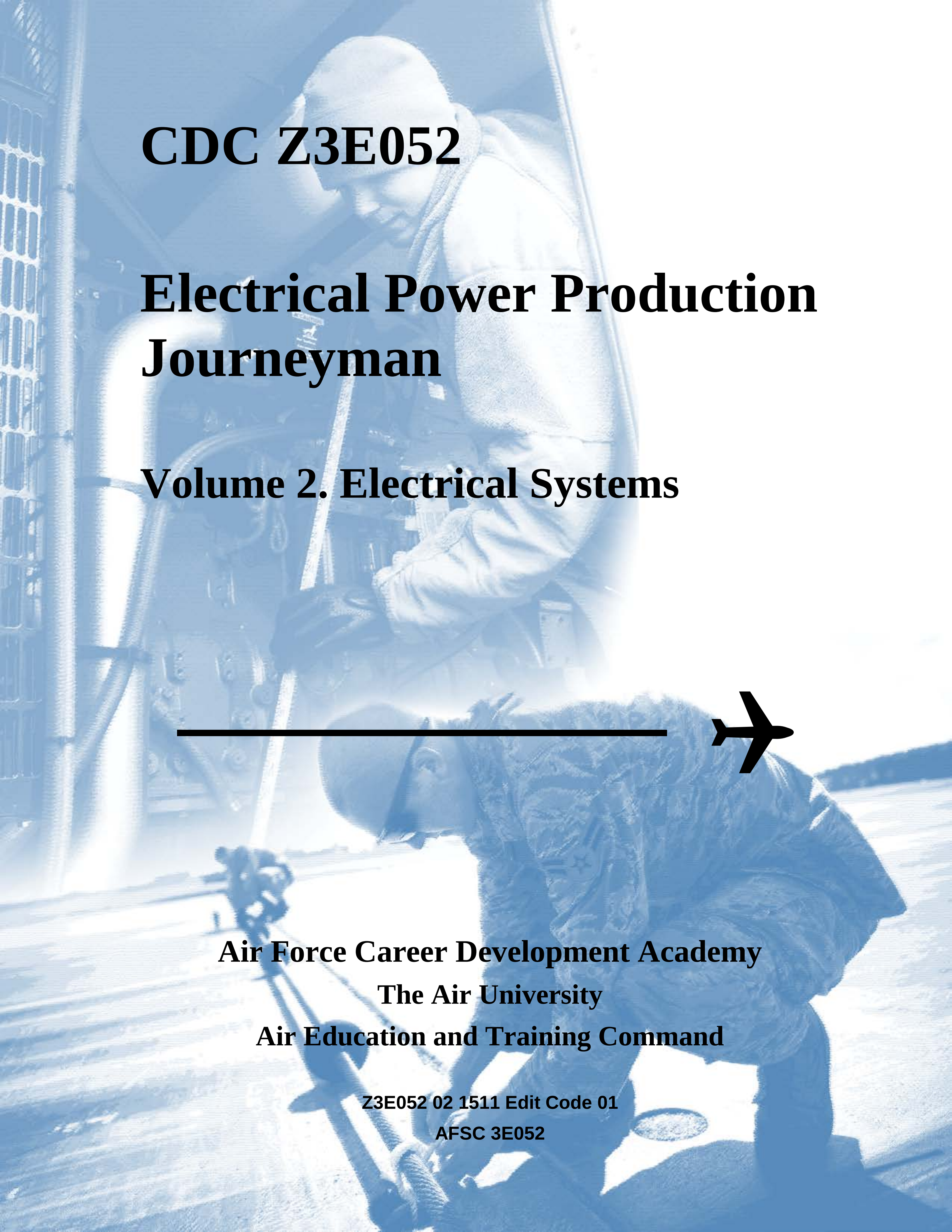

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Electrical Power Production Journeyman

Volume 2. Electrical Systems

Air Force Career Development Academy

The Air University

Air Education and Training Command

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THIS SECOND VOLUME of CDC Z3E052, *Electrical Power Production Journeyman*, introduces you to Electrical Systems.

Unit 1 covers electrical fundamentals, electrical theory, and wiring diagrams.

Unit 2 covers the engine's direct current (DC), the theory of components of an engine (battery, starter, crack relay, ingnition switch, and control circuity), and how to trouble shoot batteries and electrical systems.

Unit 3 covers how energy must be used to bring about the reaction of electrons. This unit also explores how alternators produce electricity, alternators, and how control and protective devices for generators.

Unit 4 describes how to ground electrical systems and the theory of the components of automatic transfer switches.

As an electrical power production journeyman, you have stepped into one of the most important career fields in the Air Force and we depend on you to uphold the long standing excellence that has come before you.

A glossary is included for your use.

Code numbers on figures are for preparing agency identification only.

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This volume is valued at 18 hours and 6 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings, numbers, and page location. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Acknowledgment

Preparation of this volume was aided through the cooperation and courtesy of Mike Holt Enterprises of Leesburg, Inc. Mr. Holt is a nationally recognized and highly reputable educator in the use and application of the National Electric Code. More information can be found at www.mikeholt.com.

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Page

Unit 1. Electrical Fundamentals

THE SYSTEMS YOU will work with in the power production field fall into two categories, mechanical and electrical. This volume takes a detailed look at the electrical principles you will need to understand to be able to work on the equipment. This unit begins with a look at electron theory then moves into alternating and direct currents and ends with solid-state components. You must understand this information before you can become a quality power production technician.

1–1. Electrical Theory

Electronic devices have taken over the world. They have revolutionized industry and are well on their way into more equipment within the electrical power production career field. You must have a good understanding of electronics to be able to maintain our equipment in top operating condition. Here, we discuss many aspects of electronics, beginning with the basics.

201. Electrical concepts and terms

Before we can get into a discussion on the different electronic components, you must first understand the basics of electricity. This will allow you to see how everything fits together in the world of electronics. This lesson looks at the nature of matter, atomic structure, and common terms.

Nature of matter

Before we discuss electricity, you must first understand the basics of the atom and how material is structured. This is because the atom provides the capability for electricity. We will start by looking at the different levels of material makeup.

Matter

Everything in the universe is made up of *matter*. It is anything that occupies space or has mass that you can recognize with one or more senses. This includes solids, liquids, and gases. Elements make up matter.

Compound

A compound is two or more different elements chemically joined. This creates a new substance. This new substance has become something different from the elements that make it up. Once they combine, you cannot separate the elements.

Molecule

A molecule is the *smallest* unit a compound can be broken down into *without* changing characteristics of the compound. Molecules are usually made up of two or more atoms and do not carry a charge.

Element

An element is the *purest* part of a substance that can be broken down and *retains* its properties as that element. This means like atoms make up these elements. Most elements occur naturally in the universe; however, scientists have created some elements in laboratories.

Atom

An atom, shown in figure 1–1, is the *smallest* form of an element. It is also the smallest form any material can assume without changing its characteristics. The atom is made up of three parts—proton, neutron, and electron. They usually have the same number of protons and electrons creating a neutrally charged atom.

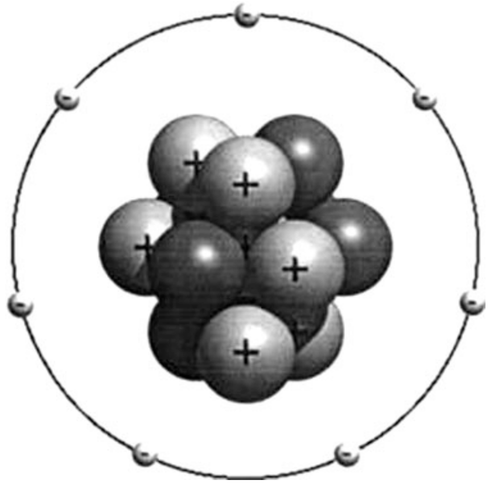

Figure 1–1. Typical atom.

Proton

The proton is part of the nucleus that makes up the center of the atom. It carries a positive charge.

Neutron

The neutron is also part of the nucleus. It carries no charge and provides mass to the atom. This is the largest part of the atom.

Electron

The electron orbits around the nucleus. It carries a negative charge.

Ionization

Ionization occurs when an atom becomes unbalanced. This usually occurs when an atom has energy added to it. When the exterior force is of sufficient strength, electrons in the outer shell can leave their orbit or an electron can join the orbit. This causes an imbalance between the positives and the negatives. This imbalance gives the atoms a charge.

Positive ion

A positive ion occurs when an atom has a deficiency in electrons. This means the atom has more protons than electrons. This imbalance gives the atom a positive charge.

Negative ion

A negative ion occurs when an atom that has an excess in electrons. This means the atom has more electrons than protons. This imbalance gives the atom a negative charge.

Atomic structure

As you know, atoms are made up of a nucleus (protons and neutrons) and electrons. The way the electrons orbit around the nucleus varies based on the number of electrons in the atom. The electrons will use different levels of orbits we refer to as shells. Each shell will hold a limited number of electrons. The only shell we worry about is the outermost shell. It really does not matter if it is the first or the tenth shell, as long as it is the outermost. We call this shell the valence shell.

Valence shell

The valence shell is the *outermost* shell of an atom. This shell will hold between one and eight electrons. The number of electrons on the valence shell will determine whether the atoms are conductors, insulators, or semiconductors.

Free electrons

A free electron is located in the valence shell. You may also hear them referred to as valence electrons. We refer to it as a *free electron* because it has the capability to break away from the shell and move to another atom. The electrons on inner shells cannot do this because they are locked in place by the structure. Two opposing forces hold electrons in place—the attraction of the nucleus and the centrifugal force of the electron that counters the nucleus' attraction.

Conductors

We call substances that have *between one to three* electrons in the valence shell conductors. These types of material are more likely to have electrons that will dislodge to move to another atom. The fewer free electrons on the valence shell, the more unstable the atom is. The farther the valence shell is away from the nucleus, the easier it is to dislodge. The more shells an atom has, the farther away from the nucleus the valence shell is. Your best conductors tend to have many shells and only one valence shell electron. This reduces the amount of pressure it takes for the electrons to move on to another atom.

When we think of conductive material, we think of metal. Generally, metals are good conductors. The best conductor is silver, followed by copper, gold, and aluminum. Other materials that are good conductors are neon, mercury, carbon dioxide, and helium, which are gases found in neon lighting that conduct electricity.

Insulators

In contrast to good conductors, we consider substances that have *five to eight* free electrons to be insulators. These types of materials become very stable because of the large number of electrons in the valence shell. This makes them less likely to have an electron to vacate or want to take another electron in. Generally, the higher the number of electrons located in the valence shell, the better the insulation qualities. Since insulators do not readily give up their electrons, they do not make very good conductors of electricity. Examples of insulators are rubber, glass, plastic, paper, air, mica, and dry wood.

Semiconductors

Substances that have *four* free electrons are not good conductors or insulators. We refer to these materials as semiconductors. This type of material has become extremely important in the world of solid-state electronics. We will take a much deeper look at solid-state electronics at the end of this unit.

Electrical terms

There are terms you must know to be able to understand electricity and electronics. We will start at the basics as we begin our look at what electricity is. You will find more terms later as we progress deeper into electronics.

Voltage

Voltage is the *force* that causes electrons to flow. Heat, light, magnetism, chemical action, and mechanical pressure are some of the many forces that create voltage. We measure voltage by the electrical unit volt and commonly represent it in formulas with the capital letters "E" or "V." We also refer to voltage as potential, potential difference, electrical pressure, or electromotive force.

Current

Current is the *flow* of electrons. It is the part of electricity that accomplishes the work. This movement of electron causes heat, chemical change, shock, electrocution, and magnetism. The amount of current determines the strength of these effects. The unit of measure for current is amperes. This refers to a given amount of electrons to pass a given point in one second. We commonly represent current using the capital letter “I” or “A” in formulas.

The original theory of electric current is that the flow is from the positive terminal through the circuit and returns to the power source at the negative terminal. This is called the conventional flow since many of the electrical pioneers based electrical theories, formulas, and symbols upon this idea. The movement of the negatively charged electrons is the definition of current flow. Over many years of research into electricity, scientists learned that the actual direction of electron flow is from negative to positive.

Resistance

Resistance is the *opposition* to current flow. The unit of measure of resistance is the ohm. We commonly represent resistance using the capital letter “R” or the Greek letter “Ω” (omega). There are factors that affect the amount of resistance. These are the type of material, the length, the cross-sectional area, and the temperature of the conductor, as described in the following table.

<table>
<tr><th>Factors</th><th>Explanation</th></tr>
<tr><td>Material</td><td>The material of which an object is made affects its resistance. The ease with which different materials give up their valence shell electrons is the determining factor. Figure 1–2 compares the resistance of some common conductors. Silver has the least resistance, though we use copper and aluminum more often for conductors because of cost factors. We use Nichrome, the highest resistance, in heater elements.
<table>
<tr><th>SUBSTANCE</th><th>RELATIVE RESISTANCE</th></tr>
<tr><td>Silver (Standard)</td><td>1.0</td></tr>
<tr><td>Copper</td><td>1.08</td></tr>
<tr><td>Gold</td><td>1.5</td></tr>
<tr><td>Aluminum</td><td>1.8</td></tr>
<tr><td>Tungsten</td><td>3.5</td></tr>
<tr><td>Brass</td><td>4.8</td></tr>
<tr><td>Steel</td><td>9.3</td></tr>
<tr><td>Nichrome</td><td>64.8</td></tr>
</table>
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Figure 1–2. Resistance comparison.</td></tr>
<tr><td>Length</td><td>The next factor affecting the resistance of a conductor is its length. The longer the conductor, the greater its resistance. The shorter the conductor, the lower its resistance. The resistance of a conductor is directly proportional to its length. For example, if a piece of copper wire 1,000 feet long has a resistance of 6 ohms, then a piece of copper wire 2,000 feet long has a resistance of 12 ohms.</td></tr>
<tr><td>Cross-sectional area</td><td>To understand what cross-sectional area means, imagine a wire cut perpendicularly and cleanly across any part of its length. The area of the cut face of the wire is the cross-sectional area. You can think of this as the thickness of the wire. The greater this area is the lower the resistance of the wire. The smaller this area is the higher the resistance of the wire. The resistance of a conductor is inversely proportional to its cross-sectional area. For example, if you have a piece of copper wire with a cross-sectional area of 0.1 square inch, that has a resistance of 6 ohms. Doubling the cross-sectional area to 0.2 square inch decreases the resistance to 3 ohms, or one-half of its original value.</td></tr>
</table>

Factors	Explanation
Temperature	The final factor affecting the resistance of a conductor is its temperature. For most materials, the hotter the material, the more resistance it offers. The colder the material, the less resistance it offers. This is due to the heat causing additional electrons to dislodge from their atoms. As they dislodge, they will *not* follow a pattern. This means they head off in every direction. This causes the electrons you want to do work to have to fight though the disarray of moving electrons in the material. This increases the amount of resistance in the material.

Types of electricity

There are two types of electricity—direct current (DC) and alternating current (AC). These both cause electrical equipment to do work, but they go about it in very different ways.

DC

DC electrons flow in *only* one direction. DC *normally* maintains the same magnitude but may vary. This means the voltage level remains at the same level most of the time. DC continually applies electrical pressure from the same direction to cause electron movement. Simply put, DC sometimes changes magnitude and never changes direction.

AC

AC electrons flow in one direction and *then reverse* their flow back to the opposite direction. AC continually changes in magnitude or amplitude, meaning that the level of AC at any moment is not the same as the moment before or after. The magnitude builds from no voltage to its maximum level and then drops back to no voltage. Once the voltage gets back to zero, the current changes direction and the magnitude again builds to a maximum level and drops again. This pattern continues with the direction of the current alternating back and forth. This is where AC gets its name. Simply put, AC continually changes magnitude and occasionally changes direction.

Ohm's Law

Ohm's Law describes the relationship between voltage, current, and resistance. This relationship explains the balance that occurs within electrical circuits. It also allows you to understand what happens when one of the values of voltage, current, or resistance change. The triangle in figure 1–3 describes the basis of Ohm's Law.

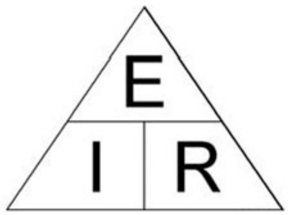


Figure 1–3. Ohm's Law triangle.

Remember the formula representatives for voltage, current, and resistance. This is the first place you see it. "E" represents voltage, "I" represents current, and "R" represents resistance. You can see these in the Ohm's Law triangle. We can sum up Ohm's Law with the statements in the following table.

Formula	Description
E = I x R	Voltage is equal to multiplying the current and resistance.
I = E/R	Current is equal to the voltage divided by the resistance.
R = E/I	Resistance is equal to the voltage divided by the current.

You can quickly figure out the formulas using Ohm’s Law triangle. Simply place your thumb over the part you are looking for and the formula appears. If the letters are side by side, you will multiply, and if the letters are above and below each other, you will divide. You will need to know these formulas because they are the basis of just about everything you will do in the electronics field.

We stated Ohm’s Law is about the relationship between voltage, current, and resistance. Simply put, *current* is *inversely* proportional to *voltage* and *directly* proportional to *resistance*. This means as you increase or decrease current, voltage will follow or react in in the opposite direction at the same rate as long as resistance remains constant. It also means that current will increase as resistance increases by the same proportion if voltage remains constant.

Changes in voltage will cause like changes in current as long as resistance is constant. These same changes will cause resistance to change in the opposite way if current remains constant. Changes in resistance will have voltage following along with a constant current and current to change in the opposite direction if voltage remains constant.

Power

Power is the amount of work done in a circuit. We sometimes refer to this as Watts Law. We use the capital letter “P” to represent power in formulas. The unit of measure for power is the watt (W). Essentially one watt is one volt of pressure moving one ampere of current in one second. You can calculate power using the formula P = I x E. You may look at this formula and the explanation of what a watt is and see the voltage and current changed place. The reason we do this is to assist you in remembering the formula because everyone knows that PIE is power.

In the power production field, you deal with many watts every day. Because of this, we use the terms kilowatts and megawatts. One kilowatt is the same as 1,000 watts and one megawatt is the same as 1,000,000 watts. When we talk, we condense the terms down even more, using kW for kilowatt and meg or MW for megawatt. Therefore, when you hear someone talking about a 12 meg power plant, they are referring to a power plant that produces 12,000,000 watts, or 12 megawatts (MW).

202. Fundamentals of direct current

Circuits contain many different components. There are multitudes of ways to make a circuit accomplish the task you need to complete. You will work with circuits that manufacturers have developed to make the equipment you work with function correctly for a long time without failures. To be able to work with these circuits, you must have a basic understanding of how they were built. This lesson discusses the bare minimum components needed to construct a circuit and then the components you will most commonly see in circuits.

Minimum required components for a circuit

When we say minimum components to construct a circuit, we are talking about everything it takes to make something work. This does not include anything extra to make it convenient to use. This also does not allow any controlling of the circuit. We are simply looking at making the circuit work.

Power source

Obviously, you need something to provide power to the circuit. Without a power source, the circuit simply will not work. DC circuits can use several items as a power source. The most common is a battery. This provides portable DC power to provide electricity to a circuit. Other DC power sources are DC generators and rectifiers.

Unit of resistance

The unit of resistance is *the* component that you want to do the work for you. This could be a light bulb, relay, motor, or solenoid. When the power source supplies electricity to the unit of resistance, work takes place.

Conductors

Conductors provide the path through which electrons flow. Good conductors use a material that allows the movement of many free electrons. You may find the conductor in several forms, including wire, solder trails, or bars. The most common type of wiring you will see is copper.

Other common components for a circuit

Though the items listed above will provide a working circuit, you will see more components in circuits you work on because they contain devices for convenience. This includes ways for controlling the circuit, items to protect it, and ways to make the circuit safer to work with.

Control device

What would happen if you had a light in your bedroom that had only the minimum components? How would you sleep at night since you have no ability to turn the light off? Control devices allow you to turn a circuit on and off when you see fit. Two common devices used as control devices are switches and relay contacts.

Switch

Switches allow you to control a circuit manually. They either complete or break the path of current flow. When you close the switch, electrons flow to energize the circuit. When you open the switch, electrons quit flowing because they have nowhere to go since the path is incomplete. Some different types of switches you will see are toggle, slide, rocker, rotary, push button, momentary, and limit.

Relay contacts

Relay contacts act the same way as a switch with one exception. You will not control them manually. The circuit design uses one part of a circuit to control another part. This comes in handy when you need part of the circuit to operate automatically when a series of events occur. The circuit may use several sets of contacts in series to operate a light. The only time the light will illuminate is when all of the relays have closed their contacts at the same time. Each of the relays will look at different parts of the circuit to make sure the predetermined events are taking place before the contacts close. You will also see relays used to provide automatic shutdown actions on the generators you operate. These sense problems and shut the generator down before the problem becomes catastrophic.

Protective devices

Protective devices provide a circuit with protection against over current concerns. Too much current in a circuit will destroy the components. These devices are the weak link of the circuit so they open before the rest of the circuit gets damaged. This way you only need to reset or replace the protective device instead of more vital and expensive devices in the circuit. The two most common protective devices are fuses and circuit breakers.

Fuses

Fuses are devices intended to destroy themselves to protect the circuit. Fuses use a small, fine wire housed inside of several types of material. The housing can be glass, plastic, or ceramic. The wire is made of a material design to melt at specific temperatures. The size of the fuse wire determines the amperage it will hold before the temperature rises enough to melt the wire. The thinner the wire, the lower the amperage manufacturers rate the fuse. Most fuses also have the properties based on the amount of overload on the fuse. The higher the amperage, the faster the fuse wire heats up and melts. Fuses slightly overloaded will take longer to melt because the temperature does not rise as fast.

Circuit breakers

Circuit breakers do the same job as a fuse. The biggest difference between a fuse and circuit breaker is that you will not replace a circuit breaker when it trips; you only need to reset it. When the circuit current exceeds the rating, the circuit breaker trips in one of two ways—thermal or magnetic.

Thermal is the use of two different metals in a strip that expand at different rates when heated. As the amount of current increases, the metal expands faster in one of the metals causing the strip to bend. The bend eventually opens the circuit, tripping the circuit breaker.

Magnetic uses a magnetic coil to trip the breaker. When electricity goes through the coil, a magnetic field develops. The more current applied to the coil, the stronger the magnetic field. Once the amperage exceeds the rating of the circuit breaker, the magnetic field operates the tripping mechanism to trip the circuit breaker. Though this type of circuit breaker is much more accurate, it is also much more expensive. You will see both types of circuit breakers during your career in power production.

Grounds

Grounds provide a means for electrons to flow harmlessly into the earth should the circuit have problems. This protects personnel in the area as well as the equipment.

Now you see the common components of a circuit. Each of these devices does a specific job within the circuit. This is what allows manufacturers to design circuits to accomplish specific functions. Next, we will look at how the arrangement of these components changes the properties.

Properties of direct current circuits

Now that you have an understanding of the components of a circuit, we discuss different ways to lay these circuits out. The ways these circuits and components react depend on their arrangement. We will look at simple, series, parallel, series-parallel, and combination circuits. When you are finished reading this lesson, you will understand the differences of each type of circuit as well as the way to determine what the electrical values are throughout the circuit.

DC series circuits

DC series circuits (fig. 1–4) are circuits with only one path for electron flow through two or more units of resistance. In other words, the components in a series circuit line up one after the other so that current must flow through each device. As you can see, the two lamps, switch, and fuse line up one after another. Conductors connect each of the devices to complete the circuit. The difference between a series circuit and a simple circuit is the number of resistors.

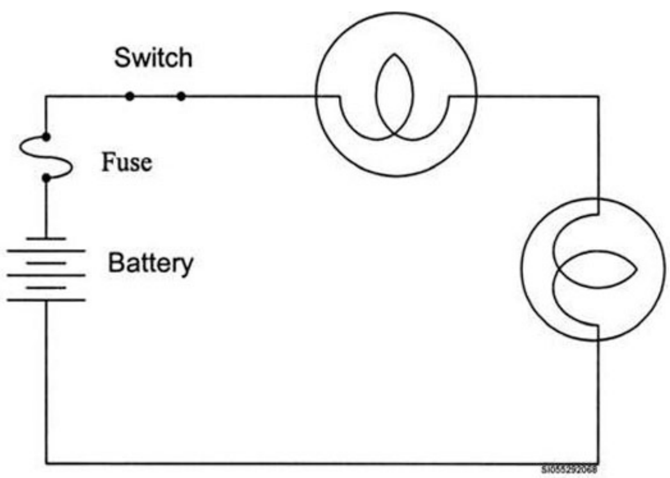


Figure 1–4. Arrangement of units in a series circuit.

As you look at a series circuit, several things will always be true. We refer to these as the characteristics of the circuit. These characteristics are the same for all series circuits, regardless of their simplicity or complexity. You must understand the characteristics of the circuit to be able to identify any problems.

The characteristics are:

1. Total voltage applied to a series circuit is equal to the sum of that circuit's individual voltage drops.
2. Total current is equal throughout the circuit.
3. Total resistance is equal to the total of the individual resistances in the circuit.
4. Total power is equal to the sum of power values used by each of the individual resistors.

Refer to figure 1–5 as we describe the characteristics. The circuit has a 24-volt source of power, a fuse, a switch, and two 6Ω resistors in series. As you can see, this circuit is much like the one you saw in the simple circuit. The difference is the series circuit has two resistors and the simple circuit only has one. The two 6Ω resistors create a total resistance of 12Ω. This is the same amount used in the simple circuit above. What this means is the total calculations in this circuit will be the same, but they will be split between the two resistors.

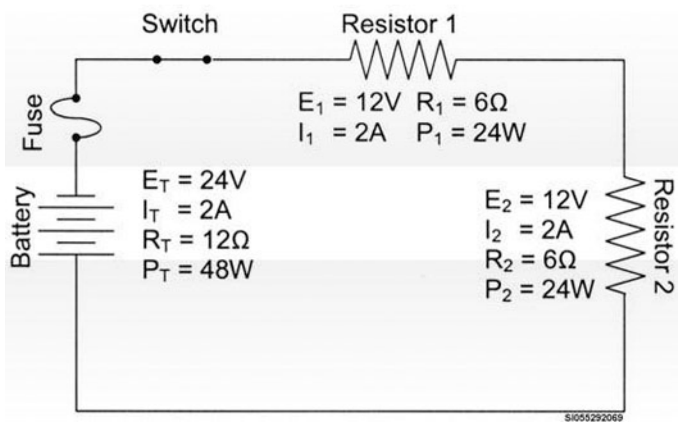


Figure 1–5. Series circuit.

The question is how do they split? This is where you must apply the characteristics of the circuit and use Ohm's Law as necessary. Look at the values for R_1. You know it is a 6Ω resistor so you know the resistance. If you apply the second characteristic of the circuit, you know that current remains the same throughout the circuit. Since you know the total current is 2A, the current at resistor 1 is also 2A. Now you know both current and resistance. Since you know two of the three values in Ohm's Law, you can calculate the third. Looking at the Ohm's Law triangle, you see the formula for calculating voltage is:

$$E = I \times R$$

This means $E = 2 \times 6$

or $E = 12V$

So now you know the voltage for resistor 1 is 12V, current is 2A, resistance is 6Ω. All you need to figure out is the power used by resistor 1. You know the formula for power is:

$$P = I \times E$$

$$P = 2 \times 12$$

$$P = 24W$$

If you use the same process for resistor 2, you will find the values you need there. Figure 1–5 lists all of these values.

The following table shows an easy way to remember the characteristics.

Voltage (E)	**Sum** in voltage drops
Current (I)	**Same** throughout
Resistance (R)	**Sum** of all resistors
Power (P)	**Sum** of all individual powers

Figure 1–6 shows a more complex series circuit with three resistors. You may also notice most of the values we look for are missing; however, the information shown on the graphic is enough to figure out the values that are missing.

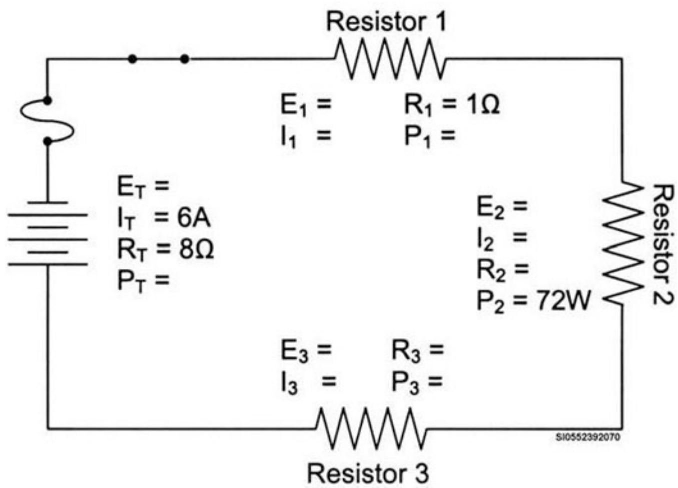


Figure 1–6. Series circuit.

Here is one way to determine the values. You know the current is the same throughout the circuit. Since I_T = 6A, you know the I_1, I_2, and I_3 are also 6A. That gives you a few new numbers in place. Now look for places where you have two figures.

