DIVISION 7
GENERATORS AND MOTORS

PRINCIPLES, CHARACTERISTICS, AND MANAGEMENT OF DC GENERATORS (DYNAMOS)

1. Direct-current generators impress on the line a direct or continuous emf, one that is always in the same direction. Commercial dc generators have commutators, which distinguish them from ac generators. The function of a commutator and the elementary ideas of generation of emf and commutation are discussed in Div. 1. Additional information about commutation as applied to dc motors, which in general is true for dc generators, is given below.

2. Excitation of generator fields. To generate an emf, conductors must cut a magnetic field which in commercial machines must be relatively strong. A permanent magnet can be used for producing such a field in a generator of small output, such as a telephone magneto or the magneto of an insulation tester, but in generators for light and power the field is produced by electromagnets, which may be excited by the machine itself or be separately excited from another source.

Self-excited machines may be of the series, shunt, or compound type, depending upon the manner of connecting the field winding to the armature. In the series type of machine, the field winding (the winding which produces the magnetic field) is connected in series with the armature winding. In the shunt type, the field winding is connected in parallel, shunt, with the armature winding. Compound machines have two field windings on each pole. One of these windings is connected in series with the armature winding, and the other is connected in parallel or shunt with the armature winding.

3. Armature winding of dc machines may be of the *lap* or the *wave* type. The difference in the two types is in the manner of connecting the armature coils to the commutator. A coil is the portion of the armature winding between successive connections to the commutator. In the lap type of winding (see Fig. 7.1) the two ends of a coil are connected to adjacent commutator segments. In the wave type of winding (see Fig. 7.2) the two ends of a coil are connected to commutator segments that are displaced from each other by approximately 360 electrical degrees.

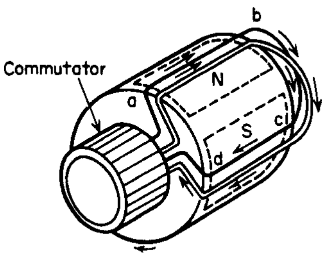

FIGURE 7.1 Two coils of a four-pole lap-wound armature.

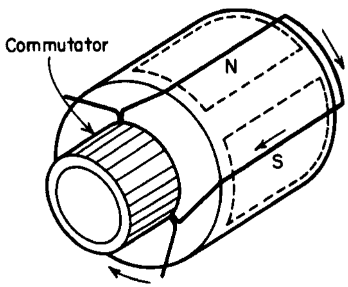

FIGURE 7.2 Coil on a four-pole wave-wound armature.

The type of armature winding employed affects the voltage and current capacity of the machine but has no effect upon the power capacity. This is due to the fact that the number of parallel paths between armature terminals is affected by the type of winding. For a wave-wound machine there are always two paths in parallel in the armature winding between armature terminals. For a lap-wound machine there are as many parallel paths in the armature winding as there are pairs of poles on the machine. For the same number and size of armature conductors, a machine when wave-connected would generate a voltage that would equal the voltage generated when lap-connected times the number of pairs of poles. But the current capacity would be decreased in the same proportion that the voltage was increased. The current capacity of a machine when wave-connected is therefore equal to the capacity when lap-connected divided by the number of pairs of poles.

4. The value of the voltage generated by a dc machine depends upon the armature winding, the speed, and the field current. For a given machine, therefore, the voltage generated can be controlled by adjusting either the speed or the field current. Since generators are usually operated at a constant speed, the voltage must be controlled by adjusting the field current.

5. Separately excited dc generators are used for electroplating and for other electrolytic work for which the polarity of a machine must not be reversed. Self-excited machines may change their polarities. The essential diagrams are shown in Fig. 7.3. The fields can be excited from any dc constant-potential source, such as a storage battery, or from a rectifier connected to an ac supply.

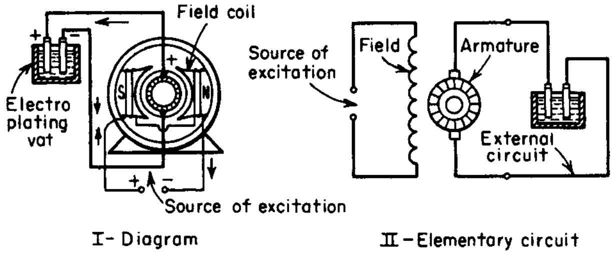

FIGURE 7.3 Separately excited generator.

The field magnets can be wound for any voltage because they have no electric connection with the armature. With a constant field excitation, the voltage will drop slightly from no load to full load because of armature drop and armature reaction.

Separate excitation is advantageous when the voltage generated by the machine is not suitable for field excitation. This is true for especially low- or high-voltage machines.

6. Series-wound generators have their armature winding, field coils, and external circuit connected in series with each other so that the same current flows through all parts of the circuit (see Fig. 7.4). If a series generator is operated at no load (external circuit open), there will be no current through the field coils, and the only magnetic flux present in the machine will be that due to the residual magnetism which has been retained by the poles from previous operation. Therefore, the no-load voltage of a series generator will be only a few volts produced by cutting the residual flux. If the external circuit is closed and the current increased, the voltage will increase with the increase in current until the magnetic circuit becomes saturated. With any further increases of load the voltage will decrease.

Series generators have been used sometimes in street-railway service. They have been connected in series with long trolley feeders supplying sections of the system distant from the supply point in order to boost the voltage. However, power rectifiers have replaced dc generators for most installations of this type.

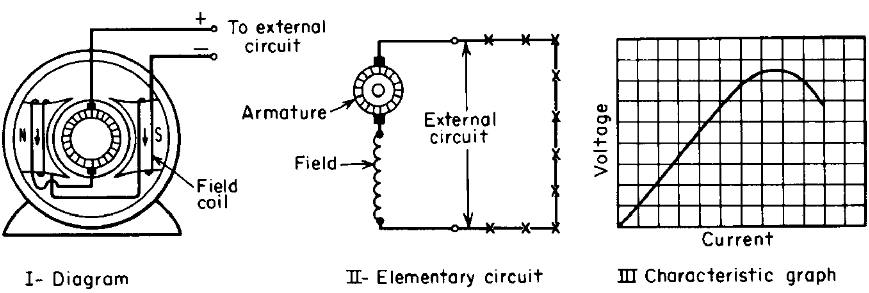

FIGURE 7.4 Series generator.

