electrical load is connected to the winding formed by these conductors, a current i will flow, delivering electrical power to the load. Moreover, the current flowing through the conductor will interact with the magnetic field to produce a reaction torque, which will tend to oppose the torque applied by the prime mover. Note that in both motoring and generating actions, the coupling magnetic field is involved in producing a torque and an induced voltage.

The basic electric machines (dc, induction, and synchronous), which depend on electromagnetic energy conversion, are extensively used in various power ratings.

Basic Structure of Electric Machines

The structure of an electric machine has two major components, stator and rotor, separated by the air gap.

Stator: *This part of the machine does not move and normally is the outer frame of the machine.*

Rotor: *This part of the machine is free to move and normally is the inner part of the machine.*

Both stator and rotor are made of ferromagnetic materials. In most machines slots are cut on the inner periphery of the stator and outer periphery of the rotor structure. Conductors are placed in these slots. The iron core is used to maximize the coupling between the coils (formed by conductors) placed on the stator and rotor, to increase the flux density in the machine and to decrease the size of the machine. If the stator or rotor (or both) is subjected to a time-varying magnetic flux, the iron core is laminated to reduce eddy current losses. The thin laminations of the iron core with provisions for slots.

The conductors placed in the slots of the stator or rotor is interconnected to form windings. The winding in which voltage is induced is called the armature winding. The winding through which a current is passed to produce the primary source of flux in the machine is called the field winding. In the dc machine, the field winding is placed on the stator and the armature winding on the rotor. Permanent magnets are used in some machines to provide the major source of flux in the machine. Rotating electrical machines take many forms and are known by many names. The three basic and common ones are dc machines, induction machines and synchronous machines. There are other machines, such as permanent magnet machines, hysteresis machines, and stepper machines.

DC MACHINES

The dc machines are versatile and extensively used in industry. A wide variety of volt-ampere or torque-speed characteristics can be obtained from various connections of the field windings.

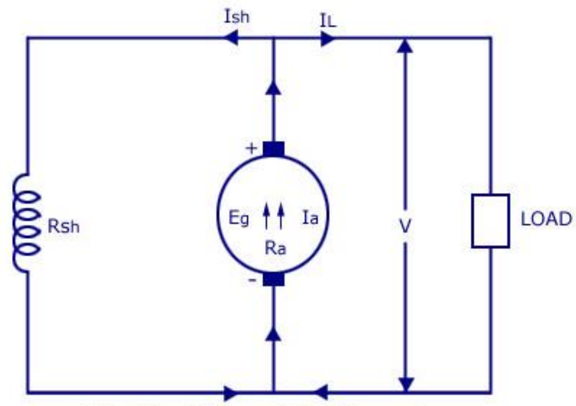


Fig: Shunt Wound DC Generator

(ii) ***Series wound:*** A series DC generator is shown in figure below in which the armature winding is connected in series with the field winding so that the field current flows through the load as well as the field winding. The field winding is a low resistance, thick wire of few turns. Series generators are also rarely used except for special purposes, eg: Boosters, etc.

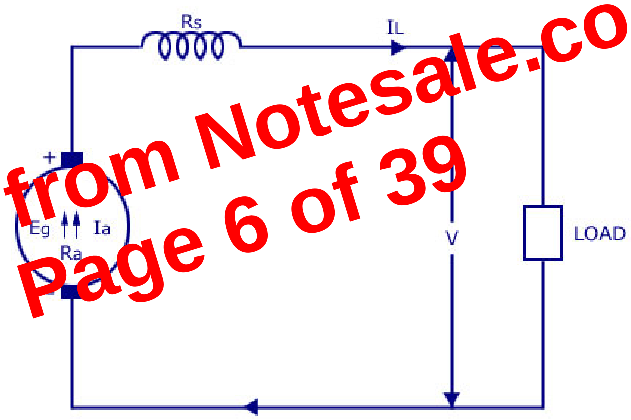


Fig: Series Wound DC Generator

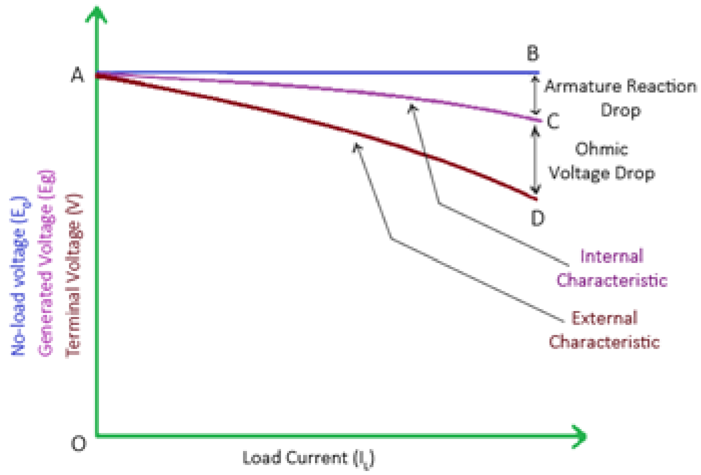
(iii) ***Compound wound:*** A compound generator is shown in figure below. It has two field findings namely Rsh and Rse. They are basically shunt winding (Rsh) and series winding (Rse).

