ATME COLLEGE OF ENGINEERING

13th KM Stone, Bannur Road, Mysore - 560 028

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

(ACADEMIC YEAR 2022-23)

COURSE: Elements of Electrical Engineering

SUB CODE: BEEE203

SEMESTER: II

Vision & Mission of ATME College of Engineering

Vision

Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources.

Mission

- To keep pace with advancements in knowledge and make the students competitive and capable at the global level.
- To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torchbearers of tomorrow's society.
- To strive to attain ever-higher benchmarks of educational excellence.

Vision & Mission of Department of Electrical & Electronics Engineering

Vision of the department

To create Electrical and Electronics Engineers who excel to be technically competent and fulfill the cultural and social aspirations of the society.

Mission of the Department

- To provide knowledge to students that builds a strong foundation in the basic principles of electrical engineering, problem solving abilities, analytical skills, soft skills and communication skills for their overall development.
- To offer outcome based technical education.
- To encourage faculty in training & development and to offer consultancy through research & industry interaction.

PROGRAMME EDUCATIONAL OBJECTIVES AND PROGRAMME OUTCOMES

PROGRAMME OUTCOMES:

Engineering Graduates will be able to:

PO1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of EXPERIMENTs, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO12. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

MODULE 1: D.C CIRCUITS

1.1 Introduction

In practice, the electrical circuits may consist of one or more sources of energy and number of electrical parameters, connected in different ways. The different electrical parameters or elements are resistors, capacitors and inductors. The combination of such elements along with various sources of energy gives rise to complicated electrical circuits, generally referred as networks. The terms circuit and network are used synonymously in the electrical literature. The d.c. circuits consist of only resistances and d.c. sources of energy. And the circuit analysis means to find a current through or voltage across any branch of the circuit.

1.2 Network Terminology

In this section, we shall define some of the basic terms which are commonly associated with a network

1.2.1 Network

Any arrangement of the various electrical energy sources along with the different circuit elements is called an **electrical network**. Such a network is shown in the Fig. 1.1.

1.2.2 Network Element

Any individual circuit element with two terminals which can be connected to other circuit element is called a **network element.**

Network elements can be either active elements or passive elements. **Active elements** are the elements which supply power or energy to the network. Voltage source and current source are the examples of active elements. **Passive elements** are the elements which either store energy or dissipate energy in the form of heat. Resistor, inductor and capacitor are the three basic passive elements. Inductors and capacitors can store energy and resistors dissipate energy in the form of heat.

1.2.3 Branch

A part of the network which connects the various points of the network with one another is called a **branch**. In the Fig. 1.1, AB, BC, CD, DA, DE, CF and EF are the various branches. A branch may consist more than one element.

1.2.4 Junction Point

A point where three or more branches meet is called a **junction point**. Point D and C are the junction points in the network shown in the Fig. 1.1.

1.2.5 Node

A point at which two or more elements are joined together is called **node**. The junction points are also the nodes of the network. In the network shown in the Fig. 1.1, A, B, C, D, E and F are the nodes of the network.

1.2.6 Mesh (or Loop)

Mesh (or Loop) is a set of branches forming a closed path in a network in such a way that if one branch is removed then remaining branches do not form a closed path. A loop also can be defined as a closed path which originates from a particular node, terminating at the same node, travelling through various other nodes, without travelling through any node twice, In the Fig. 1.1 paths A-B-C-D-A, A-B-C-F-ED-A, D-C-F-E-D etc. are the loops of the network.

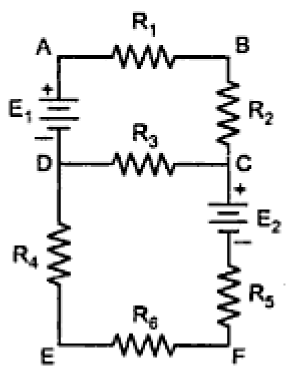


Fig 1.1 An electrical network

1.3 Energy Sources

There are basically two types of energy sources; voltage source and current source. These are classified as i) Ideal source and ii) Practical source.

Let us see the difference between ideal and practical sources.

