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Subject Name: **Network Analysis**

Subject Code: **EC-3003**

Semester: **3rd**

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UNIT 1

Introduction to circuit elements R, L, C and their characteristics in terms of linearity and time dependence, KCL and KVL analysis, dual networks, analysis of magnetically coupled circuits, Dot convention, coupling co-efficient, Tuned circuits, Series and parallel resonance, voltage and current sources, controlled sources

Introduction of Electric Circuit

Objectives

- o Familiarity with and understanding of the basic elements encountered in electric networks.
- o To learn the fundamental differences between linear and nonlinear circuits.
- o To understand the Kirchhoff's voltage and current laws and their applications to circuits.
- o Meaning of circuit ground and the voltages referenced to ground.
- o Understanding the basic principles of voltage dividers and current dividers.
- o Potentiometer and loading effects.
- o To understand the fundamental differences between ideal and practical voltage and current sources and their mathematical models to represent these source models in electric circuits.
- o Distinguish between independent and dependent sources those encountered in electric circuits.
- o Meaning of delivering and absorbing power by the source.

Introduction

The interconnection of various electric elements in a prescribed manner comprises as an electric circuit in order to perform a desired function. The electric elements include controlled and uncontrolled source of energy, resistors, capacitors, inductors, etc. Analysis of electric circuits refers to computations required to determine the unknown quantities such as voltage, current and power associated with one or more elements in the circuit. To contribute to the solution of engineering problems one must acquire the basic knowledge of electric circuit analysis and laws. Many other systems, like mechanical, hydraulic, thermal, magnetic and power system are easy to analyze and model by a circuit. To learn how to analyze the models of these systems, first one needs to learn the techniques of circuit analysis. We shall discuss briefly some of the basic circuit elements and the laws that will help us to develop the background of subject.

Basic Elements & Introductory Concepts

Electrical Network: A combination of various electric elements (Resistor, Inductor, Capacitor, Voltage source, Current source) connected in any manner what so ever is called an electrical network. We may classify circuit elements in two categories, passive and active elements.

Passive Element: The element which receives energy (or absorbs energy) and then either converts it into heat (R) or stored it in an electric (C) or magnetic (L) field is called passive element.

Active Element: The elements that supply energy to the circuit is called active element. Examples of active elements include voltage and current sources, generators, and electronic devices that require power supplies. A transistor is an active circuit element, meaning that it can amplify power of a signal. On the other hand, transformer is not an active element because it does not amplify the power level and power remains same both in primary and secondary sides. Transformer is an example of passive element.

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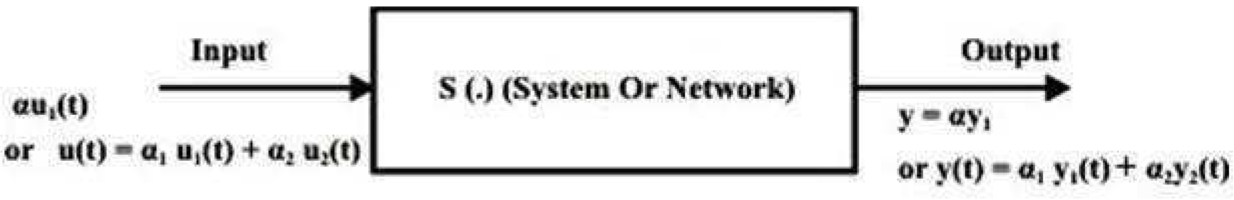
Bilateral Element: Conduction of current in both directions in an element (example: Resistance; Inductance; Capacitance) with same magnitude is termed as bilateral element.

Unilateral Element: Conduction of current in one direction is termed as unilateral (example: Diode, Transistor) element.

Meaning of Response: An application of input signal to the system will produce an output signal, the behavior of output signal with time is known as the response of the system.

Linear and Nonlinear Circuits



Input output behavior of a system

Non-Linear Circuit: Roughly speaking, a non-linear system is that whose parameters change with voltage or current. More specifically, non-linear circuit does not obey the homogeneity and additive properties. Volt-ampere characteristics of linear and non-linear elements are shown in figs. 3.2 - 3.3. In fact, a circuit is linear if and only if its input and output can be related by a straight line passing through the origin as shown in fig.3.2. otherwise, it is a nonlinear system.

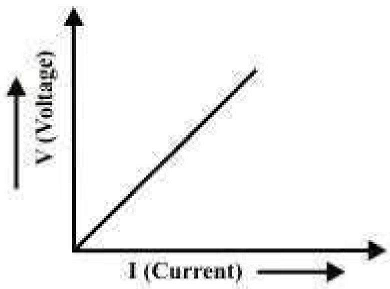


Fig. 3.2: V-I characteristics of linear element.

