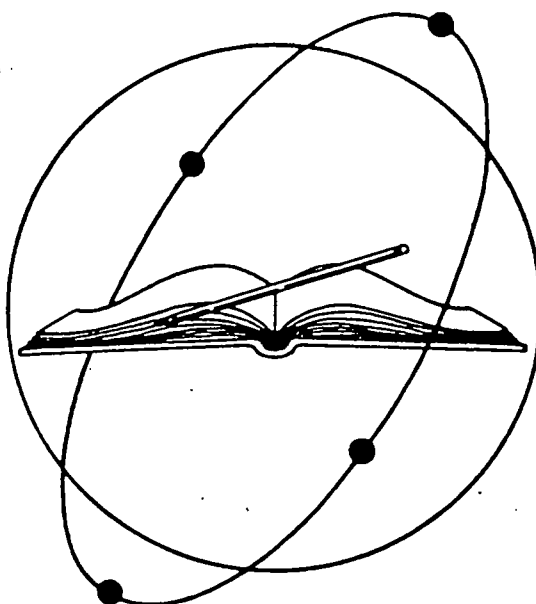# TECHNICAL
Information

BASIC

ELECTRICITY

GENERAC
CORPORATION

FORWARD

Electrical Energy was not used to produce work until the late nineteenth century. The existence of electrical energy, however, was known long before that. Electricity was unknowingly discovered by the Greeks when they observed that a piece of amber would attract tiny flakes of wood and feathers. The Greek word for amber was *elektron*.

TABLE OF CONTENTS

Section 1 — CURRENT FLOW

THE ATOM

All matter is made up of atoms. An atom may be compared to a solar system that has several planets revolving around the sun. There are more than 100 different kinds of atoms. The various atoms combined together form all known substances.

The structure of the helium atom is shown in Figure 1-1. Negatively charged particles called **electrons** revolve around a positively charged **nucleus**. The nucleus is made of positively charged **protons** and also **neutrons**, which have neutral electrical charges. The negative and positive particles that make up an atom act much like the north and south poles of a magnet, in which the north pole is positive (+) and the south pole is negative (—).

Every child who has played with a magnet knows that **like poles repel each other, and that unlike poles attract each other.**
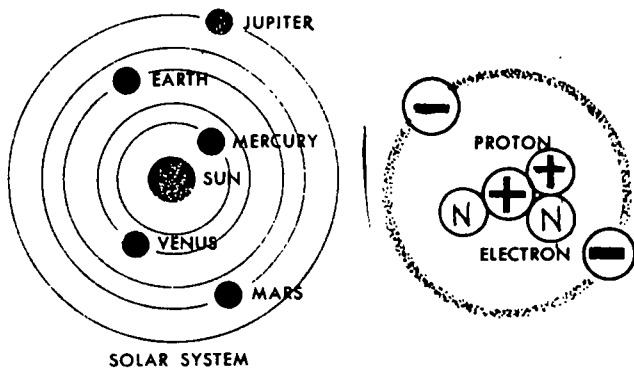

Figure 1-1 — The Helium Atom

MAGNETISM AND ELECTRICITY

Like the poles of a magnet, atomic particles with the same charges repel each other, and particles with different charges attract each other. In a normal atom, the positive charge of the nucleus exactly balances the negative charge of the electrons that rotate around it (Figure 1-2).

BORROWING OF ELECTRONS

If an atom loses electrons, the positive (+) charge of the nucleus and the negative (—) charge of the electrons is no longer balanced. The atom then becomes positively charged. The natural tendency of the positively charged atom is to attract any other negative charges, such as an electron.
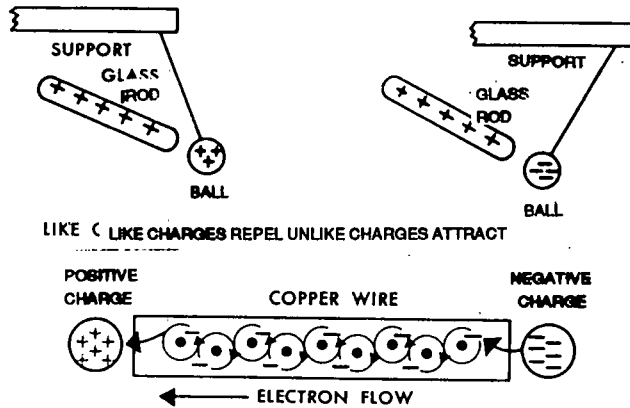
Figure 1-2 — Magnetism and Electricity

The positively charged atom attempts to return to a balanced (or neutral) state, and may even "borrow" an electron from a neighboring atom. When an atom borrows an electron from its neighbor, the neighbor then becomes positively charged. This starts a "chain reaction" in which each atom in turn borrows an electron from its neighboring atom. *This borrowing of electrons creates a flow of current that continues until all atoms have achieved a state of balance.*

Figure 1-3 illustrates the transfer of electrons from one atom to the next and the resulting flow of free electrons that occurs. This may be difficult to visualize unless you remember that an electron is so small that it finds great empty spaces for free travel even in a solid substance.

ELECTRICAL CURRENT FLOW IS BASED ON THE ABOVE PRINCIPLE: THAT ATOMS HAVE THE ABILITY TO READILY TRANSFER AND BORROW ELECTRONS.

FLOW OF FREE ELECTRONS

Figure 1-3 — Transfer of Electrons

CONDUCTORS AND NON-CONDUCTORS

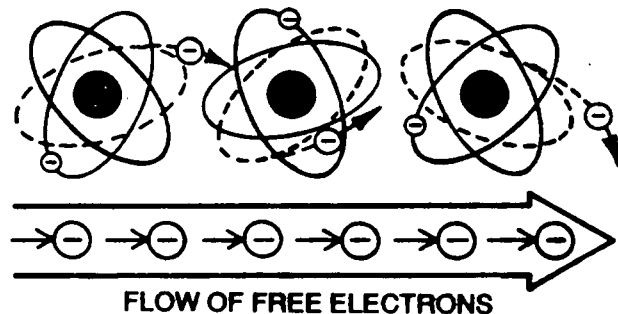Some materials (such as copper or silver) will readily transfer electrons from atom to atom. These materials are called **conductors**. Other materials hold their electrons very tightly and are said to have "bound" electrons. These **non-conductors**, materials such as wood, glass, or rubber, are often used as **insulators**.

CURRENT FLOW VERSUS ELECTRICITY

Electricity is created by the action of electrons in motion. Current flow is the flow of free electrons through a circuit. Thus, electricity is a form of energy while current flow is the harnessing of that energy.

TWO THEORIES OF CURRENT FLOW

Electron Theory: As previously discussed, current flow is based on the fact "**like charges repel, unlike charges attract.**" An electron, a negative (—) charge, is attracted to a positive (+) charge, such as a proton. The Electron Theory of Electricity states that electron or current flow in a circuit goes from the negative side of that circuit to the positive side.

Conventional Theory: This theory states that current or electrton flow in a circuit goes from the positive side of that circuit to its negative side. This difference between conventional and electron theory is discussed because the conventional theory is used more commonly in everyday applications.

