27. Characteristics of D.C. Generators

The d.c. generator have following characteristics in general:

(1) No-Load (or Magnetization) Characteristic.
(2) Load Characteristic, which is subdivided into;
 (i) Internal Characteristic (ii) External Characteristic

1. No-load Saturation Characteristic (E_0/I_f)

It is also known as *Magnetic Characteristic* or *Open-circuit Characteristic (O.C.C.)*. It shows the relation between the no-load generated e.m.f. in armature (E_0) and the field or exciting current (I_f) at a given fixed speed. Its shape is practically the same for all generators whether separately-excited or self-excited.

In general,

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

At no load, $E_o \propto \Phi$, with $(\frac{ZN}{60}\frac{P}{A})$ are constant

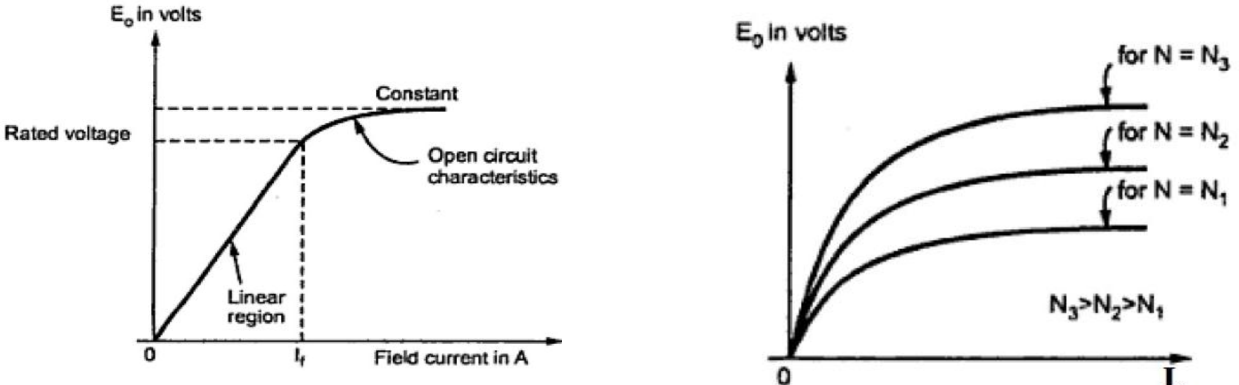
$E_o \propto I_f$ as $\Phi \propto I_f$

Thus induced e.m.f. increases directly as I_f increases. But after certain If core gets saturated and flux Φ also remains constant though If increases. Hence after saturation, voltage also remains constant.

Note: Thus characteristics is linear till saturation and after that bends such that voltage remains constant though I_f increases. The characteristics is shown in the Figure (61-a).

Now the induced e.m.f. also varies with speed. Actually, $E_o \propto N\Phi$

So if magnetization characteristics for various speeds are plotted we will get family of parallel characteristics as shown in the Figure (63-b). For lower speeds, generated voltages are less so characteristics for lower speeds are below the characteristics for higher speeds.



(a) open circuit characteristic (b) O.C.C. for different speeds

Figure (63)

2.Load Characteristic

(i) Internal or Total Characteristic (E/I_a)

It is the relation between the e.m.f. (E) actually induces in the armature (after allowing for the demagnetizing effect of armature reaction) and the armature current (I_a).

(ii) External Characteristic (V/I_L)

It is also referred to as *performance characteristic* or sometimes *voltage-regulating curve*. It gives relation between the terminal voltage (V) and the load current (I_L). This curve lies below the internal characteristic because it takes into account the voltage drop over the armature circuit resistance. The values of V are obtained by subtracting I_aR_a from corresponding values of E.

It may be obtained in two ways:

(a) By making simultaneous measurements with a suitable voltmeter and an ammeter on a loaded generator.

(b) Graphically from the O.C.C. provided the armature and field resistances are known and also if the demagnetizing effect (under rated load conditions) or the armature reaction (from the short-circuit test) is known.

28. Separately-excited Generator

(1) No-load Saturation Characteristic (E_0/I_f)

Connect the circuit shown in Figure (64).

1) The voltmeter reads the no-load voltage (E_o) and the ammeter reads the field current (I_f).
2) When switch (S_1) is open, $I_f = 0$ & $E_o = 0$.
3) Close switch (S_1) &(S_2 is still open), then adjust the value of rheostat (or variable resistor) at maximum value and read the values of (I_f) & (E_o).
4) Reduce the value of rheostat gradually (means increasing (I_f) gradually) and reads the value of (I_f) & (E_o) at each value of rheostat.

Now, the voltage equation of a d.c. generator is, $E_g = \frac{\Phi ZN}{60}\frac{P}{A}$

Hence, if speed is constant, the above relation becomes $E_g = k\Phi$

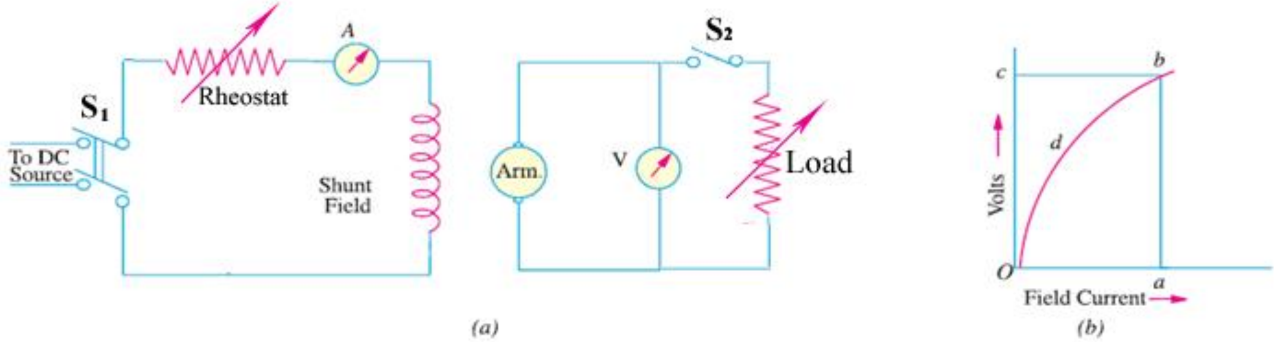


Figure (64)

It is obvious that when (I_f) is increased from its initial small value, the flux Φ and hence generated e.m.f. E_g increase directly as current so long as the poles are unsaturated. This is represented by the straight portion Od in Figure (64-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.

Note: Under no-load condition, armature reaction and armature voltage drop are neglected because armature current equal zero.

(2) Load Saturation Curve (V/I_f)

Load saturation curve is the relation between the terminal voltage (V) and field current (I_f) when the generator is loaded. The curve can be deduced from the no-load saturation curve. When the generator is loaded we take into account the voltage drop due to demagnetizing effect and armature voltage drop (I_aR_a).

1) Figure (65) shows the O.C.C (or no-load saturation curve) plotted on base (amp-turns) instead of field current.
2) From O.C.C draw horizontal line (bd) which it's length represent the demagnetizing effect.
3) From point (d) draw vertical line (de) which it's length represent the armature circuit drop (I_aR_a).
4) Repeat steps (2) & (3) for each point on O.C.C.
5) Curve (MP) represent full-load saturation curve.
6) The right-angled triangle (bde) is known as drop reaction triangle.
7) The load saturation curve for half-load can be obtained by joining the mid-points of such lines (mn) & (bd) etc.
8) In the case of self-excited generators, load saturation curves are obtained in similar way.

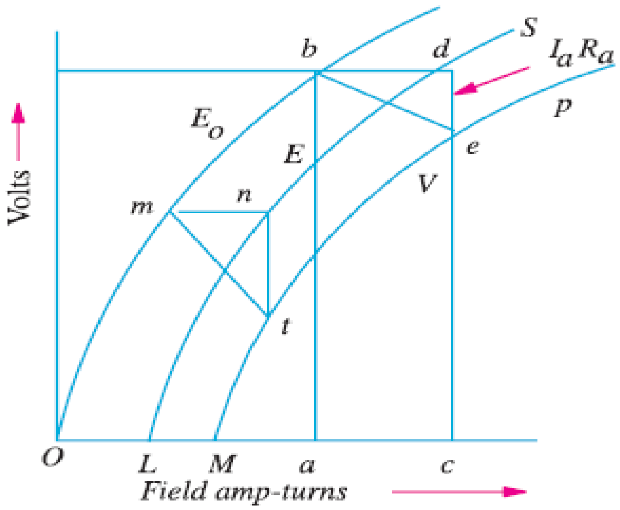


Figure (65)

(3) Internal and External Characteristics

1) If there is no armature reaction & armature voltage drop, the generator no-load voltage (E_O) would remain constant as shown by dotted line (I) in Figure (66).
2) When the generator is loaded, the voltage falls due to the armature reaction & armature voltage drop therefore giving slightly drooping characteristic.
3) Internal characteristic (curve II) can be plotted by subtracting the voltage drop due to armature reaction from (E_o) for different loads to get actually induced voltage (E).
4) 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.

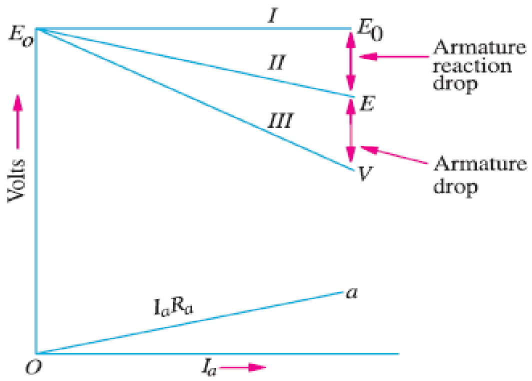


Figure (66)

29. No-load Curve for Self-excited Generator

The O.C.C. or no-load saturated curves for self-excited generators whether shunt or series connected, are obtained in a similar way.
The field winding of the generator (whether **shunt** or **series** wound) is disconnected from the machine and connected to an external source of direct current as shown in Figure (67).

