DC Machines

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Module 2 (a) DC MACHINES

Principle of operation

An electric generator is a machine that converts the mechanical energy to electrical energy. It works on the principle of dynamically induced emf . Whenever a flux is cut by a conductor, an emf is induced. DC motor and DC generator are collectively known as DC machine. A DC generator converts mechanical energy to electrical energy. It works on Faraday's laws of electromagnetic induction. A DC motor converts electrical energy into mechanical energy. It works on the principle that a current carrying conductor placed under magnetic field experiences a force.

Construction: For diagram ref class notes

- Yoke – It is the outermost cover of the machine. It forms the support for the whole machine. It also provides the path for the flow of the flux. For small machines the yoke is made of cast iron and is cast into single piece. For bigger machines, yoke is made of caste steel and is an assembly of different segments.
  Main pole – it consist of the pole core, pole shoe and the field coil. The pole core is not a single solid piece, but it is made of silicon steel laminations. These laminations are punched to correct shape , stacked together to the required length ,then they are bolted and riveted. The field coils are made up of copper and are wound separately and put on the pole. The assembly of pole core and the coil is attached to the yoke . When DC excitation is given to the filed windings the poles become electromagnets and magnetic flux is produced. The yoke, pole and the field winding form the field system
- Armature – The armature houses the armature conductor. It is an assembly of laminations made of CRGO (cold rolled grain oriented) silicon steel. The assembly is keyed on to the central shaft. In the slots, the armature conductors are arranged with proper insulation. These conductors are interconnected to form the armature winding.
- Commutator – Commutator converts AC voltage to DC voltage. It consists of copper drum divided into number of segments. Each segment is insulated from each other. It is mounted on the shaft as that of armature. The ends of the armature coil are properly connected to the commutator segments
- Armature winding – The conductors are connected suitably to form the armature winding . The armature winding can be wave winding or lap winding . In lap winding the number of parallel paths = number of poles. In wave winding the number of parallel paths = 2.
- Brushes- the DC output is taken with the help of copper or carbon brushes.

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DC GENERATOR

Expression for the emf induced in a DC generator

Let P = the number of poles
Φ = flux per pole in wb
Z = total number of armature conductors
N= Speed of rotation of armature RPM
A= number of parallel paths in the armature winding
A=P for LAP
A= 2 for WAVE

Time taken for 1 revolution = 60/N seconds
In one revolution a conductor crosses P poles and cuts a flux of PΦ webber
According to Faraday's law
Average emf induced in each conductor = flux cut / time taken
= PΦ / 60/N
= N PΦ /60
Emf of generator equals emf per parallel path and in each path Z /A conductors are in series
E = N PΦ Z/(60 A)
E = Φ Z N P / (60A)

Armature reaction :
The armature consists of number of armature conductors. These conductors form armature winding. When the current is flowing through the armature conductors; these current carrying conductors will have magnetic field around them. This magnetic field will oppose the field developed by the main poles. The resultant of this is the demagnetizing effect and the effective magnetic field in the air gap reduces. This is called armature reaction

DC GENERATOR CLASSIFICATION

DC generator is classified depending on the excitation provided to the field winding as follows
1. Separately Excited DC Generator
2. Self Excited DC Generator

1. SEPARATELY EXCITED DC GENERATOR :

The field excitation is provided from a separate, external DC source. The voltage source may be a battery or another DC generator. The circuit diagram is as shown in the following figure.

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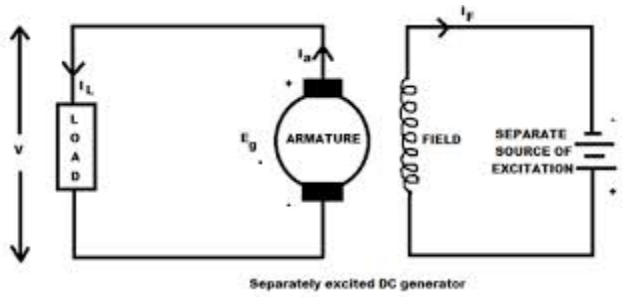


Separately excited DC generator

For the generator V = Eg- Ia Ra - brush drop

2. SELF EXCITED GENERATORS:

The field excitation is provided internally by the armature of the generator itself. No external voltage source is needed. Based on how field winding is connected the self excited generators fall into three groups

(i) Series generators

(ii) Shunt generators

(iii) Compound generators

(I) SERIES GENERATOR:

