Chapter 2

ABFC Power Plant Operations and Procedures

Topics

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Overview

Generators play an important part in your assignment with the Seabees. Whether operating a generator as a main power source or as standby or emergency power, you need a thorough knowledge of their hookup, operation, and maintenance. At the completion of this chapter, you should know how to install generators of the advanced-base type, perform preventive maintenance, and make minor repairs on power generators and control equipment. Theory for both DC and AC generators is included in Navy Electricity and Electronics Training Series (NEETS), Module 5 and AC generator theory was covered in Chapter 1 of this course. Keep in mind that the generator (or alternator) in an automobile works on the same principle as does the huge turbine generator used in a nuclear power station.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the different types of Direct Current (DC) generators.
2. Describe the purpose and components of the elementary generator.
3. Identify the classifications of DC generators.
4. Identify the conditions necessary for good commutation.
5. Describe the inspection procedures for commutators and collectors.
6. Describe the cleaning procedures for commutators and collectors.
7. Describe the different types of AC generators.
8. Describe the construction of alternators.
9. Describe the purpose and function of single and three phase alternators.
10. Identify frequency ranges associated with AC generators.
11. Describe the operation of power plants.
12. Describe the procedures for operating single and parallel units.
13. Describe procedures used to balance and maintain frequency and voltage.
14. Identify the demand and power factors.
15. Describe reasons behind voltage drop conditions.
16. Describe hunting.

Prerequisites

This course map shows all of the chapters in Construction Electrician Advanced. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Solid State Devices	↑	C E
ABFC Power Plant Maintenance		A D V
ABFC Power Plant Operations and Procedures		A N C
Advanced Electrical Theory		E D

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 DIRECT CURRENT GENERATORS

A generator is a machine that converts mechanical energy into electrical energy by using the principle of magnetic induction. This principle is explained as follows.

Whenever a conductor is moved within a magnetic field in such a way that the conductor cuts across magnetic lines of flux, voltage is generated in the conductor. The amount of voltage generated depends on the strength of the magnetic field, the angle at which the conductor cuts the magnetic field, the speed at which the conductor is moved, and the length of the conductor within the magnetic field.

The polarity of the voltage depends on the direction of the magnetic lines of flux and the direction of movement of the conductor. To determine the direction of current in a given situation, the left-hand rule for generators is used. This rule is explained in the following manner.

Extend the thumb, forefinger, and middle finger of your left hand at right angles to one another (*Figure 2-1*). Point your thumb in the direction the conductor is being moved. Point your forefinger in the direction of magnetic flux (from north to south). Your middle finger will then point in the direction of current flow in an external circuit to which the voltage is applied.

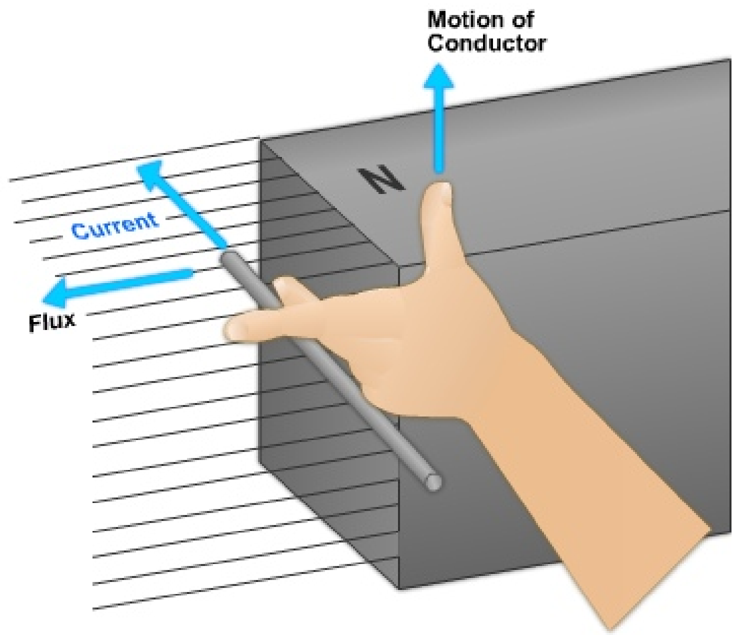

Figure 2-1 — Left-hand rule for generators.

2.0.0 ELEMENTARY GENERATOR

The simplest elementary generator that can be built is an ac generator. Basic generating principles are most easily explained through the use of the elementary ac generator. For this reason, we will discuss the ac generator first and the dc generator later.

An elementary generator consists of a wire loop placed so that it can be rotated in a stationary magnetic field (*Figure 2-2*). This will produce an induced electromagnetic field (emf) in the loop. Sliding contacts (brushes) connect the loop to an external circuit load in order to pick up or use the induced emf.

The pole pieces (marked N and S) provide the magnetic field. The pole pieces are shaped and positioned as shown to concentrate the magnetic field as close as possible to the wire loop. The loop of wire that rotates through the field is called the ***armature***. The ends of the armature loop are connected to rings called ***slip rings***. They rotate with the armature. The brushes, usually made of carbon, with wires attached to them, ride against the rings. The generated voltage appears across these brushes.

The elementary generator produces a voltage in the following manner (*Figure 2-3*). The armature loop is rotated in a clockwise direction. The initial or starting point is shown at position A. This will be considered the zero-degree position. At 0° the armature loop is perpendicular to the magnetic field. The black and white conductors of the loop are moving parallel to the field. The instant the conductors are moving parallel to the magnetic field, they do not cut any lines of flux. Therefore, no emf is induced in the conductors, and the meter at position A indicates zero. This position is called the neutral plane. As the armature loop rotates from position A (0°) to position B (90°), the conductors cut through more and more lines of flux at a continually increasing angle. At 90° they are cutting through a maximum number of lines of flux and at maximum angle. The result is that between 0° and 90°, the induced emf in the conductors builds up from zero to a maximum value. Observe that from 0° to

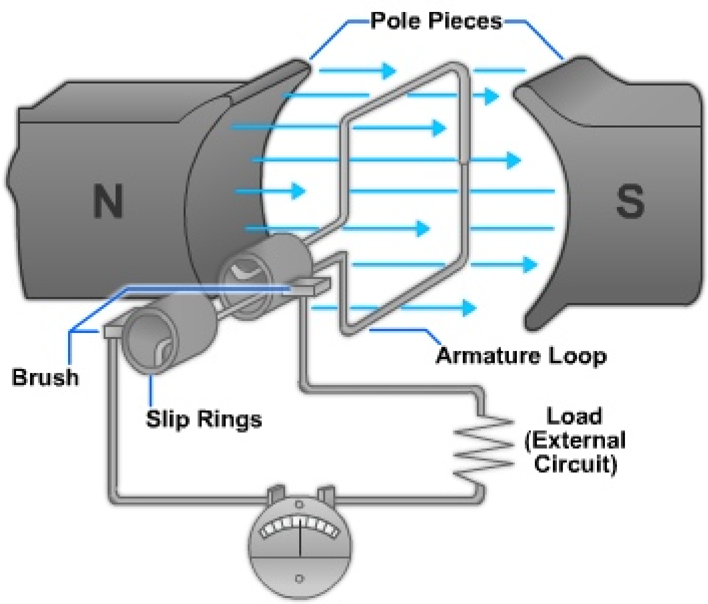

Figure 2-2 — The elementary generator.

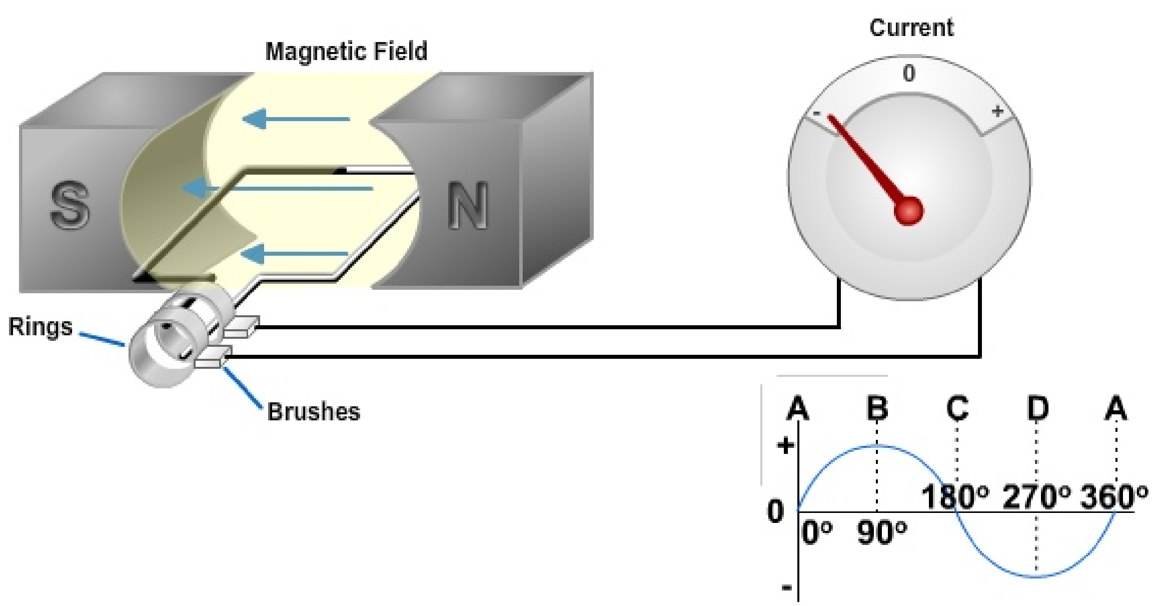

Figure 2-3 — Output voltage of an elementary generator during one revolution.

90°, the black conductor cuts down through the field. At the same time the white conductor cuts up through the field. The induced emfs in the conductors are series-adding. This means the resultant voltage across the brushes, the voltage terminal, is the sum of the two induced voltages. The meter at position B reads maximum value. As the armature loop continues rotating from 90° (position B) to 180° (position C), the conductors which were cutting through a maximum number of lines of flux at position B now cut through fewer lines. They are again moving parallel to the magnetic field at position C. They no longer cut through any lines of flux. As the armature rotates from 90° to 180°, the induced voltage will decrease to zero in the same manner that it increased during the rotation from 0° to 90°. The meter again reads zero. From 0° to 180° the conductors of the armature loop have been moving in the same direction through the magnetic field. Therefore, the polarity of the induced voltage has remained the same. This is shown by points A through C on the graph. As the loop rotates beyond 180° (position C), through 270° (position D), and back to the initial or starting point (position A), the direction of the cutting action of the conductors through the magnetic field reverses. Now the black conductor cuts up through the field while the white conductor cuts down through the field. As a result, the polarity of the induced voltage reverses. Following the sequence shown by graph points C, D, and back to A, the voltage will be in the direction opposite to that shown from points A, B, and C. The terminal voltage will be the same as it was from A to C except that the polarity is reversed as shown by the meter deflection at position D. The voltage output waveform for the complete revolution of the loop is shown on the graph (*Figure 2-3*).

3.0.0 ELEMENTARY DC GENERATOR COMPONENTS

A single-loop generator with each terminal connected to a segment of a two-segment metal ring is shown in *Figure 2-4*. The two segments of the split metal ring are insulated from each other. This forms a simple ***commutator***. The commutator in a dc generator replaces the slip rings of the ac generator. This is the main difference in their construction. The commutator mechanically reverses the armature loop connections to the external circuit. This occurs at the same instant that the polarity of the voltage in the armature loop reverses. Through this process the commutator changes the generated ac voltage to a pulsating dc voltage as shown in the graph. This action is known as commutation. Commutation is described in detail later in this chapter.

