Chapter Three

DC GENERATORS

Learning Outcomes:

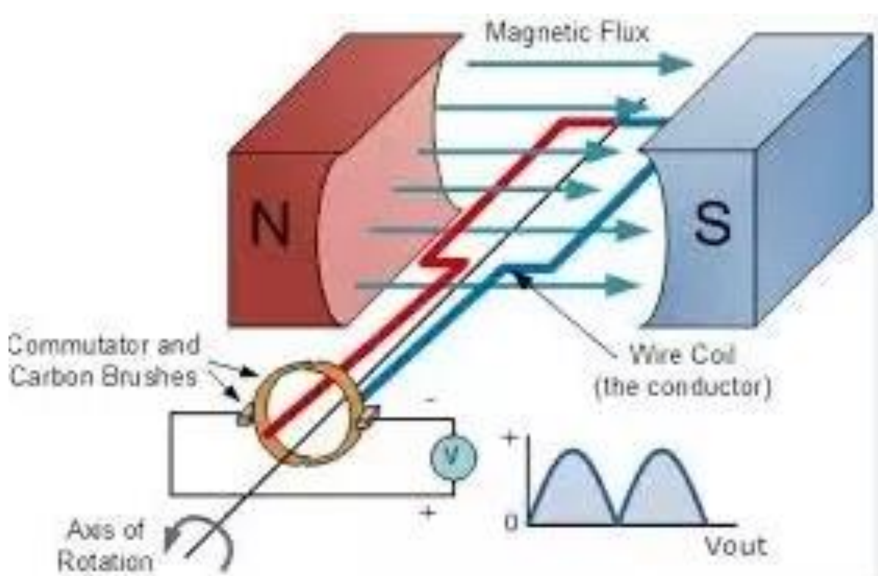
After the ending of the lesson, students will be able to know about

- the operating principle of a DC generator.
- Classification and generated voltage of a dc generator.
- Characteristics of different types dc generator
- Solution problems of dc generators

What is a D.C. Generator?

A DC generator is an electrical machine whose main function is to convert mechanical energy into DC electricity. When the conductor slashes magnetic flux, an emf will be generated based on the electromagnetic induction principle of Faraday's Laws. This electromotive force can cause a flow of current when the conductor circuit is closed.

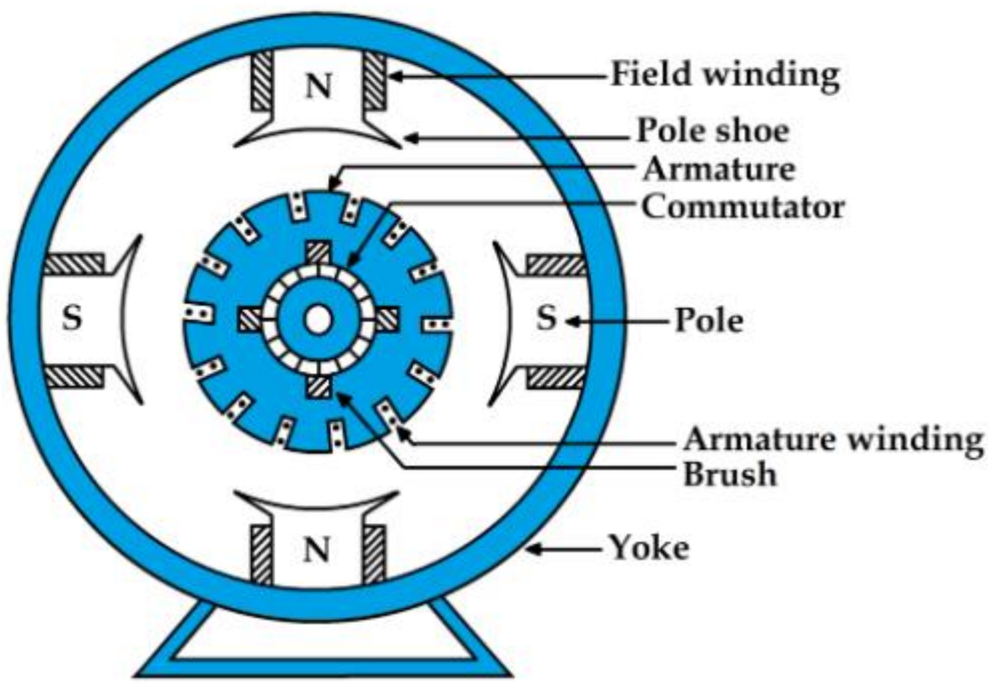
Principle of Operation of a D.C. Generator