7. The shunt-wound generator is shown diagrammatically in Fig. 7.5, I and II. A small part of the total current, the exciting current, is shunted through the fields. The exciting current varies from possibly 5 percent of the total current in small machines to 1 percent in large ones. The exciting current is determined by the voltage at the brushes and the

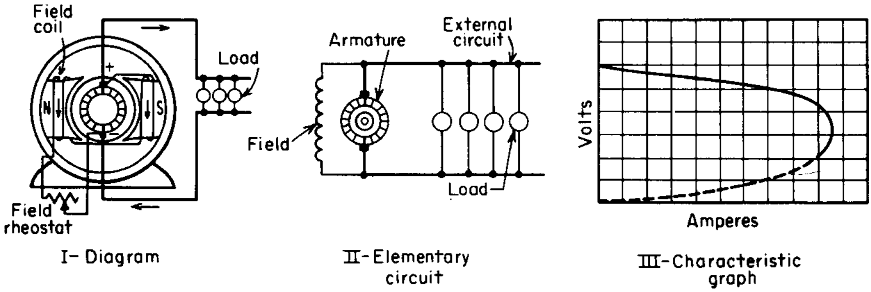

FIGURE 7.5 Shunt generator.

resistance of the field winding. Residual magnetism in the field cores permits a shunt generator to "build-up." This small amount of magnetism that is retained in the field cores induces a voltage in the armature (William H. Timbie, *Elements of Electricity*). This voltage sends a slight current through the field coils, which increases the magnetization. Thus, the induced voltage in the armature is increased. This in turn increases the current in the fields, which still further increases the magnetization, and so on, until the normal voltage of the machine is reached and conditions are stable. This "building-up" action is the same for any self-excited generator and often requires 20 to 30 s.

If a shunt generator (Timbie) runs at a constant speed, as more and more current is drawn from the generator, the voltage across the brushes fails slightly. This fall is due to the act that more and more of the generated voltage is required to force the increasing current through the windings of the armature; i.e., the armature *IR* drop increases. This leaves a smaller part of the total emf for brush emf, and when the brush voltage falls, there is a slight decrease in the field current, which is determined by the brush voltage. This and armature reactions cause the total emf to drop a little, which still further lowers the brush potential. These causes combine to lower the voltage gradually, especially at heavy overloads. The curve in Fig. 7.5, III, shows these characteristics. For small loads the curves is nearly horizontal, but at heavy overloads it shows a decided drop. The point at which the voltage of a commercial machine drops off rapidly is beyond the operating range and is of importance only for short-circuit conditions.

The voltage of a shunt machine can be kept fairly constant by providing extra resistance in the field circuit (see Fig. 7.6), which may be cut out as the brush potential falls. This will allow more current to flow through the field coils and increase the number of magnetic lines set up in the magnetic circuit. If the speed is kept constant, the armature conductors cut through the stronger magnetic field at the same speed and thus induce a greater emf and

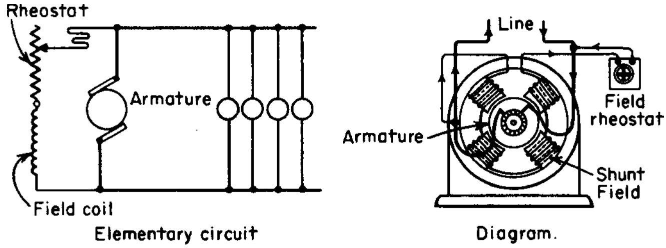

FIGURE 7.6 Shunt-wound generator with a rheostat.

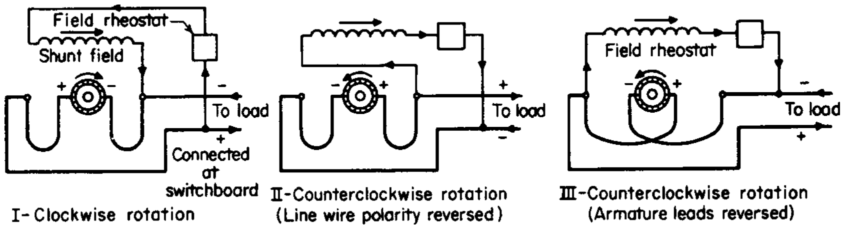

FIGURE 7.7 Changing the rotation direction of a shunt machine.

restore the brush potential to its former value. This resistance can be cut out either automatically or by hand (see Sec. 42 of Div. 1).

Shunt-wound generators give a fairly constant voltage, even with varying loads, and can be used for any system which incorporates constant-potential loads. This will operate well in parallel because the voltage of the machines decreases as the load increases. Shunt generators running in parallel will divide the load well between themselves if the machines have similar characteristics.

The necessary change in connections when reversing the direction of rotation of a shunt-wound machine is indicated in Fig. 7.7. Rotation is *clockwise* when, facing the commutator end of a machine, the rotation is in the direction of the hands of a clock. *Counterclockwise* rotation is the reverse. When changing the direction of rotation, do not reverse the direction of current through the field windings. If the direction is reversed, the magnetism developed by the windings on starting will oppose the residual magnetism and the machine will not "build up."

8. Parallel operation of shunt generators. As suggested in Sec. 7, shunt-wound generators will in general operate very well in parallel and will divide the load well if the machines have similar characteristics. If the machines do not have similar characteristics, one machine will take more than its share of the load and may tend to drive the other as a motor. When this machine is running as a motor, its direction of rotation will be the same as when it was generating; hence the operator must watch the ammeters closely for an indication of this trouble. Shunt generators are now seldom installed. Figure 7.8 shows the connections for shunt generators that are to be operated in parallel.

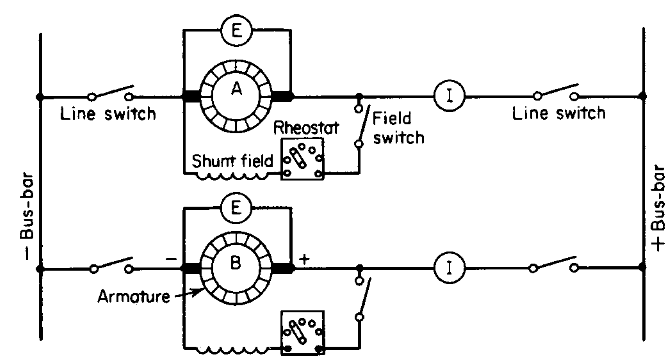

FIGURE 7.8 Connections for shunt generators for parallel operation.

9. The compound-wound generator is shown diagrammatically in Fig. 7.9, I. If a series winding is added in a proper manner to a shunt generator (Fig. 7.5), the two windings will tend to maintain a constant voltage as the load increases. The magnetization due to the series windings increases as the line current increases, thus tending to increase the generated voltage. The drop of voltage at the brushes that occurs in a shunt generator can thus be compensated for.

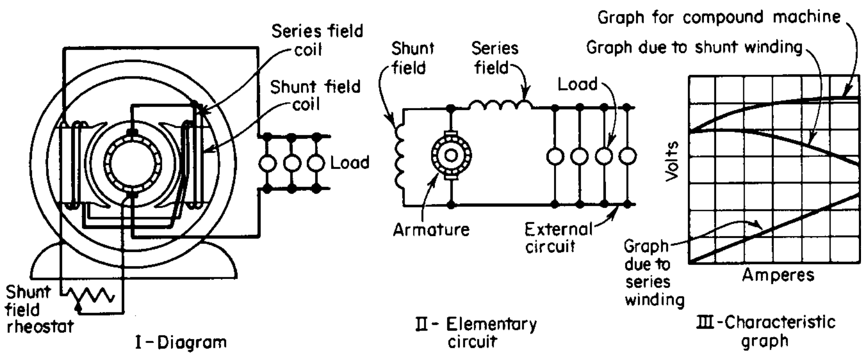

FIGURE 7.9 Compound generator.