ELECTRO-MOTIVE FORCE

Currrent flow occurs in a conductor only when there is a differece in electrical "potential" and when there is a complete path or circuit for electron flow. The force that causes the electrons to flow in a circuit is called **electromotive force** or **EMF**. This force is equal to the difference in electrical potential across the circuit.

To illustrate the difference in potential, consider a storage battery as a model. This type of battery consists of two different metal plates immersed in a fluid called electrolyte. A chemical reaction causes an electrical charge to be created on each of the metal plates. The electrolyte carries electrons away from one plate and deposits them on the other plate (Figure 1-4).
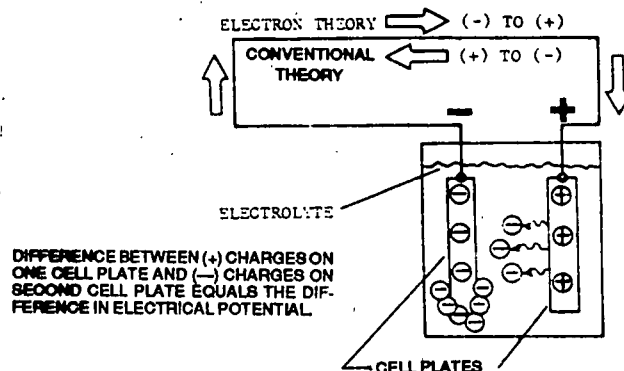
Figure 1-4 — Electrical Potential

The plate that has gained electrons has become negatively charged. This creates a difference in electrical potential between the two metal plates. If a conductor is now connected across the two metal plates, a circuit is completed, and the result is a flow of electrons to the positively charged plate.

As long as there is a difference in electrical potential between the two plates (positive versus negative charge), current continues to flow.

Section 2 — CREATING CURRENT FLOW

Several basic methods may be used to create an electrical current flow. We shall discuss four of those methods here. All of these methods are based on a fundamental law that energy can never be created nor destroyed, but can be changed to other forms of energy. Thus, **chemical, heat, light** and **magnetic** energy can be changed to electrical energy.

Four basic methods for creating electrical current flow are:

* Chemical energy (e.g., storage battery)
* Heat energy (e.g., thermocouple)
* Light energy (e.g., photo-electric)
* Magnetic energy (e.g., alternator or generator)

STORAGE BATTERY

The basic principles of storage batteries are discussed on Page 3 of this manual.

THE THERMOCOUPLE

When two dissimilar metals are welded together and the welded junction is heated or cooled, an electro-motive force (EMF) is produced. The joining process appears to disturb the atomic orbits at the junction, so that the outer electrons in both metals are loosely held. Any small addition or subtraction of heat energy will set these electrons free.

Figure 2-1 shows a union between iron and copper wires, to form a thermocouple. In Figure 2-1A, the heat of the flame has caused the copper atoms to lose electrons. The copper then draws electrons from the iron and a current flow is produced.

In Figure 2-1B, the wire junction has been cooled causing the iron to lose electrons and then attract electrons from the copper. The current flow is reversed from that of Figure 2-1A.

PHOTOELECTRIC CELL

Copper oxide and **selenium oxide** are sensitive to rays of light. Materials that create a current flow when exposed to light are said to be "photo-voltaic."

MAGNETIC ENERGY

Magnetism is closely related to electricity. It can be used to produce electricity and electricity can be used to produce magnetism. A study of one should, therefore, include a study of the other.
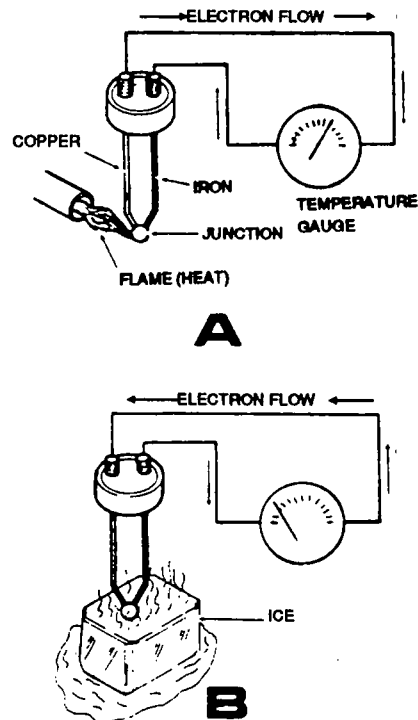
Figure 2-1 — The Thermocouple

Magnetic "lines of force" surround a magnet. These lines of force are concentrated at the magnet's NORTH and SOUTH poles and are often called "lines of flux" (Figure 2-2) The flux lines are directed away from the magnet at its north pole and re-enter the magnet at is south pole.
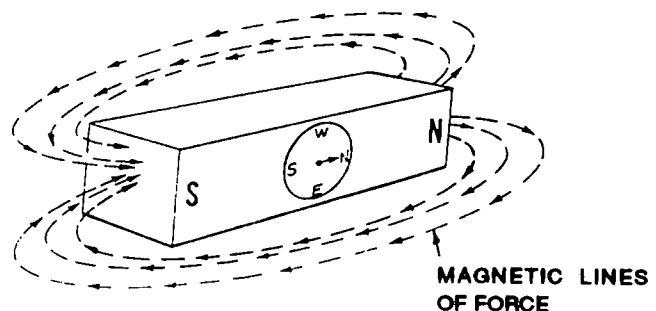
Figure 2-2 — Lines of Flux Around a Magnet

Like the positive (+) and negative (—) electrical charges previously discussed, the same magnetic poles repel each other and unlike poles attract each other. When discussing magnetism, two terms should be defined:

- **Permeability:** The ease with which any given substance can be magnetized.

- **Retentivity:** The ability of a substance to retain its magnetism when an external magnetic field is removed.

CURRENT FLOW AND MAGNETISM

All conductors through which an electrical current is flowing have a magnetic field surrounding them. The greater the current (electron) flow, the stronger or more concentrated the magnetic field. To determine the direction of magnetic lines of force around a wire, you can use a simple rule called the "Right Hand Rule". Simply place your right hand around the wire with the thumb pointing in the direction of the current flow (positive to negative). The fingers then point in the direction of the magnetic lines of force (Figure 2-3).

When conductor wires are formed into a coil, a north magnetic pole is created in half of the coil, a south magnetic pole in the other half. Determine polarity (direction of the lines of force) in the coil by grasping the it in the right hand with the fingers pointing in the direction of current flow. The thumb then points to the coil's north pole.
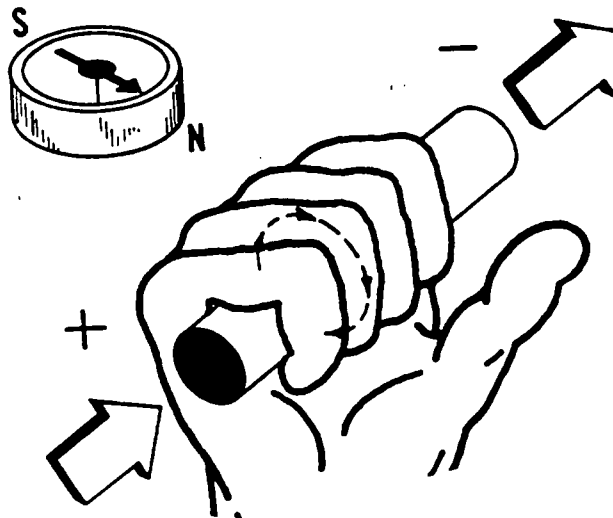