Key Point:

1. DC generators' primary function is to convert mechanical energy into electrical energy.
2. DC generators generate electricity using the principle of Faraday's law of electromagnetic induction.
3. When a conductor is placed in a varying magnetic field, an electromotive force gets induced within the conductor.
4. This induced e.m.f magnitude is measured using the equation of the electromotive force of a generator.
5. If the conductor is provided with a closed path, the induced current will circulate within the closed path. In this generator, field coils will generate an electromagnetic field as well as the armature conductors are turned into the field.
6. Therefore, an electromagnetically induced electromotive force (e.m.f) will be generated within the armature conductors.

DC Generator consists of the following parts



1. **Stator -** A stator is a set of two magnets placed in such a way that opposite polarity faces each other. The purpose of the stator is to provide a magnetic field in the region where the coil spins.
2. **Rotor -** A rotor is a cylindrical laminated armature core with slots.

3. **Armature Core -** The armature core is cylindrical in shape and has grooves on the outer surface. These slots accommodate armature winding in it.

4. **Armature Winding -** These are the insulated conductors placed in the armature core. Because of them, the actual conversion of power takes place.

5. **Field Coils -** To produce the magnetic field, field coils are placed over the pole core. The field coils of all the poles are connected in series. When current flows through them, adjacent poles acquire opposite polarity.

6. **Yoke -** The outer hollow cylindrical structure is known as Yoke. It provides support to main poles and inter poles and gives a low reluctance path for the magnetic flux.

7. **Poles -** The main function of the poles is to support the field coils. It increases the cross-sectional area of the magnetic circuit, which results in a uniform spread of magnetic flux.

8. **Pole Shoe -** To protect the field coil from falling and to enhance the uniform spread of magnetic flux pole shoe is used. The pole shoe is fixed to Yoke.

9. **Commutator -** The commutator is cylindrical in shape. Several wedge-shaped, hard drawn copper segments form a commutator. The functions of a commutator:

Process of voltage build up

When the armature is rotated, the residual flux in field winding will induce small voltage in armature. The induced voltage in armature generates a flux and it will aid(add) with field flux and the net flux will increase further. This process will be repeating until the actual terminal voltage is reached. Once the terminal voltage is reached then the winding will get saturated and hence there won't be any further increase in flux, also the voltage gets constant.

Emf Equation of a DC Generator

We shall now derive an expression for the e.m.f. generated in a d.c. generator.

Let

ϕ = flux/pole in Wb

Z = total number of armature conductors

P = number of poles

A = number of parallel paths = 2 .... for wave winding

= P .... for lap winding

N = speed of armature in r.p.m.

E_g = e.m.f. of the generator = e.m.f./parallel path

Flux cut by one conductor in one revolution of the armature,

$$d\phi = P\phi \text{ webers}$$

Time taken to complete one revolution,

$$dt = 60/N \text{ second}$$

$$\text{e.m.f. generated/conductor} = \frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60} \text{ volts}$$

$$\text{e.m.f. of generator, } E_g = \text{e.m.f. per parallel path}$$

$$= (\text{e.m.f./conductor}) \times \text{No. of conductors in series per parallel path}$$