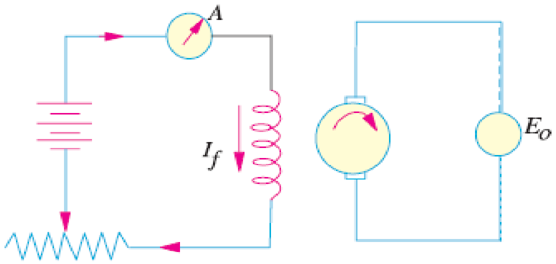
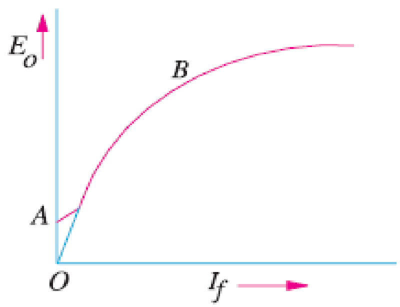


Figure (67)

The field or exciting current (I_f) is varied rheostatically and its value read on the ammeter (A). The machine is drived at constant speed by the prime mover and the generated e.m.f. on no-load is measured by the voltmeter connected across the armature. (I_f) is increased by suitable steps (starting from zero) and the corresponding values of E_0 are measured.
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, this process called **voltage build up**.
Due to residual magnetism in the poles, some e.m.f. (= OA) is generated even when (I_f = 0)as shown in Figure(68). Hence, the curve starts a little way up. It is seen that the first part of the curve is practically straight.



Figure(68)

30. Critical Resistance for Shunt Generator

Line OA is drawn such that its slope equals the field winding resistance i.e. every point on this curve is such that $\frac{E_o}{I_f} = R_f$.

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_f) is increased so much that the resistance line does not cut the O.C.C. at all (like Ol), then obviously the machine will fail to excite (no 'build up' of the voltage).

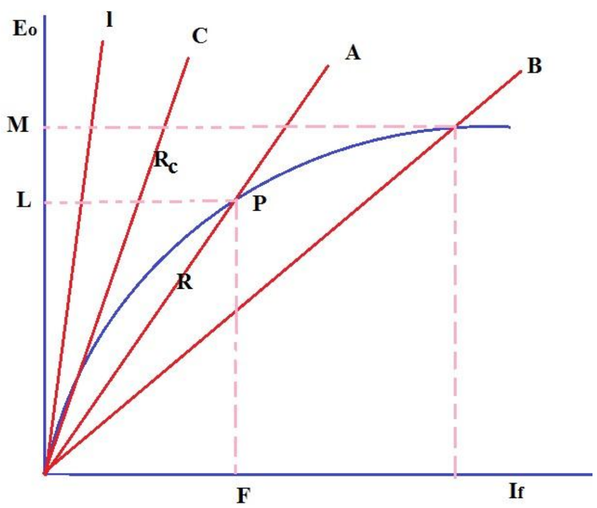


Figure (69)

The value of the resistance represented by the tangent to the curve, is known as **critical resistance** (R_c) for a given speed. **Critical resistance** can be defined as the maximum value of field resistance at which the generator voltage will build up.

31. How to Find Critical Resistance R_c ?

First, O.C.C. is plotted from the given data. Then, tangent is drawn to its initial portion. The slope of this curve gives the critical resistance for the speed at which the data was obtained.

32. How to Draw O.C.C. at Different Speeds?

Suppose we are given the data for O.C.C. of a generator run at a fixed speed, say, N_1. It will be shown that O.C.C. at any other constant speed N_2 can be deduced from the O.C.C. for N_1. In Figure (70) the O.C.C. for speed N_1 is shown.

Since $E \propto N$ for any fixed excitation,

Hence $\frac{E_2}{E_1} = \frac{N_2}{N_1}$

Or $E_2 = E_1 \times \frac{N_2}{N_1}$

As seen, for I_f = OH, E_1 = HC. The value of new voltage for the same If but at N_2,

$E_2 = HC \times \frac{N_2}{N_1} = HD$

In this way, point D is located. In a similar way, other such points can be found and the new O.C.C. at N_2 drawn.

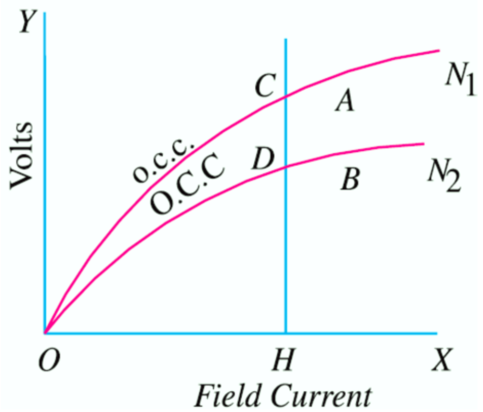


Figure (70)

33. Critical Speed Nc

Critical speed of a shunt generator is that speed for which the given shunt field resistance represents critical resistance. In Figure (71), curve 2 corresponds to critical speed because R_{sh} line is tangential to it.

$$\frac{BC}{AC} = \frac{N_c}{\text{Full Speed}} = \frac{N_c}{N}$$

$$\therefore N_c = \frac{BC}{AC} \times \text{Full Speed}(N)$$

It should be noted that O.C.C. for a higher speed would lie above curve for a lower speed.

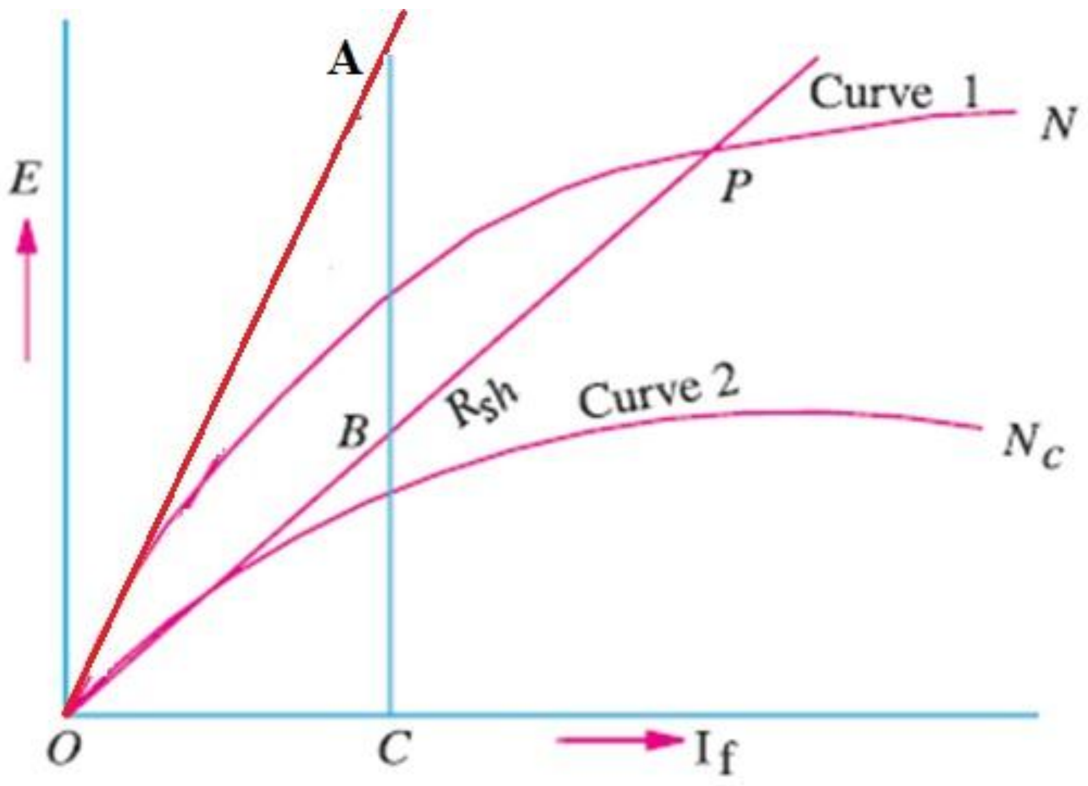


Figure (71)

Example 42: 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 the open-circuit voltage for a field resistance of 100 Ω.

Solution:

(i) The magnetization curve at 1500 r.p.m. is plotted from the given data.

The 100 Ω resistance line OA is obtained by joining the origin (0, 0) with the point (1A, 100 V), this point is chosen because $R_{sh} = \frac{E_o}{I_f} = \frac{100\ V}{1\ A} = 100\ \Omega$.

The voltage corresponding to point A is 227.5 V. Hence, no-load voltage to which the generator will build-up is 227.5 V.

(ii) The tangent OT represents the critical resistance at 1500 r.p.m. considering point B, R_c = 225/1.5 = 150 Ω.

(i) $E_{o1} = \frac{\Phi Z N_1}{60}\frac{P}{A}$, $E_{02} = \frac{\Phi Z N_2}{60}\frac{P}{A}$

$$\frac{E_{02}}{E_{01}} = \frac{\frac{\Phi Z N_2 P}{60A}}{\frac{\Phi Z N_1 P}{60A}}$$

$= \frac{N_2}{N_1}$,Φ is constant because we take the same field current values.

$$\therefore E_{o2} = E_{o1} \times \frac{N_2}{N_1}$$

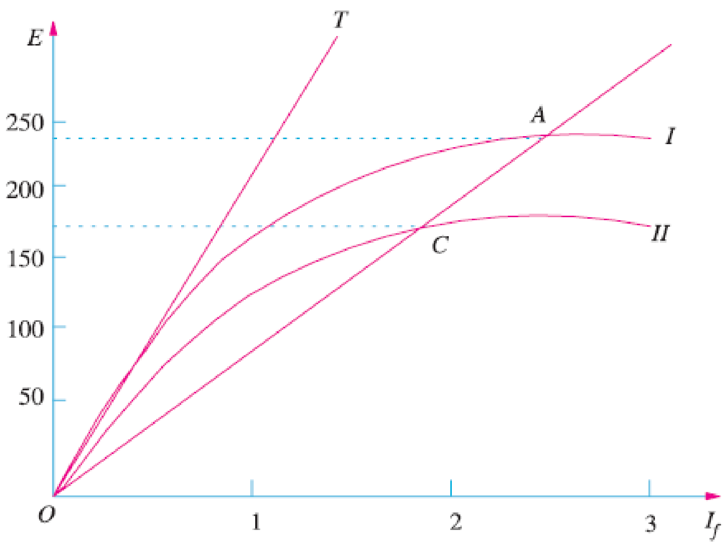


Figure (72)

For 1200 r.p.m., the induced voltages for different field currents would be (1200/1500) = 0.8 of those for 1500 r.p.m (multiply each value of induced voltage by 0.8 to get the new values of induced voltage).

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

The new magnetization curve is also plotted . The 100 Ω line cuts the curve at point C which corresponds to an induced voltage of 166 V.

Example 43: The open-circuit characteristic of a d.c. shunt generator driven at rated speed is as follows :

Field Amperes :	*0.5*	*1.0*	*1.5*	*2.0*	*2.5*	*3.0*	*3.5 A*
Induced Voltage :	*60*	*120*	*138*	*145*	*149*	*151*	*152 V*

If resistance of field circuit is adjusted to 53 Ω, calculate the open circuit voltage and load current when the terminal voltage is 100 V. Neglect armature reaction and assume an armature resistance of 0.1 Ω.