Figure 2-3 — The Right Hand Rule

SIMPLE PERMANENT MAGNET GENERATOR

When a wire is moved so that it cuts across a magnetic field, an electro-motive force (EMF) is induced into that wire (Figure 2-4). This is the principle upon which a rotating armature generator is based.
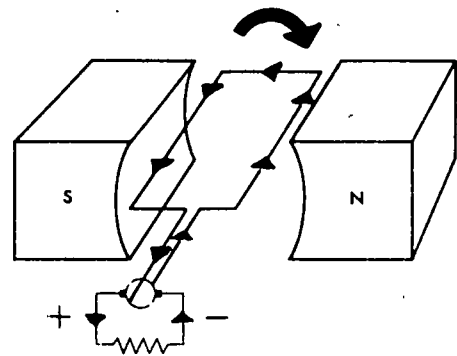

Figure 2-4 — Simple Revolving Armature Generator

SIMPLE ALTERNATOR

In an alternator (Figure 2-5) a revolving magnetic field, called a **rotor**, is moved through a stationary coil of wires called a **stator**. This movement induces an electro-motive force (EMF) into the stator.

PERMANENT MAGNET ALTERNATOR
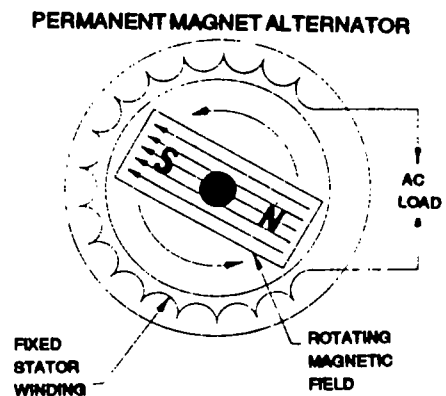
Figure 2-5 — Simple Revolving Field Alternator

ELECTROMAGNETIC INDUCTION

The basic principle of both generator and alternator operation is called **electromagnetic induction**. Another form of electromagnetic induction is the familiar automobile engine ignition coil. Current flow through a primary coil of wires creates a magnetic field around that coil which cuts through a secondary coil of wires. When the current flow through the primary wire coil is interrupted by opening a set of breaker points, the collapse of the magnetic field induces an electromotive force (EMF) into the secondary coil (Figure 2-6 on Page 6).

Figure 2-6 — Typical Automobile Ignition System

POSITION OF COILS IN A SIMPLE GENERATOR

Waveform at 0 and 180° | Waveform at 90° | Waveform at 270°

NO CURRENT | POSITIVE ALTERNATION | NEGATIVE ALTERNATION

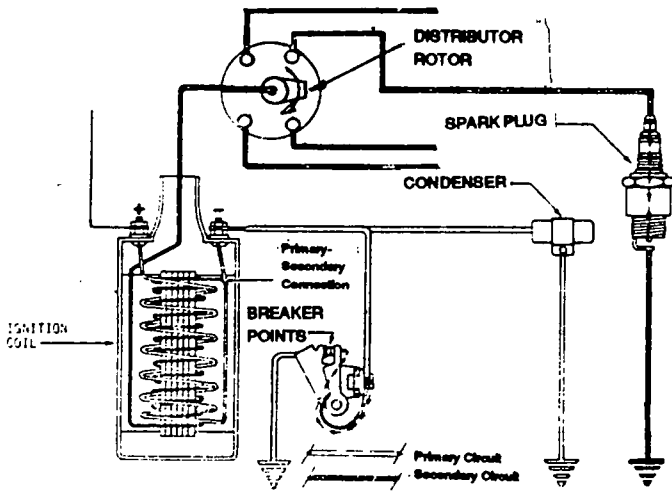Figure 2-7 — Creating an AC Sine Wave in Generator

DIRECT CURRENT (DC)

The current flow created by the storage battery previously discussed flowed in only one direction through the conductor. This type of current flow is called **direct current or DC.**

ALTERNATING CURRENT (AC)

Alternating current or AC is the flow of electrons in a conductor, first in one direction then in the other. This can be explained by showing the operation of a simple alternating current generator.

The flow of electrons changes direction (Figure 2-7) according to the rotating armature's position in relation to the poles of a magnetic field, as follows:

A wave diagram (sine wave) of alternating current shows that current goes from zero value to maximum positive value (0-90 degrees), reverses itself again and returns to zero (Figure 2-8). Two such reversals of current are called "one cycle" or "one Hertz." The number of cycles, or Hertz per second, is called frequency.

ALTERNATING CURRENT SINE WAVE

1 CYCLE
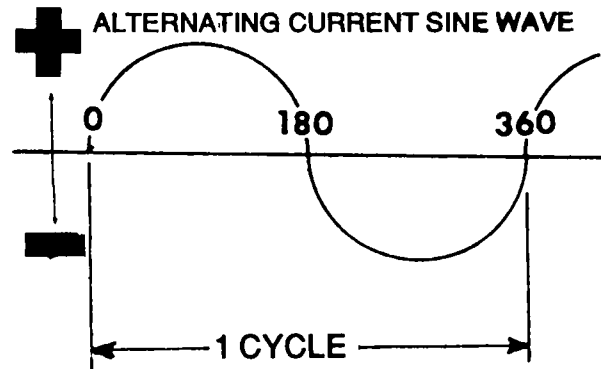
Figure 2-8 — An Alternating Current Sine Wave

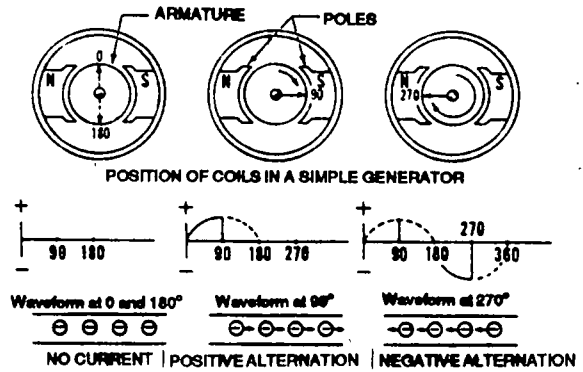| ARMATURE POSITION	CURRENT OR ELECTRON FLOW
0°	No current or electron flow occurs
90°	Armature becomes aligned with magnet's NORTH pole and current (electron) flow reaches its maximum value.
180°	Current flowdrops to zero.
270°	Armature becomes aligned with magnet's SOUTH pole and current (electron) flow reaches its maximum value, but is reversed from flow direction that occurred at 90 degrees.
360°	Current flow drops to zero.

Section 3 — UNITS OF ELECTRICAL MEASUREMENT

Just as a hydraulic circuit must have specific values — (a) rate of flow, (b) pressure, and (c) resistance to flow — established values can also be expressed for an electrical circuit. Fluid flow through a hydraulic system are generally expressed in (a) gallons per minute, (b) pounds per square inch, and (c) pressure drop or pressure differential.