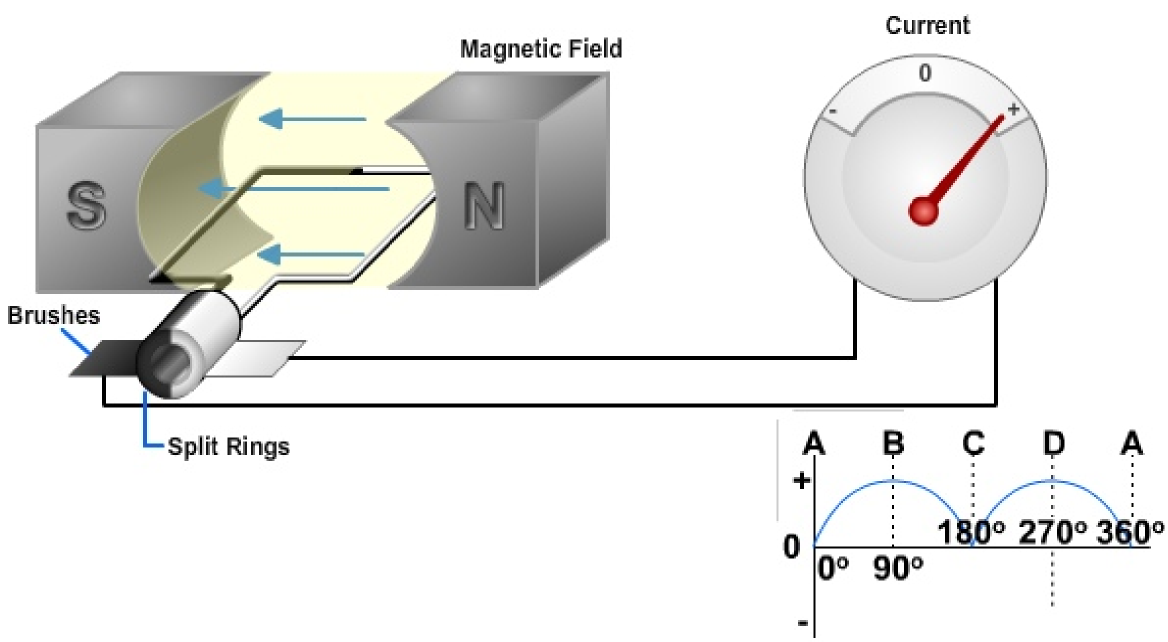

Figure 2-4 — Effects of commutation.

Refer to *Figure 2-4*, parts A through D for the remainder of this section. This will help you in following the step-by-step description of the operation of a dc generator. When the armature loop rotates clockwise from position A to position B, a voltage is induced in the armature loop which causes a current in a direction that deflects the meter to the right. Current flows through the loop, out of the negative brush, through the meter and the load, and back through the positive brush to the loop. Voltage reaches its maximum value at point B on the graph for reasons explained earlier. The generated voltage and the current fall to zero at position C. At this instant each brush makes contact with both segments of the commutator. As the armature loop rotates to position D, a voltage is again induced in the loop. In this case, however, the voltage is of opposite polarity.

The voltages induced in the two sides of the coil at position D are in the reverse direction to that of the voltages shown at position B. Note that the current is flowing from the black side to the white side in position B and from the white side to the black side in position D. However, because the segments of the commutator have rotated with the loop and are contacted by opposite brushes, the direction of current flow through the brushes and the meter remains the same as at position B. The voltage developed across the brushes is pulsating and unidirectional (in one direction only). It varies twice during each revolution between zero and maximum. This variation is called ***ripple***.

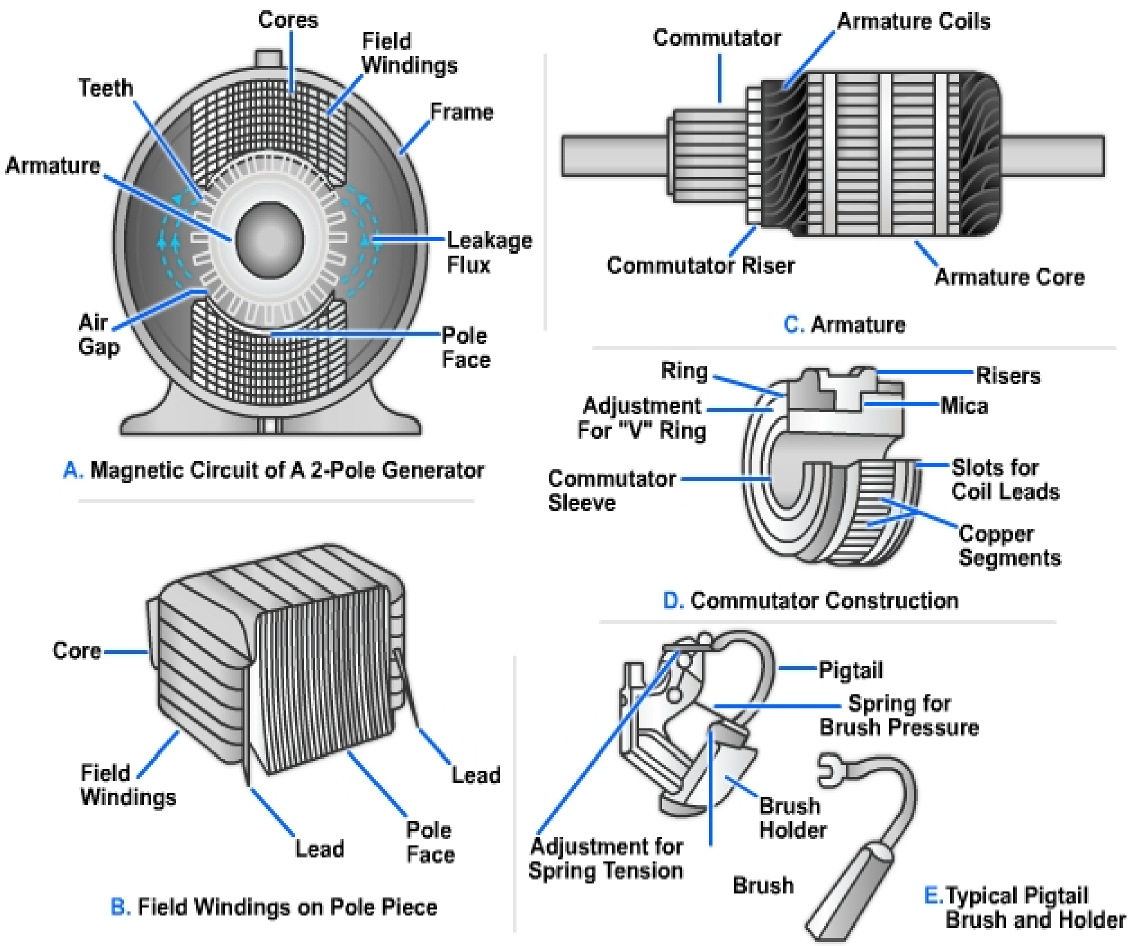

Figure 2-5 – Components of a dc generator.

A pulsating voltage, such as that produced in the preceding description, is unsuitable for most applications. Therefore, in practical generators more armature loops (coils) and more commutator segments are used to produce an output voltage waveform with less ripple.

Figure 2-5, *Views A* through *E*, shows the component parts of dc generators. *Figure 2-6* shows the entire generator with the component parts installed. The cutaway figure helps you to see the physical relationship of the components to each other.

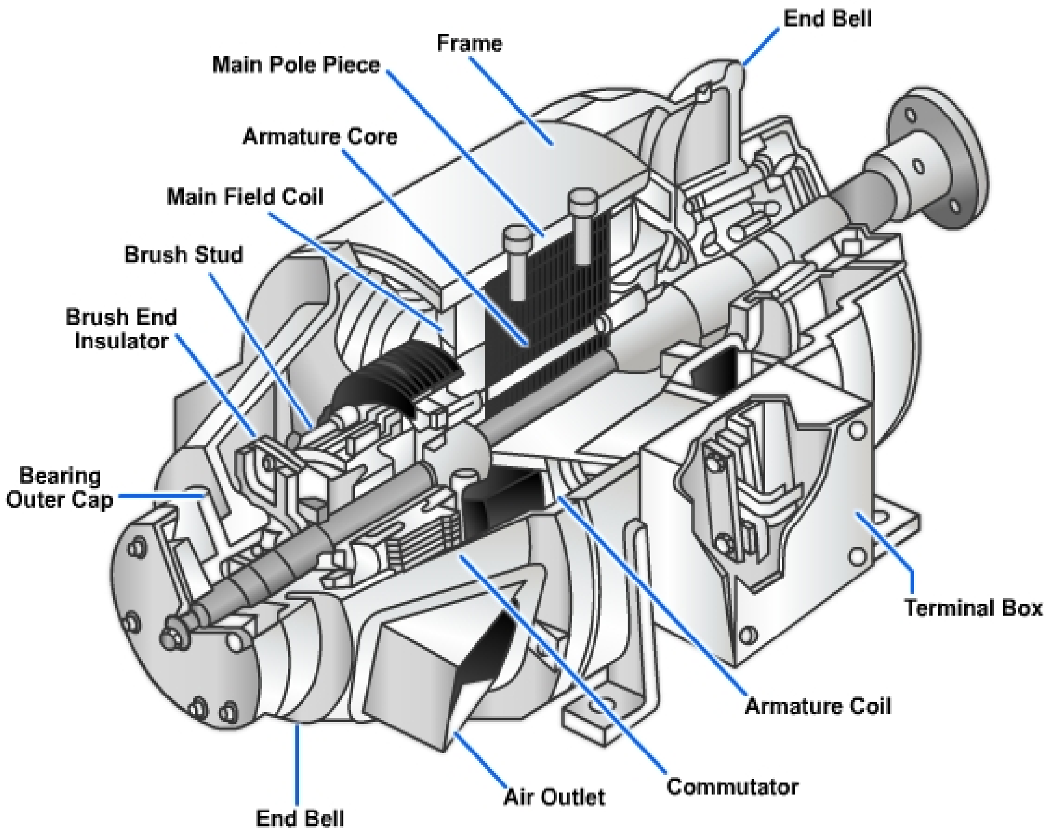

Figure 2-6 – Construction of a dc generator (cutaway drawing).

4.0.0 CLASSIFICATIONS of DC GENERATORS (SELF EXCITING TYPE)

When a dc voltage is applied to the field windings of a dc generator, current flows through the windings and sets up a steady magnetic field. This is called ***field excitation***.

This excitation voltage can be produced by the generator itself or it can be supplied by an outside source, such as a battery. A generator that supplies its own field excitation is called a self-excited generator. Self-excitation is possible only if the field pole pieces have retained a slight amount of permanent magnetism, called ***residual magnetism***. When the generator starts rotating, the weak residual magnetism causes a small voltage to be generated in the armature. This small voltage applied to the field coils causes a small field current. Although small, this field current strengthens the magnetic field and allows the armature to generate a higher voltage. The higher voltage increases the field strength, and so on. This process continues until the output voltage reaches the rated output of the generator. Self-excited generators are classed according to the type of field connection they use. There are three general types of field connections – series-wound, shunt-wound (parallel), and compound-wound. Compound-wound generators are further classified as cumulative-compound and differential-compound. These last two classifications are not discussed in this chapter.

4.1.0 Series-Wound Generator

In the series-wound generator the field windings are connected in series with the armature (*Figure 2-7*). Current that flows in the armature flows through the external circuit and through the field windings. The external circuit connected to the generator is called the load circuit. A series-wound generator uses very low resistance field coils, which consist of a few turns of large diameter wire.

The voltage output increases as the load circuit starts drawing more current. Under low-load current conditions, the current that flows in the load and through the generator is small. Since small current means that a small magnetic field is set up by the field poles, only a small voltage is induced in the armature. If the resistance of the load decreases, the load current increases. Under this condition, more current flows through the field. This increases the magnetic field and increases the output voltage. A series-wound dc generator has the characteristic that the output voltage varies with load current. This is undesirable in most applications. For this reason, this type of generator is rarely used in everyday practice.

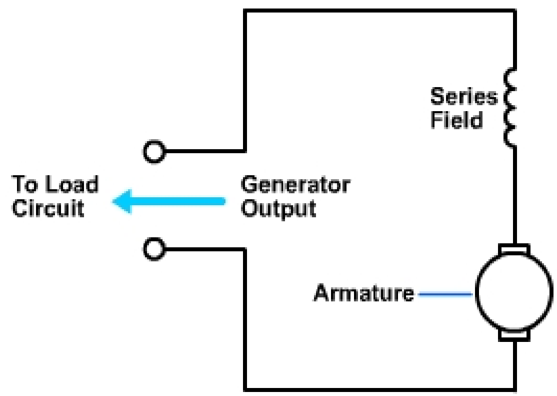

Figure 2-7 – Series-wound generator.

