UNIT 5 - CHAPTER 9

DC MACHINE

## 9.1 ELECTRO MECHANICAL ENERGY CONVERSION (EMEC)

According to electro mechanical energy conversion "Electrical energy can be converted in to mechanical energy or mechanical energy can be converted in to electrical energy".

EMEC based on the principle of energy conservation.

According to energy conservation "Energy can neither be created nor be destroyed only we can convert the energy from one form to other form".

For converting the electrical energy and mechanical energy to each other we have to connect both the energy with the help of a field called coupling field. Two types of field are available to connect both the energy namely

(1) Electric field

(2) Magnetic field

The field which we use to connect the energy is magnetic field. As shown in fig. 9.1.

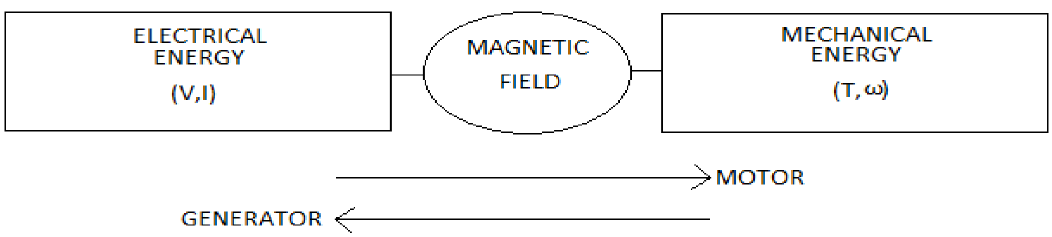



**Fig. 9.1**

**Motor:** The machines which convert electrical energy into mechanical energy is called motor. We have to supply input of voltage (V) and current (I) to motor and motor will give us torque (T) and angular speed ($\omega$) as output.

**Generator:** The machines which convert mechanical energy into electrical energy is called generator. We have to supply input of torque (T) and angular speed ($\omega$) to generator and generator will give us voltage (V) and current (I) as output.

## 9.2 CLASSIFICATION OF ELECTRICAL MACHINE

We are having two types of electrical supply so electrical machine are of two types as shown in fig. 9.2.

.

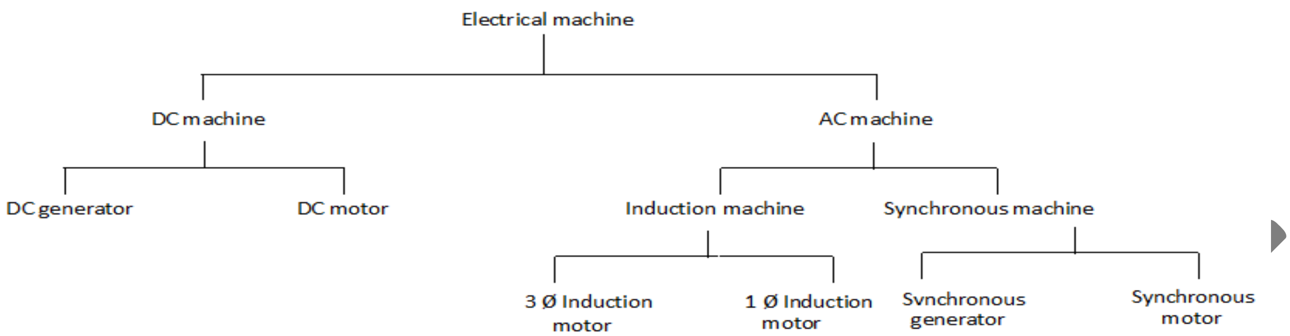



**Fig. 9.2**

## 9.3 CONSTRUCTION OF DC MACHINE

Construction of DC machine is same whether it is generator or motor. The construction of DC machine consist of the following parts is shown in fig. 9.3.