You have the current and resistance for resistor 1. This means you can use Ohm's Law to figure out the voltage. Since E = I x R, you know 6 x 1 is 6V. This now provides another number for resistor 1. You can go ahead and figure out the power of resistor 1. Knowing the formula is P = I x E, 6 x 6 is 36W. This completes all of the numbers for resistor 1.

Next, look at the resistor 2 numbers. You have the current and the power. If you use the power formula and apply some algebra, you can determine what the voltage is using the formula E = P/I, or 72/6, giving us 12V. You can now apply Ohm's Law to calculate the resistance. We know that R = E/I, so 12/6 gives us 2Ω. Now you have all of the values for resistor 2.

Now look at the totals numbers. You have the total current and total resistance. Using Ohm's Law, you know E = I x R, so 6 x 8 gives us 48V. This allows you to determine the total power; you use the formula P = I x E. This means 48 x 6 gives you 288W. The only thing you have left to calculate is the resistor 3 figures. You only have the current here so far. Since you know all of the other values to the other areas, you can use the characteristics of a series circuit to figure them out. Since voltage is the sum of the voltage drops, you can determine $E_3 = E_T – E_1 – E_2$, or 48 – 6 – 12. This gives you 30V for our resistor 3 voltage. You also know the total resistance is the sum of all resistors. This means $R_3 = R_T – R_1 – R_2$, or 8 – 1 – 2. This gives you 5Ω for resistor 3. With power, the total is also the sum of all individual powers. This means $P_3 = P_T – P_1 – P_2$, or 288 – 36 – 72. This leaves you with 180W. Now you have all of the figures for the circuit calculated.

There is another way to figure out the missing items in figure 1–6. Start with the totals bunch. You know the values for current and resistance. Therefore, the formula for voltage is E = I x R (E = 6 x 8). This gives you 48V for E_T. Now you can calculate power. Since you use the formula P = I x E, you have 48 x 6; that gives you 288W. This completes the totals figures.

Now you can look at the characteristics of a series circuit, you can see the current remains the same. This means I_1, I_2, and I_3 are 6A. Now you have two figures for resistor 2. Using the formula for power and tweaking it with algebra, you can figure the voltage for resistor 2. The formula becomes E = P/I, or 72/6. This makes E_2 12V. You can now apply Ohm's Law to the figures to get the resistance of resistor 2. R = E/I, or 12/6, making R_2 2Ω.

Looking at the circuit, you can figure the resistance for resistor 3 by applying the characteristics of resistors. Since you know the total resistance is the sum of all of the individual resistors. This means the formula for calculating R_3 is $R_3 = R_T – R_1 – R_2$, or 8 – 1 – 2. This gives you 5Ω. Now you can use Ohm's Law to calculate voltage using the formula E = I x R, or 6 x 5. This gives you 30V. All you have left is to calculate power. The formula P = I x E means 30 x 6, or 180W.

All you have left to do is to figure out the voltage and power for resistor 1. Ohm's Law tells you the formula for voltage is E = I x R, or 6 x 1. This gives you 6V for E_1. This means power is P = I x E, or 6 x 6. This gives you 36W for P_1. This completes the calculations for the circuit.

As you can see, there are many ways to go about calculating a circuit. You get to choose how you get the finished product. What you must remember is to follow both Ohm's Law and the characteristics of the circuit as you make the calculations. If you do this, you will be successful.

DC parallel circuits

Parallel circuits, shown in figure 1–7, are circuits that have more than one path for electron flow with only one resistor in each leg of the circuit. In other words, the components in a parallel circuit line next to each other and all connect to the power source. As you can see, the power source, protective source, and switch line up nose to tail and the resistors line up so there is a complete path for current flow through each of them, but without regard for the other ones.

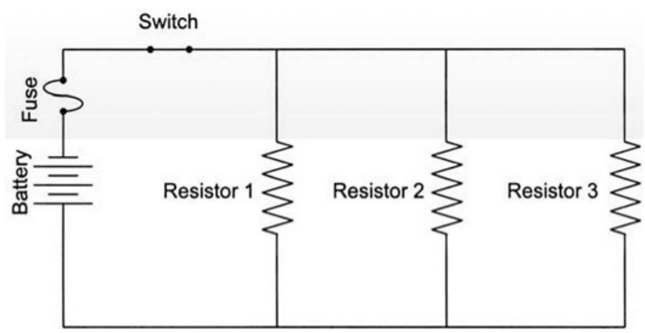


Figure 1–7. Parallel circuit.

Now let's look at the characteristics of a parallel circuit. Remember these characteristics are always true and apply to all parallel circuits. You must understand this to be able to work through them. The characteristics are:

1. Total voltage is the same throughout the circuit.
2. Total current is the sum of the current through each leg of the circuit.
3. Total resistance is less than the resistance of the smallest resistor.
4. Total power is equal to the sum of power values used by each of the individual resistors.

Look at these characteristics as they apply to a circuit. In figure 1–8, you can see the circuit has a battery, fuse, and switch lined up one after another and three resistors side by side rated at 24Ω, 12Ω, and 8Ω.

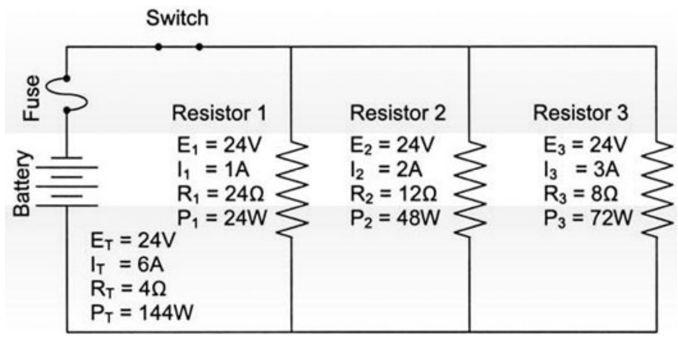


Figure 1–8. Parallel circuit.

Follow along starting with resistor 1. You know the resistance is 24Ω. If you apply the first characteristic of parallel circuits, you know that the total voltage is 24V, the voltage at resistor 1 is also 24V. This gives you two of the Ohm's Law figures so you can calculate the third. The formula to calculate for current is

$$I = E/R$$

This means $I = 24/24$

or $I = 1\text{A}$

Now you can determine how much power resistor 1 uses. You know the formula is:

$$P = I \times E$$

$$P = 24 \times 1$$

$$P = 24W$$

Now you can use the same process to see how resistor 2 and resistor 3 had their numbers calculated. Figure 1–8 shows you all of the values.

There is one more thing you need to understand, which is how to calculate total resistance. You know the individual resistors were 24Ω, 12Ω, and 8Ω. You also know the characteristic for resistance is that the total resistance will always be lower than resistance of the smallest resistor. This is great to know, but how do you figure it out? Unfortunately, there is no easy answer. The methods we describe include product over sum, reciprocal, and equal resistance methods.

The product over sum method to calculate total resistance method only works for two resistors. If you have more than one resistor, you will need to use the formula more than once. You multiply the resistors' values and then add them together. You then take the multiplied value and divide it by the added value. This will give you the total resistance. The formula below describes the process:

$$R = \frac{resistor\,1 \times resistor\,2}{resistor\,1 + resistor\,2}$$

$$R = \frac{24 \times 12}{24 + 12}$$

$$R = \frac{288}{36}$$

$$R = 8\Omega$$

Now you know the combined resistance for resistor 1 and resistor 2 is 8Ω. Now you will use this value in the formula and you can find the total resistance.

$$R = \frac{combined\ resistors \times resistor\ 3}{combined\ resistors + resistor\ 3}$$

$$R = \frac{8 \times 8}{8 + 8}$$

$$R = \frac{64}{16}$$

$$R = 4\Omega$$

Now you have the total resistance for the circuit. Another way to calculate it is called the reciprocal method. This method allows you to determine the total resistance for as many resistors the circuit has with only one calculation. This means much less in the calculations department when you have five or six resistors in parallel in a circuit. Look at the formulas below (fractions and decimals) and apply them to the circuit in figure 1–8.

Using fractions to solve

$$R = \frac{1}{\frac{1}{resistor\,1} + \frac{1}{resistor\,2} + \frac{1}{resistor\,3}}$$

$$R = \frac{1}{\frac{1}{24} + \frac{1}{12} + \frac{1}{8}}$$

$$R = \frac{1}{\frac{1}{24} + \frac{2}{24} + \frac{3}{24}}$$

$$R = \frac{1}{6/24}$$

$$R = \frac{1}{1/4}$$

$$R = 4\Omega$$

Using decimals to solve

$$R = \frac{1}{\frac{1}{resistor\,1} + \frac{1}{resistor\,2} + \frac{1}{resistor\,3}}$$

$$R = \frac{1}{\frac{1}{24} + \frac{1}{12} + \frac{1}{8}}$$

$$R = \frac{1}{.0416 + .0833 + .125}$$

$$R = \frac{1}{.2499}$$

$$R = 4\Omega$$

The example above shows that you calculated the same answer using both fractions and decimals. The difference is you can use a calculator to use the decimals where you will need to use math skills to use fractions. This is a personal choice. You should have also noticed the answer we came up with for the product over sum method matched the answers we got for the reciprocal method.

The last method to calculate the total resistance of a parallel circuit is the same resistor method. This will not work for the circuit shown in figure 1–8 because this method requires all of the resistors to be the same value. It does not matter how many resistors you have in parallel to use the same resistor method as long as they are all the same value. We will use a circuit with five 40Ω resistors in parallel.

Here is the formula:

$$R = \frac{resistors\ value}{number\ of\ resistors}$$

$$R = \frac{40}{5}$$

$$R = 8\Omega$$

When calculating the total resistance, the equal resistance method is the easiest way to find it. The only problem is you cannot use it unless all of the resistors are the same. You need to use either the product over sum method or the reciprocal method. It becomes your choice because they both have advantages and disadvantages depending on your math skills.

The following table shows an easy way to remember the characteristics of a parallel circuit.

Voltage (E)	**Same** throughout
Current (I)	**Sum** of current in each leg
Resistance (R)	**Smaller** than smallest
Power (P)	**Sum** of all individual powers

Figure 1–9 shows one more circuit where you can calculate the needed values.

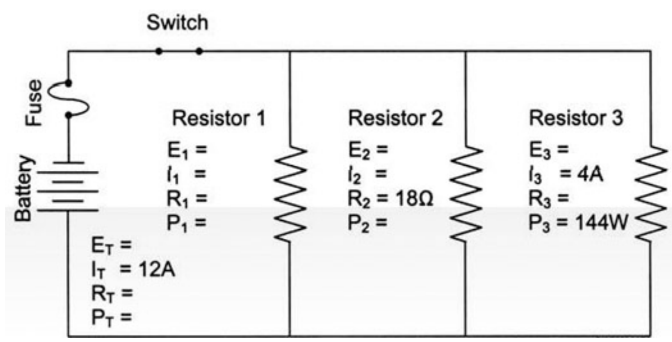


Figure 1–9. Parallel circuit.

A good starting point for this circuit is resistor 3. You have the current and power given to us. This means you can apply some algebra to the formula for power to calculate the voltage. The formula becomes E = P/I, or 144/4. This gives you a voltage of 36V. You can now calculate the resistance of resistor 3 using Ohm's Law. The formula for calculating is R = E/I, or 36/4. This gives us 9Ω.

The next thing to do would be to apply the characteristic that voltage remains the same throughout the circuit. This means the total voltage and the voltage at resistor 1 and resistor 2 is 36V. This gives you two values at the total and resistor 2.

Next, complete the values for resistor 2. You have the voltage and resistance, so you can calculate the current. Ohm's Law tells us the formula is I = E/R, or 36/18. This gives us 2A. You can now figure out power. You know that P = I x E, so 36 x 2 equals 72W.

Up to this point, you only have one value calculated for resistor 1. If you look at the characteristics of the circuit, you see the current of each of the legs is the total current. Since you have the total current and the other two values, you can figure out what the current of resistor 1 is. The formula is $I_1 = I_T - I_2 - I_3$, or 12–2–4. This gives you 6A for the resistor 1 current. This now allows you to use Ohm's Law to calculate the resistance at resistor 1. You know that R = E/I, or 36/6. This gives you 6Ω. You can also determine the power using P = I x E, or 36 x 6. This gives you 216W.

Now you can move to the totals values. You have the voltage and current. We can calculate the total resistance several ways. This example is the reciprocal method.

$$R = \frac{1}{\frac{1}{6} + \frac{1}{18} + \frac{1}{9}}$$

$$R = \frac{1}{\frac{3}{18} + \frac{1}{18} + \frac{2}{18}}$$

$$R = \frac{1}{6/18}$$

$$R = \frac{1}{1/3}$$

$$R = 3\Omega$$

You could have also used the product over sum method or just used Ohm's Law since you had voltage and current. You can calculate the power using P = I x E, or 36 x 12. This gives you 432W. This gives you all of the values for the circuit.

DC series-parallel circuits

Series-parallel circuits, shown in figure 1–10, have more than one path for current to flow but have at least one resistor that receives the total circuit current passing through it. This is the key to understanding what a series-parallel circuit is because if at least one resistor does not have the total circuit current passing through it, it is not series-parallel. You can see the circuit breaks into two paths for current to flow through. They then come back together and all of the current flows through the remaining resistor. This means the circuit will have properties of both series and parallel circuits, depending on the portion of the circuit you look at.

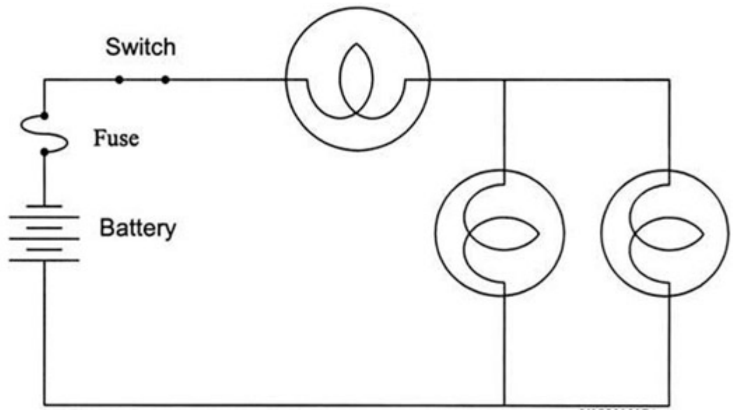


Figure 1–10. Series-parallel circuit.

The characteristics for a series-parallel circuit include:

1. Series portions of a series-parallel circuit follow the characteristics of a series circuit for voltage, current, and resistance.
2. Parallel portions of a series-parallel circuit follow the characteristics of a parallel circuit for voltage, current, and resistance.

3. Total power is equal to the sum of the power at each individual resistor.

These circuits can become very difficult quickly. Many people apply the wrong characteristics to a section of the circuit, which makes all calculations incorrect and progressively distorted from that point forward. You must know what part of the circuit you are working with to know what characteristics to apply to it.

Follow figure 1–11 as we work through a series-parallel circuit. Here, we show you how to apply the right characteristic at the correct time. Figure 1–11 is a simple series-parallel circuit. Although there are more decisions and calculations to make in a complex circuit, you will solve them in the same manner as simple circuits.

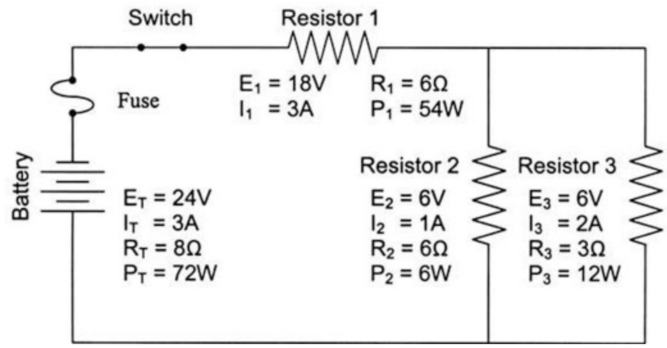


Figure 1–11. Series-parallel circuit.

Start with voltage. Notice the individual voltage drops across resistor 1, resistor 2, and resistor 3. If you add these values up, they are more than the value in the total resistance. This is because of the characteristics. Remember the characteristic of voltage in a series circuit is the sum of the voltage drops where the voltage in a parallel circuit remains the same throughout the circuit. Remember, resistor 2 and resistor 3 are in parallel, so the voltage remains the same. You do not add the voltages together to get the total. This means the combined value for resistor 2 and resistor 3 is 6V. Now we can use this value with the value of resistor 1. Since these are in series, add them together. You see that 18 + 6 = 24.

Now, look at the current. Notice the total value is the same as the value in resistor 1. This is because the current in a series circuit remains the same throughout. However, take notice that the values for resistor 2 and resistor 3 are not the same as the total. This is because the current in a parallel circuit divides between the different paths proportional to the amount of resistance. If you add the current values in resistor 2 and resistor 3 you find the calculation is equal to the total current.

When it comes to resistance, you again use the characteristics of the portions of the circuit. Resistor 2 and resistor 3 are in parallel; therefore, the total resistance for them is lower than the lowest resistor. This means the total resistance is less than 3Ω. Since there are two resistors, the easiest method to use to determine the total resistance is the product over sum method. We do this by using the formula:

$$R = \frac{resistor\,2 \times resistor\,3}{resistor\,2 + ressitor\,3} \quad R = \frac{6 \times 3}{6+3} \quad R = \frac{18}{9} \quad R = 2\Omega$$

This, however, does not give you the total resistance of the circuit. This only gives you a value that would be the same as a single resistor on a single leg. This allows you to use this value in series with resistor 1. This means you can add the resistance values to get the total resistance of the circuit.

When it comes to power, you can simply add the values of power for each resistor to get the total power of the circuit.

Remember you will use the characteristics of a series-parallel circuit and Ohm's Law to make the calculations. This will allow you to determine the values of the circuit without the running into too many difficulties.

Figure 1–12 shows you how to calculate a series-parallel circuit.

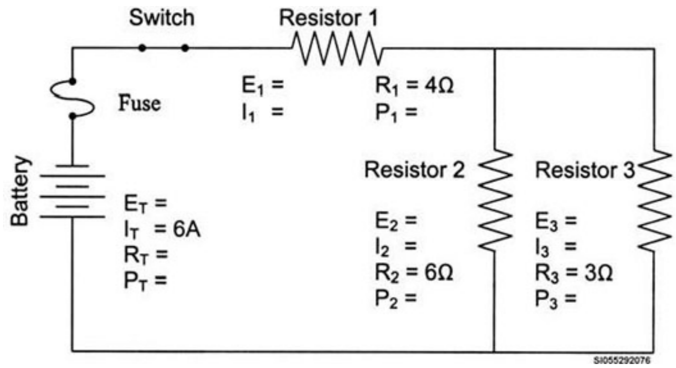


Figure 1–12. Series-parallel circuit.

There is not a lot of information included in the circuit in figure 1–12. It is important to know what part of the circuit is series and what part of the circuit is parallel. We can see resistor 2 and resistor 3 are in parallel and resistor 1 is in series. You will start using the series circuit characteristic for current. We know the current remains the same throughout the circuit. This means since you know the total current, the series portions of the circuit will also have 6A. This means I_1 is 6A.

Now you have two values for resistor 1. You can use Ohm's Law to calculate the voltage using the formula E = I x R, or 6 x 4. This gives you 24V. Now you calculate the power for resistor 1 using the formula P = I x E, or 24 x 6. This gives you 72W.

The only thing we have remaining to calculate is the total resistance using the circuit characteristics. Start by looking at resistors 2 and 3, and apply the characteristics of a parallel. Remember, the resistance of a parallel circuit is always smaller than the lowest resistor. Since you have two resistors, you use the product over sum method. The calculation is:

$$R = \frac{resistor\,2 \times resistor\,3}{resistor\,2 + resistor\,3} \quad R = \frac{6 \times 3}{6 + 3} \quad R = \frac{18}{9} \quad R = 2\Omega$$

This gives you a total resistance for the parallel legs of the circuit. Unlike the parallel circuit, this is not the total resistance. This is because you also have a series section. Now you must apply the series characteristics for resistance that say the total resistance is the sum of the individual resistors. We use the calculated value of 2Ω for the parallel legs we will call $R_{2\text{-}3}$. The formula is $R_T = R_1 + R_{2\text{-}3}$, or 4 + 2 or 6Ω.

Now you have two values for the totals. Using Ohm's Law, you know the formula for voltage is E = I x R, or 6 x 6. This gives you 36V. You can also calculate the power using P = I x E, or 36 x 6. This gives you 216W.

Now you need to figure out where to go next. You have all of the values for the totals and resistor 1 and only one value in resistor 2 and resistor 3. You can apply the characteristic for voltage to both of the circuits. You use the characteristic for voltage in a series circuit is the total is equal to the sum of the voltage drops. If you look at the series area, you take the total voltage and subtract the series resistor; therefore, in this example, 36 – 24, leaving 12V. You distribute the 12V across resistor 2 and 3 equally because the 12V applies to both of the resistors. This gives you values of 12V for both E_2 and E_3.

Now you have two values at each resistor. You have the calculations for voltage and resistance for resistor 2. If you apply Ohm's Law to the values (I = E/R), the answer is 12/6 or 2A. Now, when you apply the formula P = I x E, the answer is 12 x 2, or 24W.

Now you can finish up by calculating the resistor 3 values. Use the formula I = E/R, or 12/3. This gives you 4A. You then apply the formula for power P = I x E, or 12 x 4, or 48W.

You can see how series-parallel circuits can become very confusing. The way to make sure you get all of the correct values is to take your time as you work through them making sure you are using the correct characteristics as you go.

Combination circuits

Combination circuits (fig. 1–13) are similar to series-parallel circuits except the series resistor does not carry the full circuit current. Many people confuse these circuits with series-parallel because they contain both series and parallel features. There are wide arrangements of these circuits depending on the design needs. Typically, they will be a parallel circuit with one or more legs having series portions.

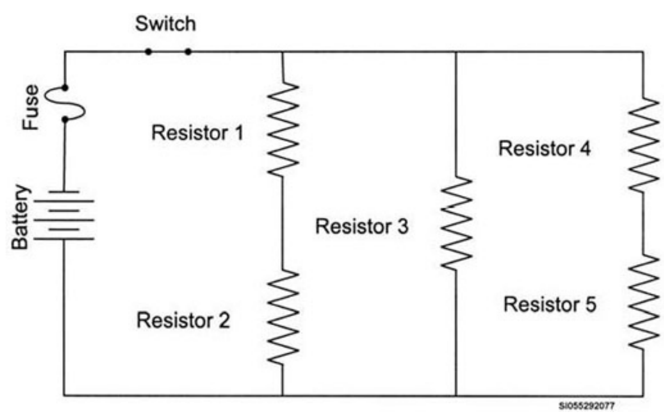


Figure 1–13. Combination circuit.

As you can see, there are three paths for current flow. You should also notice resistors 1 and 2 are in series with each other, as are resistors 4 and 5. These two series sections are in parallel with each other and in parallel with resistor 3. What makes this a combination circuit instead of a series-parallel circuit is the fact not one of the resistors take the entire circuit current.

You calculate these circuits the same way you do a series-parallel circuit. Apply the series characteristics to the series portions of the circuit and the parallel characteristics to the parallel portions of the circuit. Remember to apply Ohm's Law throughout the work to provide the values necessary to work through the circuit.

Without a circuit, AC does nothing. The circuits are the same as the ones you just finished reading about; they simply operate slightly different due to different components and conditions. We start by examining the fundamentals of AC before moving into the circuitry.

203. Fundamentals of alternating current

Electrical current flow consists of electrons moving in a circuit from negative to positive. In the AC circuit, polarity changes at regular intervals, causing the current to flow in one direction for a while and then to flow in the opposite direction. This creates an entirely new set of terms not needed when working with DC. We will look at the terms associated with AC.

Cycle

A cycle, shown in figure 1–14, is a complete series of events that begin and end at the same point. This series of events repeats itself once it gets back to the starting point. In an AC circuit, this cycle takes place in 360 electrical degrees. The voltage begins to build between 0 and 90 degrees. The voltage peaks out at 90 degrees and begins to fall until it reaches 180 degrees. The 180-degree point is where the voltage returns to zero. The voltage begins to build again between the 180 and 270 degree point. The difference here is it builds in the negative direction. This means the voltage changes direction. The voltage reaches its negative peak at 270 degrees. The voltage begins to drop again between 270 and 360 degrees. Notice the 0 and 360 degrees points are the same. This is where the negative voltage reaches zero again and begins the cycle again.

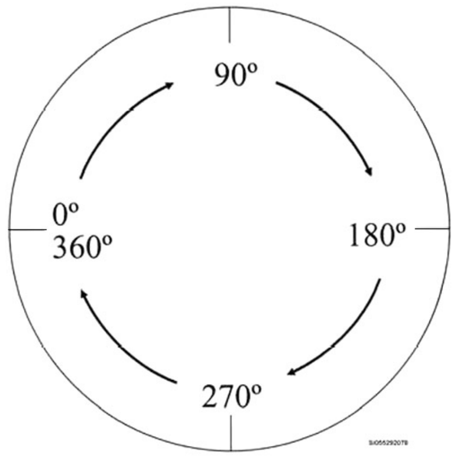


Figure 1–14. Electrical cycle.

Sine wave

The sine wave, shown in figure 1–15, is an electrical graph of one complete cycle of AC. This graph is drawn on two lines. The vertical line (up and down) represents the magnitude of the graph. The horizontal line (across) represents time. The timeline rests in the middle of the magnitude. This line also represents the zero value for magnitude. Any point above the line is positive, and any point below the line is negative. Notice the sine wave begins at zero and increases until it peaks out. It then decreases, moving past zero, and begins increasing to the negative side. It then peaks out on the negative side, begins decreasing, and moves back to zero. The start and end are at the same point so the end begins again. Throughout the rise and fall, the graph moves from the left to the right. This represents the passage of time as the values rise and fall.

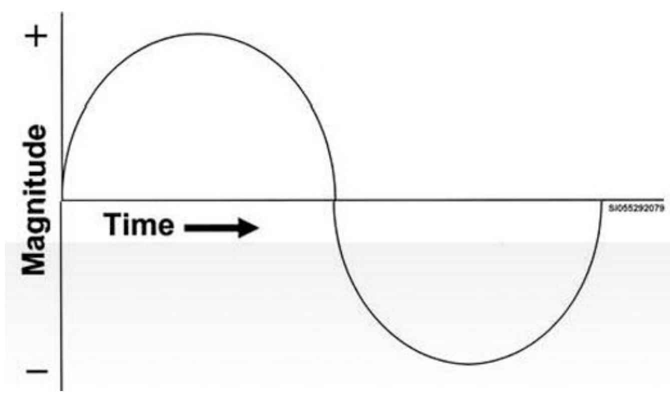


Figure 1–15. Sine wave.

Frequency

Frequency is the number of occurrences of a complete series of events over a specified time. This means several things need to happen before you can have frequency. First, you must have a cycle of events. Next, these events must recur. Finally, these events must have a specified timeframe in which they will occur.

In electricity, we have the recurring cycle. The timeframe we look at is one second. When you hear about the frequency of electricity, it refers to the number of complete cycles that occur in one second. We refer to this frequency in the unit of measure of “hertz.” You will encounter three frequencies during your power production career. The United States uses 60 hertz, most of the rest of the world uses 50 hertz, and aircraft and radar systems use 400 hertz. You will not experience the 400-hertz systems often, but may run into them occasionally. These different frequencies mean there are many cycles occurring every second. Figure 1–16 shows how frequency differs.

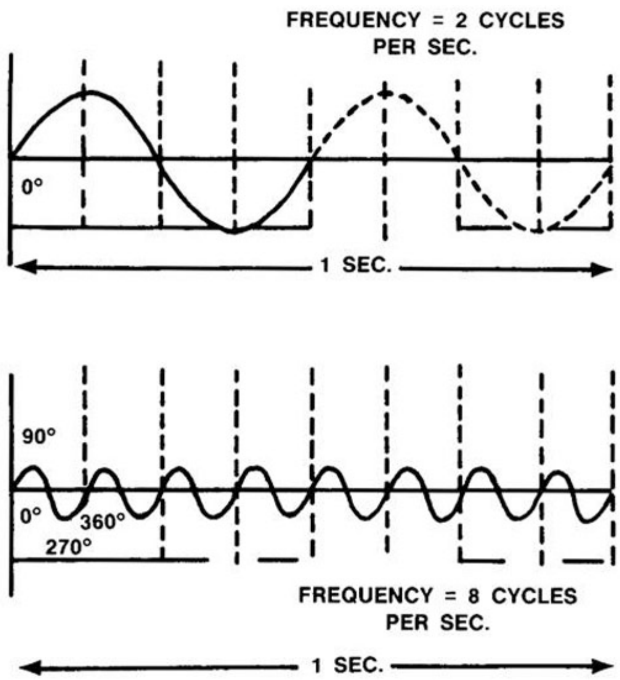


Figure 1–16. Frequency and cycle in AC.

