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ABSTRACT

Subjects covered in this text are controlling the hydroelectric generator, generator excitation, basic principles of direct current generation, direction of current flow, basic alternating current generator, alternating and direct current voltage outputs, converting alternating current to direct current, review of the basic generator and commutation, generator components, eddy currents, classification of direct current generators, generator buildup, the series generator, the shunt generator, the compound generator, commutation, armature reaction, and review of direct current generators. Thirty figures supplement the text. Forty test questions and answers are included. (MS)

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

TRAINING COURSE FOR POWER OPERATING PERSONNEL

LESSON NO. VI
ALTERNATING-CURRENT GENERATOR EXCITATION

ENGINEERING AND RESEARCH CENTER
DIVISION OF POWER OPERATION AND MAINTENANCE
DENVER, COLORADO

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Happiness is a habit - cultivate it!
--Elbert Hubbard

Happiness - a good bank account, a good cook, and good digestion.
--Jean-Jacques Rosseau

It's pretty hard to tell what brings happiness. Poverty and wealth have both failed.
--K. E. Hubbard

A man's happiness is to do a man's true work.
--Marcus Aurelius

The best way to secure future happiness is to be as happy as is rightfully possible today.
--Charles W. Eliot

He is not happy who does not think himself so.
--Publius Syrus

Happiness is a by-product of an effort to make someone else happy.
--Gretta Palmer

RANDOM QUOTATIONS ON HAPPINESS

The happiest people seem to be those who have no particular cause for being happy except that they are so.

You have to believe in happiness or happiness never comes.

And if thou wouldst be happy, learn to please.

The happy people are those who are producing something; the bored people are those who are consuming much and producing nothing.

Happiness is the half-way station between too much and too little.

LESSON NO. VI

ALTERNATING-CURRENT GENERATOR EXCITATION

Note: All figures referred to herein are on foldout sheets at the end of the lesson.

Controlling the Hydroelectric Generator

Hydraulic turbines, governors for hydraulic turbines, alternating-current generators, and alternating-current generator components have been covered in previous lessons. The hydroelectric generator will operate as it should when proper control devices are used. The two major devices that control the operation of a hydroelectric generator are the governor and the voltage regulator.

These two devices, the governor and the voltage regulator, determine the way the hydroelectric unit operates whether in isolated operation or as part of an interconnected system. Usually an interconnected system is so large that the operation of a single generating unit does not affect the voltage or frequency of the system. With the installation of large, 600,000-kw units, this philosophy may change. Today the operations office for a system usually controls, at will, all units connected to the system.

A hydroelectric generating unit, when connected to an infinite system, must operate at desired voltages within its range. The exciter and voltage regulator provide the desired rotor current in the generator to control its voltage and reactive power (var) output. The system of course must supply the var demand of the load connected to it. The generating plants tied to the system must supply the var requirements of the system. Usually the system operating center will use the larger generating stations to regulate power and voltage and vars. This is done by controlling the speed adjustment of the governor and the voltage regulator.

Most of the Bureau's hydroelectric generating stations are in between the large and small categories, with some of each. In any case the governor, by controlling the output of the hydroturbine, controls the watt output and frequency of the alternating-current generator. The exciter and its voltage regulator, by controlling the generator rotor current, control the voltage and vars at which the alternating-current generator will operate for a given output.

As the watt load is increased on alternating-current generators connected in parallel, there is a reduction in their speed which is sensed by their governors. The governors act to restore the speed to normal. The division of watt load between the alternating-current generators is determined by the characteristics of the hydroturbines and their governors. Control of the watt load on a hydrogenerating unit is obtained by adjusting the governor speed characteristic. This may be done manually or automatically, depending upon the control equipment in the powerplant.

The voltage applied to a load connected to alternating-current generators operating in parallel is determined by the direct current flowing in their rotors. Identical alternating-current generators with identical hydroturbine speed-governing characteristics will share the watt load equally, and with equal excitation, that is, equal direct-current amperes in each rotor, will share the reactive volt-amperes (vars) equally.

Generator Excitation

Excitation of a hydroelectric alternating-current generator may simply be stated as the regulated flow of direct current through its rotor to produce the desired characteristics of voltage and var loading.

Historically, control of hydroelectric alternating-current generator excitation was primarily designed for control of the unit voltage. Modern excitation systems contrast with older systems in their ability to use the excitation of the alternating-current generator to obtain maximum performance of the generator under disturbed system conditions. The older models will efficiently perform the task of regulating alternating-current generator voltage for normal changes in loading, but do not possess the extremely rapid response or rotor-forcing ability necessary to give maximum stability to the alternating-current generator when the system is subjected to short circuits, interconnected power swings, or other system disturbances.

Remember, changing the direct current flowing in the rotor of an alternating-current generator only changes the voltage and reactive power and not the kilowatt output of the generator. The exciter of an alternating-current generator is the component that supplies the direct current in the generator rotor. It is important to quickly and accurately control the direct current delivered to the rotor of the generator if we wish to improve voltage conditions and stability of interconnected systems.

The exciter is designed to provide adequate direct current in the rotor of the alternating-current generator, thus creating the required magnetic flux to cut across the armature stator windings and produce the desired alternating-current generator output voltage. The voltage in the rotor of the exciter is the same as on the rotor of the generator.

The importance of the excitation system for hydroeletric generating units cannot be emphasized too strongly. Its availability at all times is of paramount importance. Loss of excitation of a unit on a bus results in a more serious disturbance than that resulting from dropping the unit from the bus, because the remaining units must not only pick up the load dropped but also supply the large reactive current taken by the unexcited alternating-current generator unit. Remember, in this case the alternating-current hydroelectric unit is still connected to the bus until something removes it.

Excitation equipment should be designed with the greatest consideration for maximum possible continuity of service. Simplicity, ruggedness, "foolproofness," and reserve apparatus are important requirements. The methods in use for securing this optimum result are greatly varied, and much difference of opinion exists on which is best. Each powerplant and its intended use must be considered as a separate problem.

The excitation systems in general use at the present time are:

1. Direct-connected shaft-driven direct-current generators,

2. Separate prime mover or motor-driven direct-current generators, or

3. An alternating-current supply, through static or mercury-arc rectifiers.

So far in this unit of study, emphasis has been on excitation. The simple direct-current generator properly used and controlled becomes the most important component - the exciter - of our hydroeletric generating units.

The Basic Principles of Direct-current Generation

You will recall that electricity can be generated by moving a conductor through a magnetic field. Figure 1 illustrates that if there is relative motion between the conductor and the magnetic field, electricity is generated. If there is no relative motion between the conductor and the magnetic field, electricity is not generated. The generated electricity is actually a voltage, called an "induced voltage," and the method of generating this voltage by cutting a magnetic field with a conductor is called "induction." You also know that this induced voltage will cause a current to flow if the ends of the conductor are connected through a closed circuit, in our case, the rotor of a generator.

Figure 2 shows that the amount of voltage induced in a wire cutting through the magnetic field depends upon a number of factors. First, if the speed of the relative cutting action between the conductor and the magnetic field increases, the induced voltage increases. Second, if the strength of the magnetic field increases, the induced voltage increases. Third, if the number of turns cutting through the magnetic field is increased, the induced voltage increases.

The polarity of this induced voltage will be in such a direction that resultant current flow will build up a field to react with the field of the magnet and oppose the movement of the coil. This phenomenon illustrates a principle known as "Lenz's Law" which states that in all cases of electromagnetic induction, the direction of the induced voltage is such that the magnetic field it sets up tends to stop the motion which produced it. In our case, the rotation of the hydroturbine or the alternating-current motor, serving as the prime mover, is slowed down by the induced voltage.

Figure 3 shows how the direction of the induced current flow is affected by the direction of the relative motion between the magnetic field and the cutting conductor. If the coil moves to the left relative to the field, the current flows in one direction; and if the coil moves to the right, the current flows in the opposite direction.

We can now sum up what we already know as follows:

1. A conductor moving through a magnetic field generates a voltage which produces a current flow in a closed circuit,

2. The faster the movement, the greater the number of turns, and the stronger the magnetic field; the greater the induced voltage and the resultant current flow, and

3. Reversing the direction of conductor movement reverses the induced voltage polarity and the direction of current flow.

Direction of Current Flow

According to the "electron" theory, current flow is from a negative (-) charge to a positive (+) charge. Thus, if a wire is connected to a source of power, current will flow in the wire from the (-) terminal to the (+) terminal.

"Conventional" current flow, with which most of you are already familiar and perhaps may have been taught, assumes that the flow is from (+) to (-) and is used throughout this lesson.

The Basic Alternating-current Generator

The practical generator works on the same principle as the basic generator. To understand the operation of the practical generator, think in terms of the basic one. In this way, the operation of the largest most complex machine that produces thousands of kilowatts is easily explained.

In Figure 4 we can examine the basic alternating-current generator further. A loop of wire is placed in a stationary magnetic field so that the loop can be rotated to cause an induced voltage. It is connected to an external circuit through sliding contacts, sliprings, so that the induced voltage can be used.

The pole pieces, designated north and south, produce the magnetic field. The wire loop, called the "armature" or "rotor" rotates through this magnetic field and is connected to the external circuit (load) by the brushes which ride on the sliprings.

The induced voltage and resulting current flow depend on the position of the loop in the magnetic field. As the loop rotates, the sides of the loop cut through the magnetic field and the induced voltage causes a current to flow through the loop, sliprings, brushes, ammeter, and load - all connected in series.

At certain positions in the magnetic field, the loop produces no induced voltage. Referring to Figure 5(a), it can be seen that in the 0° position, the black and white conductors of the loop are moving parallel to the magnetic field. In this position they are cutting no lines of force and therefore the induced voltage and resulting current flow are zero. Note that the zero position is at the center of the ammeter scale. This permits us to observe the change in direction of current flow as the motion of the loop relative to the magnetic field changes directions.

As the loop rotates to the 90° position, Figure 5(b), the number of lines of force that it cuts increases. This increases the induced voltage and resulting current flow. The direction of current flow is indicated by the arrows adjacent to the black and white conductors. The voltage between the sliprings is the sum of the voltage induced in each side of the coil. Current flow direction and induced voltage polarity depend upon the magnetic field direction and the loop rotation direction.

As the loop moves from the 90° position to the 180° position, the induced voltage decreases in the same manner as it increased when the loop moved from 0° to 90°. The current flow will follow this same pattern as shown in Figure 6(b).

From 0° to 180° each conductor of the loop has been moving through the magnetic field in one direction and, therefore, the polarity of the induced voltage has remained the same. However, as the loop rotates on from 180° through 270° to 360° (back to the 0° position) the conductors are cutting the lines of force in the opposite direction. This gives a reversed polarity to the induced voltage and the current will flow in the opposite direction. The complete voltage sine wave generated as the loop moves through one revolution, 0° to 90° to 180° to 270° to 360°, is given in Figure 7(b).

Alternating- and Direct-current Voltage Outputs

Figure 8 compares a direct-current voltage with an alternating-current voltage sine wave. It can be seen that the direct-current voltage remains at a constant value, represented as a straight line whose distance from the zero reference line depends upon its value, whereas the alternating-current voltage does not remain the same either in magnitude or polarity.

The generated voltage sine waves shown in Figures 8 and 9 are not direct-current voltages, since direct-current voltage must have the same polarity at all times. The generated voltage is normally referred to as an alternating-current voltage since it alternates from plus to minus. It is the same type we find in our homes. Because we have an alternating voltage we will have an alternating current. The sine wave of the voltage or current for different positions of the loop can be seen in Figure 9.

Converting Alternating Current to Direct Current

Thus far we have learned that the basic generator is fundamentally a generator of alternating current. Can this same machine be changed to produce direct current? Yes, this can be done.

Turn to Figure 10 where you will see a very crude way in which the alternating current generated by the basic generator could be converted to direct current. As you remember, when the loop cuts through the magnetic lines of force in moving from 0° to 180°, the current flow is in one direction. When it moves from 180° to 360° it is in the other direction. With a reversing switch in the external circuit, as indicated in the figure, the alternating current could be converted to direct current by throwing the switch just as the 180° and 360° points are passed. This would give you a direct current output that would rise and fall as the loop rotates.

The action that takes place, when the switch is thrown as the loop moves through the 180° and 360° points, is further illustrated in Figure 11. Basically, the voltage polarity across the Load Resistor A-B remains the same. The generator output voltage changes by virtue of the switch being thrown from the right position to the left position. The arrows indicate that the direction of current flow on the load side of the switch remains the same even though the direction of current flow on the generator side reverses. In Figure 11(a), the terminal voltage is shown for the first half cycle, 0° to 180°. With the switch in the position shown, the output voltage across the resistor is of the same polarity as the generator terminal voltage.

In Figure 11(b), the polarity of the generator terminal voltage reverses as the armature loop rotates through 180° to 360°. Although the polarity across the brushes has changed, with the reversing switch in the opposite position, the output voltage is still the same. In this manner, the alternating current in the generator is converted to a varying direct current outside the generator.

With a generator putting out 60 cycles of alternating current per second, it would be necessary to reverse a switch 120 times each second to produce this pulsating direct current. Obviously, this could not be done by hand, and a mechanical device to operate the switch would be impractical. Therefore, the switch must be replaced by something that will operate at this high speed.

The "commutator," as shown in Figure 12, is the answer. Its action in converting the alternating current generated in the rotor to direct current at the terminals is called "commutation." Instead of using two sliprings, a single slipring, divided into two segments with each segment insulated from the other and from the shaft, is used. This arrangement gives the same results as the reversing switch previously described. As the loop rotates, each conductor is connected first to the positive brush and then to the negative brush. When the loop passes through the zero voltage points, the commutator segments are short circuited.

The flow of current for three positions of the loop can be seen by referring to Figure 13. With the loop in the 0° position, which is perpendicular to the magnetic field, the generated voltage is zero and the brushes are touching both segments of the commutator simultaneously. Since there is no generated voltage in this position, there is no current flow. Therefore, this short circuiting produces no ill effect. As the loop moves in the clockwise direction, the black brush is in contact with the black commutator segment, and the white brush is in contact with the white commutator segment.