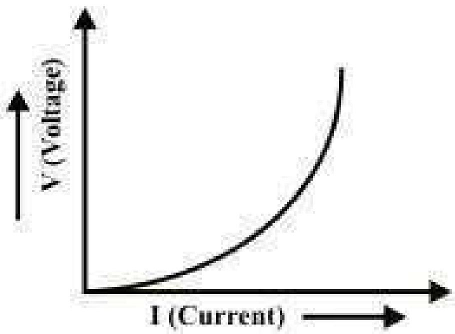


Fig. 3.3: V-I characteristics of non-linear element.

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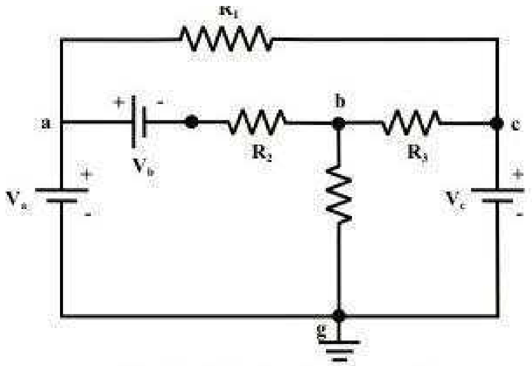
Potential Energy Difference: The voltage or potential energy difference between two points in an electric circuit is the amount of energy required to move a unit charge between the two points.

Kirchhoff's Laws

Kirchhoff's laws are basic analytical tools in order to obtain the solutions of currents and voltages for any electric circuit; whether it is supplied from a direct-current system or an alternating current system. But with complex circuits the equations connecting the currents and voltages may become so numerous that much tedious algebraic work is involve in their solutions.



Elements that generally encounter in an electric circuit can be interconnected in various possible ways. Before discussing the basic analytical tools that determine the currents and voltages at different parts of the circuit, some basic definition of the following terms are considered.

Node- A node in an electric circuit is a point where two or more components are connected together. This point is usually marked with dark circle or dot. The circuit in fig. 3.4 has nodes a, b, c, and g. Generally, a point, or a node in an circuit specifies a certain voltage level with respect to a reference point or node. Branch- A branch is a conducting path between two nodes in a circuit containing the electric elements. These elements could be sources, resistances, or other elements. Fig.3.4 shows that the circuit has six branches: three resistive branches (a-c, b-c, and b-g) and three branches containing voltage and current sources (a-, a-, and c-g). Loop- A loop is any closed path in an electric circuit i.e., a closed path or loop in a circuit is a contiguous sequence of branches which starting and end points for tracing the path are, in effect, the same node and touches no other node more than once. Fig. 3.4 shows three loops or closed paths namely, a-b-g-a; b-c-g-b; and a-c-b-a. Further, it may be noted that the outside closed paths a-c-g-a and a-b-c-g-a are also form two loops.

Mesh- a mesh is a special case of loop that does not have any other loops within it or in its interior. Fig. 3.4 indicates that the first three loops (a-b-g-a; b-c-g-b; and a-c-b-a) just identified are also 'meshes' but other two loops (a-c-g-a a-b-c-g-a) are not. With the introduction of the Kirchhoff's laws, a various types of electric circuits can be analyzed.

Kirchhoff's Current Law (KCL): KCL states that at any node (junction) in a circuit the algebraic sum of currents entering and leaving a node at any instant of time must be equal to zero. Here currents entering (+ve sign) and currents leaving (-ve sign) the node must be assigned opposite algebraic

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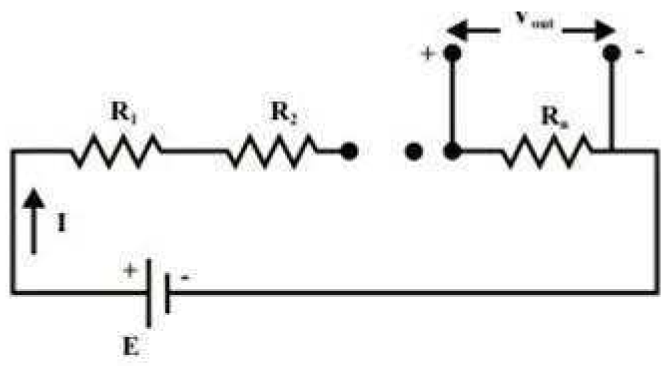
signs

Kirchhoff's Voltage Law (KVL): It states that in a closed circuit, the algebraic sum of all source voltages must be equal to the algebraic sum of all the voltage drops. Voltage drop is encountered when current flows in an element (resistance or load) from the higher-potential terminal toward the lower potential terminal. Voltage rise is encountered when current flows in an element (voltage source) from lower potential terminal (or negative terminal of voltage source) toward the higher potential terminal (or positive A, B, C, *and* E with respect to point D. Find also the value of voltage source.

