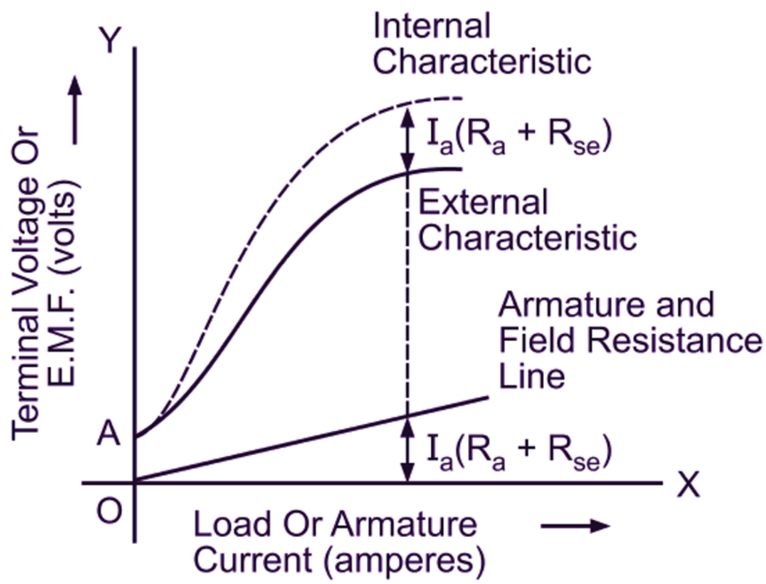
Ministry of Higher Education and Scientific Research
Al-Mustaqbal University
College of Engineering & Technology
Medical Instrumentation Techniques Engineering Department
Electrical Technology
Third Class

Weeks 15, 16

Characteristics of DC Generator



By Osamah Jaber Ghayyib

1. Introduction

The speed of a d.c. machine operated as a generator is fixed by the prime mover. For general-purpose operation, the prime mover is equipped with a speed governor so that the speed of the generator is practically constant. Under such conditions, the generator performance deals primarily with the relation between excitation, terminal voltage and load. These relations can be best exhibited graphically by means of curves known as generator characteristics. These characteristics show briefly the behavior of the generator under different load conditions.

2. D.C. Generator Characteristics

The following are the three most important characteristics of a d.c. generator:

2.1 Open Circuit Characteristic (O.C.C.)

This curve shows the relation between the generated e.m.f. at no-load (E_0) and the field current (I_f) at constant speed. It is also known as magnetic characteristic or no-load saturation curve. Its shape is practically the same for all generators whether separately or self-excited. The data for O.C.C. curve is obtained experimentally by operating the generator at no load and constant speed and recording the change in terminal voltage as the field current is varied.

2.2 Internal or Total characteristic (E/I_a)

This curve shows the relation between the generated e.m.f. on load (E) and the armature current (I_a). The e.m.f. E is less than E_0 due to the demagnetizing effect of armature reaction. Therefore, this curve will lie below the open circuit characteristic (O.C.C.). The internal characteristic is of interest chiefly to the designer. It cannot be obtained directly by experiment. It is because a voltmeter cannot read the e.m.f. generated on the load due to the voltage drop in armature resistance. The internal characteristic can be obtained from external characteristic if winding resistances are known because armature reaction effect is included in both characteristics.

2.3 External characteristic (V/I_L)

This curve shows the relation between the terminal voltage (V) and load current (I_L). The terminal voltage V will be less than E due to voltage drop in the armature circuit. Therefore, this curve will lie below the internal characteristic. This characteristic is very important in determining the suitability of a generator for a given purpose. It can be obtained by making simultaneous measurements of terminal voltage and load current (with voltmeter and ammeter) of a loaded generator.

3. Characteristics of a Separately Excited D.C. Generator

3.1 Open circuit characteristic.

The arrangement for obtaining the necessary data to plot this curve is shown in Fig. 1. The exciting or field current I_f is obtained from an external independent d.c. source. It can be varied from zero upwards by a potentiometer and its value read by an ammeter *A* connected in the field circuit as shown.