4.2.0 Shunt-Wound Generator

In a shunt-wound generator, like the one shown in *Figure 2-8*, the field coils consist of many turns of small wire. They are connected in parallel with the load. In other words, they are connected across the output voltage of the armature.

Current in the field windings of a shunt-wound generator is independent of the load current (currents in parallel branches are independent of each other). Since field current, and therefore field strength, is not affected by load current, the output voltage remains more nearly constant than does the output voltage of the series-wound generator. In actual use, the output voltage in a dc shunt-wound generator varies inversely as load current varies. The output voltage decreases as load current increases because the voltage drop across the armature resistance increases $(E = IR)$.

In a series-wound generator, output voltage

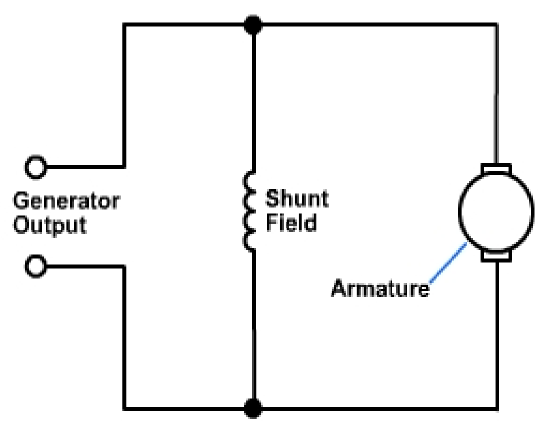

Figure 2-8 – Shunt-wound generator.

varies directly with load current. In the shunt-wound generator, output voltage varies inversely with load current. A combination of the two types can overcome the disadvantages of both. This combination of windings is called a compound-wound dc generator.

4.3.0 Compound-Wound Generator

Compound-wound generators have a series-field winding in addition to a shunt-field winding (*Figure 2-9*). The shunt and series windings are wound on the same pole pieces. In the compound-wound generator when load current increases, the armature voltage decreases just as in the shunt-wound generator. This causes the voltage applied to the shunt-field winding to decrease, which results in a decrease in the magnetic field. This same increase in load current, since it flows through the series winding, causes an increase in the magnetic field produced by that winding.

By proportioning the two fields so that the decrease in the shunt field is just compensated by the increase in the series field, the output voltage remains constant. This is shown in *Figure 2-10*, which shows the voltage characteristics of the series-, shunt-, and compound-wound generators. As you can see, by proportioning the effects of the two fields (series and shunt), a compound-wound generator provides a constant output voltage under varying load conditions. Actual curves are seldom, if ever, as perfect as shown.

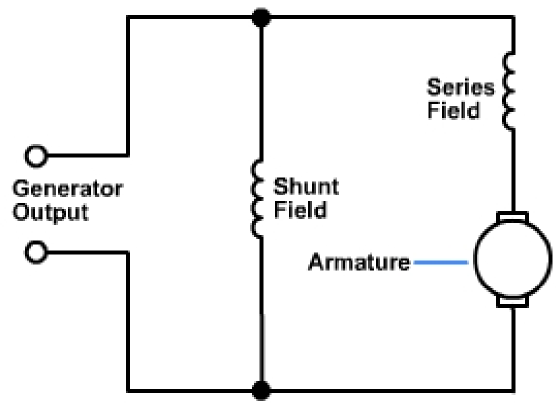

Figure 2-9 – Compound-wound generator.

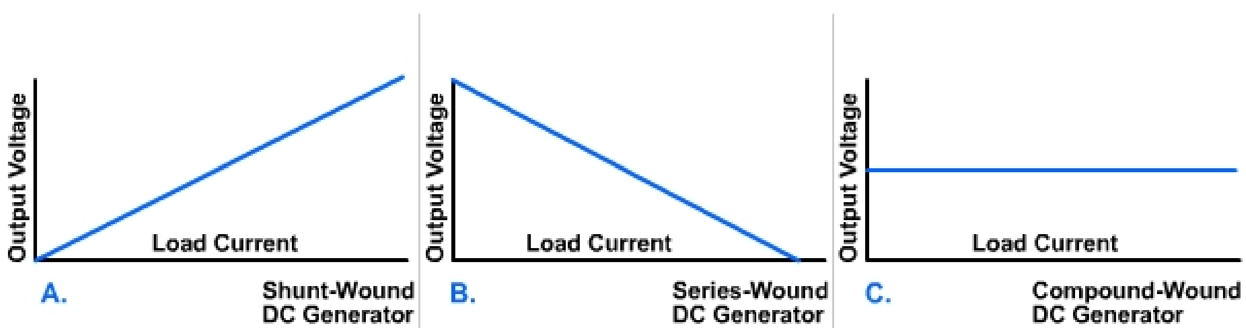

Figure 2-10 – Voltage output characteristics.

5.0.0 CONDITIONS NECESSARY for GOOD COMMUTATION

Commutation is the process by which a dc voltage output is taken from an armature that has an ac voltage induced in it. You should remember from your study earlier in this chapter about elementary dc generators that the commutator mechanically reverses the armature loop connections to the external circuit. This occurs at the same instant that the voltage polarity in the armature loop reverses. A dc voltage is applied to the load because the output connections are reversed as each commutator segment passes under a brush. The segments are insulated from each other.

In *Figure 2-11*, commutation occurs simultaneously in the two coils that are briefly short-circuited by the brushes. Coil B is short-circuited by the negative brush. Coil Y, the opposite coil, is short-circuited by the positive brush. The brushes are positioned on the commutator so that each coil is short-circuited as it moves through its own electrical neutral plane. As you have seen previously, there is no voltage generated in the coil at that time. Therefore, no sparking can occur between the commutator and the brush. Sparking between the brushes and the commutator is an indication of improper commutation. Improper brush placement is the main cause of improper commutation.

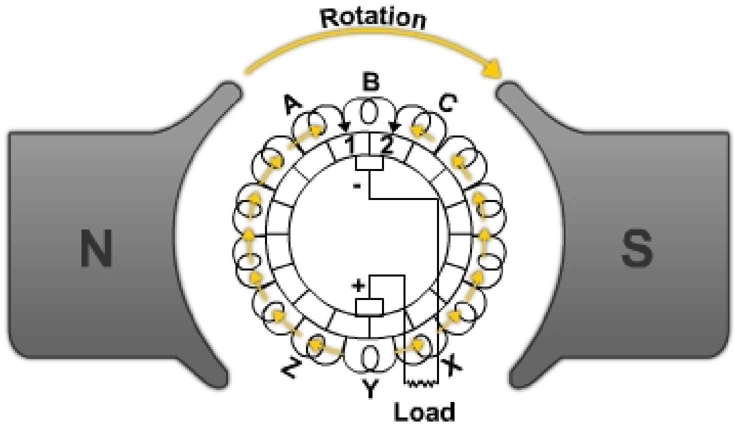

Figure 2-11 — Commutation of a dc generator.

6.0.0 INSPECTION of the COMMUTATORS and COLLECTOR or SLIP RINGS

The first test on an armature winding should be to locate grounded circuits. This test is performed with a series test lamp. Touch one test prod to the armature core shaft (*Figure 2-12*). Using the other test prod, touch each commutator segment. If the armature winding is grounded, the test lamp will light when you apply the lamp prod to the grounded armature winding or commutator segment. Replace the grounded armature when all attempts to remove the ground have failed.

When checking for a shorted armature, place the armature in an armature test set (growler). Lay the test blade lengthwise with the flat side loosely in

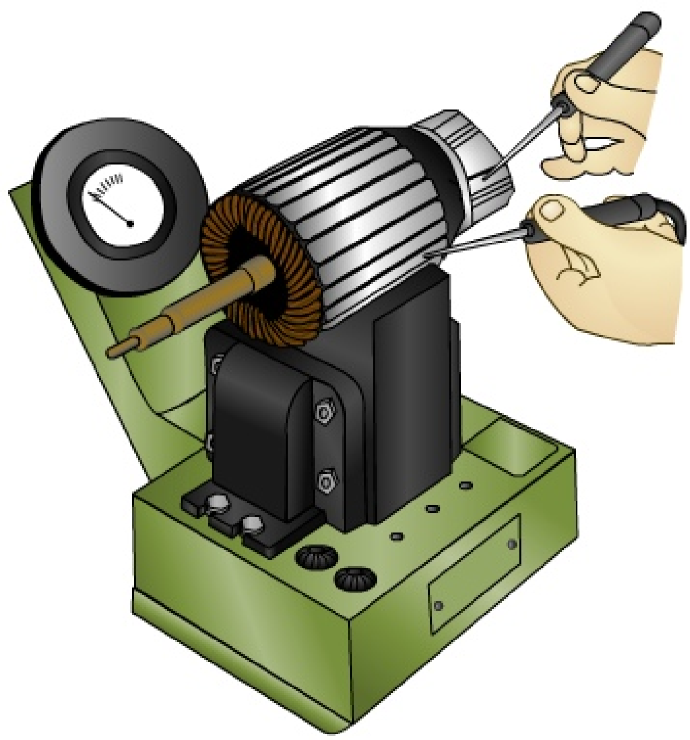

Figure 2-12 — Testing for grounds in armature windings.

contact with the armature core (*Figure 2-13*). Turn the test stand to the ON position and slowly rotate the armature while you hold the test blade stationary. If there is a short in the armature windings, the test blade will be attracted to the armature (magnetized) and will vibrate.

CAUTION

Place the test set switch in the OFF position before removing the armature, and never leave the test set turned on unless there is an armature placed in the core.

When you are testing an armature for an open circuit, place the armature in an armature test set and turn the test set ON. Place the armature double prods on two adjoining commutator segments and note the reading on the ammeter (*Figure 2-14*). Rotate the armature until each pair of adjoining commutator segments has been read. All the segments should read the same. No reading indicates an open circuit, and a high reading indicates a short circuit.

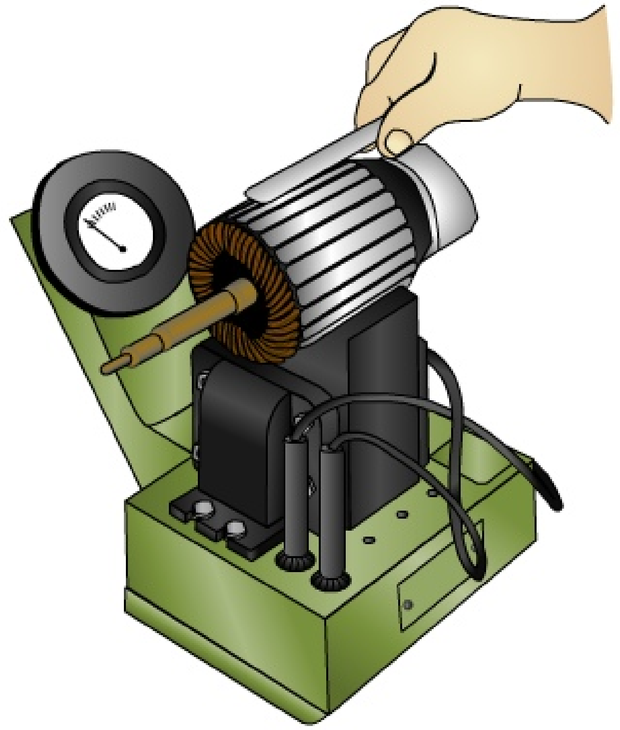

Figure 2-13 — Testing for shorts in armature windings.

CAUTION

Place the test set switch in the OFF position before removing the armature from the test stand.

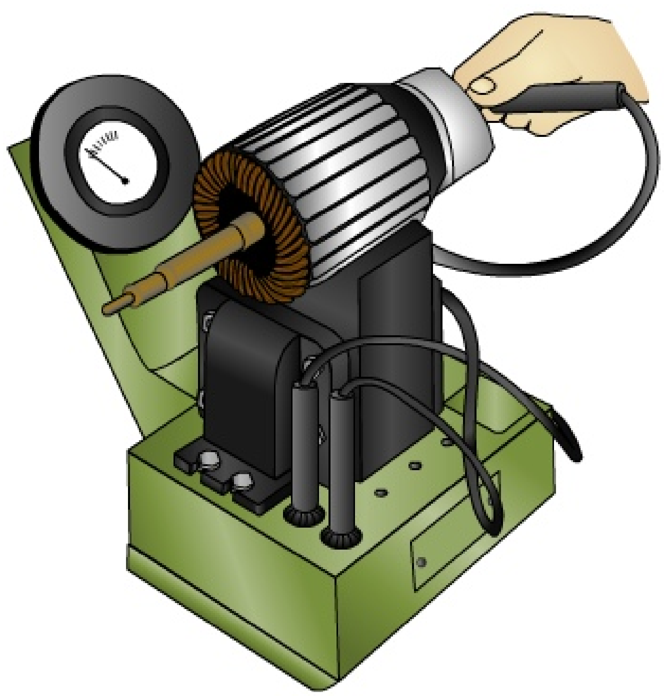

Figure 2-14 — Testing for opens in a commutator.