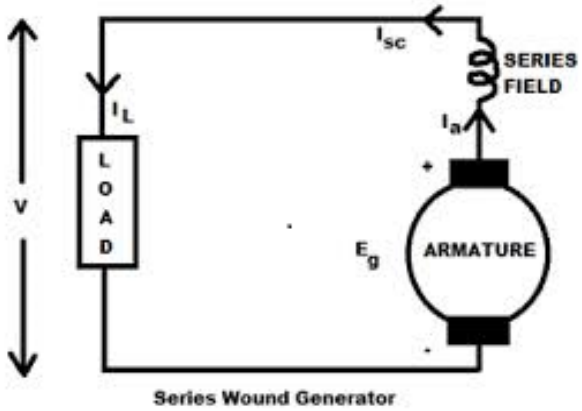
The field winding is connected in series with the armature. The circuit diagram is as shown. The equation for series generator is

V – Ia Rf – Ia Ra – brush drop – Eg =0

Where

Rf is the field resistance in series

Ra is armature resistance



Series Wound Generator

(II) SHUNT GENERATOR :

The field winding is shunted across the armature i.e. connected in parallel with armature. By this arrangement a part of armature current flows into the field winding and the rest of the current is delivered to the load . The diagram is as shown

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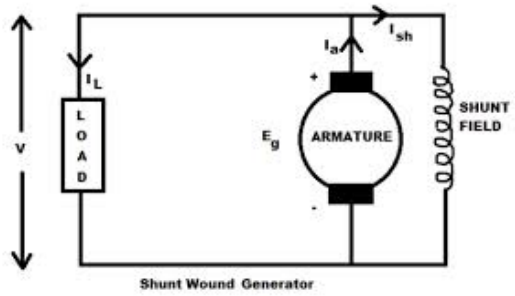


Shunt Wound Generator

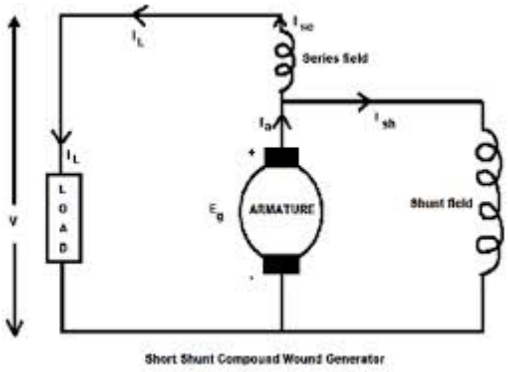
The equations V-Eg-Ia Ra- brush drop= 0

V = Ish Rsh

(III) COMPOUND GENERATOR:

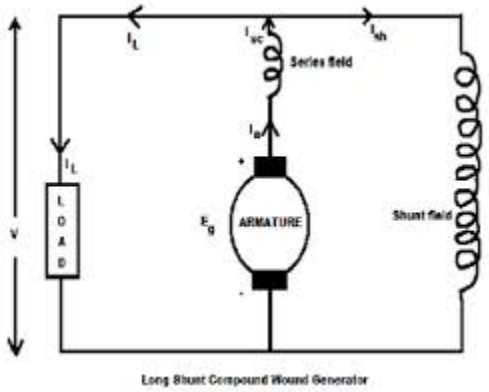
A part of field winding is connected in parallel with the armature and the remaining in connected in series with armature. Such generators are called compound generators. These are further classified as long shunt and short shunt compound generators. Also depending on the direction of the flux they are classified as Cumulative compound and differential compound generators.

a) Short shunt compound motor



Short Shunt Compound Wound Generator

b) Long shunt compound motor



Long Shunt Compound Wound Generator

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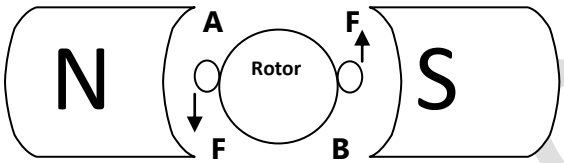
DC Motor

WORKING PRINCIPLE OF A DC MOTOR

A D.C Motor converts electrical energy into mechanical energy. It works on the principle that a current carrying conductor kept in a magnetic field experiences a force. A coil AB is kept around the armature and current is passed through it. The side A experiences a force F downwards and side B experiences a force upwards and there is net turning moment in the anticlockwise direction. When coils are placed throughout the surface of the armature and current passed through them, the armature will experience a continuous force and start rotating.