1.3.1 Voltage Source

Ideal voltage source is defined as the energy source which gives constant voltage across its terminals irrespective of the current drawn through its terminals. The symbol for ideal voltage source is shown in the Fig. 1.2 (a). This is connected to the load as shown In Fig. 1.2 (b). At any time the value of voltage at load terminals remains same. This is indicated by V-I characteristics shown in the Fig. 1.2 (c).

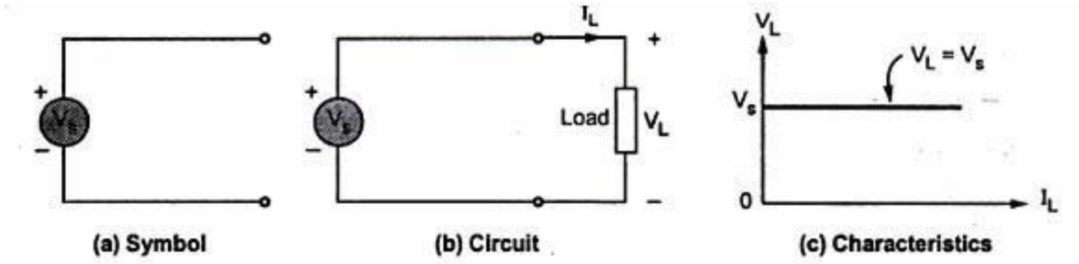


Fig 1.2 Ideal Voltage source

1.3.2 Practical voltage source:

But practically, every voltage source has small internal resistance shown in series with voltage source and is represented by R_{se} as shown in the Fig. 1.3.

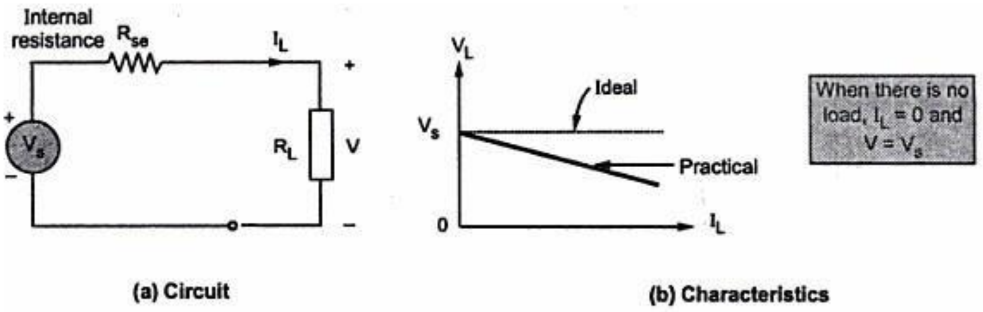


Fig 1.3 Practical Voltage Source

Because of the R_{se}, voltage across terminals decreases slightly with increase in current and it is given by expression.

$$\boxed{V_L = -(R_{sc})\, I_L + V_S = V_S - I_L R_{se}}$$

1.3.2 Current Source

Ideal current source is the source which gives constant current at its terminals irrespective of the voltage appearing across its terminals. The symbol for ideal current source is shown in the Fig. 1.4 (a). This is connected to the load as shown In the Fig. 1.4 (b). At any time, the value of the current flowing through load I_L, is same i.e. is irrespective of voltage appearing across its terminals. This is explained by V-I characteristics shown in the Fig. 1.4(c).

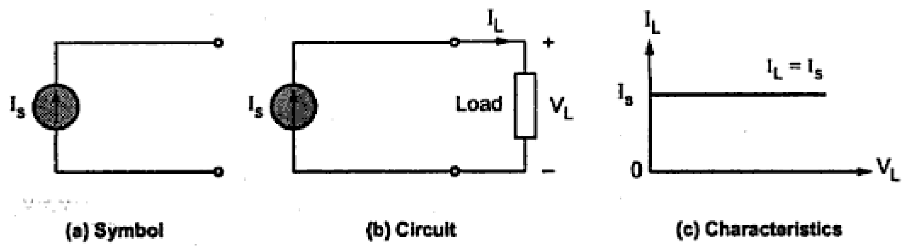


Fig 1.4 Ideal current source

But practically, every current source has high internal resistance, shown in parallel with current source and it is represented by R_{sh}. This is shown in the Fig. 1.5.