In many cases, such as in electronic circuits, the chassis is shorted to the earth itself for safety reasons. Understanding the Basic Principles of Voltage Dividers and Current dividers

Voltage Divider



Current, voltage, power and energy

The most elementary quantity in the analysis of electric circuits is the electric charge. Our interest in electric charge is centered around its motion results in an energy transfer. Charge is the intrinsic property of matter responsible for electrical phenomena. The quantity of charge q can be expressed in terms of the charge on one electron. Which are -1.602 x 10-19 coulombs? Thus, -1 coulomb is the charge on 6.24 x 10^{18}electrons. The current flows through a specified area A and is defined by the electric charge passing through that area per unit time. Thus we define q as the charge expressed in coulombs.

Charge is the quantity of electricity responsible for electric phenomena. The time rate of change constitutes an electric current. Mathematically, this relation is expressed as

$$i(t) = \frac{dq(t)}{dt}$$

$$q(t) = \int_{-\infty}^{t} i(x)dx$$

The unit of current is ampere (A); an ampere is 1 coulomb per second. Current is the time rate of flow of electric charge past a given point. The basic variables in electric circuits are current and voltage. If a

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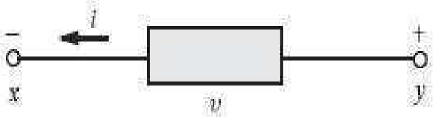
current flows into terminal of the element shown in Fig., then a voltage or potential difference exists between the two terminals a and b. Normally, we say that a voltage exists across the element.

The voltage across an element is the work done in moving a positive charge of 1 coulomb from first terminal through the element to second terminal. The unit of voltage is volt, V or Joules per coulomb. We have defined voltage in Joules per coulomb as the energy required to move a Positive charge of 1 coulomb through an element. If we assume that we are dealing with a differential amount of charge and energy,

$$v = \frac{dw}{dq}$$

$$vi = \frac{dw}{dq}\left(\frac{dq}{dt}\right) \Rightarrow \frac{dw}{dt} = p$$

Which is the time rate of change of energy or power measured in Joules per second or watts (). P could be either positive or negative. Hence it is imperative to give sign convention for power. If we use the signs as shown in Fig., the current flows out of the terminal indicated by x, which shows the positive sign for the voltage. In this case, the element is said to provide energy to the charge as it moves through. Power is then provided by the element.



Conversely, power absorbed by an element is p = vi, when i is entering through the positive voltage terminal.

Energy is the capacity to perform work. Energy and power are related to each other by the following equation:

$$Energy = w = \int_{-\infty}^{t} p\, dt$$

Linear, active and passive elements

A linear element is one that satisfies the principle of superposition and homogeneity.

Passive Circuit Elements

An element is said to be passive if the total energy delivered to it from the rest of the circuit is either zero or positive. Then for a passive element, with the current flowing into the positive (+) terminal as shown in Fig. shown above this means that

$$w = \int_{-\infty}^{t} vi\, dt \geq 0$$

Resistors

Resistance is the physical property of an element or device that impedes the flow of current; it is represented by the symbol R. Resistance of a wire element is calculated using the relation:

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$$R = \frac{\rho l}{A}$$

Where A is the cross-sectional area, ρ the resistivity, and l the length of the wire. The practical unit of resistance is ohm and represented by the symbol Ω. An element is said to have a resistance of 1 ohm, if it permits 1A of current to flow through it when 1V is impressed across its terminals. Ohm's law, which is related to voltage and current, was published in 1827 as

$$v = Ri$$
$$R = \frac{v}{i}$$

Where v is the potential across the resistive element, i the current through it, and R the resistance of the element. The power absorbed by a resistor is given by

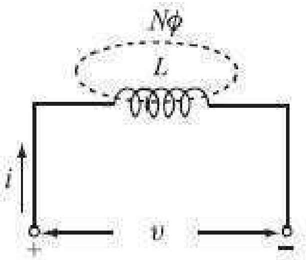
$$p = vi = v\left(\frac{v}{R}\right) = \frac{v^2}{R}$$

$$p = vi = (iR)i = i^2 R$$

Inductors

Whenever a time-changing current is passed through a coil or wire, the voltage across it is proportional to the rate of change of current through the coil. This proportional relationship may be expressed by the equation

$$v = L\frac{di}{dt}$$



Where L is the constant of proportionality known as inductance and is measured in Henrys (H). Remember v and I am both functions of time. Let us assume that the coil shown in Fig. above has N turns and the core material has a high permeability so that the magnetic flux ϕ is connected within the area A. The changing flux creates an induced voltage in each turn equal to the derivative of the flux ϕ so the total voltage across N turns is

$$v = N\frac{d\phi}{dt}$$

Capacitors

A capacitor is a two-terminal element that is a model of a device consisting of two conducting plates separated by a dielectric material. Capacitance is a measure of the ability of a device to store energy in the form of an electric field.

