1 Introduction

The speed of DC 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 DC Generator Characteristics

The following are the three most important characteristics of a DC generator:

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

This curve shows the relation between the generated EMF 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 EMF on load (E) and the armature current (I_a). The EMF 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 EMF 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.

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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 DC 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 DC 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 DC generator is: -

$$Eg = \frac{Z\,P\,\emptyset\,N}{A\,60}\ volt \tag{1}$$

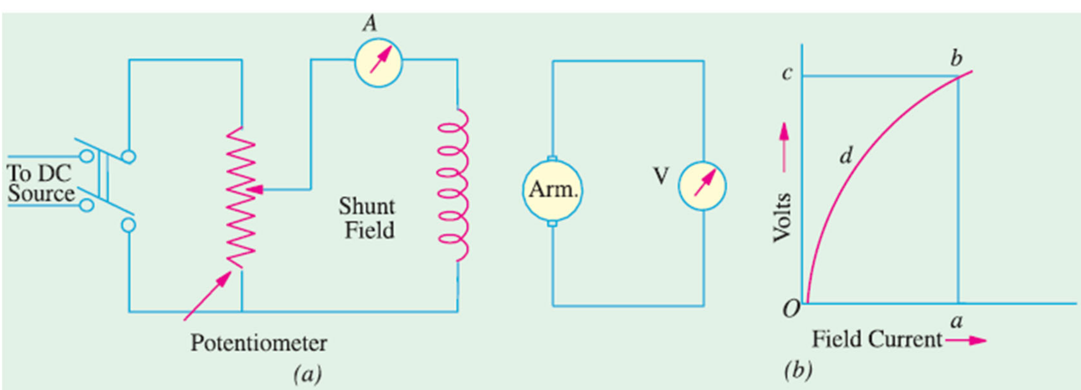

Fig. 1 Separately Exited DC Generator.

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

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

It is obvious that when I_f is increased from its initial small value, the flux $\emptyset$ and hence generated EMF 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 EMF ***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*.

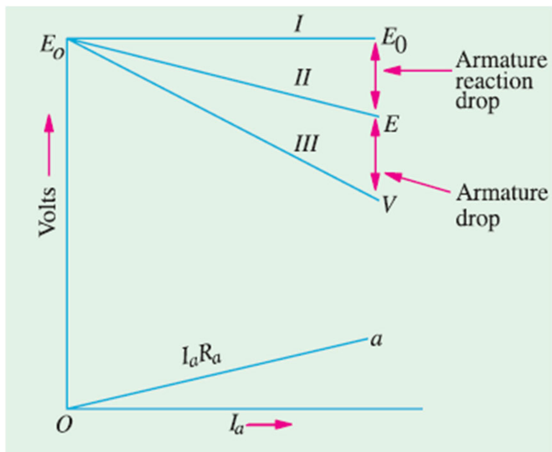

Fig. 2 Internal and External characteristics of DC shunt generator.

4 Characteristics of 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 EMF is produced initially. This EMF 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 EMF is increased which further increases the flux and so on. As shown in Fig. 3, *Oa* is the induced EMF 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 EMF *Oc*. In turn, this increased EMF *Oc* causes an even larger current *Od* which creates more flux for a still larger EMF and so on.

Now, the generated EMF in the armature has

(*a*) to supply the ohmic drop $i_f R_f$ in the winding

(*b*) to overcome the opposing self-induced EMF in the field coil *i.e.* $L\frac{di_f}{dt}$ because field coils have appreciable self-inductance.

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

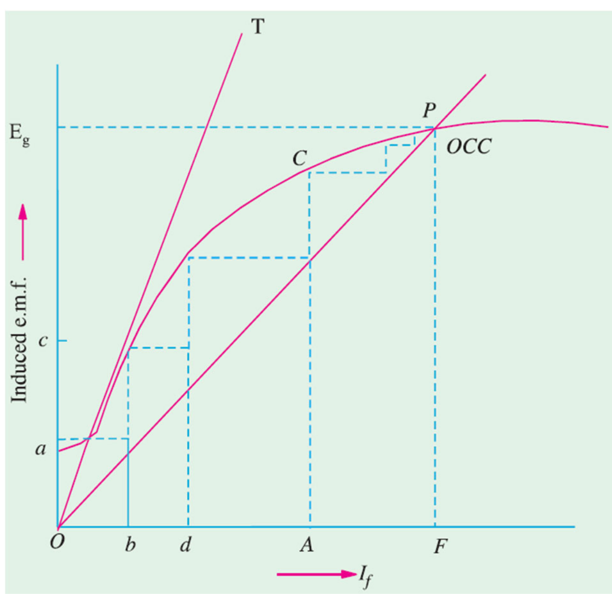

Fig. 3 Voltage Build-Up in DC generator.

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If (and so long as), the generated EMF 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 EMF is AC. Out of this, AB goes to supply ohmic drop If R_{sh} and BC goes to overcome self-induced EMF in the coil. Corresponding to i_f = OF, whole of the generated EMF 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 EMF 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).

