MEC 3102 – PRODUCTION ENGINEERING I AND ELECTRICITY & ELECTRONICS II

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LECTURE 3[1]

D.C. and A.C Machines

- DC. Generator
- A.C. Generator
- D.C. Motor
- Induction Motor

i. Electromechanical Energy Conversion Devices

- **Definition**: The conversion of electrical energy into mechanical energy or vise-versa is referred to as Electromechanical Energy Conversion
- A device (machine) which makes possible the conversion of energy from electrical to mechanical form or from mechanical to electrical form is called an Electromechanical energy conversion device.
- Depending upon the conversion of energy from one from to the other, the electromechanical device can be named as **motor** or **generator**.

1. **Motor**: This is an electromechanical device (electrical machine) which converts electrical energy or power (EI) into mechanical energy or power (ωT) is called a **motor**.

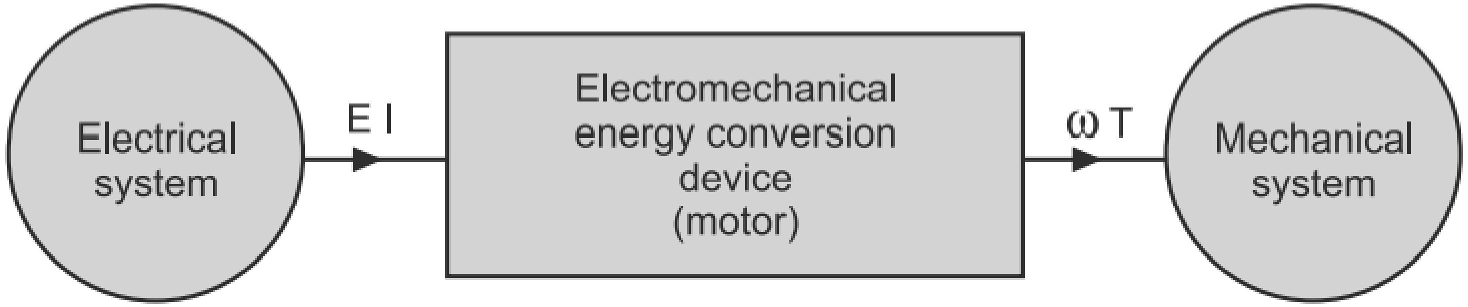


Fig. 1 Motor block diagram of energy conversion

Application:

- driving industrial machines e.g., hammer presses, drilling machines, lathes, shapers, milling machines, blowers for furnaces etc., and
- domestic appliances e.g., refrigerators, fans, water pumps, toys, mixers etc

2. **Generator**: An electro-mechanical device (electrical machine) which converts mechanical energy or power (ωT) into electrical energy or power (EI) is called **generator**.

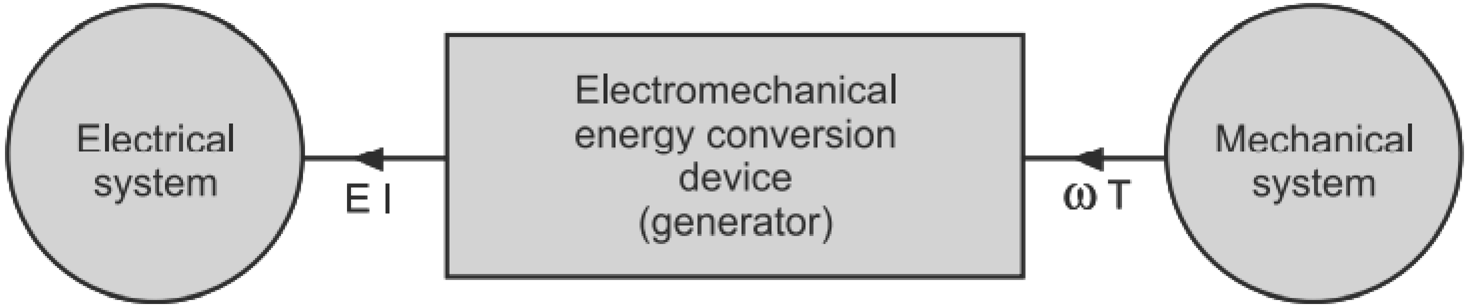


Fig. 2 Generator block diagram of energy conversion

Application:

hydro-electric power plants, steam power plants, diesel power plants, nuclear power plants and in automobiles.