Peak value

The peak value is the highest voltage or the highest current reached during a cycle. This peak occurs on both the positive alternation and the negative alternation. This means each cycle has two peaks. They occur when the cycle reaches 90 degrees for the positive alternation and 270 degrees for the negative alternation.

You can determine the peak value of voltage if you know the effective value. It involves some simple math. The formula is:

$$Peak = Effective \times 1.414$$

Effective value

Knowing the peak value is great, but the voltage level only stays there for a very short amount of time. What you really need in know is what is the voltage that will do some work for us. You know what that value is for DC circuits. You have a steady voltage that produces specific amounts of work. In AC circuits, it gets a little more difficult. Scientists experimented by comparing the work AC did to the work DC did. What they found out was that the percentage of peak voltage of AC power produced the same amount of work equivalent to a DC circuit. We refer to this percentage as the effective value. This is also the value of voltage you read in an AC circuit if you use a voltmeter. You can determine the value by using the formula:

$$Effective = Peak \times .707$$

We also call the effective value the root-mean-square (rms) value. This is due to the mathematical method used to calculate the effective value. The effective value of a voltage is equal to the square root of the average of the sums of the squares, of the instantaneous values that make up a cycle.

AC circuits

The layout of each of the circuits is the same. The properties of these circuits are also the same. The difference between AC circuits from DC circuits is the reaction the AC components have once the current begins to flow. This results from the increasing and decreasing of the voltage and current in the circuit.

Remember, one of the things that occur as current passes through a circuit is the creation of magnetism. The strength of the magnetism is directly proportional to the amount of current passing through the circuit. Since the current levels of an AC circuit are always changing, the magnetic field in continually growing stronger and then weakening as the current changes.

As you also recall, one of the forces that creates voltage is magnetism. This means as the current creates a magnetism that has a moving magnetic field from the strengthening and weakening, it can create a voltage at some of the components. We will look at how this created voltage reacts in a circuit as we look at each of the different components. Just keep this in mind as you read on through this section.

You will calculate the values in an AC circuit the same way you did in a DC circuit with one exception. Since the components act differently in an AC circuit, we will look at how they react instead of just resist current. Therefore, we will slightly change the Ohm’s Law triangle for AC circuits. Look at figure 1–17 to see if you can find the difference. Since the resistance acts a little different, we refer to the resistance in an AC circuit as reactance, which is represented by the X on figure 1–17.

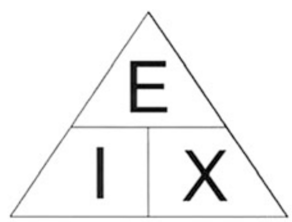


Figure 1–17. Ohm’s Law of an AC circuit.

Operation of resistors

You remember the term resistance from the DC section as being an opposition to current flow. Resistors in an AC circuit operate the same way as they do in a DC circuit. The magnetic fields have little to no influence on the resistors. This means they simply resist current from flowing.

There are two basic uses for resistors. One is as a unit to accomplish work. Examples for these are light bulbs, toasters, and electric heaters. You find them in common everyday applications. Another use for resistors is to insert them into a circuit to adjust the amount of current so the desired amount reaches the component that does the work. An example of this is a dimmer switch for a light. You will also find many of these in modern electronic devices. Some of these resistors are fixed while others are variable.

Let’s take a quick look at variable resistors. We often need a change in resistance while the equipment is in operation. Manufacturers have designed wire-wound (fig. 1–18) and carbon (fig. 1–19) variable resistors for this. They use wire-wound variable resistors to control large currents. They construct them by winding resistance wire on a porcelain or Bakelite circular form. A contact arm, which you can adjust to any position on the circular form, connects to a rotating shaft. Rotating the shaft moves the contact arm to change the length of the resistor. This change in length changes the amount of resistance supplied to the circuit.

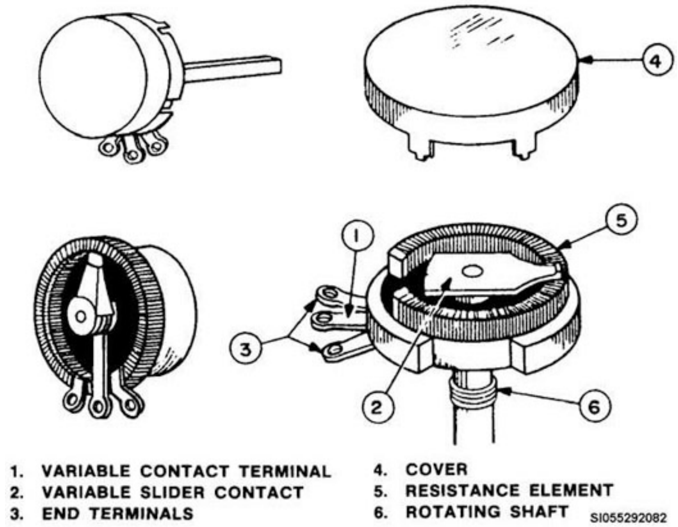


Figure 1–18. Wire-wound variable resistor.

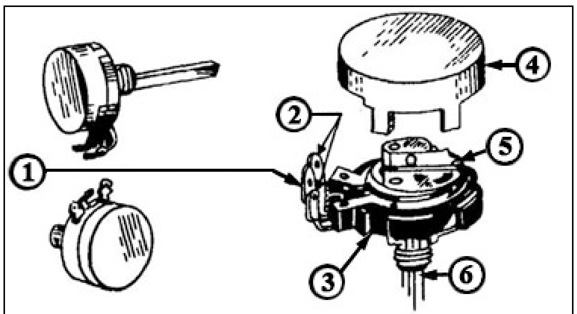


Figure 1–19. Carbon variable resistor.

To control small currents, circuits often use carbon variable resistors, shown in figure 1–19. Manufacturers construct them by depositing a carbon compound on a circular fiber disk. A variable sliding contact connected to a rotating shaft varies the resistance as you turn the shaft.

Operation of inductors

An inductor is a coil of wire placed in a circuit. You will find many inductors in AC circuits. This is because that is how manufacturers construct electric motors. This means any household appliance you have that contains a motor has inductive properties. This includes refrigerators, fans, vacuum cleaners, and blenders to name a few.

Once a manufacturer places a coil in a circuit and applies current to it, a strong magnetic field quickly builds up. This is due to the large number of conducting wires wrapped in a small area. Remember, in an AC circuit, the current is constantly changing. As the current gets stronger, the magnetic field gets stronger too. The magnetic field gets the strongest when the current peaks out at 90 degrees. The current then begins to drop off and the magnetic field follows suit. This building and collapsing of the magnetic field continues as the current continues to change. This means the magnetic field is continually moving in and out.

This movement of the magnetic field causes some things to happen within the circuit. The movement of a magnetic field induces, or creates, a voltage within a conductor called *induced voltage*. Remember, an inductor is simply a coil of wire. This means that when the magnetic field gets stronger, it crosses some conductors. It crosses these same conductors going in the opposite direction as the magnetic field collapses. It is not the magnetic field itself; its movement back and forth induces a voltage into the conductor—first one way and then the other.

There is a problem with inducing a voltage in an inductor. This inductor already has voltage applied to it. To make things worse, the induced voltage moves in the opposite direction as the applied voltage. We call this induced voltage counter electromotive force (EMF). This is because it opposes the applied voltage. This reaction to the inductor in an AC circuit opposes a change to current flow.

Inductance

Inductance is the characteristic of an AC electrical circuit that contains an inductor. This causes an opposition to any CHANGE in current flow. The counter EMF created by the expanding and contracting magnetic field causes this opposition to the change in current. The counter EMF attempts to cancel out the applied voltage. This causes the current to remain at its previous level. As the increase in magnetism peaks out, the current attempts to catch up with the applied voltage. Just as it gets started, the counter EMF resurfaces to hold it up again. Therefore, the counter EMF causes a shift in the current so it does not follow the applied voltage. This means current constantly lags the applied voltage. We refer to this as reactance, or wattless power.

Several factors determine the amount of inductance in a circuit. First, the type of core the coil is wrapped around plays a large role. An inductor that uses an iron core will have more inductance than one with an air core. This is because the iron core intensifies the magnetic field. The number of wraps in a coil also makes a difference. The more wraps in a coil, the larger the inductance. The spacing between each of the wraps in a coil makes a difference as well. The closer they are, the larger the inductance. The wire size also plays a role. Thicker wire contains more inductance. Finally, the diameter of the coil makes a difference. Smaller coils contain a larger inductance. This is because more of the magnetic field crosses the other portions of the coil in a smaller coil.

The symbol for inductance is the letter L; its unit of measurement we call the *henry*. The total inductance of an AC series circuit we can determine the same way as we did resistance in a DC series circuit. In a series circuit, the total inductance is equal to the sum of the individual inductors. Figure 1–20 shows a circuit with four inductors.

The formula for total inductance (below) explains how to calculate the total inductance in a circuit when you know the individual inductance values, as shown in figure 1–20.

$$L_T = L_1 + L_2 + L_3 + L_4$$

$$\text{or } L_T = 0.265 + 1.33 + 1.99 + 0.795$$

$$L_T = 4.38\, henrys$$

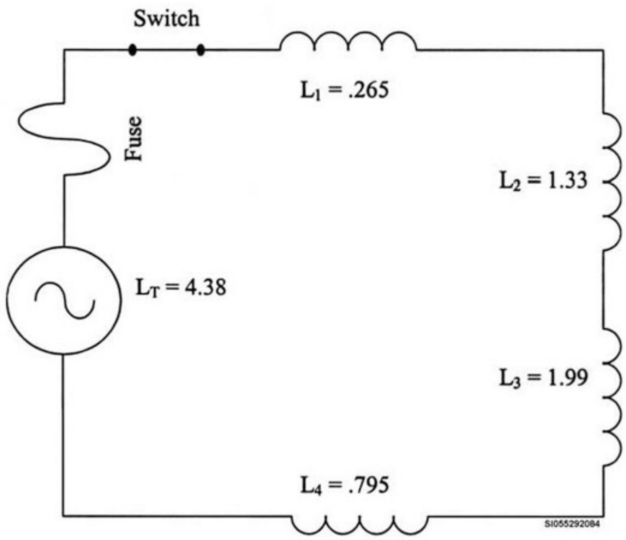


Figure 1–20. Series circuit with inductance.

Inductive reactance

In an AC circuit containing inductance, there is opposition to the flow of current in addition to the resistance that is normally present. The extent of this opposition depends on two things—the frequency of the applied voltage and the amount of inductance that is present in the circuit. Since we know the resistance in an AC circuit as reactance, we refer to the reactance caused by inductance as inductive reactance. We identify inductive reactance using the symbol X_L. Since inductive reactance opposes current flow, we measure it in ohms.

The formula we use for finding individual inductive reactance is:

$$X_L = 2\pi \times f \times L$$

The question is, "what do all of these symbols mean?" Well, you know π is 3.14 if you round it to two decimal places. Since the formula you see here uses 2π, you need to multiply π by 2. This gives you 6.28. That leaves two other symbols to figure out. You should know L because you just read about it in the inductance area. It is the symbol for inductance. You also read that one of the things that affect inductive reactance is frequency. This means the f represents the frequency of the applied voltage.

Refer back at figure 1–20 to make a calculation for inductive reactance. What you need is the value of frequency. If you are operating a generator in the sandbox at a contingency power plant, the frequency is 60 hertz. You also know the total inductance is 4.38 henries. Now you can plug all of the numbers into our formula. You can see the math below.

$$X_L = 2\pi \times \mathrm{f} \times \mathrm{L}$$
$$X_L = 6.28 \times 60 \times 4.38$$
$$X_L = 1650 \text{ ohms}$$

Another way to find the total inductive reactance is the same as you did the total inductance. Total inductive reactance is equal to the sum of the individual inductive reactances. You can use this if you know the inductive reactance value for each of the individual resistors. This means the formula is:

$$X_{LT} = X_{L1} + X_{L2} + X_{L3} + X_{L4}$$

Before you can use this, you must know the individual inductive reactance values. This example shows the calculations for figure 1–20:

$$X_L = 2\pi \times f \times L$$
$$X_{L1} = 6.28 \times 60 \times 0.265 = 100 \text{ ohms}$$
$$X_{L2} = 6.28 \times 60 \times 1.330 = 500 \text{ ohms}$$
$$X_{L3} = 6.28 \times 60 \times 1.990 = 750 \text{ ohms}$$
$$X_{L4} = 6.28 \times 60 \times 0.795 = 300 \text{ ohms}$$

Now you can add the total up:

$$X_{LT} = 100 + 500 + 750 + 300$$
$$X_{LT} = 1650 \text{ ohms}$$

This means there is 1,650 ohms of resistance in the circuit that does no actual work. This explains the wattless power you read about earlier. It uses electricity without doing any work. This causes a loss in electrical power. This means you pay more money to get the power to operate equipment without getting any more work. Refrigerators, stereo equipment, fans, and washing machines use inductors as the primary means of operation. Another use of an inductor is a transformer, which we will look at in much more detail.

Transformers

Transformers are inductive devices used to transfer power from one circuit to another using electromagnetic induction. One of the primary reasons to use a transformer is to adjust the voltage level. A transformer may increase or decrease voltage in a circuit. They also allow manufacturers to isolate circuitry from other parts of a device. These devices only work when we apply AC or pulsating DC to the transformer.

Constructions features

Transformers are simple devices made up of two or more coils of wire and a core. The first of these coils is the primary windings. This is the coil of wire the input power connects to. The second coil of wire is the secondary coil. This is where we make the output connections. Both of these coils wrap around a core. Soft iron typically makes up this core because of the ability to improve magnetic fields.

Manufacturers wind transformers with the ability to change the voltage levels between the primary and secondary coil. They do this by varying the number of coils between the primary and secondary. If the primary coil has more coil turns than the secondary, the output voltage lowers. This means it is a step down transformer. The secondary coil, having less coil turns, steps the voltage level down to meet circuit needs. If the primary coil has less coil turns than the secondary coil, the voltage output raises. This means it is a step up transformer. The secondary coil, having more coil turns, steps the voltage level up to meet circuit needs.

The number of turns on the primary and secondary coils is proportional to the voltage levels of the output. This means the output voltage will increase or decrease by the same proportion as the number of turns in the coils. If the secondary coil is half as big as the primary coil, the output voltage will be half the level of the input voltage. This is how manufacturers determine if the transformer is a step up or step down transformer.

Types

Potential transformers use primary and secondary coils with the input voltage applied to the primary. This changes the voltage to the desired level for circuit operation. Current transformers use only a secondary coil. These often look like a donut with two wires connected to it. It receives it signal from a conductor positioned through the middle of it. You will find these type of transformers used in metering circuits. Isolation transformers are potential transformers used to isolate a portion of the circuit. These often transfer the applied voltage without stepping it up or down. This allows the component to function free of other circuit components.

Theory of operation

Transformers use mutual induction to produce voltage on the secondary coil. As current enters the primary coil, a magnetic field begins to form. The higher the current flow grows, the larger the magnetic field becomes. This means the magnetic field expands and contracts as the current increases and decreases from the AC or pulsating DC signal. This movement of the magnetic field cuts through the secondary coil as it pulsates. The movement of the magnetic field induces a voltage on the secondary coil. The frequency of the secondary coil is the same as the frequency applied to the primary coil. The output voltage level produced steps up or down based on the number of turns in the two coils. The secondary voltage will be 180 electrical degrees out of phase with the input voltage.

Operation of capacitors

A capacitor is a device that temporarily stores an electrical charge. Its construction consists of two plates of conductive material separated by an insulating material called dielectric. This material resides in an insulated container with two leads sticking out, one connected to each plate.

When you place a capacitor into a circuit and apply voltage to it, the plate on the negative side of the circuit begins to accept electrons, and the plate on the positive side begins to give electrons away. Before long, the positive plate has no more electrons to give and the negative plate can no longer accept any more electrons. This means the capacitor is fully charged. It then stores the charge until it can discharge it.

When you place a capacitor in an AC circuit, as shown in figure 1–21, the changing voltage causes the capacitor to continually charge and discharge. As the voltage rises, the capacitor charges to match the applied voltage. Once the voltage peaks out, it begins to decrease. This means the capacitor has more voltage than the applied voltage and begins to discharge. The discharge of the capacitor is slower than the decrease in the dropping applied voltage. This means the voltage in the circuit remains at a higher level than if the circuit had no capacitor. The discharge rate depends on the characteristics of the particular capacitor. Some will discharge slowly enough so the applied voltage will begin charging it again before it completely discharges. Others will discharge faster and zero out before the applied voltage begins to charge it again.

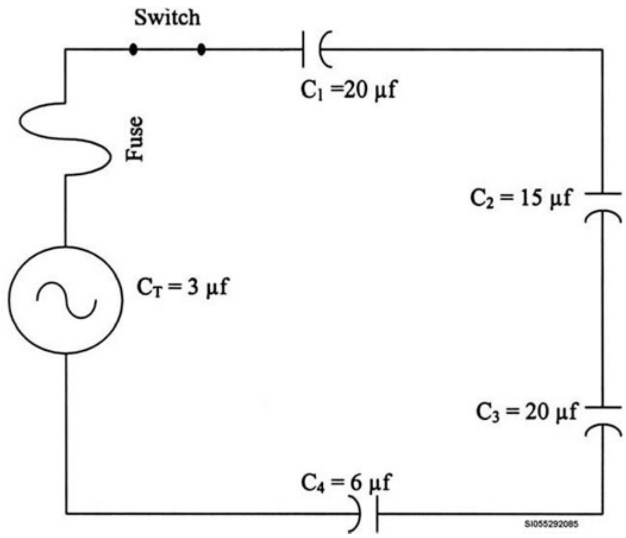


Figure 1–21. Capacitor in an AC circuit.

Capacitance

While inductance is the property of an inductor in an AC circuit, capacitance is the property of a capacitor. This causes an opposition to any CHANGE in the value of voltage. The discharge of the capacitor is what opposes this change in voltage. As it discharges, the voltage remains at a higher level than the applied voltage. This prevents it from changing. We can determine what the behavior of a capacitor in a circuit will be based on its design. Manufacturers rate capacitors as they build them using the farad as a unit of measure. Most of the capacitors you will see have a rating much lower than 1 farad. We refer to these as a microfarad, or µf. This means the capacitor has a rating of 0.000001 farad.

In a circuit where there is only capacitance, the voltage lags the impressed current. This condition is in direct contrast to a circuit containing pure inductance, where the current lags the voltage. You can find the total capacitance of an AC series circuit the same way as you did the total resistance in a DC parallel circuit. There are three ways to calculate the total capacitance: the reciprocal method, product over sum, and equal capacitance.

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}}$$

If a circuit contains only two capacitors, you can use an alternate formula, the product over the sum.

$$\mathrm{C_T} = \frac{\mathrm{C_1} \times \mathrm{C_2}}{\mathrm{C_1} + \mathrm{C_2}}$$

If a circuit contains capacitors of equal value, regardless of the number of capacitors, you can use the following formula:

$$\mathrm{C_T} = \frac{\mathrm{C}}{\mathrm{N}}$$

where C is the capacitance value and N is the number of capacitors. Perform these calculations just like you did those in a DC parallel resistive circuit.

You can calculate the total capacitance of the circuit shown in figure 1–21 using the reciprocal method.

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}}$$

$$C_T = \frac{1}{\frac{1}{20\mu f} + \frac{1}{15\mu f} + \frac{1}{20\mu f} + \frac{1}{6\mu f}}$$

$$C_T = \frac{1}{\frac{3}{60\mu\mathrm{f}} + \frac{4}{60\mu f} + \frac{3}{60\mu f} + \frac{10}{60\mu f}}$$

$$C_T = \frac{1}{20/60\mu\mathrm{f}} = \frac{60\mu f}{20} = 3\mu f$$

If the capacitors in an AC circuit are in parallel, as shown in figure 1–22, the method you use for determining the total capacitance changes. It becomes much simpler because you will simply add each of the capacitance values to get the total capacitance. They are similar to the DC series circuit formulas for determining resistance. You can see the capacitor values are the same, but the total capacitance went from 3 µf to 61 µf. This is because the capacitors act differently in a parallel circuit than they do in a series circuit.

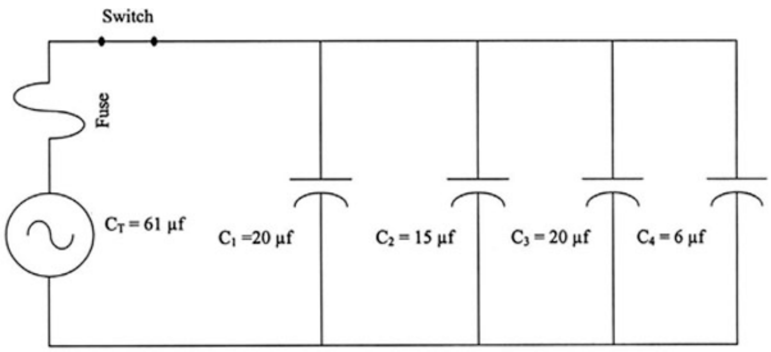


Figure 1–22. Series circuit with capacitance.

Capacitive reactance

Capacitance opposes the change in the value of voltage. We measure this opposition, called capacitive reactance, in ohms just like inductive reactance. The symbol for capacitive reactance is X_C. The formula for finding capacitive reactance is as follows:

$$X_C = \frac{1}{2\pi \times \mathrm{f} \times C}$$

To find the capacitive reactance and the current flow in a circuit, you find the reactance first and then the current. Going back to figure 1–23, assume there is an impressed voltage of 120 volts at 60 hertz and there is a capacitor with a capacitance of 61µf. Since 1 million microfarads (µf) are equal to 1 farad, this means that to change 61 µf to farads, you must divide 61 by 1,000,000. This means you will use 0.000061. The easiest way to get the decimal in the right place is to write the value for the capacitor in µf with six 0 to the left of it. Put a pencil to the right of your number and move the decimal six places to the left. This gives you the correct value for the capacitor in farads. Now you can plug the value into the formula.

$$X_C = \frac{1}{6.28 \times 60 \times 0.000061}$$

$$X_C = 43.5 \text{ ohms}$$

There are two ways to find the total capacitive reactance of the circuit. You have just seen one of them. Use the values in figure 1–22 to make the two types of calculations. First, use the simplest method. It is to use total capacitance value in the capacitive reactance equation.

$$X_{CT} = \frac{1}{2\pi \times \mathrm{f} \times \mathrm{C_T}}$$

$$X_{CT} = \frac{1}{6.28 \times 60 \times 0.000003}$$

$$X_{CT} = \frac{1}{0.0011304} = 884.6 \text{ ohms}$$

You can also calculate the capacitive reactance of each individual capacitor and then add the individual values together to get the total capacitance.

$$X_{C1} = \frac{1}{6.28 \times 60 \times 0.000020} = 132.7\ ohms$$

$$X_{C2} = \frac{1}{6.28 \times 60 \times 0.000015} = 176.9\ ohms$$

$$X_{C3} = \frac{1}{6.28 \times 60 \times 0.000020} = 132.7\ ohms$$

$$X_{C4} = \frac{1}{6.28 \times 60 \times 0.000006} = 442.3\ ohms$$

Now that you have found the individual reactance values, you can find the total capacitive reactance by adding them together.

$$X_{CT} = \mathrm{X}_{\mathrm{C1}} + X_{C2} + X_{C3} + X_{C4}$$
$$X_{CT} = 132.7 + 176.9 + 132.7 + 442.3$$
$$X_{CT} = 884.6\ \text{ohms}$$

One thing to remember is that you calculate the capacitive reactance using farads; therefore, you must write the value of the capacitors in farads, not microfarads. This means you must use all of the decimal places. Be sure you convert correctly.

ELI the ICEman

ELI the ICEman is a simple way to help you remember what phase shift takes place when you work with reactive circuits. ELI the ICEman is a mnemonic that spells the phase shift out for you. Look at ELI and think of the formula symbols you learned for the inductance and capacitance. We know the E stands for voltage, the L for inductance, and I for current. The order in the word shows you the order they appear in for the particular type of circuit. This means ELI tells us that voltage leads current in an inductive circuit. ICEman tells us voltage lags current in a capacitive circuit. We refer to it this way, instead of saying current leads voltage, because we always compare voltage to current.

Understanding this will allow you to graph the phase difference for inductive and capacitive circuits. When you do this, always remember the lag moves to the left and the lead always moves to the right.

Power in AC circuits

Electrical power is the rate at which we use electrical energy in a circuit to do work. The unit of electrical power is the watt. In DC electricity, power is equal to the voltage multiplied by the current in the circuit. As you know, the formula for power is P = I × E. Consequently, if 1 amp flows in a DC circuit with a pressure behind it of 200 volts, the power is 200 watts. All of the power used in a circuit does work. We refer to this as the *true power* in the circuit. Now we are dealing with AC circuits. We can also have similar circumstances in an AC circuit that only contains resistors. We refer to these types of circuits as *purely resistive*.

Let’s look at circuits that have inductance or capacitance in them. This changes everything because now we have reactance in the circuit. This means there is electricity being used without doing any work. This changes the way we need to look at power. Let’s start by discussing a few terms that you will become very familiar with.

True power

True power is the power in a circuit that does work. Resistive loads make this type of power. Even if you have inductors or capacitors in your circuit, you will have some resistive power because the components contain certain amounts of resistance. This is what causes them to operate when you apply power to the circuit. Remember all circuits have true power.

Reactive power

Reactive power is the power created by inductance or capacitance. Inductive or capacitive loads cause this type of power. Reactive power does no work; it simply uses electricity. Resistors will have no part in reactive power.

Apparent power

Apparent power is the power you think you are providing from your power source if you look at your voltage and current. This is the sum of the true power and the reactive power. We express apparent power in volt-amps (VA). When we look at power systems, we change it to kilovolt-amps (kVA) so we can deal with smaller numbers like 125 kVA instead of 125,000 VA. 1 kVA is equal to 1,000 VA.

Power factor

Power factor is the ratio between the apparent power and the true power. We usually express using a decimal such as .8. This decimal represents the percentages of apparent power that is true power. This means a .8 power factor has 80% true power. This is the industry standard to build power generation equipment. This does not mean all of the circuits you operate will contain a power factor of .8, but they will usually be relatively close to that. To determine the power factor you can use one of two formulas:

$$\text{Power factor} = \frac{\text{true power}}{\text{apparent power}} \quad \text{or} \quad \text{Power factor} = \frac{\text{watts}}{\text{volt-amps}}$$

Essentially, these two formulas are the same. This is because we measure true power in watts; therefore, the true power and watts means the same thing. Likewise, we measure apparent power in VA. Therefore, apparent power is the same as VA. The real question is how do you determine what values to plug into the formula?

The easiest way to get these values is to look at meters on the electrical generator. Most electrical generators have meters for voltage, frequency, current, and power. The meters provide enough information to calculate the values. First, you have a kW meter that measures power. This reading is the true power produced by the generator. Be careful the meter is not a percent power meter because it contains a different reading. If the power meter is a kW meter, the value goes in the top of the formula. If it is a percent power meter, you must multiply the generator capability by the reading on the meter.

To get the bottom value, you simply multiply the voltage reading and the current reading. Again, be careful because some of the meters you will see are percent current meters. If you have one of these, you must multiply the generator capability and the reading on the meter to get the current reading. The voltage times the current gives you the bottom number in the formula. Figure 1–23 shows the process.

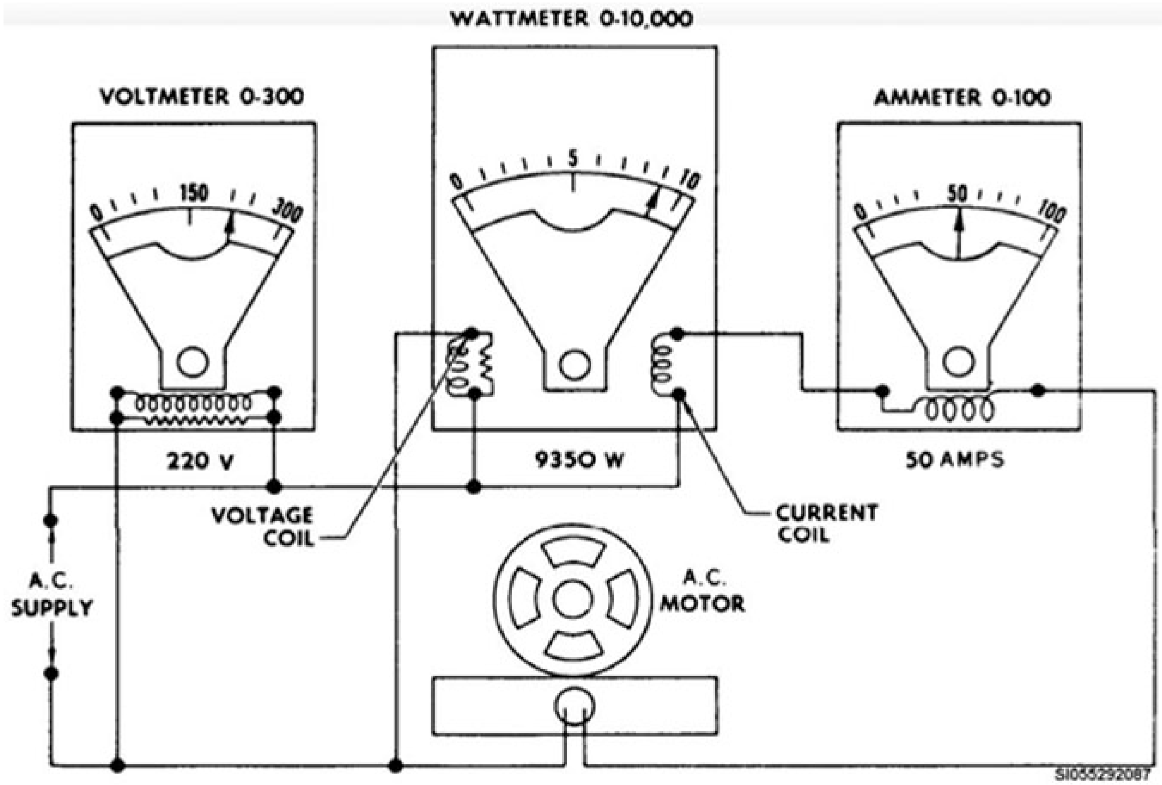


Figure 1–23. Measuring the power factor.