Now, the voltage equation of a d.c. generator is: -

$$Eg = \frac{Z\,P\,\emptyset\,N}{A\;60}\ volt \qquad (1)$$

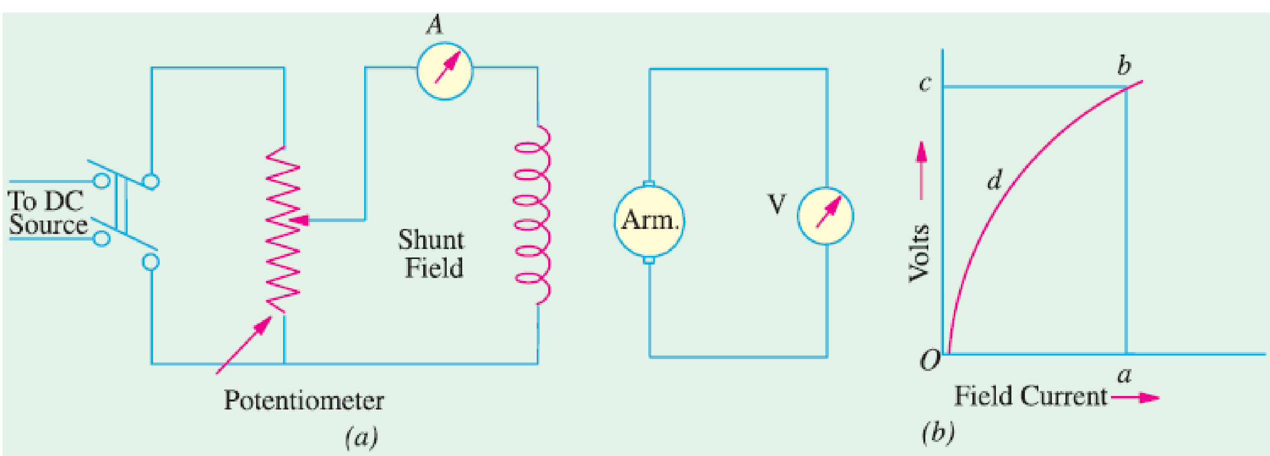


Fig. 1

Hence, if speed is constant, the above relation becomes: -

$$Eg = k\emptyset \ volt \qquad (2)$$

It is obvious that when I_f is increased from its initial small value, the flux $\emptyset$ and hence generated e.m.f. Eg increase directly as current so long as the poles are unsaturated. This is represented by the straight portion *Od* in Fig. 1 (*b*). But as the flux density increases, the poles become saturated, so a greater increase in I_f is required to produce a given increase in voltage than on the lower part of the curve. That is why the upper portion *db* of the curve *Odb* bends over as shown.

3.2 Load Saturation Curve (V/I_f)

The curve showing relation between the terminal voltage V and field current I_f when the generator is loaded, is known as Load Saturation Curve.

The curve can be deduced from the no-load saturation curve provided the values of armature reaction and armature resistance are known. While considering this curve, account is taken of the demagnetizing effect of armature reaction and the voltage drop in armature which are practically absent under no-load conditions. Under load conditions, the voltage will decrease due to demagnetizing effect of armature reaction. This decrease can be made up by suitably increasing the field amp-turns.

3.3 Internal and External Characteristics

Considering a separately excited generator giving its rated no-load voltage of E_0 for a certain constant field current. If there were no armature reaction and armature voltage drop, then this voltage would have remained constant as shown in Fig. 2 by the horizontal line *I*. But when the generator is loaded, the voltage falls due to these two causes, thereby giving slightly dropping characteristics.

If we subtract from E_0 the value of voltage drops due to armature reaction for different loads, then we get the value of *E*–the e.m.f. ***actually*** induced in the armature under load conditions. Curve II is plotted in this way and is known as the ***internal characteristic***. The straight line *Oa* represents the I_aR_a drops corresponding to different armature currents. If we subtract from

E the armature drop I_aR_a, we get terminal voltage *V*. Curve *III* represents the external characteristic and is obtained by subtracting ordinates the line *Oa* from those of curve *II*.

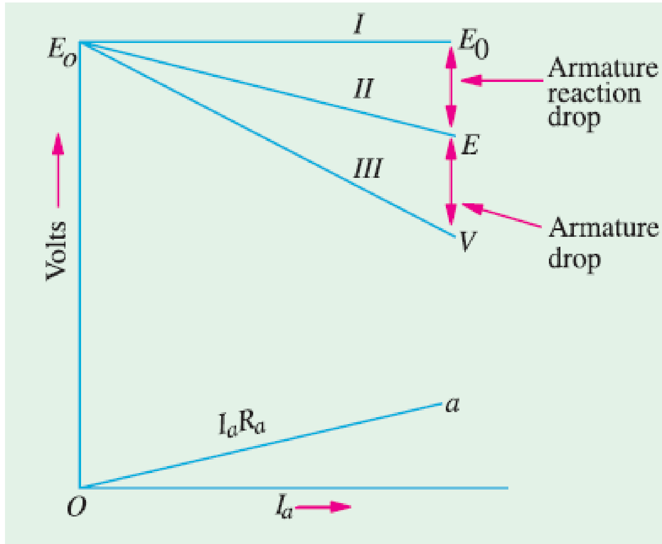


Fig. 2

4. Characteristics of a Shunt Generator

Fig (4) (i) shows the connections of a shunt wound generator. The armature current I_a splits up into two parts; a small fraction I_{sh} flowing through shunt field winding while the major part I_L goes to the external load.