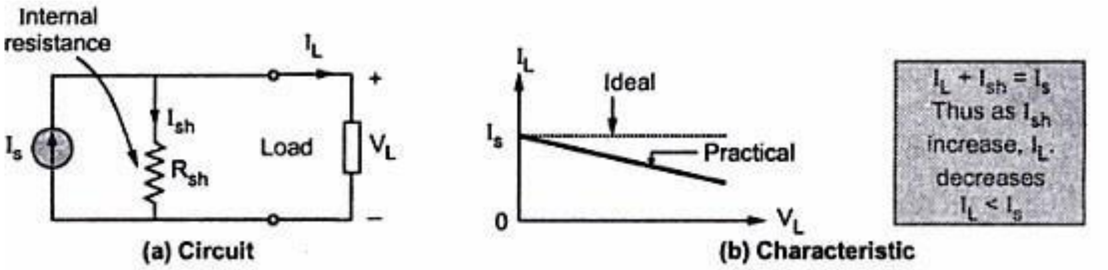


Fig 1.5 Practical Current source

1.4 Ohm's Law

This law gives relationship between the potential differences (V), the current (I) and the resistance (R) of a d.c. circuit. Dr. Ohm in 1827 discovered a law called Ohm's Law. It states,

Ohm's Law: *The current flowing through the electric circuit is directly proportional to the potential difference across the circuit and inversely proportional to the resistance of the circuit, provided the temperature remains constant.*

$$\boxed{I \propto \frac{V}{R}}$$

Where I is the current flowing in amperes, the V is the voltage applied and R is the resistance of the conductor, as shown In the Fig. 1.6,

Now $I = \frac{V}{R}$

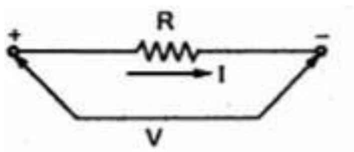


Fig 1.6 ohm`s law

The unit of potential difference is defined in such a way that the constant of proportionality is unity.

Ohm's Law is,	$I = \frac{V}{R}$	amperes
	$V = IR$	volts
	$\frac{V}{I}$ = constant = R	ohms

The Ohm's law can be defined as,

The ratio of potential difference (V) between any two points of a conductor to the current (I) flowing between them is constant, provided that the temperature of the conductor remains constant.

Key Point: *Ohm's Law can be applied either to the entire circuit or to the part of a circuit. If it is applied to entire circuit, the voltage across the entire circuit and resistance of the entire circuit should be taken into account. If the Ohm's Law is applied to the part of a circuit, then the resistance of that part and potential across that part should be used.*

1.4.1 Limitations of Ohm's Law

The limitations of the Ohms law are,

1. It is not applicable to the nonlinear devices such as diodes, zener diodes, voltage regulators etc.
2. It does not hold good for non-metallic conductors such as silicon carbide. The Law for such conductors is given by,

$V = k\, I^m$ where k, m are constants

1.5 Series Circuit

A series circuit is one in which several resistances are connected one after the other. Such connection is also called end to end connection or cascade connection. There is only one path for the flow of current.

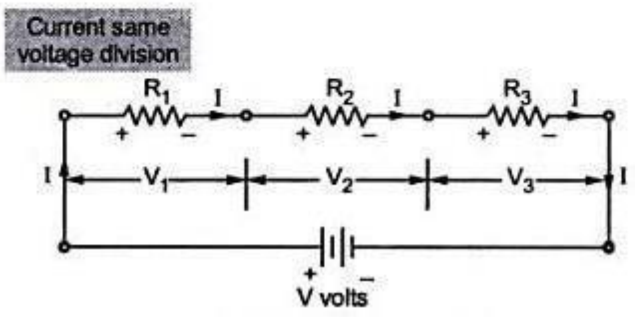


Fig 1.7 Series circuit

Consider the resistances shown in the Fig. 1.7

The resistance R1, R2 and R3 are said to be in series. The combination is connected across a source of voltage V volts. Naturally the current flowing through all of them is same indicated as I amperes. E.g. the chain of small lights, used for the decoration is good example of series combination.