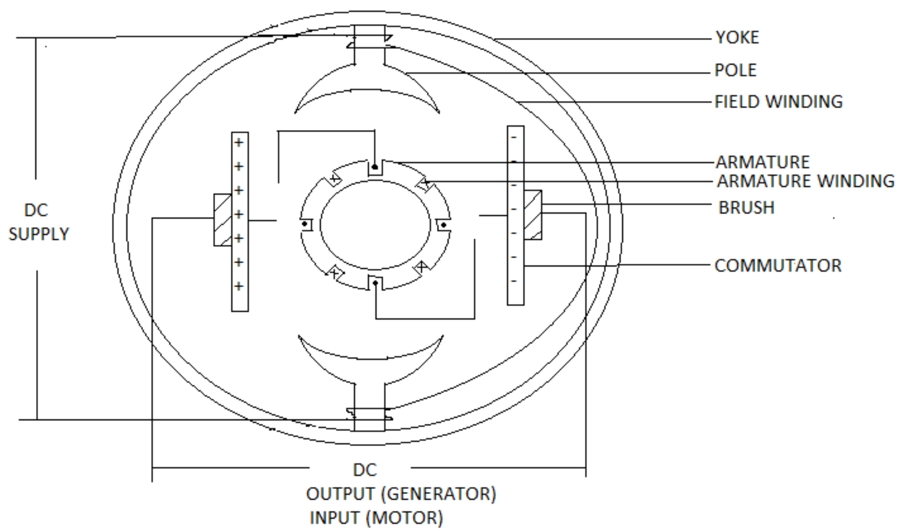



**Fig. 9.3**

(1) Yoke: It is the outer cover of the DC machine. The poles of the DC machine are fixed on the yoke. The yoke serve the following two functions.

(i) It provides the mechanical support to the machine.

(ii) It save the winding from the dust, water etc.

(2) Field system: It is the stationary part of the DC machine. The purpose of the field system is to provide the coupling magnetic field. The field system of the DC machine consist the poles and field winding. When DC supply is provided to the field winding the magnetic field is produce between the poles.

(3) Armature: It is the rotating part of the DC machine. The purpose of the armature is to rotate the armature winding in the magnetic field. The shape of the armature is cylindrical and it consist the slot on its outer surface. The conductor are placed in these slots and known as armature winding. A small air gap exists between the poles and armature.Armature winding are basically of two types.

(i) LAP winding: A = P
(ii) WAVE winding: A = 2
Where A = Number of parallel path
P = Number of poles

(4) Commutator: A commmutator is a device connected between the armature winding and brushes. The purpose of the commutator is a mechanical rectifier which convert
AC to DC in the DC generator.
DC to AC in DC motor.

(5) Brushes: The brushes are connected between the commutator and external circuit. The purpose of the brushes is to collect (generator) and supply (motor) current from the armature. In every machine 2 brush are used.

## 9.4 DC GENERATOR

The DC generator is machines which convert mechanical energy into DC electrical energy.

**Principle:** The DC generator work on the principle of faraday law of Electro Magnetic induction (EMI). According to this law "If there is the rate of change in the flux link with the winding then EMF will induced in the winding".

**Working:** The working of the DC generator is as follow.

(1) The DC supply is given to the field winding, so a uniform magnetic flux is setup.
(2) A mechanical energy is provided to the armature by which armature will rotate.
(3) Armature winding is connected on the armature so armature winding will also rotate.
(4) This armature winding cut the flux, so according to faraday law an EMF will induce in the armature winding.
(5) This EMF is in the nature of AC, with the help of commutator this AC convert into DC.
(6) So the mechanical energy given to the armature is converted in to DC electrical energy.

## 9.5 EMF EQUATION OF DC GENERATOR

Let

$\emptyset$ = Flux per pole in weber
$P$ = Number of pole
$N$ = Speed of armature in rpm
$Z$ = Total number of armature conductor
$A$ = Number of parallel path
$E_g$ = Generated emf

Magnetic flux cut by one conductor in one revolution

$$d\emptyset = P\emptyset$$

Time taken to complete one revolution

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

According to faraday law of EMI the induced emf

$$e = \frac{d\emptyset}{dt}$$

Induced emf by one conductor in one revolution

$$\frac{\text{Generated emf}}{\text{conductor}} = \frac{P\emptyset}{60/N} = \frac{P\emptyset N}{60}$$

Total generated emf

$$E_g = \text{emf per parallel path}$$
$$= \left(\frac{\text{Generated emf}}{\text{conductor}}\right) \times \text{Number of conductor in per parallel path}$$
$$= \frac{P\emptyset N}{60} \times \frac{Z}{A}$$
$$E_g = \frac{P\emptyset NZ}{60A}$$

For LAP winding A = P

$$E_g = \frac{\emptyset NZ}{60}$$

For WAVE winding A = 2

$$E_g = \frac{P\emptyset NZ}{120}$$

## 9.6 DC MOTOR

The DC motor is machines which convert DC electrical energy into mechanical energy.