Check the commutator for broken leads. Repair and resolder any you find. If you find an open winding, check the commutator for burned spots. They reveal the commutator segment to which the open winding is connected. Open circuits in the windings generally occur at the commutator and can be found by a visual inspection. If there is excessive sparking at the brushes with the motor reassembled, disassemble it and replace the armature.

In testing for a grounded brush holder or rigging, touch one test lamp prod of the armature test set to the motor housing. With the other test prod, touch each brush holder individually. If the lamp lights, there is a ground in the brush holder.

CAUTION

Remove all leads to the brush holders and brushes before you attempt this test.

7.0.0 CLEANING COMMUTATORS or COLLECTOR RINGS

The color of the commutator and slip rings will indicate the type of trouble. An even chocolate-brown color indicates a normal condition, and a black color indicates brush arcing. You can remove slight burns on the commutator segments by polishing the commutator as the armature rotates. Use a canvas pad similar to the one shown in *Figure 2-15*. To remove deeper burns, use fine sandpaper instead of the canvas pad. When a commutator is deeply scored, it must be reconditioned in a lathe or with a special tool.

CAUTION

Never use emery cloth to polish commutators because the emery particles can lodge between the segments and cause the commutator circuits to short.

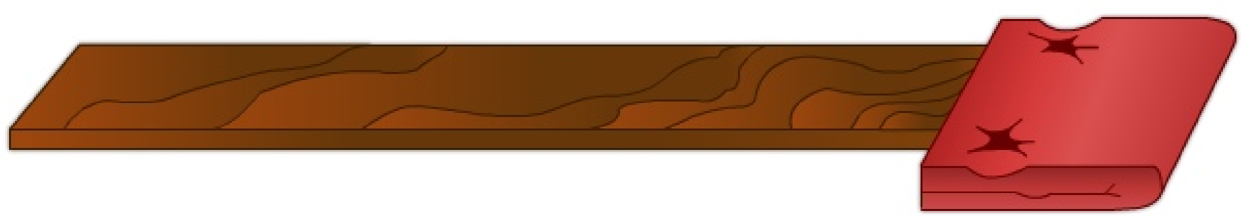

Figure 2-15 – Fabricated cleaning pad.

Slip rings used on rotors are usually made of bronze or other nonferrous metals. Under normal conditions, the wearing surface should be bright and smooth. When the rings are pitted, they should be polished. When excessively worn and eccentric, they should be trued with a special tool.

8.0.0 AC GENERATOR

Regardless of size, all electrical generators, whether dc or ac, depend upon the principle of magnetic induction. An emf is induced in a coil as a result of a coil cutting through a magnetic field, or a magnetic field cutting through a coil. As long as there is relative motion between a conductor and a magnetic field, a voltage will be induced in the conductor. That part of a generator that produces the magnetic field is called the field. That part in which the voltage is induced is called the armature. For relative motion to take place between the conductor and the magnetic field, all generators must have two mechanical parts, a rotor and a stator. The rotor is the part that rotates and the stator is the part that remains stationary. In a dc generator, the armature is always the rotor. In alternators, the armature may be either the rotor or stator.

9.0.0 ALTERNATOR CONSTRUCTION

9.1.0 Rotating-Armature Alternators

The rotating-armature alternator is similar in construction to the dc generator in that the armature rotates in a stationary magnetic field (*Figure 2-16*, *View A*). In the dc generator, the emf generated in the armature windings is converted from ac to dc by means of the commutator. In the alternator, the generated ac is brought to the load unchanged by means of slip rings. The rotating armature is found only in alternators of low power rating and generally is not used to supply electric power in large quantities.

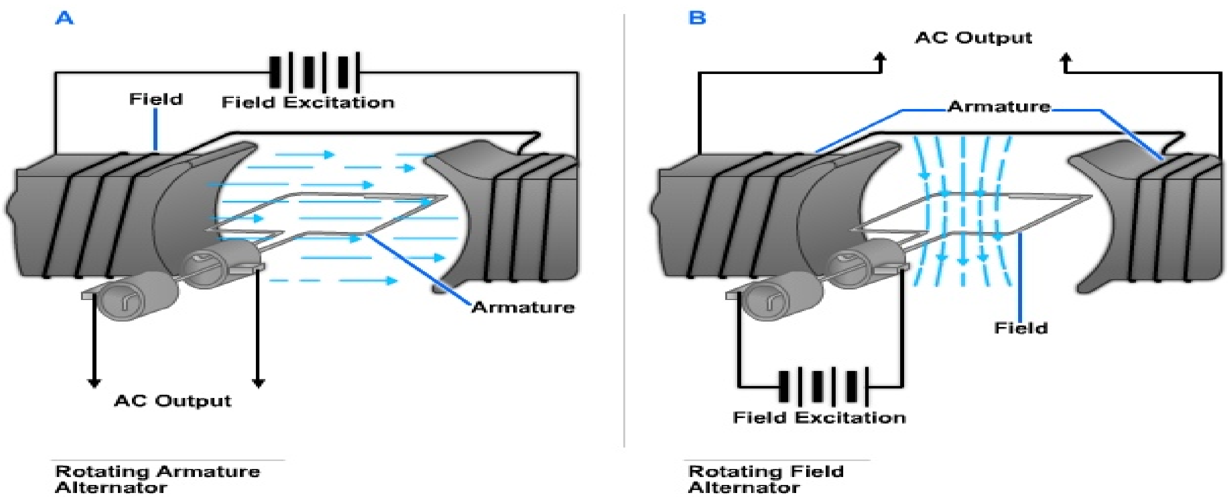

Figure 2-16 — Types of ac generators.

9.2.0 Rotating-Field Alternators

The rotating-field alternator has a stationary armature winding and a rotating-field winding (*Figure 2-16, View B*). The advantage of having a stationary armature winding is that the generated voltage can be connected directly to the load.

A rotating armature requires slip rings and brushes to conduct the current from the armature to the load. The armature, brushes, and slip rings are difficult to insulate, and arc-overs and short circuits can result at high voltages. For this reason, high-voltage alternators are usually of the rotating-field type. Since the voltage applied to the rotating field is low voltage dc, the problem of high voltage arc-over at the slip rings does not exist.

The stationary armature, or stator, of this type of alternator holds the windings that are cut by the rotating magnetic field. The voltage generated in the armature as a result of this cutting action is the ac power that will be applied to the load.

The stators of all rotating-field alternators are about the same. The stator consists of a laminated iron core with the armature windings embedded in this core (*Figure 2-17*). The core is secured to the stator frame.

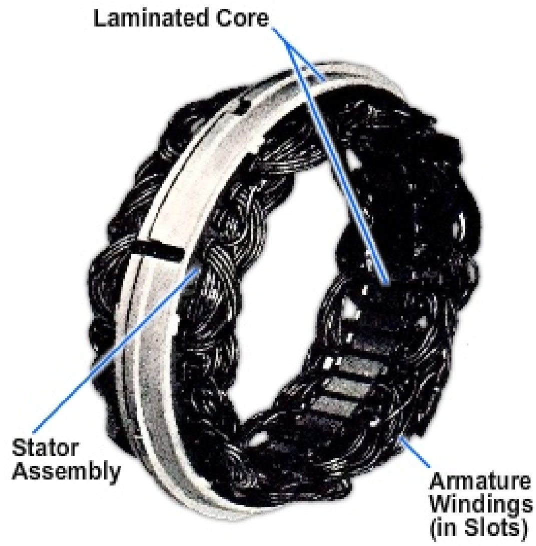

Figure 2-17 – Stationary armature windings

9.3.0 Alternator Components

A typical rotating-field ac generator consists of an alternator and a smaller dc generator built into a single unit. The output of the alternator section supplies alternating voltage to the load. The only purpose for the dc exciter generator is to supply the direct current required to maintain the alternator field. This dc generator is referred to as the exciter. A typical alternator is shown in *Figure 2-18, View A*, and a simplified schematic of the generator is shown in *Figure 2-18*, *View B*.

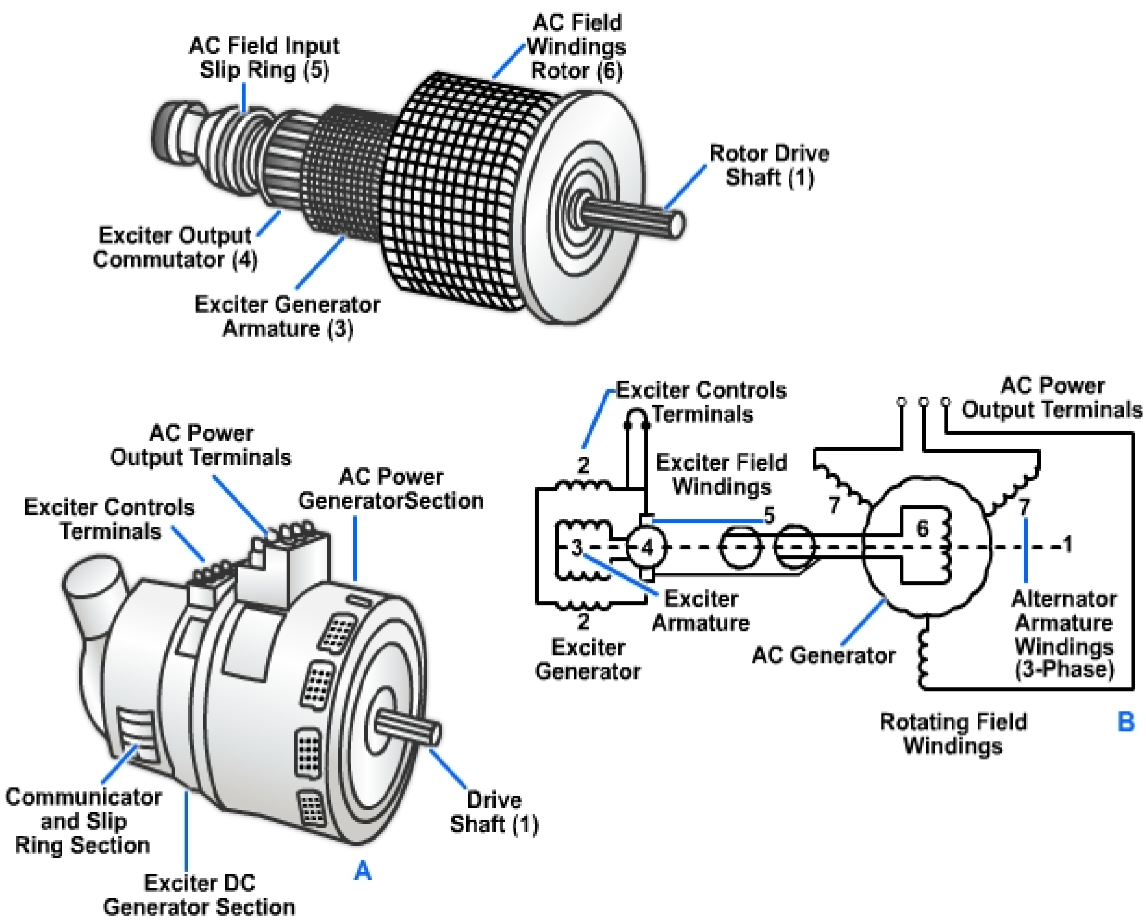

Figure 2-18 – AC generator pictorial and schematic drawings.