Now let us study the voltage distribution.

Let V_1, V_2 and V_3 be the voltages across the terminals of resistances R_1, $R_2$and R_3 respectively.

Then, $$V = V_1 + V_2 + V_3$$

Now according to ohm`s law $V_1 = IR_1$, $V_2=IR_2$ $V_3 = IR_3$

Current through all of them is same as I

Therefore, $$V = IR_1 + IR_2 + IR_3 = I (R_1 + R_2 + R_3)$$

Applying ohm`s law to the overall circuit

$$V = I R_{eq}$$

Where R_{eq} = equivalent resistance of the circuit. By comparing of two equation

$$\mathbf{R_{eq} = R_1 + R_2 + R_3}$$

I.e. total or equivalent resistance of series circuit is the arithmetic sum of resistance connected in series.

1.5.1 Characteristics of Series Circuits

1. The same current flows through each resistance.
2. The supply voltage V is the sum of the individual voltage drops across the resistances.

$$V = V_1+V_2+\ldots ....+V_n$$

3. The equivalent resistance is equal to the sum of the individual resistances.
4. The equivalent resistance is the largest of all the individual resistances.

i.e $R > R_1$, $R>R_2$, $R>R_n$

1.6 Parallel Circuit

The parallel circuit is one in which several resistances are connected across one another in such a way that one terminal of each is connected to form a junction point while the remaining ends are also joined to form another junction point.

Consider a parallel circuit shown in the Fig. 1.8.

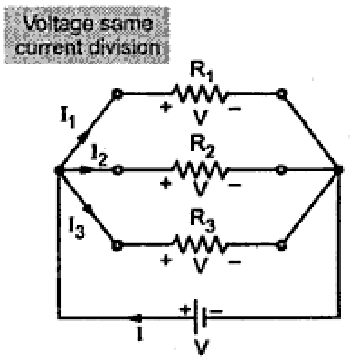


Fig 1.8 Parallel circuit

In the parallel connection shown, the three resistances R_1, R_2 and $R_3$are connected in parallel and combination is connected across a source of voltage 'V'.

In parallel circuit current passing through each resistance is different. Let total current drawn is say 'I' as shown. There are 3 paths for this current, one through R_1, second through R_2 and third through R_3. Depending upon the values of R_1 , R_2 and R_3 the appropriate fraction of total current passes through them. These individual currents are shown as I_1 , I_2 and I_3. While the voltage across the two ends of each resistances R_1 , R_2 and R_3 is the same and equals the supplyvoltage V.

Now let us study current distribution. Apply Ohm's law to each resistance.

$$V = I_1R_1, \quad V=I_2R_2 , \quad V = I_3R_3$$

$$I_1 = \frac{V}{R_1}, \quad I_2 = \frac{V}{R_2}, \quad I_3= \frac{V}{R_3}$$

$$I = I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$I = V \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

For the overall circuit if ohm`s is applied,

$$V = I\, R_{eq}$$

And $$I = \frac{V}{R_{eq}}$$

Where R_{eq} = equivalent resistance of the circuit. By comparing of two equation

$$\frac{1}{\mathbf{R_{eq}}} = \frac{1}{\mathbf{R_1}} + \frac{1}{\mathbf{R_2}} + \frac{1}{\mathbf{R_3}}$$

In general if n resistors are connected in parallel

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

Now if n=2, two resistance are in parallel then

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

1.6.1 Characteristics of Parallel Circuits

1. The same potential difference gets across all the resistances in parallel.
2. The total current gets divided into the number of paths equal to the number of resistances in parallel. The total current is always sum of all the individual currents.