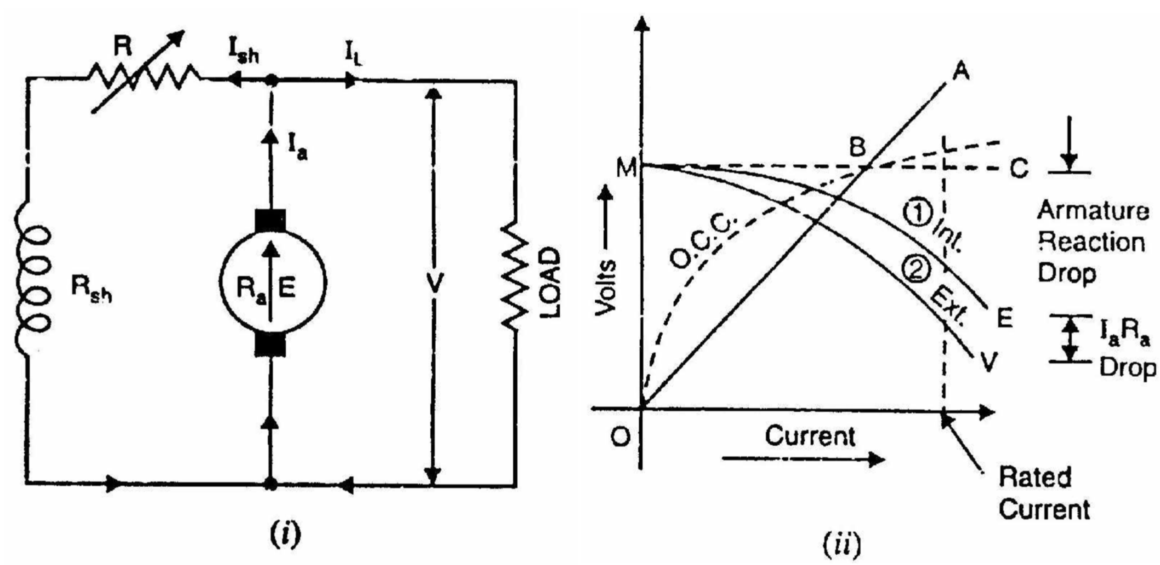

Fig. 4 Characteristics of DC shunt generator.

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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.

4.3 Internal characteristic

When the generator is loaded, flux per pole is reduced due to armature reaction. Therefore, EMF (E) generated on load is less than the EMF 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.

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

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 EMF 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 EMF Increased EMF means more current which further increases the flux and so on. This

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mutual reinforcement of EMF 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*.

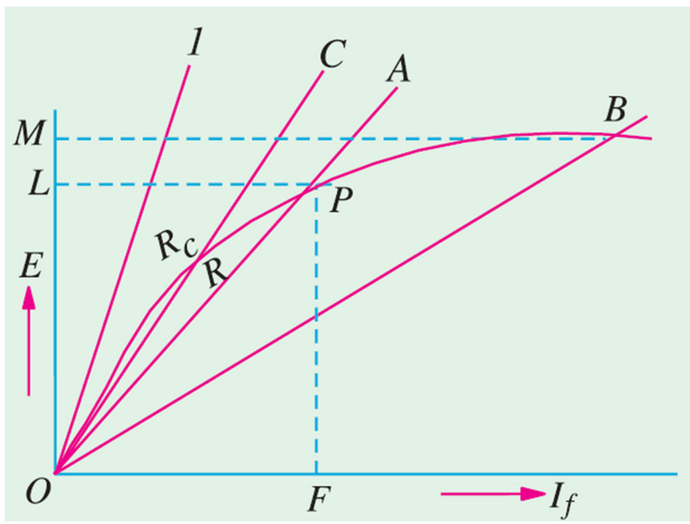

Fig. 5 Critical resistance.

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 decrease. 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***.

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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.

$\therefore$ Speed $\propto$ 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,

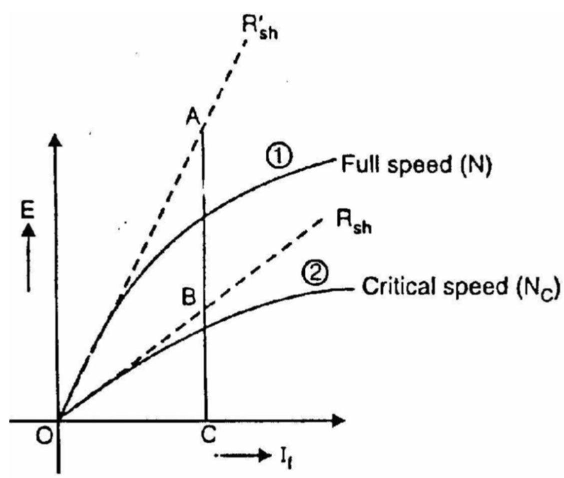

Fig. 6 Critical speed.

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

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

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.