You start by determining our VA. You know that the apparent power is equal to the volts times the amps:

$$\text{Apparent power} = E \times I$$

$$\text{Apparent power} = 220 \times 50$$

$$\text{Apparent power} = 11 \text{ kVA}$$

Now, you can apply the numbers to the power factor formula. You know the true power from the kW meter is 9,350 and the apparent power is 11 kVA or 11,000 VA. This means

$$pf = \frac{9{,}350}{11{,}000}$$

$$pf = .85$$

This means 85 percent of the power our generator produces goes to do actual work and is not wasted.

Diodes

The simplest solid-state device contains two pieces of material, one P-type and one N-type. We know these devices as diodes, shown in figure 1–24. Manufacturers use a chemical process to develop diodes using donor impurities into one region of a crystal and acceptor impurities in the other section of the crystal. We call the area between the N and P sections a junction. Leads protrude from each end of the diode so you can make the electrical connections. Figure 1–25 shows the diagram symbol. Sometimes you will see a circle around the symbol. The arrow points in the direction of conventional current; electron flow will be against the arrow.

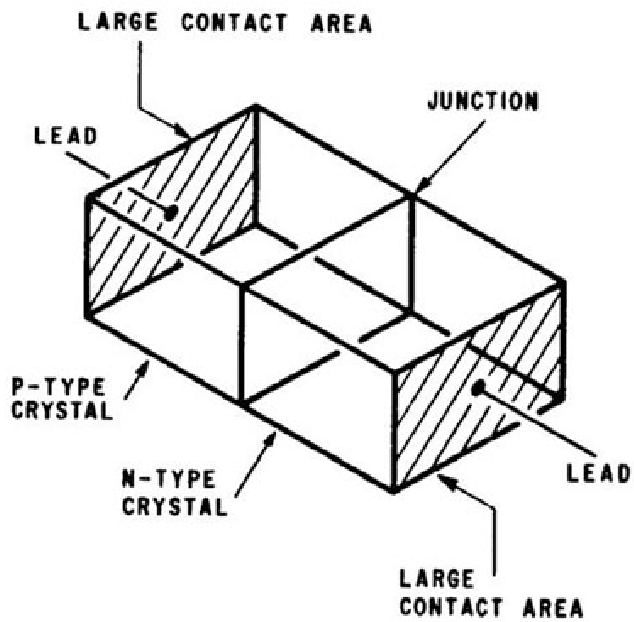


Figure 1–24. P-N junction pictorial diagram.

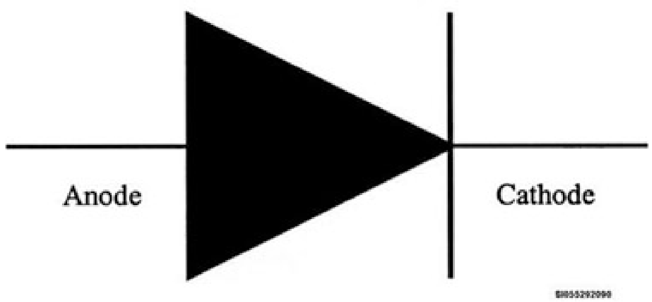


Figure 1–25. Diode diagram symbol.

The P-type material, called the anode, has a high concentration of holes. The N-type material, called the cathode, has a high concentration of extra electrons. This type of construction makes the diode have a low resistance in one direction and a high resistance in the other. This means it will only allow current to flow in one direction. The key to this is the way the junction reacts when we hook a battery up to a diode.

To understand this, you must understand how the junction acts without a power source. The junction has P-type material connected to N-type material. The N-type material has an excess of electrons and the P-type has holes waiting for electrons to move into. This attraction causes some of the electrons from the N-type material to cross the junction to fill holes next to the junction. These excess electrons and holes in the different types of material are majority carriers, meaning there are more of them than anything else in the area. As the electrons and holes connect, the area around the junction no longer has an excess of electrons or hole because they connect. This causes an area around the junction to create a barrier voltage that keeps the majority carriers in place. We call this junction the depletion region, shown in figure 1–26. You can see the way the excess electrons and holes line up when there is no power source connected. Also, notice the size of the depletion region at the junction. We will concentrate on the depletion region as we look at the operation of the diode.

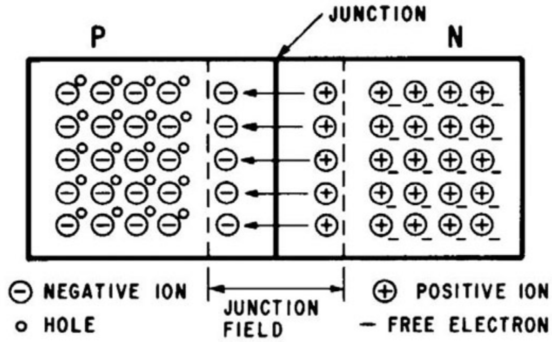


Figure 1–26. P-N junction field.

When we connect a battery across a diode, it causes the diode to react. We call this reaction biasing because it makes the electrons and holes line up. The place they line up depends on the way we connect the battery. One way pushes the electrons and holes closer together, forward bias, and the other way pulls the electrons and hole farther apart, reverse bias. Let’s take a closer look at the biasing of a diode.

Forward bias

The forward bias connection, as shown in figure 1–27, occurs when the negative side of a battery connects to the cathode and the positive side of the battery connects to the anode. This means the positive terminal of the battery connects to the P-type material and the negative terminal of the battery connects to the N-type material.

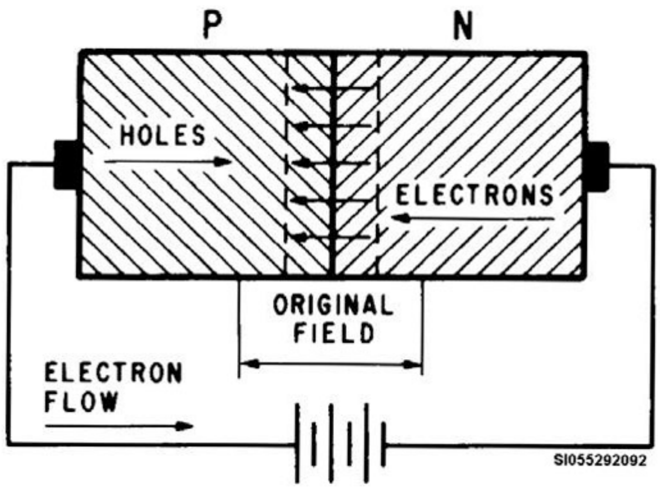


Figure 1–27. Forward-biased P-N junction.

One of the keys to understanding the operation of solid-state material is that opposites attract and likes repel. This means the positive side of the battery connected to the P-type material repels holes, pushing them toward the depletion region. The holes seem to move because electrons, attracted by the positive terminal of the battery, move away from the depletion region. In the N-type material, the negative potential repels electrons toward the junction. Thus, the effect of the battery voltage in the forward bias direction is to reduce the barrier voltage across the junction and to allow majority carriers to cross the junction.

It is important to remember that in the forward-biased condition, current flows because of the majority carriers. Remember, this is the holes in the P-type material and electrons in the N-type material. Increasing the battery voltage increases the number of majority carriers, in both the P-type and N-type materials, arriving at the junction, and the current flow increases. If the battery voltage increases to the point where the barrier potential across the junction completely neutralizes, it can cause heavy current flows. This can damage the junction from the heat created by the increased current flow.

The diode offers low resistance to the current flow when the power source connects in the forward bias direction. This means current flows in forward bias.

Reverse bias

The reverse bias connection, as shown in figure 1–28, occurs when the negative side of a battery connects to the anode and the positive side of the battery connects to the cathode. This means the positive terminal of the battery connects to the N-type material and the negative terminal of the battery connects to the P-type material.

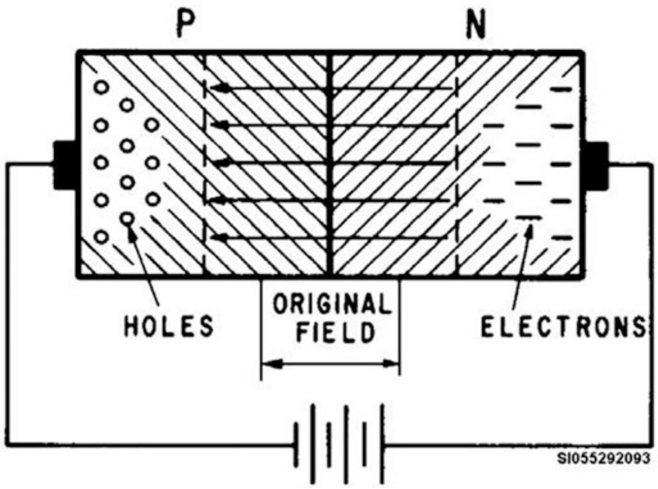


Figure 1–28. Reverse-biased P-N junction.

The positive side of the battery connected to the N-type material attracts the electrons away from the depletion region. In the P-type material, the negative potential repels electrons to push them toward the junction. This means the hole movement moves away from the depletion region. This increases the depletion region because the majority carriers move outward allowing the barrier voltage to increase.

This increase in the barrier voltage causes an increase in the internal resistance. This means current does not flow when the power source connects in reverse bias.

Current flow in a diode

When we look at current flow in a diode, we know it only flows in one direction. This flow is always from the N-type material, through the junction, to the P-type material. Of course, this means current flows into the cathode, through the depletion region, and out of the anode. If you look at the schematic symbol (fig. 1–25), you learn that current always flows against the arrow.

Rectifiers

You now know a diode only allows current to flow in one direction because it blocks the flow of current in the other direction. Having this can be very handy. All you need to know is how to use it. The most common use for diodes is the use of rectifiers. A rectifier is a device that changes AC into DC. This means it changes current flow from flowing in two directions to current flow that only flows one way There are many types, however, we will cover the three-phase bridge rectifier which is commonly found in three phase alternators.

Three-phase bridge rectifier

Many Air Force systems require three-phase power. The unfiltered output voltage of a three-phase rectifier is much smoother than that of a single-phase rectifier. Three-phase generators provide three equal single-phase voltages that have a phase angle between them of 120 degrees. Three-phase current flows from the generator to a transformer. Three-phase voltages can be rectified by a three-phase, bridge-type rectifier. Figure 1–29 shows the rectifier and three-phase input voltage waveforms. We know a bridge rectifier has four diodes. The three-phase bridge rectifier has six diodes. This is because the bridge rectifier has two connection points with two diodes per connection point. The three-phase bridge rectifier still uses two diodes per connection point and there are three connection points. This means there are six diodes.

Three-phase systems produce three separate wave forms 120 electrical degrees apart. These wave forms never intersect because they come from different places. The lower part of figure 1–29 shows three-phase wave forms. Notice that phase A is the reference phase while phase B lags phase A by 120 degrees, and phase C lags phase B by 120 degrees. In the three-phase bridge circuit shown, current flow through the load produces the output polarity shown.

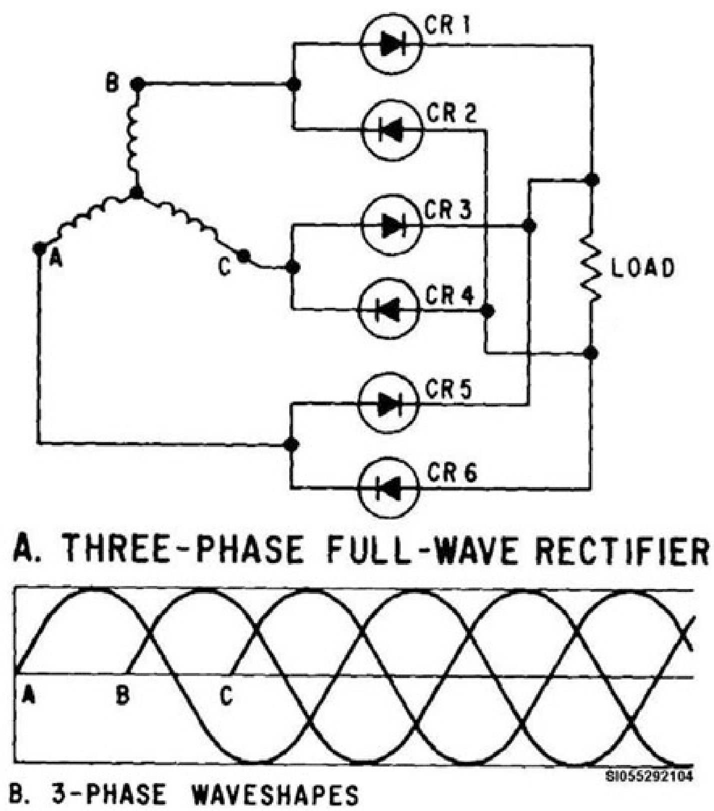


Figure 1–29. Three-phase full-wave rectifier and waveforms.

Look at the operation of a three-phase bridge rectifier by disregarding leg C. Trace an input voltage to determine the resulting output from the rectifier. Use transformer legs A and B of the wye-wound secondary of figure 1–30, view A. Notice this looks like a standard bridge rectifier when you look at only this section of the figure.

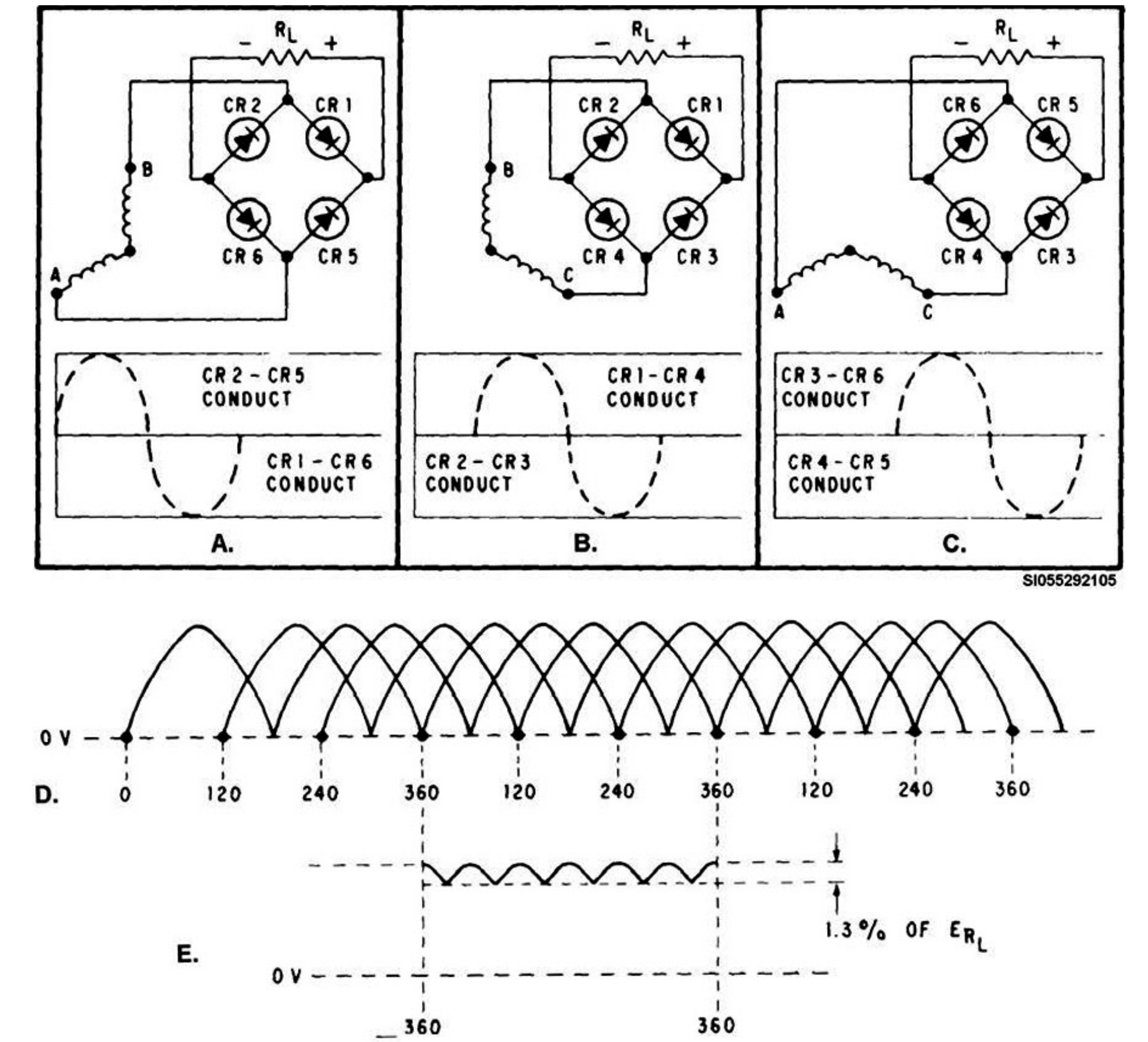


Figure 1–30. Three-phase rectifier analysis and waveforms.

On the positive alternation of phase A voltage, point A is positive with respect to point B. Current flows from point B through CR2, R_L and CR5 to point A. On the negative alternation of the cycle, current flows from point A through CR6, R_L, and CR1 to point B. The polarity of the voltage across R_L is negative at the bottom and positive at the top for both positive and negative alternations of the input. This creates a positive output.

Now, disregard leg A and use the series circuit of legs B and C in figure 1–30, view B. Point B is positive with respect to point C. Current flows from point C through CR4, R_L, and CR1 to point B. On the negative alternation, current flows from point B through CR2, R_L, and CR3 to point C. Again, the voltage across R_L is negative at the bottom and positive at the top for both alternations of the input cycle.

Now, disregard leg B and you have a series circuit with legs A and C in figure 1–30, view C. Point C is positive with respect to point A. Current flows from point A through CR6, R_L, and CR3 to point C to complete the circuit. On the negative alternation, current flows from point C through CR4, R_L, and CR5 to point A to complete the circuit. Once again, you find that R_L, has the same output polarity.

Figure 1–30, view E, shows the resulting waveform that appears across R_L, combining all three phases of rectification shown in figure 1–30, view D. Notice the ripple frequency is six times the input frequency. With a 60-hertz input, the three-phase, full-wave rectified output ripple frequency is 360 PPS. The amplitude of ripple in the output is approximately 13 percent of the amplitude of the output voltage. With this low amplitude ripple voltage, very little filtering is necessary in order to have a smooth DC output.

You must understand two things about AC circuits—what the characteristics are for each of the different types of circuits and how the components in AC circuits operate since the current moves back and forth. Remember, there is both resistance and reactance within an AC circuit. It is important you understand this so you won't overload a generator because the load is different than you expect.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

201. Electrical concepts and terms

1. What is a compound?

2. What three parts make up an atom?

3. What is a free electron?

4. What occurs when an atom becomes unbalanced?

5. What is current?

6. What are the factors that affect the amount of resistance?

7. What is a characteristic of AC?

8. What does Ohm's Law describe?

9. What is Ohm's Law?

202. Fundamentals of direct current circuits

1. What is the most common power source in a DC circuit?

2. What is the unit of resistance of a circuit?

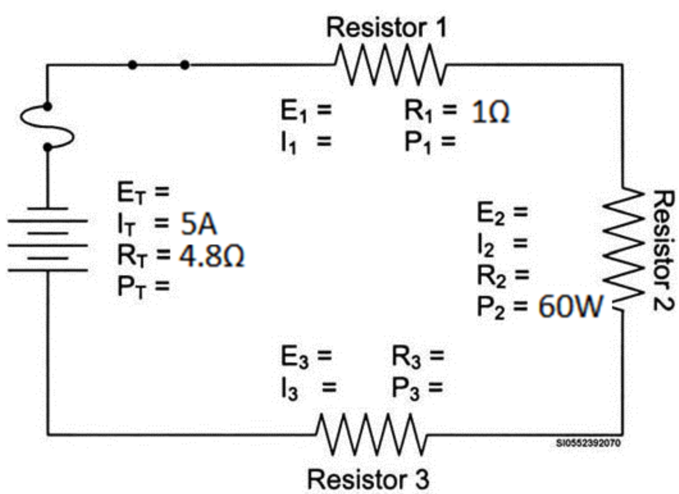
3. What determines the amperage it will hold before the temperature rises enough to melt the wire in a fuse?

4. What do grounds protect should the circuit have problems?

5. What are DC series circuits?

6. What is an easy way to remember the characteristics of a series circuit?

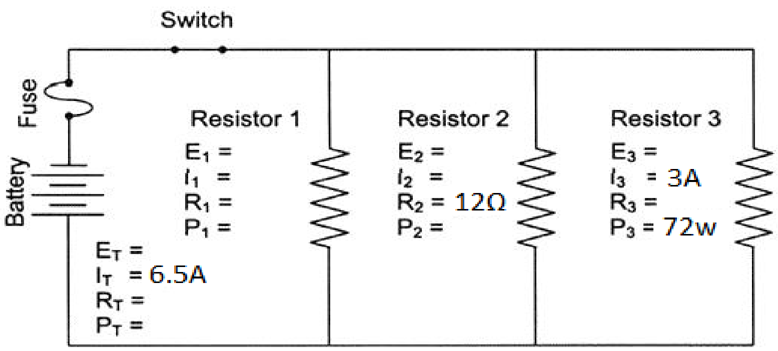
7. Determine the unknown values for the series circuit below.



8. What are parallel circuits?

9. What are the methods to calculate the total resistance in a parallel circuit?

10. Determine the unknown values for the parallel circuit below.



11. What is an easy way to remember the characteristics of a parallel circuit?

12. What are series-parallel circuits?

13. What are combination circuits?

203. Fundamentals of alternating current circuits

1. What is an electrical cycle?

2. What do the two lines on the sine wave graph represent?

3. What does the frequency of electricity refer to?

4. What is the effective value of voltage?

5. What type of household appliances have inductors?

6. Since inductance is the characteristic of an AC electrical circuit that contains an inductor, what does it cause?

7. What two things determine the extent of the opposition in an inductive circuit?

8. What typically makes up this core of a transformer because of the ability to improve magnetic fields?

9. What do transformers use to produce voltage on the secondary coil?

10. How is a capacitor constructed?

11. Since capacitance is the property of a capacitor, what does it cause in a circuit?

12. What does the mnemonic ELI the ICEman spell out for you?

13. What is true power?

14. What is reactive power?

15. What is apparent power?

16. What does a P-type material, called the anode, have a concentration of?

17. How should you connect a battery to a diode to get a forward bias connection?

18. How does current flow in a diode?

19. What is a rectifier?

20. How many diodes does a three-phase bridge rectifier have?

1–2. Wiring Diagrams

Wiring diagrams are the roadmaps for discovering the flow of electricity through a circuit. It is important to know how to use them to troubleshoot electrical systems. Without these diagrams, it can be very difficult to locate faults within the electrical systems of power production equipment. One of the first things you must know is the commonly used symbols in electrical diagrams.

204. Electrical symbols

You must first understand electrical symbols before you can effectively read and interpret diagrams. Electrical symbols used in wiring diagrams and schematics indicate the electrical systems' components. Symbology is the "language" of diagrams. To be able to read wiring diagrams, you must know how to interpret the language. Your knowledge of electrical symbols allows you to install circuits, trace circuits, and locate malfunctions. Space is often at a minimum in diagramming, so we use abbreviations.

Figures 1–31 through 1–34 provide you with typical symbology and abbreviations used to identify circuit components. Do not be alarmed by the number of symbols. Wiring diagrams and symbols tell the story of electrical circuitry. Study the figures to become familiar with these symbols and others found in manufacturers' manuals and technical orders. Experience and learning a few simple rules make recognition easy. These are not all inclusive but cover commonly used symbols.

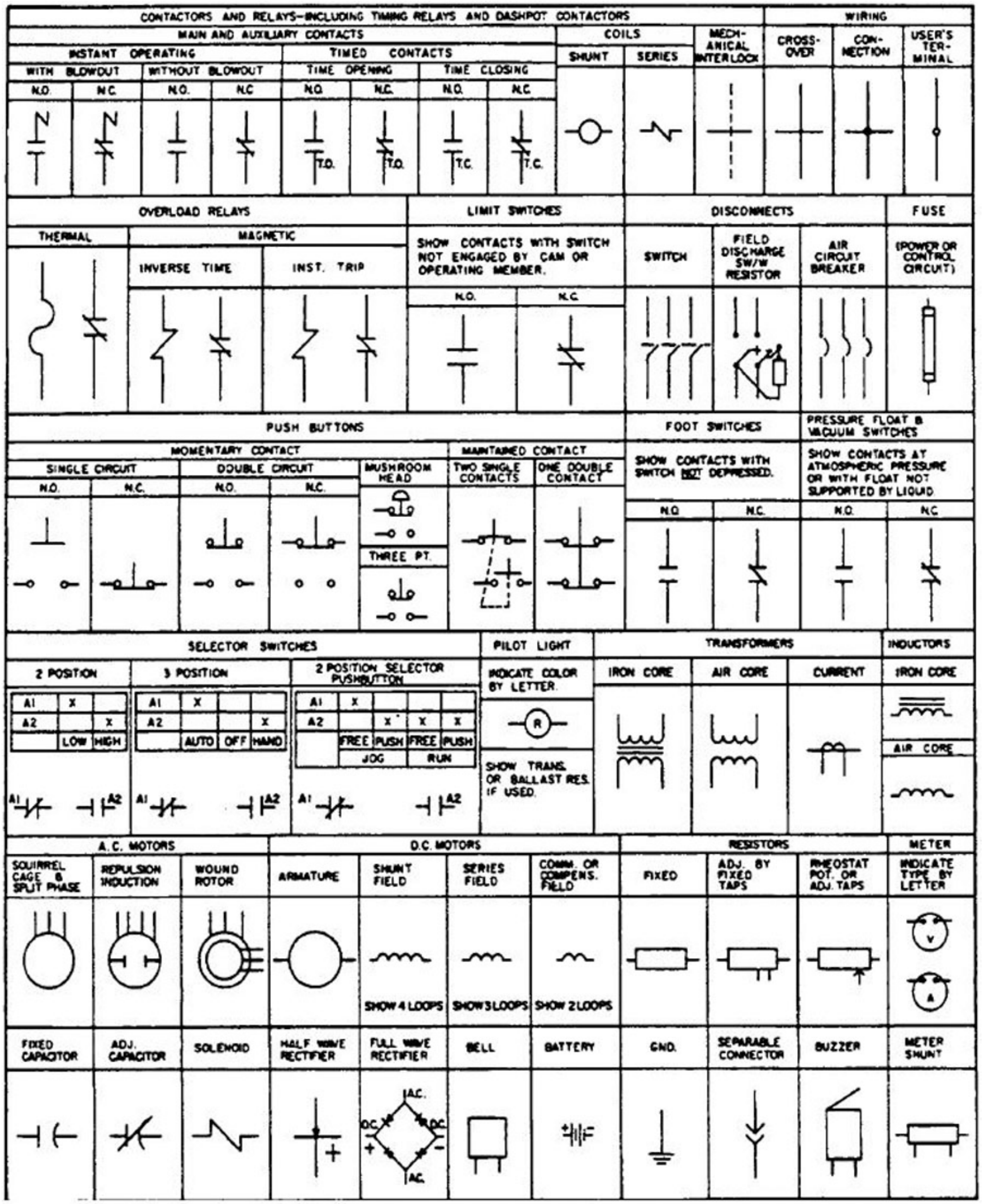


Figure 1–31. Electrical symbols.