4.1 Voltage Build-Up

Before loading a shunt generator, it is allowed to build up its voltage. Usually, there is always present some residual magnetism in the poles, hence a small e.m.f. is produced initially. This e.m.f. circulates a small current in the field circuit which increases the pole flux (provided field circuit is properly connected to armature, otherwise this current may wipe off the residual magnetism). When flux is increased, generated e.m.f. is increased which further increases the flux and so on. As shown in Fig. 3, *Oa* is the induced e.m.f. due to residual magnetism which appears across the field circuit and causes a field current *Ob* to flow. These current aids residual flux and hence produces, a larger induced e.m.f. *Oc*. In turn, this increased e.m.f. *Oc* causes an even larger current *Od* which creates more flux for a still larger e.m.f. and so on.

Now, the generated e.m.f. in the armature has

(*a*) to supply the ohmic drop $i_f R_f$ in the winding and (*b*) to overcome the opposing self-induced e.m.f. in the field coil *i.e.* $L\frac{di_f}{dt}$ because field coils have appreciable self-inductance.

$$Eg = i_f R_f + L\frac{di_f}{dt} \quad (3)$$

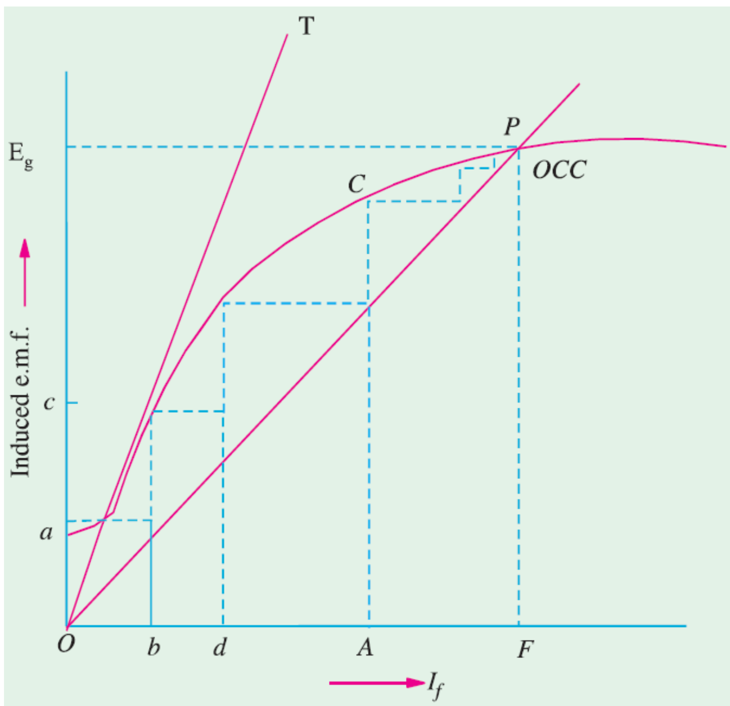


Fig. 3

If (and so long as), the generated e.m.f. is more than the ohmic drop $i_f R_f$, energy would continue being stored in the pole fields. For example, as shown in Fig. 3, corresponding to field current OA, the generated e.m.f. is AC. Out of this, AB goes to supply ohmic drop If R_{sh} and BC goes to overcome self-induced e.m.f. in the coil. Corresponding to If = OF, whole of the generated e.m.f. is used to overcome the ohmic drop. None is left to overcome $L\,{}^{di_f}/_{dt}$. Hence no energy is stored in the pole fields. Consequently, there is no further increase in pole flux and the generated e.m.f. With the given shunt field resistance represented by line OP, the maximum voltage to which the machine will build up is OE. If resistance is decreased, it will build up to a somewhat higher voltage. OR represents the resistance known as critical resistance. If shunt field resistance is greater than this value, the generator will fail to excite.