Solution:

Take $I_f = 3$ A, $R_{sh} = 53$ Ω,

Point A is (3A, 159V) point. Line OA is the 53 Ω line in Figure (73). It cuts drop = 3 × 53 = 159 V. O.C.C. at B. Line BM is drawn parallel to the base. OM represents the O.C. voltage which equals **150 V.**

Now, when V = 100 V, $I_{sh} = I_f = 100/53 = 1.89$ A

O.C. voltage corresponding to this exciting current as seen from graph is 144 V.

Now $E = V + I_aR_a$ or $I_aR_a = 144 - 100 = 44$ V

$\therefore\ 0.1\, I_a = 44$ Or $I_a = 44/0.1 =$ **440 A**

$I_L = I_a - I_{sh} = 440 - 1.89 = 438.11$ A

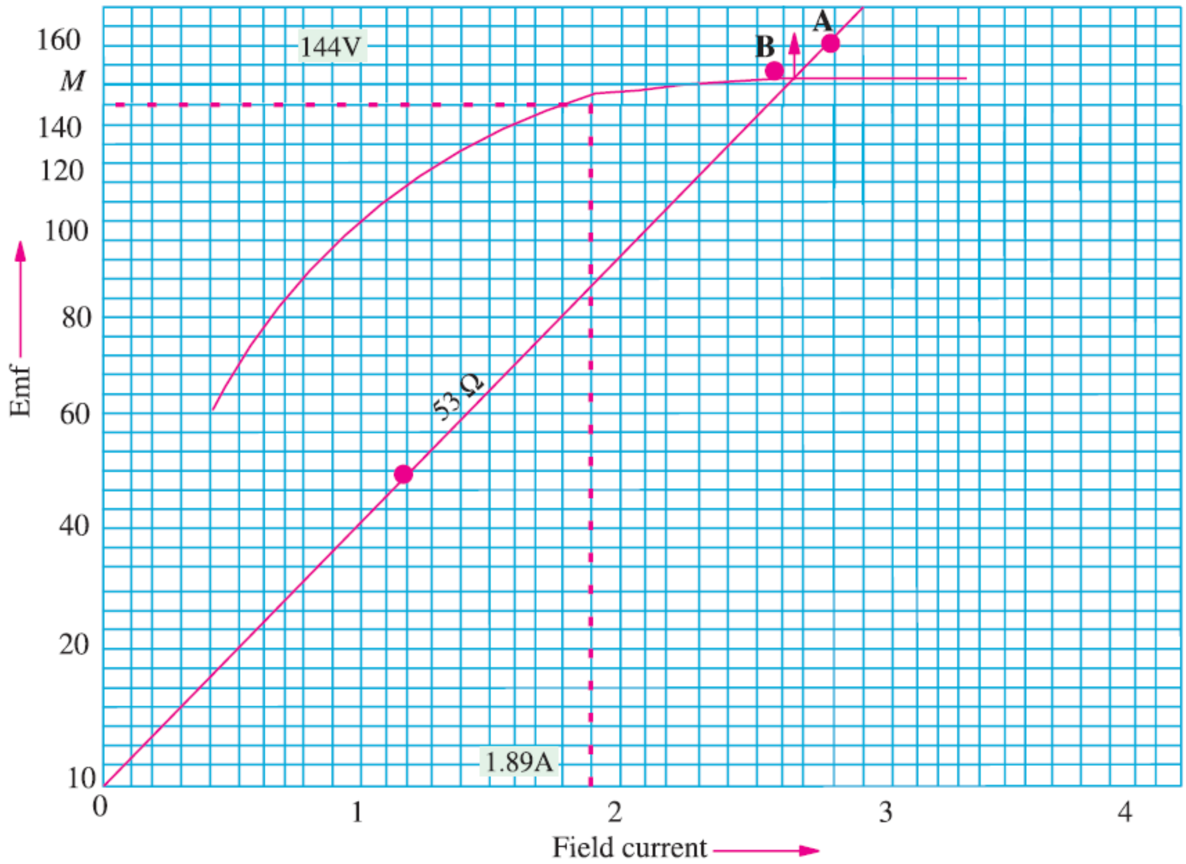


Figure (73)

Example 44: 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.

Solution:

$$E_2 = E_1 \times \frac{N_2}{N_1} = E_1 \times \frac{375}{300}$$

A new table is given with the voltages multiplied by the ratio $\left(\frac{375}{300}\right)$.

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

Draw the new O.C.C. at 375 r.p.m. as shown in Figure (74).

Draw field resistance line OA represents $R_f = \frac{E_o}{I_f}$ = 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 Figure (74), it is clear that for exciting the generator to 200 V, exciting current should be 3.8 A.

∴ R_f = 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 $E = V + I_aR_a$
∴ $I_aR_a = E - V$
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**

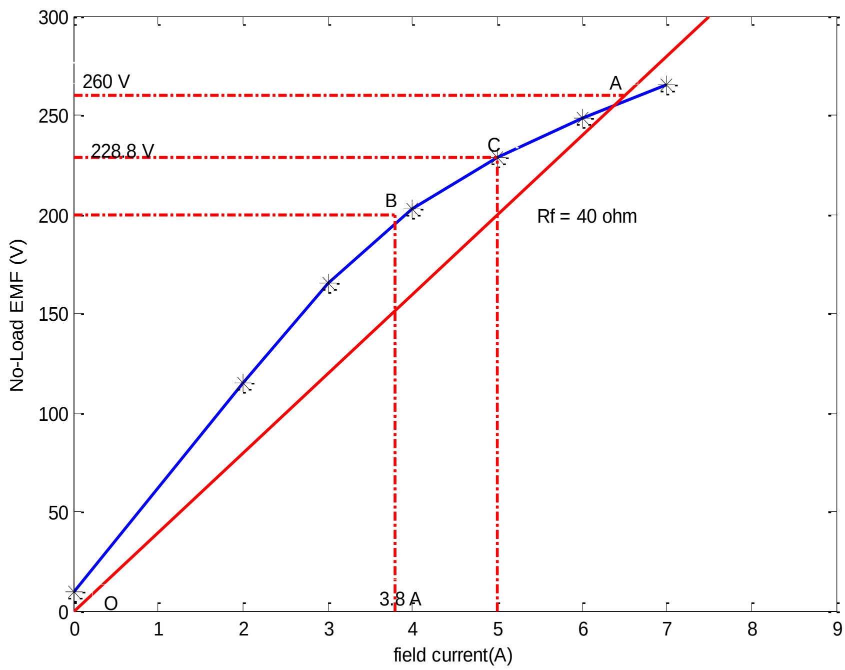


Figure (74)

Example 45: 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:

The O.C.C. has been plotted in Figure (75). The shunt resistance line OA is drawn as usual.

(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.

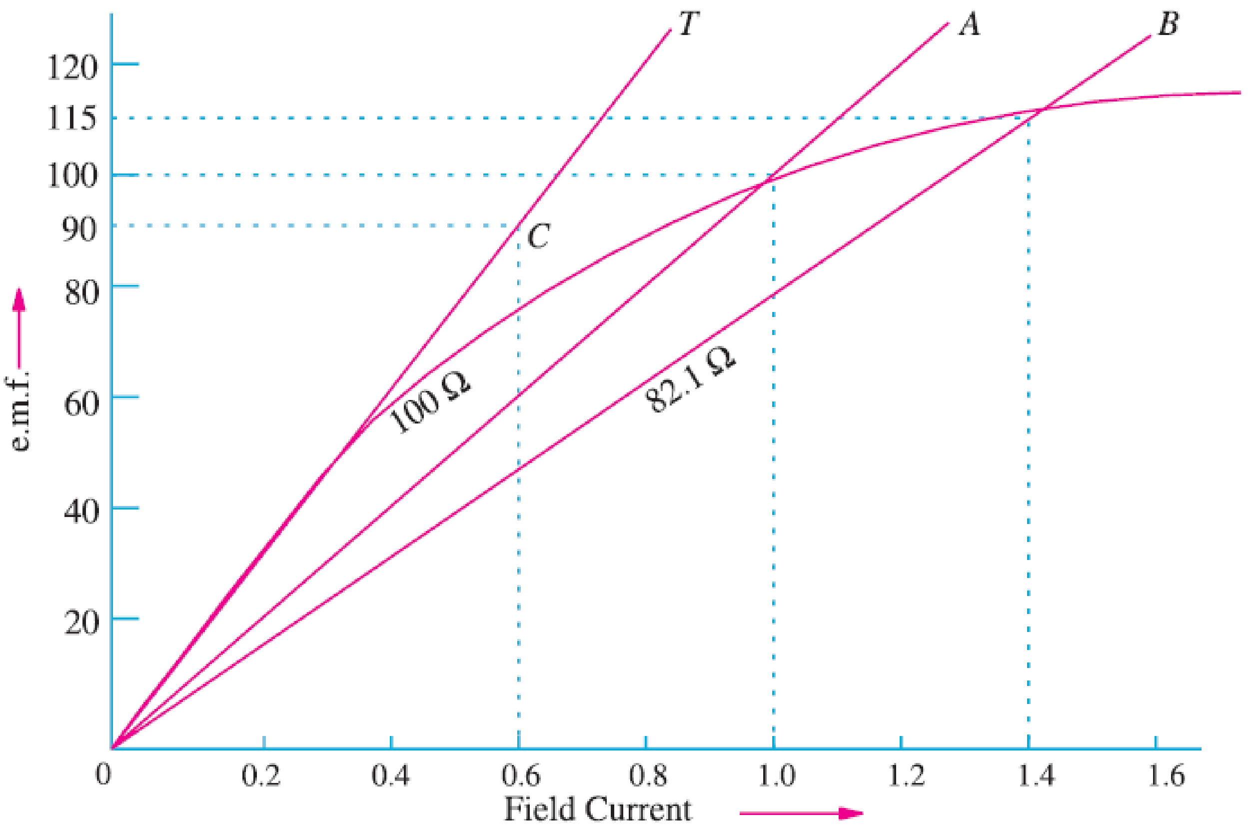


Figure (75)

Example 46: A d.c. generator has the following magnetization characteristics at 600 rpm.

Field current (A) :	1	2	3	4	5	6	7	8
Generated e.m.f. (V) :	23	45	67	85	100	112	121	126

If the generator is shunt excited, determine the load current if $R_a = 0.02\Omega$.
(a) when terminal p.d. is 120 V, the field resistance is 15 Ω at a speed of 600 r.p.m. And
(b) when terminal p.d. is 144 V, the field resistance is 18 Ω at a speed of 700 r.p.m.