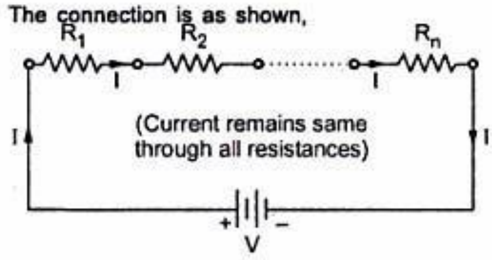
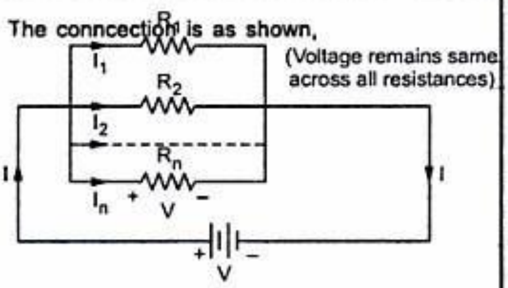
$$I = I_1 + I_2 + I_3 + \ldots + I_n$$

3. The reciprocal of the equivalent resistance of a parallel circuit is equal to the sum of the reciprocal of the individual resistances.
4. The equivalent resistance is the smallest of all the resistances.

   i.e $R < R_1$, $R < R_2$, ... $R < R_n$

5. The equivalent conductance is the arithmetic addition of the individual conductance.

1.7 Comparison of Series and Parallel Circuits

Sr. No.	Series Circuit	Parallel Circuit
1.	The connection is as shown, 	The conncection is as shown, 
2.	The same current flows through each resistance.	The same voltage exists across all the resistances in parallel.
3.	The voltage across each resistance is different.	The current through each resistance is different.
4.	The sum of the voltages across all the resistances is the supply voltage. $V = V_1 + V_2 + V_3 + ... + V_n$	The sum of the currents through all the resistances is the supply current. $I = I_1 + I_2 + ... I_n$
5.	The equivalent resistance is, $R_{eq} = R_1 + R_2 + ... + R_n$	The equivalent resistance is, $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}$
6.	The equivalent resistance is the largest than each of the resistances in series. $R_{eq} > R_1, R_{eq} > R_2 ...... R_{eq} > R_n$	The equivalent resistance is the smaller than the smallest of all the resistances in parallel.

1.8 Voltage Division in Series Circuit of Resistors

Consider a series circuit of two resistors R_1 and R_2 connected to source of V volts. As two resistors are connected in series, the current flowing through both the resistors is same, i.e. I. Then applying KVL, we get,

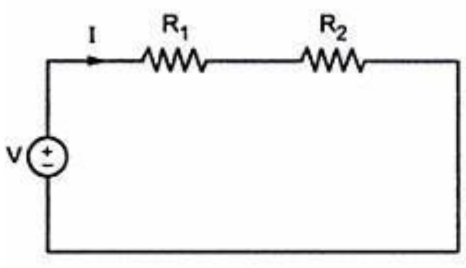


Fig 1.9

$$V = IR_1 + IR_2$$

$$I = \frac{V}{R_1 + R_2}$$

Total voltage applied is equal to the sum of voltage drops V_{R_1} and V_{R_2} across R_1 and R_2 respectively.

Therefore, $V_{R1} = IR_1$

$$\boxed{V_{R1} = \frac{V}{R_1 + R_2} \cdot R_1 = \left[\frac{R_1}{R_1 + R_2}\right] V}$$

$V_{R_2} = IR_2$

$$\boxed{V_{R2} = \frac{V}{R_1 + R_2} \cdot R_2 = \left[\frac{R_2}{R_1 + R_2}\right] V}$$

So in general, voltage drop across any resistors or combination of resistors in a series circuit is equal to the ratio of that resistance value, to the total resistance multiplied by the source voltage

1.9 Current Division in Parallel Circuit of Resistors

Consider a parallel circuit of two resistors R_1 and R_2 connected across a source of V volts. Current through R_1 is I_1 and R_2 is I_2, while total current drawn from source is I_T.