The series winding must be connected in such a manner that its current will aid that of the shunt-field winding in producing magnetic flux. With this proper connection, the machine is said to be cumulatively connected. If the series field is connected in the reverse manner, so that the series field tends to produce flux in the opposite direction to that produced by the shunt field, the machine is said to be differentially connected. Differential connection of compound machines is used in very special cases.

10. A flat-compounded generator is one having its series coils so proportioned that the voltage remains practically constant at all loads from 0 to 1¼ full load.

11. An overcompounded generator has its series windings so proportioned that its full-load voltage is greater than its no-load voltage. Overcompounding is necessary when it is desirable to maintain a practically constant voltage at some point out on the line distant from the generator. It compensates for line drop. The characteristic curve (Fig. 7.9, III) indicates how the terminal voltage of a compound-wound machine is due to the action of both shunt and series windings. Generators are usually overcompounded, so that the full-load voltage is from 5 to 10 percent greater than the no-load voltage.

Although compound-wound generators are usually provided with a field rheostat, it is not intended for regulating voltage, as the rheostat of a shunt-wound machine is. It is provided to permit initial adjustment of voltage and to compensate for changes of the resistance of the shunt winding caused by heating. With a compound-wound generator, the voltage having been once adjusted, the series coils automatically strengthen the magnetic field as the load increases. For dc power work, compound-wound generators are used almost universally when rectifiers are not employed.

12. An undercompounded generator is one with a relatively weak series-field winding, so that the voltage decreases with increased load.

13. If a compound-wound generator is short-circuited, the field strength due to the series windings will be greatly increased but the field due to the shunt winding will lose its strength. For the instant or so that the shunt magnetization is diminishing, a heavy current will flow. If the shunt magnetization constitutes a considerable proportion of the total magnetization, the current will decrease after the heavy rush and little harm will be done if the armature has successfully withstood the heavy rush. However, if the series magnetization is quite strong in proportion to the shunt, their combined effect may so magnetize the fields that the armature will be burned out.

14. A short-shunt compound-wound generator has its shunt field connected directly across the brushes (see Fig. 7.9, II). Generators are usually connected in this way because this arrangement tends to maintain the shunt-field current more nearly constant on variable loads, as the drop in the series winding does not directly affect the voltage on the shunt field.

15. A long-shunt generator has its shunt-field winding connected across the terminals of the generator (see Fig. 7.10).

16. Nearly all commercial dc generators have more than two poles. A two-pole machine is a bipolar machine; one having more than two poles is a multipolar machine. Figure 7.11 shows the connections for a four-pole compound-wound machine. Diagrams for machines having more poles would be similar. In multipolar machines there is usually one set of brushes for each pair of poles, but with wave-wound armatures, such as those used for railway motors, one set of brushes may suffice for a multipolar machine. The connections of different makes of machines vary in detail; since manufacturers will always furnish complete diagrams, no attempt will be made to give them here. The directions of the field windings on

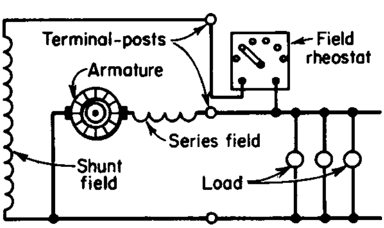

FIGURE 7.10 Long-shunt compound-wound generator.

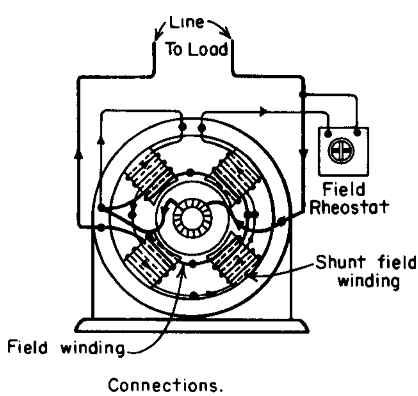

FIGURE 7.11 Four-pole compound-wound generator.

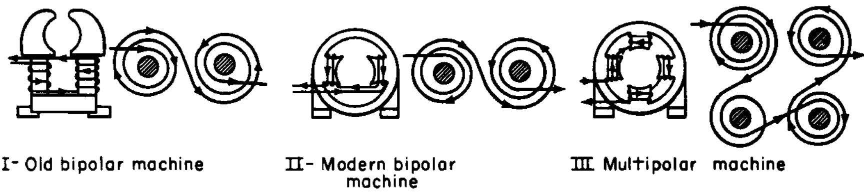

FIGURE 7.12 Directions of field windings on generator frames.

generator frames are given in Fig. 7.12. The directions of the windings on machines having more than four poles are similar in general to those of the four-pole machines.

17. A series shunt for a compound generator consists of a low-resistance connection across the terminals of the series field (see Figs. 7.13 and 7.14) through which the compounding effect of the series winding can be regulated by shunting more or less of the armature current around the series coils. The shunting resistance may be in the form of grids, on large machines, or of ribbon resistors. In the latter case it is usually insulated and folded into small compass.

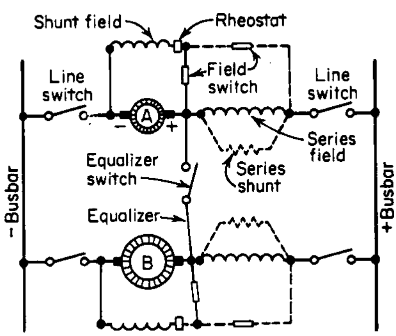

FIGURE 7.13 Elementary connections for parallel operation of compound-wound generators.

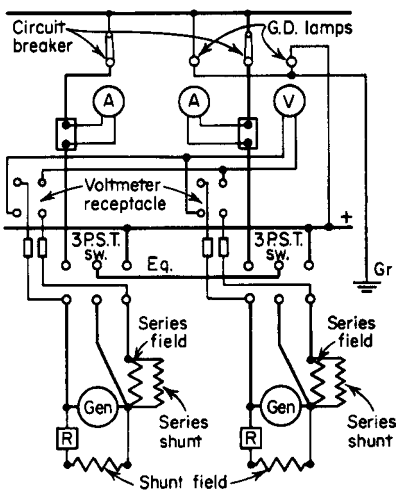

FIGURE 7.14 Connections of two compound-wound generators to a switchboard.

18. Parallel operation of compound-wound generators is readily effected if the machines are of the same make and voltage or are designed with similar electrical characteristics (Westinghouse Electric Corp.) The only change that is usually required is the addition of an equalizer connection between machines. If the generators have different compounding ratios, it may be necessary to adjust the series-field shunts to obtain uniform conditions.

19. An equalizer, or equalizer connection, connects two or more generators operating in parallel at a point where the armature and series-field leads join (see Fig. 7.13), thus connecting the armatures in multiple and the series coils in multiple so that the load will divide between the generators in proportion to their capacities. The arrangement of connections to a switchboard (Westinghouse Electric Corp.) is illustrated in Fig. 7.14. Consider, for example, two overcompound-wound machines operating in parallel without an equalizer. If for some reason there is a light increase in the speed of one machine, it will take more than its share of load. The increased current flowing through its series field will strengthen the magnetism, raise the voltage, and cause the machine to carry a still greater amount until it carries the entire load. When equalizers are used, the current flowing through each series coil is inversely proportional to the resistance of the series-coil circuit and is independent of the load on any machine; consequently, an increase of voltage on one machine builds up the voltage of the other at the same time, so that the first machine cannot take all the load but will continue to share it in proper proportion with the other generators.