The induced voltage builds up from zero to a maximum as the loop rotates from the 0° position, Figure 13(a), to the 90° position, Figure 13(b). This causes the current flow also to build up from a zero quantity to a maximum quantity at the 90° position. With the continued rotation of the coil from the 90° position to the 180° position, Figure 13(c), the induced voltage goes from maximum to zero, Figure 13(d).

To continue our discussion of this commutation procedure, refer to Figure 14. Note, as the loop goes from the 180° position, Figure 14(a), to the 270° position, Figure 14(b), the black brush has slipped off of the black segment of the commutator and has made contact with the white segment. Likewise, the white brush has slipped off of the white segment and has made contact with the black segment. Since the current flow in the conductors has changed at the same time as we have changed connections to the commutator segments, the external current flow remains unchanged in direction.

As the loop moves from the 180° position through the 270° position and back to the 360° or 0° position, the connection of the black brush to the white bar and the white brush to the black bar is such that the waveform, Figure 14(d), is the same polarity as that generated across the brushes when the coil moved from the 0° position to the 180° position. This results in the same current flow direction through the ammeter as we witnessed in the first half cycle.

We have seen in the discussions of Figures 13 and 14 that the voltage output has the same polarity at all times. Starting from zero, rising to a maximum, falling to zero, and then rising to a maximum again and falling to zero for each complete revolution of the rotor loop. We have seen thus far that the single loop generator produces a pulsating direct-current voltage. However, it is not constant enough to operate direct-current appliances and equipment. In Figure 15, we show the effect of adding an additional coil to the armature. As additional coils are added, additional segments to go with those coils are made a part of the commutator. Even this two-coil generator produces a much more uniform direct-current voltage output. Additional smoothing can be accomplished by adding additional coils to the rotor and more segments to the commutator.

Looking more closely at Figure 15, we see that the generator is made up of a two-coil rotor with the coils at right angles to each other. You will note that the white coil is in the position where it is generating a maximum voltage and the black coil where it is generating no voltage. As the rotor rotates, the white coil rotates out of the position of maximum voltage and the black coil rotates into the position of maximum voltage. The net result is that as one coil is going toward zero, the other one is building up, and therefore the terminal voltage never drops completely to zero. This variation in voltage output is commonly referred to as "generator ripple." It is apparent that this direct-current voltage output is much closer to the desired constant output than the simple single-coil generator.

Although we have improved our simple generator to make the generator truly useful for the driving of direct-current equipment, the output must be smoothed even more. This can be accomplished by providing a large number of coils and commutator segments in the machine. These coils are arranged so that they are around the rotor in such a way that at every instant there are turns cutting through the magnetic field at right angles producing a multiplicity of maximum induced voltages. This results in a generator output that has very little ripple and can be considered for all practical purposes a "pure" direct current. The waveform for a practical generator, as shown in Figure 16, has very little ripple.

Thus far in our discussion we have talked about a coil with one turn. In actual practice, one turn of a coil passing through a magnetic field would develop a very small voltage. Therefore, to get a usable voltage output, each coil on the rotor of a commercial generator is made up of many turns of wire connected in series. In this way the voltage induced in each turn is added to the voltage induced in every other turn, giving a much greater voltage at the terminals.

<u>Review of the Basic Generator and Commutation</u>

Now let us review briefly the fundamental principles we have learned in this lesson about basic generators. If your background on this subject has been sufficient, you may want to skip the review and go on to the next section on "Generator Components."

a. Alternating-current generation. - Figure 4 shows the basic generator. The armature loop is rotating in a magnetic field and is connected to sliprings. The sliprings, in turn, have brushes which make contact to the external load circuit.

The voltage output of this basic generator is essentially an alternating one which produces an alternating current. The polarity of the voltage and the current flow is reversed each time the armature rotates 180°. See Figure 9.

b. Direct-current generation. - One way to change the alternating current to direct current would be to install a reversing switch in the external circuit. See Figure 10.

A segmented commutator is substituted for the sliprings in Figure 1?. The commutator acts as an automatic reversing switch on the generator shaft and switches coil connections to the brushes each half revolution as the coil of the basic generator rotates in the magnetic field.

c. The practical generator. - The voltage output of the practical generator has only a slight ripple and is near the maximum at all times. This is accomplished by the use of many coils on the armature and correspondingly many segments on the commutator. For a graphic representation of what we have said, see Figure 16.

Generator Components

Thus far we have discussed generator fundamentals and operation theory of the basic alternating- and direct-current generators. Now let's consider how actual generators are constructed. A knowledge of these various components and their functions can be very helpful in troubleshooting and maintaining generators.

a. Rotor and stator. - Both alternating- and direct-current generators have a rotating part called the rotor and a stationary part called the stator. However, most direct-current generators have the armature coils mounted on the rotor and the field coils mounted on the stator while on most alternating-current generators the opposite is true - the field coils are on the rotor and the armature coils are on the stator.

All generators convert mechanical energy into electrical energy. Therefore, they must have some type of machine connected to them which will furnish this mechanical energy to turn the rotors. These "prime movers" may be machines such as steam engines, steam turbines, hydroturbines, electric motors, and gasoline engines. Regardless of the type of prime mover used or whether the machine is an alternating- or direct-current generator, it is the relative motion between the coils and the magnetic field, that produces the induced voltage. It is this voltage which causes current to flow through the external load.

Other basic components of a typical direct-current generator, and their function, are discussed in the following paragraphs.

Figure 17 shows a typical direct-current generator with the principal parts labeled. As you look at the figure, think back to the basic generator.

b. Main frame assembly. - The foundation of the machine which supports other components is called the main frame. Also, it is sometimes called the "yoke." In addition to its other functions, the main frame completes the magnetic circuit between the pole pieces.

The pole pieces support the field coils and are designed to produce a concentrated field. They are made of many thin layers of iron or steel called laminations which are joined together and bolted to the inside of the frame. These laminations reduce eddy currents which will be discussed later.

The end bells are attached to the ends of the main frame and contain the bearings for the armature. These bells support the bearings and in addition the outboard bell normally supports the brush rigging.

c. Field windings. - The field windings are coils of insulated wire wound to fit closely around the pole pieces. They form electromagnets which provide the magnetic field necessary for generator action. Sometimes the windings and pole pieces together are called the "field." When current flows through these coils a magnetic field is generated. The generator may have only two poles, or it may consist of a great number of poles. In all cases, there will be an even number of poles. Also, alternate poles will always be of opposite polarity. The field windings can be connected either in parallel or in series. The parallel connection is often referred to as "shunt." Series windings are composed of few turns of fairly heavy wire, whereas shunt windings consist of many turns of fine wire.

d. Brush holders and brushes. - As the name indicates, the brush holders support the brushes and their connecting wires. They are insulated from the frame and are secured to the outboard end bell with clamps. In some cases, provision is made to rotate the brush holders around the commutator for adjustment.

The brushes which carry the voltage from the commutator to the generator leads are usually made of high-grade carbon. They are held in place by brush springs which permit them to slide up and down in their holders so that they can follow irregularities in the commutator surface. Each brush is connected to the external circuit by a flexible braided conductor called a "pigtail." A typical brush assembly is shown in Figure 18.

e. Armature assembly. - In most direct-current generators, the armature rotates between the poles of the stator. The armature assembly (Figure 18) consists of the shaft, armature core, armature windings, and commutator. The laminated armature core is slotted to take the armature windings. These windings are usually wound on forms and then placed in the slots on the core. The commutator is made up of copper segments insulated from each other and from the shaft by mica. These segments are secured with retainer rings to prevent them from slipping out due to the force of rotation. Small slots are provided in the inboard ends of the commutator segments to which the armature coil leads are attached. The shaft, which supports the entire armature assembly, rotates in the end bell bearings.

The small air gap between the armature and the pole pieces prevents the armature and the pole pieces from rubbing during rotation. This gap is kept small to maintain maximum field strength.

f. Types of armatures. - Direct-current generator armatures are divided into two general types. One is the "ring" type armature, and the other is the "drum" type armature. The armature coils in the ring-type armature are wrapped around a hollow iron cylinder with taps connected at regular intervals to the commutator segments. The ring-type armature was one of the earlier designs used in rotating electrical machinery; however, today it is seldom used.

The standard armature being constructed today is the drum type, Figure 18. In this type, insulated coils are inserted into slots in the cylindrical or drum-shaped core.

Most direct-current armatures use form-made coils. They are wound by machine with the proper number of turns and to the proper shape and then are wrapped with tape and inserted into the armature slots as one unit. They are inserted in the slots in such a manner that the two legs of a coil can only be under unlike poles at any instant. For example, in a two-pole machine the legs of each coil are placed on opposite sides of the core and are therefore under opposite poles. However, in a four-pole machine, the legs of the coils are placed in slots about one-quarter the distance around the core, thus putting opposite legs of the coil under unlike poles.

Two types of windings are used on drum-type armatures, the "lap" winding and the "wave" winding. For high-current applications the lap winding is used and has many parallel paths within the armature. Therefore, there will be a large number of field poles and an equal number of brushes. For high-voltage applications the wave winding is used. It consists of only two parallel current paths and uses only two brushes, regardless of the number of poles involved.

Lap and wave windings are different only in the method used to connect the winding elements. Lap windings are connected so that each winding is made to overlap every other winding. Whereas, wave windings are connected forward so that each winding passes under every pole before it comes back to its starting pole.

Eddy Currents

You have learned that when a conductor cuts through a magnetic field, a current flow can be induced in it. This is also true when a solid piece of metal cuts through a magnetic field. Since a large solid piece of metal has a large cross section, it offers little resistance to current flow. Therefore, a strong current called an "eddy" current flows through the solid metal conductor.

These eddy currents will be induced in the metal cores of a generator just as the useful current is induced in the wires of the generator. These eddy currents flowing in the core material of rotating machinery are wasted currents, and they heat up the metal cores. This reduces the operating efficiency of the machine. To minimize these eddy currents, the cores are made of thin laminations with each lamination insulated from the other. The effect of the laminations on reducing the magnitude of the eddy currents is illustrated in Figure 19.

Classification of Direct-current Generators

Except for very small generators called "magnetos," most practical direct-current generators have electromagnetic fields. This magnetic field is obtained by connecting the field coils across a direct-current voltage source. It should be noted that in order to have a constant field we must use a direct-current voltage rather than an alternating-current voltage. This direct current in the field coils, referred to as the "excitation current," can be taken from the generator output itself or may be supplied from a separate direct-current voltage source.

The manner in which the field is supplied with excitation current leads to two direct-current generator classifications. The "separately excited" generator receives its field current from an external source. The "self-excited" generator receives its field current from its own generator output. Three basic direct-current circuits are used on various generators. They are the series, parallel, and series-parallel circuits.

Direct-current generators which are separately excited have two circuits independent of each other. They consist of the field circuit, which is connected across a separate direct-current source, and the armature circuit, which consists of the armature coil and the load resistance.

Please refer to the sketch of a separately excited direct-current generator, Figure 20. You will note that the field coil is independent of the armature circuit. It is supplied by a separate source, which could be another generator (exciter), an amplifier, or storage batteries. Very sensitive control of the output is possible through the use of this separately excited field. A slight change in field current can cause a large change in the generator output voltage.

This separately excited generator system is used mainly in automatic motor control systems. Here, the field power is normally controlled by an amplifier, and the output of the generator supplies the load current.

In Figure 21, three types of self-excited, direct-current generators are illustrated. They are series, shunt, and compound generators. Their names are derived from the manner in which the field coils are connected into the circuits.

As can be seen in Figure 21(a), the series field is connected in series with the armature, so that the entire armature current flows through both the field and the load. If there is no load connected across the generator, then there is no current through the field; therefore, there is no field excitation. The series field is normally made up of a very few turns of relatively large wire.

The shunt generator, Figure 21(b), has the field connected across the armature in such a way as to be in parallel with the load. Therefore, only a small part of the current flows through the field. However, the field is excited even when there is no load connected to the generator. This field is made up of many turns of fine wire.

Figure 21(c) shows a "compound" generator. This generator has both a series and a shunt field. Only a part of the armature current goes through the shunt field, whereas the total load current goes through the series field. With this arrangement as the load increases, the strength of the series field increases. However, that part of the field strength which is related to the shunt field remains constant.

Four types of self-excited generator field connections are shown in Figure 22.

By looking at the figure, you will note that the shunt generator is made up of many turns of small wire. This is done to make the coil resistance sufficient to limit the current flow to a low value. Keeping this current low is important, since the shunt field current is not used to supply the load.

There are two types of shunt generators - the "long shunt" type and the "short shunt" type. When the shunt field is connected across both the series field and the armature, the field is called the long-shunt type. If the shunt field is connected across the armature only, it is called a short-shunt field. Both types of connections give practically the same field characteristics.

Since series field coils must accommodate the large current flows associated with the load, they must have a low resistance to minimize the voltage drop associated with changes in load. They are made up of few turns of large conductor to accomplish these objectives.

Generator Buildup

Figure 23 is a single-line diagram of the shunt generator with its generator voltage buildup characteristic curve.

Most direct-current generators are of the self-excited type in which armature current is used to excite the field. Since the excitation depends upon the armature current and the armature current depends upon the magnetic field, you may wonder how the generator voltage output can be built up. To state it differently: If there is no voltage to start with and there is no field because there is no voltage, how can a generator produce any voltage?

The answer, of course, is that there is a certain amount of magnetism, called residual magnetism, retained in the field poles. This is as a result of the magnetic characteristics of the steel. Therefore, when the generator starts turning, this small residual magnetism, which produces a small field, builds up. This process is repeated; the increased field gives an increased voltage, which in turn increases the field. This increases until the machine reaches its normal field strength. It normally takes 20 to 30 seconds to accomplish this field buildup. The curve in Figure 23 shows how generator voltage and field current build up in a shunt generator.

It should be remembered that the term "buildup" in a generator does not refer to its mechanical rotation, but its electrical output.