Solution:

(a) When terminal p.d. = 120 V, then field current $I_f = V/R_{sh} = 120/15 = 8$ A
From the given data, it is seen that the generated e.m.f. = 126 V (We need not plot the *O.C.C.* in this particular case). ⟹ Voltage drop = 126 − 120 = 6 V
Since drop due to armature reaction is neglected, this represents the armature drop.
$\therefore$ $I_a R_a = 6$ or $I_a = 6/0.02 = 300$ A Load current = 300 − 8 = **292 A**

(b) The O.C. data at 700 r.p.m. can be obtained by multiplying the given values of generated e.m.f. by a factor of 700/600 = 7/6. Hence, the new data is :

Field current (A)	:	1	2	3	4	5	6	7	8
Generated e.m.f. (V)	:	26.8	52.5	78.2	99.2	116.6	131	141	146

When V = 144 V and R_{sh} = 18 Ω, field current = 144/18 = 8 A
From the given data, the corresponding generated e.m.f. is 146 V.
Voltage drop $I_a R_a$ = 146 − 144 = 2V
$\therefore$ $I_a = 2/0.02 = 100$ A $\therefore$ Load current = 100 − 8 = **92 A**

Example 47: The O.C.C. of a d.c. generator driven at 400 rev/min is as follows :

Field current (A)	:	2	3	4	5	6	7	8	9
Terminal volts	:	110	155	186	212	230	246	260	271

Find :
(a) voltage to which the machine will excite when run as a shunt generator at 400 rev/min with shunt field resistance equal to 34 Ω.
(b) resistance of shunt circuit to reduce the O.C.C. voltage to 220 V.
(c) critical value of the shunt field circuit resistance.
(d) the critical speed when the field circuit resistance is 34 Ω.
(e) lowest possible speed at which an O.C.C. voltage of 225 V can be obtained.

Solution:

Draw the O.C.C. as shown in Figure (76).

Draw Rf line OA, from origin joining point (If, Eo) where $R_f = \frac{E_o}{I_f} = 34\ \Omega$, choose point (8A, 272V) So $R_f = \frac{E_o}{I_f} = \frac{272}{8} = 34\ \Omega$

The 34-Ω line OA is drawn as usual from origin to point (8A, 272V).

(a) Line OA (34Ω) cuts O.C.C. at point (J), draw a horizontal line from point (J) & cut y-axis at point (M) which represent voltage equal (255V). ⟹ ∴ E = 255V.

(b) From (220V) or point (N) draw a horizontal line cuts O.C.C. at (B). Then draw vertical line from point (B) cuts x-axis at point (Z).

Point (Z) represents field current equal (5.4A). ⟹ ∴ $R_f = \frac{E_o}{I_f} = \frac{220}{5.4} = 40.7\ \Omega$

(c) Draw OC line tangent to O.C.C. which represent (R_c) .
Take any voltage on y-axis such as (140V) cut (R_c) at point (X), then from point (X) draw vertical line cut x-axis at point (Y) which represent current (2.25A).

∴ $R_c = \frac{140}{2.25} = 62.2\ \Omega$

(d) Take any convenient point *D* and erect a perpendicular which cuts both *OA* and *OC*.

$\frac{DE}{DF} = \frac{N_c}{400}$ or $\frac{110}{202} = \frac{N_c}{202}$ ⟹ N_c = **218 r.p.m.**

(e) From point *P* (225 V) drawn a horizontal line cutting *(OA)* at point *(G)*. From *(G)*, draw a perpendicular line *(GK)* cutting the *O.C.C.* at point *(H)* & cuts x-axis at point (K). If *N′* is the lowest speed possible for getting 225 volt with 34 Ω shunt circuit resistance,

then $\frac{GK}{HK} = \frac{N'}{400}$ ⟹ $\frac{225}{241} = \frac{N'}{400}$ ⟹ N' = **375 r.p.m.**

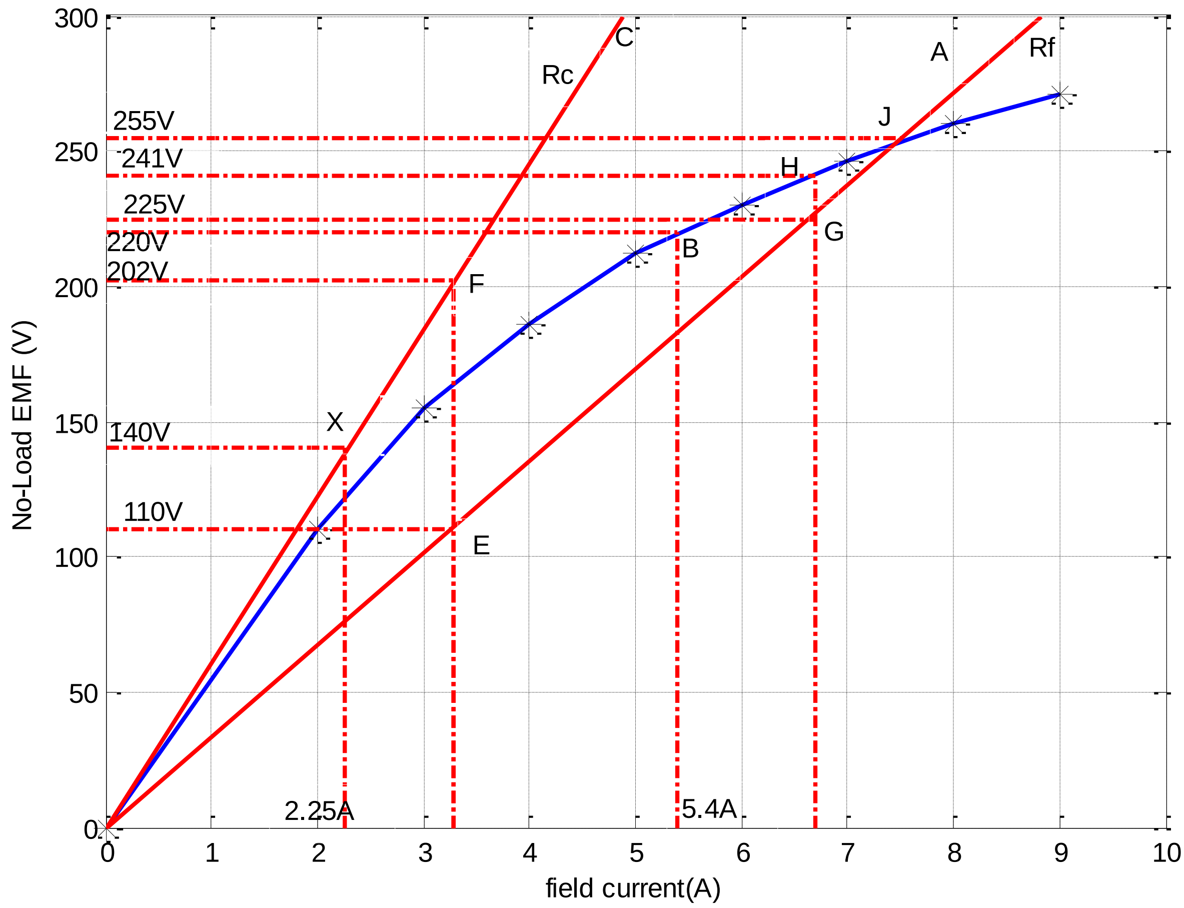


Figure (76)

Example 48: The magnetization characteristic for a 4-pole, 110-V, 1000 r.p.m. shunt generator is as follows :

Field current	0	0.5	1	1.5	2	2.5	3 A
O.C. voltage	5	50	85	102	112	116	120 V

Armature is lap-connected with 144 conductors. Field resistance is 45 ohms. Determine
(i) voltage the machine will build up at no load.
(ii) the critical resistance.
(iii) the speed at which the machine just fails to excite.
(iv) residual flux per pole.

Solution:

In Figure (77), OA represents the 45- Ω line which is drawn as usual.

(i) The voltage to which machine will build up = OM = **118 V.**

(ii) OT is tangent to the initial part of the O.C.C. It represents critical resistance. Take point B lying on this line. Voltage and exciting current corresponding to this point are 110 V and 1.1 A respectively.

∴ Rc = 110/1.1 = **100 Ω**

(iii) From any point on OT, say point B, drop the perpendicular BD on X-axis.

$$\frac{CD}{BD} = \frac{N_c}{1000} \quad \text{or} \quad \frac{49}{110} = \frac{N_c}{1000}$$

∴ Nc = **445 r.p.m.**

(iv) As given in the table, induced e.m.f. due to residual flux (i.e. when there is no exciting current) is 5 V.

$$\therefore 5 = \frac{\Phi \times 144 \times 1000}{60}\left(\frac{4}{4}\right)$$

∴ Φ = **2.08 mWb.**

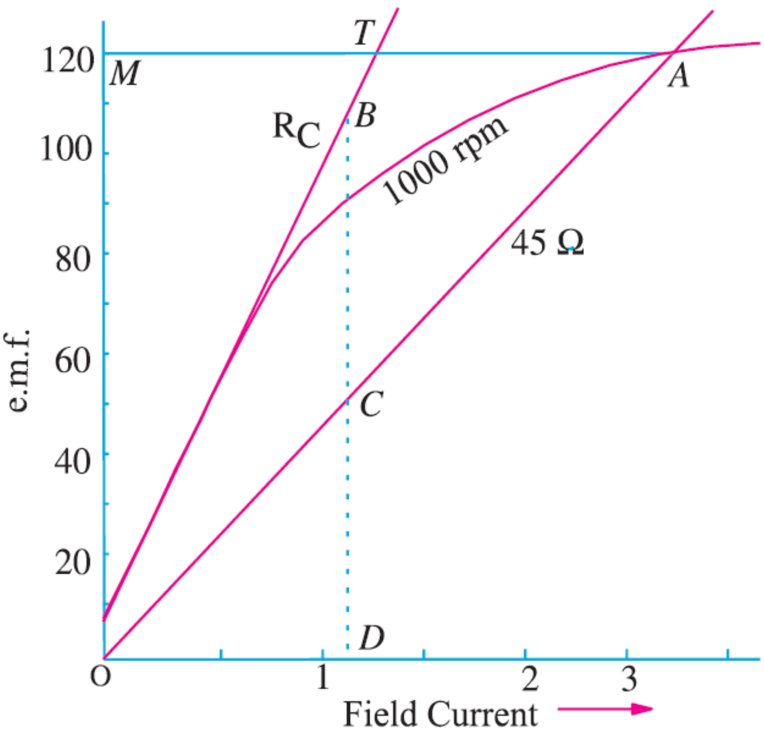


Figure (77)

Example 49: A shunt generator gave the following results in the O.C.C. test at a speed of r.p.m.

