D.C. Machines:

Syllabus: Working principle of D.C.Machine as a generator and a motor. Types, constructional features and Types of armature windings. Emf equation of generator, relation between induced Emf and terminal voltage with an enumeration of brush contact drop and drop due to armature reaction. Operation of D.C. motor, back Emf and its significance, torque equation. Types of D.C. motors, characteristics and applications. Necessity of a starter for D.C. motor.

Introduction:

- The converters which are used to continuously translate an electrical input to a mechanical output or vice versa are called as DC machines.
- If the conversion is from mechanical to electrical energy then it is called ad DC Generator and if the conversion is from electrical to mechanical energy then it is called as DC Motor.

Working principle of D.C.Machine as a generator and a motor:

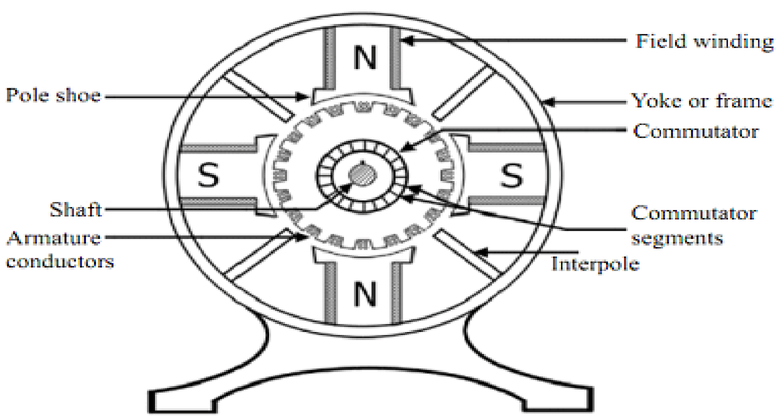
Working principle of D.C.Machine as a generator:

- Whenever a coil is rotated in a magnetic field an Emf will be induced in this coil and is given by **e=B*l*v*Sinθ** volts/coil side where, B=The flux density in Tesla, l=the active length of the coil side in meters v=the velocity with which the coil is moved in meters/sec and θ is the angle between the direction of the flux and the direction of rotation of the coil side.
- The direction of the induced voltage can be ascertained by applying **Fleming's right hand rule.**

Working principle of D.C.Machine as a motor:

- Whenever a current coil is placed under a magnetic field the coil experiences a mechanical force, and is given by **F= B*I*l*Sinθ** Newton/coil side where, I is the current through the coil.
- Applying **Fleming's left hand rule**, we note torque T_e will be produced in the counter clockwise direction causing the rotor to move in the same direction.

Construction of DC Machine:



Salient parts of a D.C.Machine are:

(i) Field system (poles)

(ii) Coil arrangement (armature)

(iii)Commutator

(iv)Brushes

(v)Yoke

Yoke:

i) It serves the purpose of outermost cover of the D.C. machine. So that the insulating materials get protected from harmful atmospheric elements like moisture, dust and various gases like SO_2, acidic fumes etc.

ii) It provides mechanical support to the poles.

iii) It forms a part of the magnetic circuit. It provides a path of low reluctance for magnetic flux.

Poles:

Each pole is divided into two parts a) pole core and b) pole shoe

- Pole core basically carries a field winding which is necessary to produce the flux.
- It directs the flux produced through air gap to armature core, to the next pole.
- Pole shoe enlarges the area of armature core to come across the flux, which isnecessary to produce larger induced emf. to achieve this, pole shoe has given a particular shape

Field winding [F1-F2]:

- The field winding is wound on the pole core with a definite direction.
- To carry current due to which pole core on which the winding placed behave as an electromagnet, producing necessary flux. As it helps in producing the magnetic field i.e. exciting the pole as electromagnet it is called Field winding or Exciting winding.

Armature:

- It is further divided into two parts namely,
  I) Armature core and
  II) Armature winding
- Armature core is cylindrical in shape mounted on the shaft. It consists of slots on its periphery and the air ducts to permit the air flow through armature which serves cooling purpose.

Commutator:

- The basic nature of Emf induced in the armature conductors is alternating.
- This needs rectifications in case of D.C. generator which is possible by device called commutator.

