Fundamentals of Electrical Engineering
(EPCE 2101)
Credit: 4Hrs (Lec.: 2 Hr, Tut:3 Hr and Lab: 3 Hr)

Chapter - One
Basic concepts of Electrical Engineering

Outline:

1. Introduction to electrical engineering
2. Basics of electric generation
3. Electrical quantities
4. Basic circuit elements
5. Solved problem

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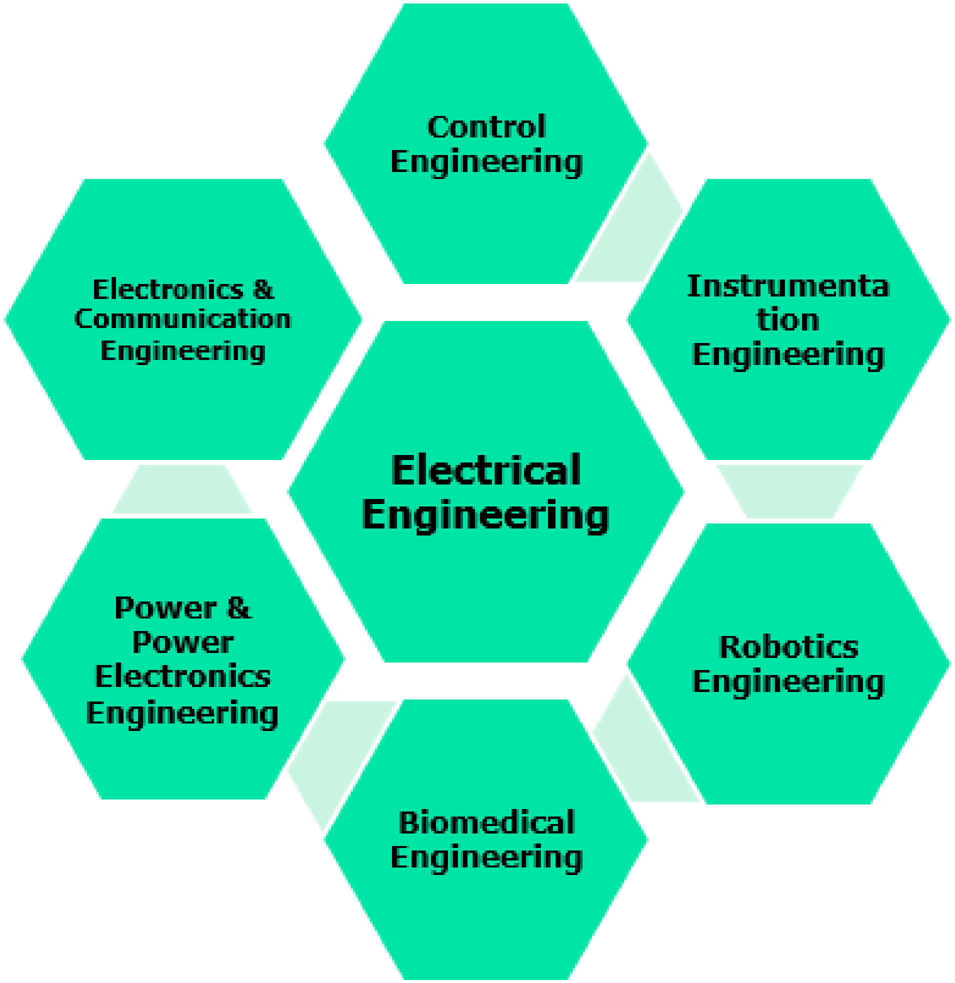
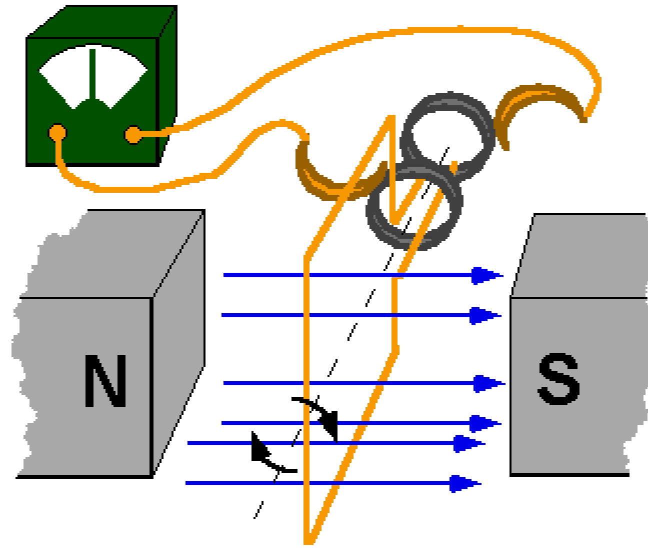
What is electrical engineering?

