BITS Pilani
Dubai Campus

Principles and Working of DC and AC machines

Dr Jagadish Nayak

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Constructional features

DC Machines

DC Generator

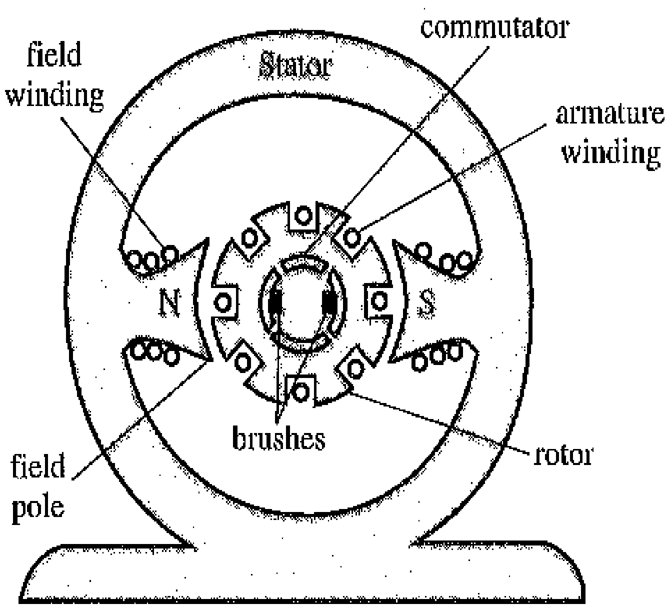

Fig. 15.25 A dc generator.

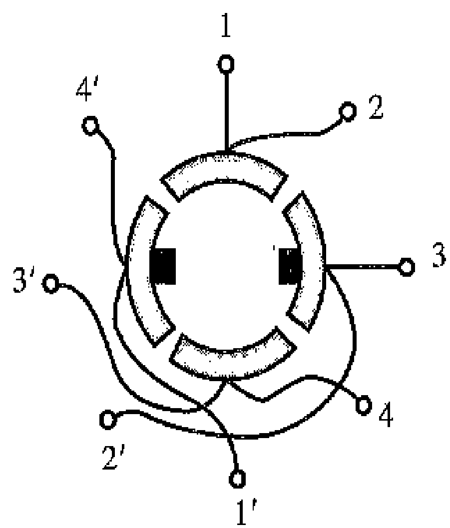

Fig. 15.26 Coil-commutator connections.

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- A generator consists of a stationary portion called the stator and the rotating portion called the rotor.

- A magnetic field is produced when a direct current is applied to windings of the coil in the stator. These coils are called field windings.

- The rotor contains the commutator and the conductors across which emf is induced. This part is called armature.

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- The stator has two poles one labeled N and the other S. The field windings are situated on the poles.

- The rotor consists of an iron core that has slots which house the armature conductors and a commutator and the brushes.

- The figure shows the connections of the coils to the commutator

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- A uniform magnetic field is produced in the small air gaps between the poles and the rotor when current is passed through the field windings. This induces an emf across the coil and looks like as shown below.

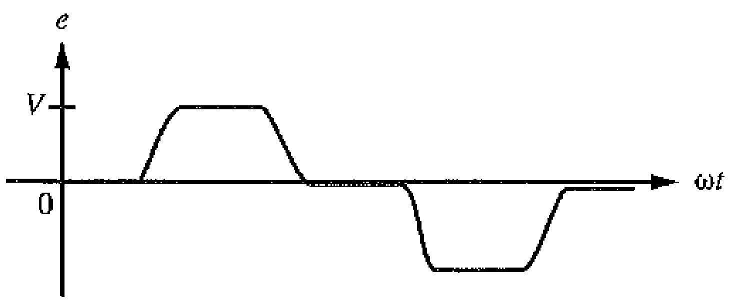

Fig. 15.27 The emf across a single coil.

- When the armature windings are connected to the commutator according to the connections shown earlier , the individual emf gets rectified and all of them add up together.