20. Operation of a shunt and a compound dynamo in parallel is not successful because the compound machine will take more than its share of the load unless the shunt-machine field rheostat is adjusted at each change in load.

21. Connecting leads for compound generators. See that all the cables for machines of equal capacity that lead from the series fields of the various machines to the busbars are of equal resistance. This means that if the machines are at different distances from the switchboard, different sizes of wire should be used or resistance inserted in the low-resistance leads.

With generators of small capacity the equalizer is usually carried to the switchboard, as suggested in Figs. 7.14 and 7.15, but with larger ones it is carried under the floor directly between the machines (Fig. 7.16). The positive and the equalizer switches of each machine may be mounted side by side on a pedestal near the generator (Fig. 7.16). The

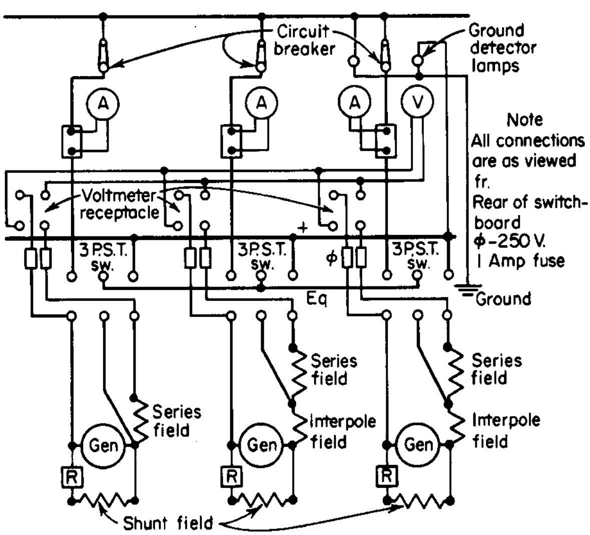

FIGURE 7.15 Connections of two dc commutating-pole generators in parallel with one generator without commutating poles.

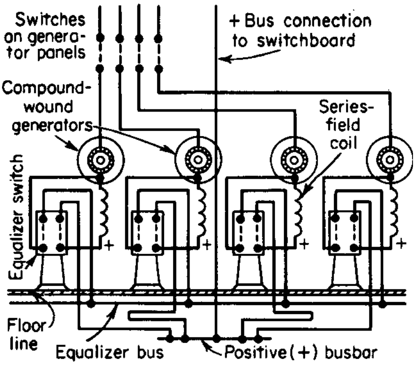

FIGURE 7.16 Equalizer carried directly between machines.

difference in potential between the two switches is only due to the small drop in the series coil. The positive busbar is carried under the floor near the machines, permitting leads of minimum length. Leads of equal length should be used for generation of equal capacities. If the capacities are unequal (see Sec. 25), it may be necessary to loop the leads (see Fig. 7.16).

22. Ammeters and circuit breakers for compound generators should, as in Fig. 7.14, always be inserted in the lead not containing the compound winding. If the ammeters are put in the compound-winding lead, the current indications will be inaccurate because current from this side of the machine can flow through either the equalizer or the compound-winding lead.

23. Starting a shunt- or compound-wound generator. (1) See that there is enough oil in the bearings, that the oil rings are working, and that all field resistance is cut in. (2) Start the prime mover slowly and permit it to come up to speed. See that the oil rings are working. (3) When machine is up to normal speed, cut out field resistance until the voltage of the machine is normal or equal to or a trifle above that on the busbars. (4) Throw on the load. If three separate switches are used, as in Fig. 7.13, close the equalizer switch first, the series-coil line switch second, and the other line switch third. If a three-pole switch is used, as in Fig. 7.14, all three poles are, of course, closed at the same time. (5) Watch the voltmeter and ammeter and adjust the field rheostat until the machine takes its share of the load. A machine generating the higher voltage will take more than its share of the load and if its voltage is too high, it will run the other machine as a motor.

24. Shutting down a shunt- or compound-wound generator operating in parallel with others. (1) Reduce the load on the machine as much as possible by cutting resistance into the shunt-field circuit with the field rheostat. (2) Throw off the load by opening the circuit breaker if one is used; otherwise open the main generator switches. (3) Shut down the driving machine. (4) Wipe off all oil and dirt, clean the machine, and put it in good order for the next run. Turn on all resistance in the field rheostat. Open the main switch.

25. Adjusting the division of load between two compound-wound generators. First adjust the series shunts of both machines so that, as nearly as possible, the voltages of both will be the same at one-fourth, one-half, three-fourths, and full load. Then connect the machines in parallel, as suggested in Fig. 7.13, for trial. If, upon loading, one machine takes more than its share of the load (amperes), increase the resistance of the path through its series-field coil path until the load divides between the machines proportionally to their capacities. Only a small increase in resistance is usually needed. The increase can be provided by inserting a longer conductor between the generator and the busbar, or iron or nickel silver washers can be inserted under a connection lug. Inasmuch as adjustment of the series-coil shunt affects both machines when the machines are connected in parallel, nothing can be accomplished through making such an adjustment.

26. Commutating-pole dc generators. Generators which do not have commutating poles (Westinghouse Electric Corp.) and which operate under severe overloads and over a wide speed range are apt to spark under the brushes at the extreme overloads and at the higher speeds. This happens because the field due to the armature current distorts the main field to such an extent that the coils being commutated under the brush are no longer in a magnetic field of the proper direction and strength. To overcome this, *commutating poles* are placed between the main poles (see Fig. 7.17). These poles introduce a magnetic field of such direction and strength as to maintain the magnetic field, at the point where the coils are commutated, at the proper strength for good communication. Commutating poles are sometimes called *interpoles*. Commutating poles is the preferable term.

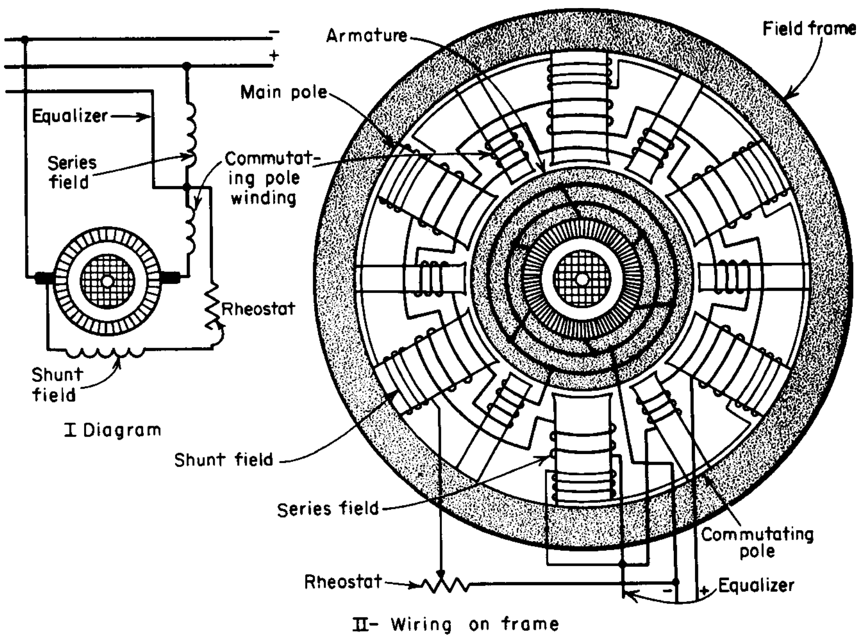

FIGURE 7.17 Compound-wound commutating-pole (interpole) machine.