**Principle:** The DC motor work on the principle of "When a current carrying conductor is placed in the magnetic field, then conductor experience a force and conductor will rotate".

**Working:** The working of the DC motor is as follow.

(1) The DC supply is given to the field winding, so a uniform magnetic flux is setup.
(2) A DC electrical energy is provided to the armature, commutator convert this DC into AC and supply this AC to the armature winding.
(3) Now armature winding is current carrying conductor and placed in the magnetic field, so armature winding experience a force and armature winding will rotate.
(4) The armature winding is connected on the armature so with the armature winding, armature will also rotate.
(5) So the DC electrical energy given to the armature is converted in to mechanical energy.

## 9.7 BACK EMF IN THE DC MOTOR

When the armature winding of the motor rotates, the armature winding cut the magnetic flux. Therefore an EMF is induced in the armature winding. This EMF is known as back EMF because this RMF always opposes the supply voltage. The expression for the back EMF is

$$E_b = \frac{P\emptyset NZ}{60A}$$

**Importance:** The presence of back emf makes the DC motor a self- regulating machine. It makes the DC motor to draw as much armature current which is sufficient to produce the required torque.

## 9.8 TORQUE EQUATION OF THE DC MOTOR

Let

$$T_a = \text{Armature torque}$$

$E_b$ = Back emf
$I_a$ = Armature current
$N$ = Motor speed tn rpm
$\omega$ = Angular speed

Electrical power in the armature = $E_b I_a$

Mechanical power developed by the armature = $T_a \omega = T_a \frac{2\pi N}{60}$

The electrical power in the armature is converted in to the mechanical power so

Electrical power in the armature = Mechanical power developed by the armature

$$E_b I_a = T_a \frac{2\pi N}{60}$$

We know

$$E_b = \frac{P\emptyset NZ}{60A}$$

So

$$\frac{P\emptyset NZ}{60A} I_a = T_a \frac{2\pi N}{60}$$

$$T_a = \frac{1}{2\pi} \frac{P\emptyset Z I_a}{A}$$

$$T_a = 0.159 \frac{P\emptyset Z I_a}{A}$$

The P, Z, A are constant, so

$$T_a \propto \emptyset I_a$$

Torque is proportional to the flux $\emptyset$ and Armature current $I_a$

For DC series motor

$$\emptyset \propto I_a \quad \text{so} \quad T_a \propto I_a^2$$

For DC shunt motor

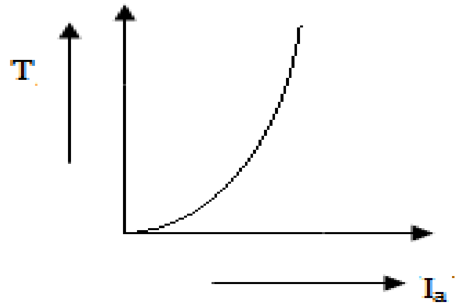
$$\emptyset \propto \text{constant} \quad \text{so} \quad T_a \propto I_a$$

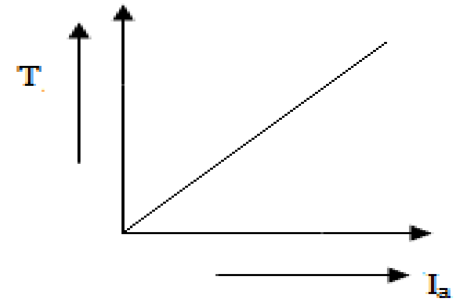
## 9.9 CHARACTERISTIC OF DC MOTOR

The characteristic of the DC motor are the graph between the different quantities.

9.9.1 **Torque and Armature current characteristic ($\mathbf{T/I_a}$):** It is the graph between the Torque ($T$) and Armature current ($I_a$).

| | DC series | DC shunt |
|---|---|---|
| We know | $T_a \propto I_a^2$ | $T_a \propto I_a$ |



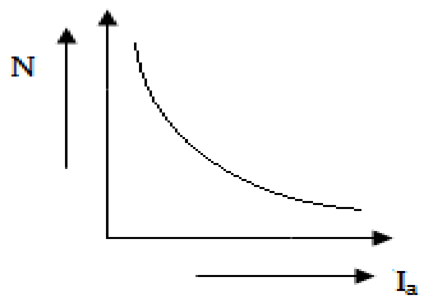




9.9.2 **Speed and Armature current characteristic** $(\mathbf{N/I_a})$**:** It is the graph between the Speed (N) and Armature current $(I_a)$.