Capacitance is defined as the ratio of the charge stored to the voltage difference between the two

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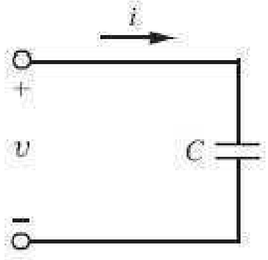
conducting plates or wires,



$$C = \frac{q}{v}$$

The current through the capacitor is given by

$$i = \frac{dq}{dt} = C\frac{dv}{dt}$$

The energy stored in a capacitor is

$$w = \int_{-\infty}^{t} vi \, d\tau$$

Active Circuit Elements (Energy Sources)

An active two-terminal element that supplies energy to a circuit is a source of energy. An ideal voltage source is a circuit element that maintains a prescribed voltage across the terminals regardless of the current flowing in those terminals. Similarly, an ideal current source is a circuit element that maintains a prescribed current through its terminals regardless of the voltage across those terminals.

These circuit elements do not exist as practical devices; they are only idealized models of actual voltage and current sources.

Ideal voltage and current sources can be further described as either independent sources or dependent sources. An independent source establishes a voltage or current in a circuit without relying on voltages or currents elsewhere in the circuit. The value of the voltage or current supplied is specified by the value of the independent source alone.

In contrast, a dependent source establishes a voltage or current whose value depends on the value of the voltage or current elsewhere in the circuit. We cannot specify the value of a dependent source, unless you know the value of the voltage or current on which it depends.

The circuit symbols for ideal independent sources are shown in Fig. 1.8.(a) and (b).

Note that a circle is used to represent an independent source. The circuit symbols for dependent sources are shown in Fig. 1.8.(c), (d), (e) and (f). A diamond symbol is used to represent dependent sources.

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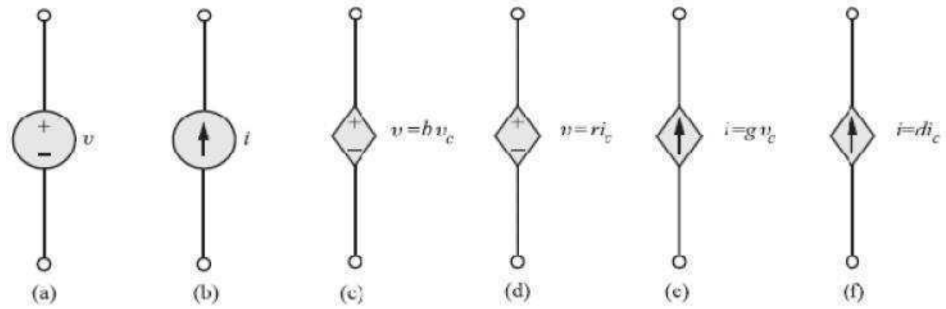


Figure 1.8 (a) An ideal independent voltage source
(b) An ideal independent current source
(c) voltage controlled voltage source
(d) current controlled voltage source
(e) voltage controlled current source
(f) current controlled current source

Unilateral and bilateral networks

A Unilateral network is one whose properties or characteristics change with the direction.
An example of unilateral network is the semiconductor diode, which conducts only in one direction.
A bilateral network is one whose properties or characteristics are same in either direction. For example, a transmission line is a bilateral network, because it can be made to perform the function equally well in either direction.

Network simplification techniques

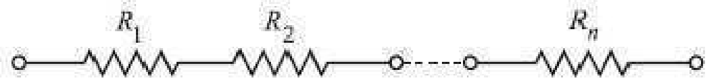
In this section, we shall give the formula for reducing the networks consisting of resistors connected in series or parallel.

Resistors in Series

When a number of resistors are connected in series, the equivalent resistance of the combination is given by

$$R = R_1 + R_2 + \cdots + R_n$$

Thus the total resistance is the algebraic sum of individual resistances.



Resistors in Parallel

When a number of resistors are connected in parallel as shown in Fig. below, then the equivalent resistance of the combination is computed as follows:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots\ldots + \frac{1}{R_n}$$

Thus, the reciprocal of a equivalent resistance of a parallel combination is the sum of the reciprocal of the individual resistances. Reciprocal of resistance is conductance and denoted by G. Consequently the equivalent conductance,

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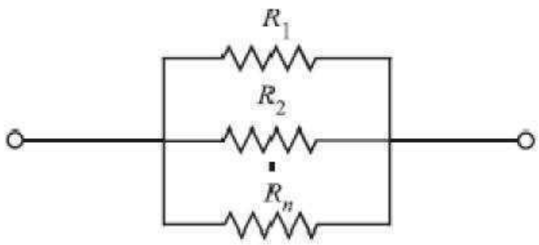
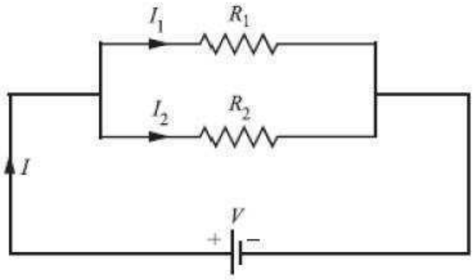