The exciter is a dc, shunt-wound, self-excited generator. The exciter shunt field (2) creates an area of intense magnetic flux between its poles. When the exciter armature (3) is rotated in the exciter-field flux, voltage is inducted in the exciter armature windings. The output from the exciter commutator (4) is connected through brushes and slip rings (5) to the alternator field. Since this is direct current already converted by the exciter commutator, the current always flows in one direction through the alternator field (6). Thus, a fixed-polarity magnetic field is maintained at all times in the alternator field windings. When the alternator field is rotated, its magnetic flux is passed through and across the alternator armature windings (7).

The armature is wound for a three-phase output, which will be covered later in this chapter. Remember, a voltage is induced in a conductor if it is stationary and a magnetic field is passed across the conductor, the same as if the field is stationary and the conductor is moved. The alternating voltage in the ac generator armature windings is connected through fixed terminals to the ac load.

9.4.0 Alternator Rotors

There are two types of rotors used in rotating-field alternators. They are called the turbine-driven and salient-pole rotors. As you may have guessed, the turbine-driven rotor shown in *Figure 2-19, View A* is used when the prime mover is a high-speed turbine. The windings in the turbine-driven rotor are arranged to form two or four distinct poles. The windings are firmly embedded in slots to withstand the tremendous centrifugal forces encountered at high speeds.

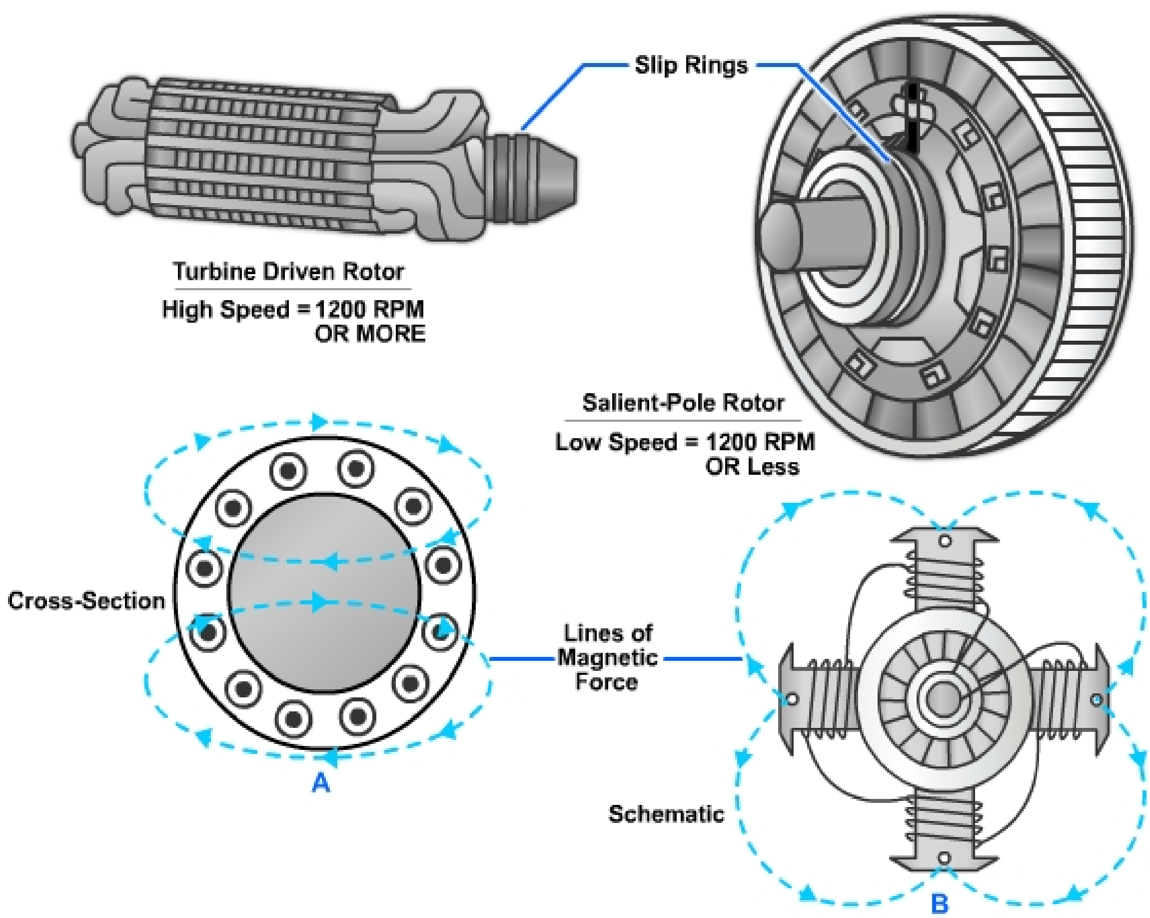

Figure 2-19 – Types of rotors used in alternators.

The salient-pole rotor shown in *Figure 2-19*, *View B* is used in low-speed alternators. The salient-pole rotor often consists of several separately wound pole pieces bolted to the frame of the rotor.

If you could compare the physical size of the two types of rotors with the same electrical characteristics, you would see that the salient-pole rotor would have a greater diameter. At the same number of revolutions per minute, it has a greater centrifugal force than does the turbine-driven rotor. To reduce this force to a safe level so that the windings will not be thrown out of the machine, the salient pole is used only in low-speed designs.

9.5.0 Alternator Characteristics and Limitations

Alternators are rated according to the voltage they are designed to produce and the maximum current they are capable of providing. The maximum current that can be supplied by an alternator depends upon the maximum heating loss that can be sustained in the armature. This heating loss, which is an I^2R power loss, acts to heat the conductors, and if excessive, destroys the insulation. Thus, alternators are rated in terms of this current and in terms of the voltage output – the alternator rating in small units is in volt-amperes; in large units it is kilovolt-amperes.

When an alternator leaves the factory, it is already destined to do a very specific job. The speed at which it is designed to rotate, the voltage it will produce, the current limits, and other operating characteristics are built in. This information is usually stamped on a nameplate on the case so that the user will know the limitations.

10.0.0 SINGLE-PHASE ALTERNATORS

A generator that produces a single, continuously alternating voltage is known as a single-phase alternator. All of the alternators that have been discussed so far fit this definition. The stator (armature) windings are connected in series. The individual voltages, therefore, add to produce a single-phase ac voltage. *Figure 2-20* shows a basic alternator with its single-phase output voltage.

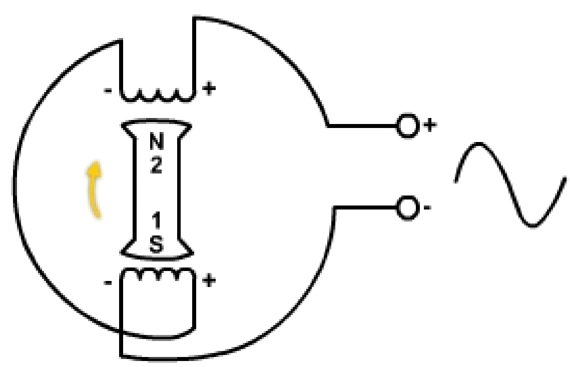

Figure 2-20 – Single-phase alternator.

The definition of phase as you learned it in studying ac circuits may not help too much right here. Remember, “out of phase” meant “out of time.”

Now, it may be easier to think of the word “phase” as meaning voltage as in single voltage. The need for a modified definition of phase in this usage will be easier to see as you progress through this chapter.

Single-phase alternators are found in many applications. They are most often used when the loads being driven are relatively light. The reason for this will be more apparent as you get into multiphase alternators, also called polyphase.

Power that is used in homes, shops, and ships to operate portable tools and small appliances is single-phase power. Single-phase power alternators always generate single-phase power. However, all single-phase power does not come from single-phase alternators. This will sound more reasonable to you as this chapter continues.

11.0.0 THREE-PHASE ALTERNATOR

The three-phase alternator, as the name implies, has three single-phase windings spaced such that the voltage induced in any one phase is displaced by 120° from the other two. A schematic diagram of a three-phase stator showing all the coils becomes complex, and it is difficult to see what is actually happening. The simplified schematic of *Figure 2-21*, *View A* shows all the windings of each phase lumped together as one winding. The rotor is omitted for simplicity. The voltage waveforms generated across each phase are drawn on a graph, phase-displaced 120° from each other. The three-phase alternator as shown in this schematic is made up of three single-phase alternators whose generated voltages are out of phase by 120°. The three phases are independent of each other.

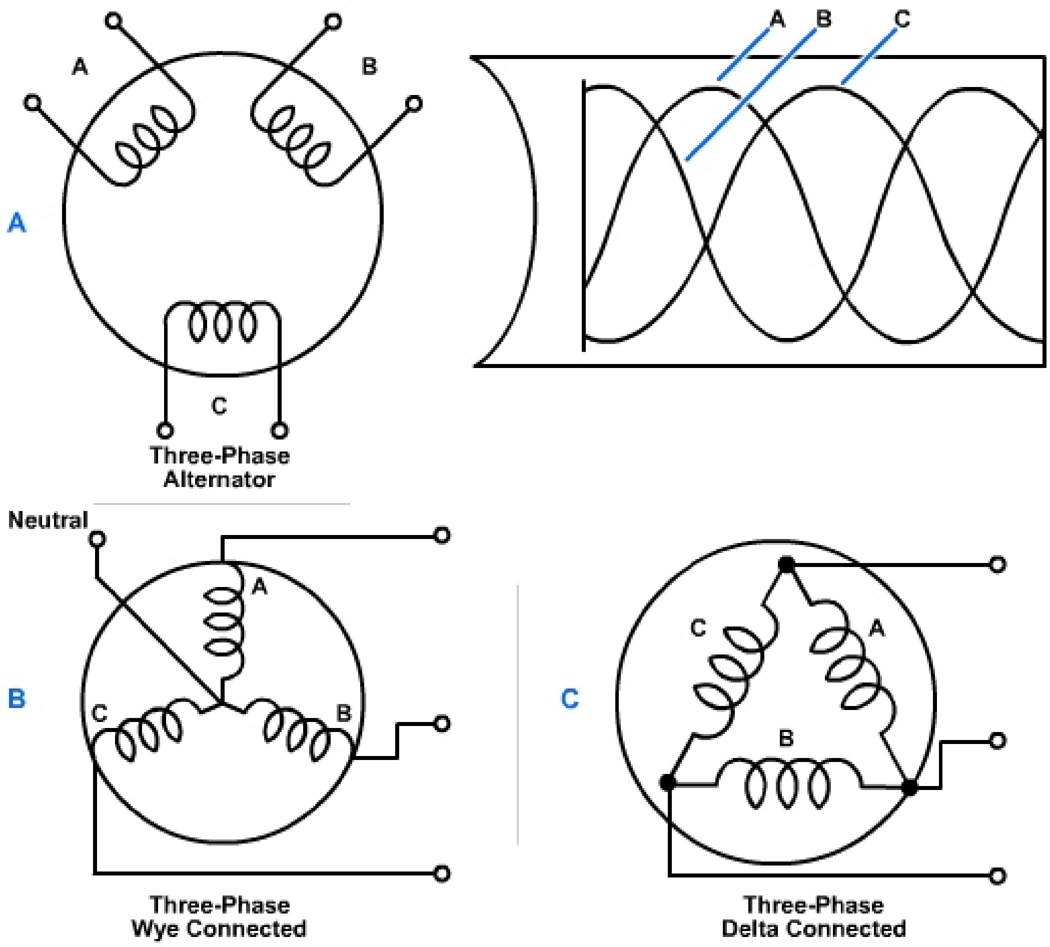

Figure 2-21 – Three-phase alternator connections.

Rather than having six leads coming out of the three-phase alternator, the same leads from each phase may be connected together to form a wye (Y) connection (*Figure 2-21*, *View B)*. It is called a wye connection because, without the neutral, the windings appear as the letter Y, in this case sideways or upside down.

The neutral connection is brought out to a terminal when a single-phase load must be supplied. Single-phase voltage is available from neutral to A, neutral to B, and neutral to C.

In a three-phase, Y-connected alternator, the total voltage, or line voltage, across any two of the three line leads is the vector sum of the individual phase voltages. Each line voltage is 1.73 times one of the phase voltages. Because the windings form only one path for current flow between phases, the line and phase currents are the same or equal.