- The same electromechanical device is capable of operating either as a motor or generator depending upon whether the input power is electrical or mechanical. Thus, the motoring and generating action is reversible.

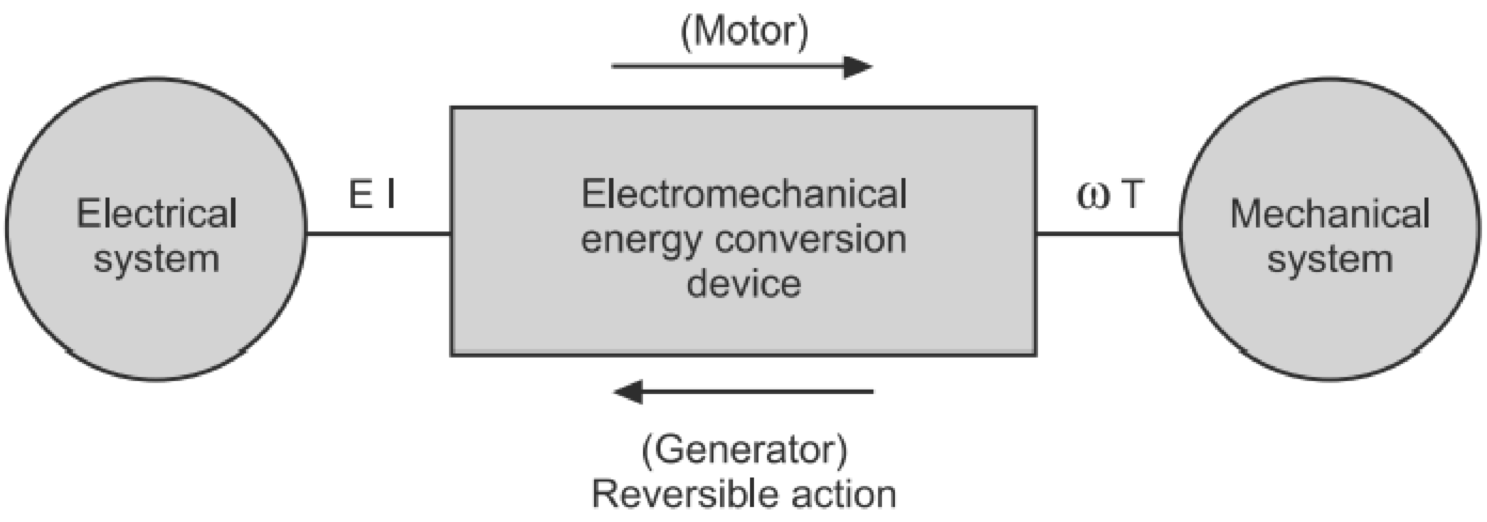


Fig. 3 Same machine can work as a generator or motor

- The conversion of energy either from electrical to mechanical or from mechanical to electrical takes place through magnetic field.

ii. Elementary Concept of Electrical Machines

Operation of Machine as a Generator

- The operation of all rotating electrical machines are based on fundamental electromagnetic laws:
- ✓ When the magnetic flux linking a conductor or coil changes, an e.m.f. is induced in it whose magnitude is given by;

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

- Faraday's law

- ✓ When a current-carrying conductor of length l is placed at right angles to a uniform magnetic field (of flux density **B**), experiences a mechanical force (F) whose magnitude is given by;