Sometimes a generator will not build up. When this happens, several things may be wrong:

1. There may be too little or no residual magnetism. In this case, it is necessary to excite the generator additionally by an external source. This is referred to as "flashing the field." An external direct-current source is used and is important to make certain when this is being done that this external field

polarity is the same as that of the residual magnetism. If these polarities are different, the residual field will be further weakened and the generator will not build up.

2. If the shunt field connections are reversed, this will cause the generator to not build up. By shifting the connections so as to reverse them again, the generator will build up properly.

3. A high shunt field resistance can also cause a generator to not build up. Since rheostats are often connected in series with the shunt field to control the field current and if this rheostat adds too much resistance to the circuit when the generator is first started, the field current will be too small to obtain a proper buildup.

4. An open field circuit can also cause a generator field to not build up. Once it has been determined that the field is open, the break or opening must be found and repaired.

The Series Generator

The armature, the field coils, and the external circuit (load) of a series generator are all in series. The same current that flows through the armature and external circuit also flows through the field coils. Since this current is large, only a relatively small number of turns are needed in the field winding to produce the required magnetic flux.

Figure 24 shows the schematic of a typical direct-current series generator. Here you will note a plot of the relationship between load current and volts. At no load there is very little voltage induced in the armature; the amount depends upon the residual magnetism. As the load current increases, the voltage increases. This in turn increases the field, which again in turn increases the voltage. When the load current reaches Point A, a further increase in current has very little effect on voltage, because the magnetic field has reached the saturation point.

Referring again to Figure 24, a series generator is always operated beyond Point A. Therefore, as the load current tends to increase, the terminal voltage drops. This keeps the load current from increasing with changes in load resistance. The net result is that the output current tends to stay constant. Therefore, series generators are called "constant-current generators."

The Shunt Generator

Since the shunt generator has its field windings connection in shunt (parallel) with the armature, the current through the field coils of the shunt generator is determined by the terminal voltage and the resistance of the field; the field current is relatively constant. Also, since the field windings have a large number of turns, the amount of current required to produce the necessary flux is relatively small.

The shunt generator is used where a nearly constant voltage is desired, regardless of load changes. Referring to Figure 25, it can be seen that as the load current increases, the terminal voltage drops only slightly from Point A to Point B. This drop is due to reaching the saturation limit of the shunt field, which is caused by the increase of load current. An increase in load current beyond Point B would cause a rapidly dropping terminal voltage due to exceeding the saturation limits of the shunt field. However, this seldom happens, because the generator is never run beyond Point B. By using a rheostat in series with the shunt field coils, the terminal voltage of the shunt generator can be controlled.

The Compound Generator

The compound generator is a combination of the series and shunt generators. There are two sets of field coils, one in series with the armature and the other in parallel; both are always mounted on a common pole piece.

There are several types of compound generators. When the series field is connected so that its field aids the shunt field, the generator is called "cumulatively" compounded. On the other hand if the series field bucks the shunt field, the generator is called "differentially" compounded. As previously discussed and as shown in Figure 26, the fields also may be connected either short shunt or long shunt, depending on whether the shunt field is in parallel with both the series field and the armature or with just the armature. The short-shunt and long-shunt types have similar operating characteristics.

Since a voltage drop is undesirable where constant voltage loads, such as lighting systems are served, compound generators are designed to overcome this drop. This drop in terminal voltage, which occurs in a shunt generator as the load increases, is compensated for by the series field. As the load current increases, the strength of the series field and, consequently, the strength of the total magnetic field is increased. This in turn overcomes the voltage drop due to saturation of the shunt field.

The relative number of turns in the shunt and series field windings determines the voltage characteristics of the cumulatively compounded generator. Where the series windings are proportioned so that the terminal voltage is practically constant at all loads within its range, it is "flat compounded." Normally, the no-load and full-load voltages are the same for these machines; voltage at intermediate points is somewhat higher. The flat-compounded generator is normally used for loads a short distance from the generator. The series turns on the "overcompounded" generator are so selected that the full-load voltage is greater than the no-load voltage. These generators are normally used to serve loads some distance away. This increased terminal voltage compensates for the voltage drop in the long feeder lines. The overcompounded generator most used is the cumulative compound generator. To give these generators flexibility, a low-resistance shunt coil called a "diverter" is placed across the series field terminal as shown in Figure 27. The terminal voltage can then be controlled by adjusting the field rheostat, which is in series with the shunt field.

"Undercompounding" results when the shunt field is opposed by the series field. This gives a rated full-load voltage lower than the no-load voltage. Generators of this type are seldom used. By placing the shunt and series fields in opposition, we have a differentially compounded generator. The difference, or resultant field, becomes weaker, and the terminal voltage drops rapidly with increase in load current. Characteristic curves for the four types of compound generators discussed are shown in Figure 27.

Commutation

In previous discussions of commutation in the study of the elementary direct-current generator, we learned that brushes are positioned so that they short circuit the armature coil when it is not cutting the magnetic field. There is no sparking in the brushes at this point, since no current flows.

Figure 28 illustrates proper and improper commutation. Movement of the brushes a few degrees off of the neutral position will cause sparking due to short circuiting the coil when the coil is cutting through the field. This is very undesirable, since the current flow due to the short circuit may seriously damage the coil and burn the commutator. It may be compensated for by rotating both brushes to the neutral position.

The "plane of commutation" or "neutral plane" is the plane of the coil which is at right angles to the field. When the plane of the coil of a direct-current generator is at right angles to the field at the instant the brushes short the coil, the generator operates most efficiently.

Armature Reaction

Let us consider the operation of a simple, two-pole, direct-current generator. In Figure 29 we have a simplified view with the two circles representing the two sides of the armature coil. With the direction of rotation indicated, the dot in the one circle indicates the current flow out of the paper, whereas the cross indicates current flow into the paper. The directional arrows around each circle indicate the direction of the magnetic field produced around the sides of the coil due to the current flow in it.

There are now two fields involved - the main field and the field induced around the coil. The interaction of these fields distorts the main field and shifts the neutral plane in the direction of rotation as indicated. Therefore, if the brushes remained in the old neutral plane, there would be a voltage induced in the coil at the time the brushes are short circuiting it, and arcing would result between the brushes and the commutator. This arcing can be prevented by shifting the brushes to the new neutral plane. The reaction of the armature in displacing the neutral plane is known as "armature reaction."

Armature reaction cannot be completely solved by shifting the brushes to the advanced position of the neutral plane because the armature reaction varies with the load current. Therefore, as the load current increases or decreases, the location of this neutral plane shifts. Obviously, the brushes cannot be moved from one point to another with each change in load.

Other methods can be used to counteract the effect of armature reaction. In small machines the effects of armature reaction are minimized by mechanically placing the brushes in a different position. With larger machines more elaborate means are required, such as the use of compensating windings and/or commutating poles (interpoles).

Compensating windings are coils embedded in slots in the main pole faces, as shown in Figure 30, and are connected in series with the armature so that the same current that flows through the armature flows through them. The polarity of these coils is such that the magnetomotive force (mmf) they produce is nearly equal and is opposite the magnetomotive force produced by the armature for all values of armature current. Thus, the field of the armature is practically neutralized, and once the proper brush location is determined, the brushes need not be moved.

Commutating poles (interpoles) are poles placed between the main field poles, as shown in Figure 30, to neutralize only the armature magnetomotive force which acts in the commutating zone. Since they must produce a flux density proportional to the armature current, they are also connected in series with the armature. Physically, commutating poles are narrow with respect to the field poles and tend to saturate at moderate overloads. Because of this tendency to saturate the commutating pole, airgaps are relatively large so their flux will remain fairly proportional to the armature current. Interpole airgap adjustment, if necessary, is accomplished by the addition or removal of shims between the interpole piece and the main frame (yoke).

Remember that both compensating windings and commutating poles (interpoles) are connected in series with the armature and produce magnetomotive forces to neutralize armature reaction; however, commutating pole magnetomotive force acts only in the neutral plane (commutating zone), while the compensating winding magnetomotive force acts to compensate for the armature magnetomotive force over the entire field pole arc.

<u>Review of Direct-current Generators</u>

Now for those who only need a refresher review of direct-current generators and for those who have studied the preceding material, a quick review is offered:

a. General classification. - Direct-current generators, as previously discussed, are classified according to the method of field excitation used.

Separately excited generators use an outside source of direct current to magnetize the fields. This outside source may be an amplifier as shown in Figure 20, a battery, a silicon rectifier, or another direct-current generator.

Self-excited generators use the output of the generator itself to excite the field. These self-excited generators can be further divided into classifications, depending upon the field winding connections. These classes are reviewed briefly in the following three subsections.

b. Series generator. - Figure 21(a) is a schematic for a series generator. The field is made up of few turns of large conductor connected in series with the armature and the load. Since this type of generator is normally operated on the constant current part of its voltage output curve, it provides a constant current output.

c. Shunt generator. - Figure 21(b) is a schematic for a shunt generator. The field has many turns of small wire and is connected across the armature rather than in series with it. As the load current increases, the output voltage drops due to increased voltage drop in the armature.

d. Compound generator. - Figure 21(c) is a schematic for a compound generator. The field has two sets of windings - a shunt field and a series field. The effect of this combination is to provide an output voltage which is fairly constant regardless of the load current.

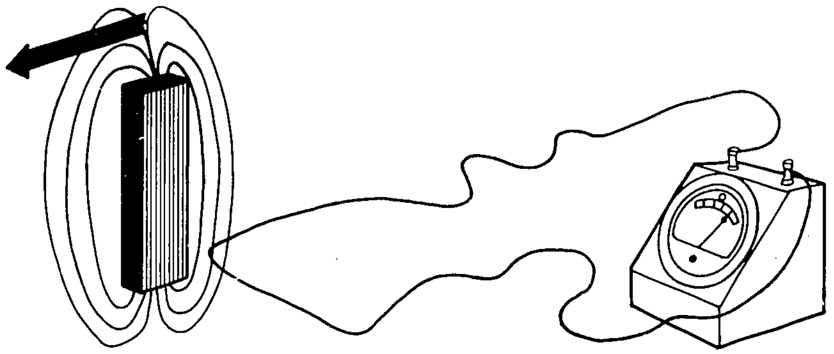
e. Commutation. - Figure 28(a) illustrates proper commutation. Here the commutator segments of a direct-current generator are shorted out by the brushes when the armature loop is at a point where no voltage is being generated. The generating conductors of the loop are moving parallel to the lines of force in the field at this instant.

Figure 28(b) shows improper commutation or commutator sparking. If the brushes short the commutator segments when the armature conductors are not moving parallel to the lines of force in the field, the generated voltage is short circuited. This causes arcing at the brushes. This arcing can be reduced by shifting the brushes in the proper direction. In doing so, the brush life is prolonged, and the armature itself is conserved.

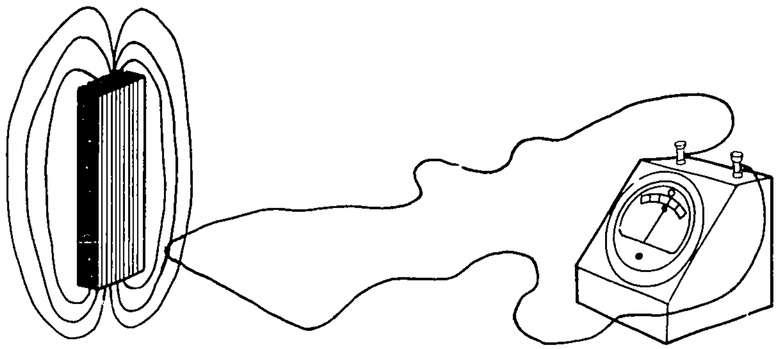
f. Armature reaction. - Figure 29 illustrates the effect of armature reaction. Current flowing in the armature coil generates a magnetic field at right angles to that of the generator field poles. The resultant total field shifts the neutral plane. Unless it is overcome by some means, this adds to the commutation problem.

Figure 30 shows one method of counteracting armature reaction by using compensating windings. Windings placed in slots in the field pole faces, carrying the same current as the armature coil but in the opposite direction, counteract the armature field influence.

Figure 30 also shows how commutating poles (interpoles) are used to counteract armature reaction. Here small poles are placed between the main field windings, and the field produced by them is proportional but in opposition to the field produced by the armature. The strength of this field is sufficient to overcome the armature reaction in the neutral plane only.



(a) Moving the magnet past the wire induces a voltage.



(b) The magnet at rest - no voltage induced.

Figure 1. Induced voltage.

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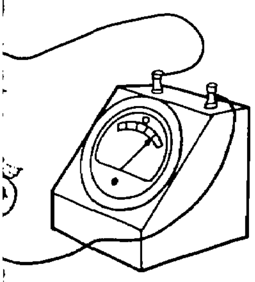
(b) The of m fiel

(c) The turns

Figure



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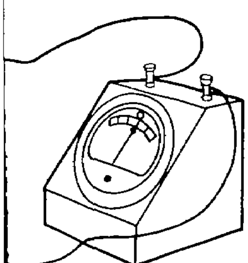

age induced.

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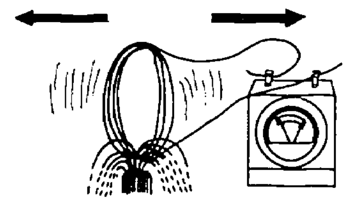
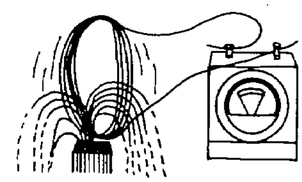
(a) The speed of conductor



(b) The strength of magnetic field



(c) The number of turns in coil

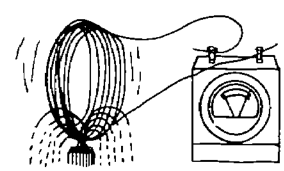


Figure 2. Factors that determine induced voltage strength.

