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CHAPTER 27

ARMATURE REACTION AND COMMUTATION

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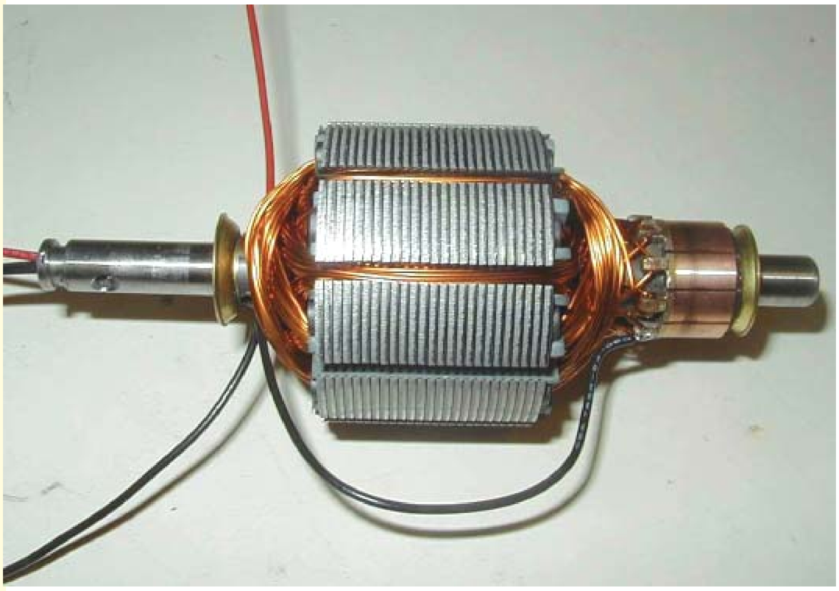

Armature reaction is the change in the neutral plane and the reaction of the magnetic field

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27.1 Armature Reaction

By armature reaction is meant the effect of magnetic field set up by armature current on the distribution of flux under main poles of a generator. The armature magnetic field has two effects :

(*i*) ***It demagnetises* or *weakens the main flux*** and

(*ii*) ***It cross-magnetises* or *distorts it.***

The first effect leads to reduced generated voltage and the second to the sparking at the brushes.

These effects are well illustrated in Fig. 27.1 which shows the flux distribution of a bipolar generator when there is no current in the armature conductors. For convenience, only two poles have been considered, though the following remarks apply to multipolar fields as well. Moreover, the brushes are shown touching the armature conductors directly, although in practice, they touch commutator segments, It is seen that

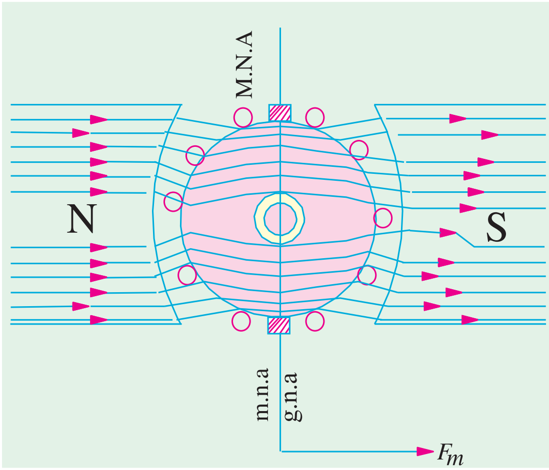


Fig. 27.1

(*a*) the flux is distributed symmetrically with respect to the polar axis, which is the line joining the centres of *NS* poles.

(*b*) The magnetic neutral axis or plane (*M.N.A.*) coincides with the geometrical neutral axis or plane (*G.N.A.*)

Magnetic neutral axis may be defined as the axis along which no e.m.f. is produced in the armature conductors because they then move parallel to the lines of flux.

Or *M.N.A.* is the axis which is perpendicular to the flux passing through the armature.

As hinted in Art. 27.2, brushes are always placed along *M.N.A.* Hence, *M.N.A.* is also called 'axis of commutation' because reversal of current in armature conductors takes place across this axis.

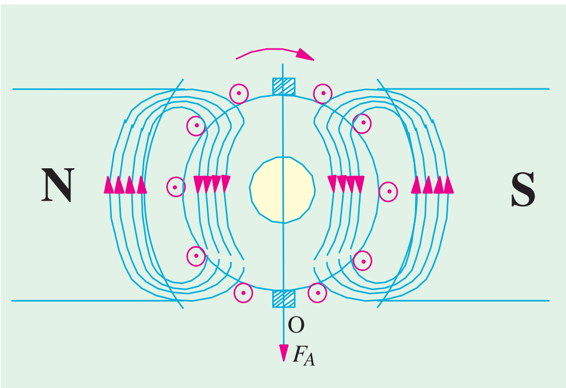


Fig. 27.2

In Fig. 27.1 is shown vector OF_m which represents, both in magnitude and direction, the m.m.f. producing the main flux and also *M.N.A.* which is perpendicular to OF_m.

In Fig. 27.2 is shown the field (or flux) set up by the armature conductors *alone* when carrying current, the field coils being unexcited. The direction of the armature current is the same as it would actually be when the generator is loaded. It may even be found by applying Fleming's Right-hand Rule. The current direction is downwards in conductors under *N*-pole and upwards in those under *S*-pole. The downward flow is represented by crosses and upward flow by dots.

As shown in Fig. 27.2, the m.m.fs. of the armature conductors combine to send flux downwards through the armature. The direction of the lines of force can be found by applying cork-screw rule. The armature m.m.f. (depending on the strength of the armature current) is shown separately both in magnitude and direction by the vector OF_A which is parallel to the brush axis.

So far, we considered the main m.m.f. and armature m.m.f. separately as if they existed independently, which is not the case in practice. Under actual load conditions, the two exist simultaneously in the generator as shown in Fig. 27.3.

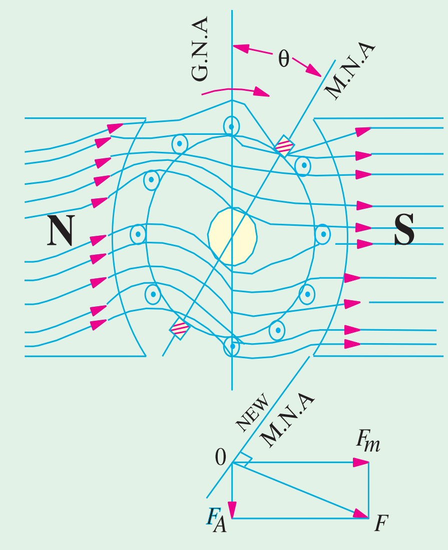


Fig. 27.3

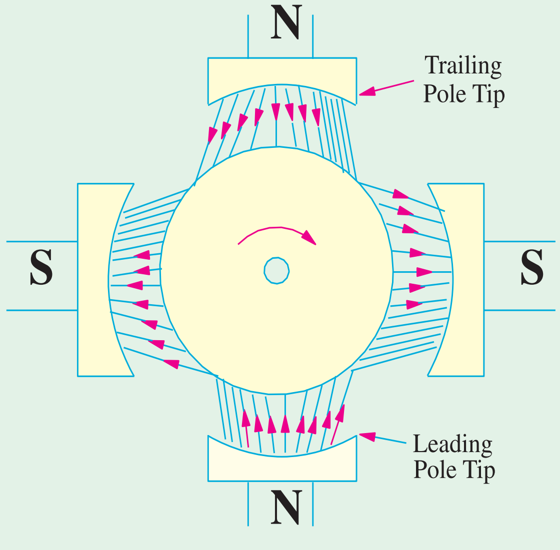
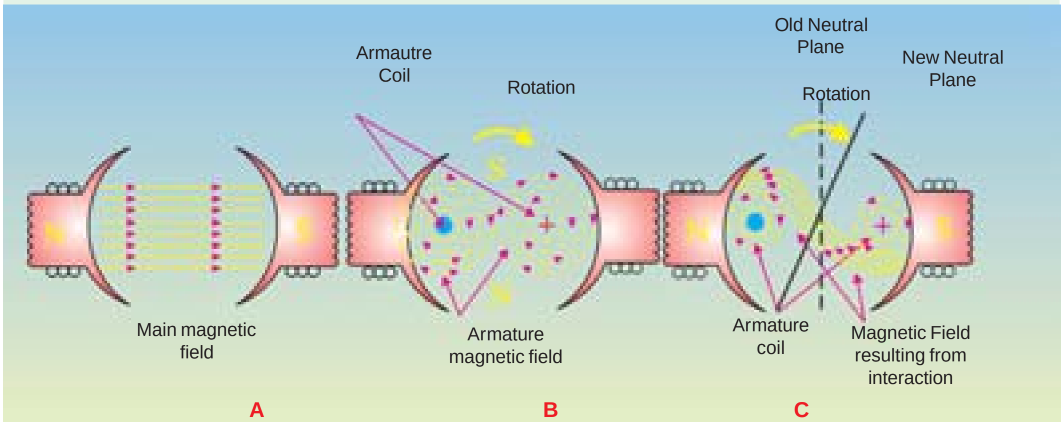


Fig. 27.4

It is seen that the flux through the armature is no longer uniform and symmetrical about the pole axis, rather it has been distorted. The flux is seen to be crowded at the trailing pole tips but weakened or thinned out at the leading pole tips (the pole tip which is first met during rotation by armature conductors is known as the leading pole tip and the other as trailing pole tip). The strengthening and weakening of flux is separately shown for a four-pole machine in Fig. 27.4. As seen, air-gap flux density under one pole half is greater than that under the other pole half.

If Fig. 27.3 is shown the resultant m.m.f. *OF* which is found by vectorially combining OF_m and OF_A.

The new position of *M.N.A.*, which is always perpendicular to the resultant m.m.f. vector *OF*, is also shown in the figure. With the shift of *M.N.A.*, say through an angle θ, brushes are also shifted so as to lie along the new position of *M.N.A.* Due to this brush shift (or forward lead), the armature conductors and hence armature current is redistributed. Some armature conductors which were earlier



Armature reaction

under the influence of *N*-pole come under the influence of *S*-pole and ***vice-versa***. This regrouping is shown in Fig. 27.5, which also shows the flux due to armature conductors. Incidentally, brush position shifts in the *same* direction as the direction of armature rotation.

All conductors to the left of new position of *M.N.A.* but between the two brushes, carry current downwards and those to the right carry current upwards. The armature m.m.f. is found to lie in the direction of the new position of *M.N.A.* (or brush axis). The armature m.m.f. is now represented by the vector OF_A which is not vertical (as in Fig 27.2) but is inclined by an angle θ to the left. It can now be resolved into two rectangular components, OF_d parallel to polar axis and OF_C perpendicular to this axis. We find that

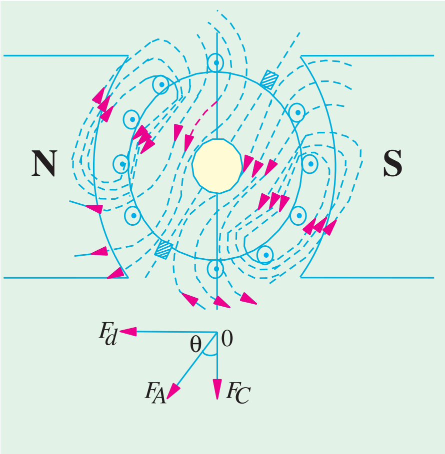


Fig. 27.5

(i) component OF_C is at right angles to the vector OF_m (of Fig. 27.1) representing the main m.m.f. It produces distortion in the main field and is hence called the cross-magnetising or distorting component of the armature reaction.

(ii) The component OF_d is in direct opposition of OF_m which represents the main m.m.f. It exerts a demagnetising influence on the main pole flux. Hence, it is called the demagnetising or weakening component of the armature reaction.

It should be noted that both distorting and demagnetising effects will increase with increase in the armature current.

27.2. Demagnetising and Cross-magnetising Conductors

The exact conductors which produce these distorting and demagnetising effects are shown in Fig. 27.6 where the brush axis has been given a forward lead of θ so as to lie along the new position of *M.N.A.* All conductors lying within angles *AOC* = *BOD* = 2θ at the top and bottom of the armature, are carrying current in such a direction as to send the flux *through* the armature from right to left. This fact may be checked by applying crockscrew rule. It is these conductors which act in direct opposition to the main field and are hence called the demagnetising armature conductors.

