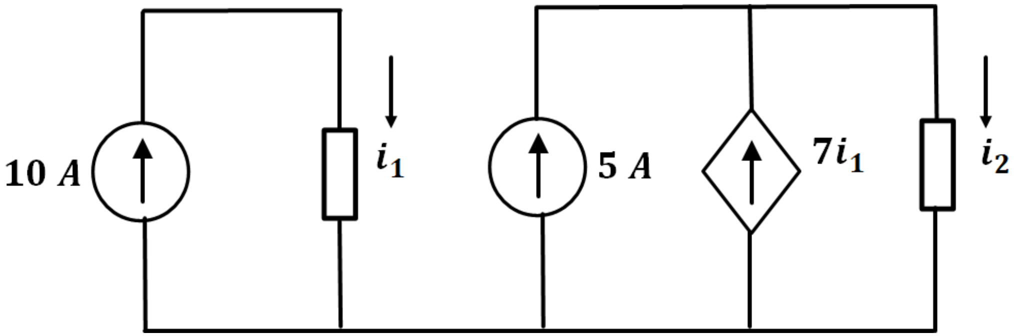



**Fig. 1.21.** Test figure of Current-Controlled Current Source

## Solution for Example of CCCS

$$i_1 = 10\ A$$

$$\therefore\ i_2 = 5 + 7i_1 = 5 + (7 \times 10)\ A = 75\ A$$

# Fundamentals of Electric Circuits

## ➢ Equivalence of voltage and current sources

- The equivalence of voltage and current sources is shown in **Fig. 1.22**.

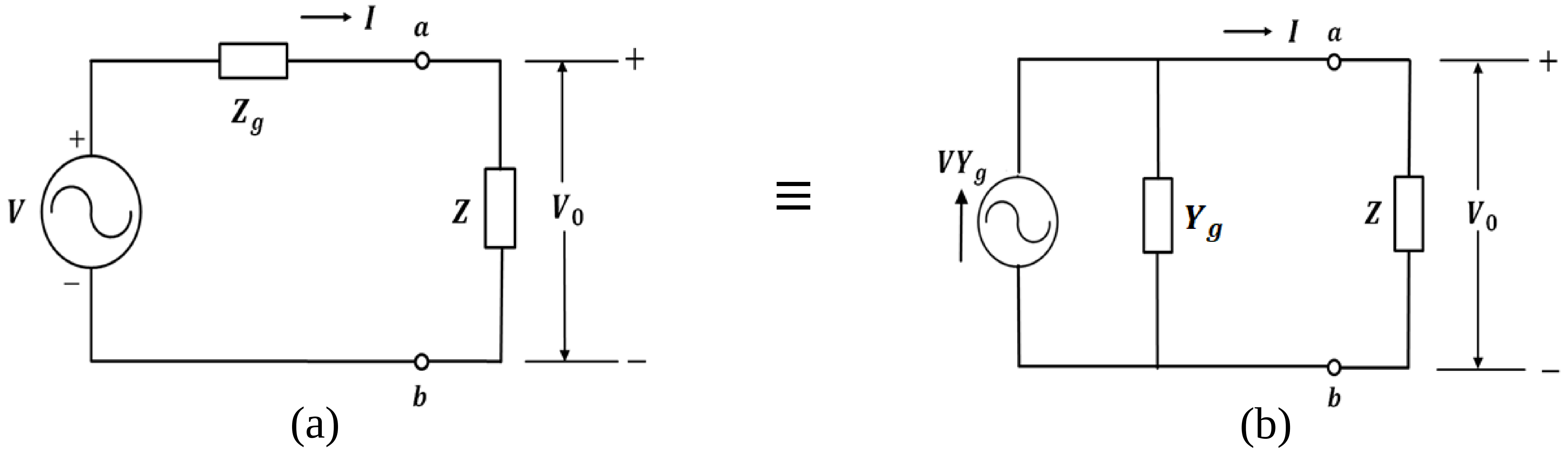



**Fig. 1.22.** Equivalence of Voltage and Current Sources

- In **Fig. 1.22(a),** a voltage source, $V$ in series with an impedance, $Z_g$ supplies a current $I$ to a load impedance $Z$.
- $Z_g$ represent the internal impedance of the source.