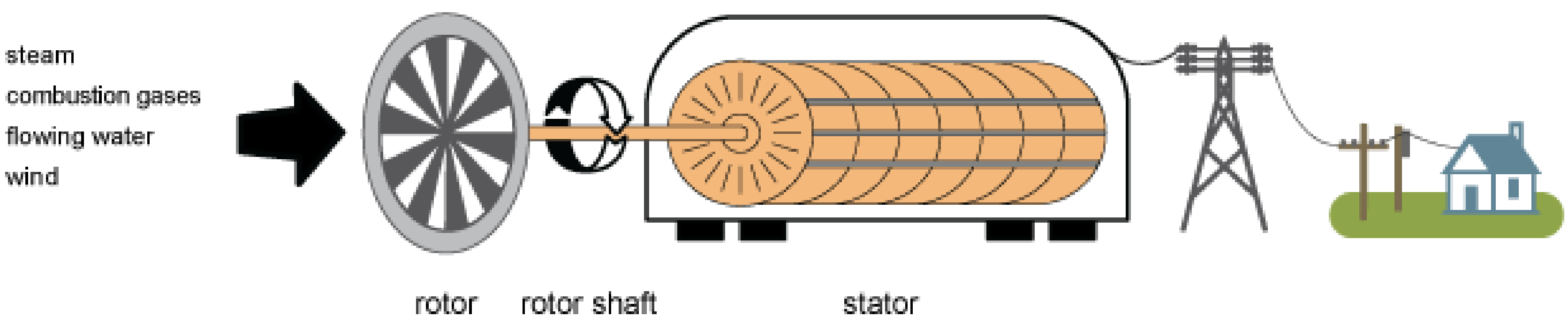


- **The two fundamental theories upon which all branches of electrical engineering are built**
  - **I. Electric circuit theory and**
    - **power**
    - **Electric machines**
    - **control**
    - **electronics**
    - **communications**
    - **instrumentation**
  - **II. Electromagnetic theory**

Basics of electric generation



kinetic energy source | turbine electric generator | electricity to consumers



- **In electrical engineering,** we are often interested in communicating or transferring energy from one point to another. To do this requires an interconnection of electrical devices.
- Such interconnection is referred to as an electric circuit, and each component of the circuit is known as an element.

An **electric circuit** is an interconnection of electrical elements

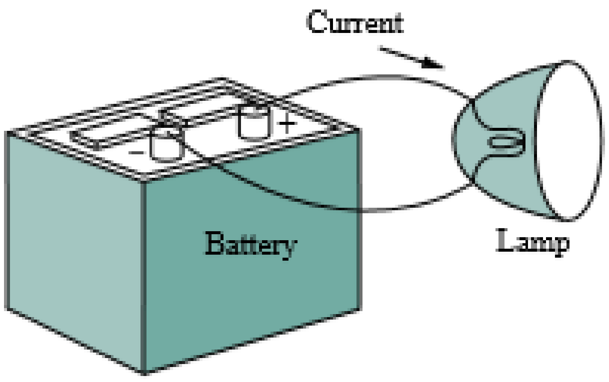


Figure1.1 A simple electric circuit.

- **To study about electric circuit we need the concepts of**
  - **Charge,**
  - **Current,**
  - **Voltage,**
  - **Circuit elements,**
  - **Power and energy**