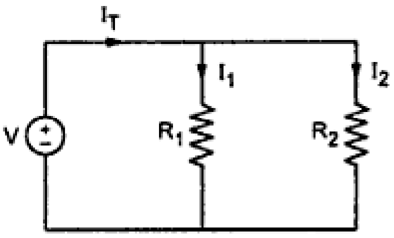


Fig 1.10

$$I_T = I_1 + I_2$$

$$I_1 = \frac{V}{R_1}, \qquad I_2 = \frac{V}{R_2},$$

$$V = I_1 R_1 = I_2 R_2$$

$$I_1 = I_2 \left(\frac{R_2}{R_1}\right)$$

Substituting the value of I_1 in I_T

$$I_T = I_2 \left(\frac{R_2}{R_1}\right) + I_2 = I_2 \left(\frac{R_2}{R_1} + 1\right) = I_2 \left(\frac{R_1 + R_2}{R_1}\right)$$

$$\mathbf{I_2} = \left[\frac{\mathbf{R_1}}{\mathbf{R_1+R_2}}\right] \mathbf{I_T}$$

Now, $$I_1 = I_T - I_2 = I_T - \left[\frac{R_1}{R_1+R_2}\right] I_T$$

$$I_1 = \left[\frac{R_1+R_2- R_1}{R_1+R_2}\right] I_T$$

$$\mathbf{I_1} = \left[\frac{\mathbf{R_2}}{\mathbf{R_1+R_2}}\right] \mathbf{I_T}$$

In general, the current in any branch is equal to the ratio of opposite branch to the total resistance value, multiplied by the total current in the circuit.

1.10 Kirchhoff`s Laws

In 1847, a German Physicist, Kirchhoff, formulated two fundamental laws of electricity. These laws are of tremendous importance from network simplification point of view.

1.10.1 Kirchhoff's Current Law (KCL)

Consider a junction point in a complex network as shown in the Fig. 1.11**.**

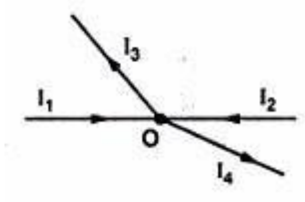


Fig 1.11 Junction point

The total current flowing towards a junction point is equal to the total current flowing away from that junction point.

Another way to state the law is,

The algebraic sum of all the current meeting at a junction point is always zero.

The word algebraic means considering the signs of various currents.

$$\sum I \text{ at junction pont} = 0$$

Sign convention: Currents flowing towards a junction point are assumed to be positive while currents flowing away from a junction point assumed to be negative.

Referring to figure 1.11, I_1 and I_2 are positive and I_3 and I_4 are negative

Applying KCL, $\sum$ I at junction pont =0

$I_1 + I_2 - I_3 - I_4 = 0$

Or $I_1 + I_2 = I_3 + I_4$

1.10.2 Kirchhoff's Voltage Law (KVL)

"In any network, the algebraic sum of the voltage drops across the circuit elements of any closed path (or loop or mesh) is equal to the algebraic sum of the e.m.fs in the path"

In other words, "***the algebraic sum of all the branch voltages, around any closed path or closed loop is always zero***."

Around a closed loop $\sum V = 0$

The law states that if one starts at a certain point of a closed path and goes on tracing and noting all the potential changes (either drops or rises), in any one particular direction, till the starting point is reached again, he must be at the same potential with which he started tracing a dosed path.

Sum of all the potential rises must be equal to sum of all the potential drops while tracing any dosed path of the circuit. The total change in potential along a closed path is always zero.

1.10.3 Sign Conventions to be Followed while Applying KVL

When current flows through a resistance, the voltage drop occurs across the resistance. The polarity of this voltage drop always depends on direction of the current. The current always flows from higher potential to lower potential.

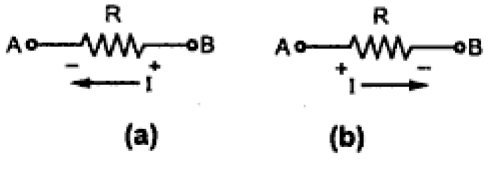


Fig 1.12

In the Fig. 1.12 (a), current I is flowing from right to left, hence point B is at higher potential than point A, as shown.

In the Fig. 1.12 (b), current I is flowing from left to right, hence point A is at higher potential than point B, as shown.

Once all such polarities are marked in the given circuit, we can apply KVL to any closed path in the circuit.

Now while tracing a closed path, if we go from -ve marked terminal to + ve marked terminal, that voltage must be taken as positive. This is called **potential rise.**

For example, if the branch AB is traced from A to B then the drop across it must be considered as rise and must be taken as + IR while writing the equations.