Electron (current) flow through a conductor can be compared to the flow of hydraulic fluid through a line. Units of measurement for an electrical circuit are (a) **volts** - pressure; (b) **amperes** - rate of flow; and (c) **ohms** - resistance to flow (Figure 3-1).
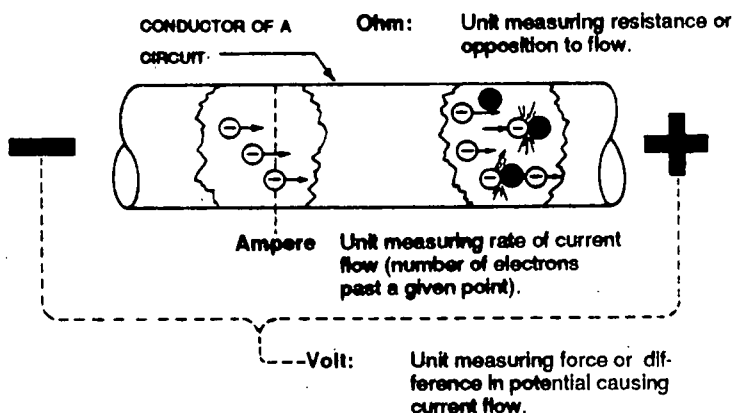

Figure 3-1 — Electrical Measurement Units

	UNIT OF MEASUREMENT	
	HYDRAULIC	ELECTRICAL
PRESSURE	Pounds per square in. (psi)	Volts (E)
RATE OF FLOW	Gallons per minute (gpm)	Amperes (I)
RESISTANCE TO FLOW	Pressure drop	Ohms (R)

AMPERE — UNIT OF CURRENT FLOW

The rate of electron flow through a conductor is measured in **amperes**, which is a measurement of electrons flowing past a given point at a given time. One ampere is equal to a little over six thousand million billion electrons per second. Written numerically, this figure looks like this: 6,000,000,000,000,000,000.

VOLT — UNIT OF RESISTANCE

The **volt** is a measurement of the difference in electrical potential (EMF) that causes electrons to flow in a circuit. This difference in electrical potential (or electro-motive force) may be described as the difference between the number of positive charges and the number of negative charges. Thus, voltage may described to be a state of electrical unbalance and current flow is the attempt to regain that balance.

The volt is the amount of electro-motive force (EMF) that will result in a current (electron) flow of one ampere through a resistance of one ohm.

OHM — UNIT OF RESISTANCE

The electron may be compared to an individual trying to make his way through a crowd of people, meeting the resistance of human bodies every step of the way. In any conductor or circuit, there is a resistance to electron flow.

A conductor's resistance depends on (a) its construction, (b) its cross-sectional area, (c) its length, and (d) its temperature.

One ohm is the amount of resistance that will permit one ampere of current to flow in a conductor when one volt of electro-motive force is applied.

OHM'S LAW

In any circuit that electrical current is flowing through, consider these three factors:

- Voltage (or EMF) that causes current to flow.
- Resistance in ohms that must be overcome before current can flow.
- Pressure in amperes, which is maintained as long as pressure, or volts, can overcome resistance (ohms).

All of the above factors are related. If any two of the values are known, the remaining value can be determined. Ohm's Law may be stated as follows:

Amperage will increase whenever voltage increases and resistance remains the same. Amperage will decrease whenever resistance increases and voltage remains the same.

The preceding Ohm's Law statement can be expressed mathematically as follows:

Volts = Amperes x Ohms

Amperes = Volts divided by Ohms

Ohms = Volts divided by Amperes

Use the circle diagram in Figure 3-2 on Page 10 to help you remember Ohm's Law. Simply cover the unknown factor and the other two will remain in their proper relationship.

Measuring Unit — Symbols	Equations
Current Flow — Amperes = I	Amperes = Volts / Ohms
Pressure — Volts = E	Volts = Amperes x Ohms
Resistance — Ohms = R	Ohms = Volts / Amperes

VOLTS (E) / AMPS (I) / OHMS (R)	Current flow in a circuit is directly proportional to the pressure and inversely proportional to the resistance.

* When two values are known, cover the unknown to obtain the formula.

Figure 3-2 — Ohms Law Expressed Mathematically

THE WATT — ELECTRICAL UNIT OF POWER

One watt is equal to one ampere of current flow under pressure of one volt. Exactly 746 Watts of electrical power is equal to one horsepower. Calculate electrical power by using this formula: WATTS = VOLTS x AMPERES (Figure 3-3).

WATTS — The Measuring Unit of Electrical Power

WATTS (P) / VOLTS (E) / AMPS (I)

EQUATIONS

Watts = Volts x Amperes

Amperes = Watts / Volts

Volts = Watts / Amperes

Figure 3-3 — The Watts Formula

INDUCTIVE REACTANCE

Inductive reactance may be defined as the condition that exists when current lags behind voltage.

Magnetic lines of force called "flux" are created around a current-carrying conductor. Since alternating current is constantly increasing to a maximum negative value, the magnetic field around the conductor must also increase, collapse to zero, then increase again with a different polarity (Figure 3-4).

Each time the magnetic field around an AC conductor collapses, a voltage (EMF) is induced into the conductor. This induced voltage causes current to continue flowing as voltage drops — this causes voltage to lead current.
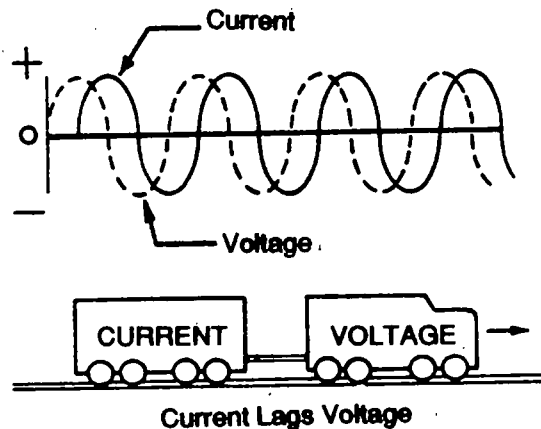

Current Lags Voltage

Figure 3-4 — Inductive Reactance

If a conductor is formed into a coil, the magnetic lines of flux are concentrated in the center of the coil. The greater density of the flux lines causes an increase in magnetically, induced voltage without increasing current flow. Coils, therefore, cause inductive reactance.

CAPACITIVE REACTANCE

Capacitive reactance is the condition that exists when current is leading voltage. Capacitance may be defined as the ability to oppose a change in voltage. It exists because some electrical components can store electrical charges when voltage is increased and discharge those electrical charges when voltage drops.
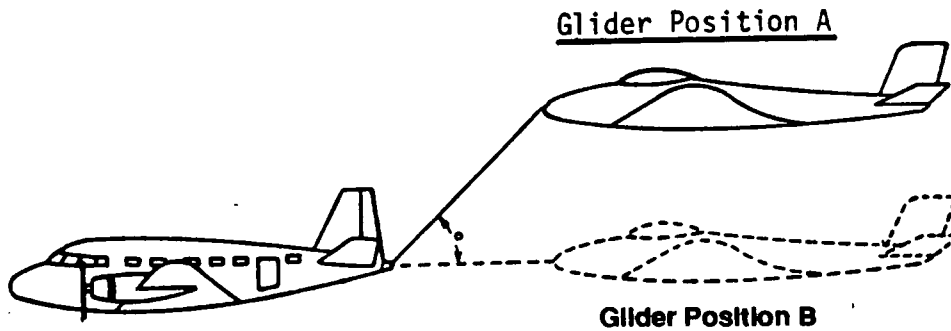
POWER FACTOR

The phrase unity power factor describes a circuit where current and voltage are "in phase." Such a circuit would have a power factor of "1". The true power (in watts) of a unity power factor circuit is the product of volts times amperes.