# Fundamentals of Electric Circuits

## ➢ Equivalence of voltage and current sources

- The phasor equation for the load voltage is

$$V_0 = V - IZ_g \longrightarrow (1)$$

$$\therefore\ I = \frac{V}{Z_g} - \frac{V_0}{Z_g} = VY_g - V_0Y_g \longrightarrow (2)$$

where $Y_g = 1/Z_g$.

- The circuit in **Fig. 1.22(b)** represents Eq. (2). Here, $VY_g$ is the current delivered by the voltage source when the terminals ab are short-circuited.
- The circuits shown in **Fig. 1.22(a) & (b)** are equivalent so far as the current through the load impedance $Z$ is concerned.
- The mutual conversion of voltage & current sources is positive when $Z_g$ is finite other than zero.

## ➢ Equivalence of voltage and current sources

**Example – P1.6**

Determine $i_1$, $v_1$, $i_x$, $v_x$ and $v_{ab}$ for the network as shown in **Fig. P1.6**, if no other components are connected to terminals $a$ and $b$.

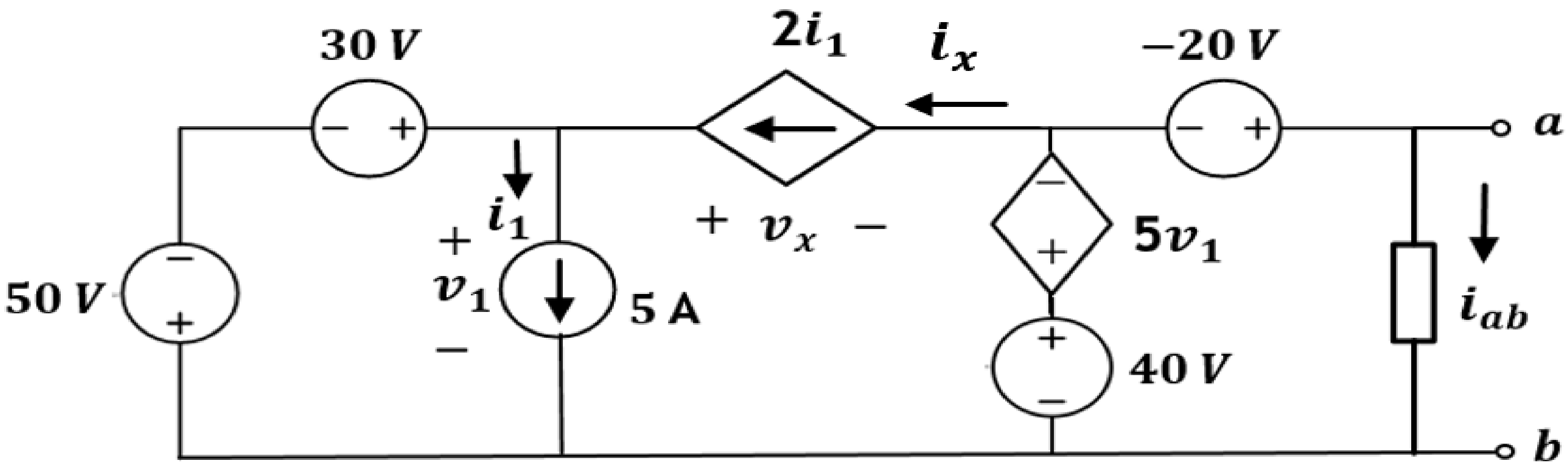



**Fig. P1.6**

# Fundamentals of Electric Circuits

## ➢ Equivalence of voltage and current sources

### Solution of Example – P1.6

$$i_1 = 5\ A$$

$$v_1 = 30 - 50 = -20\ V$$

$$i_x = 2i_1 = 2 \times 5\ A = 10\ A$$

$$v_x = v_1 - 40 + 5v_1 = (-20 - 40 - 100)V = -160\ V$$

$$v_{ab} = (-20) - 5v_1 + 40 = (-20 + 100 + 40)V = 120\ V$$

- Independent and Dependent Sources are active components.
- The source which cannot supply positive average power, these are passive components.
- A network that contains one or more active components is an active network.
- A passive network contains only passive components.
- Some physical devices convert electrical energy into heat or store energy in electric or magnetic fields. We model the properties of the devices with network components called elements.

## ➢ Equivalence of voltage and current sources

**Example – P1.7**

Find $i$ in the circuit of **Fig. P1.7**. Check the power balance condition.