A three-phase stator can also be connected so that the phases are connected end-to-end; it is now delta connected (*Figure 2-21, View C).* It is called delta because it looks like the Greek letter delta (Δ). In the delta connection, line voltages are equal to phase voltages, but each line current is equal to 1.73 times the phase current. Both the wye and the delta connections are used in alternators. The majority of all alternators in use in the Navy today are three-phase machines. They are much more efficient than either two-phase or single-phase alternators.

11.1.0 Three-Phase Connections

The stator coils of three-phase alternators may be joined together in either wye or delta connections (*Figure 2-22*). With these connections only three wires come out of the alternator. This allows convenient connection to three-phase motors or power distribution transformers. It is necessary to use three-phase transformers or their electrical equivalent with this type of system.

A three-phase transformer may be made up of three, single-phase transformers connected in delta, wye, or a combination of both. If both the primary and secondary are connected in wye, the transformer is called a wye-wye. If both windings are connected in delta, the transformer is called a delta-delta.

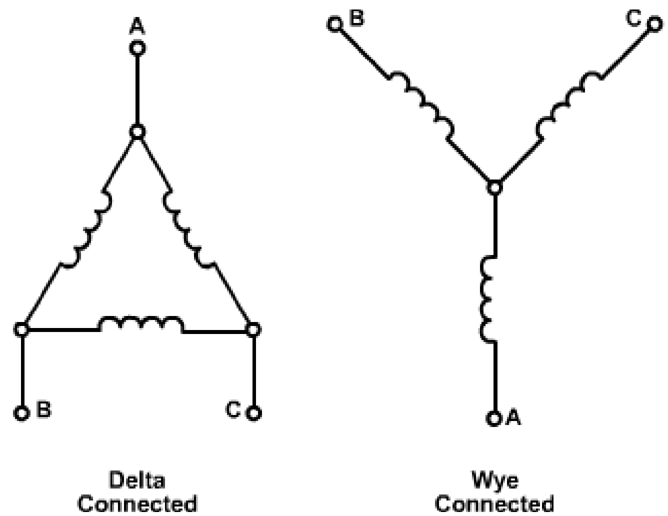

Figure 2-22 — Three-phase alternator or transformer connections.

Figure 2-23 shows single-phase transformers connected delta-delta for operation in a three-phase system. You will note that the transformer windings are not angled to illustrate the typical delta (Δ) as has been done with alternator windings. Physically, each transformer in the diagram stands alone. There is no angular relationship between the windings of the individual transformers. However, if you follow the connections, you will see that they form an electrical delta. The primary windings, for example, are connected to each other to form a closed loop. Each of these junctions is fed with a phase voltage from a three-phase alternator. The alternator may be connected either delta or wye depending on load and voltage requirements, and the design of the system.

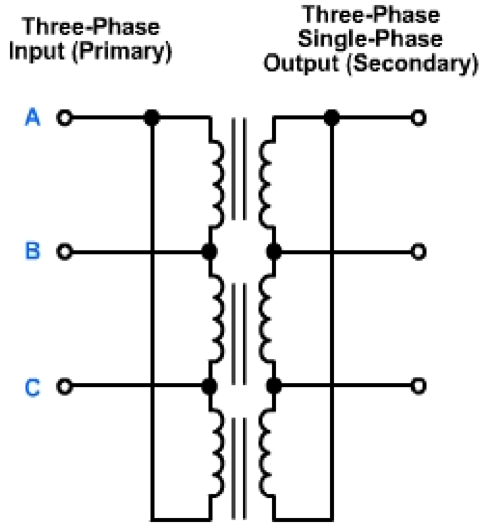

Figure 2-23 – Three single-phase transformers connected delta-delta.

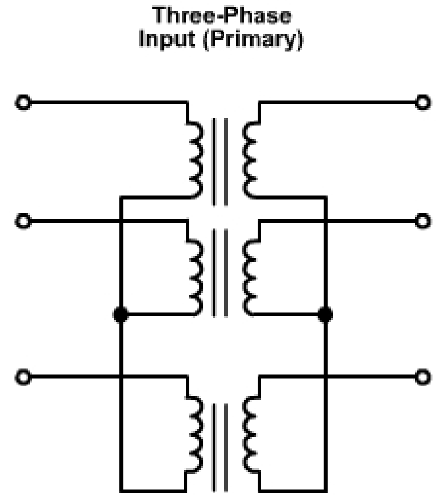

Figure 2-24 – Three single-phase transformers connected wye-wye.

Figure 2-24 shows three-phase transformers connected wye-wye. Again, note that the transformer windings are not angled. Electrically, a Y is formed by the connections. The lower connections of each winding are shorted together. These form the common point of the wye. The opposite end of each winding is isolated. These ends form the arms of the wye.

The ac power on most ships is distributed by a three-phase, three-wire, 450-volt system. The single-phase transformers step the voltage down to 117 volts. These transformers are connected delta-delta as in *Figure 2-23*. With a delta-delta configuration, the load may be a three-phase device connected to all phases, or it may be a single-phase device connected to only one phase.

At this point, it is important to remember that such a distribution system includes everything between the alternator and the load. Because of the many choices that three-phase systems provide, care must be taken to ensure that any change of connections does not provide the load with the wrong voltage or the wrong phase.

12.0.0 FREQUENCY

The output frequency of alternator voltage depends upon the speed of rotation of the rotor and the number of poles. The faster the speed, the higher the frequency. The lower the speed, the lower the frequency. The more poles there are on the rotor, the higher the frequency is for a given speed. When a rotor has rotated through an angle such that two adjacent rotor poles (a north and a south pole) have passed one winding, the voltage induced in that winding will have varied through one complete cycle. For a given frequency, the more pairs of poles there are, the lower the speed of rotation. This principle is illustrated in *Figure 2-25*; a two-pole generator must rotate at four times the speed of an eight-pole generator to produce the same frequency of generated voltage. The frequency of an ac generator in hertz (H_Z), which is the number of cycles per second, is related to the number of poles and the speed of rotation, as expressed by the equation $F = \frac{NP}{120}$ where P is the number of poles, N is the speed of rotation in revolutions per minute (rpm), and 120 is a constant to allow for the conversion of minutes to seconds and from poles to pairs of poles. For example, a 2-pole, 3600-rpm alternator has a frequency of 60 H_Z, and is determined as follows:

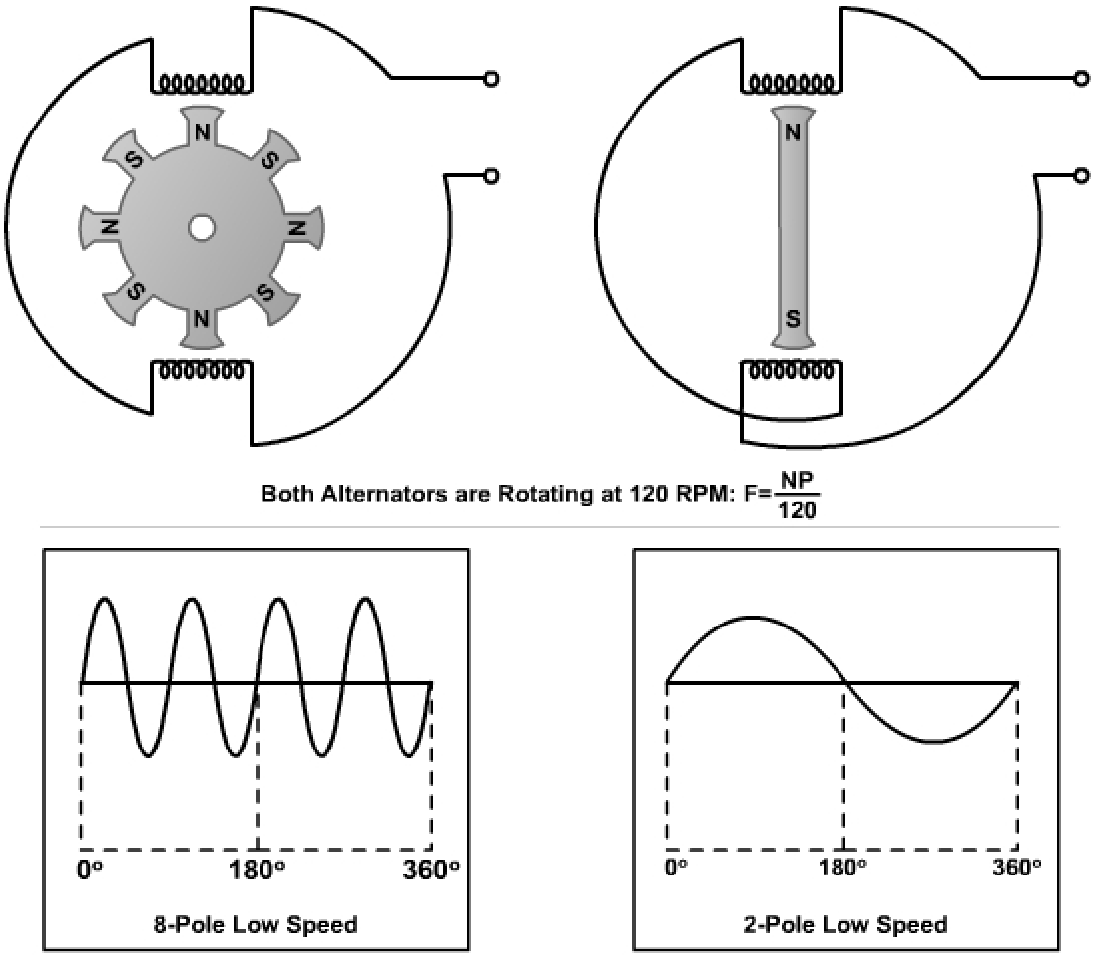

Figure 2-25 – Frequency regulation.

$$\frac{2 \times 3600}{120} = 60 H_Z$$

A 4-pole, 1800-rpm generator also has a frequency of 60 H_Z. A 6-pole, 500-rpm generator has a frequency of:

$$\frac{6 \times 500}{120} = 25\ H_Z$$

A 12-pole, 4000-rpm generator has a frequency of:

$$\frac{12 \times 4000}{120} = 400\ H_Z$$

13.0.0 INSTALLATION

Several factors should be considered before a final decision is made about where to locate a generator. The noise levels of generators sized from 5 kW to 200 kW range from 77 dBa to 93 dBa (adjusted decibels) at 25 feet. Generator noise is a problem in low-noise level or quiet areas (libraries, offices, hospitals, chapels, etc.). The operating 6 kW generator, for example, presents a noise hazard (84 dBa to 91dBa, depending on the model) to all personnel in the immediate area. The noise level near the unit exceeds the allowable limits for unprotected personnel. Therefore, everyone working around the generator needs single (noise < 84 dBa) or double hearing protection (noise > 104 dBa).

Placing a generator set near points of large demand will reduce the size of wire required, hold the line losses to a minimum, and afford adequate voltage control at the remote ends of the lines.

The following points should be considered before an exact site is chosen for a generator set:

1. Generators must not be closer than 25 feet (7.6 meters) to a load because of noise, fire hazard, and air circulation.
2. The set must be placed on a stable, preferably level, foundation. It should not be operated while inclined more than 15 degrees from level.
3. The site must be within 25 feet (7.6 meters) of any paralleled generator set and within 25 feet (7.6 meters) of any auxiliary fuel supply.
4. When preparing a temporary installation, you should move the generator set as close to the jobsite as practical. In an area where the ground is soft, do not remove the wood-skid base if you have not already done so. The wood-skid base will establish a firm foundation on soft ground, mud, or snow; otherwise, use planks, logs, or other material for a base in an area where the ground is soft.