When an "out-of-phase" condition exists, the product of volts times amperes is the apparent power (in watts) rather than the true power. Such a condition would exist when a reactance condition occurs in the circuit.

To help explain the reason for apparent and true power ratings of reactance circuits, mechanical work can be related to electrical power. Figure 3-5 on Page 11 shows an airplane towing a glider. If the airplane pulls the glider in Position A, with the tow cable at a 45-degree angle, more pulling force must be exerted. In Position B no angle exists and force and motion are in the same direction.

A situation similar to the airplane and glider exists in reactance circuits, because current either leads or lags voltage. Thus, current and voltage never reach their maximum values at the same time in a reactance circuit. If we attempt to calculate watts with the Volts times Amperes method, we will not obtain true power because when voltage is at its peak, amperage is not. To determine true power, the number of degrees that current (amperes) is "out-of-phase" with voltage must be used as a correction factor.

Figure 3-5 — Example of True vs. Apparent Power

This correction factor is called the **power factor** in AC circuits. It is the cosine of the phase angle (the cosine of any angle is given in chart form in many math and electrical books). The cosine of a 45-degree angle is 0.707 or, stated electrically, a power factor of 0.707.

EXAMPLE: Find the apparent and true ratings of a 240 volts, 55 ampere alternator when volts is 45 degrees "out-of-phase" with amperes (Figure 3-6):

1. Find KVA.

$$KVA = \frac{Volts \times Amperes}{1000}$$

$$KVA = \frac{240 \times 55}{1000}$$

$$KVA = 13.2$$

2. Find the phase angle between Amperes and Volts. Figure 3-6 shows a 45-degree angle between the two.
3. Find the cosine of the phase angle (0.707).
4. Determine TRUE POWER.

True Power	=	Kilowatts (kW)
True Power	=	KVA x Power Factor
True Power	=	13.2 x 0.707
True Power	=	9.33 kW

5. Find the APPARENT rating.

Watts	=	Volts x Amperes
Watts	=	240 x 55
Watts	=	13,200 (13.2 kW)
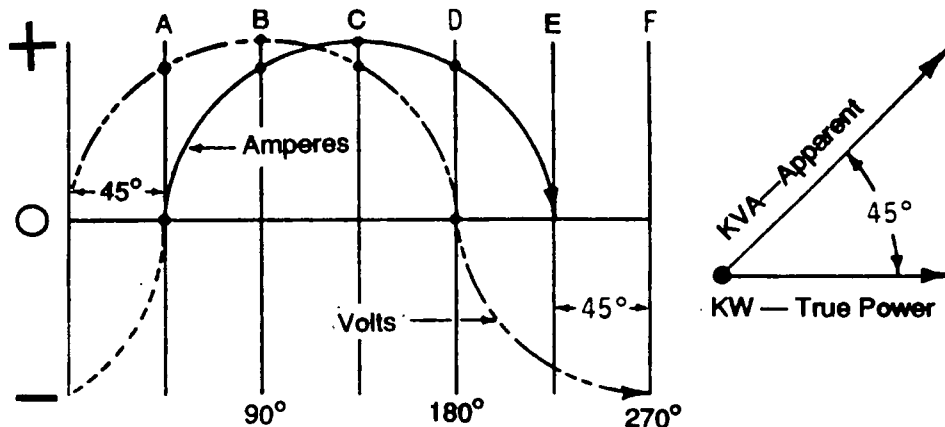
POWER FACTOR DETERMINED BY DEGREE
VOLTS ARE "OUT OF PHASE" WITH AMPERES.

Figure 3-6 — Determining the Power Factor

Section 4 — ELECTRICAL CIRCUITS

Electrical conductors and resistances (or loads) can be arranged to form any of three different types of circuits, a as follows:

- **Series** circuit
- **Parallel** circuit
- **Series-Parallel** circuit

THE SERIES CIRCUIT

A **series** circuit provides only one path in which current can flow. A break in any part of the circuit stops current flow in the entire circuit (Figure 4-1). The following basic laws may be stated for a series circuit:

- Current flow (in amperes) is the same in every part of the circuit.
- The total resistance of all resistances in series is the sum of the separate resistances.
- **Total voltage** across resistances (or loads) in series is the sum of the voltages across the resistances.

The total resistance in a series circuit is equal to the sum of the individual resistances. Thus, total resistance may be determined as follows:

$$R_T = R_1 + R_2 + R_3 + R_4$$

Find the **voltage drop** across each resistor in a series with the formula $E = IR$.

Current flow (in amperes) in a series circuit is the same at every point in the circuit. Find current flow with the following formula:
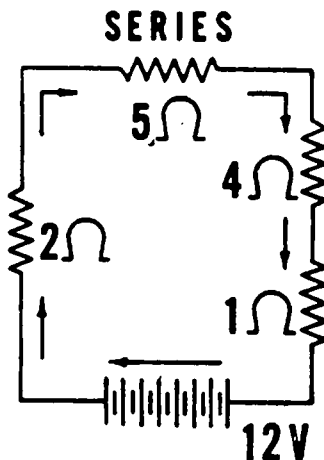
$$I = \frac{E}{TOTAL\ RESISTANCE}$$

PARALLEL CIRCUIT

The **parallel** circuit provides two or more branches or paths in which current can flow. Resistances or loads in the individual branches are completely independent of other loads in separate branches. If a shorted or open condition occurs in any branch of the circuit, remain branches may continue operating.

Resistance in a parallel circuit is less than the resistance of any of the individual branches or paths. To find total resistance in any parallel circuit, use the following formual:

$$\frac{I}{R} = \frac{1}{r} + \frac{1}{r2} + \frac{1}{r3}$$

$$\frac{I}{R} = \frac{1}{10} + \frac{1}{20} + \frac{1}{60}$$

$$\frac{I}{R} = \frac{6 + 3 + 1}{60}$$

The **voltage** applied to each component in a parallel circuit is the same as the voltage supplied by the source. The same voltage will be applied to all components in the circuit.