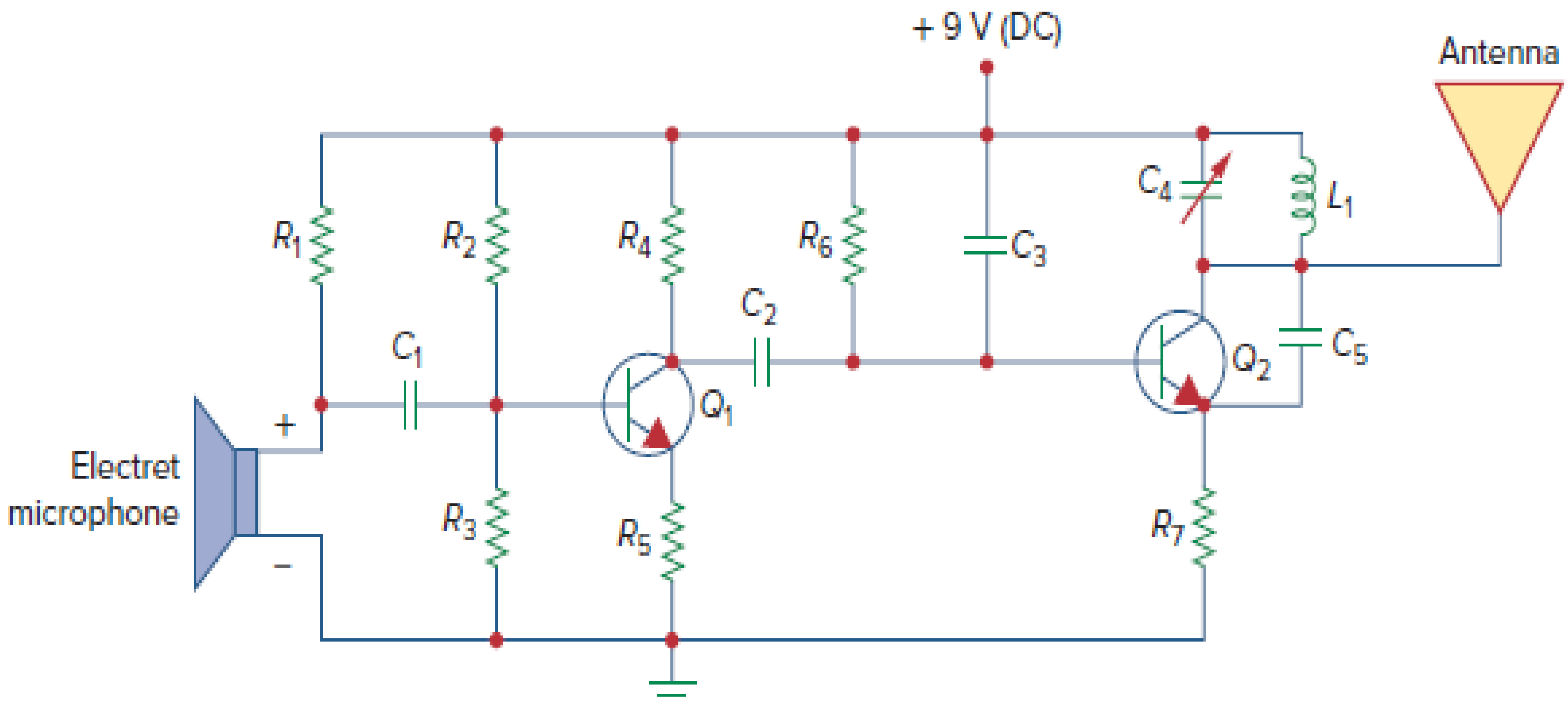


Figure 1.1 b: Electric circuit of a radio transmitter

1. 2 Systems of units

- we deal with measurable quantities.
- In this system, there are six principal (Fundamental) units from which the units of all other physical quantities can be derived. Table 1.1 shows the six units, their symbols, and the physical quantities they represent.

TABLE 1.1 The six basic SI units.

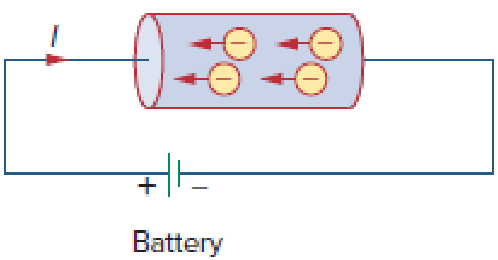
Quantity	Basic unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd

TABLE 1.2 The SI prefixes.

Multiplier	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

1.3 Charge and Current

- The most basic quantity in an electric circuit is the electric charge.
- Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs(C).
- All matter is made of fundamental building blocks known as atoms and that each atom consists of electrons, protons, and neutrons.
- We also know that the charge e on an electron is negative and equal in magnitude to 1.602×10^{-19} C, while a proton carries a positive charge of the same magnitude as the electron.
- The presence of equal numbers of protons and electrons leaves an atom neutrally charged.



- The current flow introduced by **Benjamin Franklin (1706–1790),**

Figure1.2 Electric current due to flow of electronic charge in a conductor

The following points should be noted about electric charge:

I. The coulomb is a large unit for charges. In 1C of charge, there are $1/(1.602 \times 10^{-19}) = 6.24 \times 10^{18}\ electrons$. Thus realistic or laboratory values of charges are on the order of pC, nC, or μC.

II. According to experimental observations, the only charges that occur in nature are integral multiples of the electronic charge $e = -1.602 \times 10^{-19}$ C.

III. The law of conservation of charge states that charge can neither be created nor destroyed, only transferred. Thus the algebraic sum of the electric charges in a system does not change.

- **Electric current** is the time rate of change of charge, measured in amperes (A).

Mathematically :

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

where current is measured in amperes (A), and 1 ampere = 1 coulomb/second

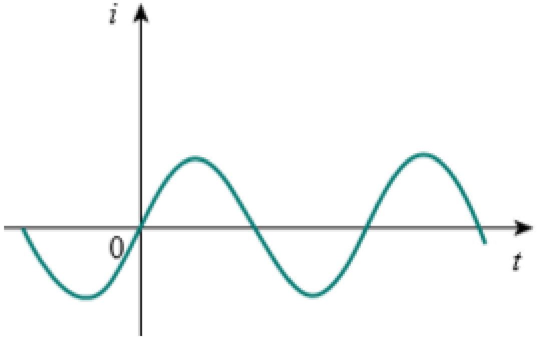
- The **charge transferred** between time t_0 and t is

$$q = \int_{to}^{t} i \, dt$$

- **Two common types of current:**

I. **A direct current (dc) is a current that remains constant with time.**

II. **An alternating current (ac) is a current that varies sinusoidally with time.**



Examples:

1. **How much charge is represented by 4,600 electrons?**

Solution: Each electron has -1.602×10^{-19} C. Hence 4,600 electrons will have -1.602×10^{-19} C/electron×4,600 electrons = $\mathbf{-7.369\times10^{-16}\ C}$

2.

a) The charge flowing through the imaginary surface of Fig. 1.4 is 0.16 C every 64 ms. Determine the current in amperes.

b) Determine the time required for $4*10^{16}$ electrons to pass through the imaginary surface of Fig. 1.4 if the current is 5 mA.