$$= \frac{P\phi N}{60} \times \frac{Z}{A}$$

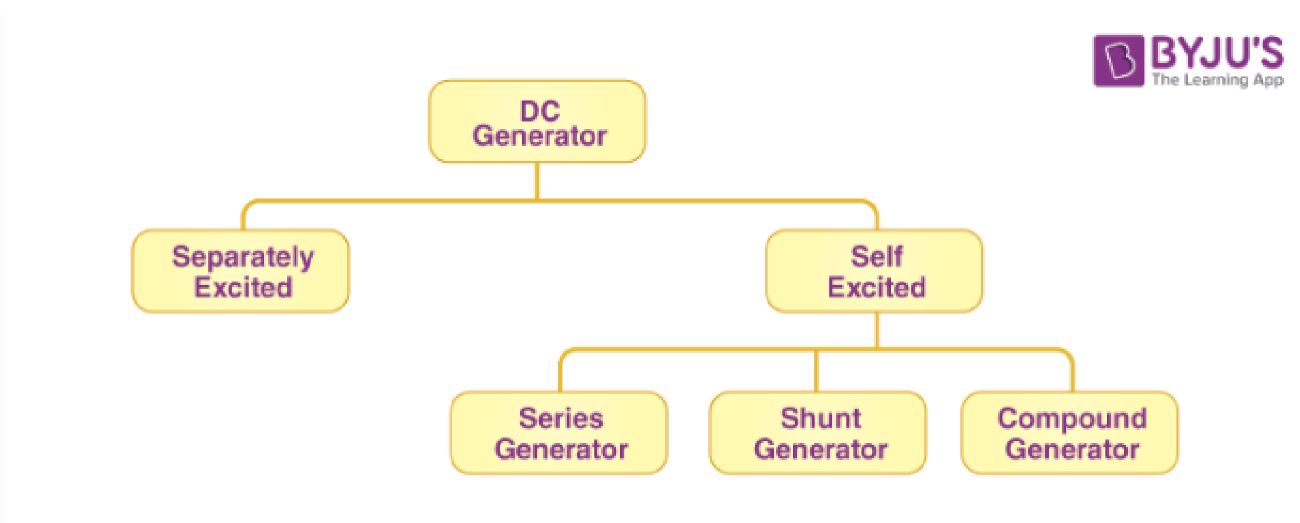
$$\therefore \quad E_g = \frac{P\phi Z N}{60\,A}$$

where $A = 2$ ... *for wave winding*

$= P$ ... *for lap winding*

Types of DC generator

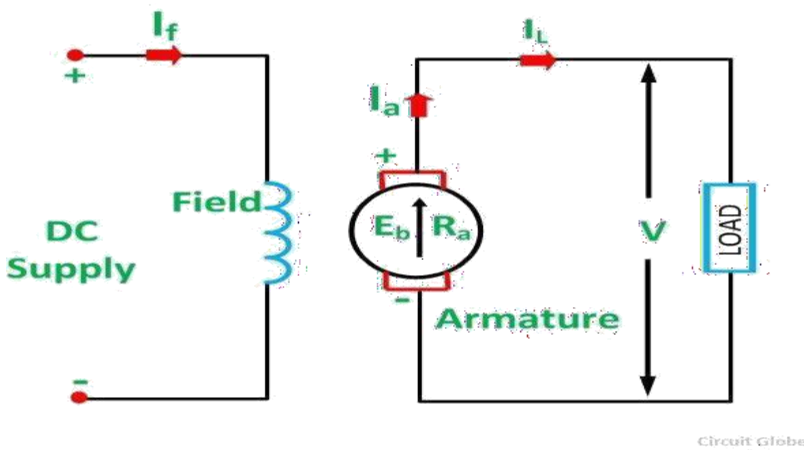
The DC generator can be classified into two main categories as separately excited and self-excited.



Separately Excited DC Generator

A DC generator whose field winding or coil is energized by a separate or external DC source is called a separately excited DC Generator. The flux produced by the poles depends upon the field current with the unsaturated region of magnetic material of the poles. i.e. flux is directly proportional to the field current. But in the saturated region, the flux remains constant.

The figure of self-excited DC Generator is shown below.



Here,

$I_a = I_L$ where I_a is the armature current and I_L is the line current.

Terminal voltage is given as

$$V = E_g - I_aR_a \quad \dots\dots(1)$$

If the contact brush drop is known, then the equation (1) is written as

$$V = E_g - I_aR_a - 2v_b \quad \dots\dots(2)$$

The power developed is given by the equation shown below.

$$\text{Power developed} = E_gI_a \quad \dots\dots\dots(3)$$

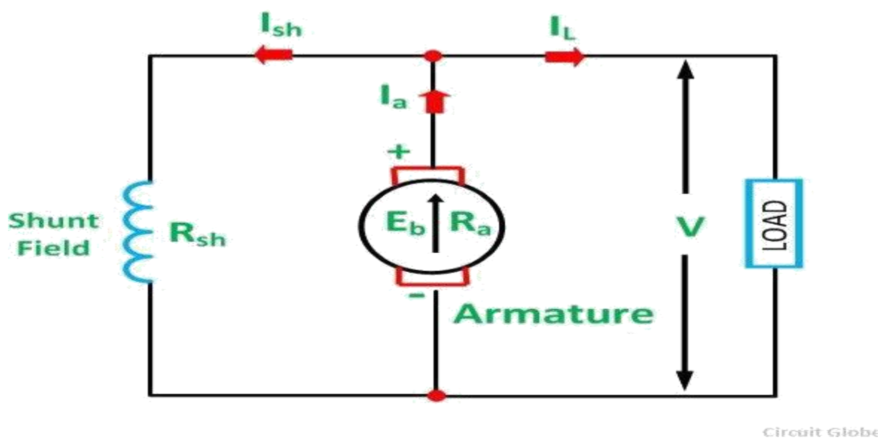
$$\text{Power output} = VI_L = VI_a \quad \dots\dots\dots(4)$$