4.2 O.C.C.

The O.C.C. of a shunt generator is similar in shape to that of a series generator as shown in Fig. (4) (ii). The line OA represents the shunt field circuit resistance. When the generator is run at normal speed, it will build up a voltage OM. At no-load, the terminal voltage of the generator will be constant (= OM) represented by the horizontal dotted line MC.

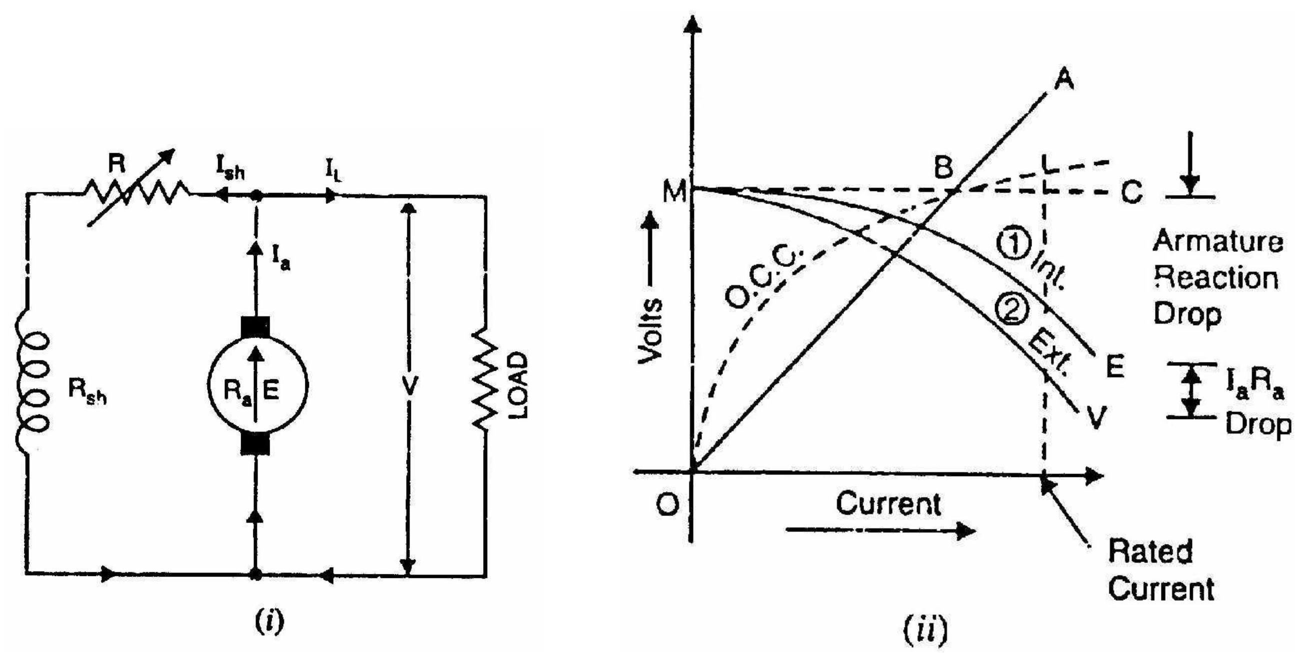


Fig. 4

4.3 Internal characteristic

When the generator is loaded, flux per pole is reduced due to armature reaction. Therefore, e.m.f. E generated on load is less than the e.m.f. generated at no load. As a result, the internal characteristic (E/I_a) drops down slightly as shown in Fig.4 (ii).

4.4 External characteristic

Curve 2 shows the external characteristic of a shunt generator. It gives the relation between terminal voltage V and load current I_L.

$$V = E - I_a R_a = E - (I_L + I_{sh}) R_a \ volt \tag{4}$$

Therefore, external characteristic curve will lie below the internal characteristic curve by an amount equal to drop in the armature circuit [i.e., $(I_L + I_{sh})R_a$] as shown in Fig. 4 (ii). Note. It may be seen from the external characteristic that the change in terminal voltage from no-load to full load is small. The terminal voltage can always be maintained constant by adjusting the field rheostat R automatically.

4.5 Critical Field Resistance for a Shunt Generator

Now, connect the field windings back to the armature and run the machine as a shunt generator. Due to residual magnetism in the poles, some e.m.f. and hence current, would be generated. This current while passing through the field coils will strengthen the magnetism of the poles (provided field coils are properly connected as regards polarity).