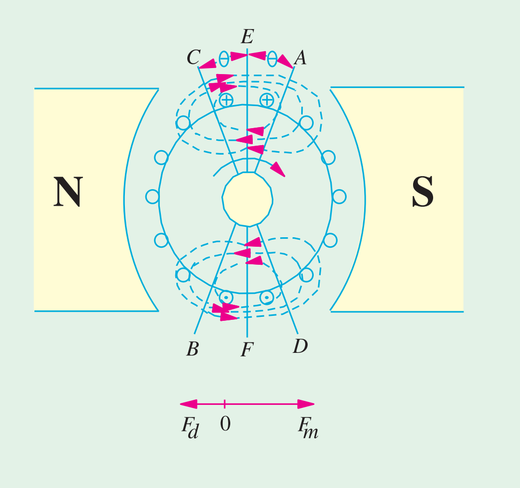


Fig. 27.6

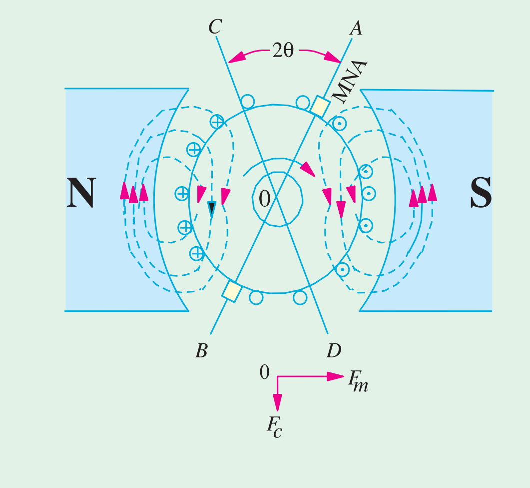


Fig. 27.7

Now consider the remaining armature conductors lying between angles *AOD* and *COB*. As shown in Fig. 27.7, these conductors carry current in such a direction as to produce a combined flux pointing vertically downwards *i.e.* at right angles to the main flux. This results in distortion of the main field. Hence, these conductors are known as cross-magnetising conductors and constitute distorting ampere-conductors.

27.3. Demagnetising AT per Pole

Since armature demagnetising ampere-turns are neutralized by adding extra ampere-turns to the main field winding, it is essential to calculate their number. But before proceeding further, it should be remembered that the number of turns is equal to half the number of conductors because two conductors-constitute one turn.

Let Z = total number of armature conductors

I = current in each armature conductor

$= I_d/2$ ... for simplex wave winding

$= I_d/P$ ... for simplex lap winding

θ_m = forward lead in mechanical or geometrical or angular degrees.

Total number of armature conductors in angles *AOC* and *BOD* is $\frac{4\theta_m}{360} \times Z$

As two conductors constitute one turn,

$$\therefore \quad \text{Total number of turns in these angles} = \frac{2\theta_m}{360} \times Z\,I$$

$$\therefore \quad \text{Demagnetising amp-turns per pair of poles} = \frac{2\theta_m}{360} \times Z\,I$$

$$\therefore \quad \text{Demagnetising amp-turns/pole} = \frac{\theta_m}{360} \times ZI \qquad \therefore AT_d \text{ per pole} = ZI \times \frac{\theta_m}{360}$$

27.4. Cross-magnetising AT per pole

The conductors lying between angles *AOD* and *BOC* constitute what are known as distorting or cross-magnetising conductors. Their number is found as under :

Total armature-*conductors*/pole both cross and demagnetising = Z/P

$$\text{Demagnetising } conductors\text{/pole} = Z.\frac{2\theta_m}{360} \qquad \text{(found above)}$$

$$\therefore \quad \text{Corss-magnetising } conductors\text{/pole} = \frac{Z}{P} - Z \times \frac{2\theta_m}{360} = Z\left(\frac{1}{P} - \frac{2\theta_m}{360}\right)$$

$$\therefore \quad \text{Cross-magnetising } amp\text{-}conductors\text{/pole} = ZI\left(\frac{1}{P} - \frac{2\theta_m}{360}\right)$$

$$\therefore \quad \text{Corss-magnetising } amp\text{-}turns\text{/pole} = ZI\left(\frac{1}{2P} - \frac{\theta_m}{360}\right)$$

(Remembering that two conductors make one turn)

$$\therefore \quad AT_c\text{/pole} = ZI\left(\frac{1}{2P} - \frac{\theta_m}{360}\right)$$

Note. (*i*) For neutralizing the demagnetising effect of armature-reaction, an extra number of turns may be put on each pole.

$$\text{No. of extra turns/pole} = \frac{AT_d}{I_{sh}} \qquad \text{–for shunt generator}$$

$$= \frac{AT_d}{I_a} \qquad \text{–for series generator}$$

If the leakage coefficient λ is given, then multiply each of the above expressions by it.

(ii) If lead angle is given in electrical degrees, it should be converted into mechanical degrees by the following relation.

$$\theta \text{ (mechanical)} = \frac{\theta \text{ (electrical)}}{\text{pair of poles}} \text{ or } \theta_m = \frac{\theta_e}{P/2} = \frac{2\theta_e}{P}$$

27.5. Compensating Windings

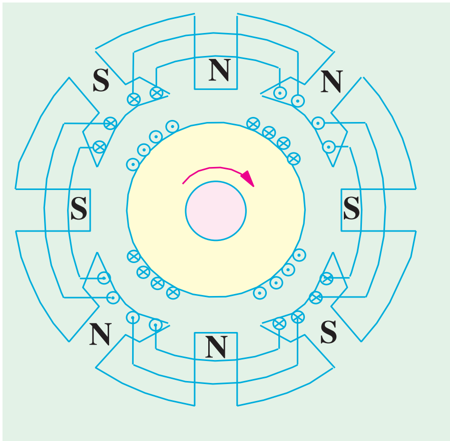
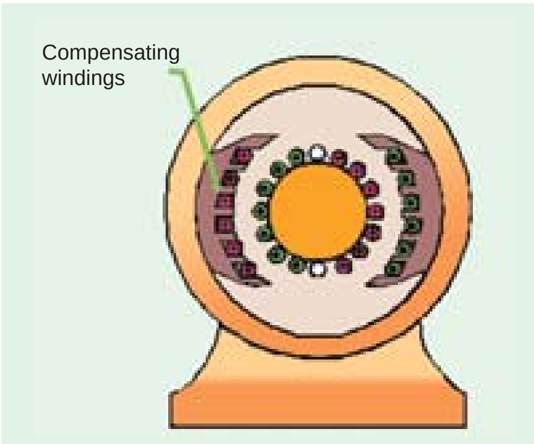


Fig. 27.8

These are used for large direct current machines which are subjected to large fluctuations in load *i.e.* rolling mill motors and turbo-generators etc. Their function is to neutralize the cross magnetizing effect of armature reaction. In the absence of compensating windings, the flux will be suddenly shifting backward and forward with every change in load. This shifting of flux will induce ***statically*** induced e.m.f. in the armature coils. The magnitude of this e.m.f. will depend upon the rapidity of changes in load and the amount of change. It may be so high as to strike an arc between the consecutive commutator segments across the top of the mica sheets separating them. This may further develop into a flash-over around the whole commutator thereby short-circuiting the whole armature.



Compensating windings

These windings are embedded in slots in the pole shoes and are connected in series with armature in such a way that the current in them flows in opposite direction to that flowing in armature conductors directly below the pole shoes. An elementary scheme of compensating winding is shown in Fig. 27.8.

It should be carefully noted that compensating winding must provide sufficient m.m.f so as to counterbalance the armature m.m.f. Let

Z_c = No. of compensating conductos/pole face

Z_a = No. of active armature conductors/pole, I_a = Total armature current

I_a/A = current/armature conductor

$$\therefore \; Z_c I_a = Z_a (I_a/A) \text{ or } Z_c = Z_a/A$$

Owing to their cost and the room taken up by them, the compensating windings are used in the case of large machines which are subject to violent fluctuations in load and also for generators which have to deliver their full-load output at considerable low induced voltage as in the Ward-Leonard set.

27.6. No. of Compensating Windings

No. of armature *conductors*/pole $= \dfrac{Z}{P}$ No. of armature *turns*/pole $= \dfrac{Z}{2P}$

$\therefore$ No. of armature-turns immediately under one pole

$$= \frac{Z}{2P} \times \frac{\text{Pole arc}}{\text{Pole pitch}} = 0.7 \times \frac{Z}{2P} \text{ (approx.)}$$

$\therefore$ No. of armature amp-*turns/*pole for compensating winding

$$= 0.7 \times \frac{Z}{2P} = 0.7 \times \text{armature amp-turns/pole}$$

Example 27.1. *A 4-pole generator has a wave-wound armature with 722 conductors, and it delivers 100 A on full load. If the brush lead is 8°, calculate the armature demagnetising and cross-magnetising ampere turns per pole.*
(Advanced Elect. Machines AMIE Sec. B 1991)

4-pole generator

Solution. $I = I_a/2 = 100/2 = 50\text{A}$; $Z = 722$; $\theta_m = 8°$

$$\text{AT}_d/\text{pole} = ZI.\frac{\theta_m}{360} = 722 \times 50 \times \frac{8}{360} = 802$$

$$\text{AT}_c/\text{pole} = ZI.\left(\frac{1}{2P} - \frac{\theta_m}{360}\right)$$

$$= 722 \times 50\left(\frac{1}{2 \times 4} - \frac{8}{360}\right) = 37/8$$

Example 27.2 *An 8-pole generator has an output of 200 A at 500 V, the lap-connected armature has 1280 conductors, 160 commutator segments. If the brushes are advanced 4-segments from the no-load neutral axis, estimate the armature demagnetizing and cross-magnetizing ampere-turns per pole.* **(Electrical Machines-I, South Gujarat Univ. 1986)**

Solution. $I = 200/8 = 25$ A, $Z = 1280$, $\theta_m = 4 \times 360/160 = 9°$; $P = 8$

$$\text{AT}_d/\text{pole} = ZI\theta_m/360 = 1280 \times 25 \times 9/360 = \mathbf{800}$$

$$\text{AT}_c/\text{pole} = ZI\left(\frac{1}{2p} - \frac{\theta_m}{360}\right) = 1280 \times 25\left(\frac{1}{2 \times 8} - \frac{9}{360}\right) = \mathbf{1200}$$

Note. No. of coils = 160, No. of conductors = 1280. Hence, each coil side contains 1280/160 = 8 conductors.

Example 27.3(*a*). *A 4-pole wave-wound motor armature has 880 conductors and delivers 120 A. The brushes have been displaced through 3 angular degrees from the geometrical axis. Calculate **(a)** demagnetising amp-turns/pole **(b)** cross- magnetising amp-turns/pole **(c)** the additional field current for neutralizing the demagnetisation of the field winding has 1100 turns/pole.*

Solution. $Z = 880$; $I = 120/2 = 60$ A ; $\theta = 3°$ angular

(*a*) $\therefore$ $\text{AT}_d = 880 \times 60 \times \dfrac{3}{360} = \mathbf{440\ AT}$

(*b*) $\therefore$ $\text{AT}_c = 880 \times 60\left(\dfrac{1}{8} - \dfrac{3}{360}\right) = 880 \times \dfrac{7}{60} \times 60 = \mathbf{6{,}160}$

or Total AT/pole = 440 × 60/4 = 6600

Hence, AT_C/pole = Total AT/pole – AT_d/ pole = 6600 – 440 = 6160

(*c*) Additional field current = 440/1100 = **0.4 A.**

Example 27.3(*b*). *A 4-pole lap-wound Generator having 480 armature conductors supplies a current of 150 Amps. If the brushes are given an actual lead of 10°, calculate the demagnetizing and cross-magnetizing amp-turns per pole.* **(Bharathiar Univ. April 1998)**

Solution. 10° mechanical (or actual) shift = 20° electrical shift for a 4-pole machine.

Armature current = 150 amp

For 4-pole lap-wound armature, number of parallel paths = 4. Hence, conductor-current = 150/4 = 37.5 amps.

$$\text{Total armature amp-turns/pole} = \frac{1}{2} \times \frac{(480 \times 37.5)}{14} = 2250$$

$$\text{Cross – magnetizing amp turns/pole} = 2250 \times \left(1 - \frac{2 \times 20°}{180°}\right) = 1750$$

$$\text{Demagnetizing amp turns/pole} = 2250 \times (2 \times 20°/180°) = 500$$

Example 27.4. *A 4-pole generator supplies a current of 143 A. It has 492 armature conductors* **(a)** *wave-wound* **(b)** *lap-wound. When delivering full load, the brushes are given an actual lead of 10°. Calculate the demagnetising amp-turns/pole. This field winding is shunt connected and takes 10 A. Find the number of extra shunt field turns necessary to neutralize this demagnetisation.*

(Elect. Machines, Nagpur Univ. 1993 & JNTU Hyderabad, 2000 & RGPU, Bhopal, 2000)

Solution. $Z = 492$; $\theta_m = 10°$; $AT_d/\text{pole} = ZI \times \dfrac{\theta_m}{360}$

$I_a = 143 + 10 = 153$ A ; $I = 153/2$ ... when wave-wound

$= 153/4$ ... when lap-wound

(a) $\therefore$ $AT_d/\text{pole} = 492 \times \dfrac{153}{2} \times \dfrac{10}{360} =$ **1046 AT**

Extra shunt field turns = 1046/10 = **105 (approx.)**

(b) $AT_d/\text{pole} = 492 \times \dfrac{153}{2} \times \dfrac{10}{360} =$ **523**

Extra shunt field turns = 523/10 = **52 (approx.)**

Example 27.5. *A 4-pole, 50-kW, 250-V wave-wound shunt generator has 400 armature conductors. Brushes are given a lead of 4 commutator segments. Calculate the demagnetisation amp-turns/pole if shunt field resistance is 50 Ω. Also, calculate extra shunt field turns/pole to neutralize the demagnetisation.*

Solution. Load current supplied = 50,000/250 = 200 A

$I_{sh} = 250/50 = 5$ A $\therefore$ $I_a = 200 + 5 = 205$ A

Current in each conductor $I = 205/2$ A

No. of commutator segments = N/A where $A = 2$ ... for wave-winding

$\therefore$ No. of segments = $\dfrac{400}{2} = 200$; $\theta = \dfrac{4}{200} \times 360 = \dfrac{36}{5}$ degrees

$\therefore$ $AT_d/\text{pole} = 400 \times \dfrac{205}{2} \times \dfrac{36}{5 \times 360} =$ **820 AT**

Extra shunt turns/poles $= \dfrac{AT_d}{I_{sh}} = \dfrac{820}{5} =$ **164**

Example 27.6. *Determine per pole the number* **(i)** *of cross-magnetising ampere-turns* **(ii)** *of back ampere-turns and* **(iii)** *of series turns to balance the back ampere-turns in the case of a d.c. generator having the following data.*

500 conductors, total current 200 A, 6 poles, 2-circuit wave winding, angle of lead = 10°, leakage coefficient = 1.3 **(Electrical Machines-I, Bombay University, 1986)**

Solution. Current/path, $I = 200/2 = 100$ A, $\theta = 10°$ (mech), $Z = 500$

(a) $AT_c/\text{pole} = ZI\left(\dfrac{1}{2P} - \dfrac{\theta_m}{360}\right) = 500 \times 100\left(\dfrac{1}{2 \times 6} - \dfrac{10}{360}\right) =$ **2,778**

(b) $AT_d/\text{pole} = 500 \times 100 \times 10/360 =$ **1390**

(*c*) Series turns required to balance the demagnetising ampere-turns are

$$= \lambda \times \frac{AT_d}{I_a} = 1.3 \times \frac{1390}{200} = \mathbf{9}$$

Example 27.7. *A 22.38 kW, 440-V, 4-pole wave-wound d.c. shunt motor has 840 armature conductors and 140 commutator segments. Its full-load efficiency is 88% and the shunt field current is 1.8 A. If brushes are shifted backward through 1.5 segments from the geometrical neutral axis, find the demagnetising and distorting amp-turns/pole.* **(Elect. Engg. Punjab Univ. 1991)**

Solution. The shunt motor is shown diagrammatically in Fig. 27.9.