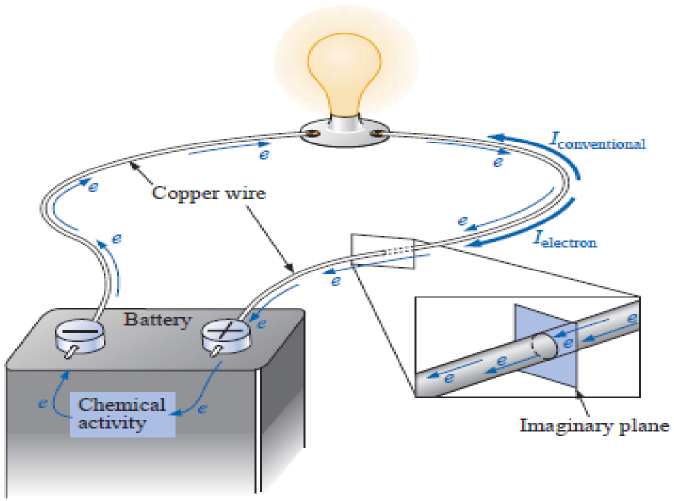


FIG. 1.4 Basic electric circuit

Solution: For (a)

$$I = \frac{Q}{t} = \frac{0.16\ \text{C}}{64 \times 10^{-3}\ \text{s}} = \frac{160 \times 10^{-3}\ \text{C}}{64 \times 10^{-3}\ \text{s}} = \mathbf{2.50\ A}$$

Solution: For (b)

First determine q: $4 \times 10^{16}\ \text{electrons} \left(\frac{1\ \text{C}}{6.242 \times 10^{18}\ \text{electrons}} \right) = 0.641 \times 10^{-2}\ \text{C}$

$$= 0.00641\ \text{C} = 6.41\ \text{mC}$$

$$t = \frac{Q}{I} = \frac{6.41 \times 10^{-3}\ \text{C}}{5 \times 10^{-3}\ \text{A}} = \mathbf{1.282\ s}$$

3. The total charge entering a terminal is given by q = 5t sin4πt mC. Calculate the current at t = 0.5 s.

Solution:

$$i = \frac{dq}{dt} = \frac{d}{dt}(5t \sin 4\pi t) \text{ mC/s} = (5 \sin 4\pi t + 20\pi t \cos 4\pi t) \text{ mA}$$

At $t = 0.5$,

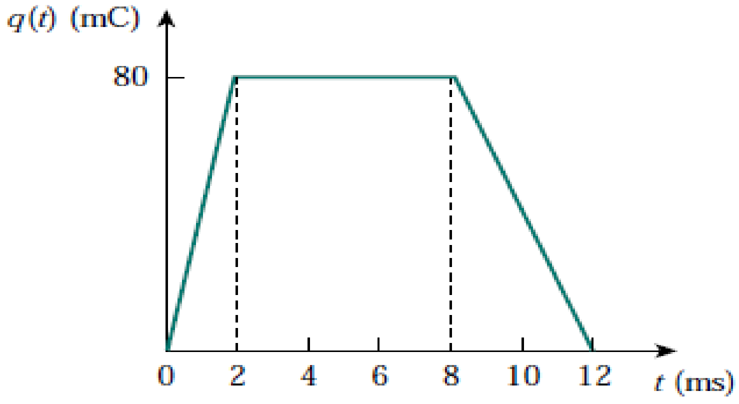
$$i = 5 \sin 2\pi + 10\pi \cos 2\pi = 0 + 10\pi = 31.42 \text{ mA}$$

4. Determine the total charge entering a terminal between t = 1s and t = 2s if the current passing the terminal is i = (3t² −t) A.

$$Q = \int_{t=1}^{2} i\, dt = \int_{1}^{2} (3t^2 - t)\, dt$$

$$= \left(t^3 - \frac{t^2}{2}\right)\Bigg|_1^2 = (8 - 2) - \left(1 - \frac{1}{2}\right) = 5.5 \text{ C}$$

5) The charge entering a certain element is shown in the figure below. Then, find the current at:
(a) t = 1 ms
(b) t = 6 ms
(c) t = 10 ms



Solution:

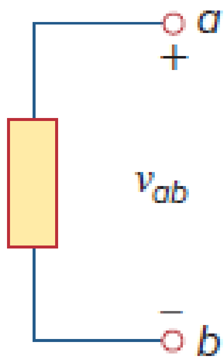
$$\text{(a) At } t = 1\text{ms}, \; i = \frac{dq}{dt} = \frac{80}{2} = \underline{\mathbf{40\ A}}$$

$$\text{(b) At } t = 6\text{ms}, \; i = \frac{dq}{dt} = \underline{\mathbf{0\ A}}$$

$$\text{(c) At } t = 10\text{ms}, \; i = \frac{dq}{dt} = \frac{80}{4} = \underline{\mathbf{-20\ A}}$$

1.4 Voltage (or potential difference)

- **It is the energy required to move a unit charge through an element, measured in volts (V).**



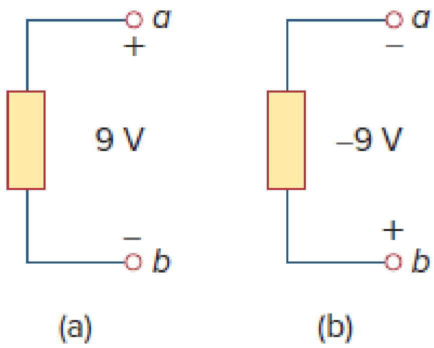
$$v_{ab} = \frac{dw}{dq}$$

where w is energy in joules (J) and q is charge in coulombs (C).