Total current flow (in amperes) through the branches of a parallel circuit is the sum of the current flow through individual components (Figure 4-2).
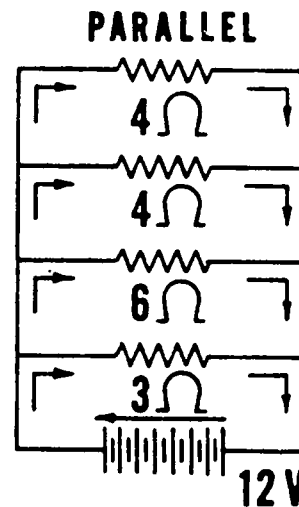
SERIES

Figure 4-1 — Series Circuit

PARALLEL

Figure 4-2 — Parallel Circuit

SERIES-PARALLEL CIRCUIT

Figure 4-2 shows a **series-parallel** circuit, in which two groups of paralleled resistors are connected in series. To find the **total resistance** of such a circuit, first determine the resistance of each group. **The sum of the two group resistances is the total circuit resistance.** Actually, you can treat the two groups of resistances exactly the same as a pair of resistances in series (See SERIES CIRCUIT on Page 12).
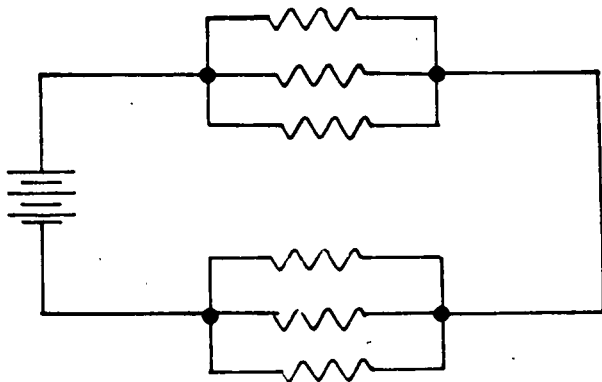

Figure 4-3 — Series-Parallel Circuit

3-WIRE CIRCUIT

Many buildings and AC alternators that have a single phase output are connected in a 3-wire circuit (Figure 4-4). The 3-wire circuit provides "dual voltage", which means it provides both 120 and/or 240 volts AC.
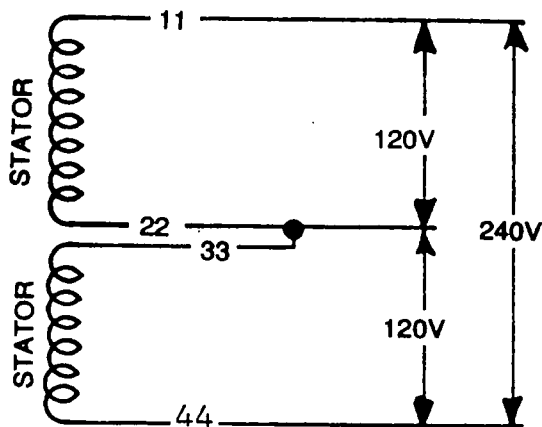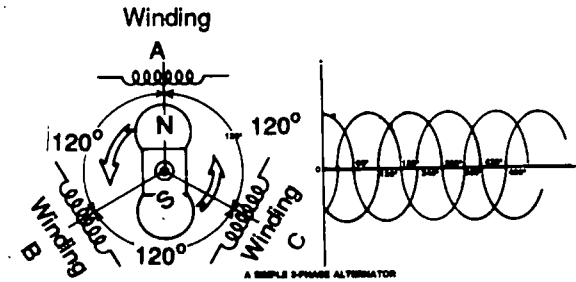

Figure 4-4 — Three-Wire Circuit

3-PHASE CIRCUITS

Three-phase circuits generate three sine waves which are 120 degrees out-of-phase with one another (Figure 4-5)

A SIMPLE 3-PHASE ALTERNATOR

Figure 4-5 — Simple 3-phase Alternator

A 3-phase circuit has several advantages, as follows:

• When the load is balanced in all three legs of a 3-phase circuit, instantaneous power is constant. This provides better capabilities for motor starting and running.

• Current flow in a 3-phase circuit produces a constant flux density, making it more effective than single phase circuits for starting and running electric motors.

• A **wye-connected**, 3-phase circuit supplies two different values of 3-phase voltage in one system. For example:

1) To apply 120 volts to a load, connect it as a 4-wire Wye load as shown in Figure 4-6.

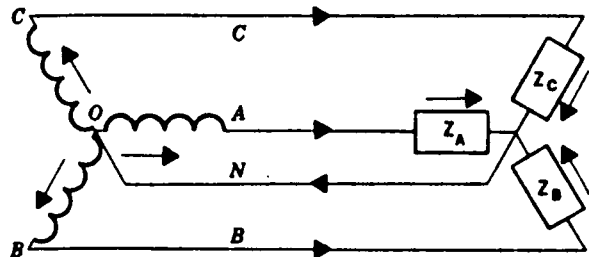2) To apply 208 volts to a load, connect the load in DELTA fashion as shown in Figure 4-7

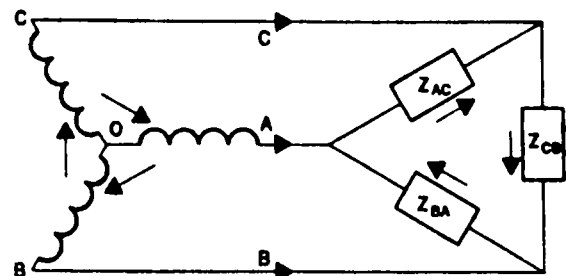*Figure 4-6 — 4-Wire Wye Load (120 Volts Applied)*

Figure 4-7 — Load Connected in Delta Fashion

The 3-phase connection systems or circuits may be (a) wye-connected, (b) delta-connected, or (c) wye-connected reconnectable (Figure 4-8). Delta-connected circuits may have either a grounded phase or an isolated ground.

CONDITIONS AFFECTING CIRCUITS

It is necessary to become familiar with certain terms used to describe some of the conditions which adversely affect the operation of electrical circuits. Some of the more common terms are:

OPEN CIRCUIT: An incomplete circuit.

PARTIALLY OPEN CIRCUIT: A circuit in which a high resistance has developed due to loose or corroded connections, or a partially broken wire. The resulting increase in resistance causes current flow to decrease.

SHORTED CIRCUIT: A condition that exists when there is a DECREASE in resistance across some part of the circuit. Since electrical current flow "seeks" the path of least resistance, current will tend to flow across the shorted section of the circuit.

PARTIALLY SHORTED CIRCUIT: A condition where positive and negative sides of a circuit only contact slightly, bypassing a small amount of current.
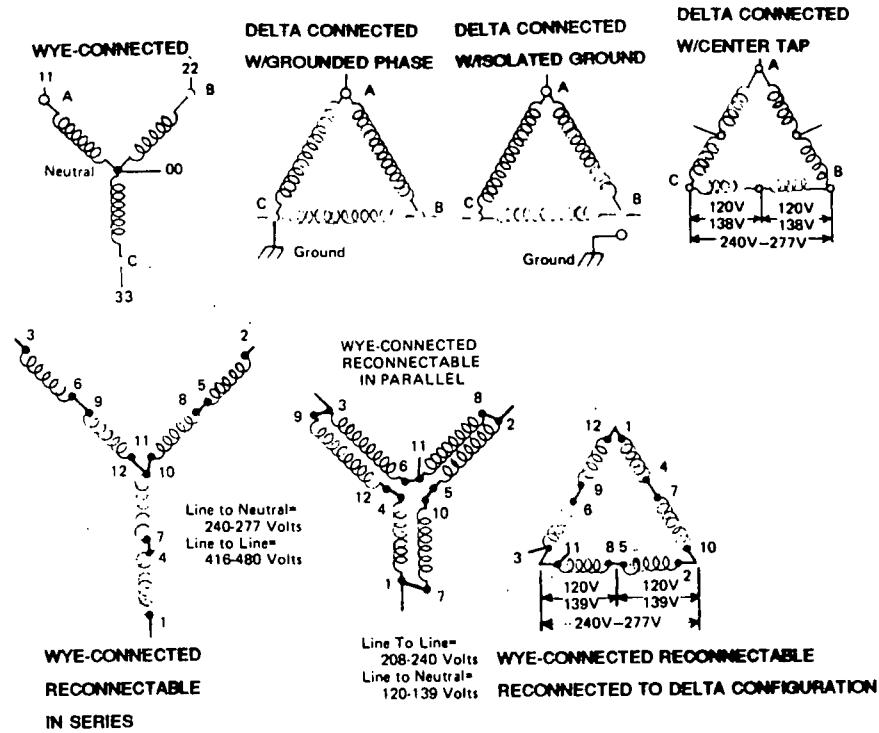