Motor output = 22,380 W ; η = 0.88

∴ Motor input = 22,380/0.88 W

$$\text{Motor input current} = \frac{22{,}380}{0.88 \times 440} = 57.8 \text{ A}$$

$I_{sh} = 1.8\ A$; I_a = 57.8 – 1.8 = 56 A

Current in each conductor = 56/2 = 28 A

θ = 1.5 × 360/140

= 27/7 degrees

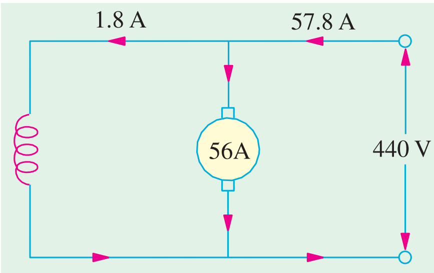


Fig. 27.9

$$\therefore \quad AT_d / \text{pole} = 840 \times 28 \times \frac{27}{7 \times 360} = \mathbf{252}$$

$$AT_c / \text{pole} = Z\,I\left(\frac{1}{2P} - \frac{\theta_m}{360}\right) = 840 \times 28\left(\frac{1}{8} - \frac{27}{7 \times 360}\right) = \mathbf{2{,}688}$$

Example 27.8. *A 400-V, 1000-A, lap-wound d.c. machine has 10 poles and 860 armature conductors. Calculate the number of conductors in the pole face to give full compensation if the pole face covers 70 % of pole span.*

Solution. AT/pole for compensating winding

$$= \text{armature amp-turn/pole} \times \frac{\text{pole arc}}{\text{pole pitch}} = 0.7 \times \frac{ZI}{2P}$$

Here I = current in each armature conductor = 1,000/10 = 100 A

Z = 860 ; P = 10

∴ AT/pole for compensating winding = 0.7 × 860 × 100/2 × 10 = **3,010**

Tutorial Problem No. 27.1

1. Calculate the demagnetising amp-turns of a 4-pole, lap-wound generator with 720 turns, giving 50 A, if the brush lead is 10° (mechanical). **(250 AT/pole)**

2. A 250-V, 25-kW, 4-pole d.c. generator has 328 wave-connected armature conductors. When the machine is delivering full load, the brushes are given a lead of 7.2 electrical degrees. Calculate the cross-magnetising amp-turns/pole. **(1886, 164)**

3. An 8-pole lap-connected d.c. shunt generator delivers an output of 240 A at 500 V. The armature has 1408 conductors and 160 commutator segments. If the brushes are given a lead of 4 segments from the no-load neutral axis, estimate the demagnetising and cross-magnetising AT/pole.
(1056, 1584) (*Electrical Engineering, Bombay Univ. 1978*)

4. A 500-V, wave-wound, 750 r.p.m. shunt generator supplies a load of 195 A. The armature has 720 conductors and shunt field resistance is 100 Ω. Find the demagnetising amp-turns/pole if brushes are advanced through 3 commutator segments at this load. Also, calculate the extra shunt field turns required to neutralize this demagnetisation. **(600, 4800, 120)**

5. A 4-pole, wave-wound generator has 320 armature conductors and carries an armature current of 400 A. If the pole arc/pole pitch ratio is 0.68, calculate the AT/pole for a compensating winding to give uniform flux density in the air gap. **(5440)**

6. A 500-kW, 500-V, 10 pole d.c. generator has a lap-wound armature with 800 conductors. Calculate the number of pole-face conductors in each pole of a compensating winding if the pole face covers 75 percent of the pitch.

(6 conductors/pole)

7. Three shunt generators, each having an armature resistance of 0.1 ohm are connected across a common bus feeding a two ohms load. Their generated voltages are 127 V, 120 V, and 119 V. Neglecting field currents, calculate the bus voltage and modes of operations of the three machines. **(JNTU, Hyderabad, 200)**

Hint : Solve the circuit from the data given. Since the voltages differ considerably, first machine with 127 V as the generated voltage with supply the largest current.

(I_1 = 70 amp, Generating mode, I_2 = 0,
Floating (= neither generating nor motoring).
I_3 = –10 amp, motoring mode I_L = 60 amp.)

27.7. Commutation

It was shown in Art 26.2 that currents induced in armature conductors of a d.c. generator are alternating. To make their flow unidirectional in the external circuit, we need a commutator. Moreover, these currents flow in one direction when armature conductors are under *N*-pole and in the opposite direction when they are under *S*-pole. As conductors pass out of the influence of a *N*-pole and enter that of *S*-pole, the current in them is reversed. This reversal of current takes place along magnetic neutral axis or brush axis *i.e.* when the brush spans and hence short-circuits that particular coil undergoing reversal of current through it. This process by which current in the short-circuited coil is reversed while it crosses the *M.N.A.* is called commutation. The brief period during which coil remains short-circuited is known as commutation period T_c.

Commutation

If the current reversal *i.e.* the change from + *I* to zero and then to – *I* is completed by the end of short circuit or commutation period, then the commutation is ideal. If current reversal is not complete by that time, then sparking is produced between the brush and the commutator which results in progressive damage to both.

Let us discuss the process of commutation or current reversal in more detail with the help of Fig. 27.10 where ring winding has been used for simplicity. The brush width is equal to the width of one commutator segment and one mica insulation. In Fig. 27.10 (*a*) coil *B* is about to be short circuited because brush is about to come in touch with commutator segment '*a*'. It is assumed that each coil carries 20 A, so that brush current is 40 A. It is so because every coil meeting at the brush supplies half the brush current lap wound or wave wound. Prior to the beginning of short circuit, coil *B* belongs to the group of coils lying to the left of the brush and carries 20 A from left to right. In Fig. 27.10 (*b*) coil *B* has entered its period of short-circuit and is approximately at one-third of this period. The current through coil *B* has reduced down from 20 A to 10 A because the other 10 A flows *via* segment '*a*'. As area of contact of the brush is more with segment '*b*' than with segment '*a*', it receives 30 A from the former, the total again being 40 A.

Fig. 27.10 (*c*) shows the coil *B* in the middle of its short-circuit period. The current through it has decreased to zero. The two currents of value 20 A each, pass to the brush directly from coil *A* and *C* as shown. The brush contact areas with the two segments '*b*' and '*a*' are equal.

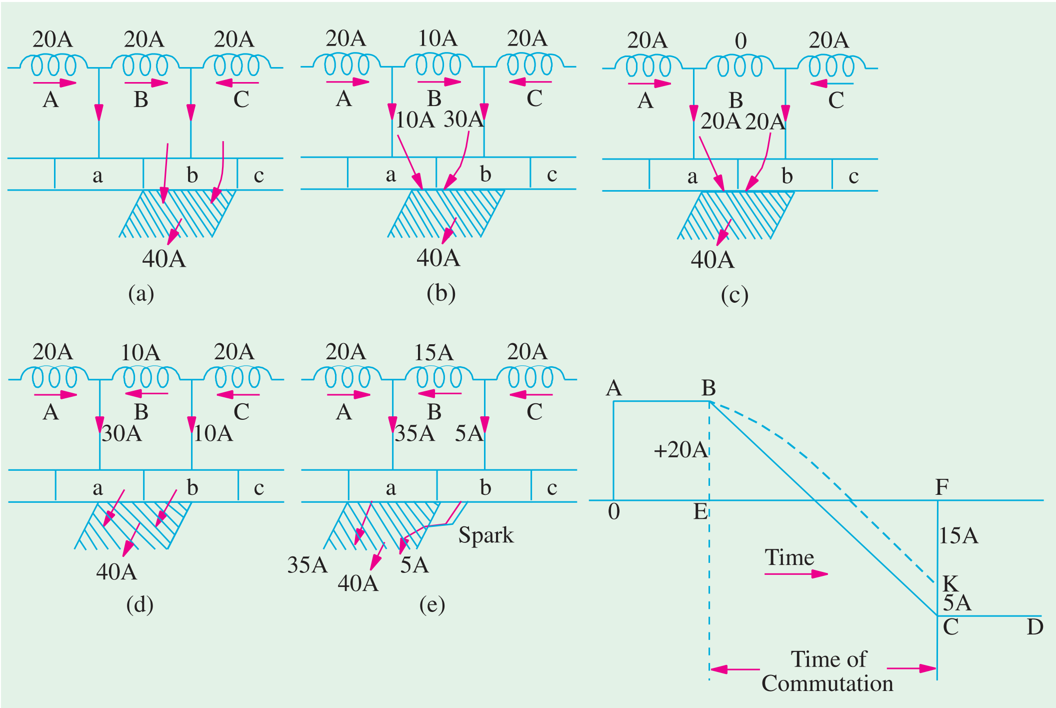


Fig. 27.10 **Fig. 27.11**

In Fig. 27.10 (*d*), coil *B* has become part of the group of coils lying to the right of the brush. It is seen that brush contact area with segment '*b*' is decreasing rapidly whereas that with segment '*a*' is increasing. Coil *B* now carries 10 A in the reverse direction which combines with 20 A supplied by coil *A* to make up 30 A that passes from segment '*a*' to the brush. The other 10 A is supplied by coil *C* and passes from segment '*b*' to the brush, again giving a total of 40 A at the brush.

Fig. 27.10 (*e*) depicts the moment when coil *B* is almost at the end of commutation or short-circuit period. For ideal commutation, current through it should have reversed by now but, as shown, it is carrying 15 A only (instead of 20 A). The difference of current between coils *C* and *B* *i.e.* 20.15 = 5 A in this case, jumps directly from segment *b* to the brush through air thus producing spark.

If the changes of current through coil *B* are plotted on a time base (as in Fig. 27.11) it will be represented by a horizontal line *AB* *i.e.* a constant current of 20 A up to the time of beginning of commutation. From the finish of commutation, the current will be represented by another horizontal line *CD*. Now, again the current value is *FC* = 20 A, although in the reversed direction. The way in which current changes from its positive value of 20 A (= *BE*) to zero and then to its negative value of 20 A (= *CF*) depends on the conditions under which the coil *B* undergoes commutation. If the current varies at a uniform rate *i.e.* if *BC* is a straight line, then it is referred to as linear commutation. However, due to the production of self-induced e.m.f. in the coil (discussed below) the variations follow the dotted curve. It is seen that, in that case, current in coil *B* has reached only a value of *KF* = 15 A in the reversed direction, hence the difference of 5 A (20 A – 15 A) passes as a spark.

So, we conclude that sparking at the brushes, which results in poor commutation is due to the inability of the current in the short-circuited coil to reverse completely by the end of short-circuit period (which is usually of the order of 1/500 second).

At this stage, the reader might ask for the reasons which make this current reversal impossibly in the specified period *i.e.* what factors stand in the way of our achieving ideal commutation. The main cause which retards or delays this quick reversal is the production of self-induced e.m.f. in the coil undergoing commutation. It may be pointed out that the coil possesses appreciable amount of self inductance because it lies embedded in the armature which is built up of a material of high magnetic permeability. This self-induced e.m.f. is known as ***reactance voltage*** whose value is found as given below. This voltage, even though of a small magnitude, produces a large current through the coil whose resistance is very low due to short circuit. It should be noted that if the brushes are set so that the coils undergoing short-circuit are in the magnetic neutral plane, where they are cutting no flux and hence have no e.m.f. induced in them due to armature rotation, there will still be the e.m.f. of self-induction which causes severe sparking at the brushes.

27.8. Value of Reactance Voltage

Reactance voltage = coefficient of self-inductance × rate of change of current.