The basic principle of operation is as shown in the diagram



Back Emf

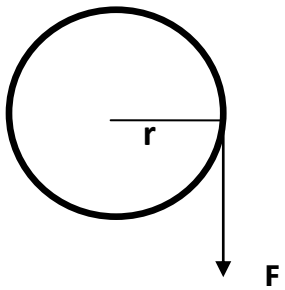
When the armature starts rotating, the armature conductors also rotate in magnetic field. An emf is induced in armature conductors developing emf. This emf opposes the applied voltage therefore it is called back emf .

Back EMF Eb = V- Ia Ra

V - applied voltage
Ia – Armature Current
Ra – Armature resistance

But Eb can also be written as = ΦZNP / 60 A
From the equation it is seen that at the instant of starting (ie at N=0) Eb = 0

EXPRESSION FOR TORQUE DEVELOPED IN DC MOTOR



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Let r meter be the radius of armature and F Newton be the force acting on it .Due to this force let the armature rotate at a speed of N RPM .

Mechanical work done by the force in one second

$= F (2 \pi r) (N/60)$

$= 2 \pi N T /60$ where $T= F X r$

Therefore Mechanical power developed by the armature = $2 \pi N T /60$

Electrical input to the armature = $E_b I_a$ Watt

Equating the electrical input to the mechanical power developed

$E_b I_a = 2 \pi N T /60$

But $E_b = \Phi Z N P / (60A)$

$I_a \Phi Z N P / (60A) = 2 \pi N T /60$

$T = I_a \Phi Z P /(2 \pi A)$----------Torque equation

CLASSIFICATION OF DC MOTOR

--- diagrams & equation ref class notes

Depending on how the field winding is connected to the armature the DC motor can be classified as

(i)Shunt Motor

(ii) Series Motor

(iii) Compound motor

(I) SHUNT MOTOR

The field winding is connected in parallel with the armature.

(II) SERIES MOTOR

The field winding is connected in series with the armature.

(III) COMPOUND MOTOR

A compound motor has both series and shunt field winding. It is classified into Short shunt compound motor and Long shunt compound motor.

The flux produced by the series field winding is in the same direction as that of the flux produced by the shunt field winding then it is called as **cumulative compounded motor**.

If the series field flux opposes the shunt field flux then it is called as **differentially compounded motor**

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SPEED CONTROL OF DC MOTOR

We know that
$E_b = \Phi Z N P / 60A$
$E_b \alpha N \Phi$ keeping physical parameter constant
$N \alpha E_b / \Phi$
$N \alpha V - Ia Ra / \Phi$

Hence speed can be controlled by varying either armature current or the flux .Accordingly there are two methods of speed control.
1. Armature control
2. Field control

1. ARMATURE CONTROL

Armature control is a method where the current flowing through the armature is controlled by adding external resistance in series. The external resistance is later removed slowly from the circuit in order to make the motor run at the rated speed. As the current flowing through the armature is very high the armature control method causes lot of losses in armature reducing the efficiency of the machine.

2. FIELD CONTROL

The field control is a method in which an external resistance is added in series with the field winding to control the current flowing through the field. The speed of the motor is inversely proportional to flux. So by reducing the flux speed can be increased. As the current flowing through the field is small compared to the armature; most of the machines use field control method for changing the speed

DC MOTOR STARTER

Principle and necessity of a starter

We know that Eb= V- Ia Ra

Ia = (V- Eb) / Ra and Eb = Φ Z N P / 60A

At starting the speed of motor is zero i.e. N= 0

Therefore back emf Eb = 0

Therefore current at the time of starting Ia = V/ Ra

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Let us assume V= 200 V and Ra =0.1 Ω