The winding on the commutating poles is connected in series with the armature so that the strength of the corrective field increases and decreases with the load. The adjustment and operation of commutating-pole generators are not materially different from those of non-commutating-pole machines.

When the brush position of a commutating-pole machine has once been properly fixed, no shifting is required afterward or should be made, and most commutating-pole generators are shipped without any shifting device. An arrangement for clamping the brush holder rings securely to the field frame is provided.

In commutating-pole apparatus, accurate adjustment of the brush position is necessary. The correct brush position is on the no-load neutral point, which is located by the manufacturer. A template is furnished with each machine, or some other provision is made so that the brush location can be determined in the field. If the brushes are given a backward lead on a commutating-pole generator, the machine will overcompound and will not commutate properly. With a forward lead of the brushes, a generator will undercompound and will not commutate properly.

27. The object in using a commutating pole is to produce within the armature coil under commutation an emf of the proper value and direction to reverse the current in the coil which it is yet under the brush—a result that is essential to perfect commutation. The variation in the flux distribution in the air gap of a commercial dc machine of the ordinary shunt-wound type, at no load and under full load, is shown in Fig. 7.18. Consider now the value and position of the flux in the coil under the brush when the machine is operating at full load. The motion of the armature through this flux causes the generation within the coil of an emf, and the sign of this emf is such as to tend to cause the current in the coil to continue in the direction which it had before the coil reached the brush; hence it opposes the desired reversal of the current before the coil leaves the brush.

There is an additional detrimental influence which tends to retard the rapid reversal of the current even when all other influences are absent. This influence is due to the local magnetizing effect of the current in the coil under the brush. This effect causes the lines of force which surround the conductor to change in value with the fluctuations of the current as it tends to be reversed. As a result, an emf which opposes the change in the value of the current is generated in the coil. This reactive emf is in the same direction as that due to the cutting of the flux by the coil under the brush and is likewise proportional to the speed.

It will be apparent that even if the field distortion were completely neutralized, the detrimental reactive emf would remain. The improved and practically perfect commutation of the commutating-pole machine is due to the fact that the flux, which is superposed locally upon the main field, not only counterbalances the undesirable main flux cut by the coil under the brush but causes an emf sufficient to equal and opposite the reactive emf to be generated within the coil. This effect will be appreciated from a study of Fig. 7.19, which represents the distorted flux of the motor of the usual design, as shown in Fig. 7.18, and indicates the results to be expected when the flux due to the auxiliary or commutating pole is given the relatively proper value.

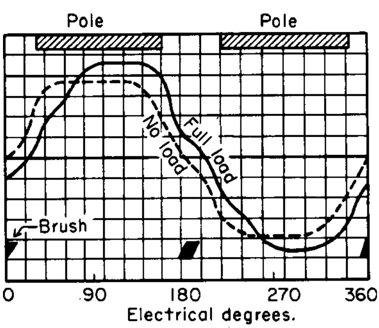

FIGURE 7.18 Distribution of magnetic flux at no load and at full load, without commutating poles.

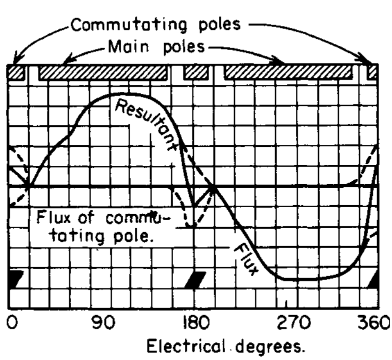

FIGURE 7.19 Distribution of magnetic flux at full load, with and without commutating poles.

This desirable effect is more pronounced the weaker the main field. The commutation voltage, if correct for a low speed, is correct for a high speed; and with the increase of load-current and main-field distortion there is a proportional increase of the counter-magnetizing field produced in the coil under the brush, up to the point of magnetic saturation of the auxiliary pole. Sparkless operation is ensured for all operating ranges of both speed and load.

28. The action of the magnetic flux in a commutating-pole generator is illustrated in Fig. 7.20. The direction of the main-field flux is shown by the dashed line. The direction of the armature magnetization is shown by the dotted lines. The direction of the flux in the commutating pole is shown by the full line. It is evident that the commutating-pole flux is in a direction opposite to that of the armature flux, and as the commutating-pole coil is more powerful at the commutating point in its magnetizing action than the armature coils, the flux of the armature coils is neutralized. With a less powerful magnetizing force from the commutating pole than from the armature at the commutating point, the armature would overpower the commutating pole and reverse the direction of the flux, which would result in a bad commutating condition.

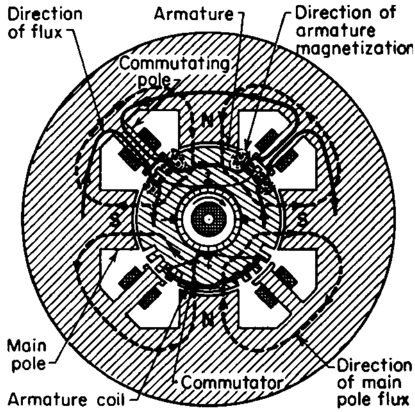

FIGURE 7.20 Distribution of flux in a commutating-pole generator.

29. Determining the neutral point of a motor or generator (Fig. 7.21). Two copper-wire contact points, or contactors, *C* are inserted in an insulating block and are allowed to extend through it about 1/16 in (1.6 mm). The distance between the centers of the points should be equal to the width of one commutator bar. The contactors are connected to a millivoltmeter *V*, which preferably should be of the differential type. Place both points on the commutator while the machine is being rotated with the brushes lifted from the commutator and the shunt field is being excited. While shifting the points around the periphery of the commutator, hold the block so that an imaginary line connecting the two contact points will be perpendicular to the axis of the commutator.

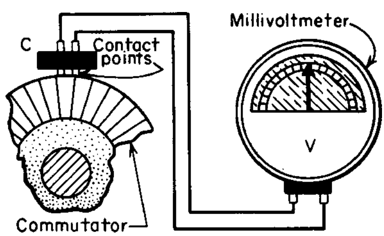

FIGURE 7.21 Connections for determination of the neutral point.

If a differential voltmeter is used, its needle will indicate either to the right or to the left of the zero point until the contacts are exactly over the neutral position; then the voltmeter will read zero. The brushes can now be shifted so that an imaginary line, parallel to the axis of the commutator and bisecting the bearing surface of the brush, will coincide with a point equidistant between the two contact points.