1 volt = 1 joule/coulomb = 1 newton meter/coulomb

Figure1.4 Polarity of voltage v_{ab}

❖ **Reference direction or voltage polarity.**



- Two equivalent representations of the same voltage v_{ab}:
  (a) Point *a* is 9 V above point *b*;
  (b) point *b* is −9 V above point *a*.

$$v_{ab} = -v_{ba}$$

1.5 Power and energy

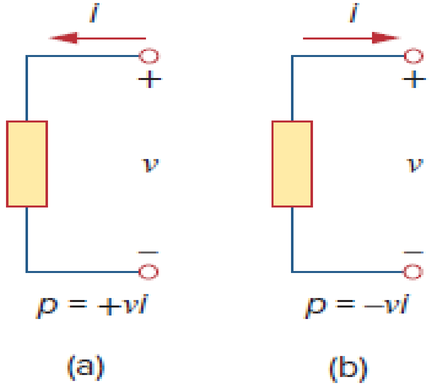
- Power is the time rate of expending or absorbing energy, measured in watts (W).

$$p = \frac{dw}{dt} \quad \Rightarrow \quad p = \frac{dw}{dt} = \frac{dw}{dq} * \frac{dq}{dt} = vi$$

  - **A time-varying quantity and is called the instantaneous power.**

❖ The sign of power

- If the power has a **+ sign**, power is being delivered to or absorbed by the element.
- Where as the power has **a − sign**, power is being supplied by the element.
- **Passive sign convention** is satisfied when the current enters through the positive terminal of an element and p=+vi. If the current enters through the negative terminal, p= −vi.



- The law of conservation of energy must be obeyed in any electric circuit

$$\sum p = 0$$

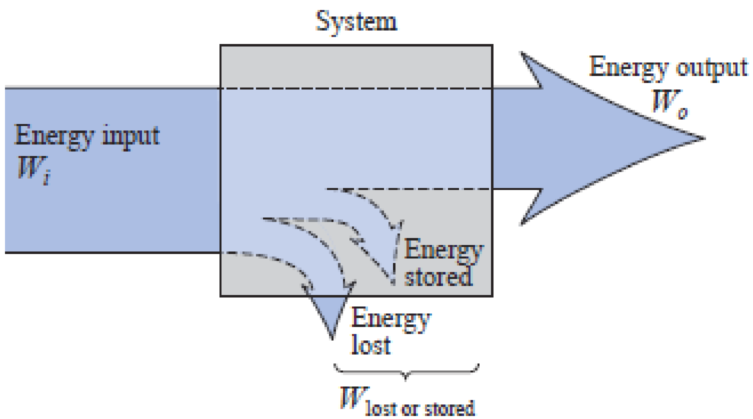
- The energy absorbed or supplied by an element from time t_0 to time t is

$$w = \int_{to}^{t} p\,dt = \int_{to}^{t} (vi)dt$$

- Energy is the capacity to do work, measured in joules (J).

1 Wh= 3,600 J

❖ Efficiency:



- Conservation of energy requires that
- **Energy input** = **energy output** + **energy lost or stored** in the system

$$\frac{w_{in}}{t} = \frac{w_{out}}{t} + \frac{w_{\text{lost or stored by the system}}}{t}$$

Since $P = W/t$, we have the following:

$$p_i = p_{out} + p_{\text{lost or stored}}$$

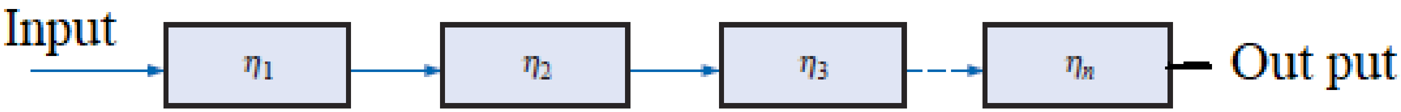
$$\text{Efficiency} = \frac{\text{power output}}{\text{power input}} \Rightarrow \eta = \frac{p_o}{p_i}$$

- In terms of the input and output energy and power, the **efficiency** in percent is given by

$$\eta\% = \frac{W_o}{W_i} \times 100\%$$

$$\eta\% = \frac{P_o}{P_i} \times 100\%$$

- The **overall efficiency** of a **cascaded system** is the multiplication of the **efficiency** of each system.



$$\eta_{total} = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdots \eta_n$$

Examples

1) An energy source forces a constant current of 2 A for 10 s to flow through a light bulb. If 2.3 kJ is given off in the form of light and heat energy, calculate the voltage drop across the bulb.