13.1.0 Site Selection

Before selecting a site, study a plot or chart of the area on which the individual buildings and facilities have been plotted (*Figure 2-26).* Select a site large enough to meet present and anticipated needs. Then select a location with sufficient space on all sides for servicing and operating the unit. It should be level, dry, and well drained. If this type

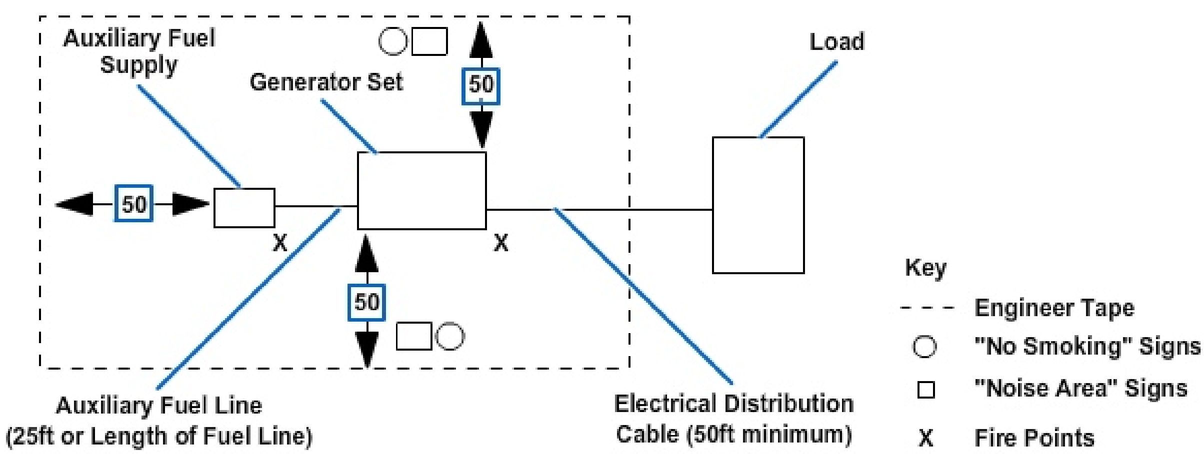

Figure 2-26 – Generator site selection.

of site is not available, place the generator set on planks or logs for a suitable base foundation.

13.2.0 Sheltering the Generator

Although advanced-base portable generators are designed to be operated outdoors, prolonged exposure to wind, rain, and other adverse conditions will definitely shorten their lives. When the generators are to remain on the site for any extended period of time, they should be mounted on solid-concrete foundations and should be installed under some type of shelter (*Figure 2-27*).

Figure 2-27 – Generator shelter.

There are no predrawn plans for shelters for a small advanced-base generating station. The shelter will be an on-the-spot affair–the construction of which is determined by the equipment and material on hand plus your ingenuity, common sense, and ability to cooperate with personnel in other ratings. Before a Builder (BU) can get started on the shelter, you will have to furnish information such as the number of generators to be sheltered, the dimensions of the generators, the method of running the generator load cables from the generator to the panelboard and from the panelboard to the feeder system outside the building, and the arrangement of the exhaust system.

Large generator units may have, connected or attached to them, engine equipment that requires extra space and working area. Included in this equipment are air-intake filters, silencers for air intake and exhaust, fuel and lubricating oil pumps, tanks, filters, and strainers. Also included are starting gear, isochronous regulating governors with over-speed trips, safety alarm and shutdown devices, gauges and thermometers, turning gear, along with platforms, stairs, and railings.

An even larger and more complete power plant may require separate equipment, such as a motor-driven starting air compressor and air storage tanks; motor-driven pumps for jacket water and lubricating oil cooling or heat exchangers with raw cooling water pumps and lubricating oil coolers; and tanks that include day-fuel storage.

Be sure to provide enough working space around each unit for repairs or disassembly and for easy access to the generator control panels. Installation specifications are available in the manufacturer’s instruction manual that accompanies each unit. Be sure to use them. Consulting with the Builder (BU) about these specifications may help cut installation costs and solve future problems affecting the shelter of the generator.

13.3.0 Generator Set Inspection

After setting up a portable generator, your crew must do some preliminary work before placing it in operation. First, they should make an overall visual inspection of the generator. Have them look for broken or loose electrical connections, bolts, and cap screws, and see that the ground terminal wire (No. 6 American Wire Gauge (AWG) minimum) is properly connected to the ground rod/grounding system. Check the technical manual furnished with the generator for wiring diagrams, voltage outputs, feeder connections, and prestart preparation. If you find any faults, correct them immediately.

13.3.1 Generator Connections

When you and your crew install a power plant that has a dual voltage alternator unit, make certain that the stator coil leads are properly connected to produce the voltage required by the equipment. Proper grounding is also a necessity for personnel safety and for prevention of unstable, fluctuating generator output.

13.3.1.1 Internal Leads

The voltage changeover board permits reconnection of the generator phase windings to give all specified output voltages (*Figure 2-28*). One end of each coil of each phase winding runs from the generator through an instrumentation package and a static exciter current transformer to the reconnection panel. This routing assures current sensing in each phase regardless of voltage connection at the reconnection board assembly. The changeover board assembly is equipped with a voltage change board to facilitate conversion to 120/208 or 240/416 generator output voltage. Positioning of the voltage change board connects two coils of each phase in series or in parallel. In parallel, the output is 120/208; in series, the output is 240/416 volts ac. The terminals on the changeover board assembly for connection to the generator loads are numbered according to the particular coil end of each phase of the generator to ensure proper connections.

Figure 2-28 – Typical changeover board assembly.

Remember that you are responsible for the proper operation of the generating unit; therefore, proceed with caution on any reconnection job. Study the wiring diagrams of the plant and follow the manufacturer's instructions to the letter. Before starting the plant up and closing the circuit breaker, double-check all connections.

13.4.0 Grounding

The generator set must be connected to a suitable ground before operation (*Figure 2-29*).

WARNING

Electrical faults in the generator set, load lines, or load equipment can cause injury or electrocution from contact with an ungrounded generator.

Figure 2-29 – Generator start up warning label.

13.4.1 Grounding Procedures

The ground can be, in order of preference, an underground metallic water piping system (*Figure 2-30, View A*), a driven metal rod (*Figure 2-30*, *View B*), or a buried metal plate (*Figure 2-30*, *View C*). A ground rod must have a minimum diameter of 5/8 inches if solid or ¾ inches if pipe. The rod must be driven to a minimum depth of 8 feet. A ground plate must have a minimum area of 2 square feet and, where practical, be embedded below the permanent moisture level.

The ground lead must be at least No. 6 AWG copper wire. Be sure to bolt or clamp the lead to the rod, plate, or piping system. Connect the other end of the ground lead to the generator set ground terminal stud (*Figure 2-31*, *View A*).

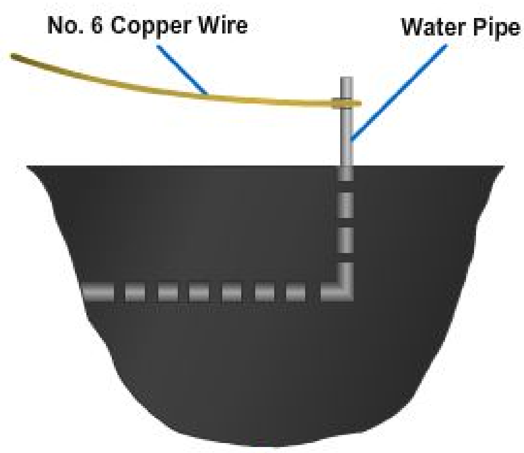

Figure 2-30 – Methods of grounding generators.

Use the following procedure to install ground rods:

- Install the ground cable into the slot in the ground stud and tighten the nut against the cable.
- Connect a ground rod coupling to the rod and install the driving stud in the coupling (*Figure 2-31*, *View B*). Make sure that the driving stud is bottomed on the ground rod.
- Drive the ground rod into the ground until the coupling is just above the ground surface.
- Connect additional rod sections, as required, by removing the driving stud from the coupling. Make sure the new ground rod section is bottomed on the ground rod section previously installed. Connect another coupling on the new section and again install the driving stud.

- After the rod(s) have been driven into the ground, remove the driving stud and the top coupling.

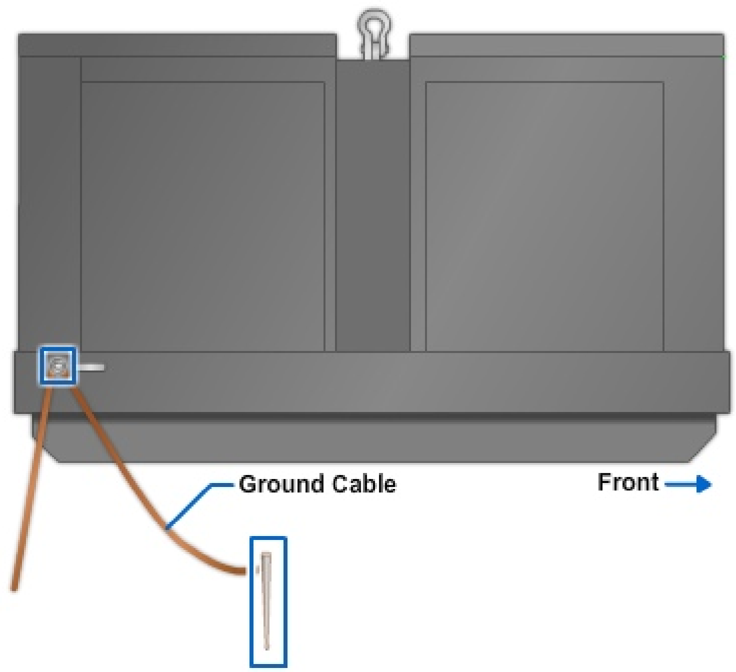

Figure 2-31 – Grounding procedure.

NOTE

The National Electrical Code© states that a single electrode consisting of a rod, pipe, or plate that does not have a resistance to ground of 25 ohms or less will be augmented by additional electrodes. Where multiple rod, pipe, or plate electrodes are installed to meet the requirements, they will be not less than 6 feet apart.

The resistance of a ground electrode is determined primarily by the earth surrounding the electrode. The diameter of the rod has only a negligible effect on the resistance of a ground. The resistance of the soil is dependent upon the moisture content. Electrodes should be long enough to penetrate a relatively permanent moisture level and should extend well below the frost line. Make periodic earth resistance measurements, preferably at times when the soil can be expected to have the least moisture.

You need to test the ground rod installation to be sure it meets the requirement for minimum earth resistance. Use the earth resistance tester to perform the test. You should make this test before you connect the ground cable to the ground rod.

When ground resistances are too high, they may be reduced by one of the following methods:

- Using additional ground rods is one of the best means of reducing the resistance to ground. For example, the combined resistance of two rods properly spaced and connected in parallel should be 60 percent of the resistance of one rod; the combined resistance of three rods should be 40 percent of that of a single rod.
- Longer rods are particularly effective where low-resistance soils are too far below the surface to be reached with the ordinary length rods. The amount of improvement from the additional length on the rods depends on the depth of the low-resistance soils. Usually, a rather sharp decrease in the resistance measurements is noticeable when the rod has been driven to a low-resistance level.
- Treating the soil around ground rods is a reliable and effective method for reducing ground resistance and is particularly suitable for improving high resistance ground. The treatment method is advantageous where long rods are impractical because of rock strata or other obstructions to deep driving. There are practical ways of accomplishing this result (*Figure 2-32*). Where space is limited, a length of tile pipe is sunk in the ground a few inches from the ground rod and tilled to within 1 foot or so of the ground level with the treatment chemical (*Figure 2-32*, *View A*). Examples of suitable non-corrosive materials are magnesium sulfate, copper sulfate, and ordinary rock salt. The least corrosive is magnesium sulfate, but rock salt is cheaper and does the job.
- The second method is applicable where a circular or semicircular trench can be dug around the ground rod to hold the chemical (*Figure 2-32*, *View B*). The chemical must be kept several inches away from direct contact with the ground rod to avoid corrosion of the rod. If you wish to start the chemical action promptly, flood the treatment material. The first treatment usually contains 50 to 100 pounds of material. The chemical will retain its effectiveness for 2 to 3 years. Each replenishment of the chemical extends the effectiveness for a longer period so that the necessity for future retreating becomes less and less frequent.
- A combination of methods may be advantageous and necessary to provide desired ground resistance. A combination of multiple rods and soil treatment is effective and has the advantages of both of these methods; multiple long rods are effective where conditions permit this type of installation.

After you are sure you have a good ground, connect the clamp and the ground cable to the top ground rod section, and secure the connection by tightening the screw (*Figure 2-32, View B*).