Brushes and brush gear:

- To collect current from commutator and make it available to the stationary external circuit.
- Ball bearings are usually used as they are more reliable.
- For heavy duty machines, roller bearings are preferred.

Types of D.C. Armature Windings

Lap Winding	Wave Winding
In this winding all the pole groups of the coils generating emf in the same direction at any instant of timeare connected in parallel by the brushes.	In this winding all the coils carrying current in the same direction are connected in series i.e., coils carrying current in one direction are connected in one series circuit and coils carrying current in opposite direction are connected in other series circuit.
2. Lap winding is also known as parallel windings.	2. Wave winding is also known as series winding.
3. The number of parallel path is equal to the number of poles i.e., A = P.	3. The number of parallel paths is always equal to 2 i.e., A = 2.
4. The number of brush required by this winding is always equal to the number of poles.	4. The number of brushes required by this winding is always equal to 2.
5. The machine using lap winding requires equalizer rings for obtaining better commutation.	5. The machine using wave winding does require dummy coils to provide the mechanical balance for the armature.
6. Lap windings are used for low voltage and high current machines.	6. Wave windings are used for high voltage and low current machines.

Emf Equation of DC Generator:

For one revolution of the conductor,
Let, Φ = Flux produced by each pole in weber (Wb) and
P = number of poles in the DC generator. Therefore,
Total flux produced by all the poles $= \phi \times P$

Time taken to complete one revolution $= \dfrac{60}{N}$

Where, N = speed of the armature conductor in rpm.

Now, according to Faraday's law of induction, the induced emf of the armature conductor is denoted by "e" which is equal to rate of cutting the flux. Therefore,

$$e = \frac{d\phi}{dt} \; and \; e = \frac{total\ flux}{time\ take}$$

Induced emf of one conductor is Induced emf of one conductor is

$$e = \frac{\phi P}{\frac{60}{N}} = \phi P \frac{N}{60}$$

Let us suppose there are Z total numbers of conductor in a generator, and arranged in such a manner that all parallel paths are always in series.
Here, Z = total numbers of conductor A = number of parallel paths
Then, Z/A = number of conductors connected in series
We know that induced Emf in each path is same across the line
Therefore, Induced Emf of DC generator E = Emf of one conductor × number of conductor connected in series.

Induced Emf of DC generator is

$$e = \phi P \frac{N}{60} X \frac{Z}{A} \, volts$$

Simple wave wound generator Numbers of parallel paths are only 2 = A Therefore,

Induced Emf for wave type of winding generator is

$$\frac{\phi PN}{60} X \frac{Z}{2} = \frac{\phi ZPN}{120} \, volts$$

Simple lap-wound generator Here, number of parallel paths is equal to number of conductors in one path i.e. P = A Therefore,

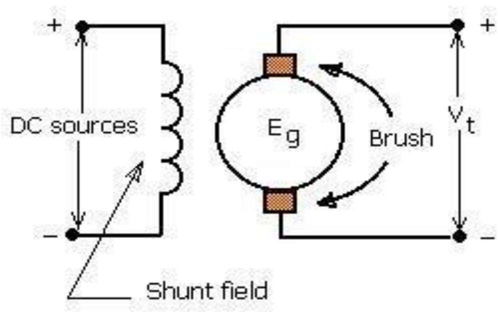
Induced **Emf** for lap-wound generator is

$$E_g = \frac{\phi ZN}{60} X \frac{P}{A} \, volt$$

Types of DC Generators

- It is characterized by the manner in which field excitation is provided.
- In general the method employed to connect field and armature winding has classify into two groups.

Separately Excited Generators:
In separately excited dc machines, the field winding is supplied from a separate power source. That means the field winding is electrically separated from the armature circuit.