Field current (A)	1	2	3	4	6	8	10
E.M.F. (volt)	90	185	251	290	324	345	360

The field resistance is adjusted to 50 Ω and the terminal is 300 V on load. Armature resistance is 0.1 Ω and assuming that the flux is reduced by 5% due to armature reaction, find the load supplied by the generator.

Solution:

When the terminal voltage is 300 V and R_{sh} = 50 Ω, then field current is = 300/40 = 6 A
With this shunt current, the induced e.m.f. as seen from the given table (we need not draw the O.C.C.) is 324 V.
Due to armature reaction, the flux and hence the induced e.m.f. is reduced to 0.95 of its no-load value.
Hence, induced e.m.f. when generator is on load = 324 × 0.95 = 307.8 V
Armature drop at the given load = 307.8 − 300 = 7.8 V
I_aR_a = 7.8, I_a = 7.8/0.1 = 78 A
Load current = 78 − 6 = 72 A ;
Generator output = 72 × 300/1000 = **21.6 kW**

Example 50: 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.
(c) The percentage reduction in speed for the machine to fail to excite on open circuit.

Solution:

(a) O.C.C. is shown in Figure (78) . 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 p.d. 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 $10 + x = 20 \therefore\ x =$ **10 V**

(c) Line OT is drawn tangential to the curve. DFG is perpendicular to the base line.

$$\frac{N_c}{N} = \frac{FG}{DG} = \frac{160}{220}$$

Or

$$\frac{N_c - N}{N} = \frac{-60}{220}$$

Percentage reduction in speed $= \frac{-60}{220} \times 100 =$ **– 27.3 %**

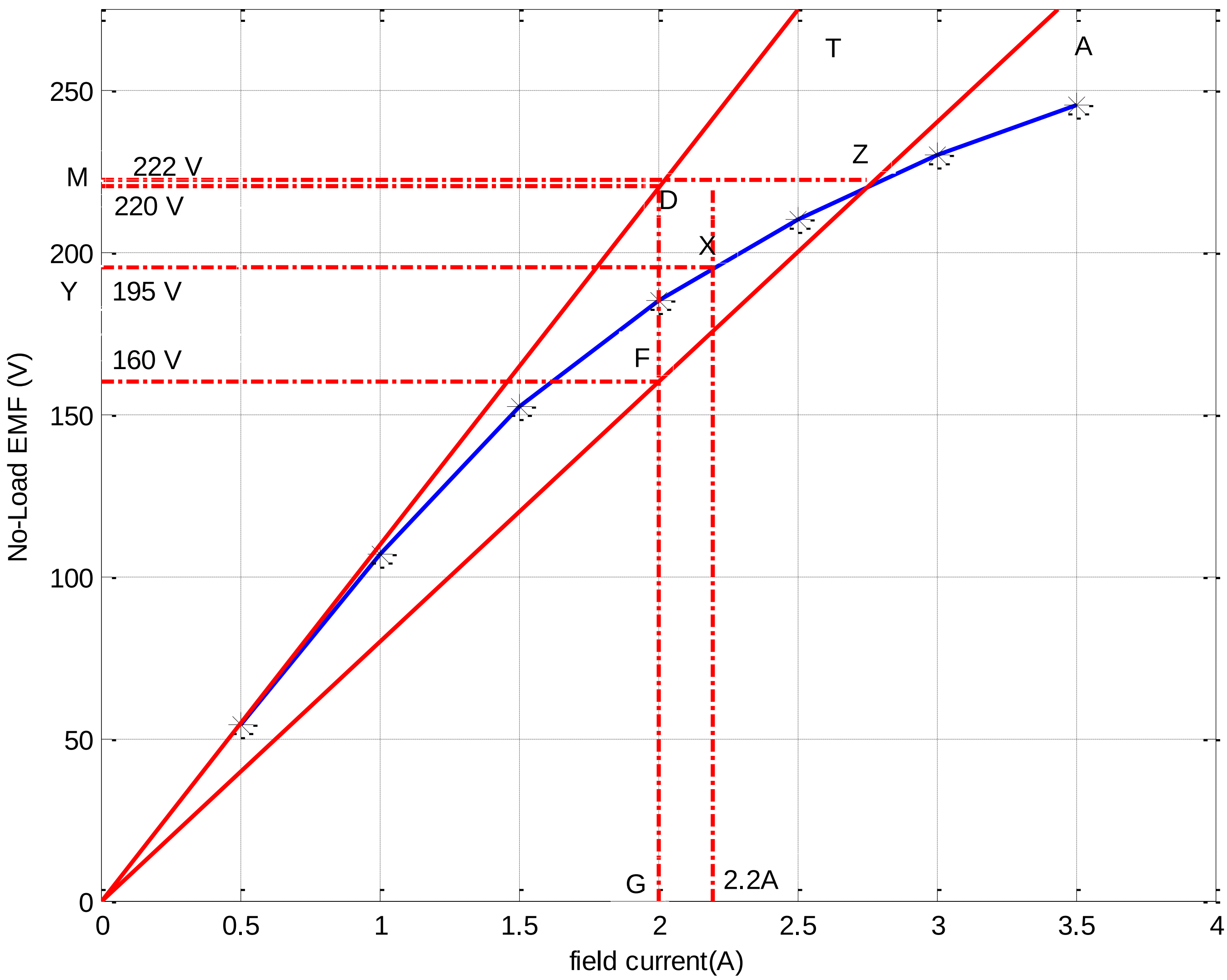


Figure (78)

Example 51: The O.C.C. of a shunt generator running at 800 r.p.m. is as follows :

Field current (amp.)	:	1	2	3	4	5	6
Induced e.m.f. (volt).	:	82.5	180	225	252	273	282

If the shunt field resistance is 60 Ω, find

(i) the voltage to which the machine will build up running at the same speed
(ii) the value of field regulating resistance if the machine is to build up to 120 V when its field coils are grouped in two parallel circuits and generator is running at half the speed.

Solution:

O.C.C. is drawn from the given data and is shown in Figure (79). OA represents 60 Ω. The voltage corresponding to point A is OM = 260 V.

(i) Generator will build up to **260 volts.**

(ii) Lower curve represents the induced e.m.f. for different exciting current values at 400 r.p.m.

From point B which represents 120 V, draw BC. From C draw a perpendicular CD which gives the exciting current of 3.6 A. It means that current through each parallel path of shunt field coils is 3.6 A. Total current which passes through the field regulator resistance is 3.6 × 2 = 7.2 A

because it is in series with the field coils.

Hence, total shunt field resistance = 120/7.2 = 16.67 Ω

Now, resistance of each shunt parallel path = 60/2 = 30 Ω

Joint resistance of two parallel paths = $\frac{30 \times 30}{30 + 30}$ = 30/2 = 15 Ω

∴ Shunt field regulator resistance = 16.67 − 15 = **1.67 Ω**

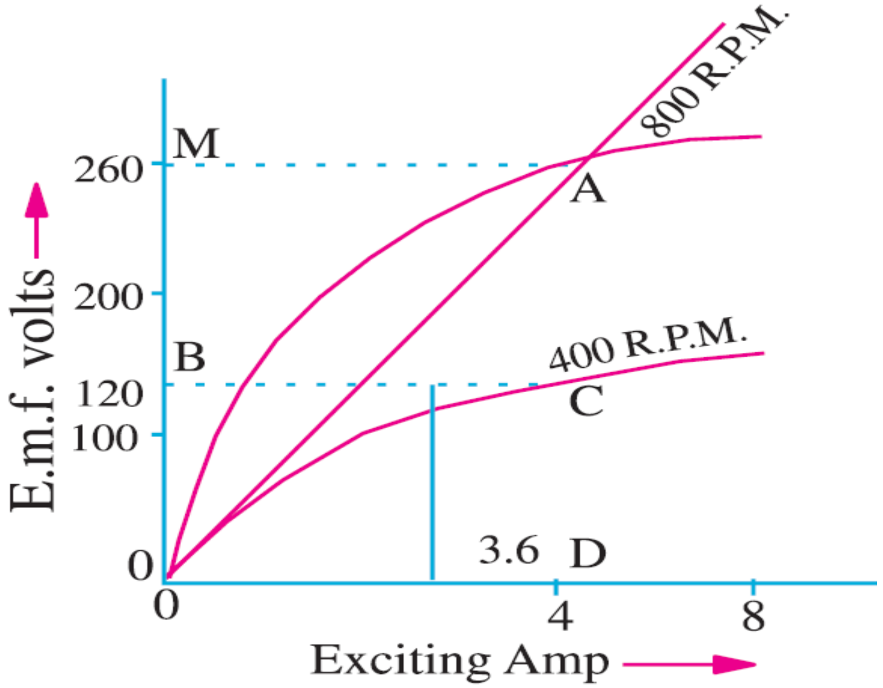


Figure (79)

34. Conditions for Build-up of a Shunt Generator

The conditions that necessary for the build-up of a (self-excited) generator are:

1) There must be some residual magnetism in the generator poles.

2) For the given direction of rotation, the shunt field coils should be correctly connected to the armature i.e. they should be so connected that the induced current reinforces the e.m.f. produced initially due to residual magnetism.

3) If excited on open circuit, its shunt field resistance should be less than the critical resistance (which can be found from its O.C.C.)

4) If excited on load, then its load resistance should be more than a certain minimum value of resistance which is given by internal characteristic.

35. Other Factors Affecting Voltage Building of a DC Generator

In addition to the factors mentioned above, there are some other factors which affect the voltage building of a self-excited d.c. generator. These factors are

- **(i)** reversed shunt field connection
- **(ii)** reversed rotation and
- **(iii)** reversed residual magnetism.

These adverse effects would be explained with the help of Figure (80) and the right-hand rule for finding the direction of the coil flux. For the sake of simplicity, only one field pole has been shown in the Figure (80).

Figure (80-a) represents the normal operation, the prime mover rotation is clockwise and both the residual flux Φ_R and the field flux Φ_F are directed to the left.

Figure (80-b) shows reversed connection of the field circuit which causes Φ_F to oppose Φ_R. Consequently, the generator voltage builds down from its original residual value.

In Figure (80-c), reversed armature rotation causes the reversal of the voltage produced by the residual magnetism. Even though the field coil connections are correct, the reversed field current flow causes Φ_F to oppose Φ_R so that the voltage builds down from its original residual value.

Figure (80-d) shows the case when due to some reason the residual magnetism gets reversed. Hence, the armature voltage is also reversed which further reverses the field current. Consequently, both Φ_F and Φ_R are reversed but are directed to the right as shown. Under this condition, the voltage buildup is in the reversed direction. Obviously, the generator will operate at rated voltage but with reversed polarity. If desired, the reversed polarity can be corrected by using an external d.c. source to remagnetise the field poles in the correct direction. This procedure is known as field flashing.