While tracing a closed path, if we go from +ve marked terminal to - ve marked terminal, that voltage must be taken as negative. This is called **potential drop**.

For example, in the Fig. 1.12 (a) only, if the branch is traced from B to A then it should be taken as negative, as - IR while writing the equations.

Similarly in the Fig. 1.12 (b), if branch is traced from A to B then there is a voltage drop and term must be written negative as - IR while writing the equation. If the branch is traced from B to A, it becomes a rise in voltage and term must be written positive as + IR while writing the equation.

1.10.4 Application of KVL to a Closed Path

Consider a closed path of a complex network with various branch currents assumed as shown in the Fig. 1.13 (a).

As the loop is assumed to be a part of complex network the branch currents are assumed to be different from each other.

Due to these currents the various voltage drops taken place across various resistances are marked as shown in the Fig. 1.13 (b).

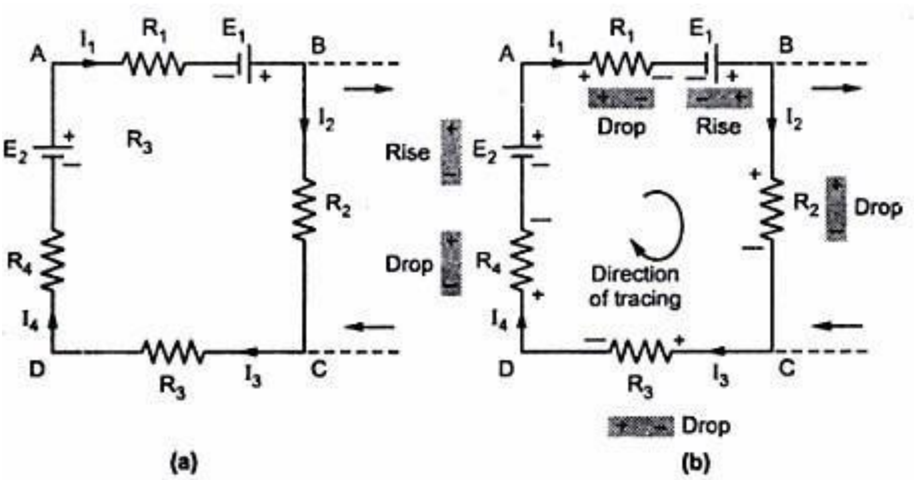


Fig 1.13

The polarity of voltage drop along the current direction is to be marked as positive (+) to negative (-).

Let us trace this closed path in clockwise direction i.e. A-B-C-D-A.

Across R_1 there is voltage drop I_1 R_1 and as getting traced from +ve to -ve, it is drop and must be taken as negative while applying KVL

Battery E_1 is getting traced from negative to positive i.e. it is a rise hence must be considered as positive.

Across R_2 there is a voltage drop I_2 R_2 and as getting traced from +ve to -ve, it is drop and must be taken negative.

Across R_3 there is a drop I_3 R_3 and as getting traced from +ve to -ve, it is drop and must be taken as negative.

Across R_4 there is drop I_3 R_3 and as getting traced from +ve to -ve, It is drop must be taken as negative.

Battery E_2 is getting traced from -ve to +ve, it is rise and must be taken as positive

:. We can write an equation by using KVL around this closed path as,

$$-I_1 R_1 + E_1 - I_2 R_2 - I_3 R_3 - I_4 R_4 + E_2 = 0$$

$$\text{i.e.} \qquad E_1 + E_2 = I_1 R_1 + I_2 R_2 + I_3 R_3 + I_4 R_4$$

If we trace the closed loop in opposite direction i.e. along A-D-C-B-A and follow the same sign convention, the resulting equation will be same as what we have obtained above.

1.10.5 Steps to Apply Kirchhoff's Laws to Get Network Equations

The steps are stated based on the branch current method.

Step 1: Draw the circuit diagram from the given information and insert all the values of sources with appropriate polarities and all the resistances.

Step 2: Mark all the branch currents with some assumed directions using KCL at various nodes and junction points. Kept the number of unknown currents minimum as far as possible to limit the mathematical calculations required to solve them later on.