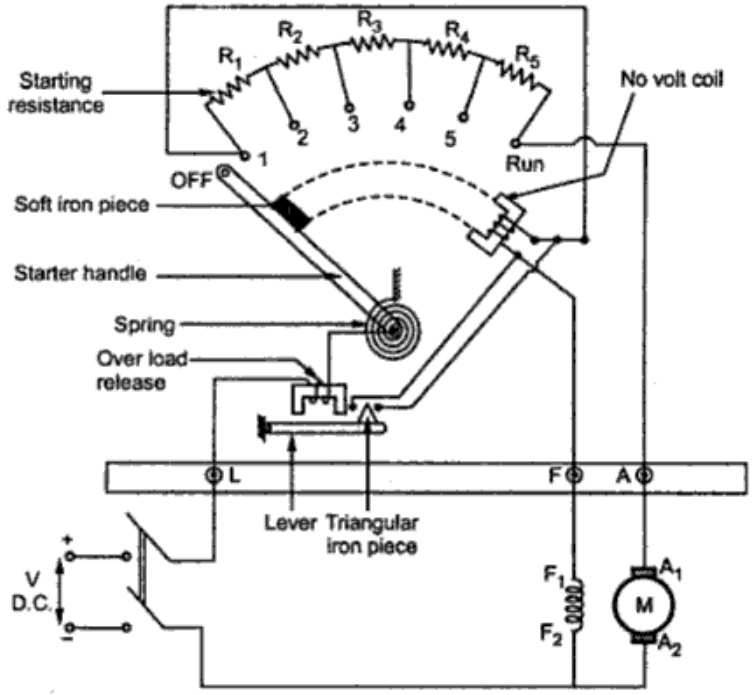
current at the time of starting Ia = 200/0.1

Ia = 2000A

This high current will burn the armature winding

Therefore at the time of starting an external resistance R is connected in series with armature and the resistance is removed slowly once the motor pics up the speed

3 POINT STARTER FOR DC SHUNT MOTOR



The 3 point starter to limit the starting current to an allowable lower value.
The construction and working of three point starter is done to lower the starting current.

Construction of 3 Point Starter

Construction wise a starter is a variable resistance, integrated into number of sections as shown in the figure. The contact points of these sections are called studs and are shown separately as OFF, 1, 2,3,4,5, RUN. Other than that there are 3 main points, referred to as

1. 'L' Line terminal. (Connected to positive of supply.)
2. 'A' Armature terminal. (Connected to the armature winding.)
3. 'F' Field terminal. (Connected to the field winding.)

And from there it gets the name 3 point starter.The point 'L' is connected to an electromagnet called overload release (OLR) as shown in the figure. The other end of 'OLR' is connected to the lower end of conducting lever of starter handle where a spring is also attached with it and the starter handle contains also a soft iron piece housed on it. This handle is free to move to the other side RUN against the force of the spring. This spring brings back the handle to its original OFF position under the influence of its own force. Another parallel path is derived from the stud '1', given to another electromagnet called No Volt Coil (NVC) which is further connected to terminal 'F'. The starting resistance at starting is entirely in series with the armature. The OLR and NVC acts as the two protecting devices of the starter.

Working of Three Point Starter

To start with the handle is in the OFF position when the supply to the DC motor is switched on. Then handle is slowly moved against the spring force to make a contact with stud No. 1. At this point, field winding of the shunt or the compound motor gets supply through the parallel path provided to starting resistance, through No Voltage Coil. While entire starting resistance comes in series with the armature. The high starting armature current thus gets limited as the current equation at this stage becomes $I_a = E/(R_a+R_{st})$. As the handle is moved further, it goes on making contact with studs 2, 3, 4 etc., thus gradually cutting off the series resistance from the armature circuit as the motor gathers speed. Finally when the starter handle is in 'RUN' position, the entire starting resistance is eliminated and the motor runs with normal speed. This is because back emf is developed consequently with speed to counter the supply voltage and reduce the armature current. So the external electrical resistance is not required anymore, and is removed for optimum operation. The handle is moved manually from OFF to the RUN position with development of speed.

Working of No Voltage Coil of 3 Point Starter

The supply to the field winding is derived through no voltage coil. So when field current flows, the NVC is magnetized. Now when the handle is in the 'RUN' position, soft iron piece connected to the handle and gets attracted by the magnetic force produced by NVC, because of flow of current through it. The NVC is designed in such a way that it holds the handle in 'RUN' position against the force of the spring as long as supply is given to the motor. Thus NVC holds the handle in the 'RUN' position and hence also called **hold on coil**.

Now when there is any kind of supply failure, the current flow through NVC is affected and it immediately loses its magnetic property and is unable to keep the soft iron piece on the handle, attracted. At this point under the action of the spring force, the handle comes back to OFF

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position, opening the circuit and thus switching off the motor. So due to the combination of NVC and the spring, the starter handle always comes back to OFF position whenever there is any supply problems. Thus it also acts as a protective device safeguarding the motor from any kind of abnormality.

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