Solution:

The total charge is

$$\Delta q = I\,\Delta t = 2 \times 10 = 20\ \mathrm{C}$$

The voltage drop is

$$v = \frac{\Delta w}{\Delta q} = \frac{2.3 \times 10^{3}}{20} = 115\ \mathrm{V}$$

2) Find the power delivered to an element at $t = 3$ ms if the current entering its positive terminal is

$i = 5 \cos 60\pi t$ A and the voltage is: (a) $v = 3i$, (b) $v = 3\, di/dt$.

Solution:

(a) The voltage is $v = 3i = 15 \cos 60\pi t$; hence, the power is

$$p = vi = 75 \cos^2 60\pi t \text{ W}$$

At $t = 3$ ms,

$$p = 75 \cos^2 (60\pi \times 3 \times 10^{-3}) = 75 \cos^2 0.18\pi = 53.48 \text{ W}$$

(b) We find the voltage and the power as

$$v = 3\frac{di}{dt} = 3(-60\pi)5 \sin 60\pi t = -900\pi \sin 60\pi t \text{ V}$$

$$p = vi = -4500\pi \sin 60\pi t \cos 60\pi t \text{ W}$$

At $t = 3$ ms,

$$p = -4500\pi \sin 0.18\pi \cos 0.18\pi \text{ W}$$

$$= -14137.167 \sin 32.4° \cos 32.4° = -6.396 \text{ kW}$$

3) How much energy does a 100-W electric bulb consume in two hours?

Solution:

$$w = pt = 100\,(W) \times 2\,(h) \times 60\,(min/h) \times 60\,(s/min)$$

$$= 720{,}000 \text{ J} = 720 \text{ kJ}$$

This is the same as

$$w = pt = 100\,W \times 2\,h = 200\,Wh$$

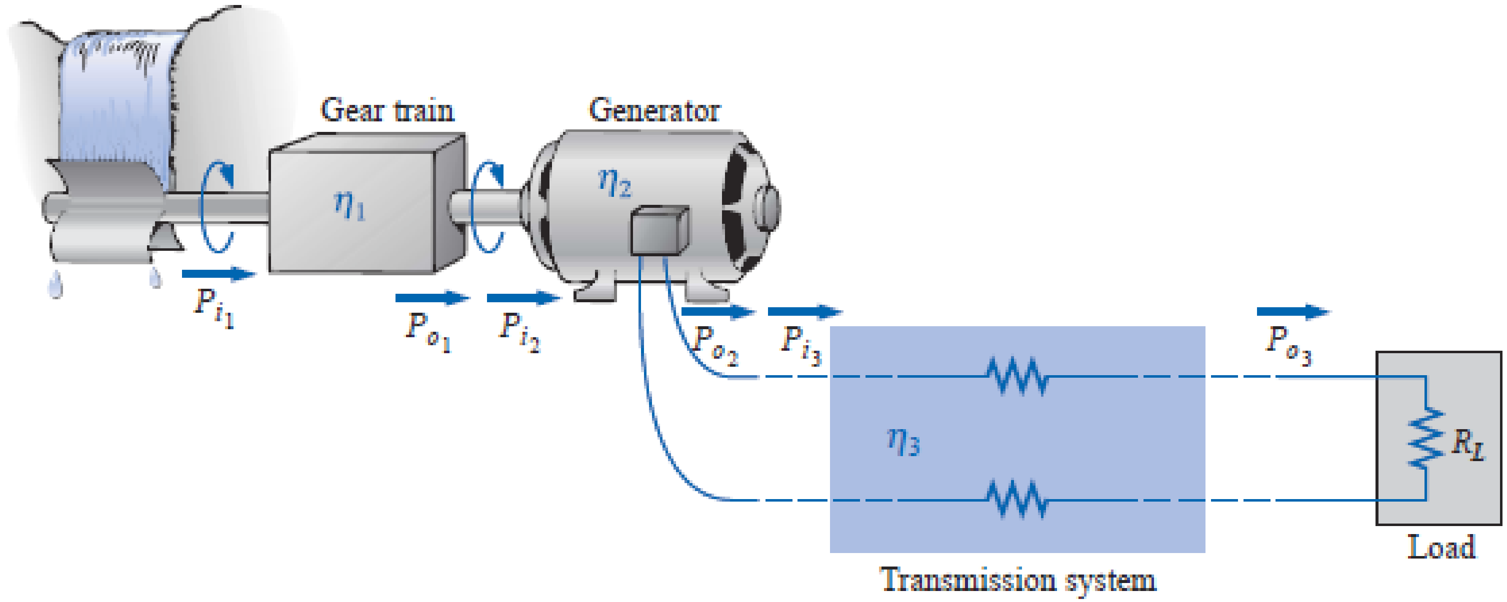
4) A 2-hp motor operates at an efficiency of 75%. What is the power input in watts? If the applied voltage is 220 V, what is the input current?