The self-excited DC Generator is further classified as

1. Shunt Wound Generator
2. Series Wound Generator
3. Compound Wound Generator

In a **shunt wound generator,** the field winding is connected across the armature winding forming a parallel or shunt circuit. Therefore, full terminal voltage is applied across it. A very small field current I_{sh}, flows through it because this winding has many turns of fine wire having very high resistance R_{sh} of the order of 100 ohms.

The connection diagram of shunt wound generator is shown below.



Shunt field current is given as

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

Where R_{sh} is the shunt field winding resistance.

The current field I_{sh} is practically constant at all loads. Therefore, the DC shunt machine is considered to be a constant flux machine.

Armature current is given as $I_a = I_L + I_{sh}$

Terminal voltage is given by the equation shown below.

$$V = E_g - I_a R_a$$

If the brush contact drop is included, the equation of the terminal voltage becomes

$$V = E_g - I_a R_a - 2v_b$$

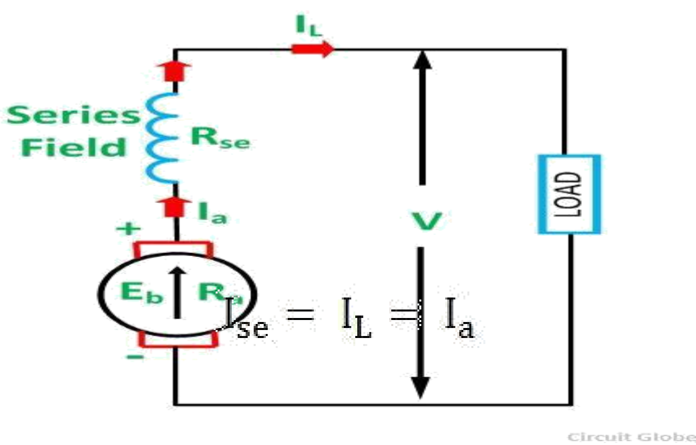
$$\text{Power developed} = E_g I_a$$

$$\text{Power output} = VI_L$$

- **Series Wound Generator**

A **series-wound generator** the field coils are connected in series with the armature winding. The series field winding carries the armature current. The series field winding consists of a few turns of wire of thick wire of larger cross-sectional area and having low resistance usually of the order of less than 1 ohm because the armature current has a very large value.

Its convectional diagram is shown below.



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

Series field current is given as

R_{se} is known as the series field winding resistance.

Terminal voltage is given as

$$V = E_g - I_a R_a - I_{se} R_{se}$$

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

If the brush contact drop is included, the terminal voltage equation is written as

$$V = E_g - I_a (R_a + R_{se}) - 2V_b$$

$$\text{Power developed} = E_g I_a$$

$$\text{Power output} = VI_L = VI_a$$

The flux developed by the series field winding is directly proportional to the current flowing through it. But it is only true before magnetic saturation after the saturation flux becomes constant even if the current flowing through it is increased.

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Math Problems

Example 2.11. *A 6-pole lap-wound d.c. generator has 600 conductors on its armature. The flux per pole is 0.02 Wb. Calculate (i) the speed at which the generator must be run to generate 300 V. (ii) What would be the speed if the generator were wave-wound ?*

Solution.