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- The net effect of the coil connections to the commutator shows a brush voltage which appears as below

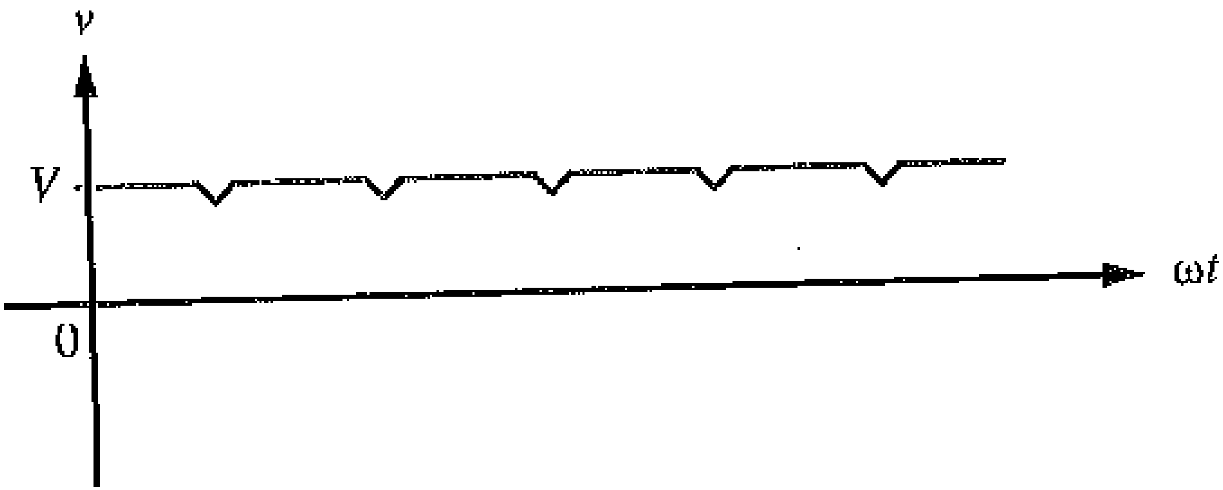

Fig. 15.28 The voltage across the brushes.

DC Machines

Generated voltage:

The generated voltage is given by:

$$v_g = \frac{N}{a} p \phi \frac{n}{60}$$

$$Where\ N = Number\ of\ armature\ conductors$$

$$a = Number\ of\ parallel\ paths\ between\ the\ brushes$$

$$p = Number\ of\ poles$$

$$\phi = Magnetic\ flux\ per\ pole$$

$$n = speed\ of\ the\ rotor\ in\ rpm$$

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Example 15.9

Let us determine the voltage produced by a dc generator such as the one shown in Fig. 15.25, which has two poles and two parallel paths between the brushes, given that each pole has a surface area of $A = 0.01\ \mathrm{m}^2$, the air-gap magnetic flux density is $B = 1$ T, and each of the four armature coils has 12 turns.

The flux per pole is

$$\Phi = BA = 1(0.01) = 0.01\ \mathrm{Wb}$$

Since each of the four armature coils has 12 turns and each turn contains two conductors, then $N = (4)(12)(2) = 96$.

For a rotor speed of 1500 rpm, the generated voltage is

$$v_g = \frac{N}{a} p\Phi \frac{n}{60} = \frac{96}{2}(2)(0.01)\frac{1500}{60} = 24\ \mathrm{V}$$

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Generator with a load:

- **The generated emf v_g is the voltage across the armature terminals (the brushes) when no load is connected to those terminals.**
- **If there is some electrical load connected to the armature, the resulting load voltage will be different from the no load voltage. Now it will depend on the resistance R_a associated with the armature due to resitance of the windings and the brush contacts.**

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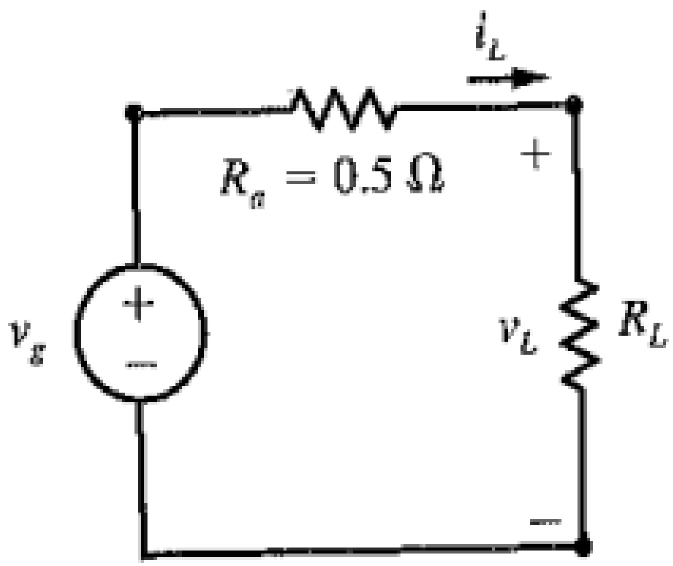
Example :