Division of Current in a Parallel Circuit

Consider a two branch parallel circuit as shown in Fig. below. The branch currents I1 and I2 can be evaluated in terms of total current I as follows:

$$I_1 = \frac{IR_2}{R_1 + R_2} = \frac{IG_1}{G_1 + G_2}$$

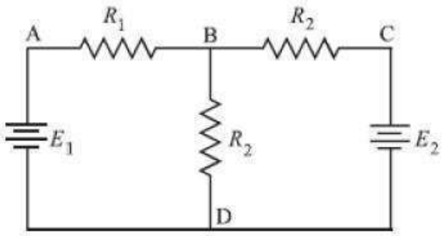
$$I_2 = \frac{IR_1}{R_1 + R_2} = \frac{IG_2}{G_1 + G_2}$$



That is, current in one branch equals the total current multiplied by the resistance of the other branch and then divided by the sum of the resistances.

Kirchhoff's laws

In the proceeding section, we have seen how simple resistive networks can be solved for current, resistance, potential etc using the concept of Ohm's law. But as the network becomes complex, application of Ohm's law for solving the networks becomes tedious and hence time consuming. For solving such complex networks, we make use of Kirchhoff's laws. Gustav Kirchhoff (1824-1887), an eminent German physicist, did a considerable amount of work on the principles governing the behavior of electric circuits. He gave his findings in a set of two laws: (i) current law and (ii) voltage law, which together are known as Kirchhoff's laws. Before proceeding to the statement of these two laws let us familiarize ourselves with the following definitions encountered very often in the world of electrical circuits:



Node: A node of a network is an equi-potential surface at which two or more circuit elements are joined. Referring to Fig. above, we find that A,B,C and D qualify as nodes in respect of the above definition.

Junction: A junction is that point in a network, where three or more circuit elements are joined. In Fig. above, we find that B and D are the junctions.

Branch: A branch is that part of a network which lies between two junction points. In Fig. above,

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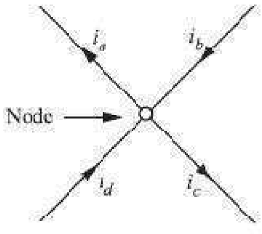
BAD,BCD and BD qualify as branches.
Loop: A loop is any closed path of a network. Thus, in Fig. above, ABDA,BCDB and ABCDA are the loops.
Mesh: A mesh is the most elementary form of a loop and cannot be further divided into other loops. In Fig. above, ABDA and BCDB are the examples of mesh. Once ABDA and BCDB are taken as meshes, the loop ABCDA does not qualify as a mesh, because it contains loops ABDA and BCDB.

Kirchhoff's Current Law
The first law is Kirchhoff's current law (KCL), which states that the algebraic sum of currents entering any node is zero. Let us consider the node shown in Fig. below. The sum of the currents entering the node is
Note that we have – in since the current is leaving the node. If we multiply the foregoing equation by -1, we obtain the expression which simply states that the algebraic sum of currents leaving a node is zero.



Which states that the sum of currents entering a node is equal to the sum of currents leaving the node? If the sum of the currents entering a node were not equal to zero, then the charge would be accumulating at a node. However, a node is a perfect conductor and cannot accumulate or store charge. Thus, the sum of currents entering a node is equal to zero.

Kirchhoff's Voltage Law
Kirchhoff's voltage law (KVL) states that the algebraic sum of voltages around any closed path in a circuit is zero. In general, the mathematical representation of Kirchhoff's voltage law is

$$\sum_{j=1}^{N} v_j(t) = 0$$

Where Vj (t) is the voltage across the Jth branch (with proper reference direction) in a loop containing N voltages. In Kirchhoff's voltage law, the algebraic sign is used to keep track of the voltage polarity. In other words, as we traverse the circuit, it is necessary to sum the increases and decreases in voltages to zero. Therefore, it is important to keep track of whether the voltage is increasing or decreasing as we go through each element. We will adopt a policy of considering the increase in voltage as negative and a decrease in voltage as positive.