Figures 1 and 2

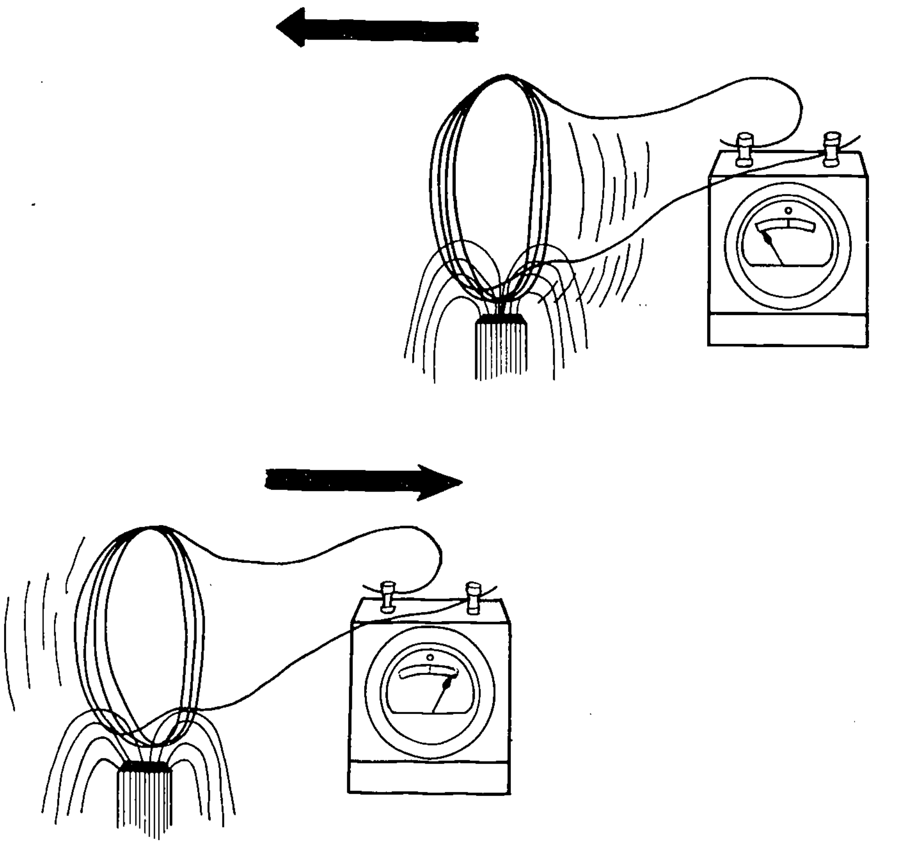


Figure 3. Direction of relative motion determines direction of current flow.

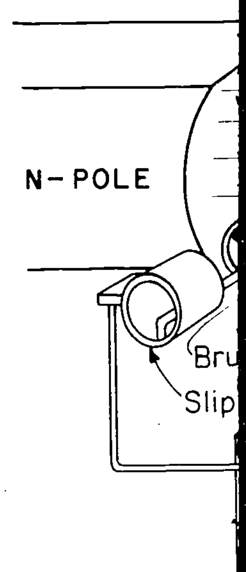
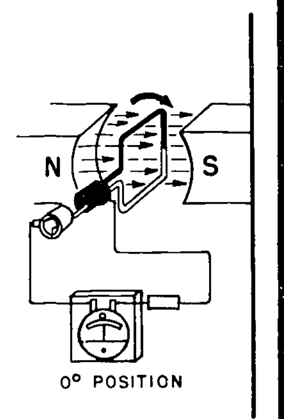
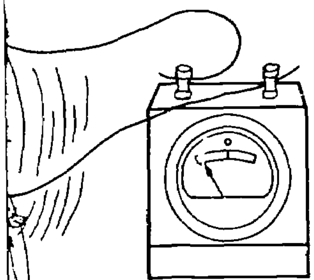


Figure 4.



(a) Zero voltage induced.

Figure 5.



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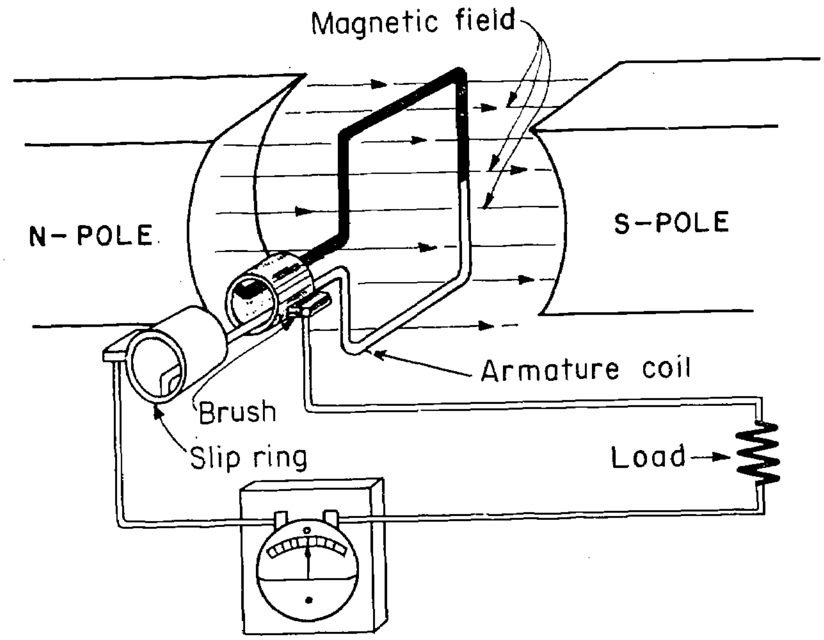
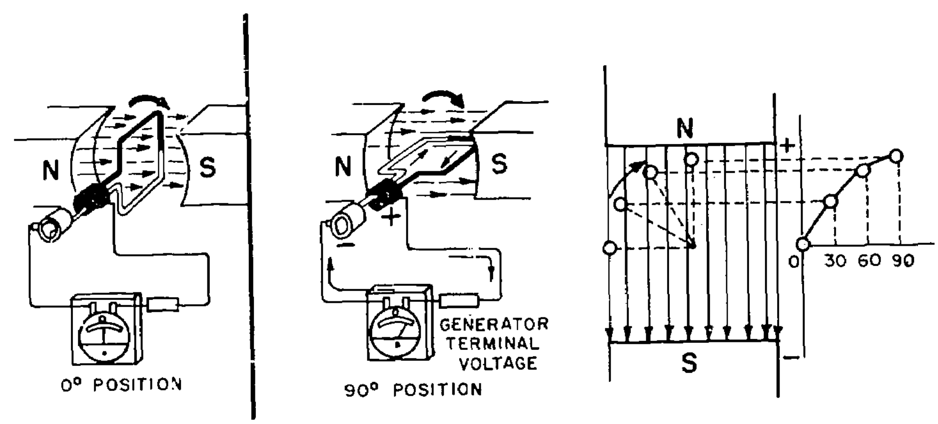


Figure 4. The basic alternating-current generator.



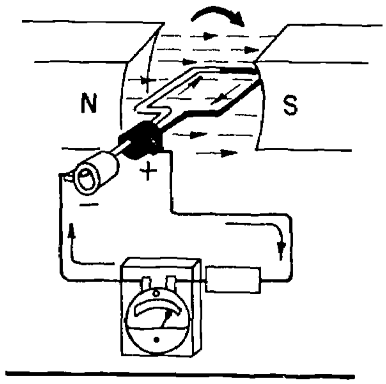
(a) Zero voltage induced.

(b) Maximum voltage induced (positive).

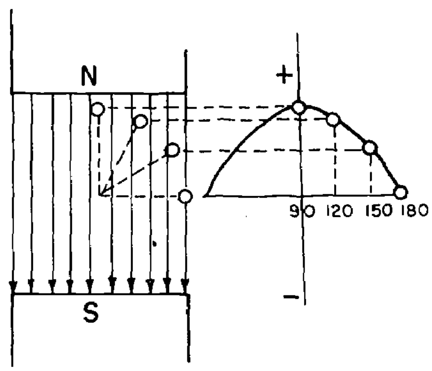
(c) 1/4-cycle wave.

Figure 5. Basic alternating-current generator induced voltages.

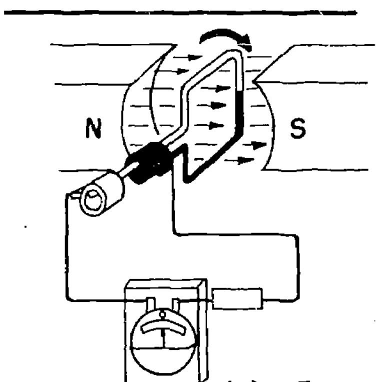
Figures 3, 4, and 5



(a) Maximum induced voltage (positive).

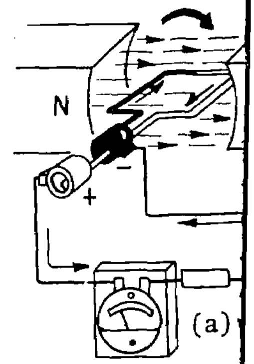


(b) 1/2-cycle wave.



(c) Zero voltage induced.

Figure 6. Basic alternating-current generator induced voltages (continued).



(a)

Generator Terminal Voltage

(b) The voltag

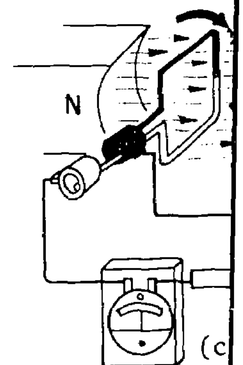


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Figure 7.

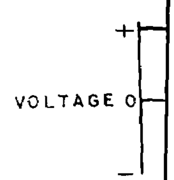
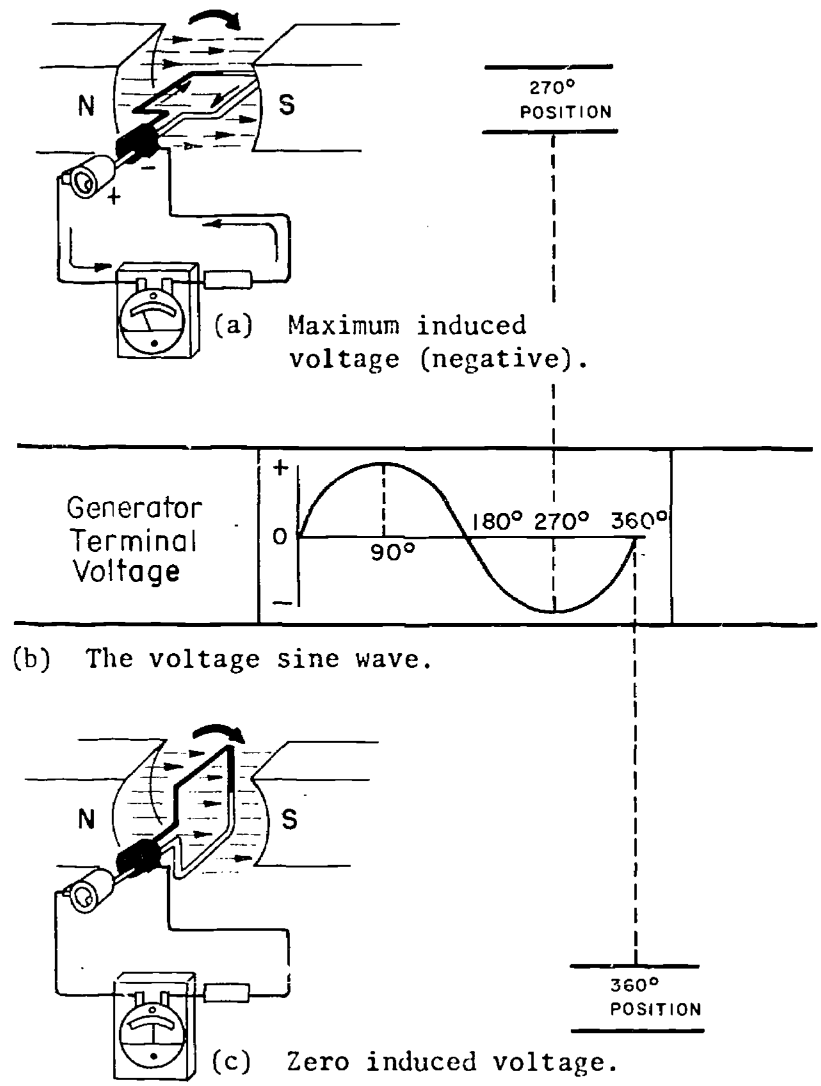


Figure 8.



(a) Maximum induced voltage (negative).

(b) The voltage sine wave.

(c) Zero induced voltage.

Figure 7. Voltage waveform for a complete revolution of the loop in the basic alternating-current generator.

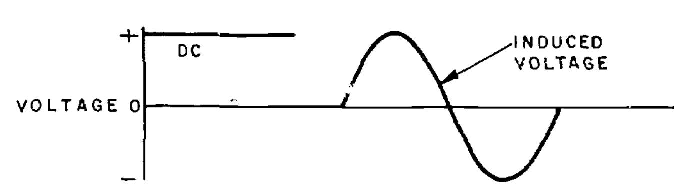


Figure 8. A direct-current voltage curve and an alternating-current voltage sine wave.

Figures 6, 7, and 8

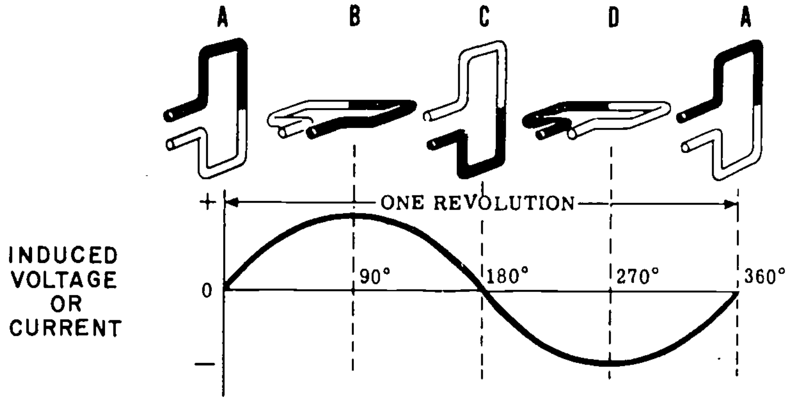


Figure 9. The alternating-current voltage or current sine wave.