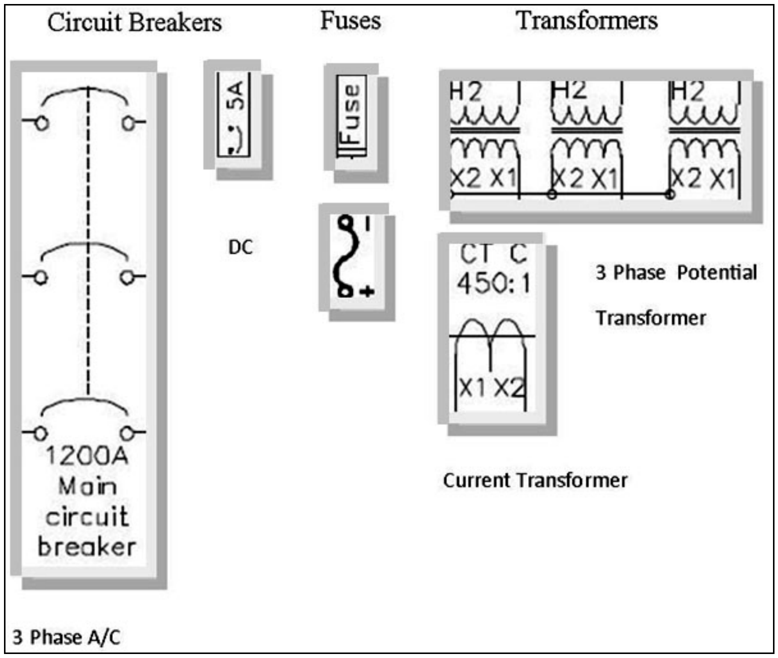


Figure 1–32. Electrical symbols.

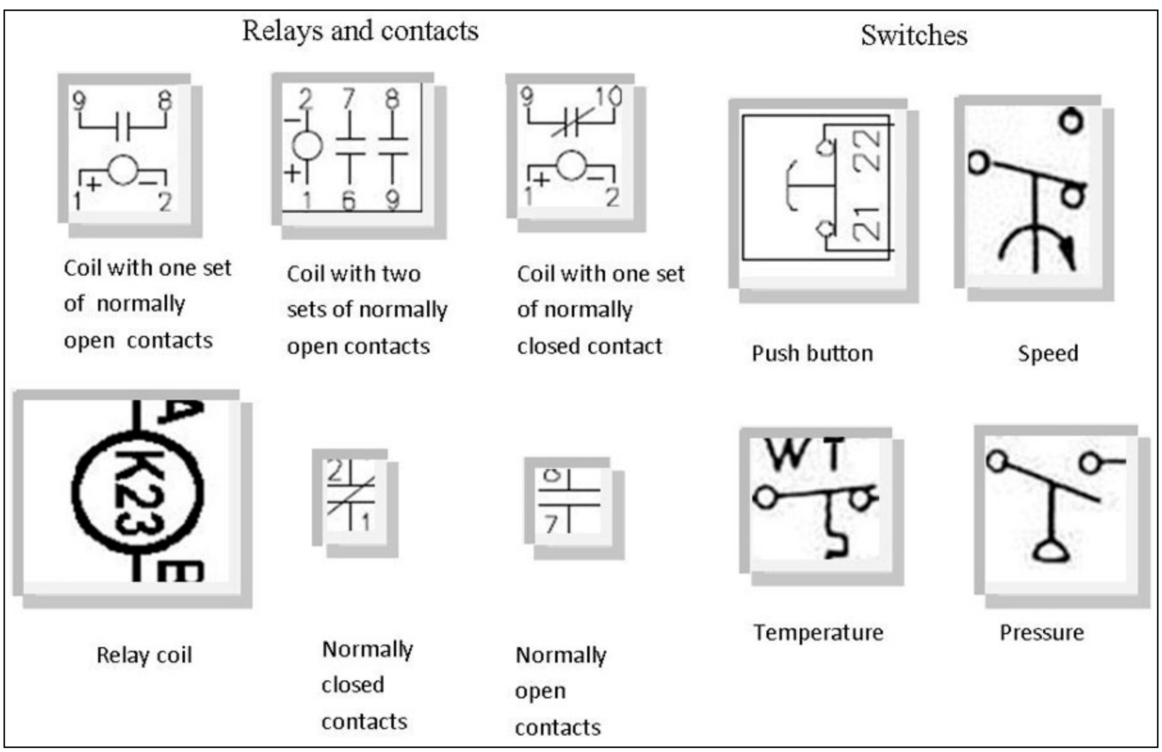


Figure 1–33. Electrical symbols.

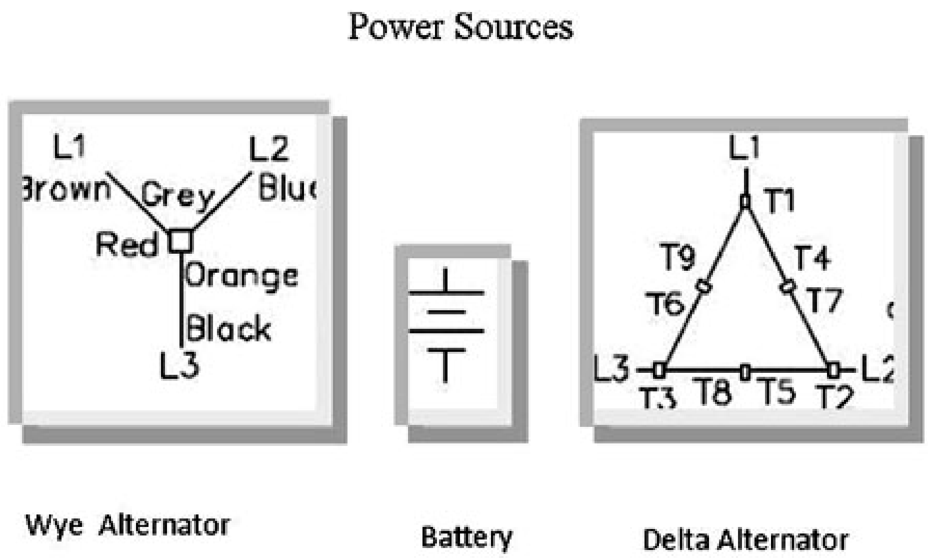


Figure 1–34. Electrical symbols.

Diagram types

Wiring diagrams are the roadmaps for electrical circuitry. They are detailed drawings that show how the wires of a circuit connect the components. Classified according to their function, there are four basic types of wiring diagrams used in the power production field.

- One-line.
- Schematic.
- Connection.
- Interconnection.

One-line diagram

The most basic diagram is the one-line diagram (fig. 1–35). A one-line diagram helps you maintain continuity in the process of extracting a diagram. However, the major devices, along with their ratings are usually shown, and the diagram follows the path of current flow. The diagram uses heavy lines to show main power circuits with secondary circuits shown with medium lines. This feature makes it easy to relate one inner circuit to another. A big help is that all wires going to and from the devices appear along with the power sources. Items do not appear in their respective location on the switchgear, but you can determine which devices receive power from current transformers and which from potential transformers. For example, in figure 1–35, lights 47 and 81 receive their power from PT (2), and light 51G receives its power from CT (1).

The one-line diagram provides you with an instant overview of a generating system, used in conjunction with the schematic diagram for a better understanding of the system’s operation when you are troubleshooting or extracting circuits. Remember, the one-line diagram does not show the connections or internal wiring of devices. The best use of this particular type of diagram is to help maintain continuity in the process of extracting a diagram.

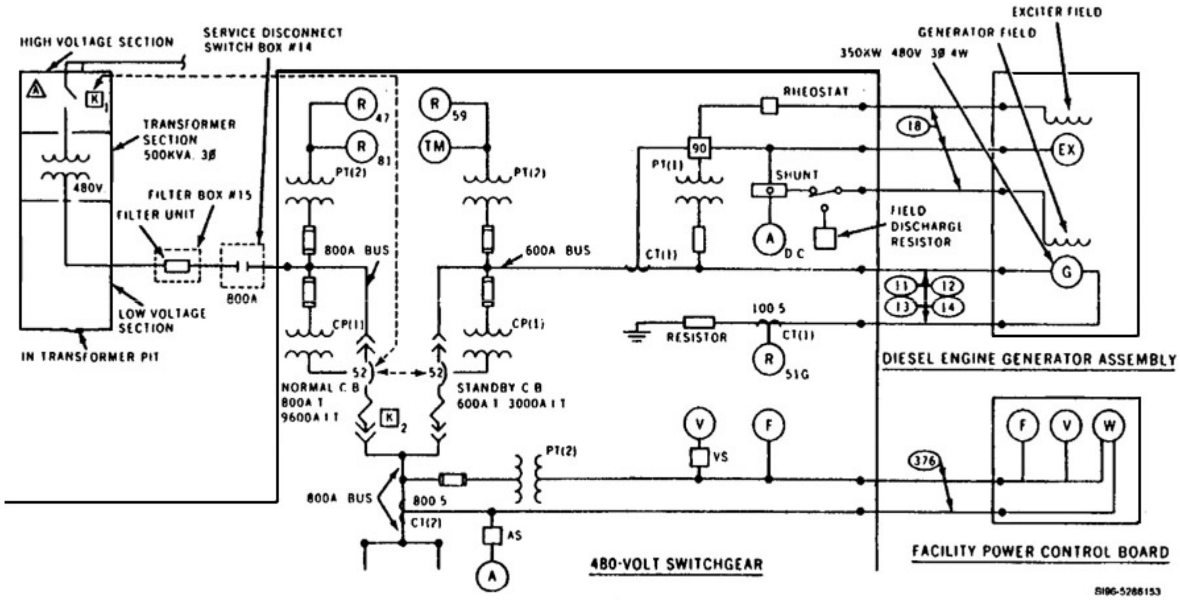


Figure 1–35. One-line diagram.

Schematic

Of all the wiring diagrams, the schematic is by far the most important and most useful for troubleshooting and extracting circuits. Schematic diagrams continue the idea of showing all circuit components in a straight line, without regard for physical location or relationship. It gives you an overall view of a particular system, shows circuit operations and shows where the functions within a circuit occur in an exact sequence.

Foldout (FO)–1 (located in the supplementary material of this volume) is an example of a schematic diagram. Since the schematic diagram usually includes elements such as solenoids, relays, contacts, meters, and possibly, mechanical linkage, it is easier to trace the circuit and it is operation. The schematic diagram also contains a legend identifying the device numbers.

A thorough understanding of schematic diagrams can simplify troubleshooting of an electrical system. Some schematic diagrams do not have the internal wires numbered but do contain the connections for all contacts numbered. Partial wire numbers may also be included on some, but not all, schematic diagrams. The internal wiring of devices is usually separate from the schematic diagram and does not show the source of power to the device.

Connection diagram

Often referred to as the “as-built” diagrams, a connection diagram shows the connection of an installation or its component devices and equipment. These diagrams work in conjunction with the one-line and schematic or elementary diagrams for extracting specific circuits during the troubleshooting process. You should note that the locations of the devices, as arranged on the diagram, are relative to the actual locations of these devices on the equipment. Because of this, wire tracing is largely simplified.

If you examine the connection diagram (fig. 1–36), you see that it would be impractical to show all of the wiring on a diagram. The heavy dark lines identify the wire bundles in which all circuitry wires are contained. The connection diagram also provides complete wire numbers, plug and jack pin numbers, and cannon plug numbers required to completely extract and troubleshoot specific circuits.

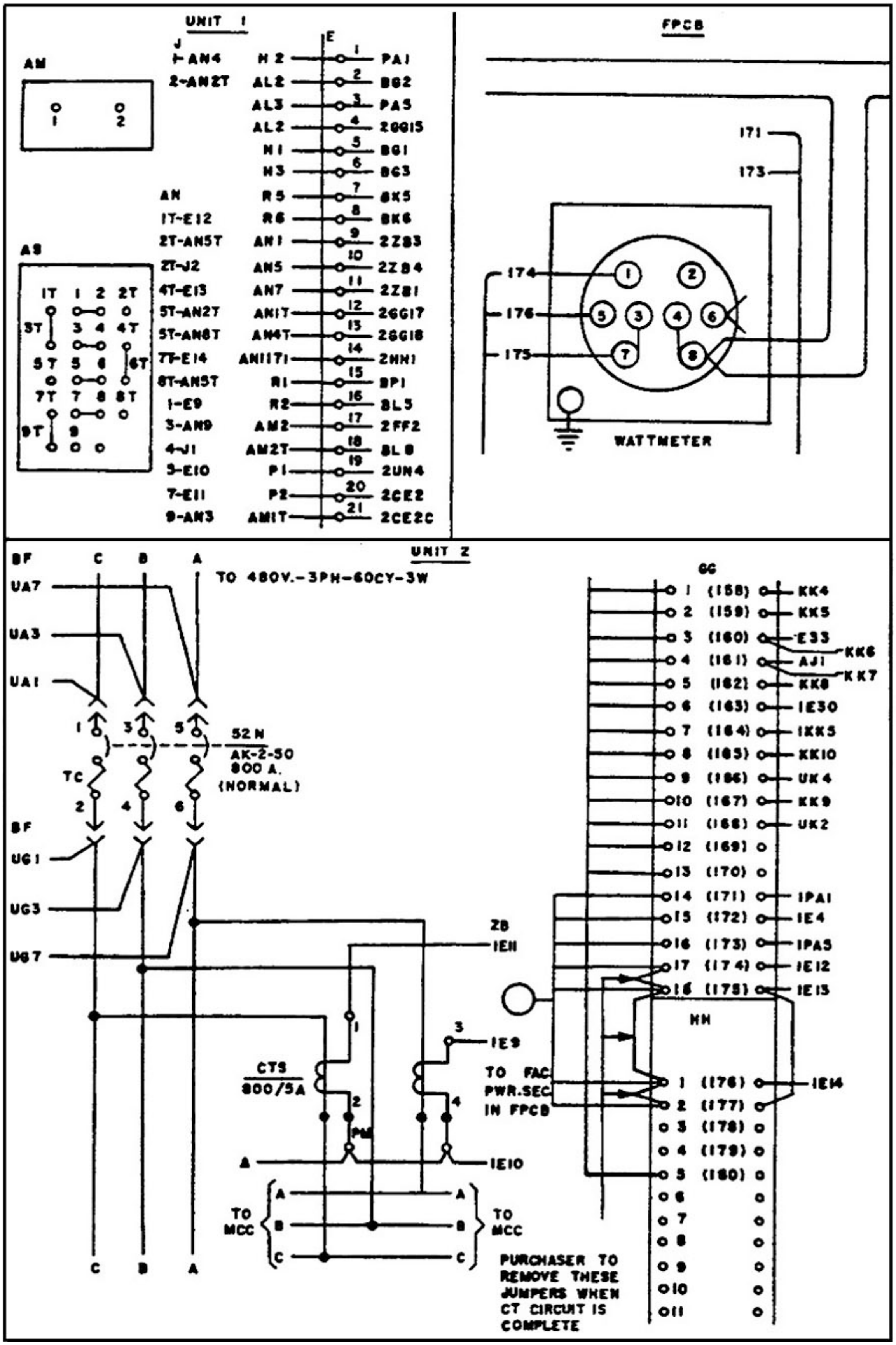


Figure 1–36. Connection diagram.

You must be able to trace and extract the wires for the specific circuits yourself. When you begin troubleshooting, you need to know how to extract the specific circuit that you need to troubleshoot. Connection diagrams work in conjunction with schematic diagrams for extracting and troubleshooting.

Even though connection diagrams vary between different manufacturers, you are able to trace circuits using the connection, one-line, and schematic wiring diagrams.

Interconnection diagram

An interconnection diagram is one that shows complete connections between equipment units, unit assemblies, and associated apparatus. Interconnection diagrams also show the connection of components inside the panel as viewed from the rear in their relative positions and determine the arrangement of conduits. Normally omitted from the diagram are the internal connections of units or unit assemblies. Figure 1–37 shows a typical interconnection diagram. A wire connection from terminal point 3 of the terminal board designated X of unit No. 8 is marked 8 X 3 in unit 7, and 7 X 3 in unit 8. We use standard conventional symbols for these interconnections and for equipment located apart from the panel. Heavy lines, exciter, and field circuits by medium lines and the smaller wiring by light lines normally show the main power circuits. Dot-dash lines outline the panel sections.

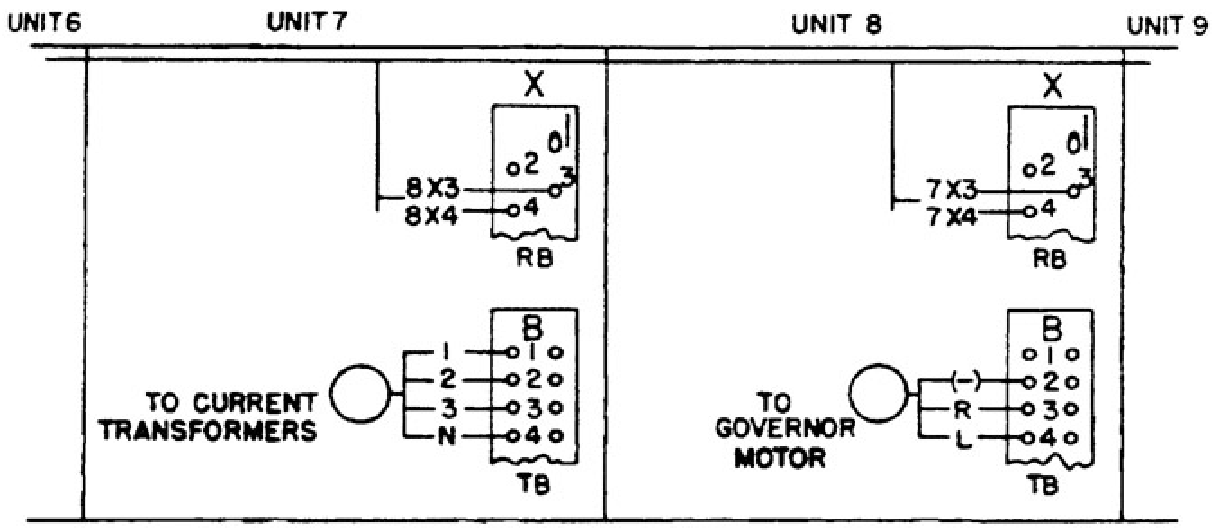


Figure 1–37. Interconnection diagram.

205. Extracting circuits

It is common for equipment manufacturers to use slightly different methods to help identify components on their respective wiring diagrams. The Mobile Electric Power (MEP) series generators often follow many of the rules listed below.

Wire code numbers and letters

Numbers and letters identify each segment of wire. These numbers and letters give information about the circuit. The following is an example of a typical wire number.

Wire Number	Code Numbers and Letters
P 140 D	P = Circuit designation letter (DC circuit)
	140 = Circuit number
	D = Progression letter

The first letter in the wire code is the circuit designator letter. Use the letter X to represent AC circuits, and P to represent DC circuits. The next number is the circuit number, which identifies the specific circuit in which you are working. The next letter is the progression letter. This letter starts at the first of the alphabet and progresses in the circuit between devices. This is the information that is going to direct you back to the power source. Whenever you are leaving a component, and a choice of two or more wires exists, normally you follow the wire with the lowest progression letter. The progression letters rise from A, the lowest letter, to Z, the highest progression letter. This is because the closer you come to the power source, the smaller the wire progression letters you find. This rule is not ironclad; there may be some exceptions, but for the most part, it holds true. If you do run into one of these situations, refer back to the schematic diagram. Remember, the schematic is your “roadmap” through the circuitry.

One piece of information that may not be included in the wire code is the wire gauge or size. If a number appears after the progression letter, it is the wire gauge. You may need to obtain this information from a separate diagram.

If the circuit is an AC circuit, there may be a letter after the wire size indicating the generator phase circuit this wire is used in—A, B, C, or N for neutral.

Tracing and extracting circuits

The Power Production career field contains many different types of generators and associated equipment. The ability to trace and extract circuits is indispensable when you troubleshoot the electrical circuitry of this equipment by using wiring diagrams, you can trace electrical circuitry and determine where to connect meters for checking electrical operation. This lesson addresses the procedures for tracing and extracting circuits in a logical manner. We limit our discussion concerning circuit extraction to the MEP-004A and MEP-005A series generators. The same rules and procedures apply to any circuit you trace and extract.

Tracing circuits

When tracing circuits on a wiring diagram for troubleshooting, it is often easier to extract (make a simple drawing of the circuit) the specific circuit in which you are interested. It is easier to work on a system with a simple drawing rather than a large, bulky wiring diagram. As you follow the circuit operation explanation circuit on a schematic diagram, it is a good idea to color code the circuit for easy identification and a clear understanding of that particular circuit. On your extraction, include all wire numbers, device code numbers, and area designations. The following table explains three well-established rules for tracing electrical circuits in the appropriate technical order or manufacturer’s manual.

Number	Rule
1	Use the appropriate technical reference to understand circuit operation. This is the most important step in circuit extractions. If you do not understand how the circuit operates, you may encounter numerous problems during the extraction and troubleshooting process. Understanding circuit operation includes an understanding of how each component operates, identification of the power source and main unit of resistance, and the electron flow in the circuit; negative (–) to positive (+) in a DC system and positive (+) to negative (–) in an AC system.
2	Identify or highlight all circuit components on the schematic diagram. This enables you to locate the components much quicker when you begin the actual tracing.
3	Trace the circuit on the schematic diagram as you are reading the circuit operation. This procedure allows you to gain a clear understanding of the circuit. First, locate the main unit of resistance on the schematic diagram and trace from the negative side of the unit of resistance to the negative side of the battery or power source. Once you have accomplished that, trace from the positive side of the unit of resistance to the positive side of the power source. The unit of resistance is the component or components, which provide the action. Normally, the name of the circuit identifies the unit of resistance. For example, in the panel light circuit, the units of resistance are the panel lights.

It is important to remember that all switches, contacts, relays, and other electrical devices are shown in the “deenergized” position on wiring diagrams, unless otherwise specified. Eventually, when you trace the positive or negative circuits, you trace through contacts of relays that are normally open. The contacts must close to maintain circuit (tracing) continuity back to the power source. This means that the relay controlling the normally open contacts must energize in order for the contacts of this particular relay to energize. Again, the negative circuit of this particular relay must trace back to the negative side of the power source. Trace the positive circuit of the relay back to the positive side of the power source. Once completely traced back to the power source, hypothetically now energized is the circuit of the relay. This allows for the normally open contacts of the relay to close, thus allowing you to continue circuit tracing of either side of the circuit back to the power source. This situation may repeat itself every time you trace through open contacts of relays until tracing the complete circuit of the main unit of resistance. Once you trace the circuit, circuit extraction is simpler because it is easier to work from simple circuit identification than a large, complex circuit.

Extracting circuits

Now that you have traced the circuit on the schematic diagram, you can extract the circuit. Remember, it is much easier to extract if you color code the circuit while you are tracing it. Both the schematic and connection diagrams are very important when extracting circuits. The schematic diagram is the most important of all diagrams because it is your guide through the connection diagram. The schematic shows where you are (present location), where you are going (future location), and from where you came (past location). Without knowing one of these factors, extraction of complex circuits becomes almost impossible.

The rules given here apply when extracting circuits. The ability to trace and extract circuits is indispensable when you troubleshoot the electrical circuitry of equipment. You often find extracting the specific circuit in which you are interested easier when tracing circuits on a wiring diagram for troubleshooting.

Rule 1

Identify and label all circuit components, conductors, wire numbers, print strips, contacts (label as normally open [NO] or normally closed [NC], and cannon plugs with an uppercase letter or an underlined lowercase letter; e.g., "t." Identify and label all connection points such as terminal boards and cannon plugs.) First, locate the main unit of resistance and record the device name on your extraction. Obtain the wire number of the wire going back to the negative side of the power source. Follow this path of current from the main unit of resistance. Record the complete wire number on the extraction. Remember to record all connection points, terminal boards, and cannon plugs along the way. The more information you have on your extraction, the easier it is for you to pin point electrical malfunctions.

Rule 2

Set all switches to the desired position and close the appropriate contacts of all relays. When tracing through switches that have several contacts, you need to know which contacts close when the handle closes. Some diagrams provide switch schematics that show this information.

Figure 1–38 gives information about a voltmeter switch used on some panel boards. Contacts 1–2, 3–4, 5–6, and 7–8 are normally open when the handle is in the OFF position. When the handle is in position 1, contacts 1–2 and 7–8 are closed. When the handle is in position 2, contacts 3–4 and 7–8 are closed. When the handle is in position 3, contacts 5–6 and 7–8 are closed.

VOLTMETER SWITCH					
CONTACTS		POSITIONS			
HANDLE END	NO.	OFF	1	2	3
2 1	1-2		X		
4 3	3-4			X	
5 6	5-6				X
8 7	7-8		X	X	X

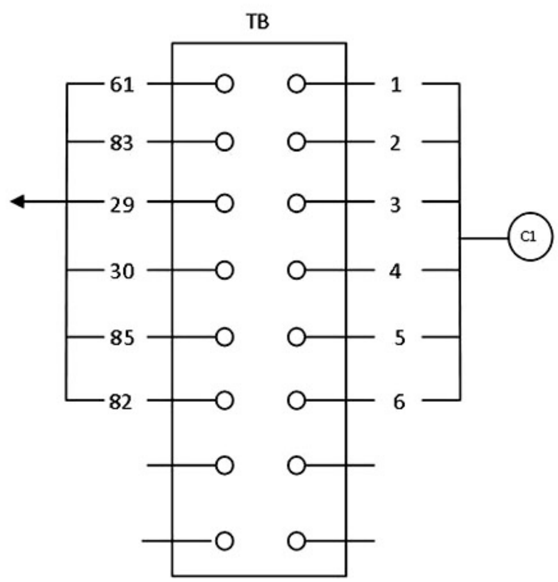


Figure 1–38. Voltmeter switch schematic.

Rule 3

Meter circuits are perhaps the most difficult of all circuits to trace on a wiring diagram. This is because most meters connect through multiple selector switches. For example, we know that a voltmeter is connected in parallel with the source of power, but when the same meter can be used to measure different phase voltages, the circuit becomes complex. A selector switch is then required in the circuit. You must consult the legend on the diagram that shows the contact positions of the switch when you trace the circuit. Often the source of power may not be readily apparent in an AC power system.

Rule 4

When your trace passes through a terminal board or device where a choice of wire numbers exists, normally the lowest progression letter is the correct one to follow (A being the lowest and Z being the highest). Continue through the rest of the circuit. Apply the rules for extracting circuits until you completely extract the entire circuit.

Portable generator circuits

Refer to FO 1 (schematic diagram) and FO 2 (DC troubleshooting diagram) for the MEP-004A and MEP-005A in this discussion on tracing and extracting circuits. You start with a simple circuit and work our way to a more difficult one. The first extraction to make is the control panel light circuit. Next, trace and extract the engine start circuit.

Depressing the DC control breaker CB1 energizes the DC electrical system. This circuit breaker, used to protect a circuit from overload and short circuit conditions, is the main protective device for the entire DC portion of the generator. If a problem arises during operation of the generator set, you can shut down the unit by deenergizing the DC electrical system with the CB1 circuit breaker.

When you depress CB1, this applies 24 volts DC to the entire DC electrical system and activates solenoids, pumps, and relays. All of these actions occur either simultaneously or within a very short time of each other. When reading the circuit descriptions, be aware of these relationships.

Panel light circuit

Using the technical order and rule 1, you note that the panel lights illuminate the control panel when there is insufficient natural or artificial lighting. The panel lights—DS1, DS2, and DS3—receive their power from the batteries BT1 and BT2. Switch S4 and CB1 are used to energize the lights. Now that you know what components are in the circuit, you can trace the circuit on the schematic diagram.

Refer to the schematic diagram (FO 1), as we trace the circuit. Again, it is a good idea to color-code the various circuits. Color-coding ensures easy identification of these components for future use. First, locate the unit of resistance on the schematic diagram. Looking at the legend, they are DS1, DS2, and DS3.

To trace a DC circuit, travel from the negative side of the unit of resistance—DS1, DS2, and DS3—to the negative side of the power source (rule 1). Starting at the negative side of DS1, notice it shown directly connected to the batteries. Now, starting at the positive side of DS1, proceed from the light to the next device. How can you determine the next device needed in this circuit? Referring to FO–1, you find that the only path for current to flow is through S4, switch panel lights. This is a normally open switch, as indicated by the letters NO.

The next device you must reach is CB1. FO–1 one shows a straight connection between S4 and CB1. Finally, trace from CB1 to the positive side of the batteries BT1 and BT2. Once you trace the circuit on the schematic diagram, trace it on the troubleshooting diagram (FO–2) to see all of the components in the circuit.

You extract a circuit from the troubleshooting diagram (FO–2). To extract the negative portion of the circuit, refer to figure 1–39 and the following extraction explanation. Locate DS1, DS2 and DS3 on figure 1–39. Starting at the negative side of DS3, proceed on wire P55EE to DS2 and to DS1 on wire P55DD. All P55 wires are negative on the MEP generators. From DS1, proceed on wire P55CC to terminal board TB1-3, 4. Applying rule 4, continue on wire P55AA to cannon plug J1 r, on wire P55BC to cannon plug J2 r, and on wire P55VV to the generator special ground stud box. To complete the circuit to the negative side of the battery, proceed on wire P55Z to cannon plug J5 t, then follow wire P55N to the starter B1.