- An 8kW, 200-V dc generator has a full load current of 40nA at 1200rpm. Given the armature resistance is Ra=0.5Ω, armature is modeled as shown below, where RL is a resistive load. Determine the full load voltage for this generator at 900 rpm.



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From the fact that

$$v_g = R_a i_L + v_L$$

under full-load conditions (at $n = 1200$ rpm), the generated voltage is

$$v_g = (0.5)(40) + 200 = 220 \text{ V}$$

and this is the no-load voltage.

If the flux per pole φ is kept constant , then the generated voltage is directly proportional to armature speed n.Thus if the field current is kept constant and the flux per pole is kept constant then at 900 rpm the no load voltage is

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$$v_g = \frac{900}{1200}(220) = 165 \text{ V}$$

Therefore under full load condition of 40 A at 900rpm the full load voltage is, by KVL

$$v_L = -R_a i_L + v_g = -(0.5)(40) + 165 = 145 \text{ V}$$

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Generator symbol:

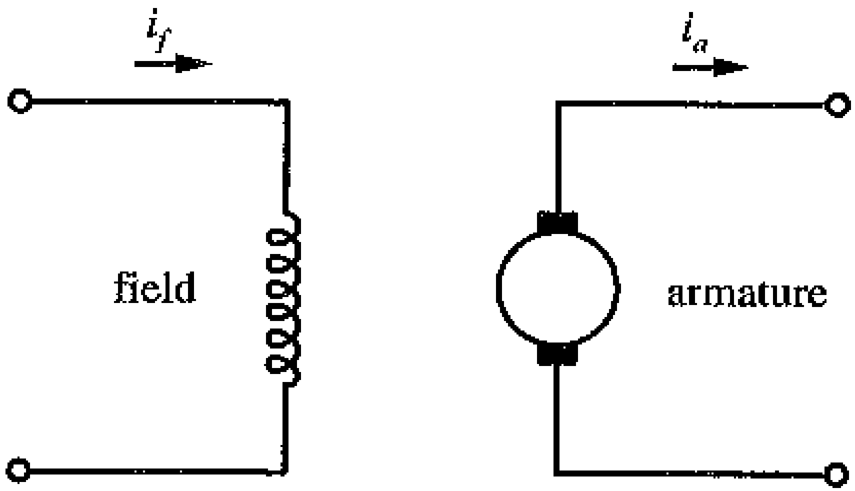

Fig. 15.30 Symbol for a dc generator.

i_f **is the field current and** i_a **denotes the armature current.**

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- The rotor of a dc generator turning at n rpm induces an emf (no load armature voltage) of

$$v_g = K\phi n$$

- Where K = Np/60a is a constant determined by the construction of the generator.

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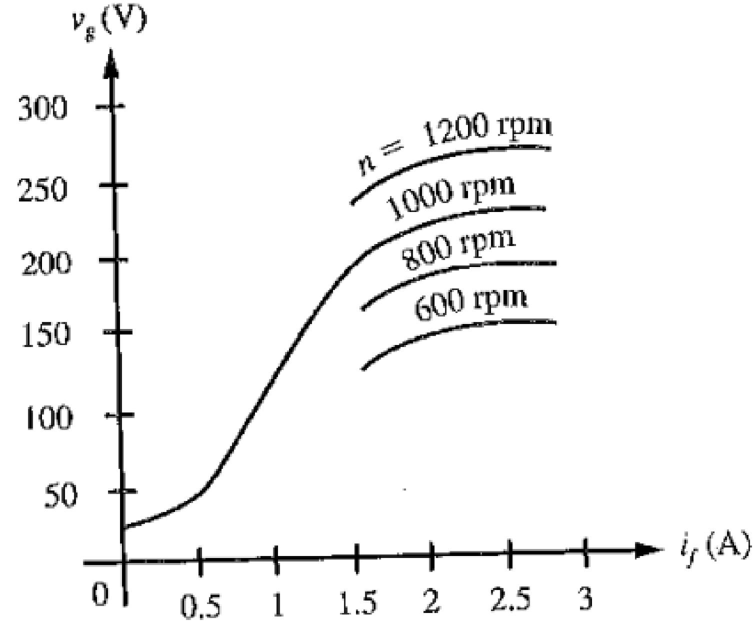
- The plot of no- load voltage v_g vs the field current i_f looks like:



Magnetization curves for a dc generator.

- These curves are called magnetization curves of the generator.

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Generator field excitation:

FIELD EXCITATION

When a dc voltage is applied to the field windings of a dc generator, current flows through the windings and sets up a - - steady magnetic field. This is called FIELD EXCITATION.

This excitation voltage can be produced by the generator itself or it can be supplied by an outside source, such as a battery.

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If it is supplied by an outside source then it is called separately excited generator as shown below.

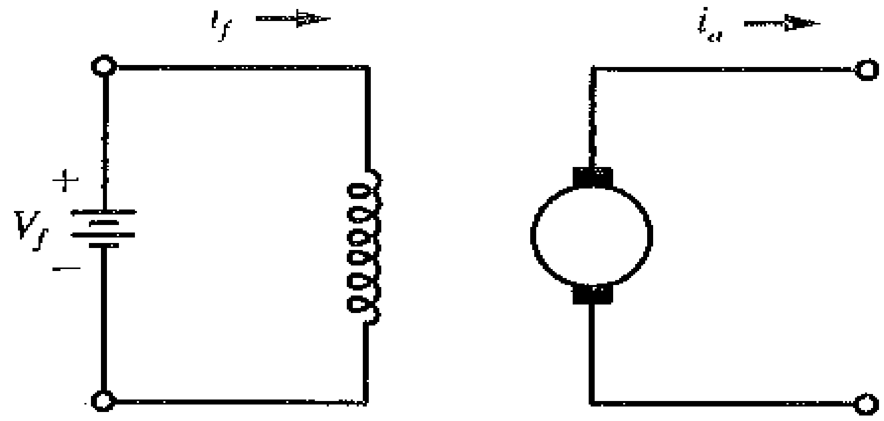

Fig. 15.32 Separately excited generator.

A generator that supplies its own field excitation is called a SELF-EXCITED GENERATOR.

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CLASSIFICATION OF GENERATORS

- Self-excited generators are classed according to the type of field connection they use.

- There are three general types of field connections - SERIES-WOUND, SHUNT-WOUND (parallel), and COMPOUND-WOUND.

- Compound-wound generators are further classified as cumulative-compound and differential-compound.

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Series-Wound Generator or Series connected generator

- In the series-wound generator, the field windings are connected in series with the armature.

- Current that flows in the armature flows through the external circuit and through the field windings.

- The external circuit connected to the generator is called the load circuit.