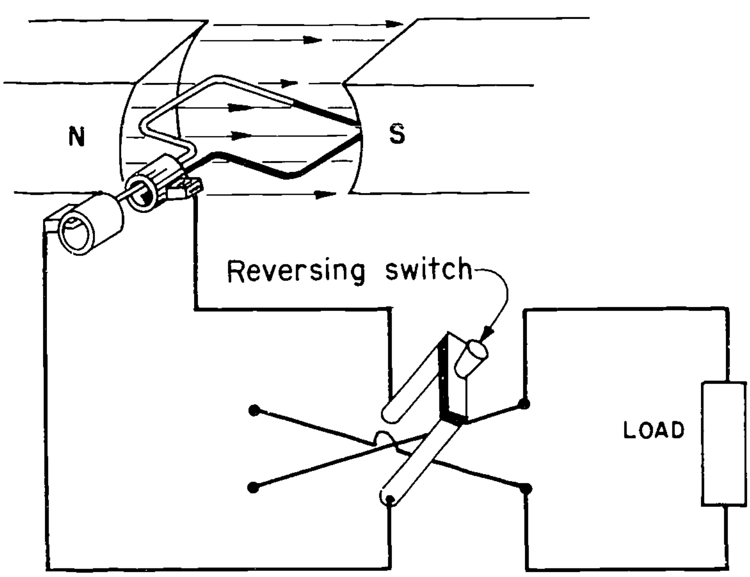


Figure 10. Changing alternating current to direct current using a reversing switch.

Figure 1

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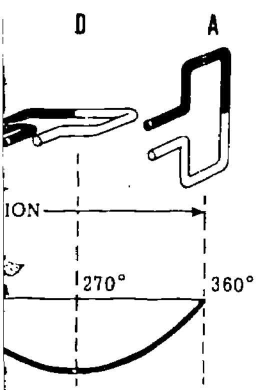
Figure 12



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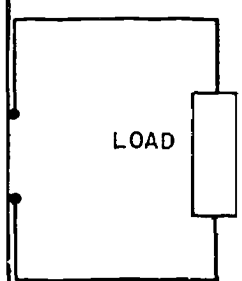

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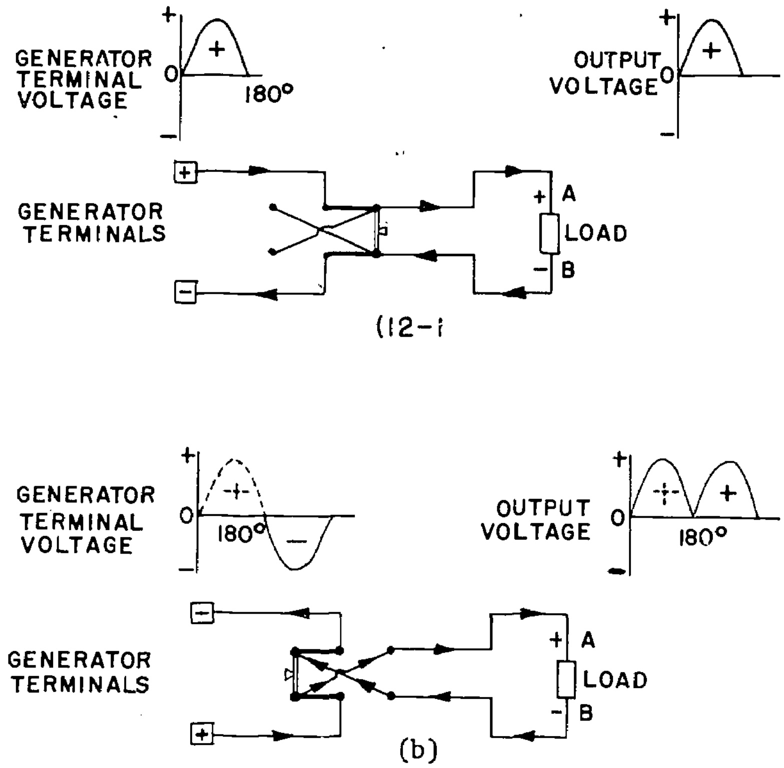


Figure 11. Changing alternating-current voltage to direct-current voltage with reversing switch.

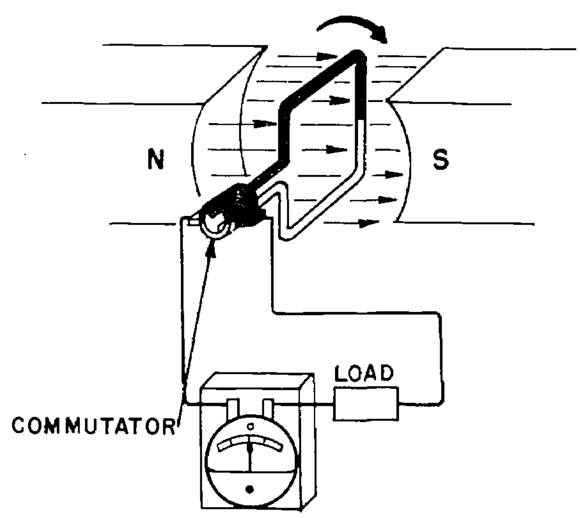
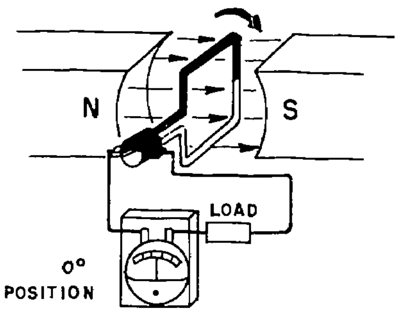
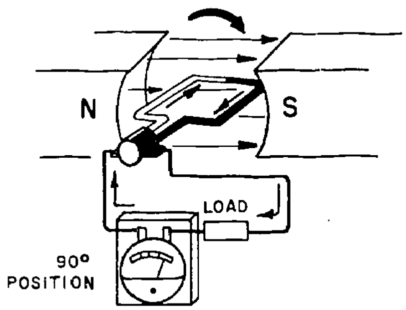


Figure 12. Changing alternating-current voltage to direct-current voltage using a commutator.

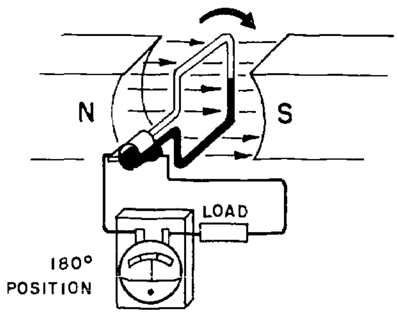
Figures 9, 10, 11, and 12



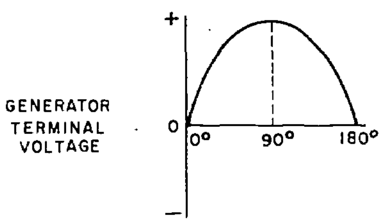
(a) Induced voltage zero.



(b) Induced voltage at maximum.

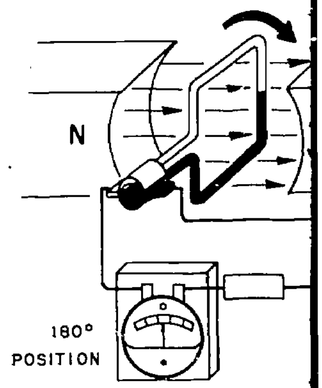


(c) Induced voltage zero.

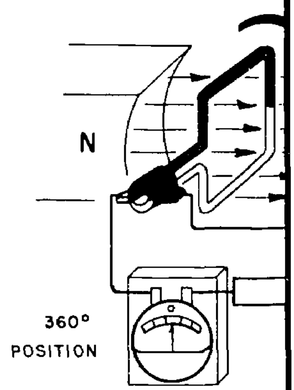


(d) 1/2-cycle wave.

Figure 13. Commutation - converting alternating-current voltage to direct-current voltage.

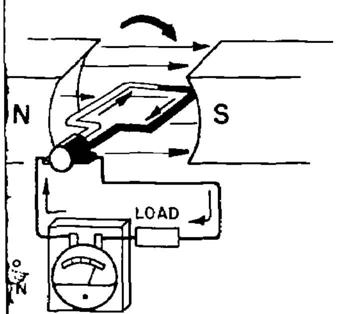


(a) Zero induced voltage.



(c) Zero induced voltage.

Figure 14.



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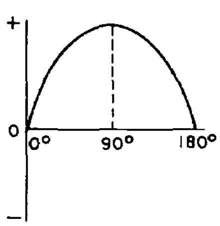

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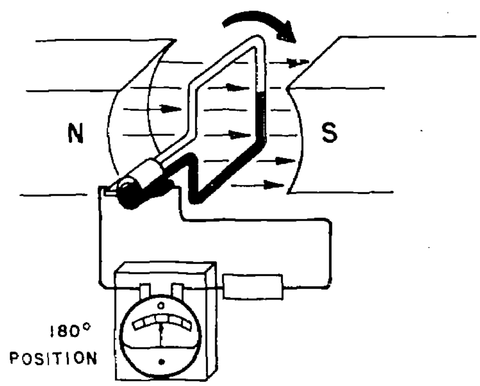
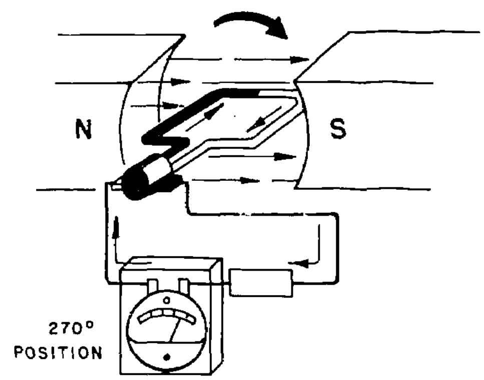
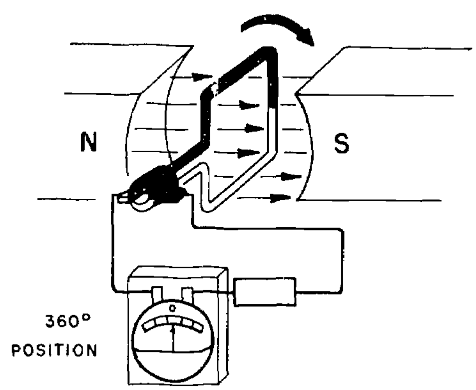


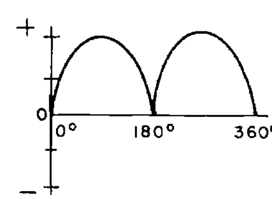
(a) Zero induced voltage.



(b) Maximum induced voltage.



(c) Zero induced voltage.



(d) 1-cycle wave.

Figure 14. Commutation - converting alternating current to direct current.

Figures 13 and 14

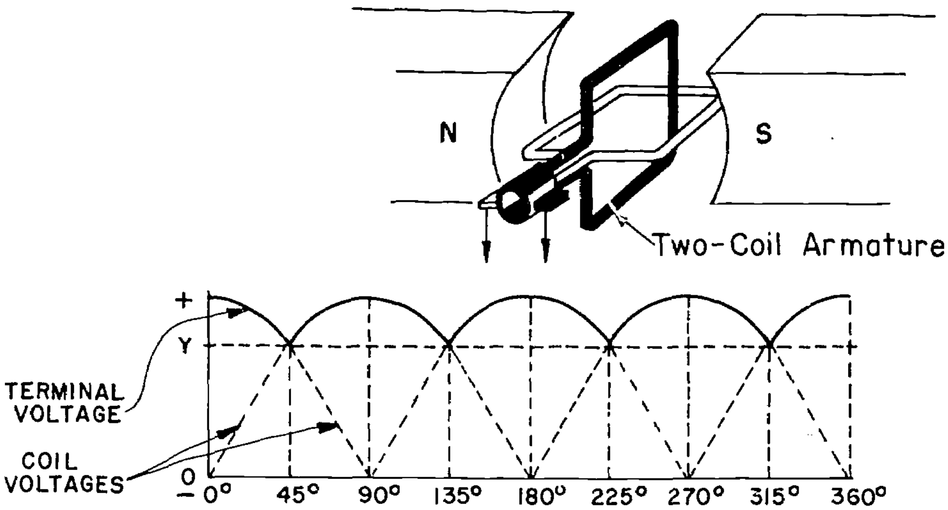


Figure 15. Reducing generator ripple.