(*i*) **Lap wound** $E_g = \dfrac{P\phi Z N}{60\,A}$

$$\therefore \quad N = \frac{E_g \times 60\,A}{P\phi Z} = \frac{300 \times 60 \times 6}{6 \times 0{\cdot}02 \times 600} = \mathbf{1500\ r.p.m.}$$

(*ii*) **Wave wound** $N = \dfrac{E_g \times 60\,A}{P\phi Z} = \dfrac{300 \times 60 \times 2}{6 \times 0{\cdot}02 \times 600} = \mathbf{500\ r.p.m.}$

Example 2.12. *An 8-pole, lap-wound armature rotated at 350 r.p.m. is required to generate 260 V. The useful flux per pole is 0·05 Wb. If the armature has 120 slots, calculate the number of conductors per slot.*

Solution. $E_g = \dfrac{P\phi Z N}{60\,A}$

$$\therefore \quad Z = \frac{E_g \times 60\,A}{P\phi N} = \frac{260 \times 60 \times 8}{8 \times 0{\cdot}05 \times 350} = 890$$

$\therefore$ No. of conductors/slot = 890/120 = 7.41

This value must be an even number.

Hence, conductors/slot = **8**

Example 2.13. *The armature of a 6-pole, 600 r.p.m. lap-wound generator has 90 slots. If each coil has 4 turns, calculate the flux per pole required to generate an e.m.f. of 288 volts.*

Solution. Each turn has two active conductors and 90 coils are required to fill 90 slots.

$$\therefore \quad Z = 90 \times 4 \times 2 = 720$$

$$E_g = \frac{P\phi Z N}{60\,A}$$

or $\phi = \dfrac{E_g \times 60\,A}{P Z N} = \dfrac{288 \times 60 \times 6}{6 \times 720 \times 600} = \mathbf{0{\cdot}04\ Wb}$

Example 2.23. *A 100 kW, 240 V shunt generator has a field resistance of 55 Ω and armature resistance of 0·067 Ω. Find the full-load generated voltage.*

Solution. Fig. 2.42 shows the shunt generator circuit.

$$I_L = \frac{100 \times 10^3}{240} = 416{\cdot}7 \text{ A}$$

$$I_{sh} = 240/55 = 4.36 \text{ A}$$

$$I_a = I_L + I_{sh} = 416{\cdot}7 + 4{\cdot}36 = 421{\cdot}1 \text{ A}$$

$$E_g = V + I_a R_a = 240 + 421{\cdot}1 \times 0{\cdot}067 = \mathbf{268{\cdot}2 \text{ V}}$$

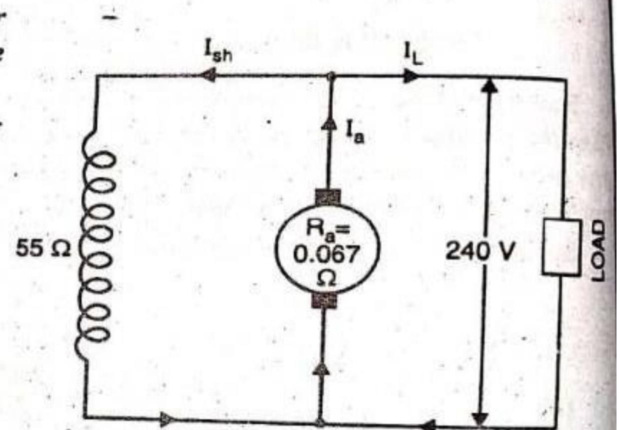

Fig. 2.42

Example 2.42. *A shunt generator supplies 96 A at a terminal voltage of 200 volts. The armature and shunt field resistances are 0·1 Ω and 50 Ω respectively. The iron and frictional losses are 2500 W. Find (i) e.m.f. generated (ii) copper losses (iii) commercial efficiency.*

Solution. Fig. 2.58 shows the connections of shunt generator.

(*i*)

$$I_{sh} = 200/50 = 4 \text{ A}$$

$$I_a = I_L + I_{sh} = 96 + 4 = 100 \text{ A}$$

$$E_g = V + I_a R_a = 200 + 100 \times 0{\cdot}1 = \mathbf{210 \text{ V}}$$

(*ii*)

$$\text{Armature Cu loss} = I_a^2 R_a = (100)^2 \times 0.1 = 1000 \text{ W}$$

$$\text{Shunt Cu loss} = I_{sh}^2 R_{sh} = (4)^2 \times 50 = 800 \text{ W}$$

$$\text{Total Cu loss} = 1000 + 800 = \mathbf{1800 \text{ W}}$$

(*iii*)

$$\text{Total losses} = \text{Rotational losses} + \text{Cu losses} = 2500 + 1800 = 4300 \text{ W}$$