This will increase the pole flux, which will further increase the generated e.m.f. Increased e.m.f. means more current which further increases the flux and so on. This mutual reinforcement of e.m.f. and flux proceeds on till equilibrium is reached at some point like *P* (Fig. 5). The point lies on the resistance line *OA* of the field winding. Let *R* be the resistance of the field winding. Line *OA* is drawn such that its slope equals the field winding resistance *i.e.* every point on this curve is such that volt/ampere = *R*.

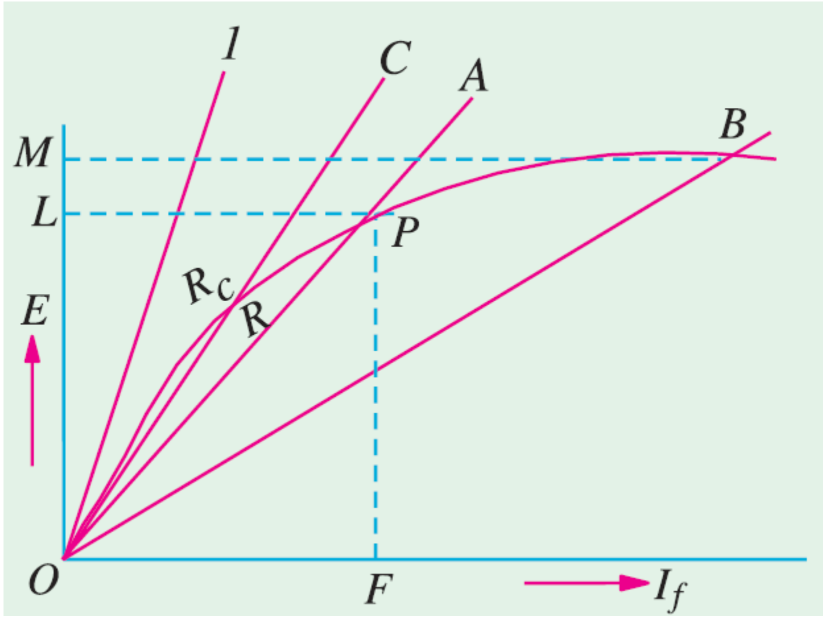


Fig. 5

The voltage *OL* corresponding to point *P* represents the maximum voltage to which the machine will build up with *R* as field resistance. *OB* represents smaller resistance, and the corresponding voltage *OM* is slightly greater than *OL*. If field resistance is increased, then slope of the resistance line increased, and hence the maximum voltage to which the generator will build up at a given speed decreases. If *R* is increased so much that the resistance line does not cut the *O.C.C.* at all (like *OT*), then obviously the machine will fail to excite *i.e.* there will be no 'build up' of the voltage. If the resistance line just lies along the slope, then with that value of field resistance, the machine will ***just*** excite. The value of the resistance represented by the tangent to the curve, is known as **critical resistance** R_c for a ***given speed***.

4.6 Critical Speed (N_C)

The critical speed of a shunt generator is the minimum speed below which it fails to excite. Clearly, it is the speed for which the given shunt field resistance represents the critical resistance. In Fig. 6, curve 2 corresponds to critical speed because the shunt field resistance (R_{sh}) line is tangential to it. If the generator runs at full speed N, the new O.C.C. moves upward and the R'_{sh} line represents critical resistance for this speed.

∴ Speed ∝ Critical resistance In order to find critical speed, take any convenient point C on excitation axis and erect a perpendicular so as to cut R_{sh} and R'_{sh} lines at points B and A respectively. Then,

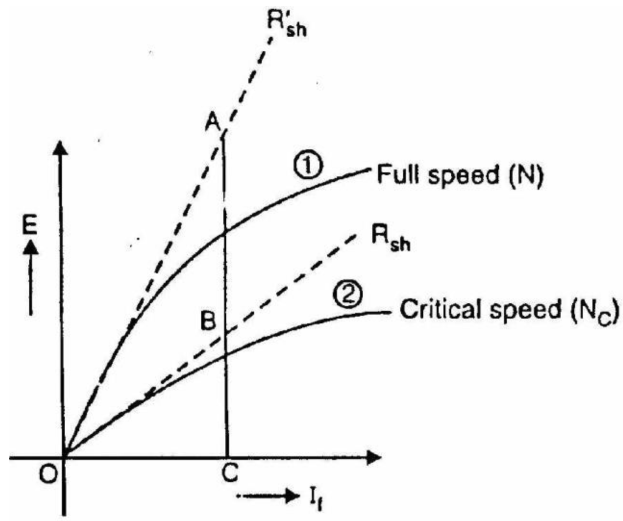


Fig. 6

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} \tag{5}$$

$$E_2 = \frac{N_2}{N_1} E_1 \tag{6}$$

4.7 Conditions for Voltage Build-Up of a Shunt Generator

The necessary conditions for voltage build-up in a shunt generator are:

(i) There must be some residual magnetism in generator poles.

