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Fundamentals of Electrical Engineering

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Abstract: Electricity plays a vital role in both day to day life of people and the economic development of a nation. Electrical engineering deals with the study and applications of physics and mathematics combined with elements of electricity, electronics, and electromagnetism to both large and small-scale systems to process information and transmit energy. It covers a wide range of subfields including power engineering, control systems, radio frequency engineering, signal processing, and telecommunications.

Keywords: Electricity, Current, Voltage, Power, Energy

I. INTRODUCTION

The invisible energy which constitutes the flow of electrons through a circuit to do work is called electricity. The electricity produced by the charges at rest is called static electricity or electrostatics. It is produced by friction, hence called as frictional electricity. The electricity produced by the charges in motion is called as current electricity. Electricity is a form of energy that depends upon the existence of electric charge in static or dynamic form. As per the existence of electric charge, the matter can be classified as- a) Positively charged b) negatively charged. A neutral matter is a composition of an equal amount of positive and negative charges. The addition of more electrons makes a neutral matter negatively charged, withdrawal of electrons from a neutral matter may result in a positively charged matter.

The fundamental unit of electricity is a charge. The electrical charge is measured in coulombs(C). The charge on a proton is approximately $1.6*10^{-19}$ C, while the charge on an electron is the same magnitude but has the opposite sign (approximately $-1.6*10^{-19}$ C). An electric current is the flow of an electric charge. Current and voltage are two fundamental quantities of electricity. Voltage is the cause and current is the effect. The voltage between two points is equal to the electrical potential difference between those points. It is the electromotive force (EMF) responsible for the movement of electrons (electric current) through a circuit. A flow of electrons forced into motion by voltage is current.

The other important electrical quantity is power. Electrical power is the rate at which a device changes electric current to another form of energy. The SI unit of the power is the watt.

II. BASIC ELECTRICAL QUANTITIES

A. Current

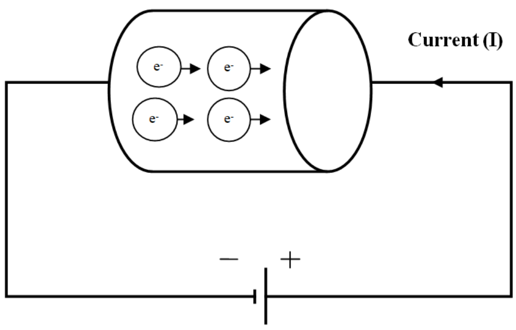

Figure (1.2) Electric current due to flow of charge through a cross-section of a conductor or circuit element

We know that a conducting wire consists of several atoms and a battery is a source of electromotive force. When a conducting wire is connected to a battery, the charges are compelled to move. Positive charges move in one direction while negative charges move in the opposite direction. This motion of charges creates an electric current. The convention is to take the current flow as the movement of positive charges, that is, opposite to the flow of negative charges as shown in figure 1.2

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The electrical effect caused by charges in motion depends on the rate of charge flow. The rate of charge flow is known as electric current.
Mathematically the relationship between current, charge and time is,

$$i = \frac{dq}{dt} \qquad (1.1)$$

Where, i= current in Ampere, q= charge in coulomb, t= time in seconds

1 Amp=1 coulomb/second

The charge transferred between time t_0 and t is obtained by integrating both sides of equation (1.1), we get,

$$q=\int_{t0}^{t} i \, dt \qquad (1.2)$$

Equation (1.1) suggests that current need not be a constant valued function. As we will see later, there can be several types of current, that is charge can vary with time in several ways.
When a current is constant with time, we say that we have direct current. Thus, a direct current (dc) is a current that remains constant with time. On the other hand, a current that varies with time, reversing direction periodically is called alternating current (ac). Thus, an alternating current is a current that varies with time periodically. Alternating current is used in our household to run the refrigerator, toaster, Air conditioner, and other electrical appliances.

Figure (1.3) shows the values of a DC and a sinusoidal AC versus time.

Figure (1.3) (a) DC

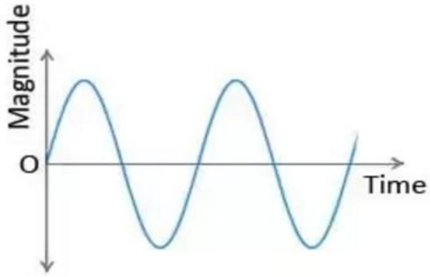

Figure (1.3) (b) AC

Figure (1.4) shows the other types of time-varying current such as the triangular and square waveforms.