$$F = Bli$$

- Maxwell's law

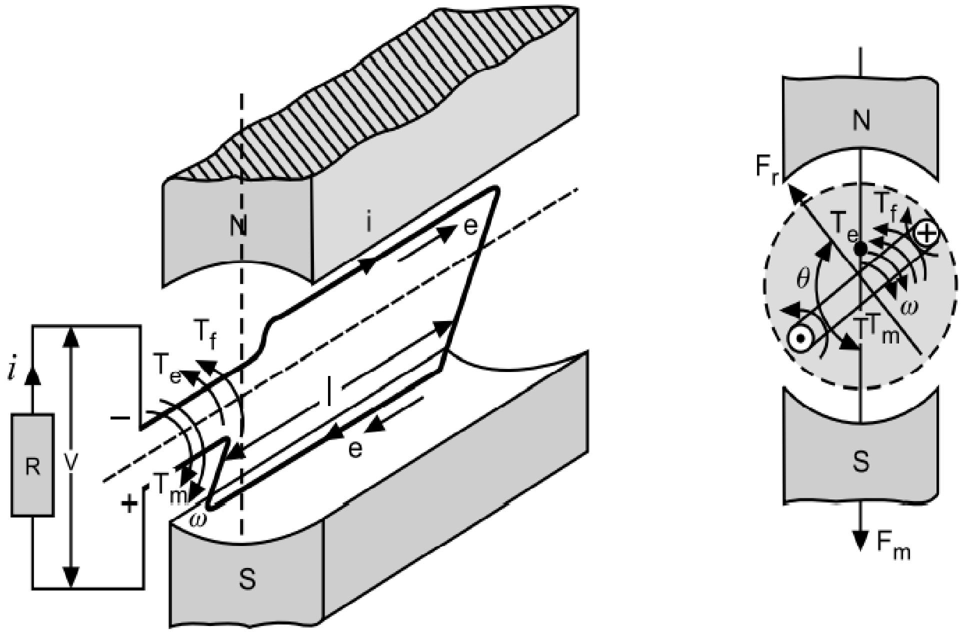


Fig. 4 Concept of generator

Operation of Machine as a Generator

In figure 4:

- The coil is rotated in clockwise direction at an angular velocity of ω radians per second by some outside driving mechanical torque T_m.
- The coil sides cut the magnetic field and emf (e) is induced in the coil.
- The coil is connected to an external load resistor R, therefore current (i) flows through the coil and external load resistor.
- When current flows through the coil conductors, they produce their own magnetic field. The direction of this rotor field is marked by arrowhead F_r.
- The rotor field F_r tries to come in line with the main field F_m and an electromagnetic torque T_e is produced in the opposite direction to that of the rotation.

Torque at no-load

- If the coil circuit is not closed, no current would flow through the coil and hence no electromagnetic torque will be developed (i.e., T_e = 0), under such a condition the opposition is only due to frictional torque (neglecting iron losses).
- Therefore, the mechanical torque Tm applied must be sufficient to overcome the frictional torque. Thus,

$$T_m = T_f$$

Where, T_f is the frictional torque. Frictional torque always acts in opposite direction to the direction of rotation.

Torque at load

- When the load resistance is connected, current flows and electromagnetic torque is produced in opposite direction to that of mechanical torque.
- The mechanical torque T_m must be sufficient to overcome the electromagnetic torque and frictional torque (iron losses neglected). Thus,

$$T_m = T_e + T_f \qquad (4.1)$$

or $$\omega T_m = \omega T_e + \omega T_f \qquad (4.2)$$

or $$\omega T_e = \omega T_m - \omega T_f \qquad (4.3)$$

Where,

$\omega T_m =$ Mechanical input power, $\omega T_f =$ Power losses due to friction, and $\omega T_e =$ Mechanical power developed in the rotor which is converted into electrical power.

- Induced emf in the coil when conductors move perpendicular to the magnetic field,

$$e = 2Blu \qquad (4.4)$$

Multiplying by current (i) through out,

$$ei = 2Bilu = 2Fu, \text{ since } F = Bil$$

expanding

$$ei = 2F \times radius \times \frac{u}{radius}, T = 2F \times radius, \text{ and } \omega = \frac{u}{radius}$$

Hence,

$$ei = T_e \times \omega$$

∴

$$ei = \omega T_e \qquad (4.5)$$

If r is the internal resistance of the coil,

$$e = ir + iR$$

multiplying both sides by i, we get,

$$ei = i^2 r + i^2 R \text{ or } ei - i^2 r = vi \qquad (4.6)$$

Where,

$ei =$ electrical power generated, $i^2 r =$ power lost in the resistance of coil, called copper losses, and vi or $i^2 R =$ electrical power output to the load.

Thus, we conclude that out of the input power (ωT_m), only ωT_e is the mechanical power which is converted into electrical power (ei)

The power flow diagram (neglecting iron losses) for the generator

- After subtracting the copper losses (i^2r), the electrical power available at the load is only i^2R. This is how the conversion of power takes place in electrical machine working as a generator.