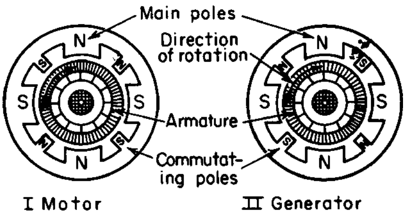

FIGURE 7.22*A* Polarity of commutating poles (clockwise rotation).

30. Determining the proper polarity of the commutating poles. For a motor, proceeding from pole to pole around the frame in the direction of armature rotation, each commutating pole should have the same polarity as the main pole which just precedes it (Fig. 7.22*A*, I). For a generator, proceeding from pole to pole around the frame in the direction of armature rotation, each commutating pole should have a polarity opposite to that of the main pole which just precedes it (Fig. 7.22*A*, II).

31. Commutating-pole machines will run in parallel with each other and with non-commutating-pole machines, provided correct connections are made (see illustrations). The series-field windings on commutating-pole machines are usually less powerful than on non-commutating-pole machines, and particular attention should therefore be paid to getting the proper drop in accordance with instructions of Sec. 25. A connection diagram is shown in Fig. 7.15.

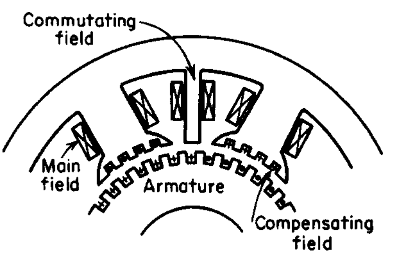

FIGURE 7.22*B* Section of a dc machine showing the location of a compensating field winding.

32. Compensating field windings. The commutating poles of a dc motor or generator do not neutralize the effect of the armature current upon the flux of the machine. They simply produce a local flux at the commutating location of the armature conductors. For machines that must operate under very severe conditions of overload and speed range, means must be provided for satisfactory operation to neutralize the tendency of the armature current to distort and change the flux of the machine. This neutralization is produced by means of an additional winding called a *compensating field winding*. A compensating field winding consists of coils embedded in slots in the pole faces of the machine, as shown in Figs. 7.22*B* and 7.22*C*. The compensating winding is connected in series with the armature in such a manner that the current through the individual conductors of the compensating field winding will be opposite to the direction of the corresponding armature conductors, as shown in Fig. 7.22*B*.

33. Three-wire dc generators are ordinary dc generators with the modifications and additions described below. They are usually wound for 125/250-V, three-wire circuits. In the case of commercial three-wire generators (Westinghouse Electric Corp.), four equidistant taps are made in the armature winding, and each pair of taps diametrically opposite each other is connected through a balance coil. The balance coil may be external (Fig. 7.23) or wound within the armature. The middle points of the two balance coils are connected, and this junction constitutes the neutral point to which the third, or neutral,

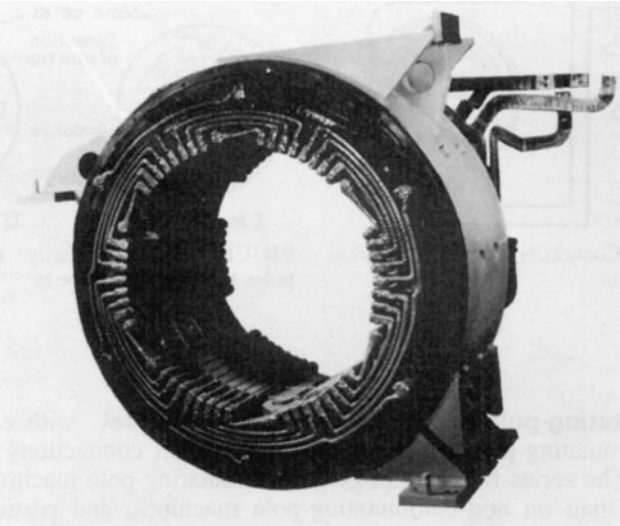

FIGURE 7.22*C* Frame and field structure of a dc motor showing compensating windings in the faces of the main poles. [Westinghouse Electric Corp.]

wire of the system is connected. A constant voltage is maintained between the neutral and outside wires which, within narrow limits, is one-half the generator voltage. The generator shaft is extended at the commutator end for the collector rings. Four collector brushes and brush holders are used in addition to the regular dc brushes and brush holders.

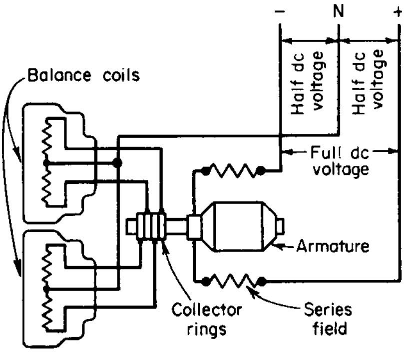

FIGURE 7.23 Connections for a three-wire generator.

34. The series coils of compound-wound three-wire generators are divided into halves (see Fig. 7.23), one of which is connected to the positive and one to the negative side. This is done to obtain compounding on either side of the system when operating on an unbalanced load. To understand this procedure, consider a generator with the series field on the negative side only and with most of the load on the positive side of the system. The current flows from the positive brush through the load and back along the neutral wire without passing through the series field. The generator is then operating as an ordinary shunt machine. If most of the load is on the negative side, the current flows out the neutral wire and back through the series fields, boosting the voltage by the maximum amount. Such operation is evidently not satisfactory, and so divided series fields are provided.

35. Switchboard connections for three-wire generators. Figure 7.24 is a diagrammatical representation of switchboard connections for two three-wire generators operated in multiple (Westinghouse publication). Two ammeters indicate the unbalanced load. The positive lead and equalizer are controlled by a double-pole circuit breaker, as are the negative lead and equalizer. Note that both the positive and the negative equalizer connections as well as both the positive and the negative leads are run to the circuit breakers as well as to the main switches on the switchboard. This must be done in all cases. Otherwise, when two or more machines are running in multiple and the breaker comes out, opening the main circuit to one of them but not breaking its equalizer leads, its ammeter is left connected to the equalizer busbars and current is fed into it from the other machines through the equalizer leads, either driving it as a motor or destroying the armature winding (see also Figs. 7.25 and 7.26).

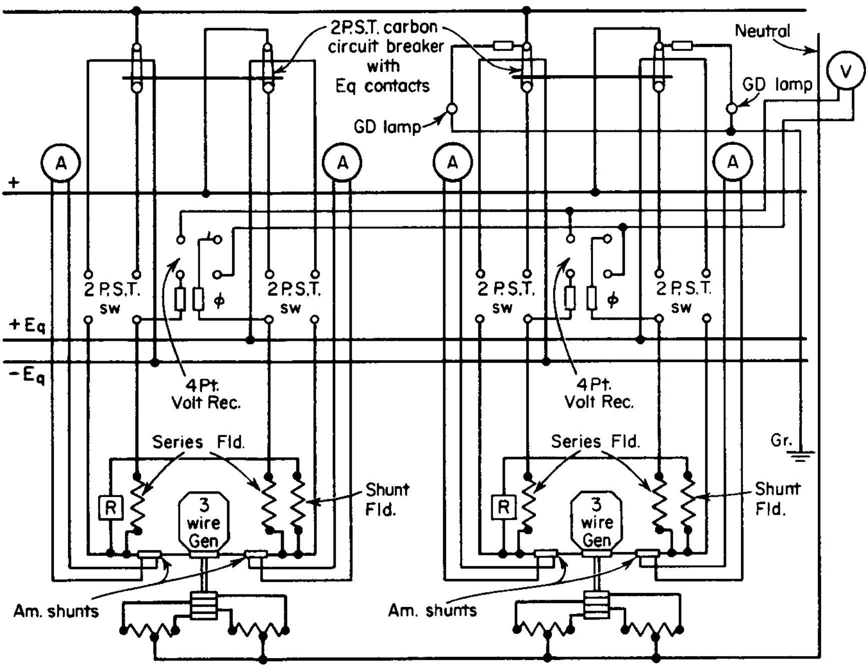

FIGURE 7.24 Connections of two three-wire dc generators operating in parallel, 125/250 V.