Assumed directions may be wrong; in such case answer of such current will be mathematically negative which indicates the correct direction of the current. A particular current leaving a particular source has some magnitude, and then same magnitude of current should enter that source after travelling through various branches of the network.

Step 3: Mark all the polarities of voltage drops and rises as per directions of the assumed branch currents flowing through various branch resistances of the network. This is necessary for application of KVL to various closed loops.

Step 4: Apply KVL to different closed paths in the network and obtain the corresponding equations. Each equation must contain some clement which is not considered in any previous equation.

1.11 Electrical Work

- In an electrical circuit, movement of electrons i.e. transfer of charge is an electric current. The electric work done when there is a transfer of charge. The unit of such work is Joule.
- One joule of electrical work done is that work done in moving a charge of 1 coulomb through a potential difference of 1 volt.
- So if V is the potential difference in volts and Q is the charge in coulombs then we can write

Electrical work $W = V * Q$ J

But $I = \frac{Q}{t}$

$W = V\,I\,t$ J

1.12 Electrical Power

- The rate at which electrical work is done in an electric circuit is called an electrical power.

$$\text{Electrical Power} = \frac{\text{electrical work}}{\text{time}} = \frac{W}{t} = \frac{V\,I\,t}{t} = V\,I \text{ J/sec}$$

- Thus the power consumed in the electric circuit is 1 watt if the potential difference of 1 volt applied across the circuit causes 1 ampere current to flow through it.
- According to Ohms law, $V = IR$ or $I = \frac{V}{R}$
- Using this power can be expressed as

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

1.13 Electrical Energy

- An electrical energy is the total amount of electrical work done in electric

  circuitElectrical Energy E = Power * Time = V I t

- The unit of energy is joules or watt-sec.

Electromagnetic Induction

Faraday's First Law: Whenever the magnetic flux linked with a closed circuit changes, an induced electromotive force is produced which produces an induced current in the circuit which lasts as long as the change lasts.
Faraday's Second Law : The induced e.m.f. is equal to negative of rate of change of flux through the circuit.

$$e = \frac{-d\phi}{dt}$$

The negative sign shows that the induced e.m.f. opposes the changes in the magnetic flux.
If the coil has N number of turns, then

$$e = -\frac{Nd\phi}{dt}.$$

LENZ'S LAW :
The direction of induced electromotive force is such that it opposes the cause that produces the electromagnetic induction.

$$e(avg) = -\frac{N(\phi_2 - \phi_1)}{t}$$

Self Inductance:

If the current in a coil changes, the magnetic flux around the coil changes. Hence emf is induced in the coil called self inductance.

If i is the current through the coil and f is the flux lines around the coil then

f a i ϕ = Li. Where L is the coefficient of self induction

$$e = -\frac{d\phi}{dt} = -L\frac{di}{dt}$$

Unit of L - Henry or wb/amp or volt-sec/amp

Energy stored in an Inductor $U = \frac{1}{2}Li^2$

Mutual Inductance

When two coils are brought in proximity to each other, the magnetic field in one of the coils tends to link with the other. This further leads to the generation of voltage in the second coil. This property of a coil which affects or changes the current and voltage in a secondary coil is called mutual inductance.

$\phi_{21} \rightarrow$ magnetic flux in one turn of coil 2 due to current I_1.
If we vary the current with respect to time, then there will be an induced emf in coil 2.

$\varepsilon_{ind} = -\frac{d\phi}{dt}$
[According to Faraday's law]

$$\varepsilon_{21} = -N_2 \frac{d\phi_{21}}{dt}$$

$$\varepsilon_{21} = -N_2 \frac{d}{dt}\left(\overline{B}.\ \overline{A}\right)$$

The induced emf in coil 2 is directly proportional to the current that passes through coil 1.

$$N_2\,\phi_{21} \propto I_1$$

$$N_2\,\phi_{21} = M_{21} I_1 \ldots . (1)$$

The constant of proportionality is called mutual inductance. It can be written as

$$M_{21} = \frac{N_2\phi_{21}}{I_1} \ldots . (2)$$

The SI unit of inductance is henry (H)

$$1H = \frac{1(\text{Tesla}).1(m^2)}{1\ \ A}$$