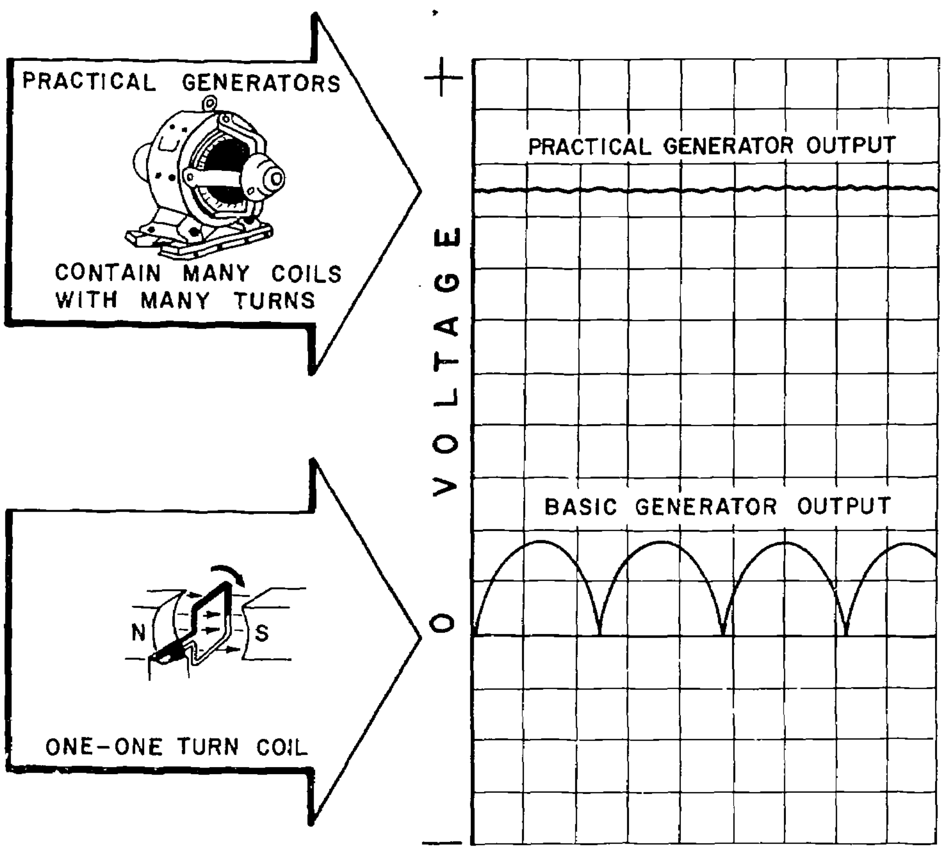


Figure 16. Comparison of the voltage outputs of the many-turn coils of the practical generator and the one-turn coil of the basic generator.

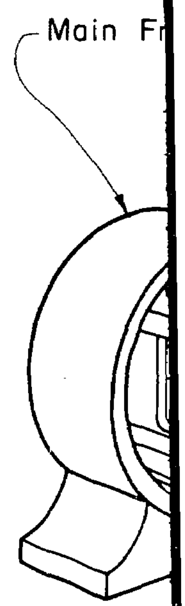


Figure 17.

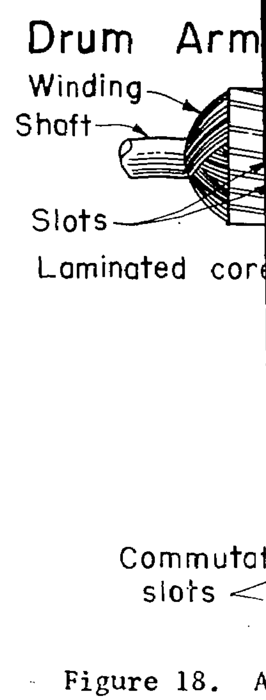
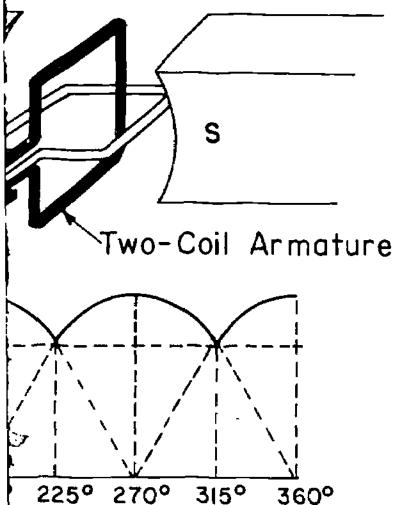
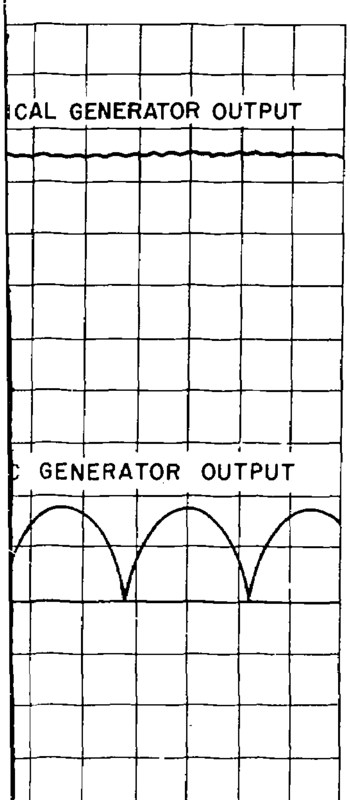


Figure 18.



generator ripple.



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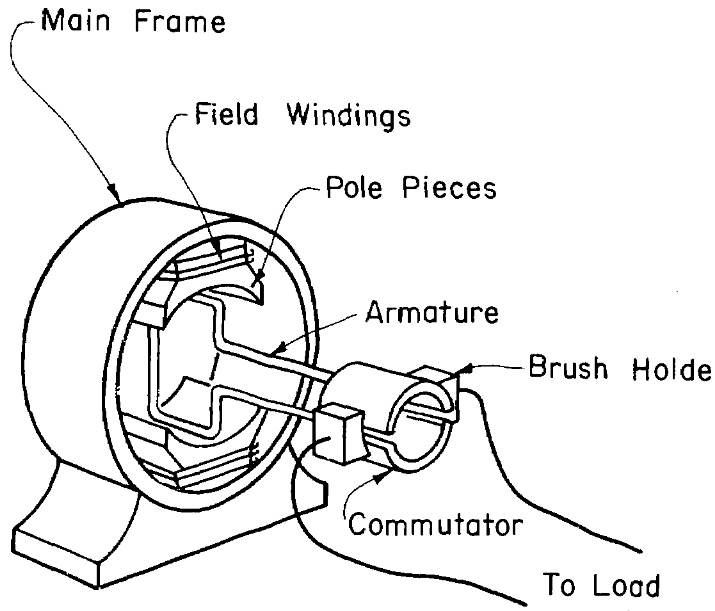


Figure 17. Major components of a direct-current generator.

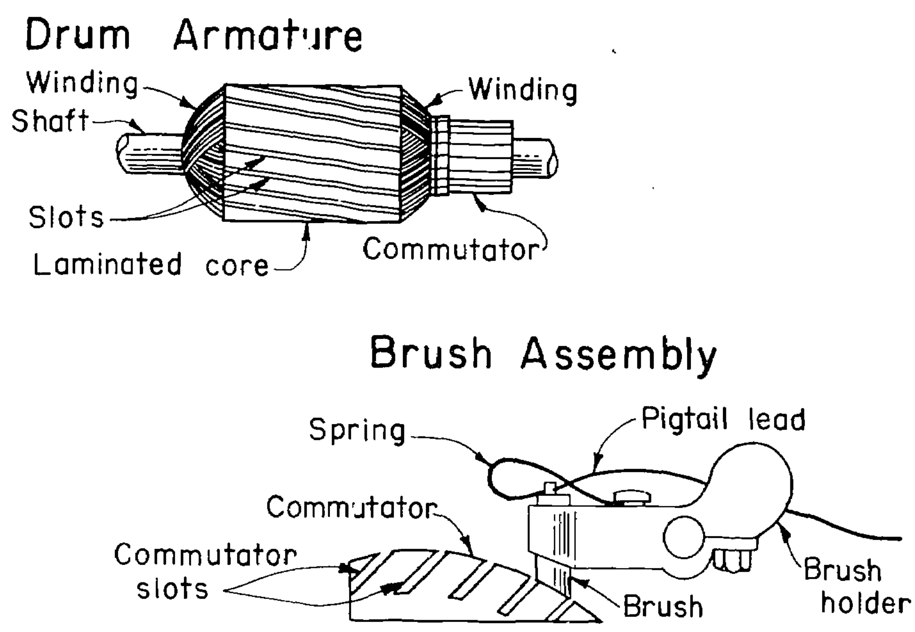


Figure 18. An armature ass^mbly and a brush assembly.

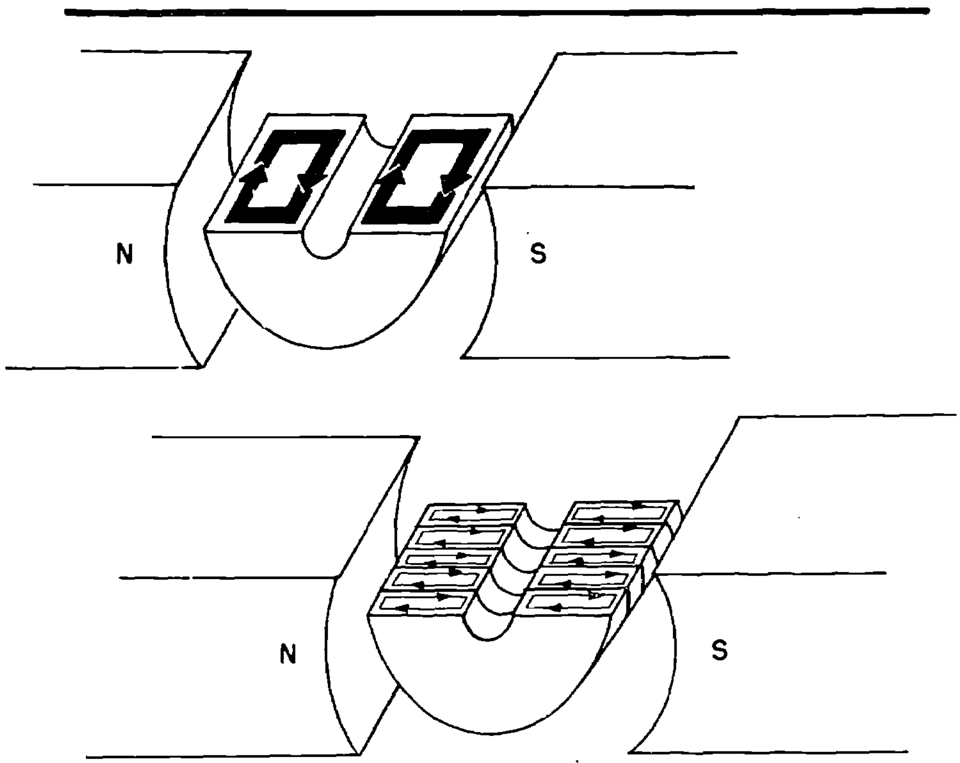


Figure 19. The effect of laminations in reducing the magnitude of eddy currents.

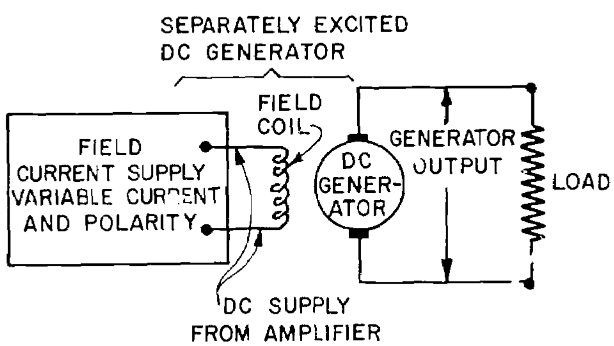
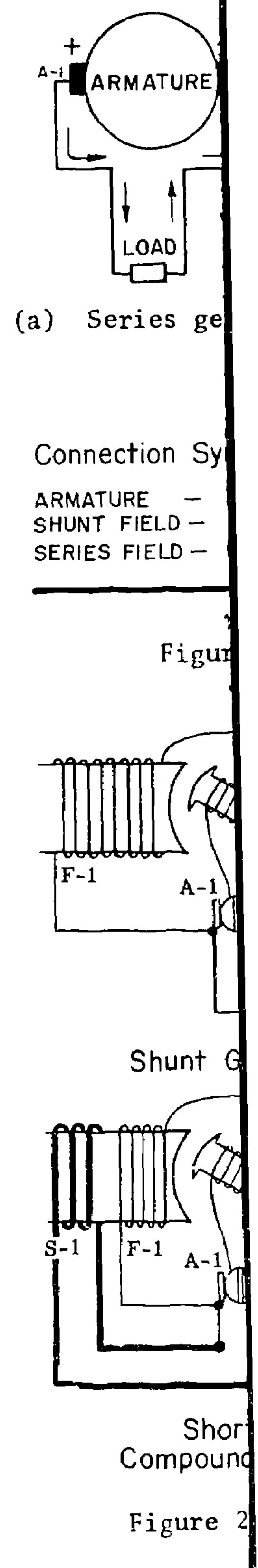


Figure 20. Separately excited direct-current generator.



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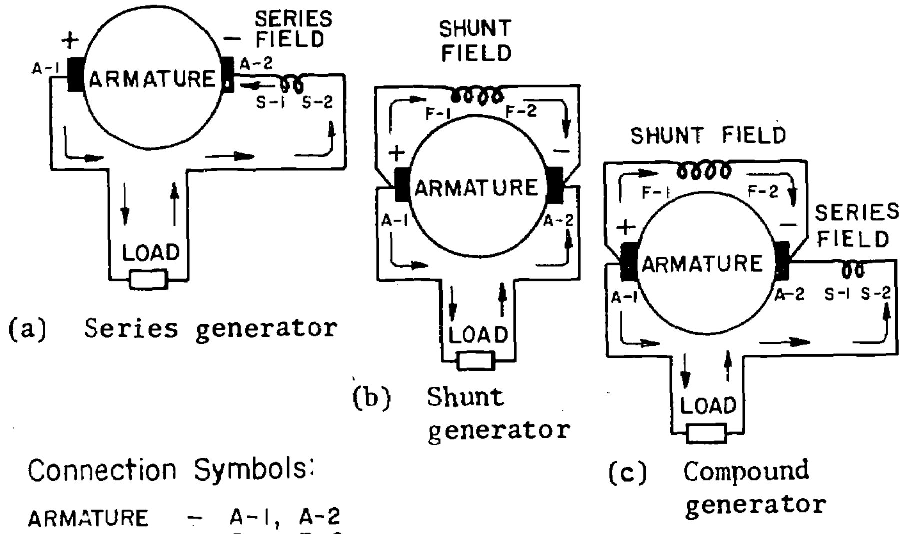


Connection Symbols:

ARMATURE — A-1, A-2
SHUNT FIELD — F-1, F-2
SERIES FIELD — S-1, S-2

Figure 21. Self-excited direct-current generators.