DC series

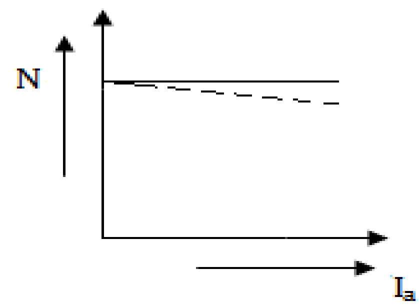
We know

$$N \propto \frac{1}{I_a}$$




DC shunt

$$N \propto \text{constant}$$

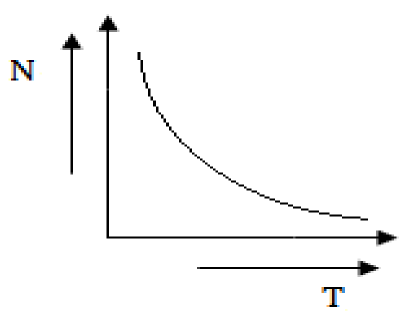



9.9.3 **Speed and Torque characteristic** $(\mathbf{N/T})$**:** It is the graph between the Speed (N) and Torque (T).

DC series

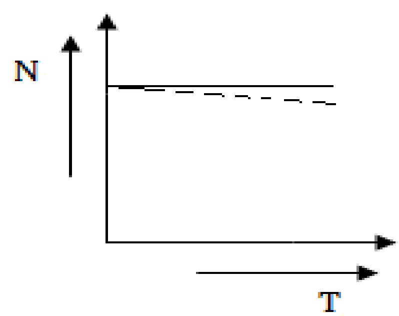
We know

$$N \propto \frac{1}{T}$$




DC shunt

$$N \propto \text{constant}$$



## 9.10 TYPES OF THE DC MACHINE

The field winding and armature winding are connected to each other. They are connected either in series or parallel, so DC machines are of two types

9.10.1 **DC series machine:** In DC series machine field and armature winding are connected in series. The DC series generator and DC series motor is shown in fig. 9.4 (a) and 9.4 (b) respectively. In the case of generator the direction of current is outward and in the case of motor the direction of current in inward.

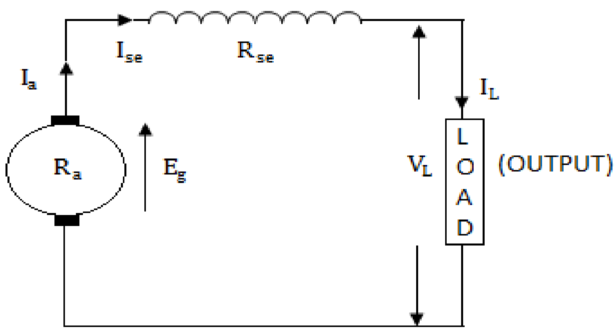



**Fig. 9.4 (a)**

Where

$R_a$ = Armature resistance

$I_a$ = Armature current

$E_g$ = Generated emf

$I_{se}$ = Series field winding current

$R_{se}$ = Series field winding resistance

$V_L$ = Load voltage (Ouptut voltage)

$I_L$ = Load current (Output current)