It should be remembered that the time of short-circuit or commutation is the time required by the commutator to move a distance equal to the circumferential thickness of the brush minus the thickness of one insulating plate of strip of mica.

Let W_b = brush width in cm; W_m = width of mica insulation in cm

v = peripheral velocity of commutator segments in cm/second

Then T_c = time of commutation or short-circuit = $\dfrac{W_b - W_m}{v}$ second

Note. If brush width etc. are given in terms of commutator segments, then commutator velocity should also be converted in terms of commutator segments per second.

If I is the current through a conductor, then total change during commutation = $I - (-I) = 2I$.

∴ Self-induced or reactance voltage

$$= L \times \frac{2I}{T_c} \qquad \text{– if commutation is linear}$$

$$= 1.11\ L \times \frac{2I}{T_c} \qquad \text{– if commutation is sinusodial}$$

As said earlier, the reactance e.m.f. hinders the reversal of current. This means that there would be sparking at the brushes due to the failure of the current in short-circuited coil to reach its full value in the reversed direction by the end of short-circuit. This sparking will not only damage the brush and the commutator but this being a cumulative process, it may worsen and eventually lead to the short-circuit of the whole machine by the formation of an arc round the commutator from brush to brush.

Example 27.9. *The armature of a certain dynamo runs at 800 r.p.m. The commutator consists of 123 segments and the thickness of each brush is such that the brush spans three segments. Find the time during which the coil of an armature remains short-circuited.*

Solution. As W_m is not given, it is considered negligible.

W_b = 3 segments and $v = (800/60) \times 123$ segments/second

∴ commutation time = $\dfrac{3 \times 60}{800 \times 123}$ = 0.00183 second = **1.83 millisecond**

Example 27.10. *A 4-pole, wave-wound, d.c. machine running at 1500 r.p.m. has a commutator of 30 cm diameter. If armature current is 150 A, thickness of brush 1.25 cm and the self-inductance of each armature coil is 0.07 mH, calculate the average e.m.f. induced in each coil during commutation. Assume linear commutation.*

Solution. Formula : $E = L\,\dfrac{2I}{T_c}$

Here $L = 0.07 \times 10^{-3}$ H, $I = 150/2 = 75$ A (It is wave-wound)

$W_b = 1.25$ cm, $W_m = 0$ ...considered negligible

$v = \pi \times 30 \times (1500/60) = 2356$ cm/s ; $T_c = W_b/v = 1.25/2356 = 5.3 \times 10^{-4}$ second

$E = L \times 2I/T_c = 0.07 \times 10^{-3} \times 2 \times 75/5.3 \times 10^{-4}$ = **19.8 V**

Example 27.11. *Calculate the reactance voltage for a machine having the following particulars. Number of commutator segments = 55, Revolutions per minute = 900, Brush width in commutator segments = 1.74, Coefficient of self-induction = 153 × 10^{-6} henry, Current per coil = 27 A.*

(Advanced Elect. Machines. AMIE Sec. Winter 1991)

Solution. Current per coil, $I = 27$ A ; $L = 153 \times 10^{-6}$ H

$v = 55 \times (900/60) = 825$ segments/second; $T_c = W_b.v = 1.74/825 = 2.11 \times 10^{-3}$ second

Assuming linear commutation, $E = L \times 2I/T_C$

$\therefore \quad E = 153 \times 10^{-6} \times 2 \times 27/2.11 \times 10^{-3}$ = **3.91 V**

Example 27.12. *A 4-pole, lap-wound armature running at 1500 r.p.m. delivers a current of 150 A and has 64 commutator segments. The brush spans 1.2 segments and inductance of each armature coil is 0.05 mH. Calculate the value of reactance voltage assuming* ***(i)*** *linear commutation* ***(ii)*** *sinusoidal commutation. Neglect mica thickness.*

Solution. Formula : $E = L\,.\,\dfrac{2I}{T_c}$ Now, $L = 0.05 \times 10^{-3}$ H; $W_b = 1.2$ segments

$$v = \frac{1500}{60} \times 64 = 1600 \text{ segments/second}$$

$$\therefore \quad T_c = \frac{1.2}{1600} = 7.5 \times 10^{-4} \text{ second ; } I = \frac{150}{4} \text{ A} = 37.5 \text{ A}$$

$$\therefore \quad \frac{2\,I}{T_c} = \frac{2 \times 37.5}{7.5 \times 10^{-4}} = 10^5 \text{ A/s}$$

For linear commutation, $E = 0.05 \times 10^{-3} \times 10^5$ = **5 V**

For sinusoidal commutation, $E = 1.11 \times 5$ = **5.55 V**

27.9. Methods of Improving Commutation

There are two practical ways of improving commutation *i.e.* of making current reversal in the short-circuited coil as sparkless as possible. These methods are known as ***(i)*** resistance commutation and ***(ii)*** e.m.f. commutation (which is done with the help of either brush lead or interpoles, usually the later).

27.10. Resistance Commutation

This method of improving commutation consists of replacing low-resistance Cu brushes by comparatively high-resistance carbon brushes.

From Fig. 27.12, it is seen that when current *I* from coil' *C* reaches the commutator segment *b*, it has two parallel paths open to it. The first part is straight from bar '*b*' to the brush and the other parallel path is ***via*** the short-circuited coil *B* to bar '*a*' and then to the brush. If the Cu brushes (which have low contact resistance) are used, then there is no inducement for the current to follow the sec-

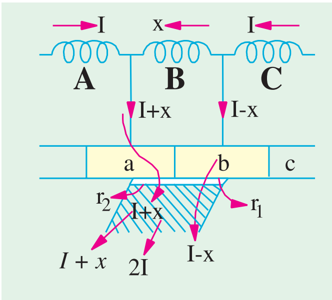


Fig. 27.12

ond longer path, it would preferably follow the first path. But when carbon brushes having high resistance are used, then current I coming from C will prefer to pass through the second path because **(*i*)** the resistance r_1 of the first path will increase due to the diminishing area of contact of bar '*b*' with the brush and because **(*ii*)** resistance r_2 of second path will decrease due to rapidly increasing contact area of bar '*a*' with the brush.

Hence, carbon brushes have, usually, replaced Cu brushes. However, it should be clearly understood that the main cause of sparking commutation is the self-induced e.m.f. (*i.e.* reactance voltage), so brushes alone do not give a sparkless commutation; though they do help in obtaining it.

The additional advantages of carbon brushes are that **(*i*)** they are to some degree self-lubricating and polish the commutator and **(*ii*)** should sparking occur, they would damage the commutator less than when Cu brushes are used.

But some of their minor disadvantages are : **(*i*)** Due to their high contact resistance (which is beneficial to sparkless commutation) a loss of approximately 2 volt is caused. Hence, they are not much suitable for small machines where this voltage forms an appreciable percentage loss. **(*ii*)** Owing to this large loss, the commutator has to be made some what larger than with Cu brushes in order to dissipate heat efficiently without greater rise of temperature. **(*iii*)** because of their lower current density (about 7-8 A/cm^2 as compared to 25-30 A/cm^2 for Cu brushes) they need larger brush holders.

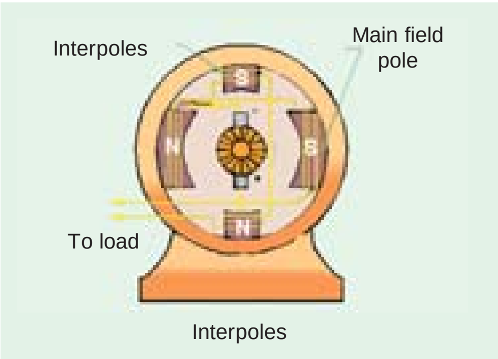
27.11. E.M.F. Commutation

In this method, arrangement is made to neutralize the reactance voltage by producing a reversing e.m.f. in the short-circuited coil under commutation. This reversing e.m.f., as the name shows, is an e.m.f. in opposition to the reactance voltage and if its value is made equal to the latter, it will completely wipe it off, thereby producing quick reversal of current in the short-circuited coil which will result in sparkless commutation. The reversing e.m.f. may be produced in two ways : **(*i*)** either by giving the brushes a forward lead sufficient enough to bring the short-circuited coil under the influence of next pole of opposite polarity or **(*ii*)** by using interpoles.

The first method was used in the early machines but has now been abandoned due to many other difficulties it brings along with.

27.12. Interpoles of Compoles

These are small poles fixed to the yoke and spaced in between the main poles. They are wound with comparatively few heavy gauge Cu wire turns and are connected in series with the armature so that they carry full armature current. Their polarity, in the case of a generator, is the same as that of the main pole ***ahead*** in the direction of rotation (Fig. 25.13).



The function of interpoles is two-fold :

(*i*) As their polarity is the same as that of the main pole ahead, they induce an e.m.f. in the coil (under commutation) which helps the reversal of current. The e.m.f. induced by the compoles is known as ***commutating* or *reversing e.m.f.*** The commutating e.m.f. neutralizes the reactance e.m.f. thereby making commutation sparkless. With interpoles, sparkless commutation can be obtained up to 20 to 30% overload with fixed brush position. In fact, interpoles raise sparking limit of a machine to *almost* the same value as heating limit. Hence, for a given output, an interpole machine can be made smaller and, therefore, cheaper than a non-interpolar machine.

As interpoles carry armature current, their commutating e.m.f. is proportional to the armature current. ***This ensures automatic neutralization of reactance voltage which is also due to armature current.*** Connections for a shunt generator with interpoles are shown in Fig. 27.14.

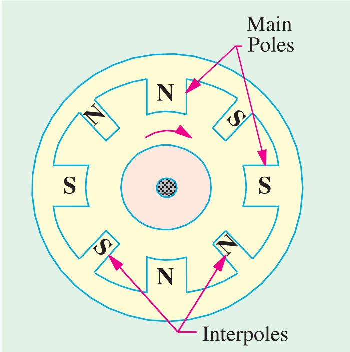


Fig. 27.13

(ii) Another function of the interpoles is to neutralize the cross-magnetising effect of armature reaction. Hence, brushes are not to be shifted from the original position. In Fig 27.15, *OF* as before, represents the m.m.f. due to main poles. *OA* represents the cross-magnetising m.m.f. due to armature. *BC* which represents m.m.f. due to interpoles, is obviously in opposition to *OA*, hence they cancel each other out. ***This cancellation of cross-magnetisation is automatic and for all loads because both are produced by the same armature current.***

The distinction between the interpoles and compensating windings should be clearly understood. Both are connected in series and thier m.m.fs. are such as to neutralize armature reaction. But compoles additionally supply m.m.f. for counteracting the reactance voltage induced in the coil undergoing commutation. Moreover, the action of the compoles is localized, they have negligible effect on the armature reaction occurring on the remainder of the armature periphery.

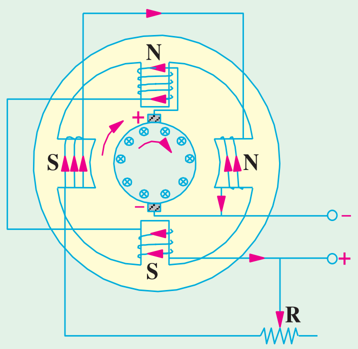


Fig. 27.14

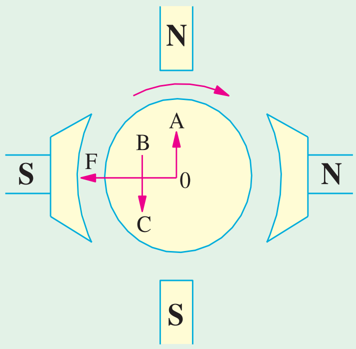


Fig. 27.15

Example 27.13. *Determine the number of turns on each commutating pole of a 6-pole machine, if the flux density in the air-gap of the commutating pole = 0.5 Wb/m² at full load and the effective length of the air-gap is 4 mm. The full-load current is 500 A and the armature is lap-wound with 540 conductors. Assume the ampere turns required for the remainder of the magnetic circuit to be one-tenth of that the air gap.* **(Advanced Elect. Machines AMIE Sec.B, 1991)**

Solution. It should be kept in mind that compole winding must be sufficient to oppose the armature m.m.f. (which is directed along compole axis) and to provide the m.m.f. for compole air-gap and its magnetic circuit.

$\therefore \quad N_{CP}\, I_a = ZI_C/2P + B_g\, l_g/\mu_0$

where N_{CP} = No. of turns on the compole ; I_a = Armature current

Z = No. of armature conductors ; I_c = Coil current

P = No. of poles ; l_g = Air-gap length under the compole

Z = 540 ; I_a = 500 A; I_c = 500/6 A; P = 6

$\therefore$ Arm. m.m.f. = $540 \times (500/6)/2 \times 6 = 3750$

Compole air-gap m.m.f. = $B_g \times l_g/\mu_0 = 0.5 \times 4 \times 10^{-3}/4\pi \times 10^{-7} = 1591$

m.m.f. reqd. for the rest of the magnetic circuit = 10% of 1591 = 159

$\therefore$ Total compole air-gap m.m.f. = 1591 + 159 = 1750

Total m.m.f. reqd. = 3750 + 1750 = 5500

$\therefore$ $N_{cp}\, I_a = 5500$ *or* $N_{cp} = 5500/500 =$ **11**

27.13. Equalizing Connections

It is characteristic of lap -winding that all conductors in any parallel path lie under one pair of poles. If fluxes from all poles are exactly the same, then e.m.f. induced in each parallel path is the same and each path carries the same current. But despite best efforts, some inequalities in flux inevitably occur due either to slight variations in air-gap length or in the magnetic properties of steel. Hence, there is always a slight imbalance of e.m.f. in the various parallel paths. The result is that conductors under stronger poles generate greater e.m.f. and hence carry larger current. The current distribution at the brushes becomes unequal. Some brushes are overloaded *i.e.* carry more than their normal current whereas others carry less. Overloaded brushes spark badly whatever their position may be. This results in poor commutation and may even limit the output of the machine.