You do not need to go through the starter, because it is a “touch-and-go” point. A “touch-and-go” point is one where two or more wires go to a device to provide multiple paths for current to flow. Touch and go on B1, then follow wire P55DC to the negative side of the battery BT2. Wire P140FO connects BT2 to BT1.

Using the traced circuit on FO–1, extract the positive side of the panel light circuit. FO–1 shows a direct path from DS1 to switch S4 and CB1, but looking at the DC troubleshooting diagram (FO–2), you find that there are many more components between S4 and CB1. Refer to figure 1–40 for the extraction while you read the following circuit explanation.

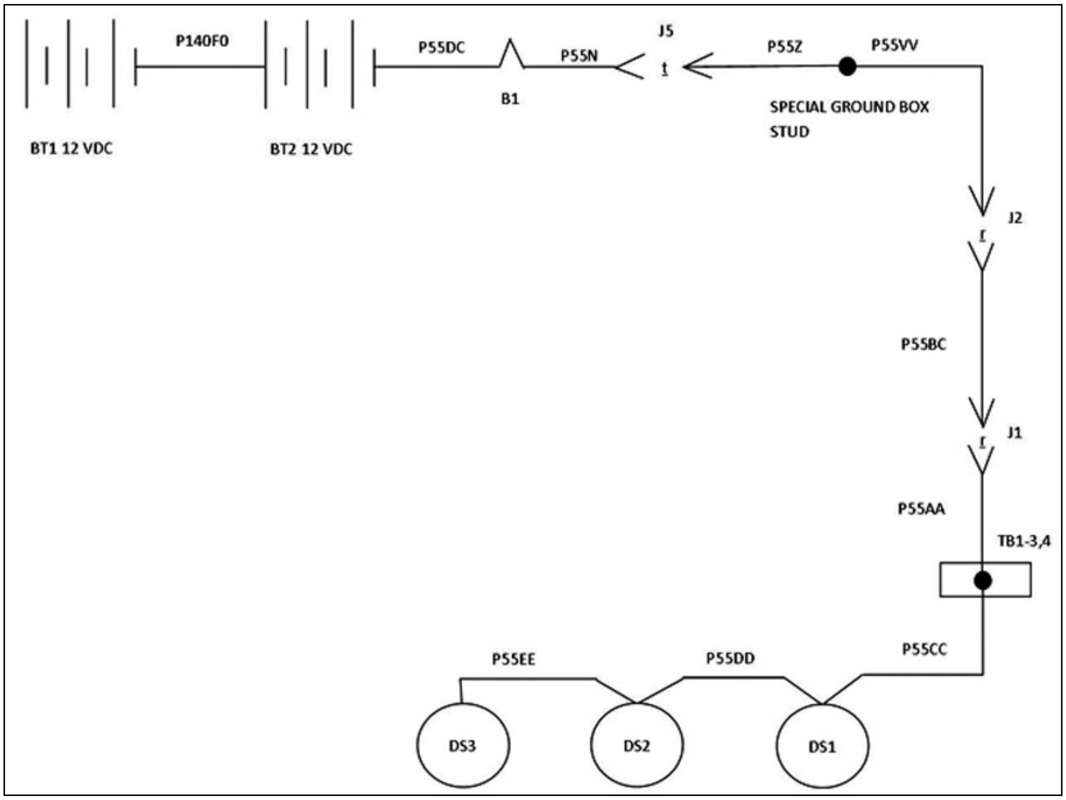


Figure 1–39. MEP panel light, negative portion.

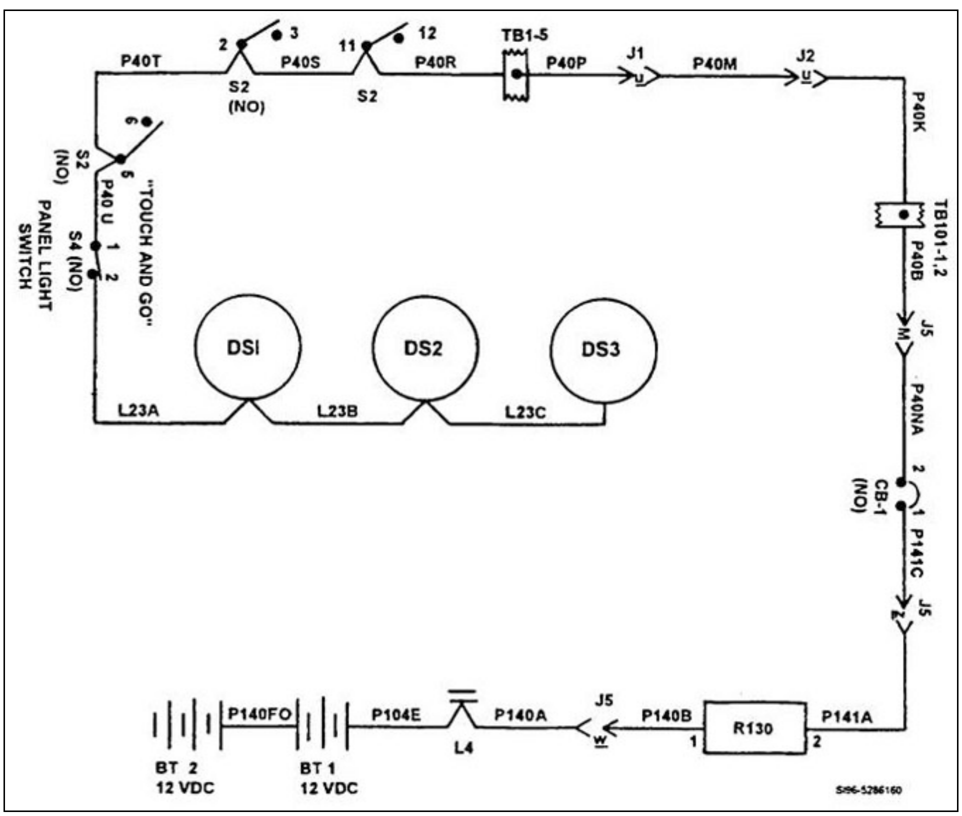


Figure 1–40. MEP panel light, positive portion.

Starting at DS3, go to DS2 on wire L23C, from there to DS1 on wire L23B, and from DS1, follow wire L23A to S4-2. Because you must go through switch S4 to energize the lights, you find there are two wires, P40U and P40V, connected to S4-1. Applying rule 4, take the next lowest progression letter, in this case U. P40U goes to S2, switch, start-run-stop, pin 5. You do not need to go through S2 to illuminate the panel lights. Again, using rule 4, the next lower progression letter is T, which connects pin 5 to pin 2. Leave pin 2 on wire P40S, which goes to S2, pin 11. From S2, pin 11, proceed on wire P40R to TB1 pin 5.

From TB1–5 follow wire P40P through a cannon plug connection, J1 u, branching there to wire P40M which leads you through a cannon plug connection, J2 u to wire P40K, which leads you, in turn, to TB101–1, 2. Taking the lowest progression wire, P40B, you come to another cannon plug connection, J5 M, and proceed to CB1–2.

The schematic diagram shows that you must go through R13, shunt battery charging, touch-and-go on L4 contacts, to get to the positive side of BT1. Leave CB1–1 by following wire P141C, through cannon plug connection J5 z, to wire P141A. Go through R13 and take wire P140B to cannon plug connection J5w. Wire P140A then takes you to L4 contacts. Touch and go on wire P140E, which takes you to the positive side of the battery, BT1. This completes the positive portion of the circuit.

This completes the tracing and extracting of the panel light circuit. Figure 1–41 shows a completed extraction of this circuit. Note the use of all the rules of extraction.

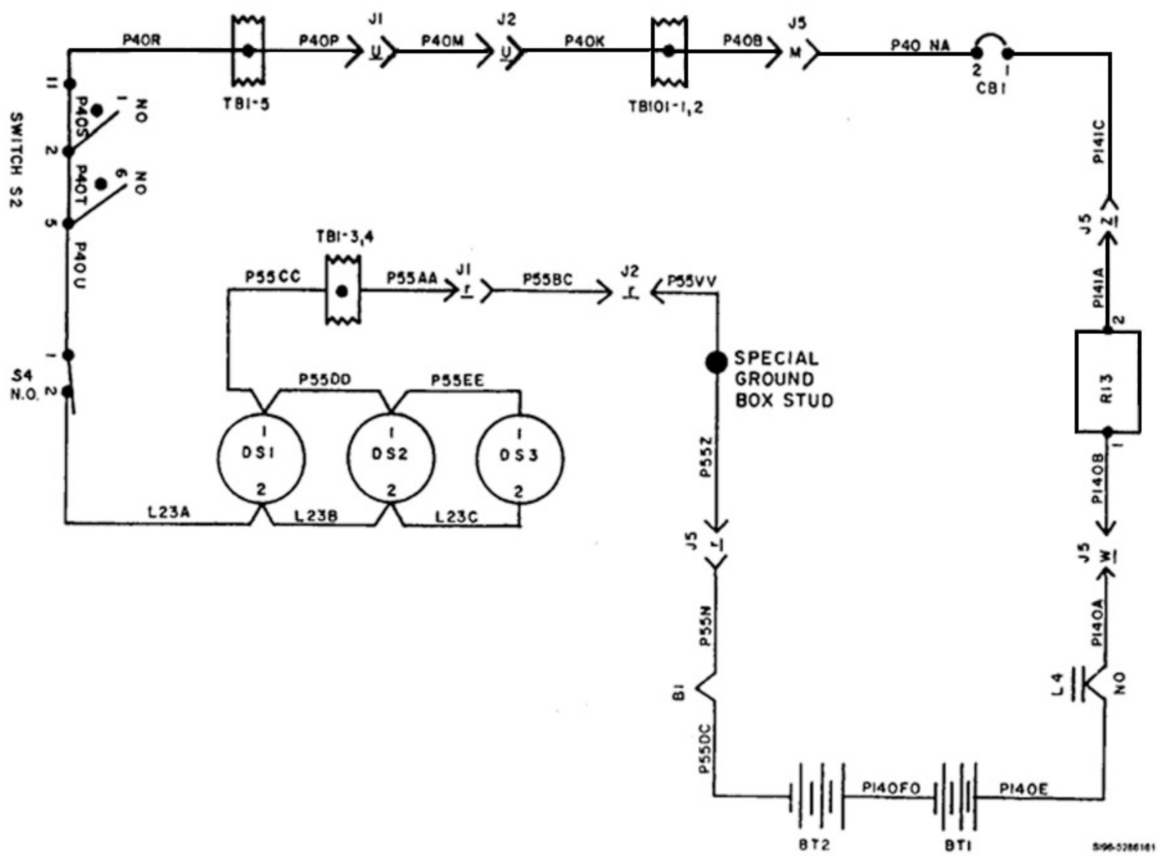


Figure 1–41. MEP panel light circuit.

After extracting this circuit, can you understand why you must use both diagrams to extract a circuit? If you only use the schematic diagram, you cannot successfully extract the circuit, and you may find yourself lost. Not having all of the components in the circuit impairs complete and successful troubleshooting of the equipment. It is not feasible to run one wire for every device. If so, there would be miles and miles of wire!

Engine start circuit

The next circuit is the engine start circuit. To begin, trace the circuit on FO–1. When toggled to the “start” position, the start-run-stop switch, S2, allows current flow from the negative side of the batteries through the crank relay K3. From K3, current flows through diode CR3 to the normally closed contacts of the start-disconnect and field flash speed switch S9–1. From S9–1, the current flows to the normally closed battle short switch, S7, to S2, on to CB1 circuit breaker. From this point, current flows through the shunt resistor R13, to the positive side of the battery BT1 and energizes the K3 relay. When K3 energizes, it closes its normally open contacts to energize the start solenoid. In turn, the start solenoid (L4) closes its normally open contacts and completes the circuit to the engine start motor, B1, which cranks the engine. Again, trace the circuit on FO–2 before proceeding with the circuit extraction.

Now it’s time for the circuit extraction. Figure 1–42 is the extraction for the circuit. Using FOs 1 and 2, work your way through the circuit. If you start with the main unit of resistance, the starter, you immediately find a coil and open contacts; therefore, the easiest place to begin extracting this circuit is with the crank relay, K3. From the K3 relay, pin X2, travel on wire P55F to the special ground stud box. At this point, follow wire P55Z to the cannon plug J5 t, through J5 t to wire P55N and on to the starter motor B1, then touch and go to starter solenoid L4 and BT2 on wire P55DC.

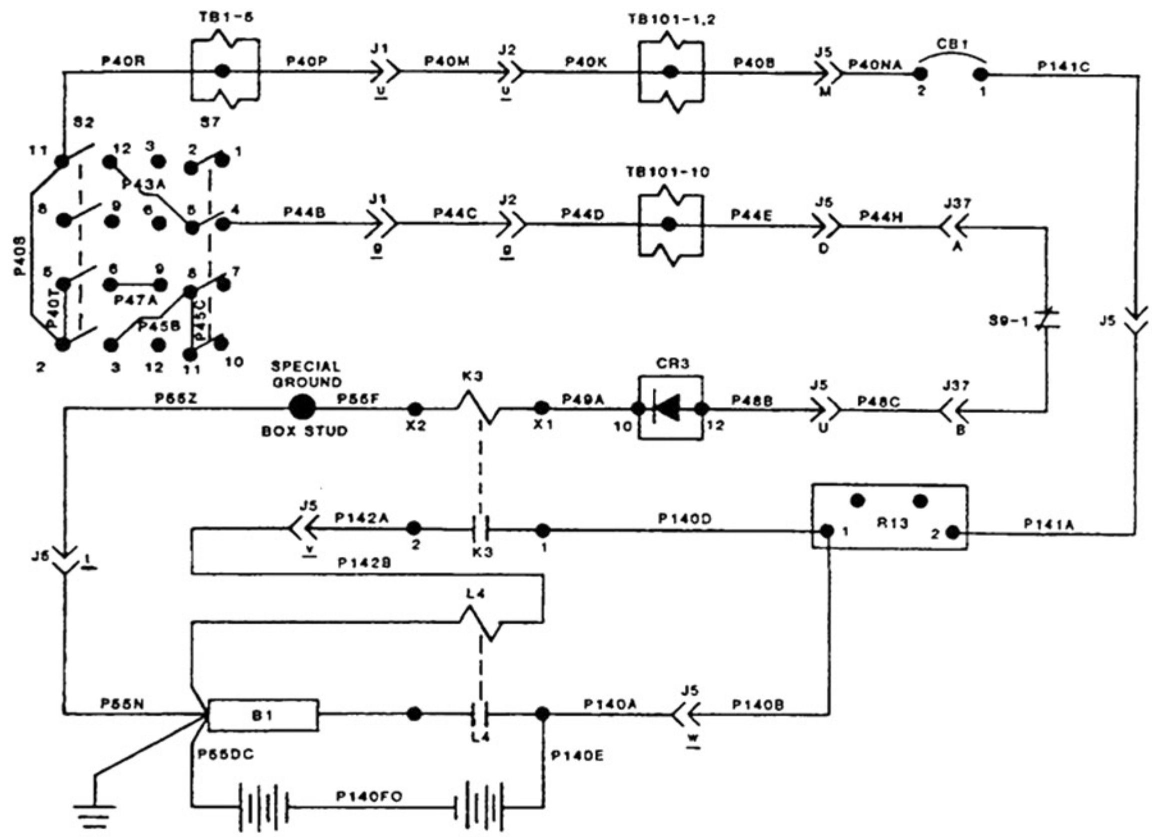


Figure 1–42. MEP engine start circuit extraction.

Working the positive side, go back to the K3 relay. From K3 pin X1, follow wire P49A into CR3. From CR3, follow wire P48B into the cannon plug J5 U, then on wire P48C go to cannon plug J37 B. Go through S9–1 to cannon plug J37 A and follow wire P44H to cannon plug J5 D. Wire P44E goes to TB101–10 and, using the lower progression letter theory, goes out on wire P44D to J2 g. From the cannon plug, wire P44C goes to J1 g, and from there we trace wire P44B to S7–4 to S7–5. The wire from S7–5, P43A, goes to the start-run-stop switch, S2–12. Remember, the S2 switch is in the start position and, therefore, the current flows through S2–12 to S2–11 on through to TB1–5 on wire

P40R. From the terminal board, the current flows through P40P to J1 u, through P40M to J2 u, through P40K to terminal board TB101–1, 2. From this terminal board, follow wire P40B through the cannon plug J5 M and follow wire P40NA to pin 2 of CB1. The current flows through CB1 and out pin 2 on wire P141C to J5 z. From here, the path is through wire P141A to R13, pin 2. Once current goes through R13, pin 1, it travels to two places. One path is through wire P140D to pin 1 of the K3 contacts. Since the K3 is now energized, the contacts close and allow the current to flow through wire P142A, cannon plug J5 v, following wire P142B to start solenoid L4. L4 is now energized and closes its contacts, allowing the current to flow from R13, pin 1, through wire P140B, to cannon plug J5 w. Then, follow wire P140A through the now-closed contacts of L4 and on to the starter motor, B1. You have now completed the engine start circuit for a MEP-004A and MEP-005A generator set.

During your Air Force career, you may be required to trace and extract circuits from power plant switchgear. Power plant switchgear is much larger than portable generators and separate from the unit. It contains all the components necessary to operate and monitor large power plant generators with loads. There is also a generator control panel for the control of the generator set. Normally all circuits for power plant switchgear are drawn in an extracted form. Although the wiring diagrams may vary in size and layout, the same rules for extracting circuits apply.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

204. Electrical symbols

1. What are the four basic types of wiring diagrams used in the Power Production career field?

2. What type of diagram is most useful when troubleshooting equipment malfunctions?

205. Extracting circuits

1. Explain what each of the letters and numbers in wire X130A12 identify.

2. List the three rules of circuit tracing.

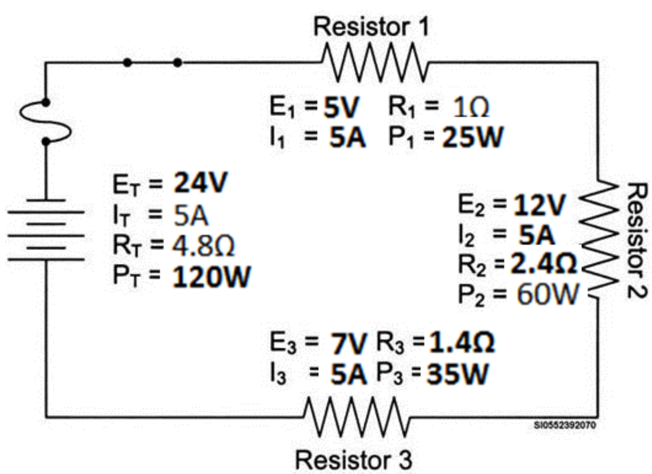
Answers to Self-Test Questions

201

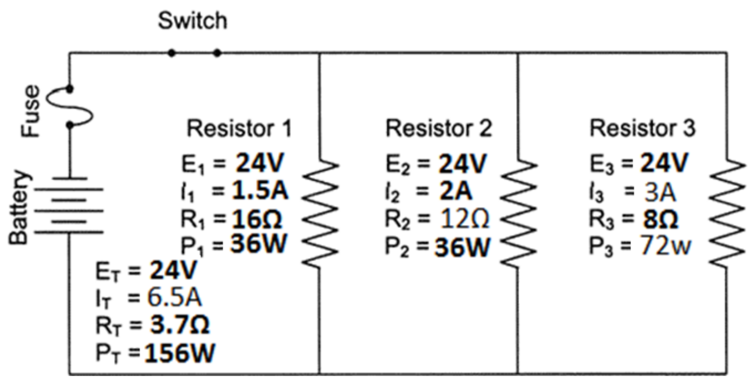
1. Two or more different elements chemically joined together.
2. (1) Proton.
   (2) Neutron.
   (3) Electron.
3. An electron located in the valence shell.
4. Ionization.
5. The flow of electrons.
6. (1) Type of material.
   (2) The length.
   (3) The cross-sectional area.
   (4) The temperature of the conductor.
7. AC continually changes magnitude and occasionally changes direction.
8. The relationship between voltage, current, and resistance.
9. A relationship, where current is inversely proportional to voltage and directly proportional to resistance.

202

1. A battery.
2. The component that a circuit operates.
3. The size of the fuse wire.
4. Personnel in the area as well as the equipment.
5. Circuits with only one path for electron flow through two or more units of resistance.
6. Sum, same, sum, sum.
7. See bolded values below.



8. Circuits that have more than one path for electron flow with only one resistor in each leg of the circuit.
9. Product over sum, reciprocal, and equal resistance methods.
10. See bolded values below.



11. Same, sum, smaller, sum.
12. More than one path for current to flow but have at least one resistor that receives the total circuit current passing through it.
13. Similar to series-parallel circuits except the series resistor does not carry the full circuit current.

203

1. A complete series of events that begin and end at the same point.
2. (1) Magnitude.
   (2) Time.
3. The number of occurrences of a complete series of events over a specified time.
4. The percentage of peak voltage it takes to produce the same amount of work as a DC circuit.
5. (1) Refrigerators.
   (2) Fans.
   (3) Vacuum cleaners.
   (4) Blenders.
6. An opposition to any CHANGE in current flow.
7. (1) The frequency of the applied voltage.
   (2) The amount of inductance that is present in the circuit.
8. Soft iron.
9. Mutual induction.
10. Two plates of conductive material separated by an insulating material called dielectric.
11. An opposition to any CHANGE in the value of voltage.
12. What phase shift takes place when you work with reactive circuits.
13. All of the power used in a circuit.
14. The power created by inductance or capacitance.
15. The power you think you are providing from your power source if you look at your voltage and current.
16. Holes.
17. With the negative side of a battery connects to the cathode and the positive side of the battery connects to the anode.
18. Only flows in one direction.
19. A device that changes AC into DC.
20. Six.

204.

1. One-line, schematic, connection, and inter-connection diagrams.
2. A schematic diagram.

205.

1. X identifies the circuit is an AC circuit, 130 is the circuit number, A is the circuit progression letter and 12 is the wire gauge (size).
2. Use the technical manual to understand the circuit operation, identify all circuit components on the diagram by circling or highlighting and trace circuit as you read the circuit description.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (201) Everything in the universe is made up of
   a. matter.
   b. electrons.
   c. compounds.
   d. valence shells.

2. (201) What is the *smallest* unit a compound can be broken down into *without* changing characteristics of the compound?
   a. Proton.
   b. Nucleus.
   c. Molecule.
   d. Compound.

3. (201) What is the *purest* part of a substance that can be broken down and *retains* its properties as that element?
   a. Element.
   b. Nucleus.
   c. Electron.
   d. Compound.

4. (201) What are the three parts of an atom?
   a. Proton, nucleus, and neutron.
   b. Proton, neutron, and electron.
   c. Nucleus, proton, and electron.
   d. Nucleus, electron, and neutron.

5. (201) How many free electrons do *conductors* have in the valence shell?
   a. 1 to 3.
   b. 4.
   c. 5 to 8.
   d. 9 or more.

6. (201) In contrast to good conductors, we consider substances that have how many free electrons to be *insulators*?
   a. Between 1 and 3.
   b. Between 3 and 5.
   c. Between 5 to 8.
   d. 9 or more.

7. (201) Semiconductors are *not* good conductors *or* insulators and are made of substances that have how many free electrons?
   a. 3.
   b. 4.
   c. 8.
   d. 9 or more.

8. (201) What symbol do we *commonly* use to represent resistance?
   a. Roman letter £ (lira).
   b. Greek letter Δ (delta).
   c. Roman letter ψ (wye).
   d. Greek letter Ω (omega).

9. (201) When it comes to resistance in a piece of wire, what does a *smaller* surface area cause?
   a. Increased power.
   b. Lower resistance.
   c. Decreased power.
   d. Higher resistance.

10. (201) What type of voltage *normally* maintains the same magnitude, but may vary?
    a. Alternating current (AC).
    b. Direct current (DC).
    c. Apparent power.
    d. Reactive power.

11. (201) What type of voltage *continually* changes magnitude and occasionally changes direction?
    a. Alternating current (AC).
    b. Direct current (DC).
    c. Apparent power.
    d. Reactive power.

12. (201) Ohm's Law describes the relationship between
    a. voltage, current, and power.
    b. resistance, current, and power.
    c. resistance, voltage, and power.
    d. voltage, current, and resistance.

13. (201) What is the relationship of *current* based on Ohm's Law?
    a. Directly proportional to power and directly proportional to voltage.
    b. Inversely proportional to power and directly proportional to resistance.
    c. Directly proportional to voltage and inversely proportional to resistance.
    d. Inversely proportional to voltage and directly proportional to resistance.

14. (202) What device allows you to control a direct current (DC) circuit *manually*?
    a. Relay.
    b. Switch.
    c. Rectifier.
    d. Transformer.

15. (202) Which direct current (DC) circuits have *only* one path for electron flow?
    a. Series.
    b. Simple.
    c. Parallel.
    d. Series-parallel.

16. (202) What method of calculating total resistance of a parallel circuit *only* works when calculating *two* resistors?
    a. Reciprocal method.
    b. Equal resistor method.
    c. Product over sum method.
    d. Adding all resistors together.

17. (202) What type of direct current (DC) circuit has more than one path for current to flow but have at least one resistor that receives the total circuit current passing through it?
    a. Series circuit.
    b. Simple circuit.
    c. Parallel circuit.
    d. Series-parallel circuit.

18. (202) What is the characteristic for *total power* in a series parallel circuit?
    a. Product of the power at the individual resistors.
    b. Less than the lowest power value at a resistor.
    c. Sum of the power at each individual resistor.
    d. The same throughout the circuit.

19. (202) What type of circuit typically has a parallel circuit with one or more legs having series portions?
    a. Series circuit.
    b. Parallel circuit.
    c. Combination circuit.
    d. Series parallel circuit.

20. (203) When you hear about the frequency of electricity, it refers to the number of complete cycles that occur in
    a. 1 second.
    b. 10 seconds.
    c. 30 seconds.
    d. 1 minute.

21. (203) In an alternating current (AC) voltage signal, how many peaks does each cycle have?
    a. 1.
    b. 2.
    c. 3.
    d. 4.

22. (203) What component does a magnetic field have little to no influence on?
    a. Resistors.
    b. Inductors.
    c. Capacitors.
    d. Transformers.

23. (203) A good example of a use for a variable resistor is a
    a. winding for an electrical motor.
    b. rectifier for a battery charger.
    c. dimmer switch for a light.
    d. coil for a power supply.

24. (203) What do we call the induced voltage that moves in the opposite direction as the applied voltage in an inductor?
    a. Cross currents.
    b. Mutual induction.
    c. Induced resistance.
    d. Counter electromotive force (EMF).

25. (203) What alternating current (AC) characteristic causes an opposition to any CHANGE in current flow?
    a. Capacitance.
    b. Inductance.
    c. Resistance.
    d. Reactance.

26. (203) What component may increase or decrease voltage in a circuit?
    a. Inductor.
    b. Capacitor.
    c. Oscillator.
    d. Transformer.

27. (203) If the secondary coil of a transformer has *less* coil turns, what does the transformer do to meet circuit needs?
    a. Steps the voltage level up.
    b. Steps the voltage level down.
    c. Maintains the voltage level the same.
    d. Isolates the circuit from other components.

28. (203) If the secondary coil of a transformer has *more* coil turns, what does the transformer do to meet circuit needs?
    a. Steps the voltage level up.
    b. Steps the voltage level down.
    c. Maintains the voltage level the same.
    d. Isolates the circuit from other components.

29. (203) What type of transformer only uses a secondary coil?
    a. Potential.
    b. Isolation.
    c. Current.
    d. Power.

30. (203) What is the insulating material called that separates the two plates of conductive material in a capacitor?
    a. Carbon.
    b. Dielectric.
    c. Sulfuric acid.
    d. N-type material.

31. (203) What alternating current (AC) characteristic causes an opposition to any CHANGE in the value of voltage?
    a. Capacitance.
    b. Inductance.
    c. Resistance.
    d. Reactance.

32. (203) Since most of the capacitors you will see have a rating much lower than one farad, what do we refer to these as, represented by µf?
    a. Microfarad.
    b. Megafarad.
    c. Minifarad.
    d. Milifarad.

33. (203) Which mnemonic spells out the phase shift in an alternating current (AC) circuit?
    a. ROY G BIV.
    b. ALI the ACE.
    c. ROE the EAR.
    d. ELI the ICEman.

34. (203) What do we call the power created by inductance or capacitance?
    a. Apparent power.
    b. Reactive power.
    c. Evident power.
    d. True power.

35. (203) What is the bias of a diode when we connect the positive terminal of the battery to the P-type material and the negative terminal of the battery to the N-type material?
    a. Forward.
    b. Cathode.
    c. Reverse.
    d. Anode.

36. (203) How much resistance does a diode offer to the current flow when the power source connects in the forward bias direction?
    a. None.
    b. Low.
    c. Moderate.
    d. High.

37. (203) In reference to reverse bias, what happens when the majority carriers move outward allowing the barrier voltage to increase?
    a. Decrease in the depletion region.
    b. Increase in the depletion region.
    c. Decrease in the forbidden band.
    d. Increase in the forbidden band.