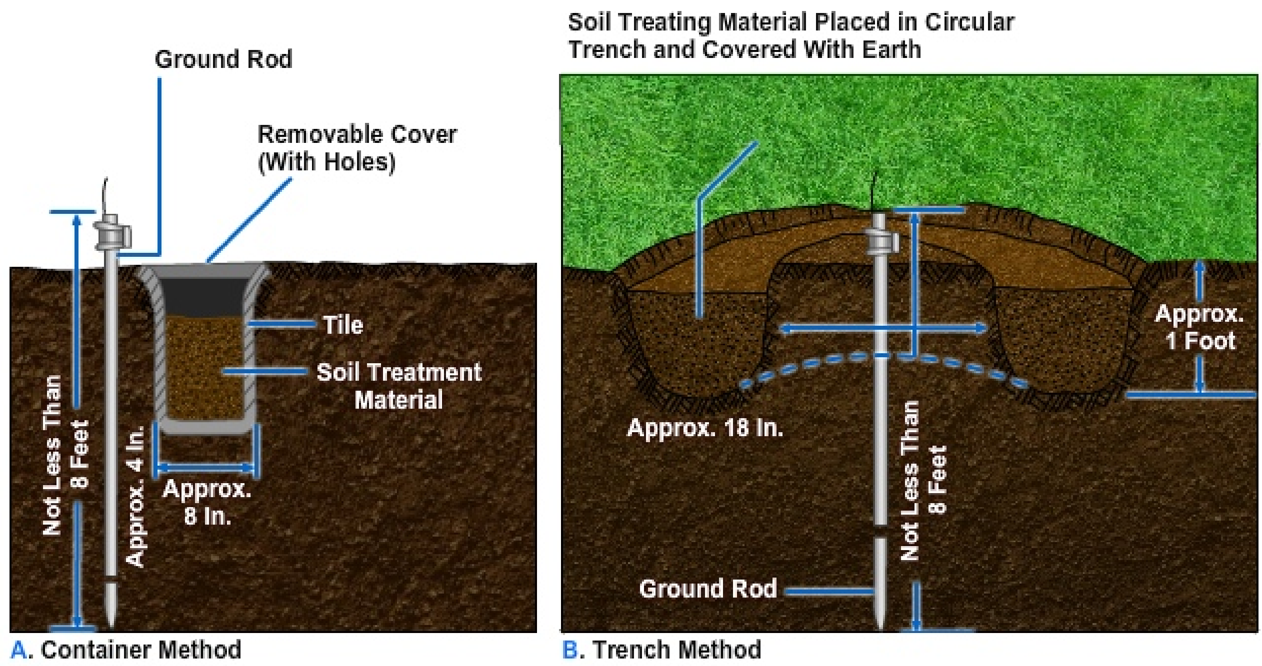

Figure 2-32 – Methods of soil treatment for lowering of ground resistance.

13.4.2 Grounding Connections

A typical generator set is outlined in *Figure 2-33*, showing the load cables and output load terminals.

WARNING

Before attempting to connect the load cables to the load terminals of a generator set, make sure the set is not operating and there is no input to the load.

Refer to *Figure 2-33* as you follow this procedural discussion for making load connections.

1. Open the access door and disconnect the transparent cover by loosening six quick-release fasteners. Remove the wrench clipped to the cover. Be sure to maintain the proper phase relationship between the cable and the load terminals, that is, A0 to L1, B0 to L2, and so forth.
2. Attach the load cables in the following order: L0, L3, L2, and L1 as specified in Step 3 below.
3. Insert the load cables through the protective sleeve. Attach the cables to their respective load terminals, one cable to each terminal, by inserting the cable in the terminal slot and tightening the terminal nut with the wrench that was clipped to the transparent cover. Install the wrench on the cover and install the cover.

4. Tighten the drawstring on the protective sleeve to prevent the entry of foreign matter through the hole around the cable.

You may convert the voltage at the load terminals to 120/208 volts or 240/416 volts by properly positioning the voltage change board (*Figure 2-28*). The board is located directly above the load terminal board.

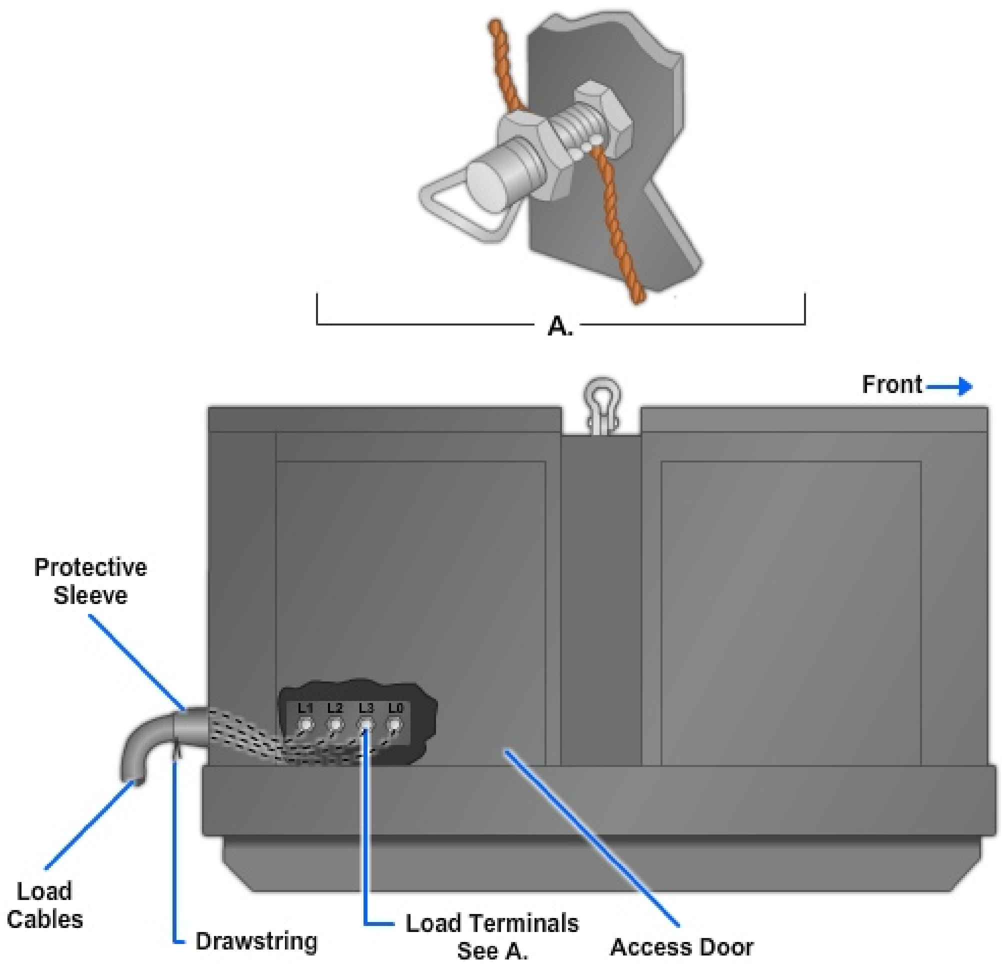

Figure 2-33 – Load cable connections.

The procedure for positioning the voltage change board for the required output voltage is as follows:

1. Disconnect the transparent cover by loosening the six quick-release fasteners.
2. Remove the 12 nuts from the board. Move the change board up or down to align the change board arrow with the required voltage arrow. Tighten the 12 nuts to secure the board.
3. Position and secure the transparent cover with the six quick-release fasteners and close the access door.

13.4.3 Generator Connections

When you install a power plant that has a dual voltage alternator unit, make certain that the stator coil leads are properly connected to produce the voltage required by the equipment.

Proper grounding is also a necessity for personnel safety and for prevention of unstable, fluctuating generator output.

13.4.3.1 Internal Leads

The voltage changeover board permits reconnection of the generator phase windings to give all specified output voltages. One end of each coil of each phase winding runs from the generator through an instrumentation and a static exciter current transformer to the reconnection panel. This routing assures current sensing in each phase regardless of voltage connection at the reconnection board assembly. The changeover board assembly is equipped with a voltage change board to facilitate conversion to 120/208 or 240/416 generator output voltage. Positioning of the voltage change board connects two coils of each phase in series or in parallel. In parallel, the output is 240/416; in series, the output is 120/208 volts ac. The terminals on the changeover board assembly for connection to the generator loads are numbered according to the particular coil end of each phase of the generator to ensure proper connections.

Remember, you are responsible for the proper operation of the generating unit; therefore, proceed with caution on any reconnection job. Study the wiring diagrams of the plant and follow the manufacturer's instructions to the letter. Before you start the plant up and close the circuit breaker, double-check all connections.

13.4.3.2 Grounding

It is imperative to solidly ground all electrical generators operating at 600 volts or less. The ground can be, in order of preference, an underground metallic water piping system, a driven metal rod, or a buried metal plate. A ground rod has to have a minimum diameter of 5/8 inch if solid and 3/4 inch if pipe, and it has to be driven to a minimum of 8 feet. A ground plate has to be a minimum of 2 square feet and be buried at a minimum depth of 2 l/2 feet. For the ground lead, use No. 6 AWG copper wire and bolt or clamp it to the rod, plate, or piping system. Connect the other end of the ground lead to the generator set ground stud.

The National Electrical Code® states that a single electrode consisting of a rod, pipe, or plate that does not have a resistance to ground of 25 ohms or less will be augmented by additional electrodes. Where multiple rod, pipe, or plate electrodes are installed to meet the requirements, they are required to be not less than 6 feet apart.

It is recommended that you perform an earth resistance test before you connect the generator to ground. This test will determine the number of ground rods required to meet the requirements, or the necessity of constructing a ground grid.

13.4.3.3 Feeder Cable Connections

While the electric generator is being installed and serviced, a part of your crew can connect it to the load. Essentially, this connection consists of running wire or cable from the generator to the load. At the load end, the cable is connected to a distribution terminal. At the generator end, the cable is connected either to the output terminals of a main circuit breaker or a load terminal board. Before running the wires and making the connections, do the following:

- Determine the correct size of wire or cable to use.
- Decide whether the wire or cable will be buried, carried overhead on poles, or run in conduit.
- Check the generator lead connections of the plant to see that they are arranged for the proper voltage output.

13.4.3.3.1 Cable Selection

If you use the wrong size conductor in the load cable, various troubles may occur. If the conductor is too small to carry the current demanded by the load, it will heat up and possibly cause a fire or an open circuit. Even though the conductor is large enough to carry the load current safely, its length might result in a lumped resistance that produces an excessive voltage drop. An excessive voltage drop results in a reduced voltage at the load end. This voltage drop should not exceed 3 percent for power loads, 3 percent for lighting loads, or 5 percent for combined power and lighting loads.

Select a feeder conductor capable of carrying 150 percent of rated generator amperes to eliminate overloading and voltage drop problems. Refer to the National Electrical Code® tables for conductor ampacities. The tables are 310-16, 310-17, 310-18, and 310-19. Also refer to the notes to ampacity tables following Table 310-19 in the NEC®.

13.4.3.3.2 Cable Installation

The load cable may be installed overhead or underground. In an emergency installation, time is the important factor. It may be necessary to use trees, pilings, 4 by 4s, or other temporary line supports to complete the installation. Such measures are temporary; eventually, you will have to erect poles and string the wire or bury it underground. If the installation is near an airfield, it may be necessary to place the wires underground at the beginning. Wire placed underground should be direct burial, rubber-jacketed cable; otherwise, it will not last long.

Direct burying of cable for permanent installation calls for a few simple precautions to ensure uninterrupted service. They are as follows:

- Dig the trench deep enough to bury the cable at least 18 inches (24 inches in traffic areas and under roadways) below the surface of the ground to prevent disturbance of the cable by frost or subsequent surface digging.
- After laying the cable and before backfilling, cover it with soil free from stones, rocks, and so forth. That will prevent the cable from being damaged in the event the surrounding soil is disturbed by flooding or frost heaving.

14.0.0 OPERATION of POWER PLANT

When you are in charge of a generating station, you will be responsible for scheduling around-the-clock watches to ensure a continuous and adequate supply of electrical power. Depending on the number of operating personnel available, the watches are evenly divided over the 24-hour period. A common practice is to schedule 6-hour watches, or they may be stretched to 8-hour watches without working undue hardship on the part of the crew members. Avoid watches exceeding 8 hours, however, unless emergency conditions dictate their use.

The duties assigned to the personnel on generator watches can be grouped into three main categories: (1) operating the equipment, (2) maintaining the equipment, and (3) keeping the daily operating log. Operating and maintaining the generating equipment