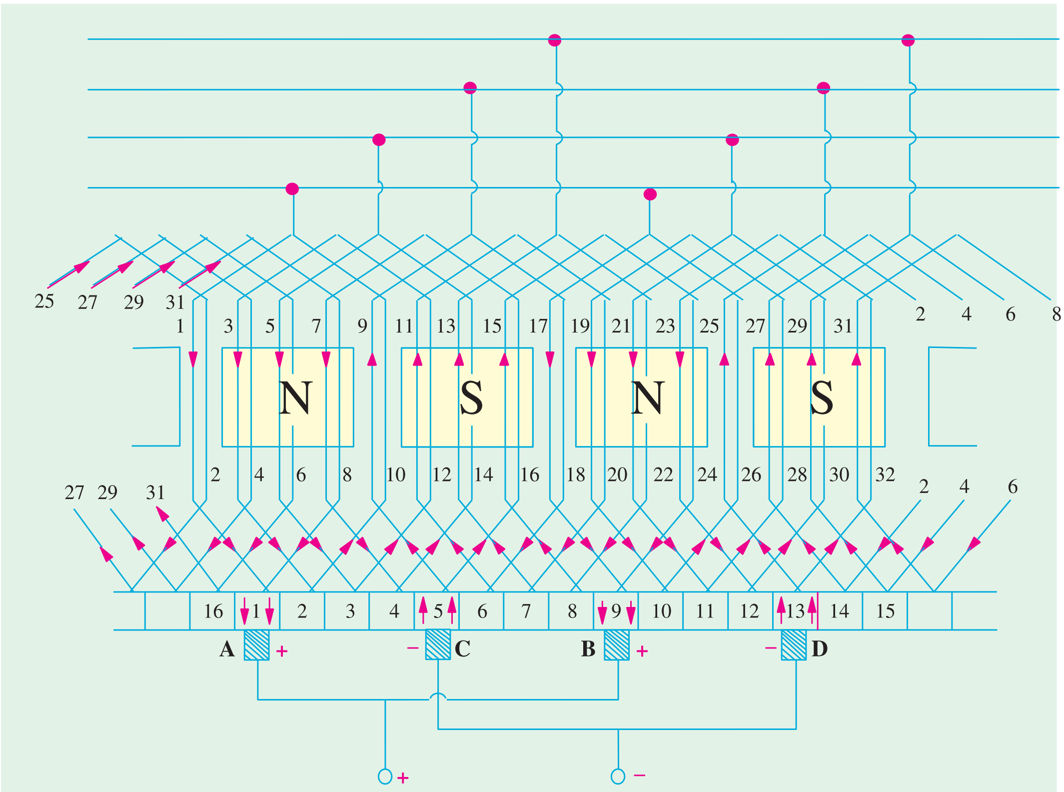


Fig. 27.16

By connecting together a number of symmetrical points on armature winding which would be at equal potential if the pole fluxes were equal, the difference in brush currents is diminished. This requires that there should be a whole number of slots per pair of poles so that, for example, if there is a slot under the centre of a *N*-pole, at some instant, then there would be one slot under the centre of every other *N*-pole. The equalizing conductors, which are in the form of Cu rings at the armature back and which connect such points are called *Equalizer Rings.* The circulating current due to the slight difference in the e.m.fs. of various parallel paths, passes through these *equalizer* rings instead of passing through the brushes.

Hence, the function of equalizer rings is to avoid unequal distribution of current at the brushes thereby helping to get sparkless commutation.

Equalizer rings

One equalizer ring is connected to all conductors in the armature which are two poles apart (Fig. 27.17). For example, if the number of poles is 6, then the number of connections for each equalizer ring is 3 *i.e.* equal to the number of pair of poles. Maximum number of equalizer rings is equal to the number of conductors under one pair of poles. Hence, number of rings is

$$= \frac{\text{No. of conductors}}{\text{No. of pair of poles}}$$

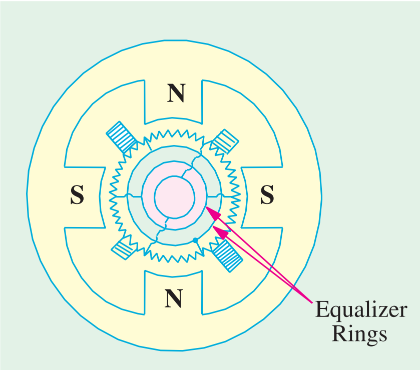


Fig. 27.17

In practice, however, the number of rings is limited to 20 on the largest machines and less on smaller machines. In Fig. 27.16 is shown a developed armature winding. Here, only 4 equalizing bars have been used. It will be seen that the number of equalizing connections to each bar is two *i.e.* half the number of poles. Each alternate coil has been connected to the bar. In this case, the winding is said to be 50% equalized. If all conductors were connected to the equalizer rings, then the winding would have been 100% equalized.

Equalizer rings are not used in wave-wound armatures, because there is no imbalance in the e.m.fs. of the two parallel paths. This is due to the fact that armature conductors in either parallel path are not confined under one pair of poles as in lap-winding but are distributed under all poles. Hence, even if there are inequalities in the pole flux, they will affect each path equally.

27.14. Parallel Operation of Shunt Generators

Power plants, whether in d.c. or a.c. stations, will be generally found to have several smaller generators running in parallel rather than large single units capable of supplying the maximum peak load. These smaller units can be run single or in various parallel combinations to suit the actual load demand. Such practice is considered extremely desirable for the following reasons :

(*i*) Continuity of Service

Continuity of service is one of the most important requirements of any electrical apparatus. This would be impossible if the power plant consisted only of a single unit, because in the event of breakdown of the prime mover or the generator itself, the entire station will be shut down. In recent years, the requirement of uninterrupted service has become so important especially in factories etc. that it is now recognized as an economic necessity.

(*ii*) Efficiency

Usually, the load on the electrical power plant fluctuates between its peak value sometimes during the day and its minimum value during the late night hours. Since generators operate most efficiently when delivering full load, it is economical to use a single small unit when the load is light. Then, as the load demand increases, a larger generator can be substituted for the smaller one or another smaller unit can be connected to run in parallel with the one already in operation.

(*iii*) Maintenance and Repair

It is considered a good practice to inspect generators carefully and periodically to forestall any possibility of failure or breakdown. This is possible only when the generator is at rest which means that there must be other generators to take care of the load. Moreover, when the generator does actually breakdown, it can be repaired with more care and not in a rush, provided there are other generators available to maintain service.

(*iv*) Additions to Plant

Additions to power plants are frequently made in order to deliver increasingly greater loads. Provision for future extension is, in fact, made by the design engineers fight from the beginning. It becomes easy to add other generators for parallel operation as the load demand increases.

27.15. Paralleling DC Generator

Whenever generators are in parallel, their +ve and –ve terminals are respectively connected to the +ve and –ve sides of the bus-bars. These bus-bars are heavy thick copper bars and they act as +ve and –ve terminals for the whole power station. If polarity of the incoming generator is not the same as the line polarity, as serious short-circuit will occur when S_1, is closed.

Moreover, paralleling a generator with reverse polarity effectively short-circuits it and results in damaged brushes, a damaged commutator and a blacked-out plant. Generators that have been tripped off the bus-because of a heavy fault current should always be checked for reversed polarity before paralleling.

In Fig. 27.18 is shown a shunt generator No. 1 connected across the bus-bars *BB* and supplying some of the load. For putting generator No. 2 in parallel with it the following procedure is adopted.

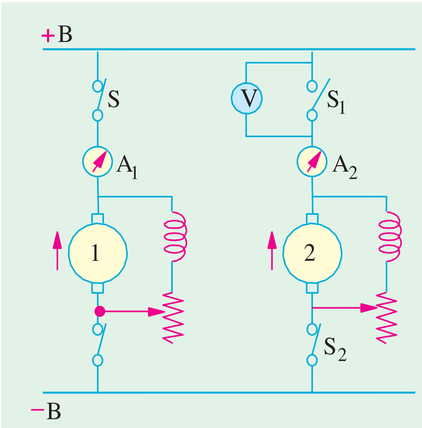


Fig. 27.18

The armature of generator No. 2 is speeded by the prime-mover up to its rated value and then switch S_2 is closed and circuit is completed by putting a voltmeter *V* across the open switch S_1. The excitation of the incoming generator No. 2 is changed till *V* reads zero. Then it means that its terminal voltage is the same as that of generator No. 1 or bus-bar voltage. After this, switch S_1 is closed and so the incoming machine is paralleled to the system. Under these conditions, however, generator No. 2 is not taking any load, because its ***induced*** e.m.f. is the same as bus-bar voltage and there can be no flow of current between two points at the same potential. The generator is said to be 'floating' on the bus-bar. If generator No. 2 is to deliver any current, then its induced e.m.f. *E* should be greater than the bus-bar voltage *V*. In that case, current supplied by it is $I = (E - V)/R_a$ where R_a is the resistance of the armature circuit. The induced e.m.f. of the incoming generator is increased by strengthening its field till it takes its proper share of load. At the same time, it may be found necessary to weaken the field of generator No. 1 to maintain the bus-bar voltage *V* constant.

27.16. Load Sharing

Because of their slightly drooping voltage characteristics, shunt generators are most suited for stable parallel operation. Their satisfactory operation is due to the fact that any tendency on the part of a generator to take more or less than its proper share of load results in certain changes of voltage in the system which immediately oppose this tendency thereby restoring the original division of load. Hence, once paralleled, they are automatically held in parallel.

Similarly, for taking a generator out of service, its field is weakened and that of the other generator is increased till the ammeter of the generator to be cleared reads zero. After that, its breaker and then the switch are opened thus removing the generator out of service. This method of connecting in and removing a generator from service helps in preventing any shock or sudden disturbance to the prime-mover or to the system itself.

It is obvious that if the field of one generator is weakened too much, then power will be delivered to it and it will run in its original direction as a motor, thus driving its prime-mover.

In Fig. 27.19. and 27.20 are shown the voltage characteristics of two shunt generators. It is seen that for a common terminal voltage V, the generator No. 1 delivers I_1 amperes and generator No. 2, I_2 amperes. It is seen that generator No. 1, having more drooping characteristic, delivers less current. It is found that two shunt generators will divide the load properly at all points if their characteristics are similar in form and each has the same voltage drop from no-load to full-load.

If it desired that two generators of different kW ratings automatically share a load in proportion to their ratings, then their external characteristics when plotted in terms of their percentage full-load currents (not actual currents) must be identical as shown in Fig. 27.21. If, for example, a 100-kW generator is working in parallel with a 200-kW generator to supply a total of 240-kW, then first generator will supply 80 kW and the other 160 kW.

When the individual characteristics of the generators are known, their combined characteristics can be drawn by adding the separate currents at a number of equal voltage (because generators are running in parallel). From this combined characteristic, the voltage for any combined load can be read off and from there, the current supplies by each generator can be found (Fig. 27.20).

If the generators have straight line characteristics, then the above result can be obtained by simple calculations instead of graphically.

Let us discuss the load sharing of two generators which have unequal no-load voltages.

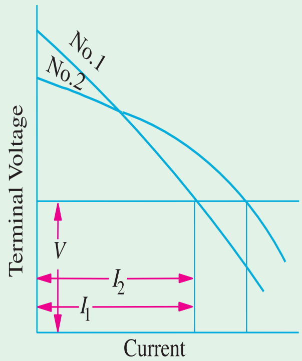


Fig. 27.19

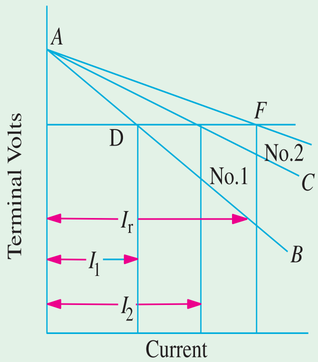


Fig. 27.20

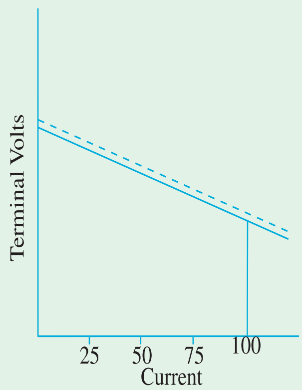


Fig. 27.21

Let E_1, E_2 = no-load voltages of the two generators

R_1, R_2 = their armature resistances

V = common terminal voltage

Then $I_1 = \dfrac{E_1 - V}{R_1}$ and $I_2 = \dfrac{E_2 - V}{R_2}$

$$\therefore \quad \frac{I_2}{I_1} = \frac{E_2 - V}{E_1 - V} \cdot \frac{R_1}{R_2} = \frac{K_2 N_2 \Phi_2 - V}{K_1 N_1 \Phi_1 - V} \cdot \frac{R_1}{R_2}$$

From the above equation, it is clear that bus-bar voltage can be kept constant (and load can be transferred from 1 to 2) by increasing Φ_2 or N_2 or by reducing N_1 and Φ_1.N_2 and N_1 are changed by changing the speed of driving engines and Φ_1 and Φ_2 are changed with the help of regulating shunt field resistances.