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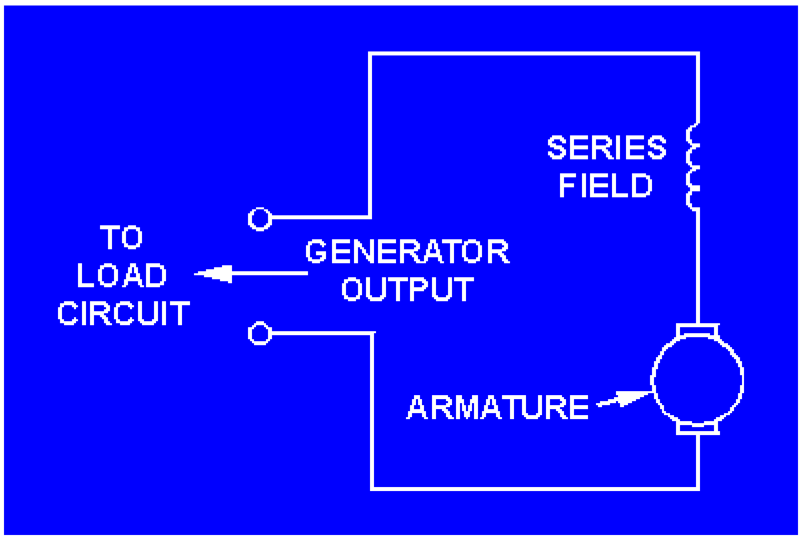
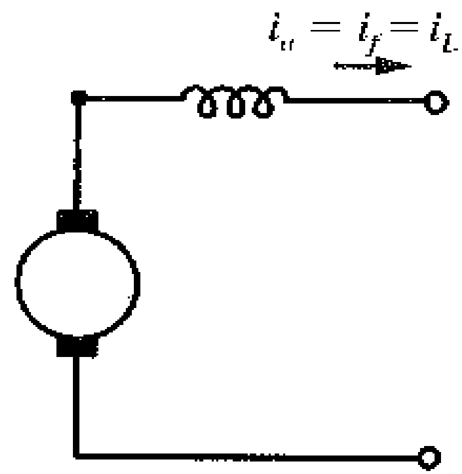
Series Connected generators





- The field current is equal to the armature current, the field winding has very few turns and relatively low resistance.

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Shunt-Wound Generators

- In a shunt-wound generator, the field coils consist of many turns of small wire and relatively high field resistance.

- They are connected in parallel with the load. In other words, they are connected across the output voltage of the armature.

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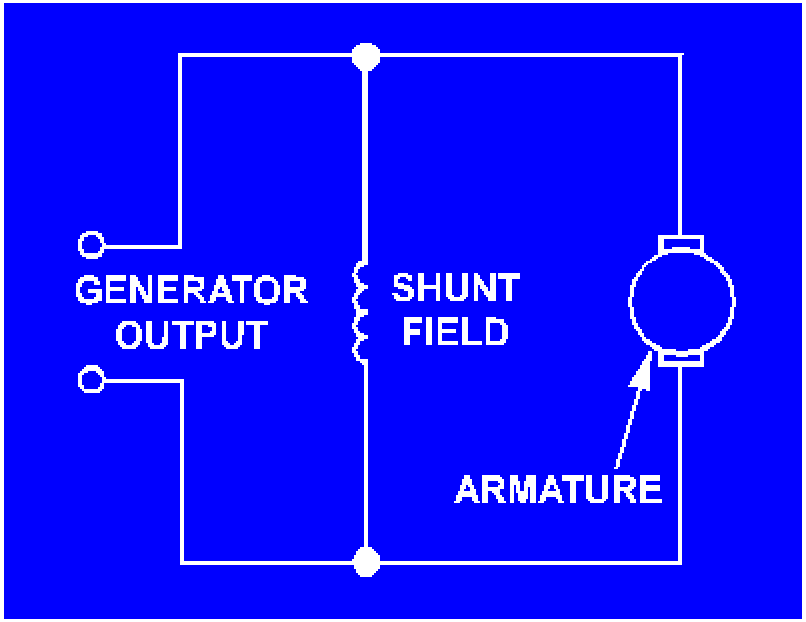
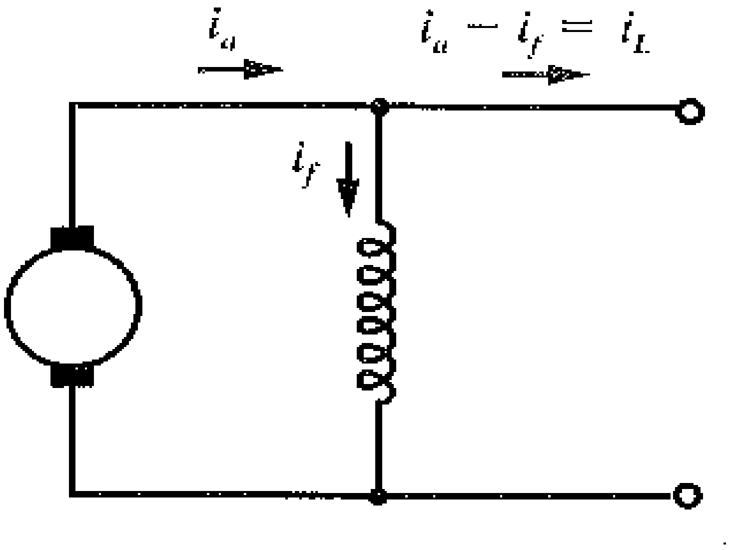
Shunt Connected generators