$$\text{Output power} = 96 \times 200 = 19200 \text{ W}$$

$$\text{Input power} = 19200 + 4300 = 23500 \text{ W}$$

$$\therefore \quad \eta_c = \frac{19200}{23500} \times 100 = \mathbf{81.7\%}$$

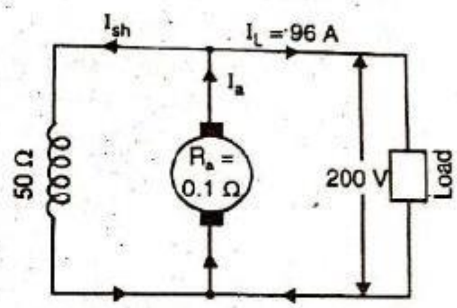

Fig. 2.58

Example 28.4. *The following figures give the O.C.C. of a d.c. shunt generator at 300 r.p.m.*

Field amperes :	*0*	*2*	*3*	*4*	*5*	*6*	*7*
Armature volt :	*7.5*	*92*	*132*	*162*	*183*	*190*	*212*

Plot the O.C.C. for 375 r.p.m. and determine the voltage to which the machine will excite if field circuit resistance is 40 Ω.

(*a*) *What additional resistance would have to be inserted in the field circuit to reduce the voltage to 200 volts at 375 r.p.m.?*

(*b*) *Without this additional resistance, determine the load current supplied by the generator, when its terminal voltage is 200 V. Ignore armature reaction and assume speed to be constant. Armature resistance is 0.4 Ω.* **(Elect. Machines - I, South Gujarat Univ. 1986)**

Solution. The e.m.f. induced at 375 r.p.m. would be increased in the ratio 375/300 corresponding to different shunt field current values. A new table is given with the voltages multiplied by the above ratio.

Field amperes :	*0*	*2*	*3*	*4*	*5*	*6*	*7*
Armature volt :	*9.4*	*115*	*165*	*202.5*	*228.8*	*248.8*	*265*

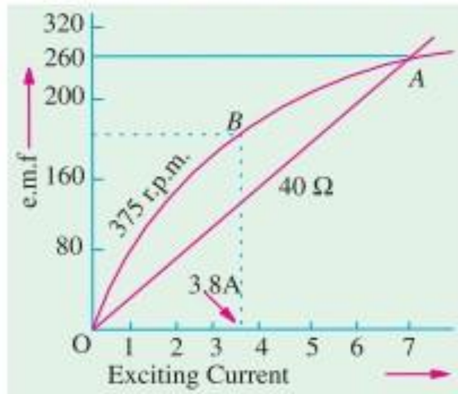

Fig. 28.11

The new *O.C.C.* at 375 r.p.m. is shown in Fig. 26.11. Line *OA* represents 40-Ω line.

The voltage corresponding to point *A* is 260 V. Hence machine will excite to 260 volt with 40 Ω shunt field resistance.

(*a*) From Fig. 28.11, it is clear that for exciting the generator to 200 V, exciting current should be 3.8 A.

∴ Field circuit resistance = 200/3.8 = 52.6 Ω

∴ Additional resistance required = 52.6 − 40 = **12.6 Ω**

(*b*) In this case, shunt field resistance = 40 Ω ...(as above)

Terminal voltage = 200 V ∴ Field current = 200/40 = 5 A

Generated e.m.f. for exciting current of 5 A = 228.8 V

For a generator $E = V + I_a R_a \therefore I_a R_a = E - V$ or $0.4\, I_a = 228.8 - 20 = 28.8$

∴ $I_a = 28.8/0.4 = 72$ A ∴ Load current $I = 72 - 5 =$ **67 A**

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OBE Based Questions (for practice)

Q.1. The open circuit characteristics of a shunt excited dc generator at 1000 rpm speed is given in Table 1. The armature resistance is 0.05 ohm. The generator is driven by a prime-mover at 1000 rpm and running at no load.

If(A)	0.2	0.4	0.6	0.8	1	1.2	1.4	1.52	1.54	1.6	2	2.4
Ea(V)	20	40	60	79	93	103	110	113.5	113.9	115	120	122.4

The operator adjusts the field resistance to 60-ohm. Ignoring armature voltage drop (except in Q(c))

a) What is the EMF induced in armature?
b) What is the field current?
c) What is the voltage drop in armature windings?
d) If the operator increases the field resistance up to 93-ohm, what is the terminal voltage?
e) What is the critical resistance? What will happen if the field resistance is increased to a value greater than the field resistance?