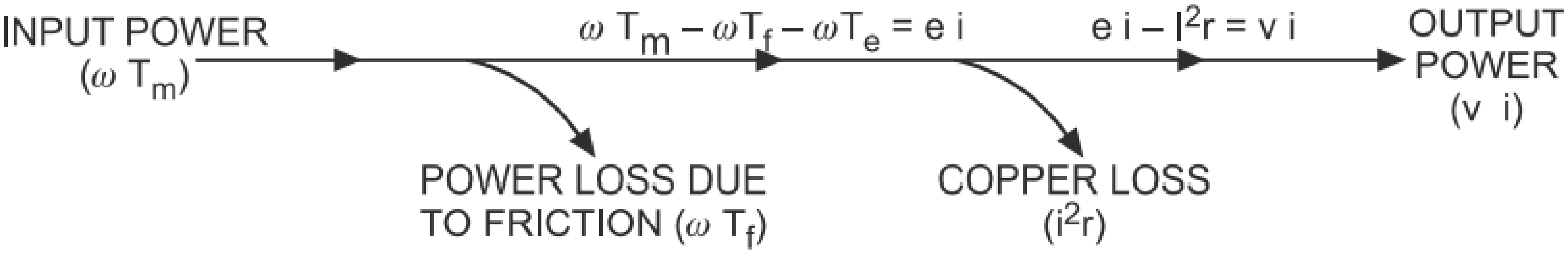


Fig. 5 Power flow in generator action

1. DC Generator

- An electro-mechanical energy conversion device (or electrical machine) that converts mechanical energy or power (ωT) into DC electrical energy or power (EI) is called **D.C. generator**.
- The basic principle of a DC generator is electro-magnetic induction i.e., “When a conductor cuts across the magnetic field, an emf is induced in it.