In compound generator, shunt field is stronger than series field. When the series field aids shunt field, the generator is said to be commutatively compounded and when the series field opposes the shunt field the generator is said to be differentially compounded. Compound generator is of two types *(1) Short shunt and (2) Long shunt.*

Short shunt: - Here the shunt field winding is wired parallel to armature and series field winding is connected in series to the load. It is shown in figure below:

Therefore, this type of characteristic is sometimes also called as performance characteristic or load characteristic.

Internal and external characteristic curves are shown below for each type of generator.



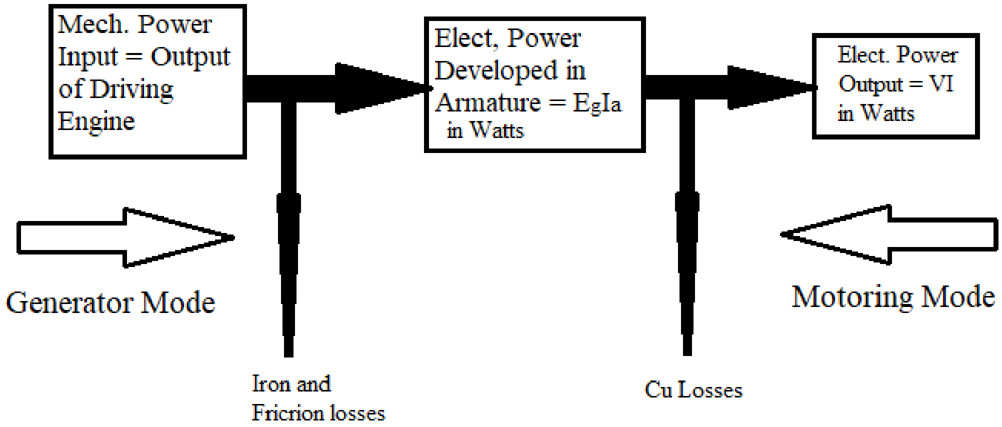
Characteristics of separately excited DC generator

If there is no armature reaction and armature voltage drop, the voltage will remain constant for any load current. Thus, the straight lines AB in above figure represents the no-load voltage vs load current I_L. Due to the demagnetizing effect of armature reaction, the on-load generated emf is less than the no-load voltage. The curve AC represents the on-load generated emf Eg vs. load current I_L i.e. internal characteristic (as $I_a = I_L$ for a separately excited dc generator). Also, the terminal voltage is lesser due to ohmic drop occurring in the armature and brushes. The curve AD represents the terminal voltage vs. load current i.e. external characteristic.

Characteristics of DC Shunt Generator

To determine the internal and external load characteristics of a DC shunt generator the machine is allowed to build up its voltage before applying any external load. To build up voltage of a shunt generator, the generator is driven at the rated speed by a prime mover. Initial voltage is induced due to residual magnetism in the field poles. The generator builds up its voltage as explained by the O.C.C. curve. When the generator has built up the voltage, it is gradually loaded with resistive load and readings are taken at suitable intervals. Connection arrangement is as shown in the figure below.

Power Stages for DC Generator



DC Generator Efficiency

Electrical Efficiency (η) = $\frac{OutputPower}{InputPower}$

Output Power = VI

Input Power = Output Power + Losses

$= VI + I_a^2R_a + W_c$

$= VI + (I + I_f)^2 R_a + W_c$

It is obvious that, overall efficiency for good generator should be as higher as 95%, and unless specified otherwise, commercial efficiency is always to be understood.