It should be kept in mind that

(*i*) Two parallel shunt generators having equal no-load voltages share the load in such a ratio that the load current of each machine produces the same drop in each generator.

(*ii*) In the case of two parallel generators having unequal no-load voltages, the load currents produce sufficient voltage drops in each so as to keep their terminal voltage the same.

(*iii*) The generator with the least drop assumes greater share of the change in bus load.

(*iv*) Paralleled generators with different power ratings but the same voltage regulation will divide any oncoming bus load in direct proportion to their respective power ratings (Ex. 27.14).

27.17. Procedure for Paralleling D.C. Generators

(*i*) Close the disconnect switch of the incoming generator

(*ii*) Start the prime-mover and adjust it to the rated speed of the machine

(*iii*) Adjust the voltage of the incoming machine a few volts higher than the bus voltage

(*iv*) Close the breaker of the incoming generator

(*v*) Turn the shunt field rheostat of the incoming machine in the raise-voltage direction and that of the other machine(s) already connected to the bus in the lower-voltage direction till the desired load distribution (as indicated by the ammeters) is achieved.

27.18. Compound Generators in Parallel

In Fig. 27.22 are shown two compound generators (designated as No. 1 and No. 2) running in parallel. Because of the rising characteristics of the usual compounded generators, it is obvious that in the absence of any corrective devices, the parallel operation of such generators is unstable. Let us suppose that, to begin with, each generator is taking its proper share of load. Let us now assume that for some reason, generator No. 1 takes a slightly increased load. In that case, the current passing through its series winding increases which further strengthens its field and so raises its generated e.m.f. thus causing it to take still more load. Since the system load is assumed to be constant, generator No. 2 will drop some of its load, thereby weakening its series field which will result in its further dropping off its load. Since this effect is cumulative. Generator No. 1 will, therefore, tend to take the entire load and finally drive generator No. 2 as a motor. The circuit breaker of at least one of the two generators will open, thus stopping their parallel operation.

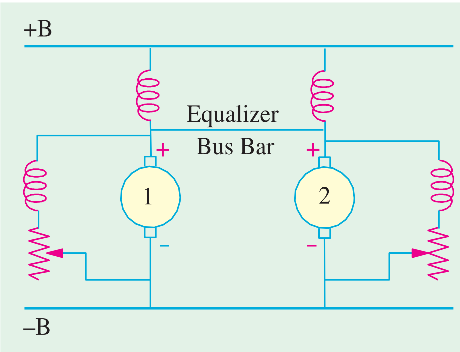


Fig. 27.22

For making the parallel operation of over-compound and level-compound generators stable,* they are always used with an equalizer bar (Fig. 27.22) connected to the armature ends of the series coils of the generators. The equalizer bar is a conductor of low resistance and its operation is as follows :

* Like shunt generators, the under-compound generators also do not need equalizers for satisfactory parallel operation.

Suppose that generator No. 1 starts taking more than its proper share of load. Its series field current is increased. But now this increased current passes partly through the series field coil of generator No. 1 and partly it flows via the equalizer bar through the series field winding of generator No. 2. Hence, the generators are affected in a similar manner with the result the generator No. 1 cannot take the entire load. For maintaining proper division of load from no-load to full-load, it is essential that

(*i*) the regulation of each generator is the same.

(*ii*) the series field resistances are inversely proportional to the generator rating.

27.19. Series Generators in Parallel

Fig 27.23 shows two identical series generators connected in parallel. Suppose E_1 and E_2 are initially equal, generators supply equal currents and have equal shunt resistances. Suppose E_1 increases slightly so that $E_1 > E_2$. In that case, I_1 becomes greater than I_2. Consequently, field of machine 1 is strengthened thus increasing E_1 further whilst the field of machine 2 is weakened thus decreasing E_2 further. A final stage is reached when machine 1 supplies not only the whole load but also supplies power to machine 2 which starts running as a motor. Obviously, the two machines will form a short-circuited loop and the current will rise indefinitely. This condition can be prevented by using equalizing bar because of which two similar machines pass approximately equal currents to the load, the slight difference between the two currents being confined to the loop made by the armatures and the equalizer bar.

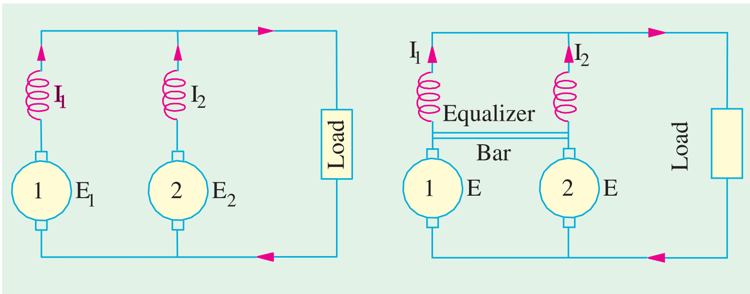


Fig. 27.23

Example 27.14. *A 100-kW, 250-V generator is paralleled with a 300 kW, 250-V generator. Both generators have the same voltage regulation. The first generator is supplying a current of 200 A and the other 500 A. What would be the current supplied by each generator if an additional load of 600 A is connected to the bus ?*

Solution. As explained in Art. 27.17, this additional load would be divided in direct proportion to the respective power ratings of the two generators.

$$\Delta I_1 = \left(\frac{100}{100+300}\right)\times 600 = 150 \text{ A} ;$$

$$\Delta I_2 = \left(\frac{300}{100+300}\right)\times 600 = 450 \text{ A}$$

Example 27.15. *Two 220–V, d.c. generators, each having linear external characteristics, operate in parallel. One machine has a terminal voltage of 270 V on no-load and 220 V at a load current of 35 A, while the other has a voltage of 280 V at no-load and 220 V at 50 A. Calculate the output current of each machine and the bus-bar voltage when the total load is 60 A. What is the kW output of each machine under this condition ?*

Solution. Generator No. 1.

Voltage drop for 35 A = 270–220 = 50 V

$\therefore$ Voltage drop/ampere = 50/35 = 10/7 V/A

Generator No. 2

Voltage drop/ampere $= (280-220)/50 = 1.2$ V/A

Let V = bus-bar voltage

I_1 = current output of generator No.1

I_2 = current output of generator No.2

then $V = 270-(10/7)\, I_1$ ...for generator No. 1

$= 280-1.2\, I_2$ ...for generator No. 2

Since bus-bar voltage is the same.

$\therefore \quad 270-10\, I_1/7 = 280-1.2\, I_2 \quad$ or $\quad 4.2\, I_2 - 5\, I_1 = 35$ ...(*i*)

Also $\quad I_1 + I_2 = 60$ ...(*ii*)

Solving the two equations, we get I_1 = **23.6 A**; I_2 = **36.4 A**

Now $\quad V = 280-1.2\, I_2 = 280-1.2 \times 36.4$

$=$ **236.3 V**

Output of Ist machine

$= 236.3 \times 23.6/1000$

$=$ **5.577 kW**

Output of 2nd machine

$= 236.3 \times 36.4/1000$

$=$ **8.602 kW**

Graphical Solution.

In Fig. 27.24, total load current of 60 A has been plotted along X-axis and the terminal voltage along Y-axis. The linear characteristics of the two generators are drawn from the given data. The common bus-bar voltage is given by the point of intersection of the two graphs. From the graph, it is seen that $V = 236.3$ V ; I_1 = 23.6 A ; I_2 = 36.4 A.

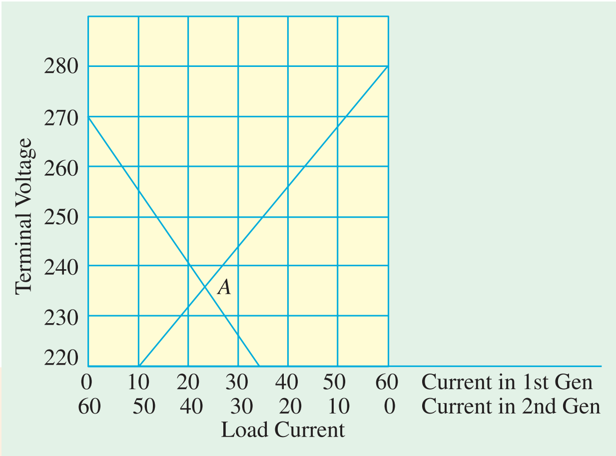


Fig. 27.24

Example 27.16. *Two shunt generators each with an armature resistance of 0.01 Ω and field resistance of 20 Ω run in parallel and supply a total load of 4000 A. The e.m.f.s are respectively 210 V and 220 V. Calculate the bus-bar voltage and output of each machine.* **(Electrical Machines-1, South Gujarat Univ. 1988)**

Solution. Generators are shown in Fig. 27.25.

Let V = bus-bar voltage

I_1 = output current of G_1

I_2 = output current of G_2

Now, $\quad I_1 + I_2 = 4000$ A, $I_{sh} = V/20$.

$I_{a1} = (I_1 + V/20)$; $I_{a2} = (I_2 + V/20)$

In each machine,

V + armature drop = induced e.m.f.

$\therefore \quad V + I_{a1} R_a = E_1$

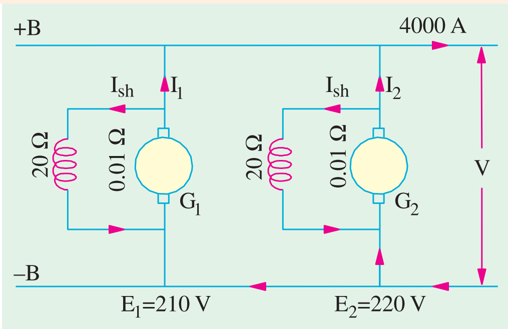


Fig. 27.25

or $V + (I_1 + V/20) \times 0.01$

$= 210$ ...1st machine

Also $V + I_{a2} R_a = E_2$

or $V + (I_2 + V/20) \times 0.01 = 220$ ...2nd machine

Subtracting, we have $0.01 (I_1 - I_2) = 10$ or $I_1 - I_2 = 1000$

Also, $I_1 + I_2 = 4000$ A $\therefore$ $I_1 =$ **2500 A ; I_2 = 1500 A**

Substituting the value of I_1 above, we get

$V + (2500 + V/20) \times 0.01 = 210$ $\therefore$ $V =$ **184.9 V**

Output of Ist generator $= 184.9 \times 2500/1000 =$ **462.25 kW**

Output of 2nd generator $= 184.49 \times 1500/1000 =$ **277.35 kW**

Example 27.17. *Two shunt generators operating in parallel deliver a total current of 250 A. One of the generators is rated 50 kW and the other 100 kW. The voltage rating of both machine is 500 V and have regulations of 6 per cent (smaller one) and 4 percent. Assuming linear characteristics, determine **(a)** the current delivered by each machine **(b)** terminal voltage.*

(Elect. Machines, Nagpur Univ. 1991)

Solution. 50 kW generator

F.L. voltage drop $= 500 \times 0.06 = 30$ V ; F.L. current $= 50{,}000/500 = 100$ A

Drop per ampere $= 30/100 = 3/10$ V/A

100 kW generator

F.L. drop $= 500 \times 0.04 = 20$ V ; F.L. current $= 100{,}000/5000 = 200$ A

Drop per ampere $= 20/200 = 1/10$ V/A

If I_1 and I_2 are currents supplied by the two generators and V the terminal voltage, then

$V = 500 - (3I_1/10)$ –1st generator

$= 500 - (I_2/10)$ –2nd generator

$\therefore$ $3I_1/10 = I_2/10$ or $3I_1 = I_2$; Also $I_1 + I_2 = 250$ –given

(a) Solving the above two equations, we get I_1 = **62.5 A ; I_2 = 187.5 A**

(b) $V = 500 - (3 \times 62.5/10) =$ **481.25 V**

Example 27.18. *Two shunt generators, each with a no-load voltage of 125 V are running parallel. Their external characteristics can be taken as straight lines over this operating ranges. Generator No. 1 is rated at 25 kW and its full-load voltage is 119 V, Generator No. 2 is rated at 200 kW at 116 V. Calculate the bus-bar voltage when the total load is 3500 A. How is the load divided between the two ?*

(Elect. Machinery - I, Mysore Univ. 1988)

Solution. Let V = bus-bar voltage

x_1, x_2 = load carried by each generator in terms of percentage of rated load

P_1, P_2 = load carried by each generator in watts

$V = 125 - [(125 - 119)(x_1/100)]$ ...Generator No. 1

$V = 125 - [(125 - 116)(x_2/100)]$ ...Generator No. 2

$$\therefore \quad 125 - \frac{6x_1}{100} = 125 - \frac{9x_2}{100} \qquad x_2 = \frac{6x_1}{9} = \frac{2x_1}{3}$$

Since in d.c. circuits, power delivered is given by VI watt, the load on both generators is

$$\left(250\, x_1 \times \frac{1000}{100}\right) + \left(200\, x_2 \times \frac{1000}{100}\right) = V \times 3500$$

Now, replacing V and x_2 by terms involving x_1, we get as a result

$$\left(250\, x_1 \times \frac{1000}{100}\right) + \left(200 \times \frac{2x_1}{3} \times \frac{1000}{100}\right) = \left(125 - \frac{6x_1}{100}\right) \times 3500$$

$$x_1 = 108.2 \text{ per cent}$$

$\therefore$ Bus-bar voltage $V = 125 - (6 \times 108.2/100) =$ **118.5 V**

The division of load between the two generators can be found thus :

$$x_1 = \frac{P_1 \times 1000}{250,000} \quad \text{and} \quad x_2 = \frac{P_2 \times 1000}{200,000}$$

$$\therefore \quad \frac{x_1}{x_2} = \frac{P_1 \times 200,000}{P_2 \times 250,000} = \frac{4P_1}{5P_2} = \frac{3}{2} \quad \therefore \quad \frac{3}{2} = \frac{4P_1}{5P_2} = \frac{4\,VI_1}{5\,VI_2} = \frac{4I_1}{5I_2} \quad \text{...}(i)$$

Since $I_1 + I_2 = 3500$ $\quad \therefore \; I_2 = 3500 - I_1$

Hence (i) above becomes, $\dfrac{3}{2} = \dfrac{4I_1}{5(3500 - I_1)}$

$\therefore$ $I_1 =$ **2,283** A and $I_2 =$ **1,217 A**

Example 27.19. *Two shunt generators A & B operate in parallel and their load-characteristics may be taken as straight lines. The voltage of generator A falls from 240 V at no load to 220 V at 200 A, while that of B falls from 245 V at no load to 220 V to 150 A. Determine the currents supplied by each machine to a common load of 300 A and the bus-bar voltage.*

(Bharathithasan Univ. April 1997)

Solution. Two graphs are plotted as shown in Fig. 27.26.