1.1 Simple Loop Generator

Note that e.m.f. generated in the loop is alternating one

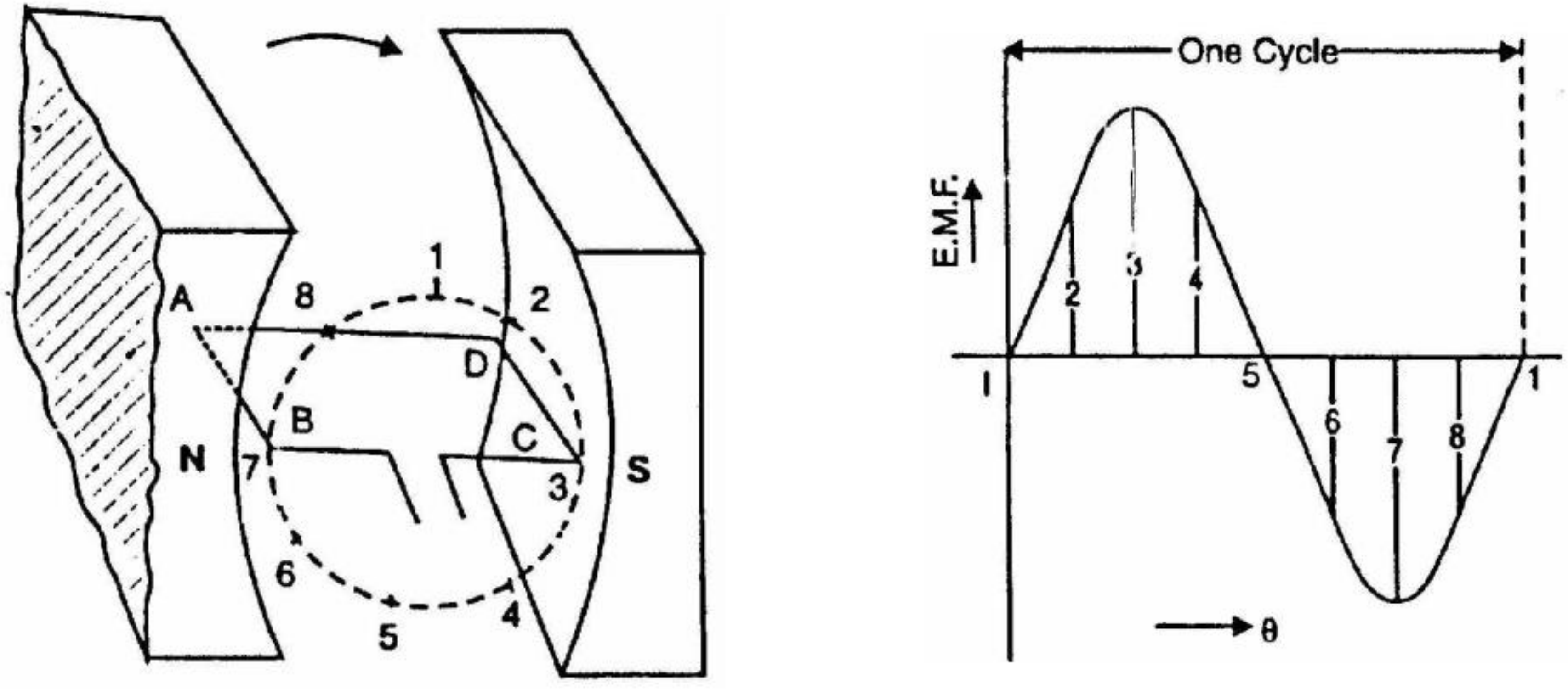


Fig. 1.1 Generated e.m.f.

1.2 Main Constructional Features

The d.c. generators and d.c. motors have the same general construction. Any d.c. generator can be run as a d.c. motor and vice-versa. All d.c. machines have five principal components viz.,

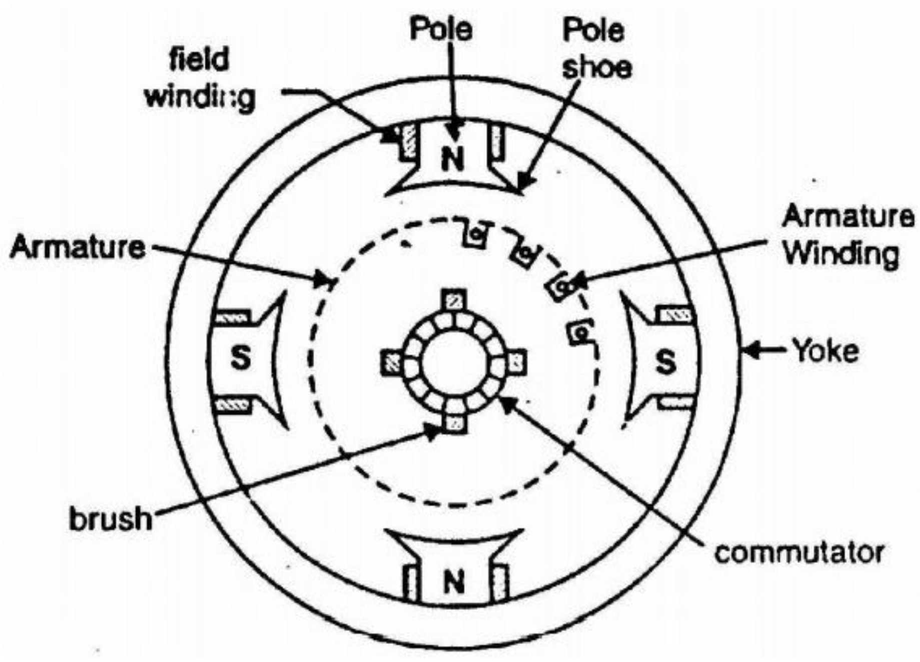
(i) Field system

(ii) Armature core

(iii) armature winding

(iv) Commutator

(v) Brushes



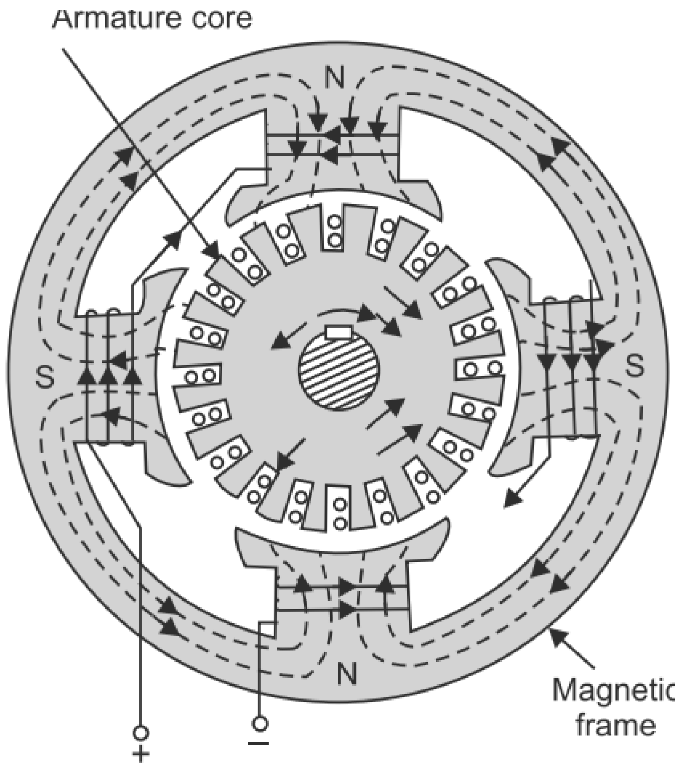


Fig. 1.2

1.6 E.M.F. Equation of a D.C. Generator

❖Derivation of an expression for the e.m.f generated in a d.c. generator.