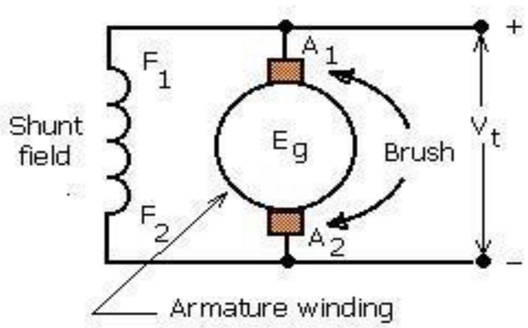


Self Excited Field Generators:

- This type of generator has produced a magnetic field by itself without DC sources from an external.
- The electromotive force that produced by generator at armature winding is supply to a field winding (shunt field) instead of DC source from outside of the generator.
- Therefore, field winding is necessary connected to the armature winding.
  They may be further classified as: a) DC Shunt generator
  b) DC Series generator
  c) DC Compound generator.

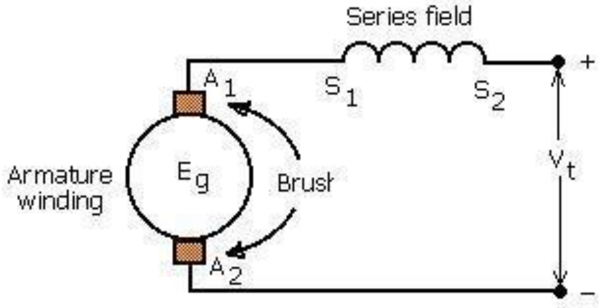
a) Shunt generator:

- This generator, shunt field winding and armature winding are connected in parallel through commutator and carbon brush.



b) Series generator:

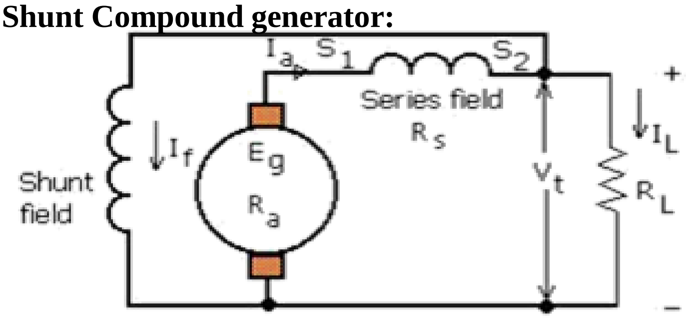
- The field winding and armature winding is connected in series.
- There is different from shunt motor due to field winding is directly connected to the electric applications (load).
- Therefore, field winding conductor must be sized enough to carry the load current consumption and the basic circuit



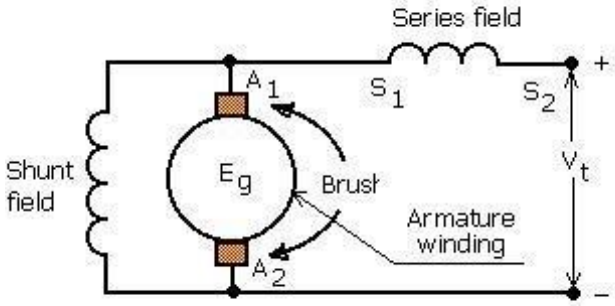
c) Compound generator :

- The compound generator has provided with magnetic field in combine with excitation of shunt and series field winding, the shunt field has many turns of fine wire and caries of a small current, while the series field winding provided with a few turns of heavy wire since it is in series with an armature winding and caries the load current.
- There are two types of Compound generators such as
  (i) Long shunt Compound Generator
  (ii) Short Shunt Compound Generator

Long Shunt Compound generator:



Short Shunt Compound Generator:



DC Motors:

Operation of a DC motor:

- When a DC machine is loaded as a motor, the rotor conductors carry current.
- These conductors lie in the magnetic field of the air gap.
- Thus, each conductor experiences a force.
- The conductors lie near the surface of the rotor at a common radius from its centre
- Hence, a torque is produced around the circumference of the rotor, and the rotor starts rotating.

Back Emf and its Significance:

- When the armature of a D.C. motor rotates under the influence of the driving torque, the armature conductors move through the magnetic field and hence an emf is induced in them.
- The induced emf acts in opposite direction to the applied voltage V(Lenz's law) and is known as back emf.
- Back EMF always acts to reduce the changing magnetic field through the coils. It does so by generating a voltage which opposes the supply voltage, thus reducing the current.