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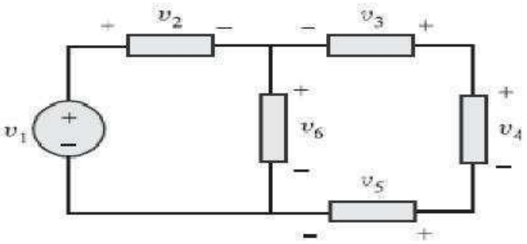
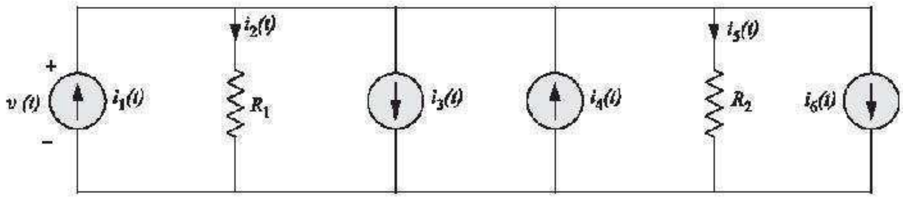


Consider the circuit shown in Fig. above, where the voltage for each element is identified with its sign. The ideal wire used for connecting the components has zero resistance, and thus the voltage across it is equal to zero. The sum of voltages around the loop incorporating v6 , v3 , v4 and v5. The sum of voltages around a loop is equal to zero. A circuit loop is a conservative system, meaning that the work required to move a unit charge around any loop is zero. However, it is important to note that not all electrical systems are conservative. Example of a non conservative system is a radio wave broadcasting system.

Multiple current source networks

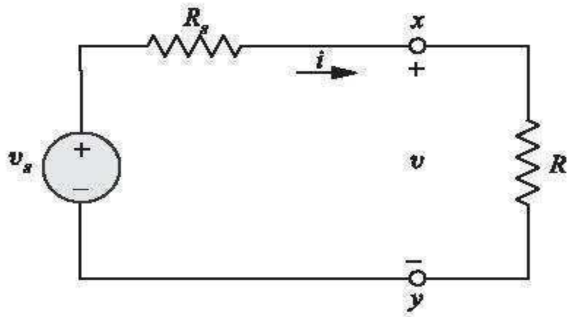
Let us now learn how to reduce a network having multiple current sources and a number of resistors in parallel. Consider the circuit shown in Fig. below. We have assumed that the upper node is v(t) volts positive with respect to the lower node. Applying KCL to upper node yields

$$i_1(t) - i_2(t) - i_3(t) + i_4(t) - i_5(t) - i_6(t) = 0$$
$$i_1(t) - i_3(t) + i_4(t) - i_6(t) = i_2(t) + i_5(t)$$
$$i_o(t) = i_2(t) + i_5(t)$$

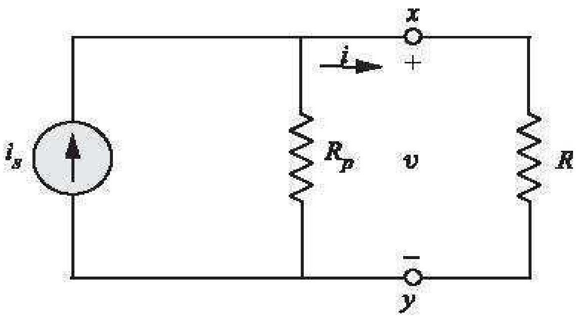


Source transformations

Source transformation is a procedure which transforms one source into another while retaining the terminal characteristics of the original source. Source transformation is based on the concept of equivalence. An equivalent circuit is one whose terminal characteristics remain identical to those of the original circuit. The term equivalence as applied to circuits means an identical e.ect at the terminals, but not within the equivalent circuits themselves.



Current source connected to an external resistance R



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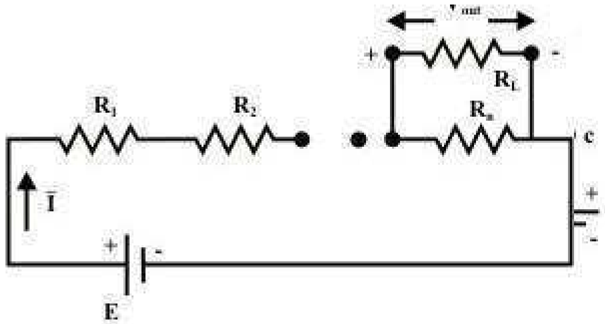

However, real or practical dc voltage sources do not exhibit such characteristics (see fig. 3.14) in practice. We observed that as the load resistance R connected across the source is decreased, the corresponding load current I_L increases while the terminal voltage across the source decreases (see eq.3.1). We can realize such voltage drop across the terminals with increase in load current provided a resistance element (R_S) present inside the voltage source. Fig. 3.15 shows the model of practical or real voltage source of value .