Their equations are :

$$240 - (20/200)\, I_A = 245 - (25/150)\, I_B$$

$$\text{Futher,} \quad I_A + I_B = 300$$

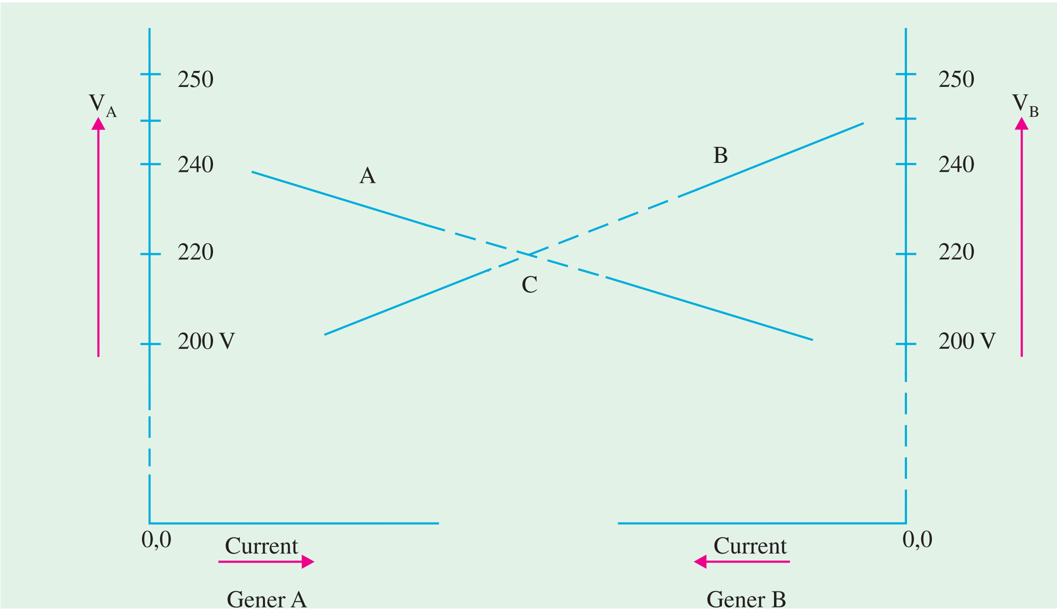


Fig. 27.26. Parallel operation of two D.C. Generators

This gives I_A = 168.75 A, I_B = 131.25 A

And common voltage of Bus-bar, V_{BUS}

= 240 – (20/200) × 168.75, or

V_{BUS} = 245 – (25/150) × 131.25 = 223.125 volts.

It is represented by the point *C*, in graph, as an intersection, satisfying the condition that two currents (I_A and I_B) add up to 300 amp.

Example 27.20. *In a certain sub-station, there are 5 d.c. shunt generators in parallel, each having an armature resistance of 0.1 Ω, running at the same speed and excited to give equal induced e.m.f.s. Each generator supplies an equal share of a total load of 250 kW at a terminal voltage of 500 V into a load of fixed resistance. If the field current of one generator is raised by 4%, the others remaining unchanged, calculate the power output of each machine and their terminal voltages under these conditions. Assume that the speeds remain constant and flux is proportional to field current.*
(Elect. Technology, Allahabad Univ. 1991)

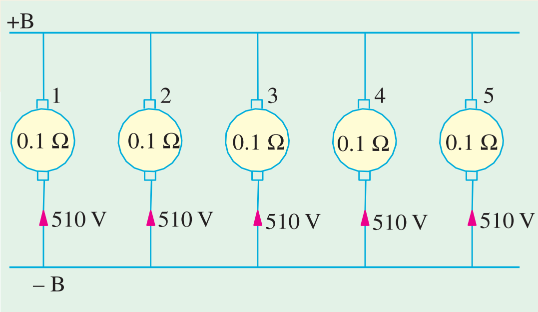


Fig. 27.27

Solution. Generator connections are shown in Fig. 27.27.

Load supplied by each =250/5 = 50kW

∴ Output of each = 50,000/500 = 100 A

Terminal voltage of each = 500 V

Armature drop of each = 0.1 × 100 = 10 V

Hence, induced e.m.f. of each = 510 V

When field current of one is increased, its flux and hence its generated e.m.f. is increased by 4%. Now, 4% of 510 V = 20.4 V

∴ Induced e.m.f. of one =510 + 20.4 = 530.4 V

Let I_1 = current supplied by one generator after increased excitation

I_2 = current supplied by each of the other 4 generators

V = new terminal or bus-bar voltage

∴ $530.4 - 0.1\, I_1 = V$ ...(*i*)

$510 - 0.1\, I_2 = V$ ...(*ii*)

Now, fixed resistance of load = 500/500 = 1 Ω ; Total load current = $I_1 + 4I_2$

∴ $1 \times (I_1 + 4I_2) = V$ or $I_1 + 4I_2 = V$ ...(*iii*)

Subtracting (*ii*) from (*i*), we get, $I_1 - I_2 = 204$ ...(*iv*)

Subtracting (*iii*) from (*ii*), we have $I_1 + 4.1\, I_2 = 510$ ...(*v*)

From (*iv*) and (*v*), we get I_2 = 3060/51 = 59/99 = 60 A (approx.)

From (*iv*) I_1 = 204 + 60 = 264 A

From (*iii*) V = 264 + 240 = **504 Volt**

Output of Ist machine = 504 × 264 watt = **133 kW**

Output of *each* of other four generators = 504 × 60 W = **30.24 kW**

Example 27.21. *Two d.c. generators are connected in parallel to supply a load of 1500 A. One generator has an armature resistance of 0.5 Ω and an e.m.f. of 400 V while the other has an armature resistance of 0.04 Ω and an e.m.f. of 440 V. The resistances of shunt fields are 100 Ω and 80 Ω respectively. Calculate the currents I_1 and I_2 supplied by individual generator and terminal voltage V of the combination.* **(Power Apparatus-I, Delhi Univ. Dec. 1987)**

Solution. Generator connection diagram is shown in Fig. 27.28.

Let V = bust–bar voltage

I_1 = output current of one generator

$$I_2 = \text{output current of other generator} = (1500 - I_1)$$

Now, $I_{sh1} = V/100 \text{ A} \; ; \; I_{sh2} = V/80 \text{ A}$

$$I_{a1} = \left(I_1 + \frac{V}{100}\right) \text{ and } I_{a2} = \left(I_2 + \frac{V}{80}\right)$$

or $$I_{a2} = \left(1500 - I_1 + \frac{V}{80}\right)$$

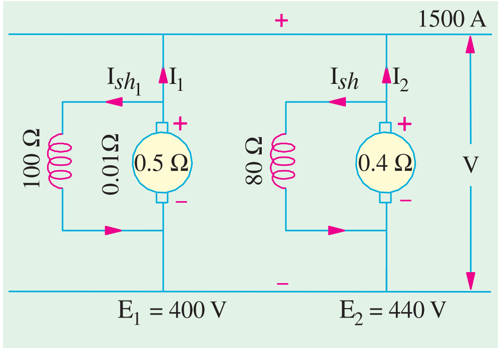


Fig. 27.28

For each machine

$$E - \text{armature drop} = V$$

$$\therefore \; 400 - \left(I_1 + \frac{V}{100}\right) \times 0.5 = V$$

or $$400 - 0.5\, I_1 - 0.005\, V = V \text{ or } 0.5\, I_1 = 400 - 1.0005 = V \qquad ...(i)$$

Also $440 - (1500 - I_1 + \frac{V}{80}) \times 0.04 = V$ or $0.04\, I_1 = 1.0005\, V - 380$ ...(*ii*)

Dividing Eq. (*i*) by (*ii*), we get

$$\frac{0.5\, I_1}{0.04\, I_2} = \frac{400 - 1.005\, V}{1.0005\, V - 380} \quad \therefore V = \mathbf{381.2\ V}$$

Substituting this value of V in Eq. (*i*), we get $0.5\, I_1 = 400 - 1.005 \times 381.2$

$$\therefore \quad I_1 = \mathbf{33.8\ A} \; ; \; I_2 = 1500 - 33.8 = \mathbf{1466.2\ A}$$

Output of Ist generator $= 381.2 \times 33.8 \times 10^{-3} = \mathbf{12.88\ kW}$

Output of 2nd generator $= 381.2 \times 1466.2 \times 10^{-3} = \mathbf{558.9\ kW}$

Example 27.22. *Two shunt generators and a battery are working in parallel. The open circuit voltage, armature and field resistances of generators are 250 V, 0.24 Ω, 100 Ω are 248 V, 0.12 Ω and 100 Ω respectively. If the generators supply the same current when the load on the bus-bars is 40 A, calculate the e.m.f. of the battery if its internal resistance is 0.172 Ω.*

Solution. Parallel combination is shown in Fig. 27.29.

Values of currents and induced e.m.fs. are shown in the diagram.

$$V + \left(I + \frac{V}{100}\right) \times 0.24 = 250 \qquad ...(i)$$

$$V + \left(I + \frac{V}{100}\right) \times 0.12 = 248 \qquad ...(ii)$$

Also $$I + I + I_b = 40$$

$$I_b + 2\,I = 40 \qquad ...(iii)$$

Subtracting (*ii*) from (*i*), we get $\left(I + \frac{V}{100}\right) \times 0.12 = 2$ ...(*iv*)

Putting this value in (*ii*) above, $V = 246$ volt.

Putting this value of V in (*iv*), $\left(I + \frac{246}{100}\right) \times 0.12 = 2$ ...(*v*)

$$\therefore \quad I = 50/3 - 2.46 = 14.2 \text{ A}$$

From (*iii*), we have $I_b = 40 - (2 \times 14.2) = 11.6$ A

Internal voltage drop in battery $= 11.6 \times 0.172 = 2$ V $\therefore E_b = 246 + 2 = \mathbf{248\ V}$

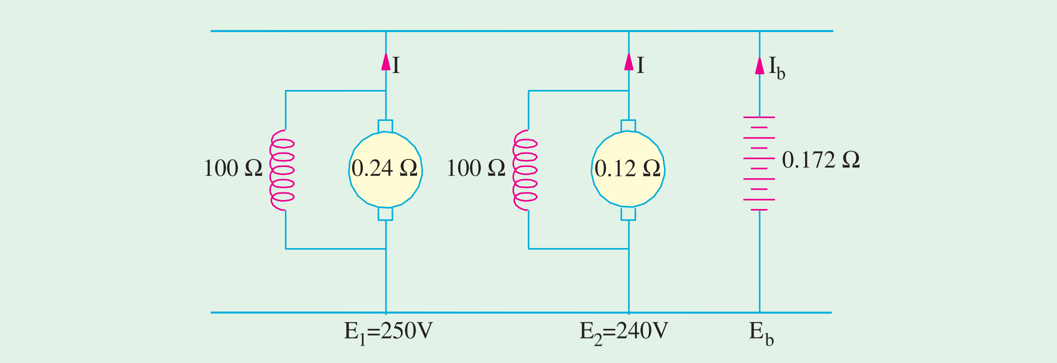


Fig. 27.29

Example 27.23. *Two d.c. generators A and B are connected to a common load. A had a constant e.m.f. of 400 V and internal resistance of 0.25 Ω while B has a constant e.m.f. of 410 V and an internal resistance of 0.4 Ω. Calculate the current and power output from each generator if the load voltage is 390 V. What would be the current and power from each and the terminal voltage if the load was open-circuited ?* **(Elect. Engg; I, Bangalore Univ. 1987)**

Solution. The generator connections are shown in Fig. 27.30 (*a*).