Significance:

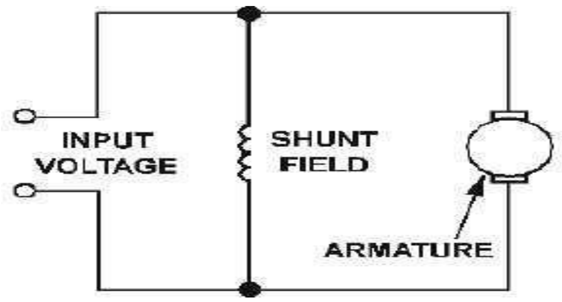
- The presence of back emf. makes the d.c. motor a self-regulating machine i.e., it makes the motor to draw as much armature current as is just sufficient to develop the torque required by the load.
- Back emf in a D.C. motor regulates the flow of armature current i.e., it automatically changes the armature current to meet the load requirement.

Types of DC Motors:

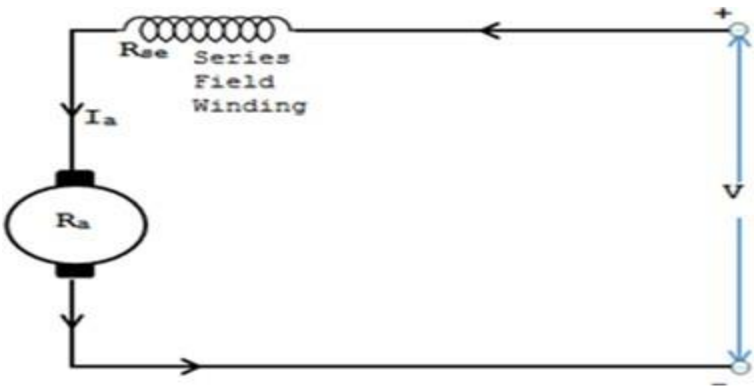
Motors are classified into 3 types: a) DC Shunt motor.
b) DC Series motor.
c) DC Compound motor.

a) DC Shunt motor:

- In shunt wound motor the field winding is connected in parallel with armature.
- The current through the shunt field winding is not the same as the armature current.



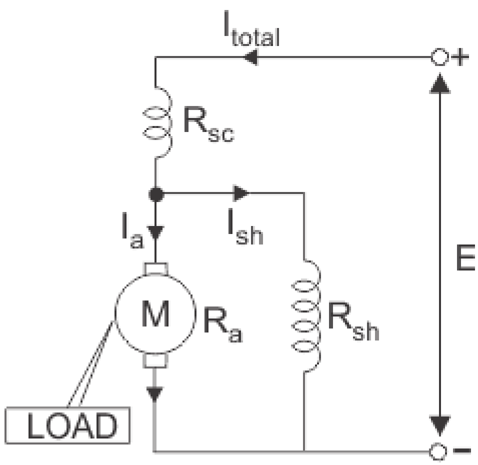
b) DC Series motor:



- In series wound motor the field winding is connected in series with the armature.
- Therefore, series field winding carries the armature current.

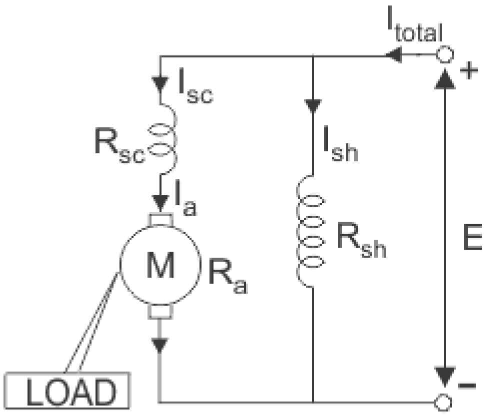
c) DC Compound motor:

- Compound wound motor has two field windings; one connected in parallel with the armature and the other in series with it.
- There are two types of compound motor connections :
  1) Short-shunt connection Compound Motor



- When the shunt field winding is directly connected across the armature terminals it is called short-shunt connection.

2) Long shunt connection Compound Motor



- When the shunt winding is so connected that it shunts the series combination of armature and series field it is called long-shunt connection.

Wasted in series field.