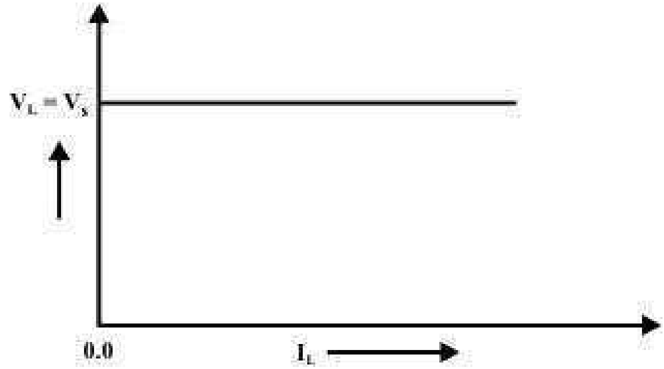

Fig. 3.14: V-I characteristics of ideal voltage source

The terminal $V - I$ characteristics of the practical voltage source can be described by an equation $V_L V - I_L R$ (3.1) and this equation is represented graphically as shown in fig.3.16. In practice, when a load resistance R_L more than 100 times larger than the source resistance R_S , the source can be considered approximately ideal voltage source. In other words, the internal resistance of the source can be omitted. This statement can be verified using the relation R_L $100R$ in equation (3.1). The practical voltage source is characterized by two parameters namely known as (i) Open circuit voltage (V) (ii) Internal resistance in the source's circuit model. In many practical situations, it is quite important to determine the source parameters experimentally. We shall discuss briefly a method in order to obtain source parameters.

Method-: Connect a variable load resistance across the source terminals (see fig. 3.15). A voltmeter is connected across the load and an ammeter is connected in series with the load resistance. Voltmeter and Ammeter readings for several choices of load resistances are presented on the graph paper (see fig. 3.16). The slope of the line is $-R$, while the curve intercepts with voltage axis (at I_L) is the value of V .

The $V - I$ characteristic of the source is also called the source's **"regulation curve" or "load line"**. The open-circuit voltage is also called the "no-load" voltage, V_C . The maximum allowable

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load current (rated current) is known as full-load current $_{Fl}$ and the corresponding source or load terminal voltage is known as "full-load" voltage $_{FL}$. We know that the source terminal voltage varies as the load is varied and this is due to internal voltage drop inside the source. The percentage change in source terminal voltage from no-load to full-load current is termed the "voltage regulation" of the source. It is defined as

For ideal voltage source, there should be no change in voltage from no-load to full-load and this corresponds to "zero voltage regulation". For best possible performance, the voltage source should have the lowest possible regulation and this indicates a smallest possible internal voltage drop and the smallest possible internal resistance.

Ideal and Practical Current Sources

Another two-terminal element of common use in circuit modeling is `current source` as depicted in fig.3.17. An ideal current source, which is represented by a model in fig. 3.17(a), is a device that delivers a constant current to any load resistance connected across it, no matter what the terminal voltage is developed across the load (i.e., independent of the voltage across its terminals across the terminals).

$_{s}$

It can be noted from model$_{L}$ of the current source that the current flowing from the source to the load is always constant for any load resistance (see fig. 3.19(a)) i.e. whether $_{L}$ is small (V_L is small is large (V_L is large). The vertical dashed line in fig. 3.18 represents the $V - I_L$ characteristic of ideal current source. In practice, when a load R is connected across a practical current source, one can observe that the current flowing in load resistance is reduced as the voltage across the current source's terminal is increased, by increasing the load resistance R . Since the distribution of source current in two parallel paths entirely depends on the value of external resistance that connected across the source (current source) terminals. This fact can be realized by introducing a parallel resistances in parallel with the practical current source, as shown in fig. 3.17(b). The dark lines in fig. 3.18 show the $V - I$ characteristic (load-line) of practical current source. The slope of the curve represents the internal resistance of the source. One can apply KCL at the top terminal of the current source in fig. 3.17(b) to obtain the following expression. respectively. It can be noted from the fig.3.18 that source 1 has a larger internal resistance than source 2 and the slope the curve indicates the internal resistance R_S of the current source. Thus, source 1 is closer to the ideal source. More specifically, if the source internal resistance

then source acts nearly as an ideal current source.

Current source to Voltage Source

Remarks on practical sources: (i) The open circuit voltage that appears at the terminals A & B for two sources (voltage & current) is same (i.e., V). $_{s}$

(ii) When the terminals A & B are shorted by an ammeter, the shot-circuit results same in both cases (i.e.,).

(iii) If an arbitrary resistor (R) is connected$_{L}$ across the output terminals A & B of

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either source, the same power will be dissipated in it.
(iv) The sources are equivalent only as concerns on their behavior at the external terminals.
(v) The internal behavior of both sources is quite different (i.e., when open circuit the voltage source does not dissipate any internal power while the current source dissipates. Reverse situation is observed in short-circuit condition).8 Independent and Dependent Sources that encountered in electric circuits Independent Sources
So far the voltage and current sources (whether ideal or practical) that have been discussed are known as independent sources and these sources play an important role to drive the circuit in order to perform a specific job. The internal values of these sources (either voltage source or current source) – that is, the generated voltage V_s or

The generated current $_S$ (see figs. 3.15 & 3.17) are not affected by the load connected across the source terminals or across any other element that exists elsewhere in the circuit or external to the source.