Figure 4.8 — Some Examples of 3-Phase Connection System

An alternator produces an electro-motive force (EMF) by rotating a magnetic field (rotor) within a coil of stationary windings (stator). As the magnetic lines of flux cut across the stationary stator windings, a difference in electrical "potential" is induced into the stator windings. When a complete circuit is formed by connecting a load to the stator windings, current flow occurs. The current flow (in amperes) delivered to the load is equal to (a) the number of turns of wire in the fixed stator windings, and (b) the strength of the magnetic field.

THE STATOR

The number of turns of wire in a stator winding are determined when it is manufactured. A typical stator assembly may be a single-phase type, or a 3-phase type, as previously discussed. The greater the number of turns of wire in a stator winding, the greater the induced EMF when magnetic lines of flux cut through the wiring.

THE REVOLVING MAGNETIC FIELD (Rotor)

The rotor is essentially an electro-magnet, since the flow of direct current through its windings creates a magnetic field around those windings. The strength of the magnetic field can be increased by (a) forming the wires into a coil, (b) increasing the wire size, or (c) increasing the current flow through the wires (Figure 5-1).
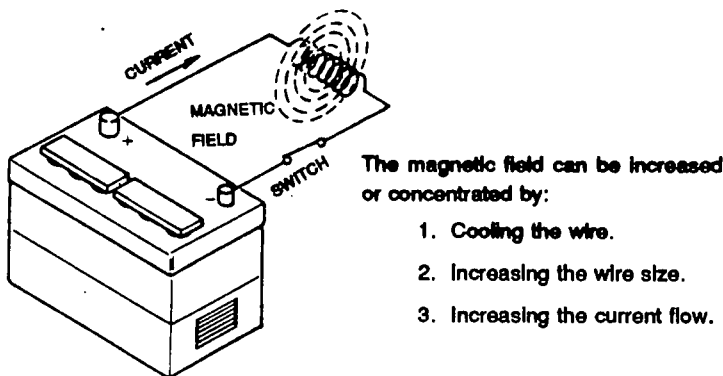

The magnetic field can be increased or concentrated by:

1. Cooling the wire.
2. Increasing the wire size.
3. Increasing the current flow.

Figure 5-1 — Basic Principles of Operation

The number of turns of wire in a rotor, as well as the wire size, are established when the rotor is manufactured. When the alternator is operating, you can vary the strength of the rotor's magnetic field by increasing or decreasing the current flow through the rotor windings. Thus, by controlling current flow through the rotor windings, the EMF induced into the stator windings can be regulated or controlled. Since the EMF is the equivalent of VOLTAGE, it can be said that voltage regulation is accomplished by controlling rotor winding current flow.

Several methods may be employed to regulate current flow through rotor windings, as follows:

- Direct Excitation
- Reactor
- Electronic Voltage Regulator

DIRECT EXCITATION

Figure 5-2 is an operating diagram of a revolving field alternator having the direct excitation feature. Operation may be described as follows:

- The rotor is rotated at a pre-determined speed.
- Residual or "stored" magnetism in the rotor creates magnetic lines of flux which cut through stator Windings "A" and "B", to induce an EMF into both windings.
- Winding "B" is the Direct Excitation Winding. The EMF induced into this winding produces an alternating current flow, which is applied to a Bridge Rectifier.
- The Bridge Rectifier changes an alternating current to direct current.
- Direct current (DC) from the bridge rectifier is applied to the Rotor windings via the Slip Ring and Brush Assembly, to create a magnetic field that is stronger than that created by residual magnetism.
- The stronger magnetic field induces a greater EMF (and resultant current flow) into both Windings "A" and "B". The cycle then repeats itself until a pre-determined AC output is reached. Any loads connected across AC output wires from Winding "A" (called the power winding) completes the Winding "A" circuit.
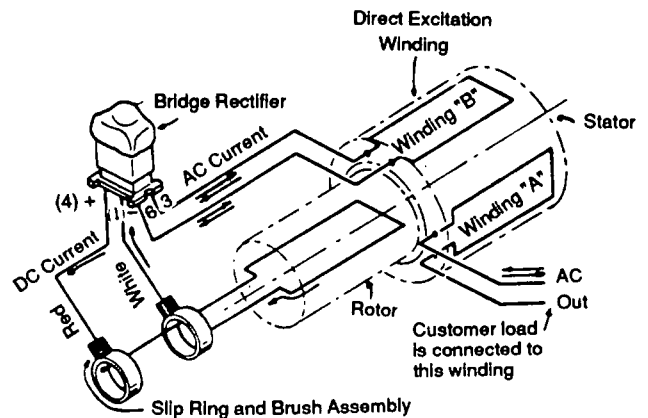

Figure 5.2 — Operation of Direct Excited Alternator

REACTOR EXCITATION

Figure 5-3 illustrates a very simple **reactor or transformer**. It consists of a **primary** and **secondary** coil of wire wound around a laminated iron or steel core. The core concentrates the magnetic lines of force created by current flow through the coils. Alternating current (AC) flow through primary winding creates a magnetic field which cuts through the secondary coil to induce a current flow into the secondary coil.
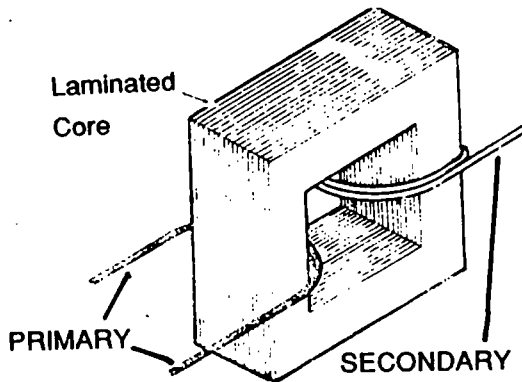

Figure 5.3 — A Simple Reactor

The amount of induced EMF (voltage or current flow) depends on (a) current flow through primary winding, and (b) the number of turns of wire in the secondary winding, as follows:

• The greater the currrent flow through the primary coil, the greater the current flow induced into the secondary coil.

• The larger the number of turns of wire in the secondary coil, proportional to the number of turns in the primary coil, the greater the current flow induced into the secondary coil.

The reactor method of excitation uses a current transformer, often called a **reactor**. This type of **transformer**, or reactor, changes current from one level to a higher or lower level. In Generac's circuit, it acts as a voltage regulator (Figure 5-4). This type of alternator and the direct excited type have two basic differences, which are as follows:

• A reactor or current transformer has been added to the circuit.