**Current equation**

$$I_a = I_{se} = I_L$$

**Voltage equation**

$$E_g = I_a R_a + I_{se} R_{se} + V_L$$

**Electrical power develop in armature**

$$P_a = E_g I_a$$

**Power delivered to the load (Output power)**

$$P_L = V_L I_L$$

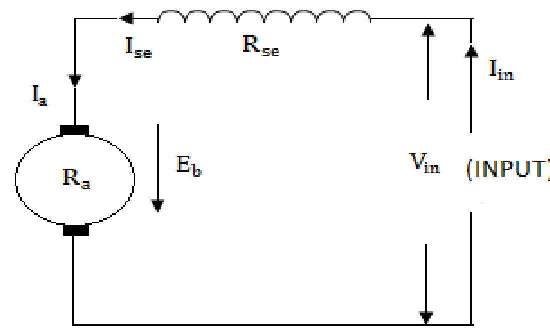



**Fig. 9.4 (b)**

Where

$R_a$ = Armature resistance

$I_a$ = Armature current

$E_b$ = Back emf

$I_{se}$ = Series field winding current

$R_{se}$ = Series field winding resistance

$V_{in}$ = Input voltage

$I_{in}$ = Input current

**Current equation**

$$I_a = I_{se} = I_{in}$$

**Voltage equation**

$$V_{in} = I_{se} R_{se} + I_a R_a + E_b$$

**Electrical power develop in armature**

$$P_a = E_b I_a$$

**Power input to the motor (Input power)**

$$P_{in} = V_{in} I_{in}$$

9.10.2 **DC shunt machine:** In DC shunt machine field and armature winding are connected in parallel. The DC shunt generator and DC shunt motor is shown in fig. 9.5 (a) and 9.5 (b) respectively.

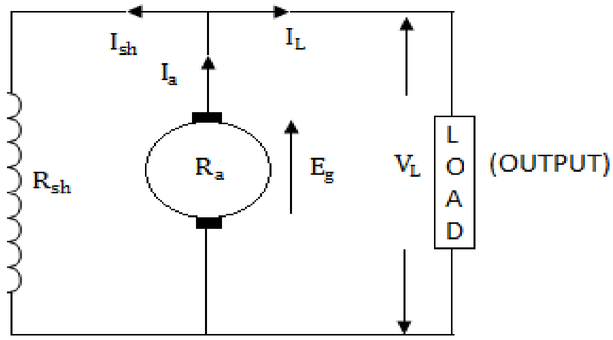



**Fig. 9.5 (a)**

Where

$R_a$ = Armature resistance

$I_a$ = Armature current

$E_g$ = Generated emf

$I_{sh}$ = Shunt field winding current

$R_{sh}$ = Shunt field winding resistance

$V_L$ = Load voltage (Ouptut voltage)

$I_L$ = Load current (Output current)

**Current equation**

$$I_a = I_{sh} + I_L$$

**Voltage equation**

$$E_g = I_a R_a + V_L$$

**Electrical power develop in armature**

$$P_a = E_g I_a$$

**Power delivered to the load (Output power)**

$$P_L = V_L I_L$$

**Shunt field winding current**

$$I_{sh} = \frac{V_L}{R_{sh}}$$

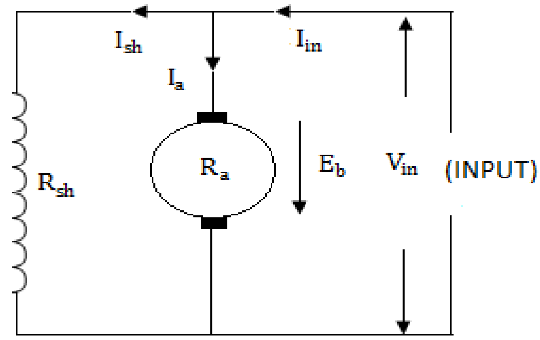



**Fig. 9.5 (b)**

Where

$R_a$ = Armature resistance

$I_a$ = Armature current

$E_b$ = Back emf

$I_{sh}$ = Shunt field winding current

$R_{sh}$ = Shunt field winding resistance

$V_{in}$ = Input voltage

$I_{in}$ = Input current

**Current equation**

$$I_{in} = I_a + I_{sh}$$

**Voltage equation**

$$V_{in} = I_a R_a + E_b$$

**Electrical power develop in armature**

$$P_a = E_b I_a$$

**Power input to the motor (Input power)**

$$P_{in} = V_{in} I_{in}$$

**Shunt field winding current**

$$I_{sh} = \frac{V_{in}}{R_{sh}}$$

## 9.11 APPLICATION OF DC MOTOR

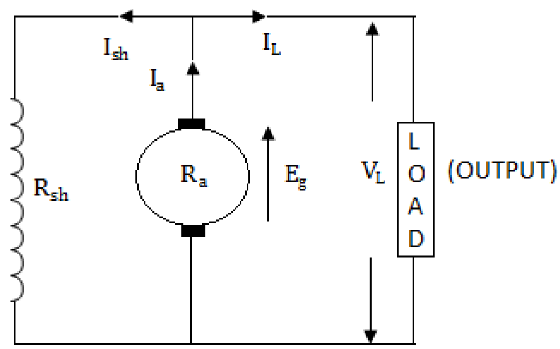
9.11.1 **Application of series motor:** (1) Cranes (2) Elevators (3) Trolleys (4) Conveyors (5) Hoists (6) Electric locomotives

9.11.2 **Application of shunt motor:** (1) Blowers (2) Centrifugal pump (3) Lathe machine (4) Milling machine (5) Drilling machine (6) Reciprocating machine

## 9.12 NUMERICAL OF DC MACHINE

**Example 9.1** A 20 kW, 250 V DC shunt generator has an armature resistance of 0.04 Ω and a shunt field resistance of 250 Ω. Calculate the power developed in the armature and power delivered to the load.