(ii) The connections of the field winding should be such that the field current strengthens the residual magnetism.

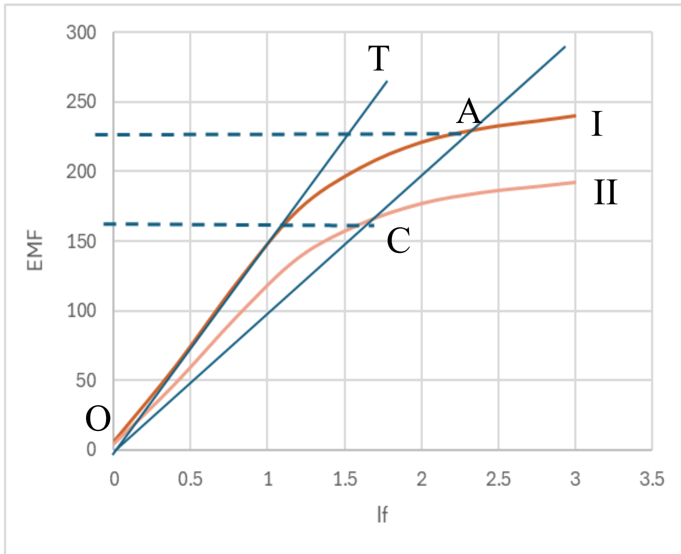
(iii) The resistance of the field circuit should be less than the critical resistance. In other words, the speed of the generator should be higher than the critical speed.

Example 1: The magnetization curve of a d.c. shunt generator at 1500 r.p.m. is.

I_f (A) :	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.0
E_0 (V) :	6	60	120	172.5	202.5	221	231	237	240

For this generator find **(i)** no load e.m.f. for a total shunt field resistance of 100 Ω **(ii)** the critical field resistance at 1500 r.p.m. and **(iii)** the magnetization curve at 1200 r.p.m. and therefrom the open-circuit voltage for a field resistance of 100 Ω

Solution



N_1=1500 rpm (Curve I)

N_2=1200 rpm (Curve II)

Point A (EMF , If) at full load

(i) From figure Emf = **227.5 V**

(ii) Rc = 225/1.5=**150 Ω** at 1500 rpm

(iii) $\frac{N_2}{N_1} = \frac{1200}{1500} = \mathbf{0.8}$

The values of these voltages are tabulated below :

$I_f(A)$:	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.0
$E_0\,(V)$:	4.8	48	96	138	162	176.8	184.8	189.6	192

Then emf = **166 V** at R_f=**100 Ω**

Example 2: The open-circuit characteristic of a separately-excited d.c. generator driven at 1000 r.p.m. is as follows :

Field current :	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6
E.M.F. volts :	30.0	55.0	75.0	90.0	100.0	110.0	115.0	120.0

If the machine is connected as shunt generator and driven at 1,000 r.p.m. and has a field resistance of 100 Ω, find

(a) open-circuit voltage and exciting current

(b) the critical resistance and

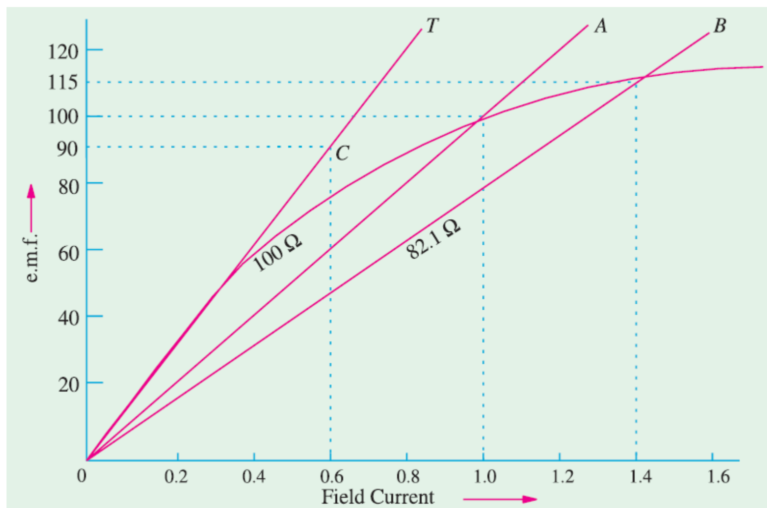
(c) resistance to induce 115 volts on open circuit.