PROBLEMS

1) Calculate the flux in a 4-pole dynamo with 722 armature conductors generating 500 V when running at 1000 r.p.m. when the armature is (a) lap connected and (b) wave connected [(a) 41.56 mWb (b) 20.78 mWb]

Solution:

Given: Ø=?, P=4, Z=722, E=500 V, N=1000 r.p.m, A=P (Lap), A=2 (Wave)

$$E = \frac{ZN\phi}{60} * \frac{P}{A}$$

Lap connected:

$$\phi = \frac{60EA}{ZNP} = \frac{60*500*4}{722*1000*4} = 0.041..Wb$$

Wave connected:

$$\phi = \frac{60EA}{ZNP} = \frac{60*500*2}{722*1000*4} = 0.02..Wb$$

2) A 4-pole machine running at 1500 r.p.m. has an armature with 90 slots and 6 conductors per slot. The flux per pole is 10 mWb. Determine the terminal E.M.F. of d.c. generator if the coils are lap-connected. If the current per conductor is 100 A, determine electrical power. [135 V, 54 kW]

Solution:

Given: P=4, N=1500 r.p.m., Slots=90, cond/slot=6, Ø=10mWb, E=?, A=P (lap), A/Z=100 A/cond, P=4

$$Z = Slots * \frac{Cond}{slot} = 90*6 = 540$$

$$E = \frac{ZN\phi}{60} * \frac{P}{A} = \frac{540*1500*0.01}{60} * \frac{4}{4} = 135..V$$

$$I_a = A*100 = 4*100 = 400A$$

$$P = EI_a = 135*400 = 54000..W$$

3) An 8-pole lap-wound d.c.generator has 120 slots having 4 conductors per slot. If each conductor can carry 250 A and if flux per pole is 0.05 Wb, calculate the speed of the generator for giving 240 V on open circuit. If the voltage drops to 220 V on full load, find the rated output of the machine. [600 V, 440 kW]

Solution:

Given: P=8, A=P (lap), slots=120, Cond/slot=4, I/Z=250A, Ø=0.05 Wb, N=?, E=240V, V=220 V, P=?

$$N = \frac{60EA}{Z\phi P} = \frac{60*240*8}{(120*4)*0.05*8} = 600V$$

$$P = V*I_a = 220*(250*8) = 440000..W$$

4) A wave connected armature of a 2-pole, 200 V generator has 400 conductors and runs at 300 r.p.m. Calculate the useful flux per pole. If the number of turns in each field coil is 1200, what is the average value of E.M.F. induced in each coil on breaking the field if the flux dies away completely in 0.1 sec ? [0.1 Wb, 1200 V]

WHAT IS CONCEPT OF BACK EMF?

When the armature of a d.c. motor rotates under the influence of the driving torque, the armature conductors move through the magnetic field and hence e.m.f. is induced in them as in a generator. The induced e.m.f. acts in opposite direction to the applied voltage V (Lenz's law) and in known as back or counter e.m.f.

Or back EMF

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APPLICATIONS OF DC MACHINES

- In the present day world, the electrical energy is generated in bulk in the form of an alternating current.
- Hence, the use of DC machines, i.e., DC generators and motors are very limited. They are mainly used in supplying excitation of small and medium range alternators.
- The Industrial **Applications** of DC are in Electrolytic Processes, Welding processes and Variable speed motor drives.

APPLICATIONS OF DC MOTORS

- The main applications of the three types of direct current motors are given below.
- **Series Motors**
- The series DC motors are used where high starting torque is required, and variations in speed are possible. For example – the series motors are used in Traction system, Cranes, air compressors, Vaccum Cleaner, Sewing machine, etc.

SHUNT MOTORS, COMPOUND MOTORS

- **Shunt Motors**
- The shunt motors are used where constant speed is required and starting conditions are not severe. The various applications of DC shunt motor are in Lathe Machines, Centrifugal Pumps, Fans, Blowers, Conveyors, Lifts, Weaving Machine, Spinning machines, etc.
- **Compound Motors**
- The compound motors are used where higher starting torque and fairly constant speed is required. The examples of usage of compound motors are in Presses, Shears, Conveyors, Elevators, Rolling Mills, Heavy Planners, etc.
- The small DC machines whose ratings are in fractional kilowatt are mainly used as control device such in Techno generators for speed sensing and in Servo motors for positioning and tracking.