Let $\mathrm{P} =$ Number of poles of the machine.

$\emptyset =$ Flux per pole in Wb

$\mathrm{Z} =$ Total number of armature conductors.

$\mathrm{N} =$ Speed of armature in rpm

$E_g =$ e.m.f. of the generator $=$ e.m.f./parallel path

$A =$ number of parallel paths $= 2$ ... for wave winding

$=$ P ... for lap winding.

Flux cut by one conductor in one revolution of the armature,

$$d\emptyset = P\emptyset \text{ Wb}$$

Time taken to complete one revolution,

$$dt = 60/N \text{ second}$$

Average induced emf in one conductor,

$$e = \frac{d\emptyset}{dt} = \frac{P\emptyset \times N}{60} \text{ Volts}$$

∴ Average induced emf across each parallel path or across the armature terminals,

E_g = (e.m.f/conductor) × No. of conductors in series per parallel path

$$E_g = \frac{P\emptyset N}{60} \times \frac{Z}{A} = \frac{PZ\emptyset N}{60A} \quad \text{Volts} \qquad (1.1)$$

Or

$$E_g = \frac{PZ\emptyset n}{A} \qquad (1.2)$$

For,

$$n = \frac{N}{60}$$

Note the following:

i. Equation (1.1) is also valid for a d.c. motor. Only that the induced voltage is called counter e.m.f. or back e.m.f. E_b(= $PZ\emptyset N/60A$)

ii. For a given machine, the number of poles and number of conductors per parallel path (Z/A) are constant.

$$E_g = K\emptyset n, \text{ where } K = \frac{PZ}{A} \text{ is a constant or } E_g \propto \emptyset n$$

$$E_g \propto \emptyset \omega, \text{ where } \omega = \frac{2\pi N}{60} \text{ is the angular velocity in radian/second}$$

- Thus, we can conclude that the induced e.m.f is directly proportional to flux per pole and speed.
- This induced e.m.f is fundamental phenomenon to all DC machines whether they are working as generator or motor. However, when the machine is working as a generator, this induced emf is called generated emf and is represented as E_g.
- Whereas, in case the machine is working as a motor, this induced emf is called back emf as it acts opposite to the supply voltage V. Then

$$E_b = \frac{PZ\emptyset N}{60A} \text{ Volts}$$

Examples:

1. A 6-pole lap-wound d.c. generator has 600 conductors on its armature. The flux per pole is 0.02 Wb. Calculate:

i. The speed at which the generator must be run in order to gerate 300 V.

ii. What would be the speed if the generator were wave-wound?

Solution.

i. Lap-wound: A = P

$$E_g = \frac{PZ\emptyset N}{60A}$$

$$\therefore \quad N = \frac{60A \times Eg}{PZ\phi} = \frac{60 \times 6 \times 300}{6 \times 600 \times 0.02} = \mathbf{1500\ r.p.m}$$

ii. Wave-wound:

$$N = \frac{60A \times Eg}{PZ\phi} = \frac{60 \times 2 \times 300}{6 \times 600 \times 0.02} = \mathbf{500\ r.p.m}$$

2. A 6-pole, 600 r.p.m. lap-wound generator has an armature with 90 slots. If each coil has 4 turns, Calculate the flux per pole required to generate an e.m.f of 288 volts.

Solution:

Given, $P = 6, N = 600 \text{ rpm}, E_g = 288\,V, \quad \emptyset = ?$

Each turn has two active conductors and 90 coils are required to fill all the 90 slots.

$\therefore \quad Z = 90 \times 4 \times 2 = 720$

But, $\quad E_g = \frac{PZ\emptyset N}{60A}$

=> $\quad \phi = \frac{E_g \times 60A}{PZN} = \frac{288 \times 60 \times 6}{6 \times 720 \times 600} = \mathbf{0.04\,Wb}$