Solution

(*a*) *O.C.* voltage = **100 V**; Exciting current = **1 A**

(*b*) Line *OT* is tangent to the initial part of the *O.C.C.*

It represents critical resistance. As seen from point *C*,



value of critical resistance is 90/0.6 = **150 Ω**.

(*c*) Line *OB* represents shunt resistance for getting 115 V on open-circuit.

Its resistance = 115/ 1.4 = **82.1 Ω** .

Example 3: A shunt generator gave the following open-circuit characteristic

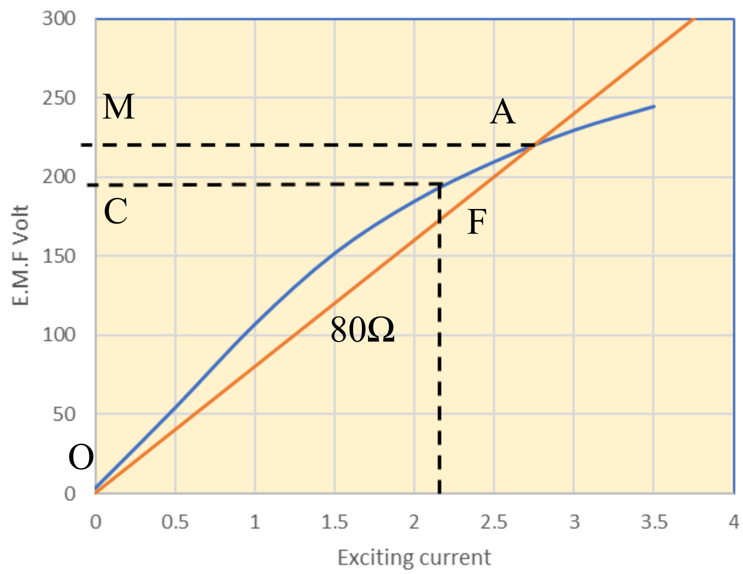
Field current :	*0.5*	*1.0*	*1.5*	*2.0*	*2.5*	*3.0*	*3.5 A*
O.C. e.m.f. :	*54*	*107*	*152*	*185*	*210*	*230*	*245 V*

The armature and field resistances are 0.1 Ω and 80 Ω respectively. Calculate

(a) the voltage to which the machine will excite when run as a shunt generator at the same speed. **(b)** The volts lost due to armature reaction when 100 A are passing in the armature at a terminal voltage of 175 V.

Solution

(*a*) *OA* represents 80 Ω line. The maximum voltage to which the generator will build up is given by *OM* = **222 V.**



(*b*) With 175 V terminal on load

I_{sh} = 175/80 = **2.2** A

Voltage corresponding to this field current is given by *OC* = **195 V**.

Voltage lost due to armature reaction and armature drop = 195 –175 = **20 V**.

Now, armature drop = 0.1 × 100 = **10 V**

Let '*x*' be the volts lost due to armature reaction.

Then 10 + *x* = 20 4 *x* = **10 V**

5. Characteristics of Series Generator

Fig. 7 (i) shows the connections of a series wound generator. Since there is only one current (that which flows through the whole machine), the load current is the same as the exciting current.

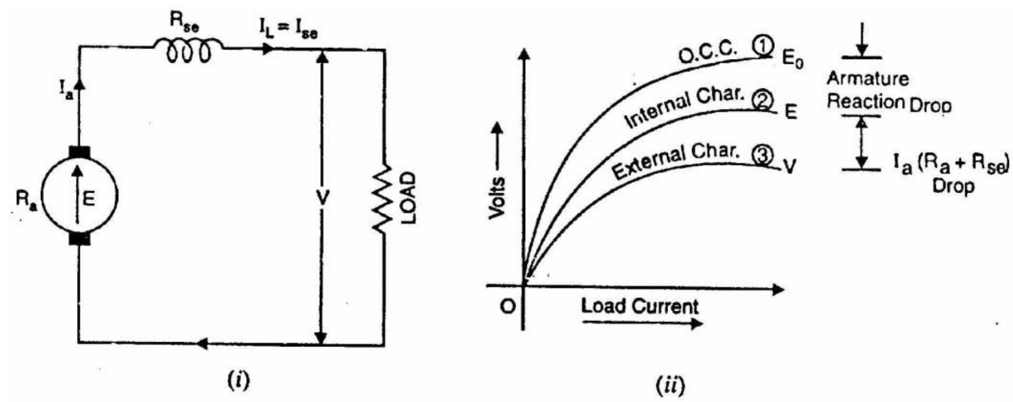


Fig. 7

5.1 O.C.C.

Curve 1 shows the open circuit characteristic (O.C.C.) of a series generator. It can be obtained experimentally by disconnecting the field winding from the machine and exciting it from a separate d.c. source.