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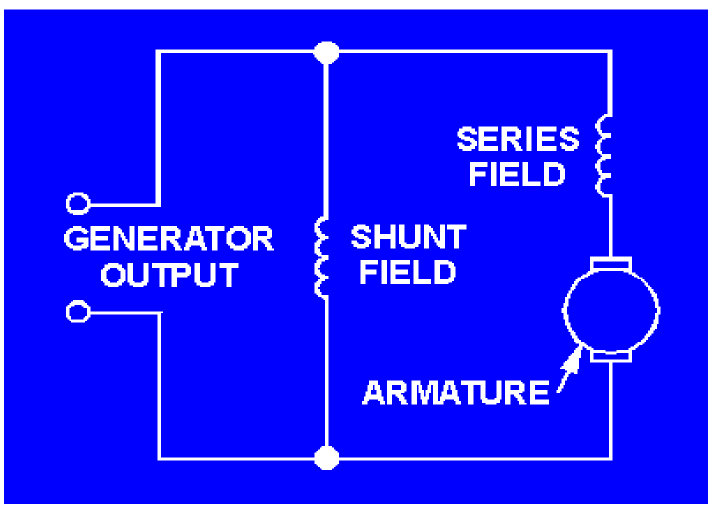
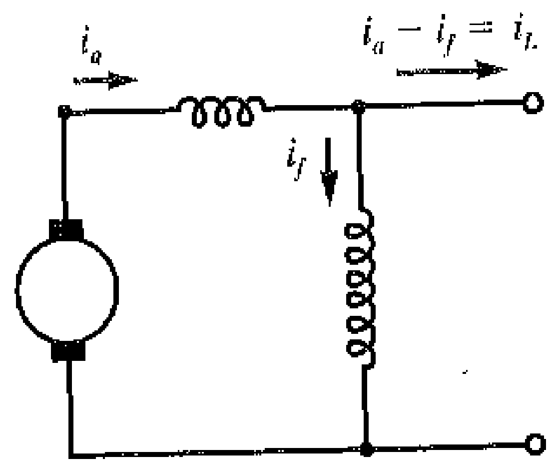
Compound-Wound Generators

Compound-wound generators have a series-field winding in addition to a shunt-field winding.

The shunt and series windings are wound on the same pole pieces.





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GENERATOR BUILD UP:

-For for a separately excited generator turning at n rpm, the value of the field current determines the value of generated voltage and the following magnetization curve can be used to find it.

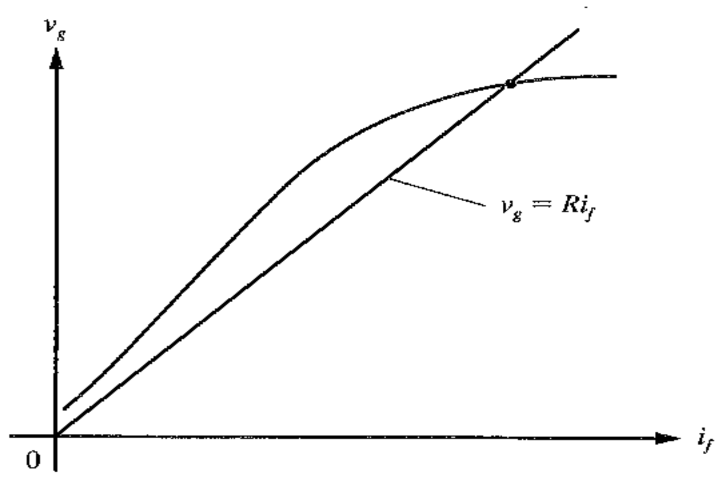

Fig. 15.37 Magnetization curve.