Condition for Maximum Efficiency

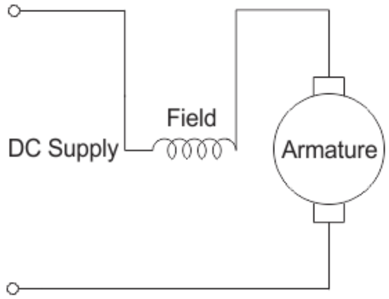
For the efficiency of the machine to be maximum, ***Variable Losses should be equal to the Constant losses.*** ie:- $\mathbf{I^2R_a = W_c}$ **or** $I = \sqrt{\frac{W_C}{R_a}}$

Examples

1. *A shunt generator delivers 195A at a p.d of 250V. The armature and shunt field resistance are 0.02 ohms and 50 ohms respectively. The iron and friction losses equal to 950W. Find;*
   (a) Emf generated.
   (b) Cu losses.
   (c) Electrical efficiency.
   (d) Overall efficiency.
2. *A shunt generator has a full load current of 196A at 220V. The stray losses are 720W and shunt field coil resistance of 55 ohms. If it has a full load efficiency of 88%, find the armature resistance. Also find the load current corresponding to maximum efficiency.*

Voltage and Current Equation of Series DC Motor

The electrical layout of a typical series wound DC motor is shown in the diagram below.



Series Excited DC Motor

Let the supply voltage and current given to the electrical port of the motor be given by V and I respectively.

Since the entire supply current flows through both the armature and field conductor,

$$Therefore, \quad I_{total} = I_{se} = I_a$$

Where, I_{se} is the series current in the field coil and I_a is the armature current.

Now form the basic voltage equation of the DC motor.

$$V = E_b + I_a R_a + I_a R_{se}$$

Where, E_b is the back emf.

R_{se} is the series coil resistance and R_a is the armature resistance.

Since $I_{se} = I_a$, we can write,

$$V = E_b + I_a(R_a + R_{se})$$

This is the basic voltage equation of a series wound DC motor.

Another interesting fact about the DC series motor worth noting is that, the field flux like in the case of any other DC motor is proportional to field current.

$$I_{se} \propto \phi$$

$$I_{se} = I_a = I_{total}$$

But since here

$$\phi \propto I_{se} \propto I_a$$

Hence the speed can be varied by changing:

(i) The terminal voltage of the armature, V.

(ii) The external resistance in armature circuit, R_a.

(iii)The flux per pole, φ.

We will discuss brief how both of these methods control the speed of DC series motors and DC shunt motors.

Speed Control of DC Series Motor
Speed control methods for a DC series motor can be classified as:

(i) Flux control method

(ii) Variable resistance in series with the motor

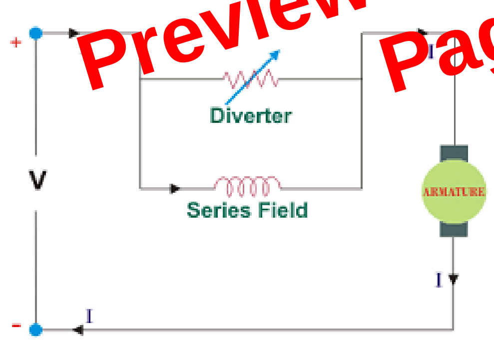
Flux Control DC Series Motor
Variation of flux in series motor can be bought in any of these methods:

(i) Field Diverters

(ii) Armature diverters

(iii)Trapped field control

(iv)Paralleling field coil



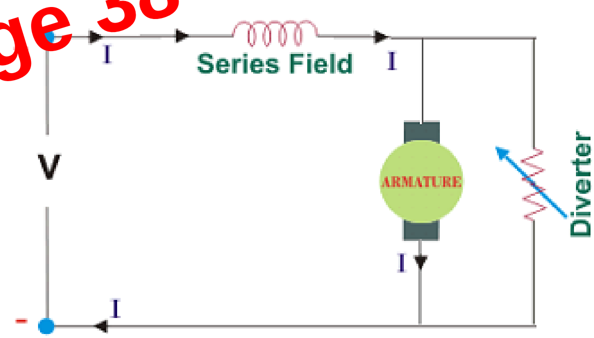
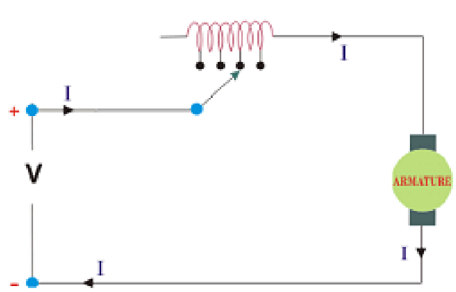


Fig (i) Field Diverter

Fig (ii) Armature Diverter



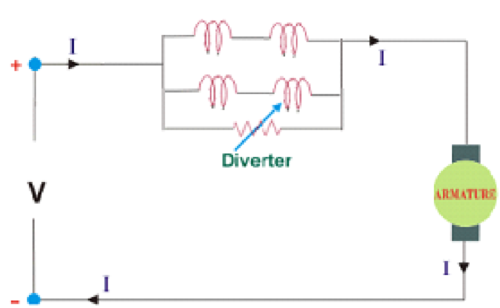


Fig (iii) Trapped Field control

Fig (iv) Paralleling field coil