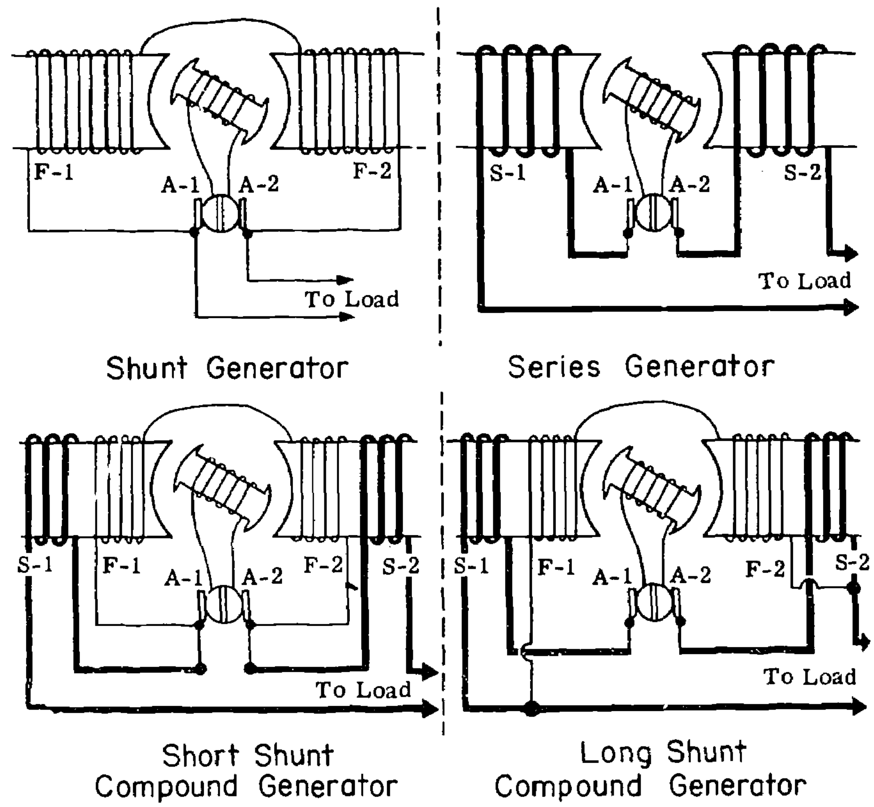


Figure 22. Self-excited generator field connections.

Figures 19, 20, 21, and 22

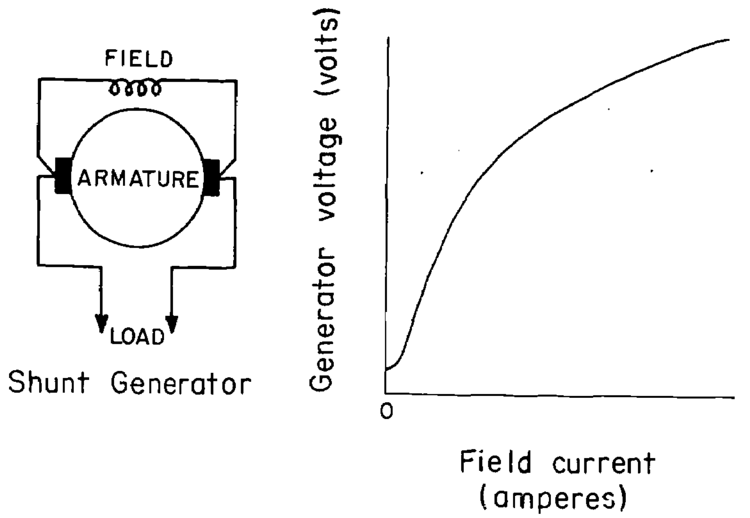


Figure 23. Single-line diagram of the shunt generator and its voltage buildup characteristic curve.

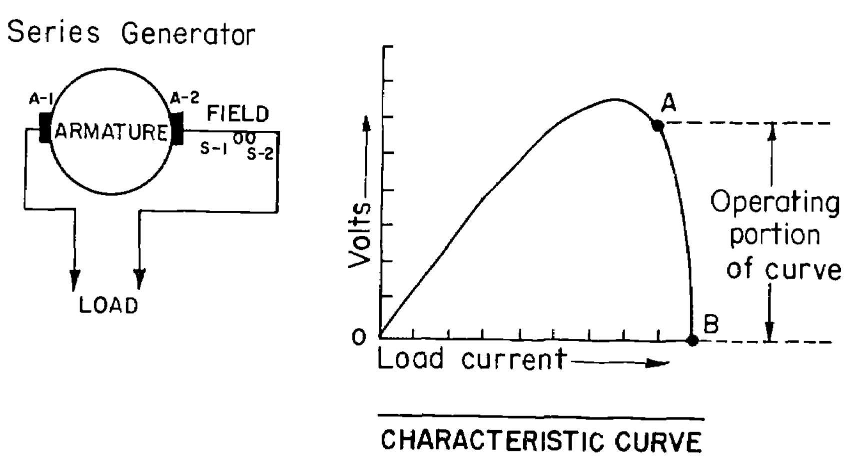
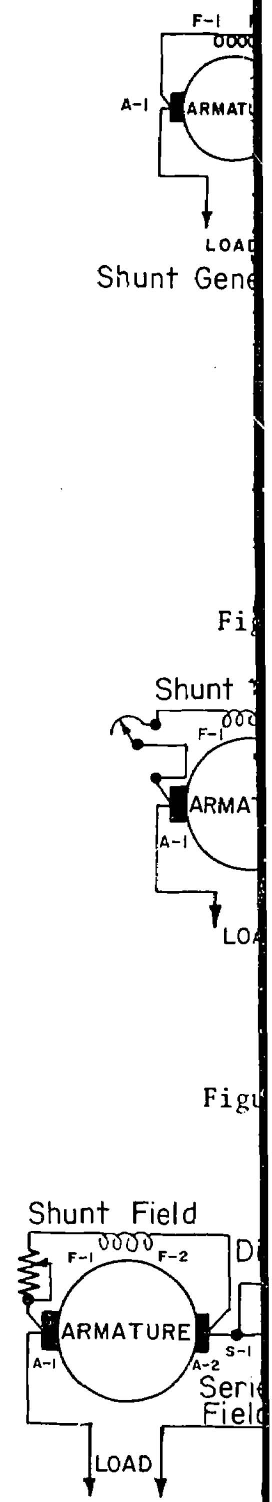
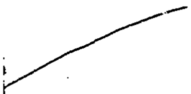


Figure 24. The series generator.





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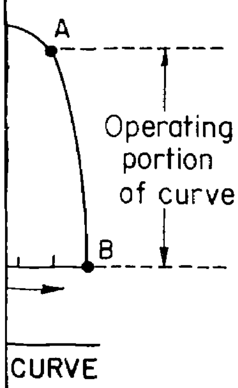

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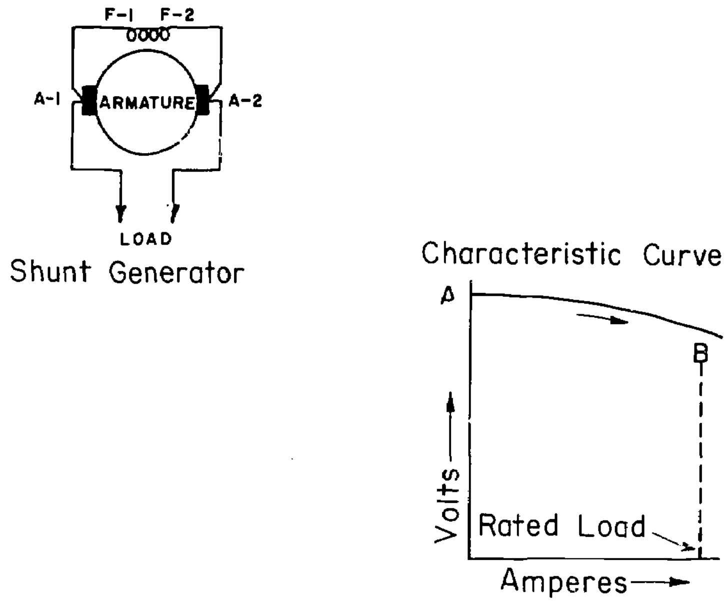


Figure 25. The shunt generator.

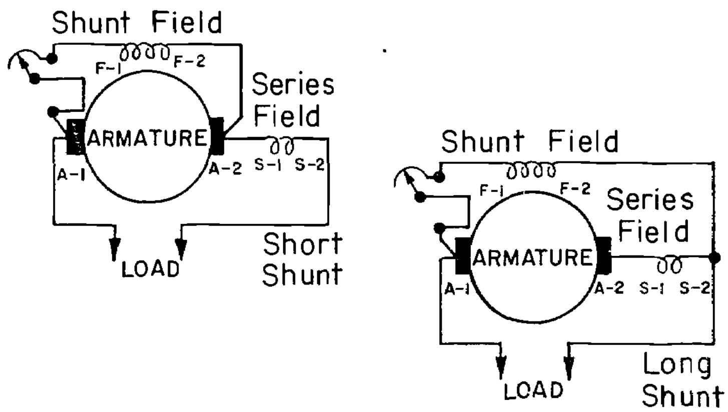


Figure 26. Compound generators.

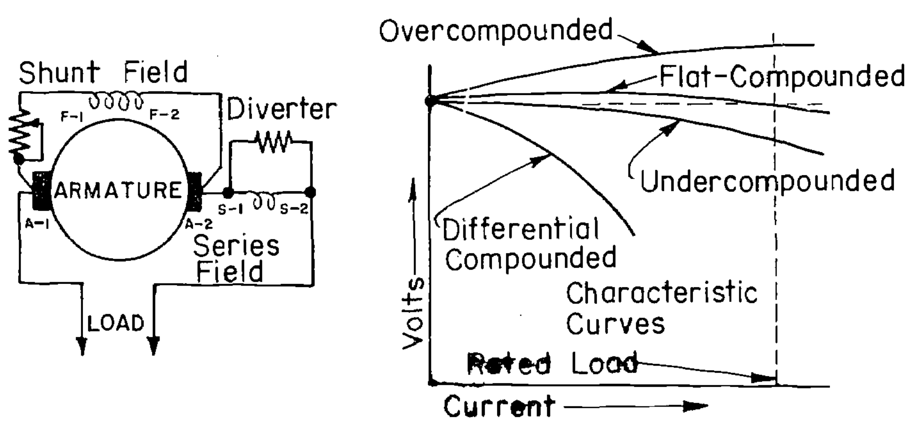
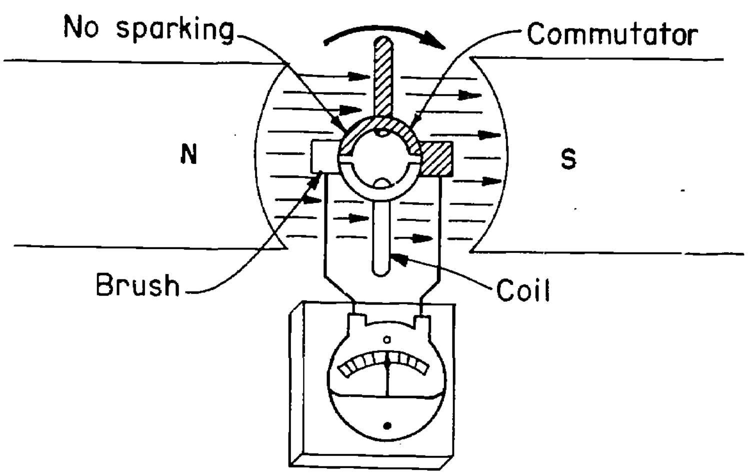
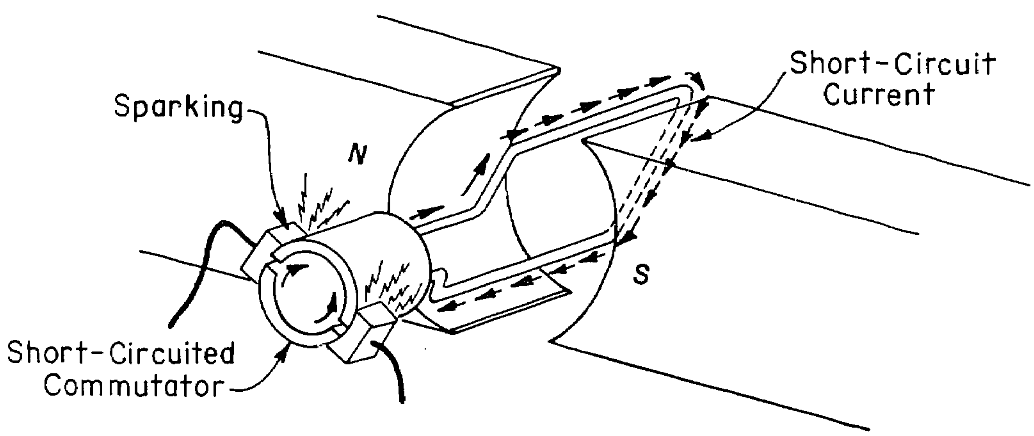


Figure 27. The compound generator.

Figures 23, 24, 25, 26, and 27



(a) Proper commutation.



(b) Improper commutation.

Figure 28. Proper and improper commutation.