• The AC output to the load is taken from the same stator winding that the excitation current is taken from.
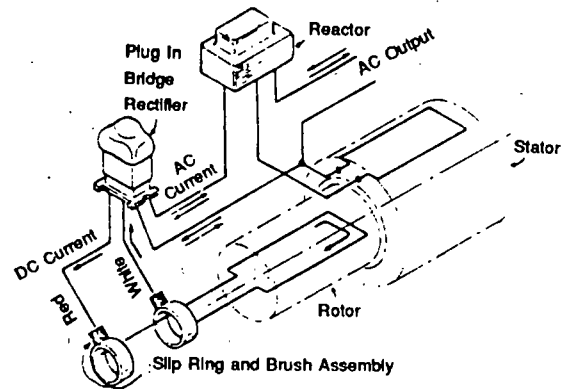

*Figure 5.4 — Operation of Reactor-Excited Alternator*

Operation of a Reactor-Excited alternator may be described as follows:

• The Rotor turns at a pre-determined speed.

• Residual or "stored" magnetism in the Rotor creates mangetic lines of flux which cut through the stator windings.

• The reactor is connected in series with the AC output to the load. The greater the flow of current to the load, the greater the current flow through the reactor's primary winding. The greater the current flow through the reactor's primary winding, the greater the current induced into the Reactor's secondary winding. Thus, the greater the current demand of the connected load, the greater the currrent flow through the plug-in bridge rectifier and the rotor.

• The plug-in bridge rectifier converts the alternating current output of the reactor to direct current, which is then applied to the rotor via the slip ring and brush assembly.

• The current flow through the rotor creates a stronger magnetic field, which, in turn, induces more current flow into the stator. The greater the current flow demanded by the connected load, the greater the current flow through the rotor and the stronger the magnetic field of the rotor. Thus, the more current that the load requires, the higher the current flow delivered to the load.

SOLID STATE VOLTAGE REGULATION

This type of voltage regulator is often called a "Voltage-over-Frequency" or "V/F" regulator. The regulator provides a constant voltage-to-frequency characteristic — an alternator operating at the speed required to provide a 60 Hertz AC frequency will provide a 120 volts AC output. An alternator producing a 30 Hertz AC frequency will provide a 60 volts AC output, and so on. (A conventional voltage regulator will provide a fixed, voltage output, regardless of frequency). If output frequency is held constant, voltage will remain constant over the entire electrical load range.
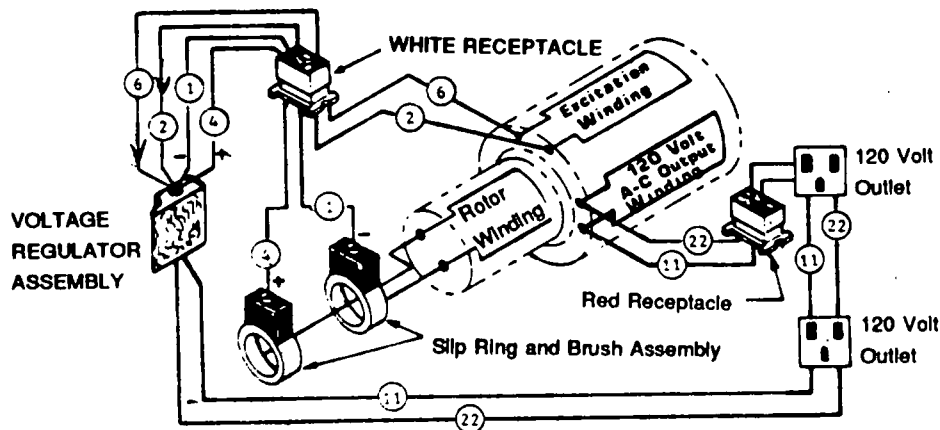
Figure 5-5 — Operating Diagram

Figure 5-5 is an operating diagram for alternators equipped with a "Voltage-over-Frequency" type of regulator. Notice the unit still has an excitation winding, just as was the case with direct-excited units.

Operating sequence for this type of unit may be described as follows:

- The rotor turns at a pre-determined speed.

- An EMF (voltage) is induced into the stator windings by residual magnetism in the rotor.

- Voltage from the 120 volts AC output winding is available through Wires #11 and #22 to a RED receptacle and to the 120 volts outlets. Any electrical load connected to the 120 volts outlets will complete the circuit.

- Alternating current voltage and frequency signals are delivered from the 120 volt outlets to the Voltage Regulator.

- Excitation winding output is delivered through Wires #2 and #6 to the WHITE receptacle and the voltage regulator.

- The voltage regulator converts the AC excitation winding output to DC and delivers the DC output to the rotor via Wire #4 and Pin #4 of the WHITE receptacle and the +brush and slip ring, Wire #1 and Pin #1 of the white receptacle, and back to the Voltage Regulator. The DC output from the voltage regulator to the rotor is based on the voltage and frequency signals received from the 120 volts outlets.

- Thus, the Voltage Regulator acts to increase or decrease current flow to the Rotor windings, based on the demands of the load connected across the 120 volts outlets. The increase or decrease in current flow through the Rotor windings results in a proportional increase or decrease in the Rotor's magnetic field strength.

ELECTRICAL FORMULAS

TO FIND	KNOWN VALUES	1-PHASE	3-PHASE
KILOWATTS (kW)	Volts, Current, Power Factor	$\dfrac{E \times I}{1000}$	$\dfrac{E \times I \times 1.73 \times PF}{1000}$
KVA	Volts, Current	$\dfrac{E \times I}{1000}$	$\dfrac{E \times I \times 1.73}{1000}$
AMPERES	kW, Volts, Power Factor	$\dfrac{kW \times 1000}{E}$	$\dfrac{kW \times 1000}{E \times 1.73 \times PF}$
WATTS	Volts, Amps, Power Factor	Volts x Amps	$E \times I \times 1.73 \times PF$
NO. OF ROTOR POLES	Frequency, RPM	$\dfrac{2 \times 60 \times Frequency}{RPM}$	$\dfrac{2 \times 60 \times Frequency}{RPM}$
FREQUENCY	RPM, No. of Rotor Poles	$\dfrac{RPM \times Poles}{2 \times 60}$	$\dfrac{RPM \times Poles}{2 \times 60}$
RPM	Frequency, No. of Rotor Poles	$\dfrac{2 \times 60 \times Frequency}{Rotor\ Poles}$	$\dfrac{2 \times 60 \times Frequency}{Rotor\ Poles}$
kW (required for Motor)	Motor Horsepower, Efficiency	$\dfrac{HP \times 0.746}{Efficiency}$	$\dfrac{HP \times 0.746}{Efficiency}$
RESISTANCE	Volts, Amperes	$\dfrac{E}{I}$	$\dfrac{E}{I}$
VOLTS	Ohm, Amperes	$I \times R$	$I \times R$
AMPERES	Ohms, Volts	$\dfrac{E}{R}$	$\dfrac{E}{R}$

E = VOLTS   I = AMPERES   R = RESISTANCE (OHMS)   PF = POWER FACTOR