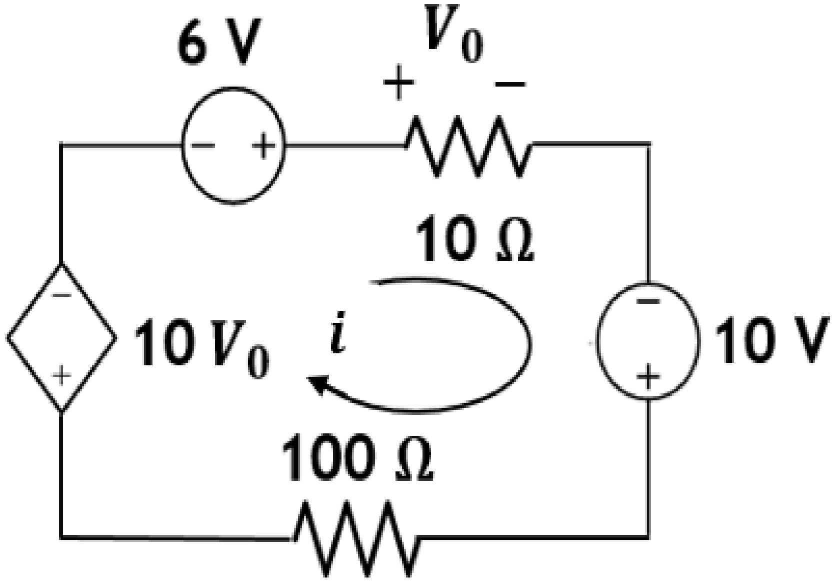



**Fig. P1.7**

# Fundamentals of Electric Circuits

## ➢ Equivalence of voltage and current sources

### Solution of Example – P1.7

Applying KVL in the given loop

$$10\,V_0 - 6 + V_0 - 10 + 100\,i = 0$$

$$11\,V_0 - 16 + 100\,i = 0$$

$$100\,i = 16 - 11\,V_0$$

$$100\,i = 16 - 11(10\,i) \quad [\because\; V_0 = 10\,i\,]$$

$$100\,i = 16 - 110\,i$$

$$\therefore\; i = \frac{16}{210} = 76.2\,mA$$

The dependent source offers a terminal voltage of $10\,V_0$ = $10\,(10\,i) = 7.62\,V$

In the circuit, power is supplied by 6 V and 10 V source while power is absorbed by 110 Ω resistor (dissipating heat) and the dependent source.

# Fundamentals of Electric Circuits

## ➢ Equivalence of voltage and current sources

### Solution of Example – P1.7

Thus power supplied by 6 V source $= 6 \times 0.0762\ W = 0.4572\ W$

Power supplied by 10 V source $= 10 \times 0.0762\ W = 0.762\ W$

$$\therefore \text{Total power supplied} = (0.4572 + 0.762)W = 1.219\ W \approx 1.22\ W$$

Power absorbed by the dependent source is $(7.62 \times 0.0762)W = 0.5806\ W$ and

power absorbed by the 110 Ω resistance is 110$\times\ (0.0762)^2 = 0.6387\ W$

$$\therefore \text{Total power absorbed} = (0.5806 + 0.6387)W \approx 1.22\ W$$

Thus, the total power balance is maintained.

## ➢ Analysis of simple circuits−Mesh Method

**Example – P1.8**

Find the loop currents $I_1, I_2$ and $I_3$ of the circuit in **Fig. P1.8** by mesh method.