36. As there are two series fields, two equalizer buses are required when several three-wire machines are installed (see Fig. 7.24) and are to be operated in parallel. The two equalizers serve to distribute the load equally between the machines and to prevent crosscurrents due to differences in voltage on the different generators. Because of the equalizer connections, two small terminal boards, one for each side of the generator, are supplied. Arrangement is also made for ammeter shunts on the terminal boards.

An ammeter shunt is mounted directly on each of the contact boards of the machine. The total current output of the machine can thereby be read at the switchboard. Because the shunts are at the machine, there is no chance for current to leak across between generator

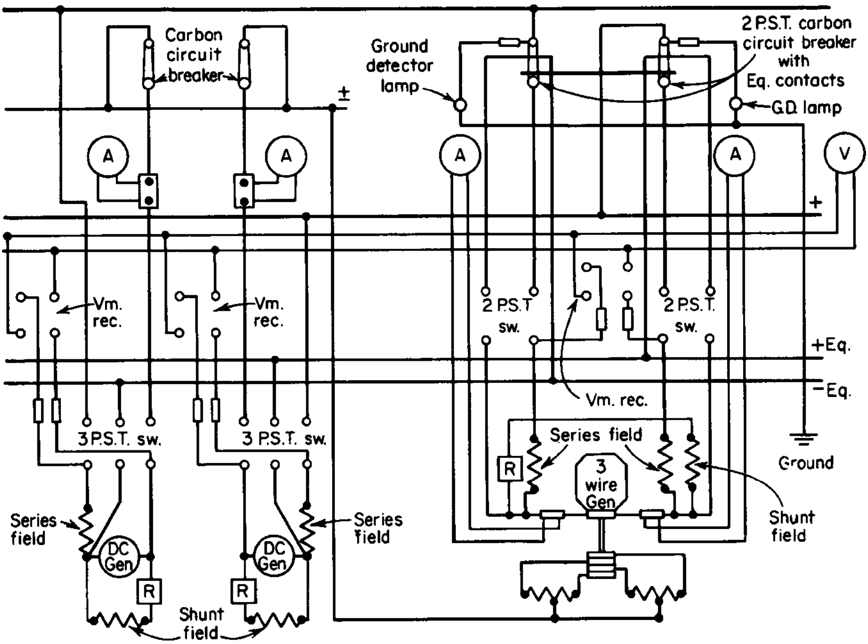

FIGURE 7.25 Connections of a three-wire dc generator, 125/250 V, in parallel with two two-wire generators, 125 V.

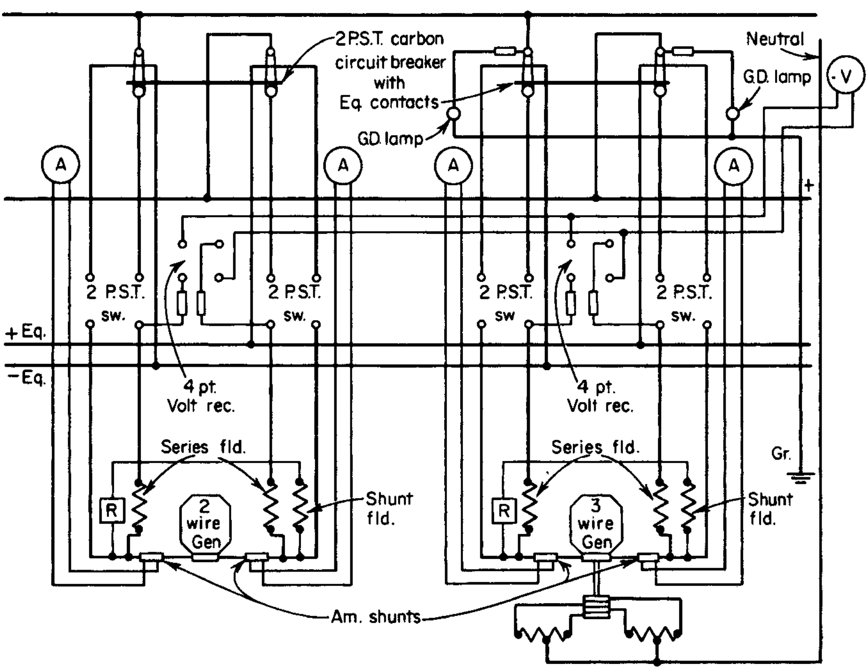

FIGURE 7.26 Connections of a three-wire dc generator, 125/250 V, in parallel with a two-wire generator, 250 V.

switchboard leads without causing a reading on the ammeters. Two ammeters must be provided for reading the current in the outside wires. It is important that the current be measured on both sides of the system, because with an ammeter on one side of the system only it is possible for a large unmeasured current to flow in the other side with disastrous results.

37. Wires connecting the balance coils to a three-wire generator must be short and of low resistance. Any considerable resistance in these wires will affect the voltage regulation. The unbalanced current flows along these connections; consequently, if they have much resistance, the resulting drop in voltage reduces the voltage on the heavily loaded side.

Switches are not ordinarily placed in the circuits connecting the four collector rings to the balance coils. When necessary, the coils can be disconnected from the generator by raising the brushes from the collector rings. Switching arrangements often make it necessary to run the balance-coil connections to the switchboard and back, requiring heavy leads to keep the drop low, or if heavy leads are not used, poor regulation may result. The balance coils are so constructed that there is very little likelihood of anything happening to them that will not be taken care of by the main circuit breakers. Complete switchboard connection diagrams are given in Figs. 7.24, 7.25, and 7.26.

38. Commutating-pole three-wire generators. In three-wire generators, connections are so made that one-half of the commutating-pole winding is in the positive side and the other half is in the negative side. This ensures proper action of the commutating pole at an unbalanced load (see Figs. 7.24, 7.25, and 7.26 and the text accompanying them).

39. Three-wire dc generators can be operated in parallel with each other (Westinghouse publication) and in parallel with other machines on the three-wire system (see Figs. 7.24, 7.25, and 7.26). When a three-wire, 250-V generator is operated in multiple with two-wire, 125-V generators, the series fields of the two two-wire generators must be connected, one on the positive side and one on the negative side of the system, and an equalizer must be run to each machine. Similarly, when a three-wire, 250-V generator is operated in multiple with a 250-V two-wire generator, the series field of the 250-V two-wire generator must be divided and one-half connected to each outside wire. The method of doing this is to disconnect the connectors between the series-field coils and to reconnect these coils so that all the *N* pole fields will be in series on one side of the three-wire system and all the *S* pole fields in series on the other side of the system.