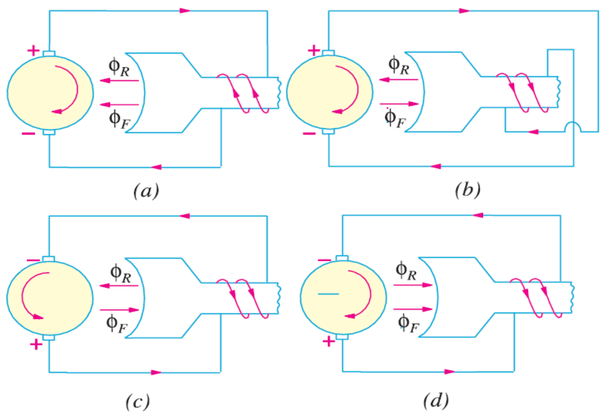


Figure (80)

36. External Characteristic of Shunt Generator

After building up a shunt generator, if it is loaded then its terminal voltage V drops with increase in load current. Such a drop in voltage is undesirable especially when the generator is supplying current for light and power for which purpose it is desirable that V should remain practically constant and independent of the load.

This condition of constant voltage is almost impossible to be fulfilled with a shunt generator unless the field current is being automatically adjusted by an automatic regulator. These are three main reasons for the drop in terminal voltage of a shunt generator when under load.

(i) Armature resistance drop (ii) Armature reaction drop (iii) The drop in terminal voltage V due to (i) and (ii).

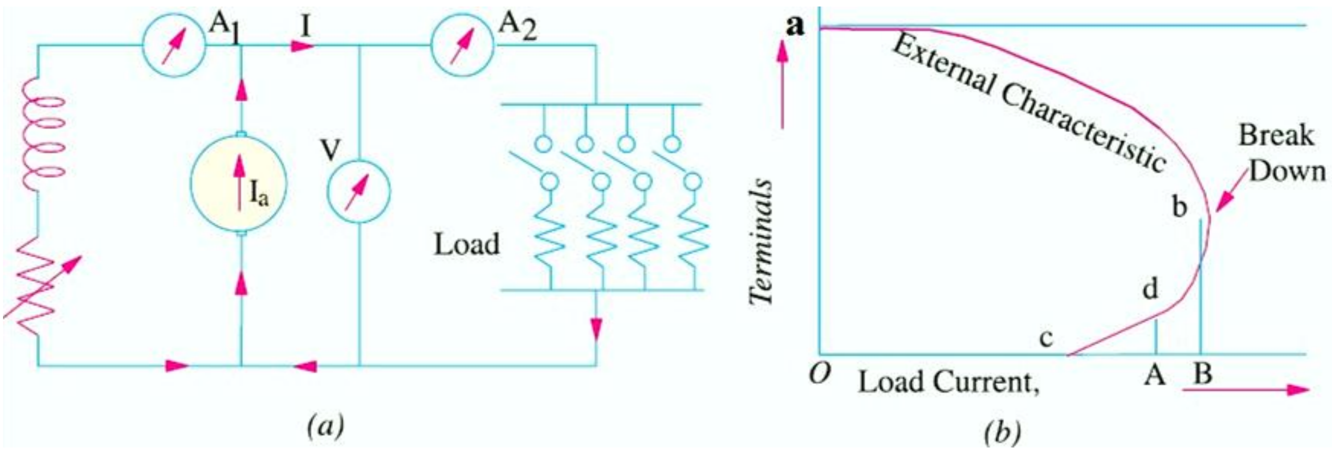


Figure (81)

The shunt generator is first excited on no-load so that it gives its full open circuit voltage = Oa [Figure (81-b)]. Then, the load is gradually applied and, at suitable intervals, the terminal voltage V (as read by the voltmeter) and the load current I (as read by the ammeter A_2) are noted. The field current as recorded by ammeter A_1. By plotting these readings, the external characteristic of Figure (81-b) is obtained. Point (b) is known as breakdown point. It is found that beyond this point (where load is maximum = OB) **any effort to increase load current by further decreasing load resistance results in decreased load current (like OA) due to a very rapid decrease in terminal voltage.**

Hence, any, further decrease in load resistance actually causes a **decrease** in load current. As load resistance is decreased beyond point b, the curve turns back till when the generator is actually short circuited, it cuts the current axis at point c. Here, terminal voltage V is reduced to zero, though there would be some value of E due to residual magnetism.

37. Voltage Regulation

Voltage regulation of a generator is meant the change in its terminal voltage with the change in load current when it is running at a constant speed. If the change in voltage between no-load and full load is small, then the generator is said to have good regulation but if the change in voltage is large, then it has poor regulation.

$$V_{reg.} = \frac{V_{no-load} - V_{full-load}}{V_{full-load}} \quad 100\%$$

If no-load voltage of a certain generator is 240 V and rated-load voltage is 220 V, then, $V_{reg.} = (240 - 220)/220 = 0.091$ or 9.1 %

38. How to Draw Internal & External Characteristic

1) Plot O.C.C (as shown in curve Q).
2) (AB) or (OZ) represents the terminal voltage of generator on no-load (E_o).
3) Draw line (OB) where it's tangent represent the field resistance value.
4) When the generator is loaded, the terminal voltage is reduced to (CD), the shunt current is (OC) and generated e.m.f equal to line (CF).

$$V = E - I_aR_a,\ \ CD = CF - I_aR_a\ ,\ \therefore I_a = \frac{CF - CD}{R_a} = \frac{DF}{R_a}\ ,\ I_L = I_a - I_{sh} = \frac{DF}{R_a} - OC = OG$$

5) From point (G), draw vertical line (GX).
6) From point (D), draw horizontal line intersect with line (GX) at point (J) which represents a point on external characteristic.
7) From point (F), draw horizontal line intersect with line (GX) at point (H) which represents a point on internal characteristic.
8) From intersection point (B) between (O.C.C) and line (AB), draw horizontal line intersect with y-axis at point (Z) which is a common point on internal and external characteristic.
9) Reduce the load resistance, then (I_L) increases to a maximum value equal (OK) and then reduced to (OL) when the terminals of generator are short circuited (reduce the load resistance to minimum value).then (OL) being the current due to the e.m.f generated by the residual magnetism.
10) From intersection point of (O.C.C) with y-axis, draw horizontal line equal (OL), which intersect external characteristic.
11) Draw line from origin equal to (OL) which intersect internal characteristic.

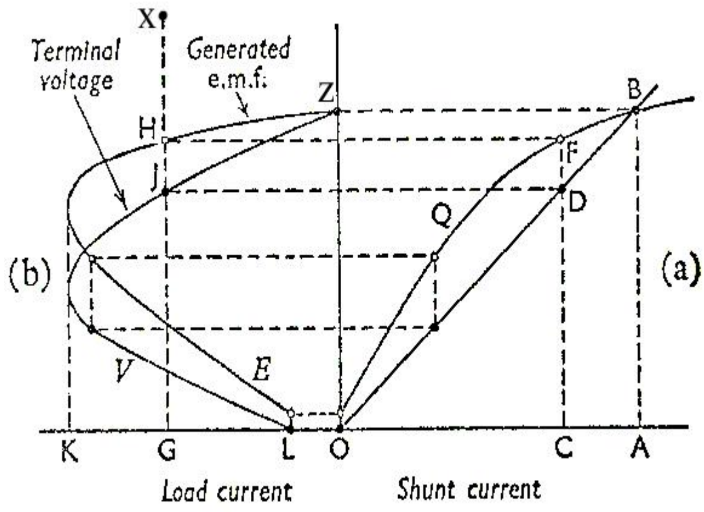


Figure (82)

39. Series Generator

Because field windings are in series with the armature, they carry full armature current I_a. As I_a is increased, flux and hence generated e.m.f. is also increased as shown by the curve.

1) Curve Oa is the O.C.C.
2) Draw horizontal line ab which represents extra exciting current necessary to neutralize the demagnetising effect of armature reaction at full load. Hence, point b is on the internal characteristic.
3) Draw line bc = armature voltage drop (= gh), then point c lies on the external characteristic [Figure (83)].

It will be noticed that a series generator has rising voltage characteristic i.e. with increase in load, its voltage is also increased. But it is seen that at high loads, the voltage starts decreasing due to excessive demagnetising effects of armature reaction.
In fact, terminal voltage starts decreasing as load current is increased as shown by the dotted curve. For a load current OC′, the terminal voltage is reduced to zero as shown.

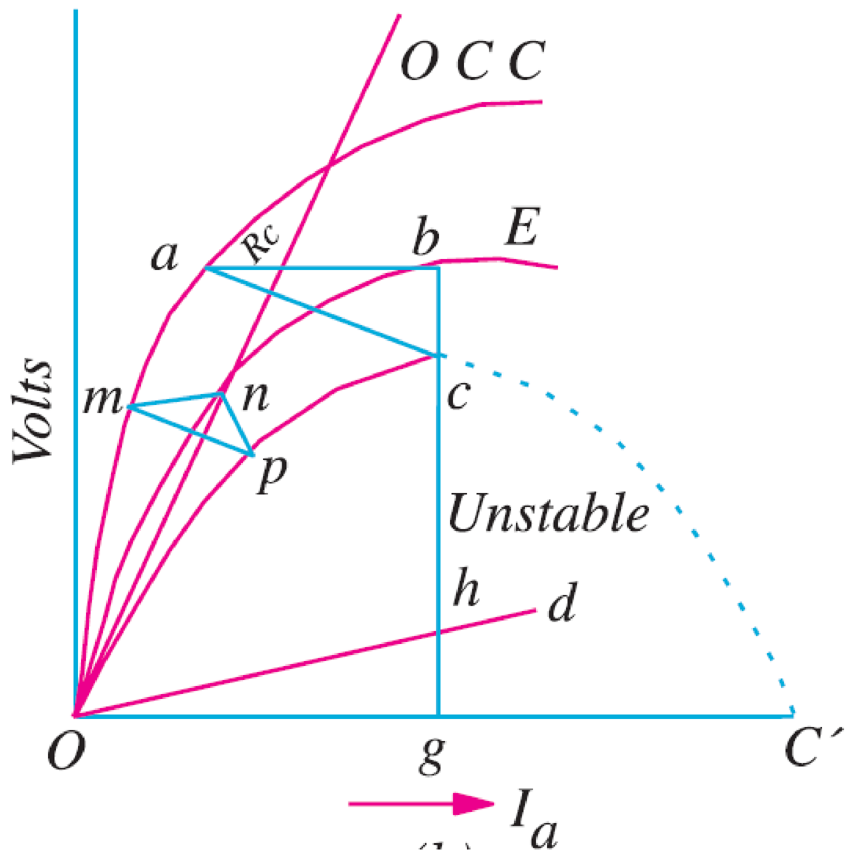


Figure (83)

40. Compound-wound Generator

A shunt generator is unsuitable where constancy of terminal voltage is essential, because its terminal voltage decreases as the load on it increases. This decrease in V is particularly objectionable for lighting circuit where even slight change in the voltage makes an appreciable change in the candle power of the incandescent lamps. A shunt generator may be made to supply substantially constant voltage (or even a rise in voltage as the load increases) by adding to it a few turns joined in series with either the armature or the load. These turns are so connected as to aid to shunt turns when the generator supplies load (cumulatively compound). As the load current increases, the current through the series windings also increase thereby increasing the flux. Due to the increase in flux, induced e.m.f. is also increased. By adjusting the number of series turns, this increase in e.m.f. can be made to balance the combined voltage drop in the generator due to armature reaction and the armature drop. Hence, V remains practically constant which means that field current is also almost unchanged.