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- Consider a shunt connected generator where a rheostat and switch is included in the circuit..
- When the switch is open ie when i_f =0 there will be a small generated emf due to residual magnetism .
- When the switch is closed, there will be a voltage applied across the series combination of field winding and the control rheostat.
- This will produce a nonzero field current and hence increases the flux, thereby resulting in an increase in the generated emf.

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This repetitive process of increasing generated voltage and field current is known as generator build up.

The intersection point on the graph shown before shows generator build up has ceased.

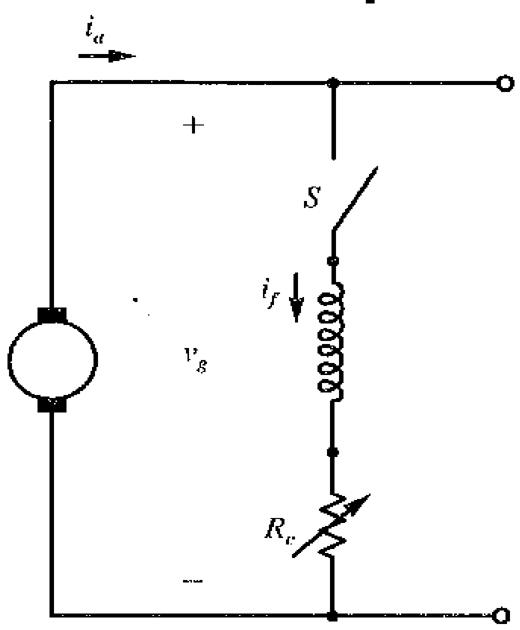
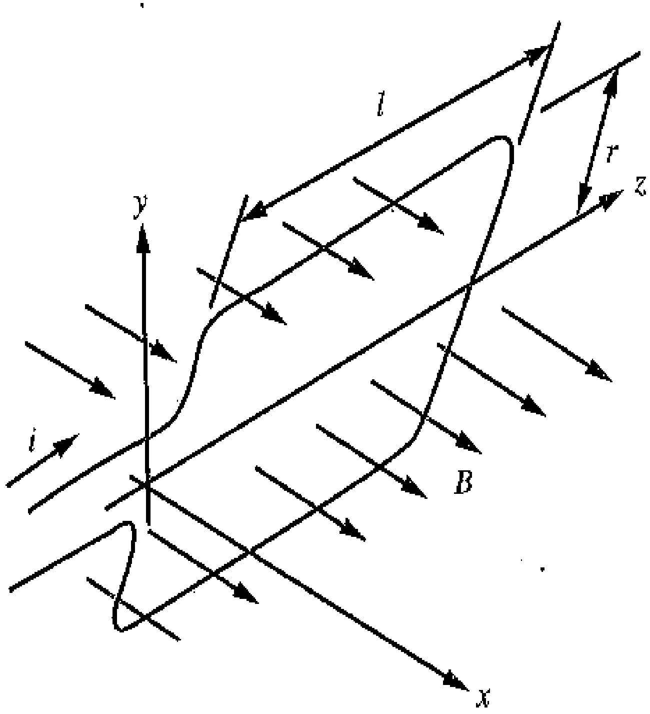


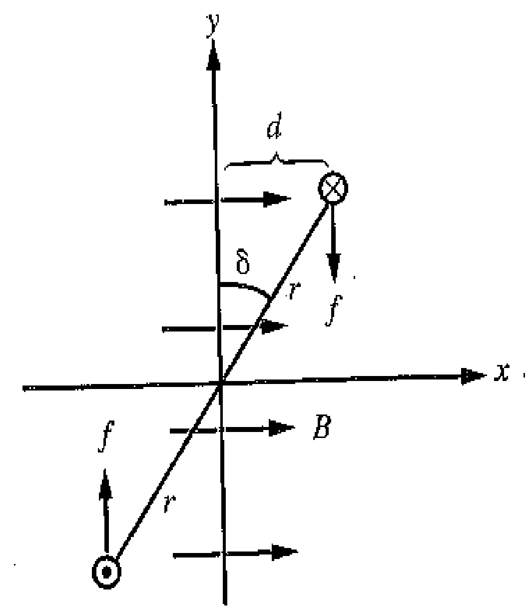
Fig. 15.36 Shunt-connected generator.