40. Testing for polarity. When a machine that is to operate in parallel with others is connected to the busbars for the first time, it should be tested for polarity. The + lead of the machine should connect to the + busbar and the − lead to the − busbar (Fig. 7.27, I). The machine to be tested should be brought up to normal voltage but not connected to the bars. The test can be made with two lamps (Fig. 7.27, II), each lamp of the voltage of the circuit. Each is temporarily connected between a machine terminal and the bus terminal of the main switch. If the lamps do not burn, the polarity of the new machine is correct, but if they burn brightly, its polarity is incorrect and should be reversed. A voltmeter can be used (Fig. 7.27, III). A temporary connection is made across one pair of outside terminals, and the voltmeter is connected across the other pair. No deflection or a small deflection indicates correct polarity. (Test with voltmeter leads one way and then reverse them, as

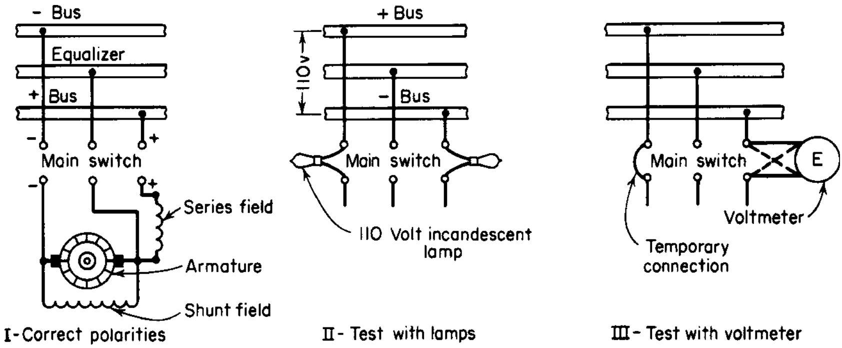

FIGURE 7.27 Tests for polarity.

indicated by the dotted lines.) A full-scale deflection indicates incorrect polarity. Use a voltmeter having a voltage range equal to twice the voltage on the busbars.

41. Third-brush generators were often used on automobiles to provide the necessary electric power for the changing of the storage battery and the operation of lights. If an ordinary generator were employed for this purpose, the voltage would vary over a wide range as the speed of the car changed. The voltage would vary nearly proportionally to the speed. This, of course, would not be satisfactory either for the proper charging of the battery or for operation of the car lights. The third-brush generator is a special shunt generator with the field winding connected between one of the main brushes and the auxiliary, or third, brush (see Fig. 7.28). As the speed of the automobile increased, thereby increasing the speed of the generator, the voltage tended to increase. This increase in voltage increased the current delivered by the generator. But the increase in current so changed the magnetic-flux distribution in the machine that the voltage between the third brush and main brush *A* was reduced. This reduced the field current and therefore the flux of the machine and tended to bring the main voltage between brushes *A* and *C* back to its former value. This action did not maintain an absolutely constant voltage for different speeds, but the voltage

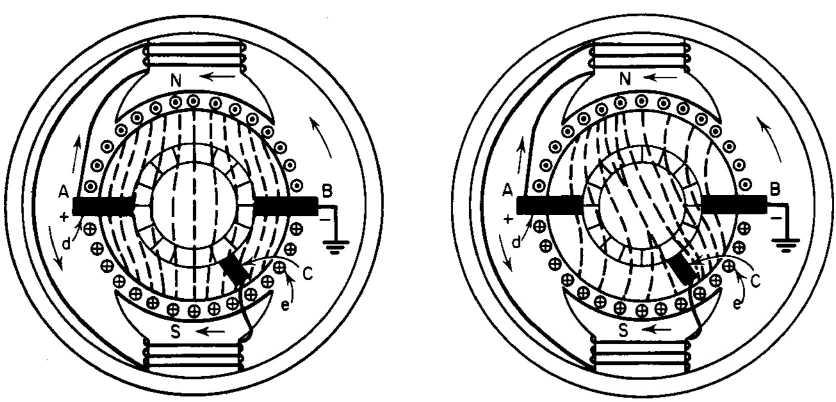

FIGURE 7.28 Third-brush generator. [Charles L. Dawes, "Direct Currents," *A Course in Electrical Engineering*]

was held within certain limits so that an excessive voltage which would overcharge the battery and shorten the life of the lamps was not developed at high speeds. It should be noted that present-day automobiles use an ac generator (alternator) with rectifier diodes to provide a 12-V dc supply.

42. Diverter-pole generators are a special type of dc generators (developed by the Electric Products Co.) that have particular advantages for the charging of batteries by the floating method. The machine is constructed with additional pole pieces (the diverter poles) located midway between the main poles in the same manner as commutating poles. Each main pole is connected by a magnetic bridge to one diverter pole. The windings of the main poles are connected in shunt with the armature winding, and the windings of the diverter poles in series with the armature winding. The construction, connections, and load-voltage characteristics for such a generator are shown in Fig. 7.29. These generators will produce an almost constant terminal voltage from no load to 110 percent of rated load. Above 110 percent of rated load, the voltage drops very rapidly.

At no load, a part of the magnetic flux resulting from the shunt coil on the main pole piece is diverted and does not pass through the armature. As the load increases, the series winding on the diverter pole rediverts this flux to the armature and provides a commutating field.

If the shunt and series windings are properly proportioned, the flux in the armature varies with the load to compensate for the *IR* drop in the generator and for speed changes of the driving motor.

A flat voltage curve is obtained, since the necessary magnetic changes produced by the series winding take place only in the diverter pole, the flux from the main pole remaining constant. The flux densities in the diverter pole are kept low, so that the magnetic changes which occur in this part of the magnetic circuit take place on the straight portion of the magnetization curve, thus eliminating most of the curvature from the voltage characteristic. By correct adjustment of the diverter-pole winding by means of an adjustable shunt, a very straight, flat curve is obtained with only a very slight rise on approaching zero load.

At some value of the load current the ampere-turns on the diverter pole will equal those on the main pole, and at this time the magnetic flux leaking across the ridge to the diverter pole is all rediverted across the air gap; hence there is no further leakage flux for an increased current to be rediverted to the armature. When the load is increased beyond this point, the increased ampere-turns on the diverter pole combine with the armature cross-magnetizing force to send magnetic flux in the reverse direction across the leakage bridge, which tends to demagnetize the main pole and reduce the generator voltage. Good commutation is assured, as the diverter pole provides a commutating field of the correct direction for improving commutation, and this field varies with the current output just as in a commutating-pole generator.

43. Control generators are specifically designed dc generators which are employed for the precise automatic control of dc motors. They are used to perform a wide variety of functions, such as:

1. Controlling and regulating speed, voltage, current, or power accurately over a wide range
2. Controlling tension and torque to maintain product uniformity in winding, drawing, and similar operations
3. Speeding up acceleration or deceleration to increase the production of high-inertia machines, etc.