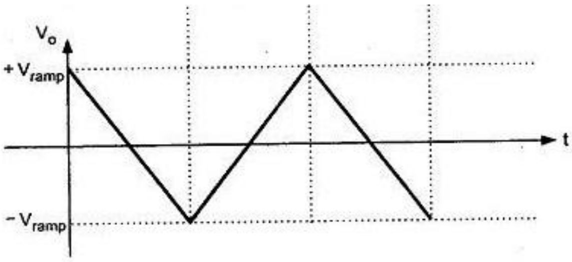

Figure (1.4) (a) Triangular waveform

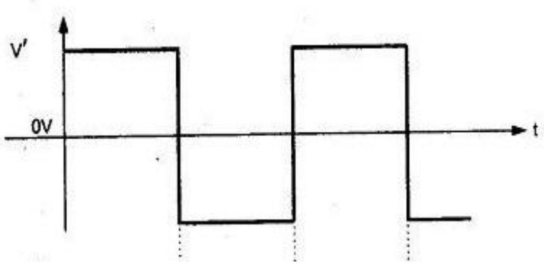

Figure (1.4) (b) Square waveform

As mentioned earlier, the direction of the current flow is conventionally taken as the direction of the positive charge movement. Based on this convention, a current of 4Amp may be represented positively or negatively. This is shown in figure (1.5) where a lamp is connected in series with the battery.

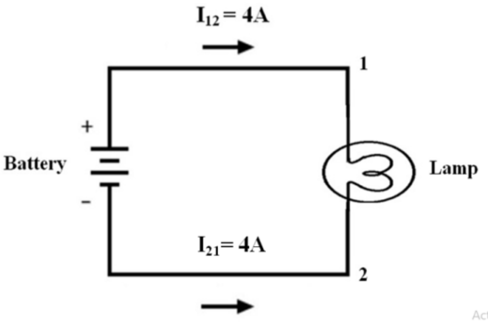

Figure (1.5) A lamp in series with battery: positive and negative current flow

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In figure (1.5), I_{12}= 4Amp, this means the current through the lamp with its reference direction pointing from 1 to 2. Similarly, I_{21} is current with its reference directed from 2 to 1. Of course, I_{12} and I_{21} are the same in magnitude and opposite in sign, because they denote the same current but in opposite direction. Thus we have

$$I_{12} = -I_{21} = 4 \text{ Amp} \qquad (1.3)$$

B. *Voltage*

As explained in the previous section, to move an electron in a conductor in a particular direction requires some work or energy transfer. This work is done by an external electromotive force (EMF), typically represented by the battery in figure (1.2). This EMF is also known as potential difference or voltage. Actually, whenever positive and negative charges are separated, energy is expanded. Voltage is the energy per unit change created by the separation. Thus the voltage v_{12} between two points 1 & 2 in an electric circuit is the energy or work needed to move a unit charge from 1 to 2. We express this ratio in differential form as,

$$v = v_{12} = \frac{dw}{dq} \qquad (1.4)$$

Where, w= energy in joules, q= charge in coulomb, v= voltage in volts
From equation (1.4), it is evident that,
1 volt= 1 Joule/coulomb= 1 Newton-metre/coulomb
Thus, voltage or potential difference is the energy required to move a unit charge through an element.
Figure (1.6) shows the voltage across the lamp connected between points 1 & 2. The plus (+) and minus (-) signs are used to represent reference direction or voltage polarity.