Dependent Sources
Another class of electrical sources is characterized by dependent source or controlled source. In fact the source voltage or current depends on a voltage across or a current through some other element elsewhere in the circuit. Sources, which exhibit this dependency, are called dependent sources. Both voltage and current types of sources may be dependent, and either may be controlled by a voltage or a current. In general,

Dependent source is represented by a diamond ()-shaped symbol as not to confuse it with an independent source. One can classify dependent voltage and current sources into four types of sources as shown in fig.3.21. These are listed below:
(i) Voltage-controlled voltage source (VCVS) (ii) Current-controlled voltage source (ICVS) (iii) Voltage-controlled current source (VCIS) (iv) Current-controlled current source(ICIS)

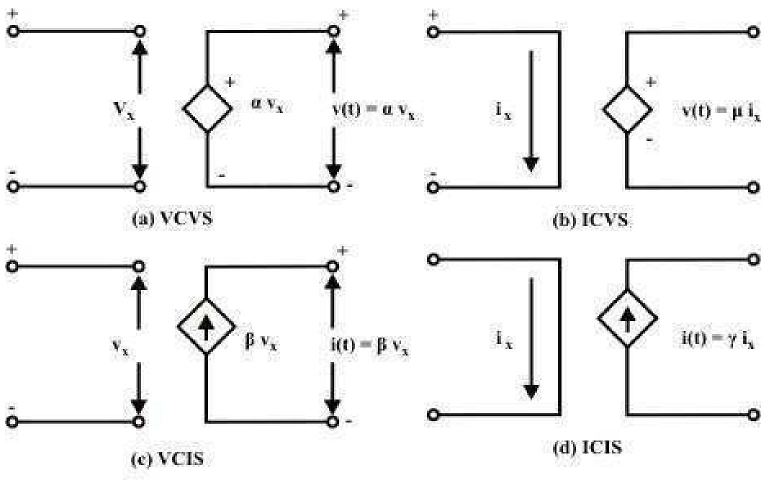

Fig. 3.21: Ideal dependent (controlled) sources

Note: When the value of the source (either voltage or current) is controlled by a voltage (v_x) somewhere else in the circuit, the source is said to be voltage-controlled source. On the other hand, when the value of the source (either voltage or current) is controlled by a current (i_x) somewhere else in the circuit, the source is said to be current-controlled source. KVL and KCL laws can be applied to networks containing such dependent sources. Source conversions, from dependent voltage source models to dependent current source models, or visa-versa, can be employed as

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needed to simplify the network. One may come across with the dependent sources in many equivalent-circuit models of electronic devices (transistor, BJT (bipolar junction transistor), FET(field-effect transistor) etc.) and transducers.

9 Understanding Delivering and Absorbing Power by the Source. It is essential to differentiate between the absorption of power (or dissipating power) and the generating (or delivering) power. The power absorbed or dissipated by any circuit element when flows in a load element from higher potential point (i.e +ve terminal) toward the lower terminal point (i.e., -ve terminal). This situation is observed when charging a battery or source because the source is absorbing power. On the other hand, when current flows in a source from the lower potential point (i.e., -ve terminal) toward the higher potential point (i.e., +ve terminal), we call that source is generating power or delivering power to the other elements in the electric circuit. In this case, one can note that the battery is acting as a "source" whereas the other element is acting as a "sink".

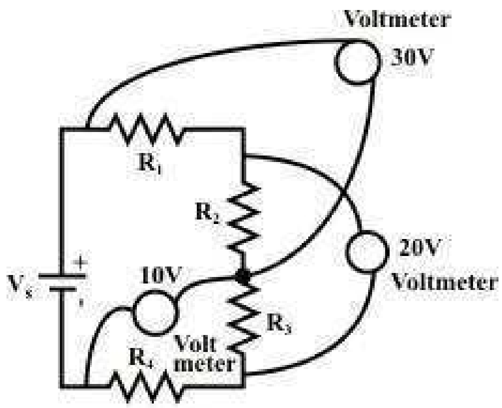

Fig. 3.33

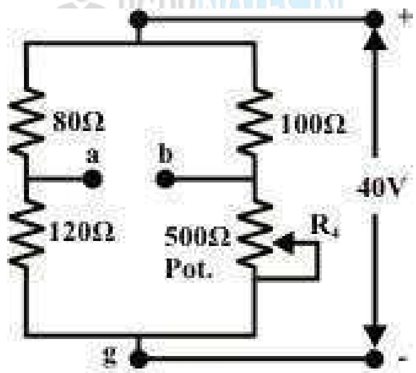

Fig. 3.36

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