

# CIRCUIT ANALYSIS

## INTRODUCTION TO AC AND DC CIRCUIT ANALYSIS

### Definitions

- ELECTRICAL CHARGE** has four characteristics:
  - Its magnitude is measured in **coulombs (C)**. The charge carried by an **electron** is  $q_e = -1.60 \cdot 10^{-19} \text{C}$ . A **proton** has the same amount of charge, but with positive polarity.
  - Charges are, therefore, of two types: positive and negative.
  - Charges exist in discrete, integral multiples of  $\pm q_e$ .
  - Charges are conserved: They can be neither created nor destroyed.
- CURRENT**. In an electric circuit, the charges move along specified, closed paths. The motion of charges constitutes an electric conduction current. Current is measured in **amperes (amperes/second)**. That is, one ampere is the current that flows when one coulomb of charge flows per second. Or, current  $I(t)$  in amperes is:

$$I(t) = \frac{dq(t)}{dt} \text{ amperes, where } q(t) \text{ is the charge in coulombs, and } t \text{ is the time in seconds.}$$

- Conventions:** A negative quantity of charge traveling from B to A along a conductor is equivalent to a positive quantity of charge going from A to B. Hence, current is a vector.
- Unidirectional transfer of electric charge through a conductor constitutes the direct electric current, or **dc**. This is in contrast to ac (alternating current) which implies a time-reversal of direction of current such as a sinusoidal wave.

- VOLTAGE.** Voltage difference (also known as potential difference) between two points is defined as the work  $[w(t)]$  in joules required to move a unit charge from one point to the other. The unit of potential difference is the **volt (V)**. Voltage ( $v$ ) can be positive or negative.

$$\text{Note that: } v(t) = \frac{dw(t)}{dq} \text{ volts}$$

- POWER.** Power  $p(t)$  is the rate of doing work or the rate of change of energy. The electrical unit of power is the **watt (W)**.

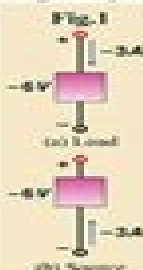
$$p(t) = \frac{dw(t)}{dt} \text{ joules/sec or watts}$$

$$\text{Note: } v(t)I(t) = \frac{dw(t)}{dq} \frac{dq}{dt} = \frac{dw(t)}{dt} = p(t)$$

Thus,  $p(t) = v(t)I(t)$  is subject to the following sign convention: *Whenever the reference direction for the current in an element is in the direction of the voltage drop across the element, use the formula  $p = vI$ . That is, the current must enter the positive terminal to use the above formula. Otherwise use  $p = -vI$ . If  $p(t) > 0$ , then the element absorbs power. If  $p(t) < 0$ , then the element delivers power. See the following examples:*

- In Fig. 1(a) the element is consuming/absorbing 18W of power, and in Fig. 1(b) the element is delivering 18W.
- FACT:** The total power delivered must equal the total power absorbed in any circuit.

- BRANCH.** A branch is an element (for example, resistor, sources, etc.).
- NODE.** A node is a junction where two or more elements come together.
- GROUND.** A ground is the voltage reference point which has zero potential.



### Ideal Independent Sources

#### IDEAL INDEPENDENT VOLTAGE SOURCE

This element maintains a specified voltage between its terminals regardless of the rest of the circuit where it is inserted. The voltage is completely independent of the current through the element. The symbol for the element is shown in Fig. 2.



Fig. 3 shows other variations of Fig. 2:



Fig. 3(a) shows an ideal battery which has a constant voltage with respect to time and (b) shows a sinusoidal voltage source which swings up and down between the peak values  $+v_m$  and  $-v_m$  producing an alternating current.

**IDEAL INDEPENDENT CURRENT SOURCE.** This element maintains a specified current through it independent of the voltage across it. See Fig. 4.



### Ideal Dependent Sources

**IDEAL DEPENDENT VOLTAGE SOURCE.** Is a dependent (or controlled) voltage source, the voltage across the source depends upon the voltage or current across some other element in the network. There are two types of controlled voltage sources:

- voltage controlled voltage source**  
 $v = \alpha v_x$ , where  $v_x$  is a voltage somewhere else in the circuit and  $\alpha$  is a constant. See Fig. 5.



- current controlled voltage source**  
 $v = \beta i_x$ , where  $i_x$  is a current somewhere else in the circuit and  $\beta$  is a constant. See Fig. 6.



**IDEAL DEPENDENT CURRENT SOURCE.** In a dependent (or controlled) current source, the current through the source depends upon the voltage or current through another element in the network. There are two types of controlled current sources:

- voltage controlled current source**  
 $i = \gamma v_x$ , where  $v_x$  is a voltage somewhere else in the circuit and  $\gamma$  is a constant. See Fig. 7.



- current controlled current source**  
 $i = \alpha i_x$ , where  $i_x$  is a current somewhere else in the circuit and  $\alpha$  is a constant. See Fig. 8.



### Resistance & Conductance

- RESISTANCE.** A resistor is a circuit element used to model the resistance to the flow of electrical charge. The unit of resistance is the **ohm** denoted by  $(\Omega)$ .



- CONDUCTANCE.** Conductance ( $G$ ) is defined as the reciprocal of resistance; that is,  $G = 1/R$ . Conductance is measured in **siemens (S)**.

### Ohm's Law

- OHM'S LAW** (at a given temperature) is given by  $v = iR$  volt, and is based on the following convention:  $v = iR$  applies whenever the reference direction for the current in the resistor is in the direction of the voltage drop across the resistor. Otherwise use  $v = -iR$ .



### Open & Short Circuit

- OPEN CIRCUIT.** The graphical representation of an "open circuit" ( $R = \infty$ ) is shown in Fig. 11. Note that the current can't flow due to infinite resistance. The terminals maintain an open circuit voltage.



- SHORT CIRCUIT.** The graphical representation of a "short circuit" ( $R = 0$ ) is shown in Fig. 12. Note that a short circuit can be considered as a piece of wire assumed as a perfect conductor (voltage = 0, resistance = 0). Short circuit current flows in the loop.



### Kirchhoff's Laws

- KIRCHHOFF'S VOLTAGE LAW (KVL):** The algebraic sum of all the voltages around any closed path in a circuit equals zero for every instant of time.



- Common Convention:** To avoid sign errors regarding KVL, use the voltage polarity sign of the element which you first encounter in passing by that element. Example: If in Fig. 13 we choose to take the loop clockwise, we hit the negative sign of the voltage source and the positive sign of  $v_x$ . Thus  $-v + v_x = 0$ .

- KIRCHHOFF'S CURRENT LAW (KCL):** The algebraic sum of all the currents at any node in a circuit equals zero for every instant of time.



- Common Convention:** Currents entering will be negative. Currents leaving will be positive. (Opposite method is also permitted if you are consistent.) Example: In Fig. 14, KCL for the node is  $-12A + 10A + i_x = 0$ .

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**Bill Dillard**



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