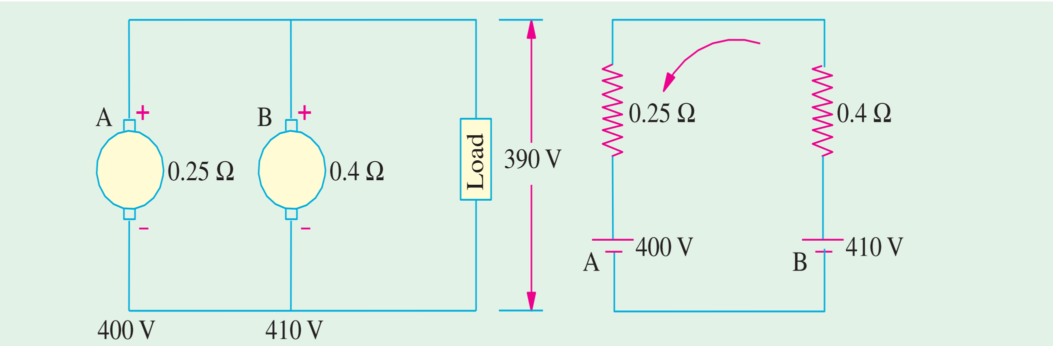


Fig. 27.30

Since the terminal or output voltage is 390 V, hence

Load supplied by $A = (400 - 390)/0.25 =$ **40 A**

Load supplied by $B = (410 - 390)/0.4 =$ **50A**

$\therefore$ Power output from $A = 40 \times 390 =$ **15.6 kW**

Power output from $B = 50 \times 390 =$ **19.5 kW**

If the load is open-circuited as shown in Fig. 27.30.(*b*), then the two generators are put in series with each other and a circulatory current is set up between them.

Net voltage in the circuit $= 410 - 400 = 10$ V

Total resistance $= 0.4 + 0.25 = 0.65\ \Omega$

$\therefore$ circulatory current $= 10/0.65 = 15.4$ A

The terminal voltage $= 400 + (15.4 \times 0.25) =$ **403.8 V**

Obviously, machine *B* with a higher e.m.f. acts as a generator and drives machine *A* as a motor.

Power taken by *A* from *B* $= 403.8 \times 15.4 =$ **6,219 W**

Part of this appears as mechanical output and the rest is dissipated as armature Cu loss.

$$\text{Mechanical output} = 400 \times 15.4 = \mathbf{6.16\ kW}\ ;\ \text{Armature Cu loss} = 3.8 \times 15.4 = \mathbf{59\ W}$$

$$\text{Power supplied by } B \text{ to } A = \mathbf{6{,}219}\ \text{W}\ ;\ \text{Armature Cu loss} = 6.16 \times 15.4 = \mathbf{95\ W}$$

Example 27.24. *Two compound generators A and B, fitted with an equalizing bar, supply a total load current of 500 A. The data regarding the machines are :*

	A	*B*
Armature resistance (ohm)	*0.01*	*0.02*
Series field winding (ohm)	*0.004*	*0.006*
Generated e.m.fs. (volt)	*240*	*244*

Calculate **(a)** *current in each armature* **(b)** *current in each series winding* **(c)** *the current flowing in the equalizer bar and* **(d)** *the bus-bar voltage. Shunt currents may be neglected.*

Solution. The two generators (with their shunt windings omitted) are shown in Fig. 27.31.

Let V = bus-bar voltage ; v = voltage between equalizer bus-bar and the negative

i_1, i_2 = armature currents of the two generators

Now, $i_1 + i_2 = 500$

or $$\frac{240 - v}{0.01} + \frac{244 - v}{0.01} = 500$$

Multiplying both sides by $\frac{1}{100}$ we get

$$240 - v + 122 - (v/2) = 5$$

$\therefore \quad v = 238$ volts

(a) $\therefore$ $$i_1 = \frac{240 - 238}{0.01} = \mathbf{200\ A}$$

$$i_2 = \frac{244 - 238}{0.02} = \mathbf{300\ A}$$

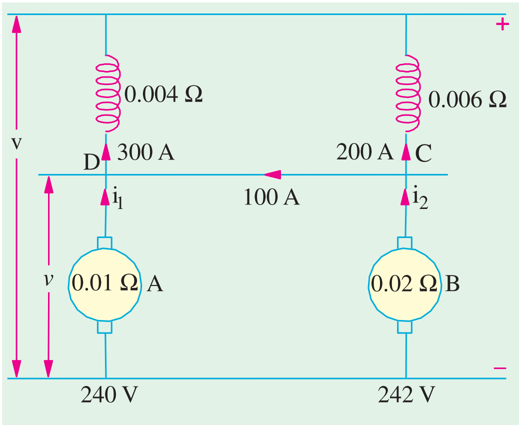


Fig. 27.31

(b) The total current of 500 A divides between the series windings in the inverse ratio of their resistance *i.e.* in the ratio of $\frac{1}{0.004} : \frac{1}{0.006}$ or in the ratio 3 : 2.

Hence, current in the series winding of generator $A = 500 \times 3/5 = \mathbf{300\ A}$

Similarly, current in the series winding of generator $B = 500 \times 2/5 = \mathbf{200\ A}$

(c) It is obvious that a current of 100 A flows in the equalizing bar from *C* to *D*. It is so because the armature current of generator *A* is 200 A only. It means that 100 A comes from the armature of generator, *B*, thus making 300 *A* for the series field winding of generator *A*.

(d) $V = v$ – voltage drop in one series winding $= 238 - (300 \times 0.004) = \mathbf{236.8\ V}$

Tutorial Problem No. 27.2

1. Two separately-excited d.c. generators are connected in parallel supply a load of 200 A. The machines have armature circuit resistances of 0.05 Ω and 0.1 Ω and induced e.m.fs. 425 V and 440 V respectively. Determine the terminal voltage, current and power output of each machine. The effect of armature reaction is to be neglected. **(423.3 V ; 33.3 A ; 14.1 kW ; 166.7 A ; 70.6 kW)**

2. Two shunt generators operating in parallel given a total output of 600 A. One machine has an armature resistance of 0.02 Ω and a generated voltage of 455 V and the other an armature resistance of 0.025 Ω and a generated voltage of 460 V. Calculate the terminal voltage and the kilowatt output of each machine. Neglect field currents.

(450.56 V ; 100 kW ; 170.2 kW)

3. The external characteristics of two d.c. shunt generators *A* and *B* are straight lines over the working range between no-load and full-load.

	Generator A		*Generator B*	
	No-load	*Full-load*	*No-load*	*Full-load*
Terminal P.D. (V)	400	360	420	370
Load current (A)	0	80	0	70

Determine the common terminal voltage and output current of each generator when sharing a total load of 100 A.

(57.7 A ; 42.3 A ; 378.8 V)

4. Two shunt generators operating in parallel have each an armature resistance of 0.02 Ω. The combined external load current is 2500 A. If the generated e.m.fs. of the machines are 560 V and 550 V respectively, calculate the bus-bar voltage and output in kW of each machine. **(530 V; 795 kW; 530 kW)**

5. Two shunt generators *A* and *B* operate in parallel and their load characteristics may be taken as straight lines. The voltage of *A* falls from 240 *V* at no-load to 220 V at 200 A, while that of *B* falls from 245 V at no-load to 220 V at 150 A. Determine the current which each machine supplies to a common load of 300 A and the bus-bar voltage at this load.

(169 A ; 131 A ; 223.1 V)

6. Two shunt-wound d.c. generators are connected in parallel to supply a load of 5,000 A. Each machine has an armature resistane of 0.03 Ω and a field resistance of 60 Ω, but the e.m.f. of one machine is 600 V and that of the other is 640 V. What power does each machine supply ?

(1,004 kW ; 1,730 kW including the fields)

7. Two shunt generators running in parallel share a load of 100 kW equally at a terminal voltage of 230 V. On no-load, their voltages rise to 240 V and 245 V respectively. Assuming that their volt-ampere characteristics are rectilinear, find how would they share the load when the total current is reduced to half its original value ? Also, find the new terminal voltage. **(20 kW ; 30 kW, 236 V)**

8. Two generators, each having no-load voltage of 500 V, are connected in parallel to a constant resistance load consuming 400 kW. The terminal p.d. of one machine falls linearly to 470 V as the load is increased to 850 A while that of the other falls linearly to 460 V when the load is 600 A. Find the load current and voltage of each generator.

If the induced e.m.f. of one machine is increased to share load equally, find the new current and voltage. **(I_1 = 626 A ; I_2 = 313 A ; V = 479 V ; I = 469.5 A ; V = 484.4 V)**

9. Estimate the number of turns needed on each interpole of a 6-pole generator delivering 200 kW at 200 V ; given : number of lap-connected armature conductors = 540 ; interpole air gap = 1.0 cm ; flux-density in interpole air-gap = 0.3 Wb/m^2. Ignore the effect of iron parts of the circuit and of leakage.

[10] (*Electrical Machines, B.H.U. 1980*)

OBJECTIVE TEST – 27

1. In d.c. generators, armature reaction is produced actually by
(*a*) its field current
(*b*) armature conductors
(*c*) field pole winding
(*d*) load current in armature

2. In a d.c. generator, the effect of armature reaction on the main pole flux is to
(*a*) reduce it (*b*) distort it
(*c*) reverse it (*d*) both (*a*) and (*b*)

3. In a clockwise-rotating loaded d.c. generator, brushes have to be shifted
(*a*) clockwise
(*b*) counterclockwise
(*c*) either (*a*) or (*b*)
(*d*) neither (*a*) nor (*b*).

4. The primary reason for providing compensating windings in a d.c. generator is to
(*a*) compensate for decrease in main flux
(*b*) neutralize armature mmf
(*c*) neutralize cross-magnetising flux
(*d*) maintain uniform flux distribution.

5. The main function of interpoles is to minimize .... between the brushes and the commutator when the d.c. machine is loaded.
(*a*) friction (*b*) sparking
(*c*) current (*d*) wear and tear

6. In a 6-pole d.c. machine, 90 mechanical degrees correspond to .... electrical degrees.
(*a*) 30 (*b*) 180
(*c*) 45 (*d*) 270

7. The most likely cause(s) of sparking at the brushes in a d.c. machine is /are
(*a*) open coil in the armature
(*b*) defective interpoles
(*c*) incorrect brush spring pressure
(*d*) all of the above

8. In a 10-pole, lap-wound d.c. generator, the number of active armature conductors per pole is 50. The number of compensating conductors per pole required is
(*a*) 5 (*b*) 50
(*c*) 500 (*d*) 10

9. The commutation process in a d.c. generator basically involves
(*a*) passage of current from moving armature to a stationary load
(*b*) reversal of current in an armature coil as it crosses MNA
(*c*) conversion of a.c. to d.c.
(*d*) suppression of reactance voltage

10. Point out the WRONG statement. In d.c. generators, commutation can be improved by
(*a*) using interpoles
(*b*) using carbon brushes in place of Cu brushes
(*c*) shifting brush axis in the direction of armature rotation
(*d*) none of the above

11. Each of the following statements regarding interpoles is true **except**
(*a*) they are small yoke-fixed poles spaced in between the main poles
(*b*) they are connected in parallel with the armature so that they carry part of the armature current
(*c*) their polarity, in the case of generators is the same as that of the main pole ahead
(*d*) they automatically neutralize not only reactance voltage but cross-magnetisation as well

12. Shunt generators are most suited for stable parallel operation because of their voltage characteristics.
(*a*) identical (*b*) dropping
(*c*) linear (*d*) rising

13. Two parallel shunt generators will divide the total load equally in proportion to their kilowatt output ratings only when they have the same
(*a*) rated voltage
(*b*) voltage regulation
(*c*) internal I_aR_a drops
(*d*) boths (*a*) and (*b*)

14. The main function of an equalizer bar is to make the parallel operation of two over-compounded d.c. generators
(*a*) stable (*b*) possible
(*c*) regular (*d*) smooth

15. The *essential* condition for stable parallel operation *A* Two d.c. generators having similar characteristics is that they should have
(*a*) same kilowatt ouput ratings
(*b*) droping voltage characterisitcs
(*c*) same percentage regulation
(*d*) same no-load and full-load speed

16. The main factor which loads to unstable parallel operation of flat-and over-compound d.c. generators is
(*a*) unequal number of turns in their series field windings
(*b*) unequal series field resistances
(*c*) their rising voltage characteristics
(*d*) unequal speed regulation of their prime movers

17. The simplest way to shift load from one d.c. shunt generator running in parallel with another is to
(*a*) adjust their field rheostats
(*b*) insert resistance in their armature circuits
(*c*) adjust speeds of their prime movers
(*d*) use equalizer connections

18. Which one of the following types of generators does NOT need equalizers for satisfactory parallel operation ?
(*a*) series (*b*) over-compound
(*c*) flat-compound (*d*) under-compound.

ANSWERS

1. (*d*) **2.** (*d*) **3.** (*a*) **4.** (*c*) **5.** (*b*) **6.** (*d*) **7.** (*d*) **8.** (*a*) **9.** (*b*) **10.** (*d*) **11.** (*b*) **12.** (*b*) **13.** (*d*) **14.** (*a*) **15.** (*b*) **16.** (*c*) **17.** (*a*) **18.** (*d*)

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