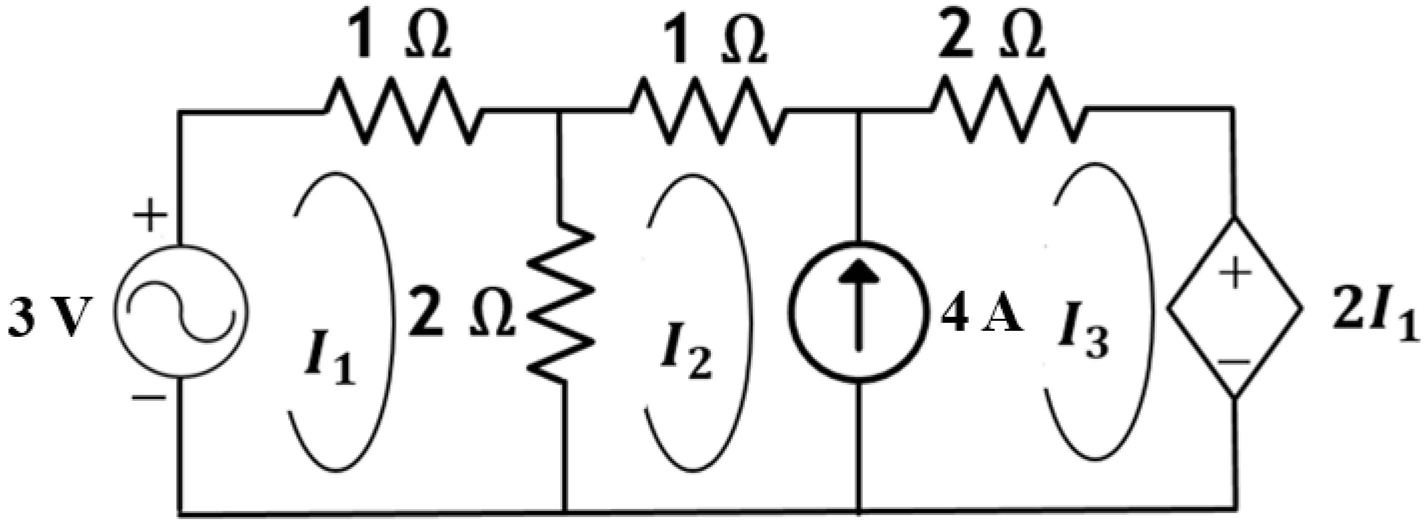



**Fig. P1.8**

# Fundamentals of Electric Circuits

## ➢ Analysis of simple circuits−Mesh Method

### Solution of Example – P1.8

In loop 1, mesh analysis gives

$$I_1 \times 1 + (I_1 - I_2) \times 2 - 3 = 0$$

or, $3I_1 - 2I_2 = 3 \longrightarrow (1)$

In loop 2, mesh analysis gives

$$2 \times (I_2 - I_1) + I_2 \times 1 + v = 0$$

or, $3I_2 - 2I_1 + v = 0 \longrightarrow (2)$

In loop 3, mesh analysis gives

$$v = 2I_3 + 2I_1 \longrightarrow (3)$$

From loop 3, we also get

$$I_3 - I_2 = 4 \longrightarrow (4)$$

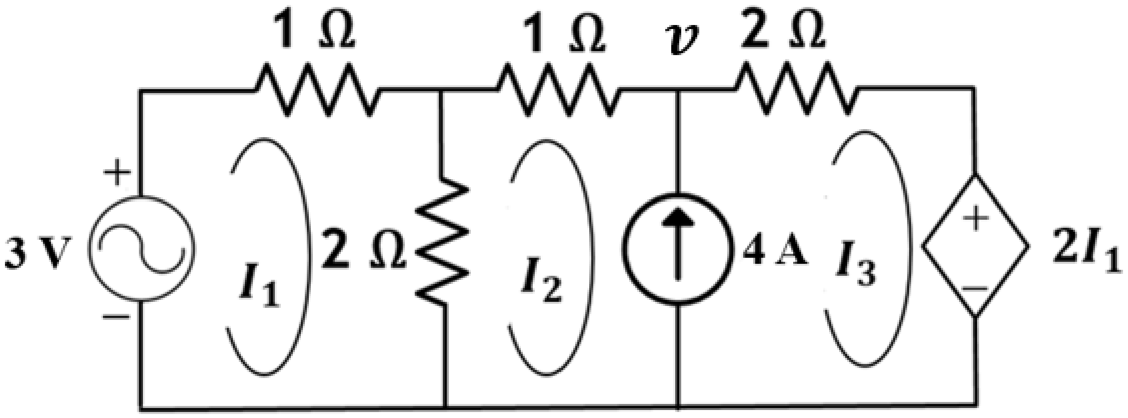



**Fig. P1.8**

Answer

$$I_1 = -\frac{1}{17}\ Amp = -0.0588\ Amp$$

$$I_2 = -\frac{27}{17}\ Amp = -1.588\ Amp$$

$$I_3 = \frac{41}{17}\ Amp = 2.412\ Amp$$


Thank you