- If the series field amp-turns are such as to produce the same voltage at rated load as at no-load, then the generator is **flat-compounded**. However, even in the case of a flat-compounded generator, the voltage is not constant from no-load to rated- load.

- If the series field amp-turns are such that the rated-load voltage is greater than the no-load voltage, then generator is **over-compounded.**
- If rated-load voltage is less than the no-load voltage, then the generator is **under-compounded** but such generators are seldom used.

For short distances such as in hotels and office buildings, flat-compound generators are used because the loss of voltage over small lengths of the feeder is negligible. But when it is necessary to maintain a constant voltage then an over-compounded generator, which combines the functions of a generator and a booster, is invariably used.

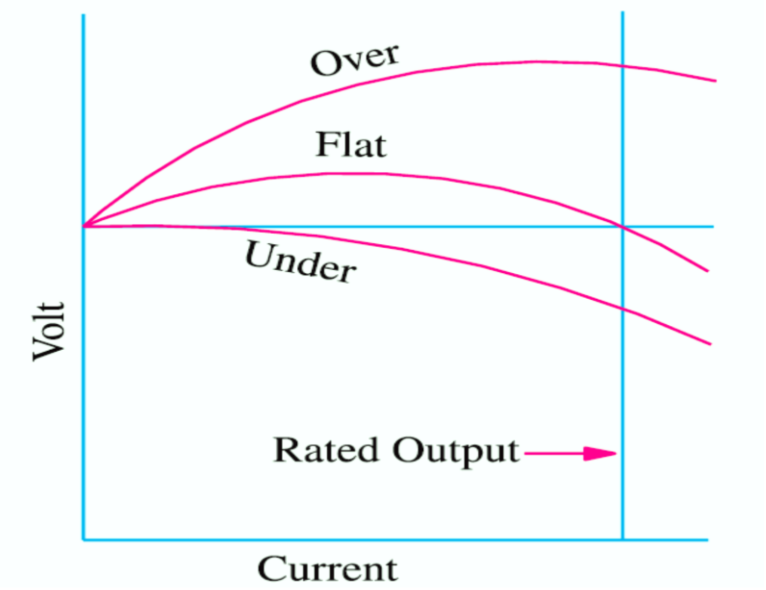


Figure (84)

41. How to Calculate Required Series Turns ?

In general, let

ΔI_{sh} = increase in shunt field current required to keep voltage constant from no-load to full load
N_{sh} = No. of shunt field turns per pole (or the total number of turns)
N_{se} = No. of series turns per pole (or the total number of turns)
I_{se} = current through series winding
= armature current I_a …for long-shunt
= load current I …for short-shunt

It is seen that while running as a simple generator, the increase in shunt field ampere-turns necessary for keeping its voltage constant from no-load to full-load is ($N_{sh}\cdot\Delta_{sh}$). This increase in field excitation can be alternatively achieved by adding a few series turns to the shunt generator [Figure (85-a)] thereby converting it into a compound generator.

$$\therefore \quad N_{sh} \cdot \Delta I_{sh} = N_{se} I_{se}$$

If other things are known, N_{se} may be found from the above equation.
In practice, a few extra series amp-turns are taken in order to allow for the drop in armature. Any surplus amp-turns can be changed with the help of a divertor across the series winding as shown in Figure (85-b).
As said above, the degree of compounding can be adjusted with the help of a variable-resistance, divertor as shown in Figure (85-b). If I_d is the current through the divertor of resistance R_d, then remembering that series windings and divertor are in parallel,

$$\therefore \quad I_{se} \cdot R_{se} = I_d \,.\, R_d \qquad \text{or} \qquad R_d = I_{se} \,.\, (R_{se}/I_d)$$

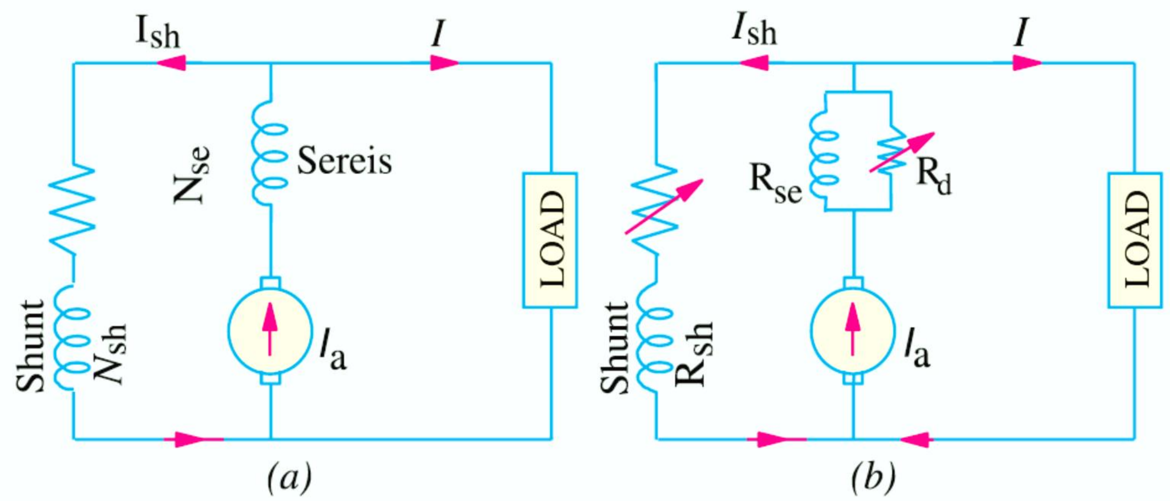


Figure (85)

Example 52: A shunt generator is to be converted into a level compounded generator by the addition of a series field winding. From a test on the machine with shunt excitation only, it is found that the shunt current is 3.1 A to give 400 V on no load and 4.8 A to give the same voltage when the machine is supplying its full load of 200 A. The shunt winding has 1200 turns per pole. Find the number of series turns required per pole.

Solution:

At no-load the ampere turns required to produce 400 V = 3.1 × 1200 = 3720

On full-load ampere turns required to produce the same voltage = 4.8 × 1200 = 5760

Additional amp-turns required due to demagnetizing effect of load current is,

= 5760 − 3720 =2040

If N is no. of series turns required when I_L is 200 A, then $N \times 200 = 2040$, $N = 10.2$

Example 53: A shunt generator is converted into a short-shunt compound generator by addition of a series field winding. From the test on the machine with shunt excitation only, it is found that a field current of 5 A gives 440 V on no-load and that 6 A gives 440 V at full load current of 200 A. The shunt winding has 1600 turns per pole. Find the number of series turns required.

Solution:

It would be assumed that shunt generator is converted into a short shunt compound generator. It is given that for keeping the voltage of shunt generator constant at 440 V both at no load and full-load, shunt field ampere-turns per pole have to be increased from 1600 × 5 = 8000 to (1600 × 6) = 9600 *i.e.* an increase of (9600 − 8000) = 1600 *AT*.

The same increase in field *AT* can be brought about by adding a few series turns.

Let n be the number of series turns required per pole. Since they carry 200 A,

∴ $n \times 200 = 1600$, $n =$ **8 turns/pole**

Example 54: A long shunt compound generator has a shunt field winding of 1000 turns per pole and series field winding of 4 turns per pole and resistance 0.05 Ω. In order to obtain the rated voltage both at no-load and full-load for operation as shunt generator, it is necessary to increase field current by 0.2 A. The full-load armature current of the compound generator is 80 A. Calculate the divertor resistance connected in parallel with series field to obtain flat compound operation.

Solution:

Additional AT required to maintain rated voltage both at no-load and full-load (Figure (86)) = 1000 × 0.2 = 200

No. of series turns/pole = 4

Current required to produce 200 AT by the series field = 200/4 = 50 A.

Since I_a = 80 A, the balance of 30 A must pass through the parallel divertor resistance.

∴ 30 R = 50 × 0.05

R = 0.0833 Ω

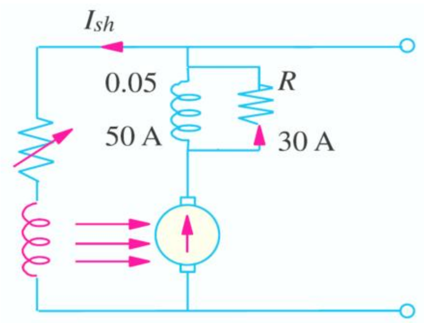


Figure (86)

Example 55: A 220-V compound generator is supplying a load of 100 A at 220 V. The resistances of its armature, shunt and series windings are 0.1 Ω, 50 Ω and 0.06 Ω respectively. Find the induced e.m.f. and the armature current when the machine is connected **(a)** short shunt **(b)** long shunt **(c)** how will the series amp-turns be changed in **(b)** if a divertor of 0.14 Ω is connected in parallel with the series windings ? Neglect armature reaction and brush contact drop.

Solution:

(a) Short-shunt (Figure (87-a)).

Voltage drop in series = 100 × 0.06 = 6 V; I_{sh} = (220+6)/50 = 4.52 A.