**Solution:** Given $P_L = 20\text{ kW}, V_L = 250\text{ V}, R_a = 0.04\ \Omega, R_{sh} = 250\ \Omega$, DC SHUNT GENERATOR




We know $P_L = V_L I_L \Rightarrow I_L = \frac{P_L}{V_L} = \frac{20\times10^3}{250} = 80\text{ Amp.}$

Shunt field current $I_{sh} = \frac{V_L}{R_{sh}} = \frac{250}{250} = 1\text{ Amp.}$

From the current equation $I_a = I_{sh} + I_L = 1 + 80 = 81\text{ Amp.}$

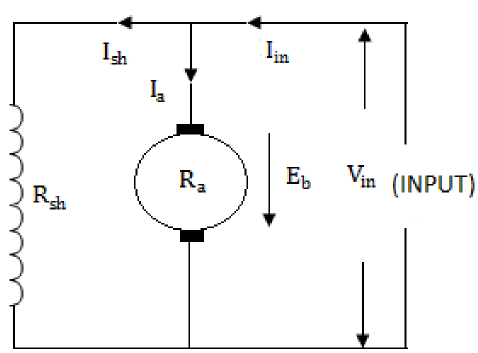
From the voltage equation $E_g = I_a R_a + V_L = 81 \times 0.04 + 250 = 3.24 + 250 = 253.24\text{ V}$

Power developed in the armature $P_a = E_g I_a = 253.24 \times 81 = 20512.44\text{ W} = 20.5124\text{ kW}$ **Ans.**

Power delivered to the load $P_L = V_L I_L = 250 \times 80 = 20000\text{ W} = 20\text{ kW}$ **Ans.**

**Example 9.2** A 30 kW, 250 V DC shunt motor has an armature resistance of 0.04 Ω and a shunt field resistance of 250 Ω. Calculate the power developed in the armature and power input to the motor.

**Solution:** $P_{in} = 30\text{ kW}, V_{in} = 250\text{ V}, R_a = 0.04\ \Omega, R_{sh} = 250\ \Omega$, DC SHUNT MOTOR




We know $P_{in} = V_{in} I_{in} \Rightarrow I_{in} = \frac{P_{in}}{V_{in}} = \frac{30\times10^3}{250} = 120\text{ Amp.}$

Shunt field current $I_{sh} = \frac{V_{in}}{R_{sh}} = \frac{250}{250} = 1\text{ Amp.}$

From the current equation $I_{in} = I_a + I_{sh} \Rightarrow I_a = I_{in} - I_{sh} = 120 - 1 = 119\text{ A}$

From the voltage equation $V_{in} = I_a R_a + E_b \Rightarrow E_b = V_{in} - I_a R_a = 250 - 119 \times 0.04 = 245.24\text{ V}$

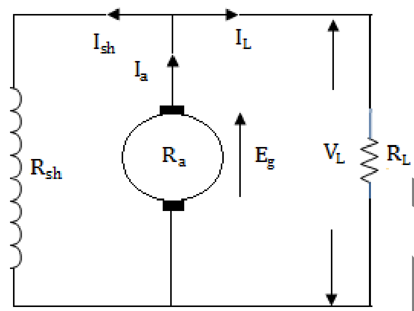
Power developed in the armature $P_a = E_b I_a = 245.24 \times 119 = 29183.56\text{ W} = 29.183\text{ kW}$ **Ans.**

Power delivered to the load $P_{in} = V_{in} I_{in} = 250 \times 120 = 30000\text{ W} = 30\text{ kW}$ **Ans.**

**Example 9.3** A 4 – pole DC shunt generator armature has 40 slots each having 12 conductors. Armature resistance is 1 Ω and shunt field resistance is 250 Ω. The flux per pole is 25 mWb. If a load of 50 Ω is connected across the armature terminal. Calculate the voltage across the load when the generator is driven at 1000 rpm. What will be the load voltage if