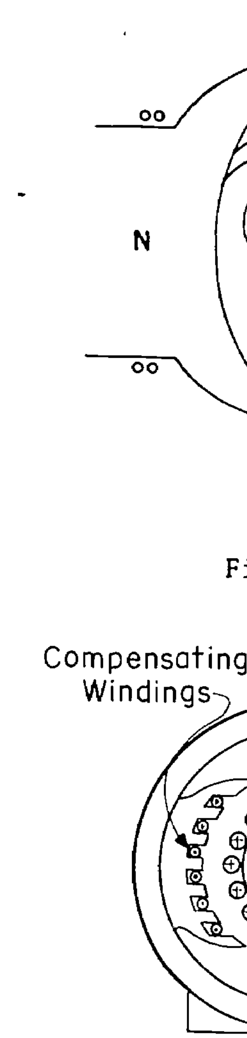
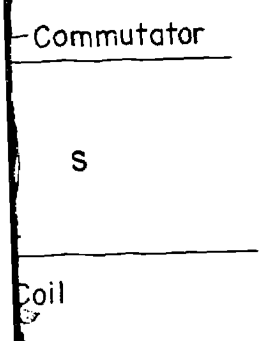


Figure 3



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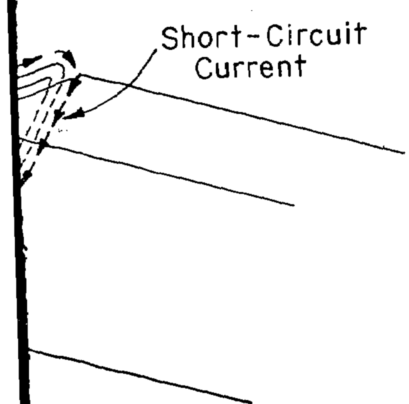

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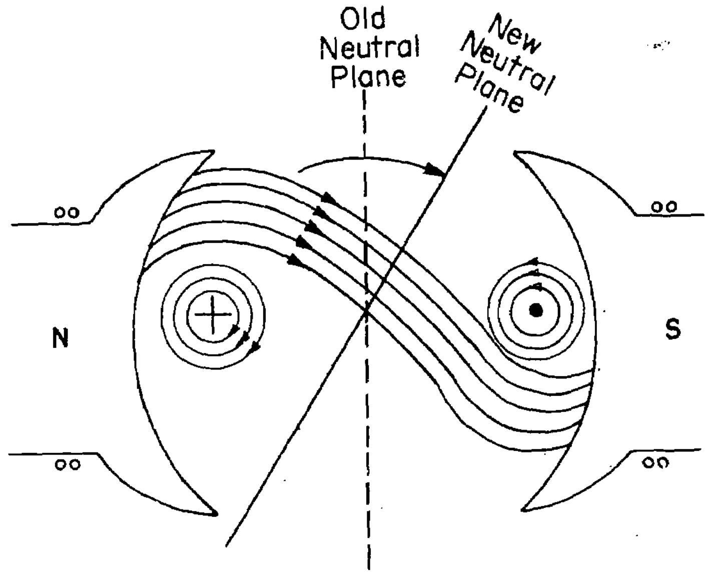

Figure 29. Armature reaction.

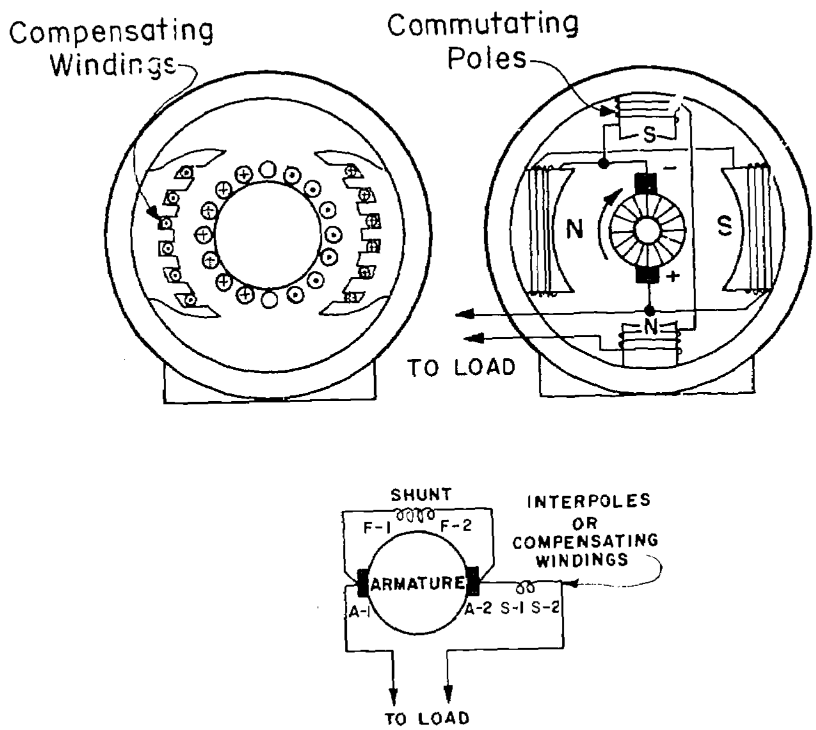

Figure 30. Correcting armature reaction.

Figures 28, 29, and 30

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

TRAINING COURSE

FOR

POWER OPERATING PERSONNEL

LESSON NO. VI

ALTERNATING-CURRENT GENERATOR EXCITATION

POST TEST QUESTIONS AND ANSWERS

ENGINEERING AND RESEARCH CENTER
DIVISION OF POWER OPERATION AND MAINTENANCE
DENVER, COLORADO

REVISED JUNE 1973

LESSON NO. VI

ALTERNATING-CURRENT GENERATOR EXCITATION

Name ____________________

Date ____________________

Score ____________________

MULTIPLE CHOICE QUESTIONS

Select the one best answer, a, b, c, d, e, or f. Place your selection in the space provided opposite the number of the question.

_____ 1 There are two major devices that control the proper operation of a hydroelectric generator, they are:

(a) The powerplant operator and his assistant

(b) The system operator and the powerplant operator

(c) The governor and the voltage regulator of the hydroelectric unit

(d) The available amount of water and its effective head

____ 2 The average single hydroelectric generating unit of the Bureau of Reclamation:

(a) Does not affect the voltage or frequency of the interconnected system

(b) Does affect the voltage and frequency in its own powerplant

(c) Is always automatically controlled by the requirements of the substation bus

(d) Never changes, once it is set on the correct load and speed setting

____ 3 The exciter and voltage regulator for a hydroelectric unit provide the desired rotor current in the generator to:

(a) Meet the voltage and var requirements of the load

(b) Meet the voltage and var requirements of the system

(c) Control the voltage and vars carried by the unit

(d) Control the amount of kilowatt load it is carrying

____ 4 The division of load between two alternating-current generators operating in parallel is controlled by:

(a) The net operating head on each unit

(b) The sensitivity of the exciter control mechanism

(c) The load requirements of the load they are connected to

(d) The characteristics of the hydroturbines and their governor linkages

_____ 5 The division of voltage to a load connected to two alternating-current generators operating in parallel is determined by:

(a) The speed of each generating unit

(b) The excitation current flowing in their rotors

(c) The requirements of the system to which they are connected

(d) The volt-ampere characteristics of each unit

_____ 6 Modern excitation systems for hydroelectric generators contrast with older systems:

(a) In their inability to improve unit reliability

(b) In their inability to meet system requirements

(c) In their ability to use the excitation of the alternating-current generator to obtain maximum performance of the unit under disturbed system conditions

(d) In that they are more nearly true direct-current systems

_____ 7 The voltage induced in the rotor of the exciter is usually:

(a) Of a true direct current characteristic

(b) The same voltage as that on the rotor of the alternating-current generator

(c) Always different from that on the rotor of the alternating-current generator

(d) One-half that on the rotor of the alternating-current generator

_____ 8 Excitation equipment used on Bureau hydroelectric generating units should be designed for:

(a) Simplicity

(b) Ruggedness

(c) Foolproofness

(d) Continuity of service

(e) All of the above

(f) None of items (a) through (d)

_____ 9 The simple direct-current generator with proper use and control:

(a) Is used to drive all our direct-current exciters

(b) Is always driven by alternating current controlled motors

(c) Is the most important excitation component of our hydroelectric powerplant generating system

(d) Is of very minor importance in our hydroelectric powerplant generating system

_____ 10 Commutation is the action of:

(a) Calculating the speed of the exciter to provide proper direct-current voltage for the rotor of the hydroelectric generator

(b) Carrying the exciter current from the direct-current exciter to the rotor of the hydroelectric generator

(c) Converting the alternating current generated in the rotor of the exciter to direct current

(d) Commuting the power generated by the hydroelectric generator to its load point

_____ 11 The most important components used in commutation are:

(a) Brushes properly positioned on the commutator

(b) The segments of the direct-current generator commutator

(c) The type of wire used in winding the coils on the rotor of the direct-current generator

(d) The leads that carry the direct current from the exciter to the hydroelectric generator

_____ 12 In comparing the construction of alternating- and direct-current generators:

(a) The armature coil is mounted on the rotor

(b) The field coil is mounted on the stator

(c) Neither (a) nor (b) is true for both alternating- and direct-current generators

(d) The rotating part is called the "rotor" and the stationary part the "stator" in both cases

_____ 13 For direct-current generators:

(a) The armature coils are mounted on the "rotor"

(b) The armature coils are mounted on the "stator"

(c) The armature coils carry only direct current

(d) The field coils carry only alternating current

_____ 14 For large alternating-current generators

(a) The armature coils carry the exciter current

(b) The field coils carry the higher voltage current

(c) Field coils carrying direct current are wound on the rotor

(d) Field coils carrying direct current are wound on the stator

_____ 15 Pole pieces upon which the generator coils are wound are made up of:

(a) Hard-surfaced special-treated monel metal to prevent deterioration due to stray eddy currents

(b) Solid pieces of high conductive metal to cut down the resistance so the heat losses will be less

(c) Soft malleable iron so they may be easily shaped to fit the stator or rotor section of the unit

(d) Many thin layers of iron or steel called laminations to reduce eddy currents

_____ 16 Most large direct-current generators used as exciters have:

(a) Permanent magnet fields

(b) Separately excited fields

(c) Electromagnetic fields

(d) Alternating current generated high-frequency fields

_____ 17 Direct-current generators used as exciters are classified according to:

(a) Speed and direction of rotation

(b) Ampere and voltage rating

(c) Source of motive power

(d) The manner in which the field is supplied with excitation current

_____ 18 A compound direct-current generator has:

(a) All its generated current flowing through all its field coils

(b) Two coils, one which carries only a part of the armature current and another that carries all of the load current

(c) Shunt field coils only

(d) Series field coils only

_____ 19 "Buildup" in a direct-current generator refers to:

(a) How it was originally constructed

(b) Whether it is shaft mounted or sits on the floor and driven by some form of motive power

(c) Its mechanical rotation

(d) Its electrical output in direct-current volts and amperes

_____ 20 All direct-current generators have armature reaction which is minimized by:

(a) Shifting the position of the brushes each time the load changes 25 percent

(b) Installing compensating windings and/or interpoles

(c) Adjusting the phase angle of the alternating-current hydroelectric generator to which it is supplying excitation current

LESSON NO. VI - ALTERNATING-CURRENT GENERATOR EXCITATION
POST TEST QUESTION SHEET

TRUE AND FALSE QUESTIONS

If the statement is TRUE, enter T in the blank space provided. If the statement is FALSE, enter F in the blank space provided.

_____ 1 Armature reaction is counteracted by embedding windings in slots in the field pole faces, carrying the same current as the armature coil but in the opposite direction.

_____ 2 Small poles mounted between the main field windings are never used to generate a field exactly opposite to that of the armature coil.

_____ 3 Armature reaction is that electromotive force that aids the rotation of the armature in the electromagnetic field.

_____ 4 Commutator sparking may be reduced by shifting the brushes in the proper direction which prolongs brush life as well as conserves the armature itself.

_____ 5 A compound-wound generator has two sets of windings - a shunt field and a series field.

_____ 6 A series exciter, or direct-current generator, is connected in series with the stator of the alternating-current generator it controls.

_____ 7 Self-excited, direct-current generators use the output of the generator itself to excite its field.

_____ 8 Separately excited direct-current generators, exciters, are used extensively in the excitation of large alternating-current generators.

_____ 9 For proper commutation, the coil short circuited by the brushes should be in the neutral plane of the field magnetic lines of force.

_____ 10 Compound direct-current generators are designed to overcome the drop in terminal voltage which occurs in a shunt generator when the load is increased.

_____ 11 When a shunt generator is started up, the buildup time for rated terminal voltage at the brushes is very long because its field winding is connected in parallel with the armature.

_____ 12 In the series direct-current generator, with no load, no current can flow and therefore very little voltage can be induced in the armature - the amount really depends on the strength of the residual magnetism.

_____ 13 In practically all direct-current generators the stator rotates around the poles of the armature.

_____ 14 The exciter and its voltage regulator provide the desired rotor current in the alternating-current generator to control its voltage and power factor.

_____ 15 The volt-ampere loading of a hydroelectric alternating-current generator has a negligible effect on the kilowatt loading of the unit.

_____ 16 If two alternating-current generators are operating in parallel and a sudden load is applied, there is a slight reduction in their speed. If the governors are working properly, they restore the speed to normal.

_____ 17 Control of the load on a hydrogenerating unit is obtained by adjusting the governor speed characteristic.

_____ 18 If two alternating-current generators are operating in parallel and a sudden load is applied, there is a slight drop in terminal voltage but with equal excitation they will share the reactive volt-amperes equally.

_____ 19 The changing of the direct current flowing in the rotor of an alternating-current generator only changes the voltage and/or reactive power and not the kilowatt output of the generator.

_____ 20 Loss in excitation of an alternating-current generating unit connected to a bus results in a more serious disturbance than that resulting from dropping the generating unit from the bus.

LESSON NO. VI - ALTERNATING-CURRENT GENERATOR EXCITATION
POST TEST ANSWER SHEET

MULTIPLE CHOICE QUESTIONS

Correct answers - Score three points per question

Question No.	Correct answer	Question No.	Correct answer
1	c	11	a
2	a	12	d
3	c	13	a
4	d	14	c
5	b	15	d
6	c	16	c
7	b	17	d
8	e	18	b
9	c	19	d
10	c	20	b

TRUE AND FALSE QUESTIONS

Correct answers - Score two points per question

1	T	11	F
2	F	12	T
3	F	13	F
4	T	14	T
5	T	15	T
6	F	16	T
7	T	17	T
8	F	18	T
9	T	19	T
10	T	20	T

GPO 848-619