38. (204) What are the four basic types of wiring diagrams used in the power production field?
    a. One-line, schematic, connection, and interconnection diagrams.
    b. One-line, schematic, connection, and troubleshooting diagrams.
    c. One-line, connection, troubleshooting, and interconnection diagrams.
    d. Schematic, connection, troubleshooting, and interconnection diagrams.

39. (204) Which diagram shows the connection of an installation or its component devices and equipment?
    a. One-line.
    b. Schematic.
    c. Connection.
    d. Interconnection.

40. (204) Which diagram provides complete wire numbers, plug and jack pin numbers, and cannon plug numbers required to completely extract and troubleshoot specific circuits?
    a. One-line.
    b. Schematic.
    c. Connection.
    d. Interconnection.

41. (204) What do dot-dash lines mean on an interconnection diagram?
    a. Outline of the generator.
    b. Outline the panel sections.
    c. Sections that work together.
    d. Sections that work independent.

42. (205) What diagram should include all wire numbers, device code numbers, and area designations?
    a. A one-line.
    b. A schematic.
    c. An extraction.
    d. A circuit card.

43. (205) Which diagram is the *most important* of all diagrams because it is your guide through the connection diagram?
    a. One-line.
    b. Schematic.
    c. As-built.
    d. Interconnection.

Please read the unit menu for unit 2 and continue ➔

Unit 2. Engine Direct Current Electrical System

THE ENGINE ELECTRICAL system and battery chargers play a vital role in the success of the mission. They are often the forgotten part of the generator and aircraft arresting systems; however, they are very important. This unit gives vital information on the components of the direct current (DC) electrical system and on batteries and troubleshooting.

2–1. Components and Theory of Operation

The engine electrical system contains circuitry to start and operate the engine. This includes the circuitry to monitor the engine during operation. The ability to monitor allows you to prevent many mechanical malfunctions before they occur.

206. Components

In order for you to be able to operate and monitor an engine, the components of the engine electrical system must work together. Any one failure of a component prevents normal operation of the engine. The components common to most engine electrical systems are the battery, starter motor, starter solenoid, crank relay, ignition switch, and control circuitry.

Battery

Batteries (fig. 2–1) are devices that change chemical energy into electrical energy. We use batteries as auxiliary sources of power, which store DC. The engine electrical system uses batteries to provide the power required for starting and operating the engine. Typical engines use either 12 or 24 volts systems.

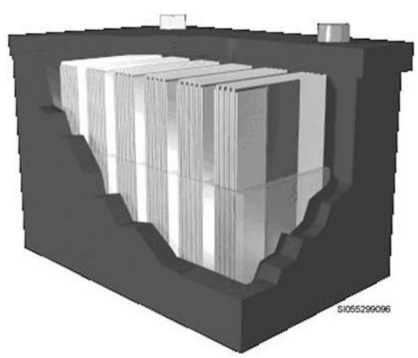


Figure 2–1. Battery.

Starter motor

The starter motor (fig. 2–2) changes electrical energy into mechanical energy to rotate the engine for startup. The motor receives its DC power from the batteries and begins to rotate. The rotating motor turns the engine through a gear that is meshed into the flywheel. Engineers design starter motors to rotate the engine fast enough to create compression for startup.

Starter motors fall into two categories—direct drive and gear reduction. Direct drive starters do not use any type of gearing to drive the pinion gear. Gear reduction starters use an internal gear to drive the pinion gear. This reduces the speed of the pinion gear, which increases the amount of torque at the flywheel. Smaller gasoline and diesel engines use direct drive starters while larger diesel engines use gear reduction starters.

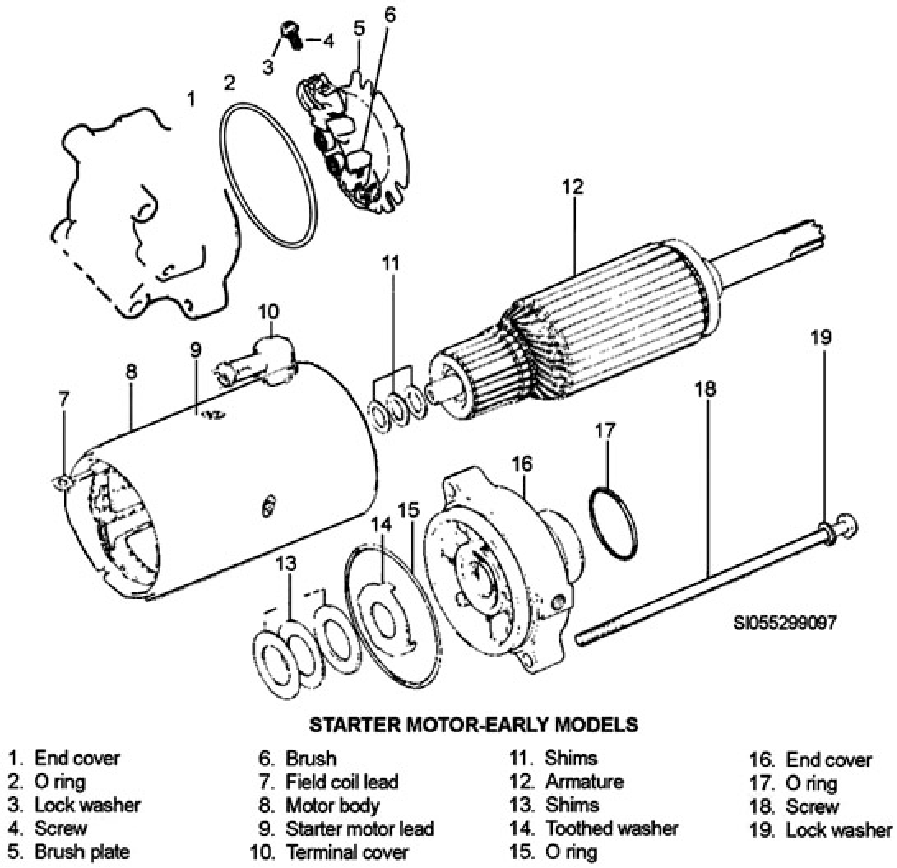


Figure 2–2. Starter motor.

Starter housing

The starter housing protects and supports the internal components of the starter. It mounts to the engine block, providing access to the flywheel for the pinion gear.

Field coils

The field coils are constructed of heavy copper ribbon that is capable of handling high current flow. These insulated coils mount to the starter housing so the north and south poles created by the current flow alternate. The coils also use shoes to direct and align the magnetic fields for better operation of the starter.

Armature

The armature consists of a shaft, iron core, commutator, and armature segments. The segments rotate past the field coils with opposing magnetic fields. This difference in the magnetic fields causes the armature to rotate since the field coils mount to the housing.

Commutator and brushes

The commutator mounts to the end of the armature. It consists of heavy copper segments separated by insulation material. Brushes ride against the commutator segments allowing current to flow from the field coils to the armature. These copper segments are positioned so every other bar is opposite in polarity. This creates a change in the polarity of current to the armature segment as it reaches the midway point of the rotation past the field coils, which changes the polarity of the magnetic field. This allows the opposing forces of the magnetic fields to continue to push the armature around.

Pinion gear

The pinion gear mounts to the end of the armature shaft. It moves back and forth on the end of the shaft to engage the engine flywheel during the start sequence. The pinion gear rotates freely on the armature shaft.

Overrun clutch

The overrun clutch (fig. 2–3) prevents damage to the starter motor during engine startup. The overrun clutch connects the armature shaft to the pinion gear. It uses a clutch housing splined to the armature shaft to rotate the pinion gear. The clutch housing uses a series of spring-loaded rollers forced into small ends of matching slots on the pinion gear. This allows the overrun clutch to turn the pinion gear during the start sequence.

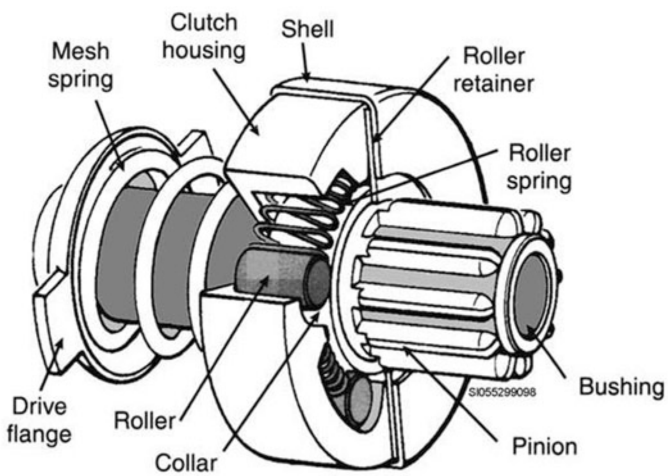


Figure 2–3. Overrun clutch.

Once the engine starts, the flywheel begins to drive the pinion gear. As the speed of the clutch increases, centrifugal force causes the spring-loaded rollers to move, releasing the slots on the pinion gear. This allows the pinion gear to rotate at engine speed until it disengages from the flywheel without damaging the armature.

Starter solenoid

The starter solenoid (fig. 2–4) performs two functions—one mechanical and one electrical. First, it moves the mechanical drive to engage the pinion gear into the flywheel. Second, it closes a set of contacts to energize the starter motor once the pinion gear is meshed with the flywheel. The solenoid consists of a coil with a hollow center, plunger, and contacts. Most coils have two separate coils, one for pulling in the plunger and another to hold in the plunger. The starting circuit initially energizes both coils to pull the plunger in. Once the plunger moves all the way in, and the contacts close, the pulling coil de-energizes and the holding coil keeps the plunger in place for the rest of the starting sequence.

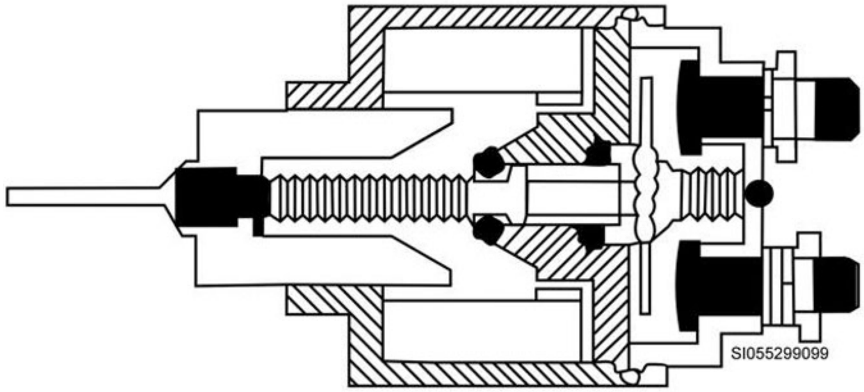


Figure 2–4. Starter solenoid.

Crank relay

The crank relay (fig. 2–5) energizes the circuit to the starter solenoid. The current draw of the solenoid requires larger wire than most other control circuits in the system. The crank relay draws much less current, allowing the control circuitry to use smaller wire.

Figure 2–5. Crank relay.

Start switch

The start switch controls the starting circuit. It is often a spring-loaded toggle or push button switch. This allows the switch to open once you let go to de-energize the starting circuit.

Control circuitry

The control circuitry connects all of the engine electrical components to allow you to operate and monitor the engine. These circuits include the starting, safety, and monitoring aspects of the engine. Safety circuits include alarm and engine shutdown components to identify problems that could cause damage to the engine. The monitoring system includes gauges and meters to let you determine the operation condition of the engine. You will read more about the safety circuits and monitoring system in the various sections throughout this volume.

Battery-charging alternator

The battery provides power to start the engine; however, the alternator provides power to charge the battery and power to operate electrical systems. The charging system includes the battery, alternator, voltage regulator, connecting wires and cables, and all associated electrical loads in the system. The charging system recharges the batteries as needed and provides the current to power the electrical loads in the system. It does this by converting part of the engine's mechanical energy into electrical energy. In this lesson, we discuss how the battery-charging alternator operates and how to replace it.

Components

Battery-charging alternators have come a long way since the days of the DC generators. They are more reliable and require much less maintenance that the DC generator did. The components that make up the battery-charging alternator include the rotor, stator, rectifier, and voltage regulator.

Rotor

The rotor (fig. 2–6) is the only moving part of the battery-charging alternator. It consists of a shaft, coil, and two pole pieces. The crankshaft drives the rotor through a belt and pulley system. The coil, also called the field winding, has insulated wire wrapped around a soft iron core. The rotor generates a strong magnetic field when a small amount of current passes through it. The pole pieces create the north and south poles.

The rotor typically gets its current from the battery through a set of slip rings. The current passes through one of the slip rings, to the coil, and then through the other slip ring back to the battery. Once the engine is operating, the alternator can support itself by using the current it produces for its input.

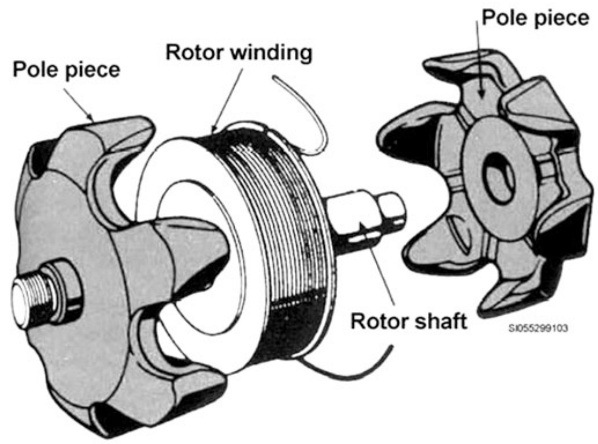


Figure 2–6. Battery-charger rotor.

Stator

The stator (fig. 2–7) is the stationary conductor on the battery-charging alternator. The stator uses a laminated iron frame to support the three output windings. The three windings are necessary to produce the current necessary to charge the battery. Manufacturers arrange these windings in either a wye or a delta connection. This means there are three output terminals.

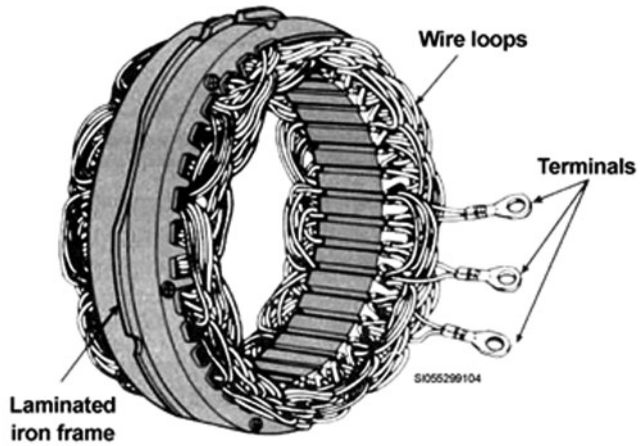


Figure 2–7. Battery-charger stator.

Rectifier

The battery-charging alternator uses a three-phase, full-wave rectifier (fig. 2–8) to provide the DC output to charge the battery. These rectifiers use six diodes—three positive and three negative. This changes the AC created by the stator windings into the DC needed for the output to charge the batteries.

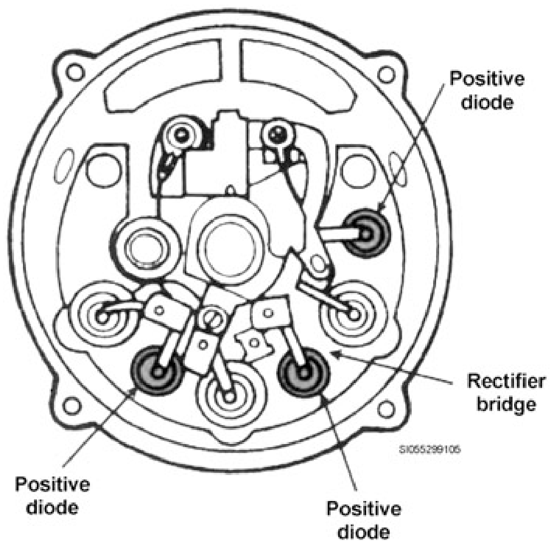


Figure 2–8. Battery-charger rectifier.

Voltage regulator

The voltage regulator controls the charging rate of the battery by turning the current to the rotor on and off as necessary. If the battery voltage is low, the regulator sends current to the rotor, creating the magnetic field to induce a voltage to the stator. This allows the battery to charge. Once the battery reaches the preset value, the regulator stops the flow of current to the rotor, collapsing the magnetic field. This makes the alternator have no output voltage.

207. Theory of operation

DC electrical systems create a number of faults as components wear out. It is important to know the normal operations of these systems to better diagnose faults when they occur.

Theory of operation of the starting system

The engine start circuit (fig. 2–9), begins with the start switch closing. The closing of the switch provides a path for current to flow through the speed switch and crank relay coil. This energizes the coil, creating a magnetic field and pulling the movable contact closed. The closing of the crank relay contacts provides a path of current flow through it and the starter solenoid. When the starter solenoid energizes, the mechanical drive pushes the pinion gear into the flywheel. As the pinion gear completely meshes with the flywheel, the starter solenoid closes its contacts. This provides a path for current flow to the starter motor. The starter motor begins to turn causing the engine to rotate. Once the rotating engine starts, the speed increases. This increase in engine speed activates the speed switch, causing it to open. When the speed switch opens, the crank relay coil de-energizes, opening its contacts. This causes the starter solenoid to de-energize, opening its contacts and pulling the pinion gear from the flywheel. The opening of the starter solenoid contacts de-energizes the starter motor.

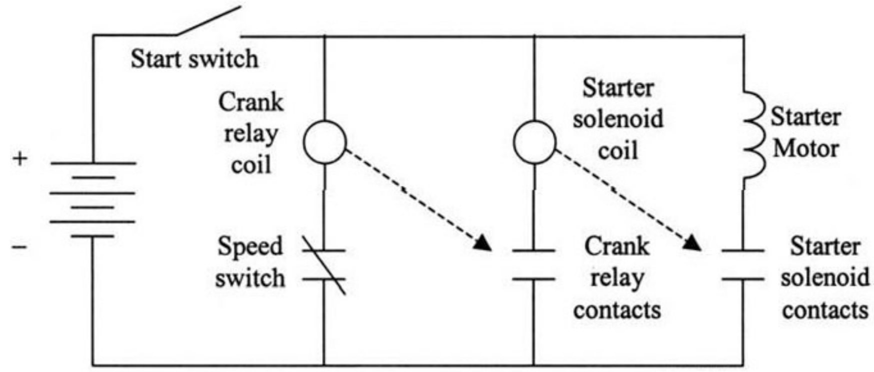


Figure 2–9. Engine start circuit.

Operations of the battery-charging alternator

As electrical loads drain the battery, the battery's voltage drops. When the voltage falls below a preset level, an electrical switch called the voltage regulator turns on the alternator. The alternator produces electric current and sends it to the battery to restore voltage to the required levels. The specific operations of a Mobile Electric Power (MEP) series battery-charging alternator begin with the alternator generating a DC voltage when the engine is operating. This voltage, applied through a regulator, which is part of the alternator, keeps both batteries in a fully charged state. The 24-volt field voltage for the alternator couples through the contacts of a relay and diode. Consequently, the alternator field disconnects when the engine is in the process of shutting down thereby preventing possible alternator damage. Most alternators work on the same basic theory; however, the electrical circuits vary in design.

The engine DC electrical system provides control for almost every aspect of power generation. In addition, it is the means for starting and stopping an engine. Knowing how this system works is vital to operating and maintaining a reliable power generating system.

208. Direct current system maintenance and replacement

Maintaining the engine electrical system is the key to the proper operation of your engine. Many of the problems you see with engines are electrical related. The engine will not operate if the electrical system is not functioning due to its design. You need to maintain these systems in top condition.

Inspecting the starter motor and starter solenoid

The starter motor and starter solenoid are essential components in the DC electrical system on a generator. You must perform periodic inspections during the startup of the generator to ensure proper operation. Failure to spend the time on these inspections could leave your customer without power. Be sure to do the following:

1. Inspect the starter solenoid terminals for corrosion. If there is corrosion, disconnect the negative battery terminal and clean all of the terminals.
2. Inspect the starter and starter solenoid for signs of damage and security of mounting bolts.
3. Look for discoloration or other signs of overheating of the starter motor and starter solenoid.

Replacing the starter motor and starter solenoid

The starter and starter solenoid can have problems that range from burned windings to mechanical failures. You often find it necessary to replace the starter or starter solenoid if problems occur. Before you replace the starter motor and starter solenoid, observe proper safety procedures. Make sure you shut the generator down before doing maintenance.

Refer to figure 2–10 as you read through the steps to replace the starter and starter solenoid. First, make sure you disconnect the negative battery cable before working on the starter and that you maintain the correct terminal polarity during installation. Because the starter is heavy, observe proper lifting procedures and get assistance as needed.

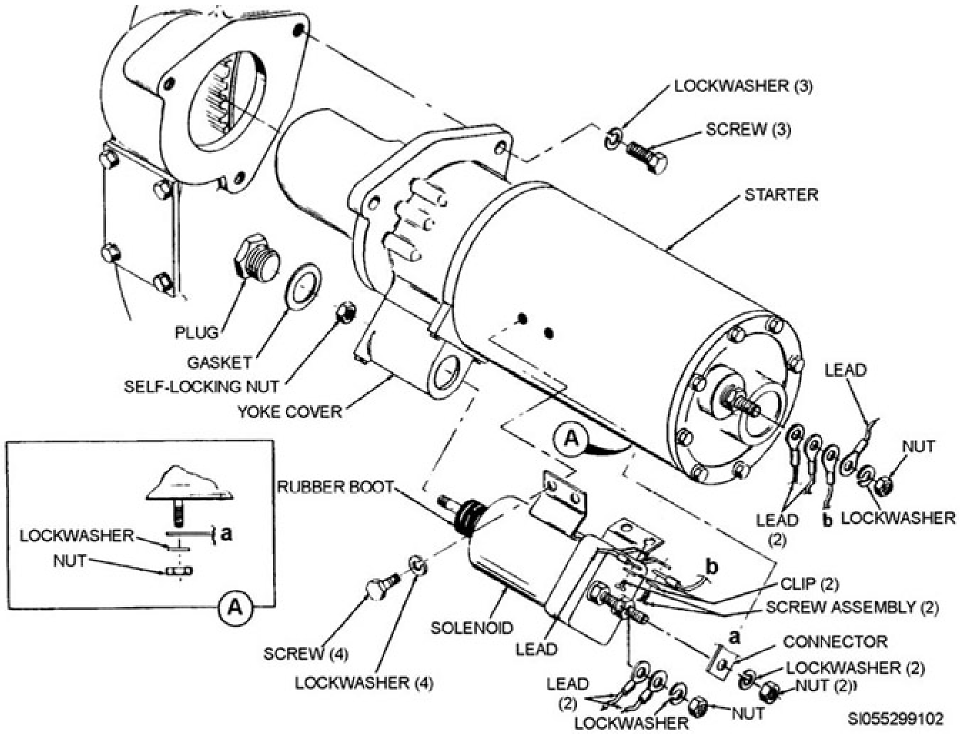


Figure 2–10. Starter and starter solenoid.

Removing a damaged starter motor

To remove the damaged starter motor, disconnect the negative cable from the battery terminal. Disconnect the electrical leads from the starter motor and tag each lead; disconnect the electrical leads from the solenoid and tag each lead. Carefully pull the starter motor out of the flywheel housing until the pinion housing is free, and inspect the flywheel ring gear.

Installing a new starter

Inspect the flywheel ring gear for signs of damage before installing the starter. Carefully insert the pinion gear into the flywheel housing. While supporting the starter, install the three mounting fasteners and tighten them securely. Connect the properly tagged electrical leads to the solenoid and connect the properly tagged electrical leads to the starter. Lastly, reconnect the negative battery cable to the negative battery terminal.

NOTE: To avoid damage to the battery and other electrical components, make sure you reconnect the electrical leads to the appropriate lugs and match the polarity of the battery.

Inspection and adjustment

The inspection and adjustment of charging-system components must comply with the directives in the applicable technical order (TO). You must observe all recommended safety practices when working on electrical equipment. It is important to keep the battery-charging alternator in top operating condition for the proper operation of the engine. You may also find it necessary to adjust the charging levels of the battery-charging alternator to charge the battery properly. Charging rates too high can damage the battery, and charging rates too low can prevent the battery from reaching a full charge.

The inspection of the battery-charging alternator varies according to the type of alternator. Regardless of the type, clean the alternator thoroughly of all grease with an approved solvent. Be sure the belt tension is correct. Remember to disable the engine from starting, and use the back of your hand to check belt tension to prevent the possibility injury during an accidental startup. Inspect the casing and pulleys for damage. Look at the wiring for any sign of cracks and overheating.

To adjust the output voltage of a MEP-series battery-charging alternator, start the engine. Once the engine is running, disconnect the negative terminal from the battery. Connect a voltmeter across the terminals of the slave receptacle and adjust the voltage to the desired level by rotating the adjusting screw on the back of the alternator. Turn the screw clockwise to increase the output voltage and counterclockwise to lower the output voltage. Once you make the adjustments, reconnect the negative battery terminal.

Replacing a battery-charger alternator

If you find problems with the battery-charging alternator that you cannot correct, you must replace it. Before beginning any maintenance, make sure to shut the generator down. Follow all safety precautions we discussed earlier. Make sure you disconnect the negative battery cable before working on the battery-charging alternator.

First, remove fan guards, alternator guard bolts, and washers. Loosen the alternator bolt and pivot the alternator fan guard away from the alternator. Loosen the adjusting rod bolt. Back off the lower adjusting rod nut until you can remove the alternator belt from the alternator. Remove the alternator belt from the alternator pulley. Remove the bolt and nut securing the adjusting block to the alternator. Disconnect the electrical connector from the alternator. While supporting the alternator, remove the mounting bolts. Lastly, remove the alternator.

Align the alternator with the mounting holes and install the mounting bolts. Connect the electrical connector to the alternator. Install the alternator belt on the alternator pulley. Install the adjusting block on the alternator and tighten the nut. Return the alternator fan guard to its position and bolt it in place. Install the fan guards.

If you fail to maintain the starting systems and battery chargers in peak operating condition, your generator systems could fail to start during a power outage.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

206. Components

1. What is the purpose of the starter motor?

2. What two functions does the starter solenoid accomplish?

207. Theory of operation

1. What occurs when the coil of a crank relay energizes?

2. Which battery-charging alternator components turn on the alternator when voltage drops below a preset level?

208. Direct current system maintenance and replacement

1. What do you inspect on a starter and a starter solenoid?

2. What are the first two things you do when replacing a starter motor and solenoid?

3. Why must you ensure you keep correct polarity when reinstalling a starter motor?

4. What can happen if a charging rate is too high?

5. What must you do before working on a battery-charging alternator?

2–2. Batteries and Troubleshooting

Batteries provide a portable power source necessary for many of today's electronics and machinery. Our cars use them to provide the energy necessary to start and operate. The generators we work on use them for the same reason. They are one of the more important items we take care of because without a battery in top operating condition, our generators are nothing more than large paperweights. In this section, we describe the types of batteries and explain how to maintain them.

209. Battery maintenance

We use batteries as auxiliary sources of power. We use the power from these batteries for emergency lighting in power buildings, the engine alarm and shutdown systems, the main DC bus, operation of the substation switchgear, and the starting system of the engine.

A battery consists of single electrical cells connected together to give a desired voltage or capacity. When we connect these cells in series, battery voltage increases; cells connected in parallel increase battery capacity.

Capacity

The rated capacity of a battery refers to the ampere-hours a charged battery will deliver continuously at its normal discharge rate before its voltage drops. For example, a battery delivering 50 amperes for 8 hours has a 400 ampere-hour battery rating. We can increase the capacity of a battery by increasing its temperature or by increasing its plate area.

Lead-acid cells

A lead-acid cell consists of spongy lead negative plates and lead peroxide positive plates immersed in a diluted solution of 30 percent sulfuric acid and 70 percent distilled water, enclosed in a container of hard rubber or glass. Porous separators insulate the positive and negative plates from each other and prevent the cells from shorting. Each lead-acid cell, regardless of size, produces approximately two working volts when charged. The cell continues to produce two volts until it is almost discharged. If left in a discharged condition, the plate of a cell becomes sulfated so that the cell cannot be recharged.

We can determine the state of charge of a lead-acid cell using a hydrometer. The hydrometer indicates the specific gravity of the electrolyte (the percentage of sulfuric acid in the electrolyte). Since the temperature of the electrolyte has an effect on hydrometer values, the manufacturer provides a thermometer and scale on the hydrometer to correct the specific gravity reading to normal 80 degrees temperature. The specific gravity of a fully charged lead-acid cell at 80 degrees is 1.280. The correcting factor is plus or minus .004 for every 10 degrees above or below 80°F.

Continual overcharging, continual state of undercharge, low electrolyte level, sulfation, and freezing temperature cause rapid deterioration of lead-acid cells and should be avoided.