Solution:

$$\eta\% = \frac{P_o}{P_i} \times 100\% \quad \text{and} \quad P_i = \frac{1492 \text{ W}}{0.75} = \mathbf{1989.33 \text{ W}}$$

$$0.75 = \frac{(2 \text{ hp})(746 \text{ W/hp})}{P_i} \qquad P_i = EI \quad \text{or} \quad I = \frac{P_i}{E} = \frac{1989.33 \text{ W}}{220 \text{ V}} = \mathbf{9.04 \text{ A}}$$

5) Hydro power system



a) Find the overall efficiency of the system. if η_1= 90%, η_2= 85%, and η_3= 95%.

b) If the efficiency η_1 drops to 40%, find the new overall efficiency and compare the result with that obtained in (a)?

Solution:

(a)

$$\eta_T = \eta_1 \cdot \eta_2 \cdot \eta_3 = (0.90)(0.85)(0.95) = 0.727, \text{ or } 72.7\%$$

(b)

$$\eta_T = \eta_1 \cdot \eta_2 \cdot \eta_3 = (0.40)(0.85)(0.95) = 0.323, \text{ or } 32.3\%$$

- **Certainly 32.3% is noticeably less than 72.7%. The total efficiency of a cascaded system is therefore determined primarily by the lowest efficiency (weakest link) and is less than (or equal to if the remaining efficiencies are 100%) the least efficient link of the system.**

1.6 Circuit Elements

- An **element** is the basic building block of a circuit.
- **An electric circuit** is simply an interconnection of the elements.
- **Circuit analysis** is the process of determining voltages across (or the currents through) the elements of the circuit.

❑ **There are two types of elements found in electric circuits:**

I. **passive elements and**
II. **Active elements.**

- **An active element** is capable of **generating energy** while a passive element is not.
- Examples of **passive elements** are **resistors, capacitors**, and **inductors**.
- Typical **active elements** include **generators, batteries**, and **operational amplifiers.**

- The **most important active elements** are **voltage** or **current sources** that generally deliver power to the circuit connected to them.
- **There are two kinds of sources:**
  I. **independent and**
  II. **dependent sources.**
- **An ideal independent source** is an active element that provides a specified voltage or current that is completely independent of other circuit variables.

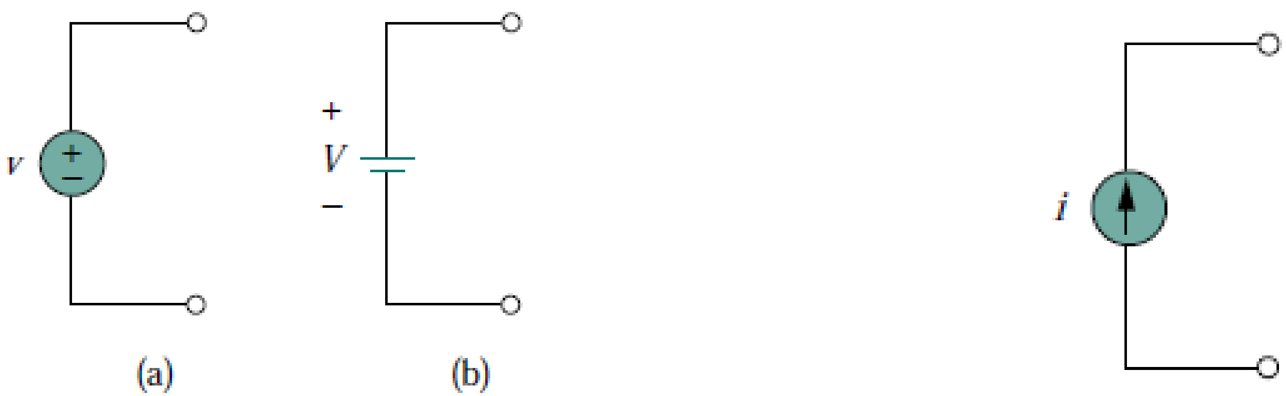


Figure 1.6 a) Symbols for independent voltage sources **(b)**Symbol for independent current source

- **An ideal dependent (or controlled) source is** an active element in which the source quantity is controlled by another voltage or current.

❑ **There are four possible types of dependent sources, namely:**

1. A voltage-controlled voltage source (VCVS).

2. A current-controlled voltage source (CCVS).

3. A voltage-controlled current source (VCCS).

4. A current-controlled current source (CCCS).

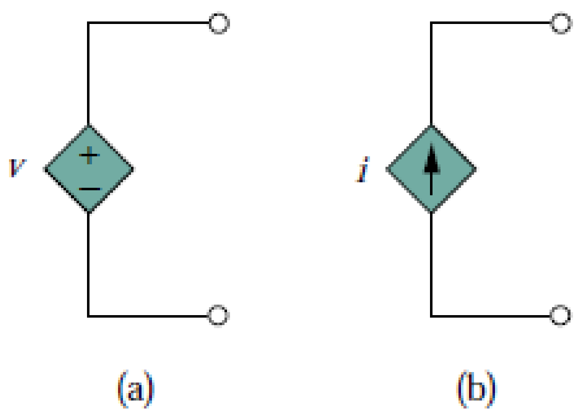
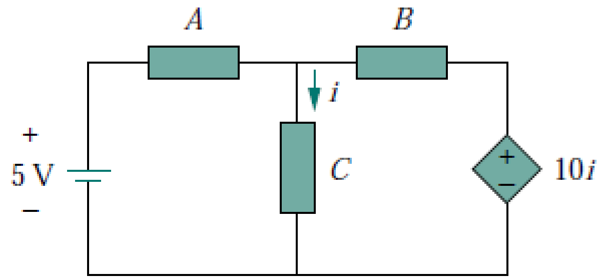