∴ I_a = 100 + 4.52 = **104.52**

Armature drop = 104.52 × 0.1 = 10.452 V

∴ Induced e.m.f. = 220 + 6 + 10.452 = **236.452 V**

(b) Long-shunt (Figure (87-b))

I_{sh} = 220/50 = 4.4 A ∴ I_a = 100 + 4.4 = **104.4 A**

Voltage drop over armature and series field winding = 104.4 × 0.16 = 16.7 V

∴ Induced e.m.f. = 220 + 16.7 = **236.7 V**

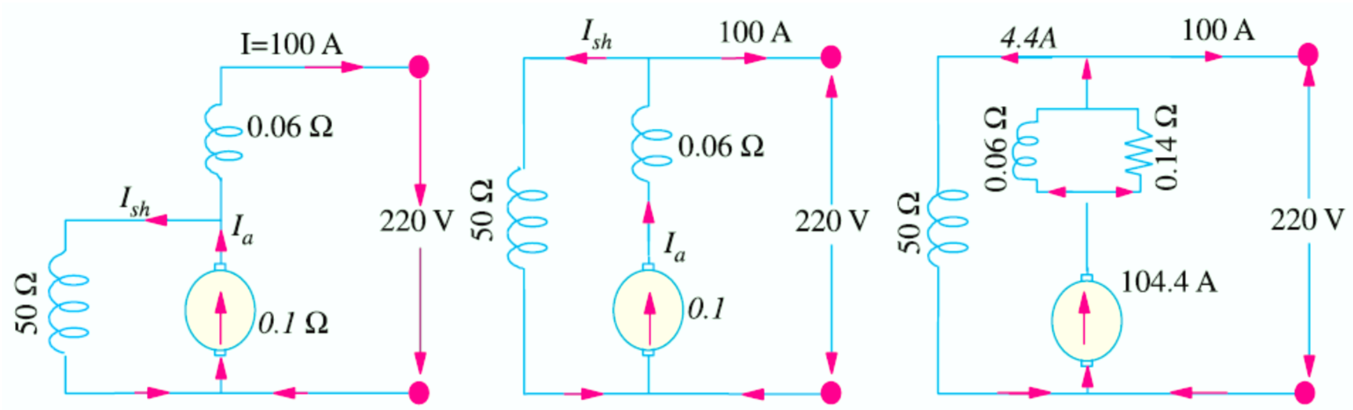
(c) As shown in (Figure (87-c)), a divertor of resistance 0.14 Ω is connected in parallel with the series field winding. Let n be the number of series turns.

Number of series amp-turns without divertor = n × 104.4 = 104.4 n

When divertor is applied, then current through series field is $= \frac{104.4 \times 0.14}{(0.14+0.06)} = 73.08$ A

∴ Series amp-turns = 73.08 × n

∴ Series amp-turns are reduced to $\frac{73.08 \times n}{104.4 \times n} \times 100$ =**70 %**



(a) (b) (c)

Figure (87)

Example 56: A 250-kW, 240-V generator is to be compounded such that its voltage rises from 220 volts at no-load to 240 V at full load. When series field is cut out and shunt field is excited from an external source, then from the load test it is found that this rise in voltage can be obtained by increasing the exciting current from 7 A at no-load to 12 A at full-load. Given shunt turns/pole = 650, series turns/pole = 4 and resistance of series winding, 0.006 Ω. If the machine is connected long-shunt, find the resistance of the series amp-turns at no-load and drop in series winding resistance at full-load.

Solution:

Full-load current = 250 × (10^3/240) = 1042 A

Increase in shunt field ampere-turns to over-compound the shunt generator

= 650 (12 − 7) = 3,250. As seen from Figure (88)

$4 \times I_{se} = 3250 \Longrightarrow I_{se} = 3250/4 = 812.5$ A

∴ $I_d = 1042 - 812.5 = 229.5$ A

It is so because no-load shunt current being negligible,

$I_a = I = 1042$ A.

Since series winding and divertor are in parallel is,

$I_d R_d = I_{se} R_{se}$

or $229.5 R_d = 812.5 \times 0.006$

∴ $R_d =$ **0.0212 Ω**

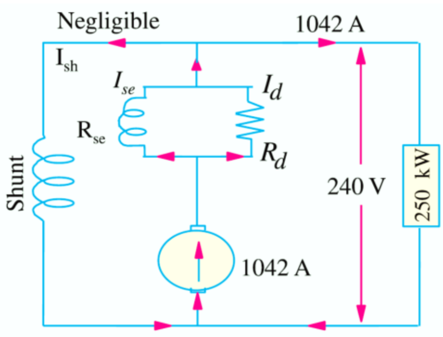


Figure (88)

Example 57: A 60-kW d.c. shunt generator has 1600 turns/pole in its shunt winding. A shunt field current of 1.25 A is required to generate 125 V at no-load and 1.75 A to generate 150 V at full load. Calculate

(i) the minimum number of series turns/pole needed to produce the required no-load and full load voltages as a short-shunt compound generator.

(ii) if the generator is equipped with 3 series turns/pole having a resistance of 0.02 Ω, calculate divertor resistance required to produce the desired compounding.

(iii) voltage regulation of the compound generator.

Solution:

Extra excitation ampere-turns required = 1600 (1.75 − 1.25) = 800

$I_{se} = I = 60{,}000/150 = 400$ A, ∴ No. of series turns/pole required = 800/400 = **2**

Hence, minimum number of series turns/pole required for producing the desired compound generator terminal voltage is **2**.

(ii) Now, actual No. of series turns/pole is 3. Hence, current passing through it can be found from

$3 \times I_{se} = 800$

∴ $I_{se} = 800/3$ A

As shown in Figure (89), $I_d = 400 - (800/3) = 400/3$ A

Also $(800/3) \times 0.02 = (400/3) \times R_d$

∴ $R_d =$ **0.04 Ω**

(iii) % regn. = $\dfrac{(125 - 150)}{150} \times (100) =$ **− 16.7%**

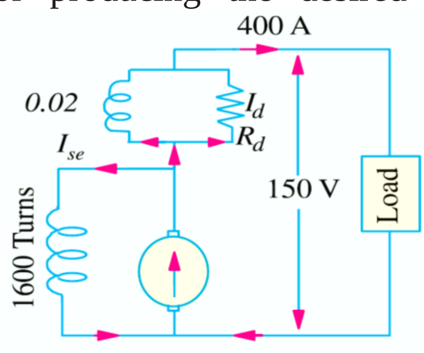


Figure (89)

42. Uses of D.C. Generators:

1. Shunt generators with field regulators are used for ordinary lighting and power supply purposes. They are also used for charging batteries because their terminal voltages are almost constant or can be kept constant.

2. Series generators are not used for power supply because of their rising characteristics. However, their rising characteristic makes them suitable for being used as boosters in certain types of distribution systems particularly in railway service.

3. Compound generators
The cumulatively-compound generator is the most widely used d.c. generator because its external characteristic can be adjusted for compensating the voltage drop in the line resistance. Hence, such generators are used for motor driving which require d.c. supply at constant voltage, for lamp loads and for heavy power service such as electric railways.
The differential-compound generator has an external characteristic similar to that of a shunt generator but with large demagnetization armature reaction. Hence, it is widely used in arc welding where larger voltage drop is desirable with increase in current.

Tutorial Problems (3)

[1] The OC curve of a d.c. shunt generator for a speed of 1000 r.p.m. is given by the following table.

Field current :	2.0	3.0	4.0	5.0	6.0	7.0
E.M.F. volts :	102	150	188	215	232	245

The shunt has a resistance of 37 Ω. Find the speed at which excitation may be expected to build up. The aramture resistance of 0.04 Ω. Neglecting the effects of brush drop and armature reaction, estimate the p.d. when the speed is 1000 r.p.m. and the armature delivers a current of 100 A. **[725 r.p.m.; 231 V]**

[2] A d.c. shunt generator running at 850 r.p.m. gave the following O.C.C. data :

Field current (A) :	0	0.5	1	2	3	4	5
E.M.F. (V) :	10	60	120	199	232	248	258

If the resistance of the shunt field is 50 Ω, determine the additional resistance required in the shunt field circuit to give 240 V at a speed of 1000 r.p.m. **[64.3 Ω]**

[3] Sketch the load characteristic of a d.c. generator with (i) shunt (ii) series excitation. Give reasons for the particular shape in each case.

The O.C.C. at 700 r.p.m. of a series generator with separately-excited field is as follows :

Field current (A) :	20	40	50	60	75
Armature e.m.f. (V) :	190	360	410	450	480

Determine the current and terminal voltage as a self-excited series machine when running at 600 r.p.m. with a load of 6 Ω connected to the terminal. Resistance of armature and series winding is 0.3Ω. Ignore effect of armature reaction. **[369 V; 61.5 A]**

[4] The O.C.C. data for separately-excited generator when run at 130 r.p.m. on open circuit is

E.M.F. (V) :	12	44	73	98	113	122	127
Exciting current :	0	0.2	0.4	0.6	0.8	1.0	1.2

Deduce the curve of e.m.f. and excitation when the generator is running separately-excited at 100 r.p.m. To what voltage will the generator build up on no-load when running at 100 r.p.m. if the total field resistance is 100 Ω ? **[91 V]**

[5] The following figures give the O.C.C. of d.c. Shunt generator driven at a constant speed of 700 r.p.m.

Terminal voltage (V):	10	20	40	80	120	160	200	240	260

Field Current (A) :	0	0.1	0.24	0.5	0.77	1.2	1.92	3.43	5.2

Determine the critical resistance at (a) 700 r.p.m. (b) 850 r.p.m. If resistance of field coils is 50 Ω, find the range of the field rheostat required to vary the voltage between the limits of 180 V and 250 V on open circuit at a speed of 700 r.p.m. **[160 Ω; 194 Ω; 70 Ω to 10 Ω]**

[6] The O.C.C. of a shunt generator when separately-excited and running at 1000 r.p.m. is given by :

O.C.C. volt :	56	112	150	180	200	216	230
Field amp. :	0.5	1.0	1.5	2.0	2.5	3.0	3.5

If the generator is shunt-connected and runs at 1100 r.p.m. with a total field resistance of 80 Ω, determine
(a) no-load e.m.f., (b) the output current when the terminal voltage is 200 V if the armature resistance is 0.1 Ω., (c) the terminal voltage of the generator when giving the maximum output current. Neglect the effect of armature reaction and of brush contact drop. **[236 V; 197.5A V; 460 V; 150 V (approx.)]**

[7] A long-shunt compound d.c. generator with armature, series field and shunt field resistance of 0.5, 0.4 and 250 Ω respectively gave the following readings when run at constant speed :

Load current (A) :	0	10	20	30	40
Terminal p.d. (V) :	480	478	475	471	467

Plot the curve of internal generated e.m.f. against load current. Explain fully the steps by which this curve is obtained and tabulate the values from which it is plotted.
[For 40 A; E = 504.7 V (approx.)]

[8] A shunt generator has the following open-circuit characteristic at 800 r.p.m.

Field amperes :	0.5	1.0	1.5	2.0	2.5	3.0	3.5
E.M.F. Volt :	54	107	152	185	210	230	245

Armature and shunt field resistances are respectively 0.1 Ω and 80 Ω. The terminal p.d. falls to 175 V, when the armature current is 100 A. Find the O.C. volts and the volts lost due to (i) reduction in the field current (ii) armature resistance (iii) armature reaction.
[220 V (i) 27 V (ii) 10 V (iii) 8 V]