(1) Generator is Lap wound (2) Generator is wave wound

**Solution:** Given $P = 4, R_a = 1\ \Omega, R_{sh} = 250\ \Omega, Z = 40 \times 12 = 480, \emptyset = 25\ \text{mWB}, N = 1000\ \text{rpm}, R_L = 50\ \Omega$, DC SHUNT GENERATOR




(1) Generator is Lap wound $A = P = 4$

$$E_g = \frac{P\emptyset NZ}{60A} = \frac{4 \times 25 \times 10^{-3} \times 1000 \times 480}{60 \times 4} = 200\ \text{V}$$

Load current $I_L = \frac{V_L}{R_L} = \frac{V_L}{50}$

Shunt field current $I_{sh} = \frac{V_L}{R_{sh}} = \frac{V_L}{250}$

From the current equation $I_a = I_{sh} + I_L = \frac{V_L}{250} + \frac{V_L}{50} = \frac{6V_L}{250}$

From the voltage equation $E_g = I_a R_a + V_L$

$$200 = \frac{6V_L}{250} \times 1 + V_L \Rightarrow V_L = \frac{200 \times 250}{256} = 195.3125\ \textbf{Ans}.$$

(2) Generator is wave wound $A = 2$

$$E_g = \frac{P\emptyset NZ}{60A} = \frac{4 \times 25 \times 10^{-3} \times 1000 \times 480}{60 \times 2} = 400\ \text{V}$$

Load current $I_L = \frac{V_L}{R_L} = \frac{V_L}{50}$

Shunt field current $I_{sh} = \frac{V_L}{R_{sh}} = \frac{V_L}{250}$

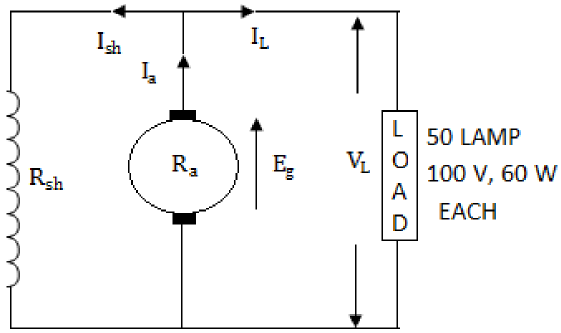
From the current equation $I_a = I_{sh} + I_L = \frac{V_L}{250} + \frac{V_L}{50} = \frac{6V_L}{250}$

From the voltage equation $E_g = I_a R_a + V_L$

$$400 = \frac{6V_L}{250} \times 1 + V_L \Rightarrow V_L = \frac{400 \times 250}{256} = 390.625\ \textbf{Ans}.$$

**Example 9.4** A 4 – pole Dc shunt generator with Lap connected armature has field and armature resistance of 100 Ω and 0.2 Ω respectively. It supplies power to 50 lamp rated for 100 V, 60 W each. Calculate the total armature current and the generated emf by allowing a contact drop of 1 V per brush.

**Solution:** Given $P = 4, A = P = 4, P_L = 50 \times 60 = 3000\ \text{W}, V_L = 100\ \text{V}, R_a = 0.2\ \Omega, R_{sh} = 100\ \Omega$, VOLTAGE DROP PER BRUSH (VDPB) $= 1$ V, DC SHUNT GENERATOR




We know $P_L = V_L I_L \Rightarrow I_L = \frac{P_L}{V_L} = \frac{3000}{100} = 30\ \text{Amp.}$

Shunt field current $I_{sh} = \frac{V_L}{R_{sh}} = \frac{100}{100} = 1\ \text{Amp}$

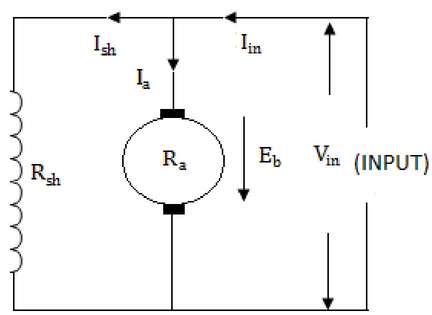
Total armature current $I_a = I_{sh} + I_L = 1 + 30 = 31\ \text{Amp.}\ \mathbf{Ans.}$

The generated emf $E_g = I_a R_a + V_L + 2(\text{VDPB}) = 31 \times 0.2 + 100 + 2 \times 1$

$= 6.2 + 100 + 2 = 108.2\ \text{V}\ \mathbf{Ans.}$

**Example 9.5** A DC shunt motor runs at 600 rpm taking 60 A from a 240 V supply. Armature resistance is 0.1 Ω and field resistance is 120 Ω. Find the speed when the current through the armature is 40 A.