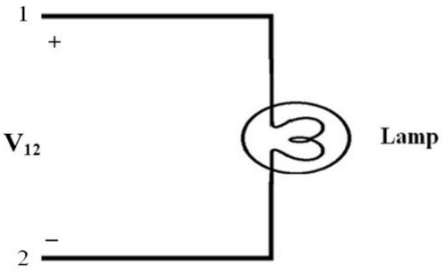
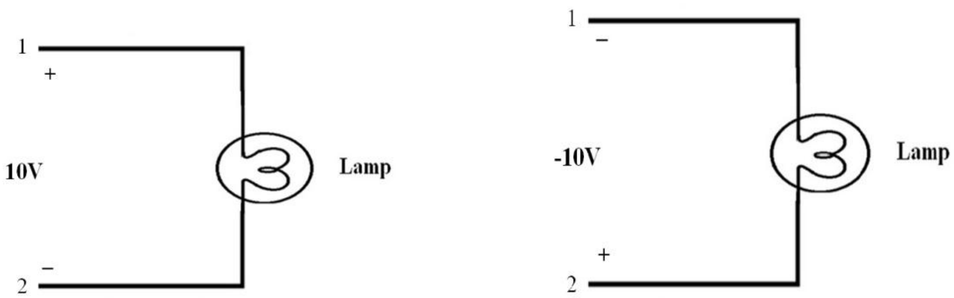


Figure (1.6) Polarity of voltage v_{12}

The voltage v_{12} can be interpreted in two ways:
1. Point 1 is at a potential of v_{12} volts higher than point 2 (or)
2. The potential at point 1 concerning 2 is v_{12}. Therefore, it logically follows that,

$$v_{12} = -v_{21} \qquad (1.5)$$

For the purpose of further explanation, figure (1.7) shows two representations of the same voltage.



(a) Point 1 is 10V above point 2 (b) Point 2 is -10V above point 1
Figure (1.7) Two equivalent representation of the same voltage v_{12}

We can say that in figure (1.7) (a) there is a 10V drop from point 1 to 2 or equivalently a 10V rise from 2 to 1.

C. *Power and Energy*

Power & energy calculations are very important in circuit analysis. Although voltage and current are useful variables in an electric circuit, they are not sufficient by themselves. One reason is that the useful output of the system often is non-electrical and this output is conveniently expressed in terms of power and energy. Another reason is that all practical devices have limitations on the amount of power that they can handle. For example, we all know from our experience that a 60watt bulb gives more light than a 40watt bulb. We also know that when we pay our electricity bills, we are paying for the electric energy (watt-hour) consumed over a certain period.

We now relate power and energy to voltage and current. We recall from physics that: Power is the time rate of expanding or absorbing energy. Power is measured in Watts (W).

Mathematically we write the relationship as,

$$P = dw/dt \qquad (1.6)$$

Where, P= Power in watts, w= Energy in Joules, t= time in seconds.

Thus, 1 watt= 1 Joule/second

From equations (1.1), (1.4) and (1.6) it follows that,

$$P = \frac{dw}{dt} = \frac{dw}{dq} * \frac{dq}{dt} = vi$$

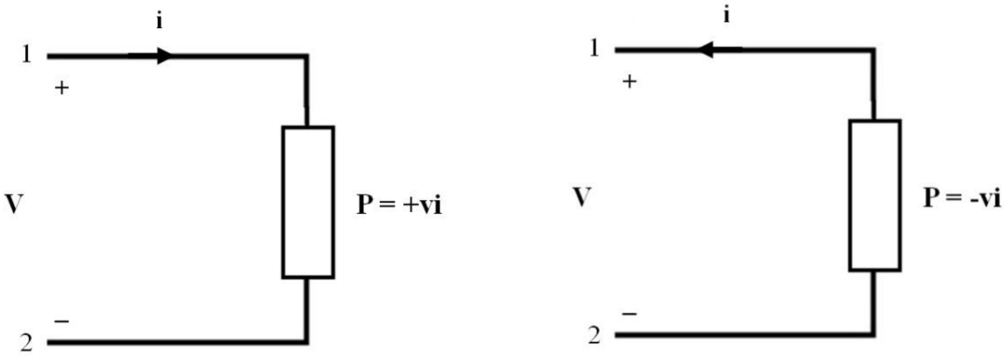
$$P = vi \qquad (1.7)$$

Equation (1.7) shows the power associated with a basic circuit element is simply the product of the current in the element and the voltage across the element. Therefore power is a quantity associated with a pair of terminals and we have to be able to tell from our calculation whether the power is being delivered to the element or supplied by the element.

If the power has a positive sign, power is being delivered to or absorbed by the element. If, on the other hand, the power has a negative sign, power is being supplied by the element. But how do we know when the power has a positive or a negative sign.