5.2 Internal characteristic

Curve 2 shows the total or internal characteristic of a series generator. It gives the relation between the generated e.m.f. E. on load and armature current. Due to armature reaction, the flux in the machine will be less than the flux at no load. Hence, e.m.f. E generated under load conditions will be less than the e.m.f. E_0 generated under no load conditions. Consequently, internal characteristic curve lies below the O.C.C. curve; the difference between them representing the effect of armature reaction [See Fig. 7 (ii)].

5.3 External characteristic

Curve 3 shows the external characteristic of a series generator. It gives the relation between terminal voltage and load current I_L:.

$$V = E - I_a(R_a + R_{sh})\ volt \tag{7}$$

Therefore, external characteristic curve will lie below internal characteristic curve by an amount equal to ohmic drop [i.e., $I_a(R_a + R_{sh})$] in the machine as shown in Fig. 7 (ii).

The internal and external characteristics of a d.c. series generator can be plotted from one another as shown in Fig. 8. Suppose we are given the internal characteristic of the generator. Let the line OC represent the resistance of the whole machine i.e. $I_a(R_a + R_{sh})$. If the load current is OB, drop in the machine is AB i.e.

AB = Ohmic drop in the machine = OB($(R_a + R_{sh})$ Now raise a perpendicular from point B and mark a point b on this line such that ab = AB. Then point b will lie on the external characteristic of the generator. Following similar procedure, other points of external characteristic can be located. It is easy to see that we can also plot internal characteristics from the external characteristic.

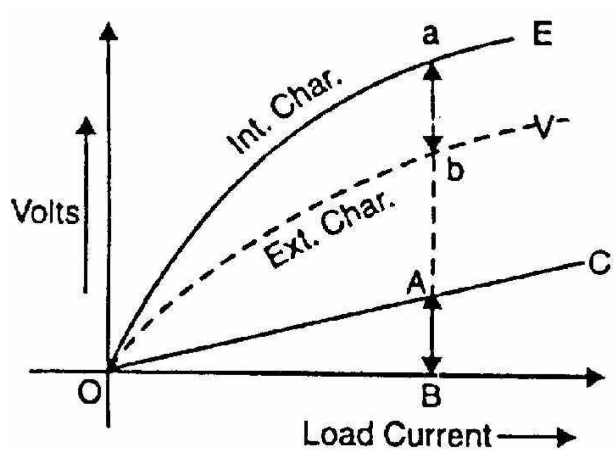


Fig. 8

5.4 Critical Resistance for a Series Generator

Fig. 9 shows the voltage build up in a series generator. Here R_1, R_2 etc. represent the total circuit resistance (load resistance and field winding resistance). If the total circuit resistance is R_1, then the series generator will build up a voltage OL.

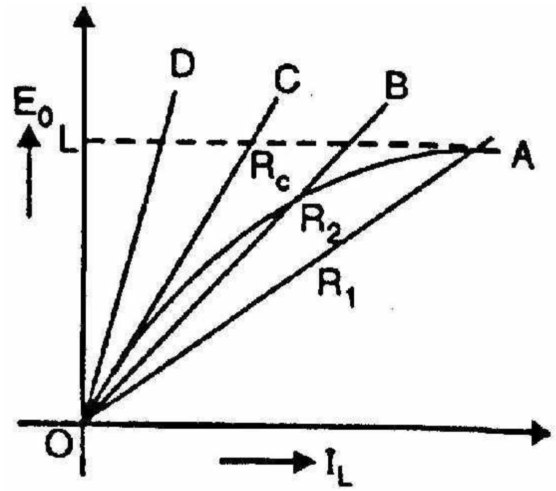


Fig. 9

The line OC is tangent to O.C.C. and represents the critical resistance RC for a series generator. If the total resistance of the circuit is more than RC (say line OD), the generator will fail to build up voltage.