**Solution:** Given $V_{in} = 240\ \text{V}, R_a = 0.1\ \Omega, R_{sh} = 120\ \Omega$, DC SHUNT MOTOR




Case 1 When $N_1 = 600\ \text{rpm}, I_{in} = 60\ \text{A}$

Shunt field current $I_{sh} = \frac{V_{in}}{R_{sh}} = \frac{240}{120} = 2\ \text{Amp.}$

From the current equation $I_{in} = I_{a1} + I_{sh} \Rightarrow I_{a1} = I_{in} - I_{sh} = 60 - 2 = 58\ \text{A}$

From the voltage equation $V_{in} = I_a R_a + E_{b1} \Rightarrow E_{b1} = V_{in} - I_{a1} R_a = 240 - 58 \times 0.1 = 234.2\ \text{V}$

Case 2 When $N_2 =$ Find, $I_{a2} = 40\ \text{A}$

From the voltage equation $V_{in} = I_{a2} R_a + E_{b2} \Rightarrow E_{b2} = V_{in} - I_{a2} R_a = 240 - 40 \times 0.1 = 236\ \text{V}$

We know $N \propto E_b$

So $N_1 \propto E_{b1}$ and $N_2 \propto E_{b2}$

By dividing, we get

$$\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}}$$

$$\frac{600}{N_2} = \frac{234.2}{236} \Rightarrow N_2 = \frac{600 \times 236}{234.2} = 604.6\ \text{rpm}$$

$$N_2 = 605\ \text{rpm}\ \mathbf{Ans.}$$

**Example 9.6** A DC shunt generator running at 1200 rpm supplies a load of 60 kW at 250 V. Find the speed at which it runs as a shunt motor when taking 60 kW from 250 V supply. Take armature resistance is 0.1 Ω and field resistance is 50 Ω. Brush drop is 2 V per brush.

**Solution:** Given $R_a = 0.1\ \Omega, R_{sh} = 50\ \Omega$, VOLTAGE DROP PER BRUSH (VDPB) $= 2$ V

Case 1 DC shunt generator $N_g = 1200$ rpm, $P_L = 60$ kW, $V_L = 250$ V

We know $P_L = V_L I_L \Rightarrow I_L = \frac{P_L}{V_L} = \frac{60000}{250} = 240$ Amp.

Shunt field current $I_{sh} = \frac{V_L}{R_{sh}} = \frac{250}{50} = 5$ Amp.

From the current equation $I_a = I_{sh} + I_L = 5 + 240 = 245$ Amp.

From the voltage equation $E_g = I_a R_a + V_L + 2(\text{VDPB}) = 245 \times 0.1 + 250 + 2 \times 2$

$$= 24.5 + 250 + 4 = 278.5\ \text{V}$$

Case 2 DC shunt motor $N_m = $ Find, $P_{in} = 60$ kW, $V_{in} = 250$ V

We know $P_{in} = V_{in} I_{in} \Rightarrow I_{in} = \frac{P_{in}}{V_{in}} = \frac{60000}{250} = 240$ Amp.

Shunt field current $I_{sh} = \frac{V_L}{R_{sh}} = \frac{250}{50} = 5$ Amp.

From the current equation $I_{in} = I_{sh} + I_a \Rightarrow I_a = I_{in} - I_{sh} = 240 - 5 = 235$ Amp.

From the voltage equation $V_{in} = I_a R_a + E_b + 2(\text{VDPB})$

$$E_b = V_{in} - I_a R_a - 2(\text{VDPB}) = 250 - 235 \times 0.1 - 2 \times 2$$
$$= 250 - 23.5 - 4 = 222.5\ V$$

We know $N_g \propto E_g$ and $N_m \propto E_b$

By dividing, we get

$$\frac{N_g}{N_m} = \frac{E_g}{E_b}$$

$$\frac{1200}{N_m} = \frac{278.5}{222.5} \Rightarrow N_m = \frac{1200 \times 222.5}{278.5} = 958.7\ \text{rpm}$$

$$N_m = 959\ \text{rpm}\ \textbf{Ans}.$$