DC MOTORS:

Rotating Machines



(a) Three-dimensional view



(b) Side view

Fig. 15.40 Simple rotating machine.

DC MOTORS:

Consider a conducting loop through which i is the current flowing.

The slip rings and brushes are also present though not shown here.

The end view of the loop is shown in the figure b, where the current in the upper conductor is directed into the page (shown by cross X) and the current in the lower conductor is directed out of the page.(shown by dot.)

By the Right hand rule or by using unit vectors the force on the upper conductor is

F= Bil in the downward direction.

DC MOTORS:

Similrly on the lower conductor the force of same magnitude acts in the upward direction.

Since the line of action of the two forces is not the same, a torque is developed which is

Fd= Blirsinδ, where δ is the angle formed by the y-z plane and the plane of the loop and is called the torque angle or power angle.

For N turns in a coil and 2 conductors the torque becomes

T = 2NBlir sinδ = NBAisinδ, where A = 2rlis the area of the coil.

DC MOTORS:

The torque is max when $\delta = 90$deg when $\sin\delta = 1$

This torque tends to rotate the loop in the clockwise direction.

Due to the loop rotating clockwise , the emf is induced which tends to produce a current in the direction opposite to the applied current.

This is the principle on which the dc motor works.

DC MOTORS:

Armature model for the dc motor:

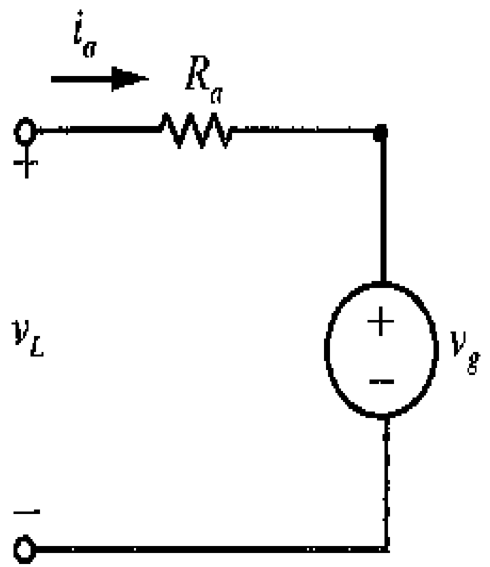


Fig. 15.41 Model of armature portion of a dc motor.

DC MOTORS:

The figure shows the armature portion of the motor.

R_a is the armature resistance v_L is the applied or the line voltage of the motor.

WKT $v_g = K\varphi n$, where K is a constant, φ is the flux per pole and n is the rptor (armature) speed.

For a dc motor, from the circuit by KVL we have

$V_L = R_a i_a + v_g$

And since $v_g = K\varphi n$ then

$V_L = R_a i_a + K\varphi n$

Hence speed (in rpm) of the motor is

$$n = \frac{v_L - R_a i_a}{K\Phi}$$

This is known as the speed equation of a dc motor.

DC MOTORS:

The torque developed by the dc motor is determined by the armature current and the magnetic flux density and hence the field flux (flux per pole).

Therefore Torque can be written as

$$T = K'\Phi i_a$$

where K' is a constant that is determined by the construction of the motor.

DC MOTORS:

A 220 volt dc shunt motor has a speed of 1200 rpm and an armature current of 6A at no load. Given that the armature resistance is 0.5 Ω, determine the motor speed when the armature current is 40A at full load.

$$K\Phi = \frac{v_L - R_a i_a}{n}$$

Thus at no load,

$$K\Phi = \frac{220 - (0.5)(6)}{1200} = 0.181$$

Hence at full load,

$$n = \frac{v_L - R_a i_a}{K\Phi} = \frac{220 - (0.5)(40)}{0.181} = 1105 \text{ rpm}$$

DC MOTORS:

The motor speed at full load written as n_{FL} differs from the speed at no load n_{NL} .

A measure of change in speed is the speed regulation of the motor, which is defined as

$$SR = \frac{n_{NL} - n_{FL}}{n_{FL}}$$

Therefore

$$SR = \frac{1200 - 1105}{1105} = 0.086 = 8.6\%$$