The polarity of voltage and direction of current plays a major role in determining the sign of power.

So that power has a positive sign, the direction of current and polarity of voltage must conform to those shown in figure (1.8). By the passive sign convention, the current enter through the positive polarity of the voltage, and in this case, P= +vi or vi>0 implies that element is absorbing power. But if P= -vi or vi<0 as in figure (1.8) (b), the element is releasing or supplying power.



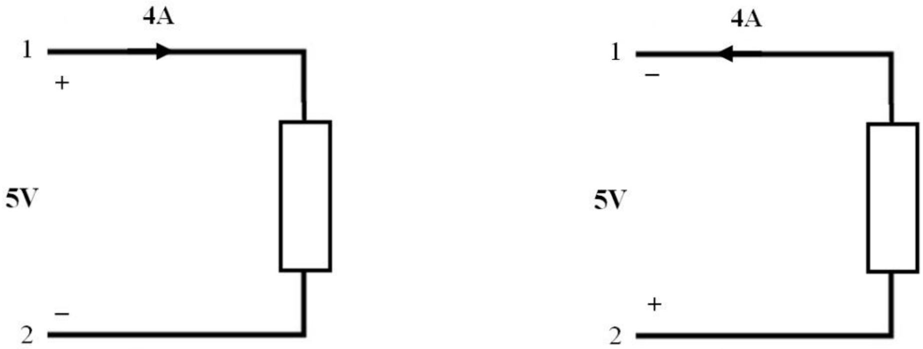
(a) Absorbing power (b) Supplying power

Figure (1.8) Reference polarities for power using the passive sign convention

The passive sign convention is satisfied when the current enters the positive terminal of an element and P= +vi. However if the current enters through the negative terminal, P= -vi.

In general, we can write, + power absorbed= -power supplied

Figure (1.9) shows the two cases of an element with absorbing power



(a) P =5*4=20W (b) P =5*4=20W

Figure (1.9) Two cases of an element with an absorbing power 20W

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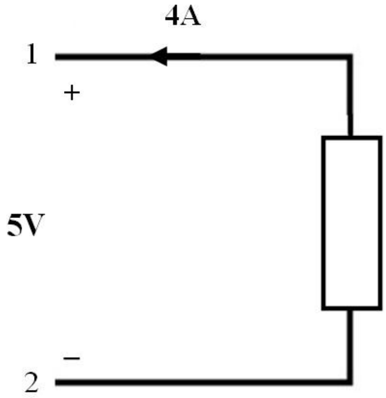
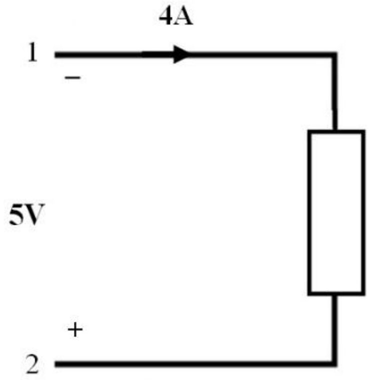
Figure (1.10) shows two cases of an element with a supplying power



(a) P =5*(-4) = -20W



(b) P =5*(-4) = -20W

Figure (1.10) Two cases of an element with supplying power of 20 W

For any electric circuit, the law of conservation of energy must be obeyed. For this reason, at any instant of time, the algebraic sun of power in a circuit must be zero. Therefore we can write

$$\sum P = 0 \qquad (1.8)$$

Equation (1.8) confirms the fact that the power supplied to the circuit must balance the total power absorbed.
To calculate energy (w) supplied or absorbed by a circuit element between time instants t0 and t, we integrate power. Therefore,

$$W = \int_{t0}^{t} P\, dt = \int_{t0}^{t} v * i\, dt \qquad (1.9)$$

Thus energy is the capacity to do work. Energy is measured in joules. The electric power utility companies measure energy in watt-hour (Wh) where 1 Wh= 3600 Joules.

III. CONCLUSION

Electrical engineering is concerned with the analysis and design of electric circuit systems and devices. The study of basic electrical quantities is important because these quantities are necessary for circuit model analysis which helps us to predict mathematically the approximate behavior of the actual system. The circuit model also provides insides into how to design a physical circuit to perform the desired task.

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