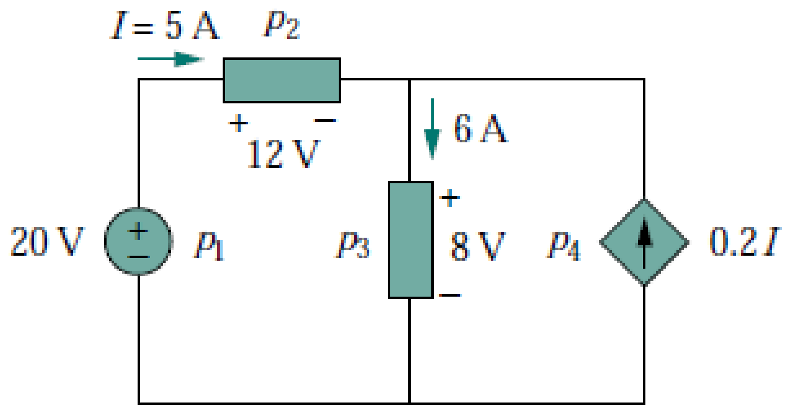
Figure 1.7 Symbols for: (a) dependent voltage source, (b) dependent current source.

- **Dependent sources are useful in modeling elements such as transistors, operational amplifiers and integrated circuits.**



Examples

1) **Calculate the power supplied or absorbed by each element in the Figure shown below.**



Solution:

For $\mathbf{p}_1$, the 5-A current is out of the positive terminal (or into the negative terminal); hence,

$$p_1 = 20(-5) = -100\,W$$ Supplied power

For $\mathbf{p}_2$ and $\mathbf{p}_3$, the current flows into the positive terminal of the element in each case.

$$p_2 = 12(5) = 60\,W$$ Absorbed power

$$p_3 = 8(6) = 48\,W$$ Absorbed power

- For $\mathbf{p_4}$, we should note that the voltage is **8V** (positive at the top), the same as the voltage for $\mathbf{p_3}$, since both the passive element and the dependent source are connected to the same terminals. (Remember that voltage is always measured across an element in a circuit.) Since the current flows out of the positive terminal,

$$\mathbf{p_4 = 8(-0.2I) = 8(-0.2 \times 5) = -8\,W} \quad \textbf{Supplied power}$$

We should observe that the **20V** independent voltage source and **0.2I** dependent current source are supplying power to the rest of the network, while the two passive elements are absorbing power. Also,

$$\mathbf{p_1 + p_2 + p_3 + p_4 = -100 + 60 + 48 - 8 = 0}$$

- There for the **total power supplied equals** the **total power absorbed**.

Practical Problem

1) **The electron beam in a TV picture tube carries 10^{15} electrons per second. As a design engineer, determine the voltage *Vo* needed to accelerate the electron beam to achieve 4 W**

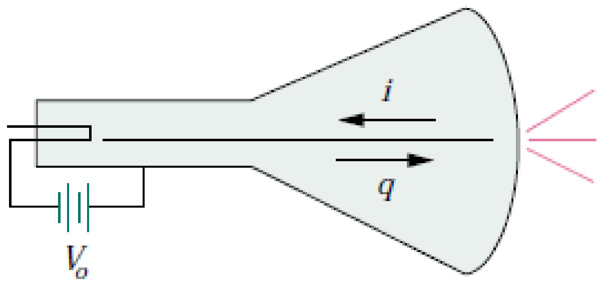


Figure 1.9 A simplified diagram of the cathode-ray tube.

Solution:

- The charge on an electron is $e = -1.6 \times 10^{-19}$ C
- If the number of electrons is n, then $q = ne$ and

$$i = \frac{dq}{dt} = e\frac{dn}{dt} = (-1.6 \times 10^{-19})(10^{15}) = -1.6 \times 10^{-4} \text{ A}$$

- **The beam power is** $p = V_o i$ or $V_o = \frac{p}{i} = \frac{4}{1.6 \times 10^{-4}} = 25{,}000$ V

Thus the required voltage is 25 kV.

2) **A home owner consumes 400 kWh in January. Determine the electricity bill for the month using the following residential rate schedule:**

Base monthly charge of $12.00.

First 100 kWh per month at 16 cents/kWh.

Next 200 kWh per month at 10 cents/kWh.

Over 200 kWh per month at 6 cents/kWh.

Solution:

We calculate the electricity bill as follows.

$$\text{Base monthly charge} = \$12.00$$

$$\text{First 100 kWh @ \$0.16/kWh} = \$16.00$$

$$\text{Next 200 kWh @ \$0.10/kWh} = \$20.00$$

$$\text{Remaining 100 kWh @ \$0.06/kWh} = \$6.00$$

$$\text{Total Charge} = \$54.00$$

$$\text{Average cost} = \frac{\$54}{100 + 200 + 100} = 13.5 \text{ cents/kWh}$$

Thank You For Your Attention!

Questions?