Maintenance-free

Maintenance-free batteries are similar to the lead acid battery, but the manufacturer seals the casing; therefore, we cannot add any electrolyte to the battery. This type of battery is very common on the equipment we see in power production.

Absorbent glass mat

Absorbent glass mat batteries are similar to maintenance-free batteries. However, instead of using free cells, the manufacturer uses glass matting to absorb the electrolytes. As with maintenance-free batteries, the electrolytes are sealed. These are very common on our equipment.

Gel cells

The gel cell battery is very similar to the absorbent glass mat battery, except the electrolyte is in the form of a gel. Just like the maintenance-free battery, we cannot add any electrolyte to the gel cell battery. We also are beginning to see some of these batteries on our equipment.

Servicing batteries

You must observe safety precautions at all times when working on or around batteries. Make sure you shut the generator down before performing maintenance. Use caution because the engine and its components may be hot and could cause severe burns. Remove all rings, watches, and jewelry. Wear the proper safety equipment (elbow length rubber gloves, rubber apron, and face shield) when working on batteries.

You can make sure of the longevity of the batteries you use by doing inspections and preventive maintenance. Take the time to perform these maintenance steps to the best of your abilities. Some examples of these inspections and preventive maintenance are as follows:

1. Check the post clamps for cracks and corrosion; clean as necessary.
2. Check the case seams for cracks.
3. Check for signs of wetness or leakage.
4. Check the cables for fraying and damage.
5. Check the battery compartment/tray for corrosion or damage. If you find corrosion, remove the battery, and clean and treat the area.

Cleaning batteries

Clean dirt and oil from a battery with a rag or towel. Use a wire brush to remove excessive dirt. Clean corrosion and acid from a lead-acid battery and compartment with a solution of baking soda and water. Do *not* let baking soda solution enter the battery because it will neutralize the electrolyte. Rinse with clean water.

Testing and servicing batteries

You test a lead-acid battery by using a hydrometer to check specific gravity of electrolyte. Before testing a battery, let it stand for 30 minutes after you shut down the generator. Remove the battery cell filler caps. Test each cell of the battery. A fully charged battery should read 1.280 ± 0.005 at 80°F. If specific gravity is less than 1.250, charge the battery. Replace the battery if it will not hold a charge. If we measure the specific gravity above or below 80°F, we must correct the reading to match 80°F. The specific gravity of battery electrolyte changes .004 for every 10 degrees in temperature change.

This turns into a mathematical formula. First, determine how far away the electrolyte's temperature is from 80°F. Next, divide that number by 10. Then multiply that number by .004. Finally add or subtract that number from your hydrometer reading. If the temperature is higher than 80°F, add; and, if it is lower, subtract. Here is an example:

Hydrometer reading: 1.267 @ 40°F

$80 – 40 = 40$

$40/10 = 4$

$4 \times .004 = .016$

$1.267 – .016 = 1.255$

Corrected hydrometer reading: 1.255 @ 80°F

Servicing lead-acid battery

Visually check the electrolyte level in each cell. If the level is low, add distilled water until the electrolyte reaches the proper level. Using tap water decreases the life of the battery because the minerals in the tap water attract to the battery plates and could cause them to short out. Replace caps, and wipe up any spills. Inspect the battery terminals for tightness, defects, and corrosion.

Replacing batteries

As stated earlier, we must observe safety procedures at all times when working on or around batteries. The same precautions apply when replacing batteries that apply when servicing batteries. Make sure to maintain the correct terminal polarity during installation. Incorrect polarity could cause battery explosion!

The first step is to disconnect the negative battery cable and then the positive battery cables. You have to remove the connecting cables if two or more batteries are used. Remove the battery hold-down clamp. Remove the battery using a battery-carrying strap or the carry handles. Batteries are heavy, so follow proper lifting procedures to avoid injury. After you remove the batteries, clean the battery tray and paint it as necessary.

Position the battery on the tray with the positive post to front of the generator. Install the battery hold-down clamp. Connect the positive cable and connecting cables, if used. Connect the negative battery cable. Make sure you seat the terminals all the way down on the battery posts and tighten them down so they are unable to move. This will prevent corrosion due to loose connections.

Batteries are a vital component on the generator systems you will work on. If the battery fails, the generator will not operate, and the mission may fail. Understanding the way a battery operates and taking the necessary steps to maintain it will keep the batteries operating for a long time without incident.

210. Troubleshooting electrical systems

Engine DC electrical systems control many aspects of power generation. Because of this, many of the problems that you will encounter will involve this electrical system. Even though starting and charging systems are reliant on each other, we will break them down for troubleshooting purposes. The starting system has many components that must work together to start an engine. If just one of them fails, it will cause the entire system to fail. Because troubleshooting is a process, we discuss the general aspects, and then explain how it specifically applies to DC electrical systems.

Troubleshooting process

Listed below are five steps in the troubleshooting process to follow each time you have a problem:

1. Perform an operational check.
2. Analyze the malfunction.

3. Locate the malfunction.
4. Perform corrective action.
5. Perform an operational check.

Since troubleshooting is a systematic procedure, your effectiveness depends on your knowledge of troubleshooting and your concentration on the job at hand. You can learn procedures, but actual troubleshooting depends on your ability to think, consider various components in a logical sequence, and pinpoint a problem.

Perform an operational check

The first step in troubleshooting is to perform an operational check of the equipment. This is where you become aware that you have a problem. You must first determine whether an actual trouble exists. TOs or manufacturer's manuals prescribe the correct operating procedures to prevent malfunctions or damage when you are operating any piece of equipment. Performing proper inspections and researching the correct operating procedures ensures efficient operation and a long life for equipment. In your inspections and operating procedures, you must follow the systematic procedures in the technical manual for your particular item of equipment.

Analyze the malfunction

Analyzing the problem is where you build your plan. Look at the problem from a simple point of view. Use your knowledge and experience as a guide to develop a list of possibilities. Refer to TOs, manufacturers' manuals, coworkers' expertise, and books about theory for the equipment that you are working. Build this list without sorting or looking for feasibility because it hinders the creative thinking process that you are using. Once the list is complete, scrub it to arrange it in a logical order. It is often best to work from simple to complex. Your new list is your plan of attack to correct the malfunction.

Locate the malfunction

Once you have a plan, it is time to find the problem. You may need to disassemble a component, remove inspection plates, perform a fluid test, or use a multimeter to perform electrical tests. Work through your list until you have found the problem. Once you determine the problem, double-check your findings to make sure that you have really found the defect.

Perform corrective action

Once you figure out what is wrong, it is time to fix it. You need to determine you can fix the component that was causing the problem. The component's type, availability, and cost many times determine this. Often, it is more cost effective to replace a component instead of repairing it. Other times, you may not be able to get the critical component that you need in time to meet the mission requirements. This forces you to repair a component, if possible.

Perform an operational check

Once you have found and fixed the malfunction, you must check to see whether your efforts have paid off. You must perform an operational check to make sure that the equipment is working correctly. Carefully check all of the systems for normal operation. Once everything checks out satisfactory, you can call the unit back into service.

Once the operational check is complete, you should document your actions in the equipment historical records. If you are operating a power plant, this is a great time to document your troubleshooting activities in the logbook. One of the first places to look when experiencing an unusual fault in the power plant is the logbooks.

Electrical malfunctions

The most common types of malfunctions are opens, shorts, grounds, and low power. Here, we discuss each malfunction in depth and include causes, symptoms, and procedures for locating each malfunction.

Opens

The cause for an open is an incomplete path for current flow within the circuit. Opens can occur when a conductor becomes broken, a fuse blows, relay or switch contacts fail to close properly, or when any other device in the circuit fails to provide a complete path for current flow.

Symptoms

Naturally, if there is an open there can be no current flow. Consequently, the unit does not operate. Figure 2–11 shows a circuit with an open wire. If the fault is an open, the (1) circuit is inoperative, (2) protective device does not activate, or (3) indicator lamps do not illuminate.

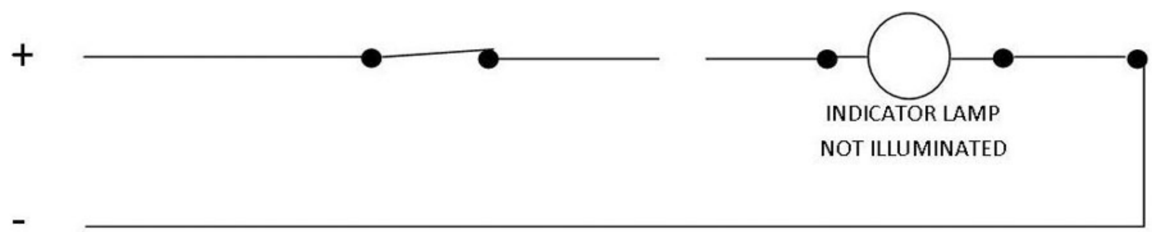


Figure 2–11. Open circuit.

Procedures

The possible location of an open can be anywhere in the circuit. You find an open by using the voltmeter or ohmmeter. Figure 2–12 shows what a voltmeter should read in an operating circuit. Remember to connect a voltmeter in parallel with the circuit or component.

A voltmeter indicates the difference in potential voltage when connected across two points, which are positive and negative. This is because one connecting lead (fig. 2–12) attaches to a potential of 28 volts, while the other lead connects to 0 volts potential. The difference in potential between the two points is 28 volts; the reading indicated on the voltmeter.

A voltmeter connected between negative to negative or between positive to positive indicates 0 volts. This is because there is no difference in potential between the two connection points. When both meter leads connect at the conductor at 28 volts potential, or 0 volts potential, there is no difference of potential for the meter to indicate.

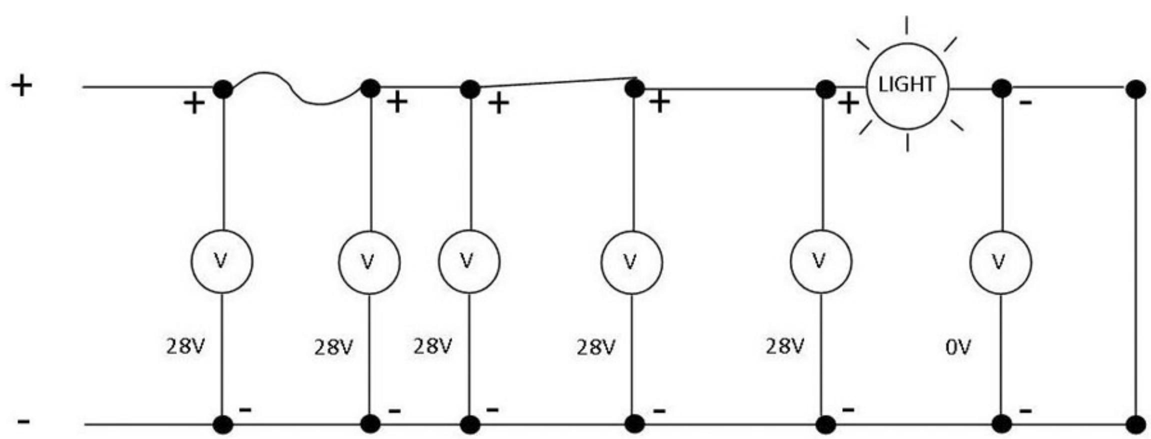


Figure 2–12. Normal operating circuit.

When using a voltmeter to locate an open, the generator set must have the power supply turned on. Place the black lead on the negative conductor or frame and the red lead on the positive conductor at the main unit of resistance. Observe the meter indication. If the meter indicates applied voltage (28 volts), a difference of potential exists and the circuit back to the power source is good. However, if the meter indicates 0 volts, there is no difference of potential and the open is located somewhere between the power source and the test point. Check the positive terminals in sequence, moving back towards the power source until the voltage indication on the voltmeter changes from zero volts to the applied voltage. The open electrical malfunction is located between the last zero voltage reading and the first applied voltage reading.

Figure 2–13 shows using a voltmeter to locate an open. The open is located in wire 1D. With one meter lead on the negative wire and the other on wire 1D, the meter reads zero volts. With one meter lead on the negative wire and the other on 1A, 1B, or 1C, the meter indicates 28 volts. Because wire 1D breaks the complete path for current flow to the unit of resistance, the circuit is not operational.

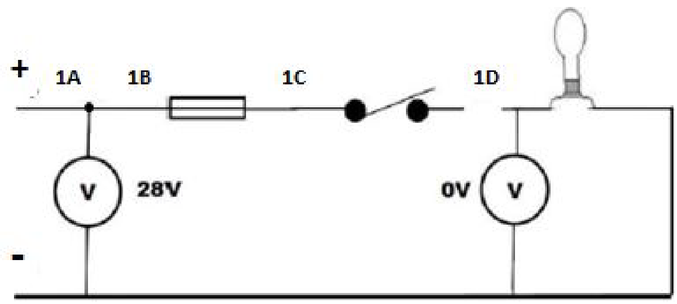


Figure 2–13. Voltmeter used to locate an open.

As discussed in volume one, you can use an ohmmeter to find an open as well. Simply turn off the power to the circuit, and then isolate the device or wire you are testing. Next, check the portion of the circuit for the proper reading.

Shorts

There are three types of electrical shorts—direct, cross, and shorted control. The basic symptoms, which indicate some type of short has occurred, are an inoperative circuit, protective device actuated, two or more circuits operate from one control device, or if circuits can't be turned off. Discussed next is each specific type of short.

Direct short

Positive and negative conductors making direct contact cause a direct short. The short provides a shortcut for the current back to the power source, bypassing the unit of resistance. As the unit of resistance bypasses, current flow increases to a point where the protective device is actuated (fig 2–14).

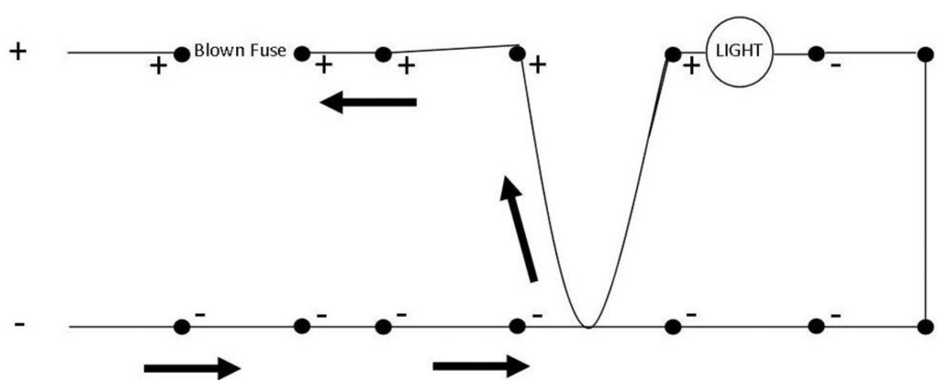


Figure 2–14. Direct short.

Symptoms—The symptoms of a direct short are: (1) an inoperative circuit and (2) the protective device actuated. In addition, if the excessive current remains in the circuit long enough, the insulation on the wires may begin to melt or even burn. You may smell smoke and see burnt conductors.

Procedures—The location of direct shorts is between the positive and negative conductors and between the power source and unit of resistance. Locate all shorts by using an ohmmeter, because this is the only true method of isolating the exact location of the short. When symptoms indicate a direct short, isolate the positive conductors in the circuit. Turn off the power to the circuit. Using the ohmmeter, place a meter lead on the negative conductor. Move the other lead from one positive conductor to another in the circuit until you locate the direct short. An infinity reading on the ohmmeter indicates a good (no short) component. A zero reading on the ohmmeter indicates the location of the direct short. The direct short in figure 2–15 is between wire 1C and the negative wire.

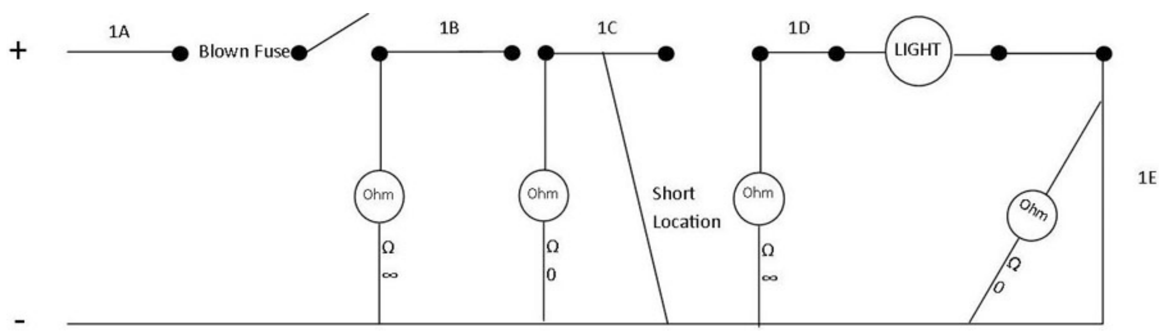


Figure 2–15. Ohmmeter used to locate a direct short.

Cross short

The positive conductors of two or more independent circuits making contact will cause a cross short. The contact causes units in all the shorted circuits to operate when only one control device is turned on.

Symptoms—The symptoms of a cross short are: (1) two or more independent circuits operate from one control device, and (2) the protective device may or may not actuate, depending on the current rating of each circuit (fig. 2–16).

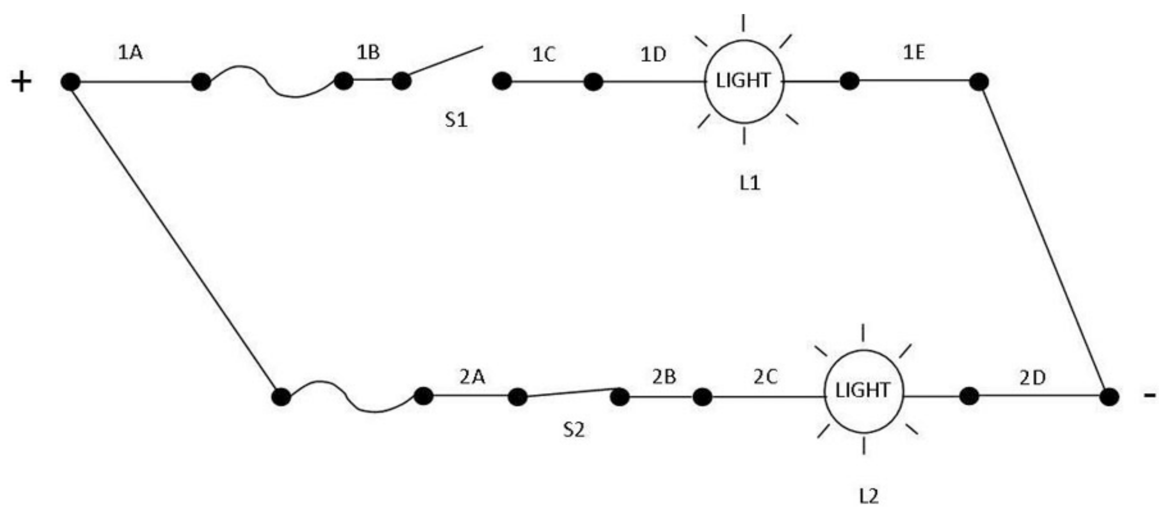


Figure 2–16. Cross short.

Procedures—The possible location of a cross short is between the control devices and units of resistance of two or more independent circuits. When you use ohmmeters for locating electrical short malfunctions, shut off the power to the circuit. Isolate the positive conductors of the circuits involved. Place one meter lead on a positive conductor of one circuit and the other lead on the positive conductors of the other circuit or circuits, one at a time. If you do not find the cross short, move the first ohmmeter lead to another positive conductor in the first circuit. Then, move the other lead through the other circuit as you did before. Repeat these procedures until the location of the cross short is isolated. A zero reading on the ohmmeter indicates the location of the cross short. The cross short in figure 2–17 is located between wires 1C and 2C.

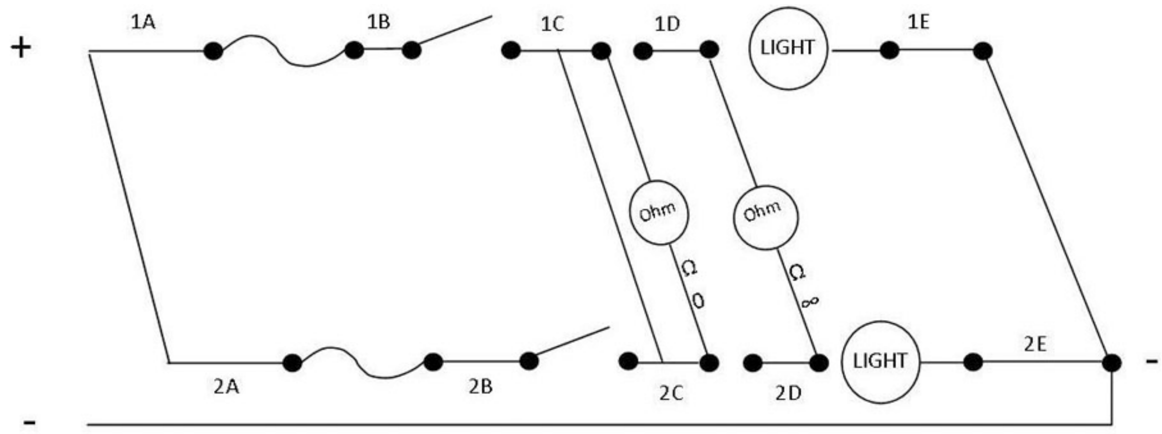


Figure 2–17. Ohmmeter used to locate a cross short.

Shorted control

A shorted control is caused by the welded closed contacts of a switch or relay. Shorted controls are usually the result of over current conditions or dirty contacts. Figure 2–18 shows a shorted control. Even though switch S1 appears to be open, the circuit remains energized.

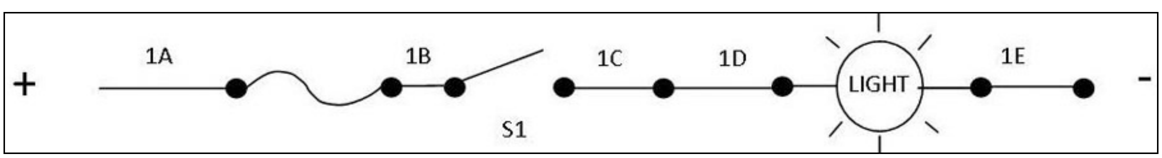


Figure 2–18. Shorted control.

Symptoms—The symptoms of a shorted control are: (1) the circuit continues to operate with the control device in the OFF position, and (2) the protective device does not actuate.

Procedures—When the symptoms indicate a shorted control, turn off power to the circuit, and isolate control devices as shown in figure 2–19. Using an ohmmeter, place the leads across the contacts of the control device or switch with the control device or switch in the off position. An infinity reading on the ohmmeter indicates proper switch or control device operation. A zero reading on the ohmmeter indicates a shorted control device or switch. Figure 2–19 shows a shorted switch at S1.

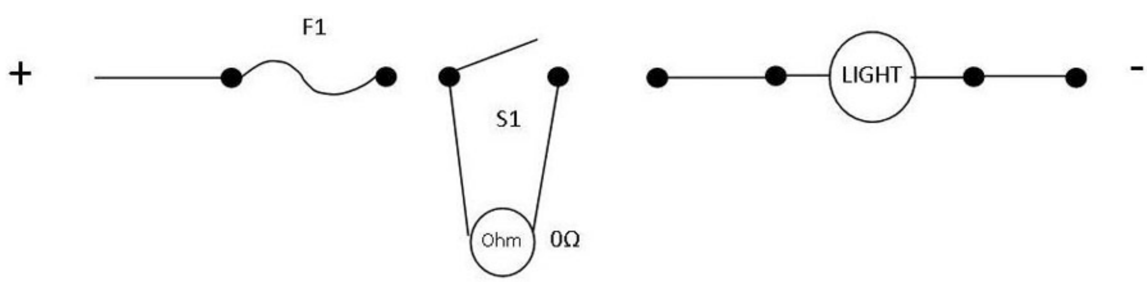


Figure 2–19. Ohmmeter used to locate a shorted control.

Ground

If the positive conductor in a one-wire circuit makes contact with the conduit, frame, chassis, or any other metallic part of the wiring system, you have a grounded circuit. Figure 2–20 shows a grounded circuit malfunction. The positive wire 1E is making contact with the frame of the unit.

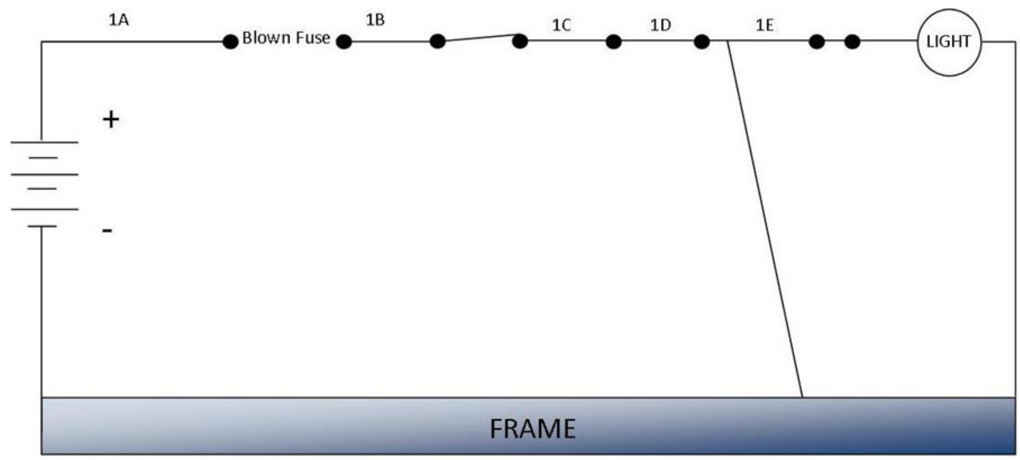


Figure 2–20. Ground.

Symptoms

A ground has the same symptoms as a direct short. The symptoms are: (1) the circuit is inoperative and (2) an actuated protective device. Power bypasses the unit of resistance and goes to ground, causing the protective device to actuate.

Procedures

The location of a ground can be between the positive conductor and the frame, somewhere between the power source and unit of resistance. The procedures for locating a ground are identical to the procedures for locating a direct short with one exception; substitute the frame for the negative conductor. Figure 2–21 shows the procedures for locating a ground.

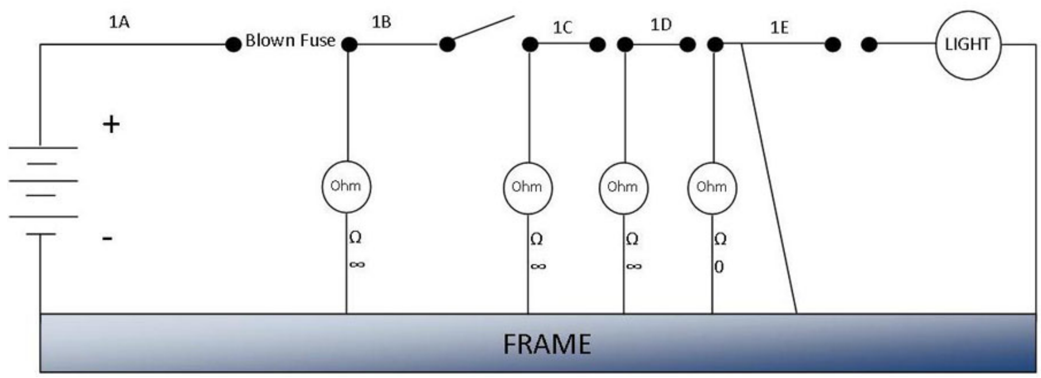


Figure 2–21. Ohmmeter used to locate a ground.

Low power

The common cause of low power is weak batteries, a loose connection, dirty switch contacts, or conductors too small to carry the load.

Symptoms

The symptoms of a low-power condition can be an electric motor that is running sluggishly, lights that are burning dim, or relays that are chattering.

Procedures

The possible location of a low-power condition could be anywhere in the circuit. When locating a low-power condition, turn power to the circuit on. Use a voltmeter to measure the voltage drop across each wire, component, and connection in the circuit. A zero volt reading on the voltmeter indicates that the wire, component (provided it does not normally have a voltage drop), or connection you are testing is good.

Troubleshooting engine DC electrical systems

Now that you have learned the type of faults and the general rules for troubleshooting, we will cover how to apply these principles to the DC electrical systems on engines that you will find in the field. Even though there are specific items, the process of troubleshooting never changes.

Engine starting systems

As you know, there are many items that must work together to start an engine. If even one of them fails, the engine will fail to start as required.

Possible problems with starting system faults

Low battery voltage is a primary reason for engines failing to start. Many times a battery may read 12 volts before cranking but once the start switch engages nothing will happen or you will hear chattering relays or solenoids. One of the best ways to diagnose this problem is to use a battery load tester. If one is not available, have one person put a voltmeter across the battery and check the voltage of the battery during the cranking cycle. When doing this test, make sure you disconnect any installed battery charger. If you fail to do this, the battery charger will cause a false reading.

CAUTION: When doing this test, make sure all personnel are clear of any rotating objects and make sure that the voltmeter is connected correctly to avoid any potential electrical shorts.

If the battery voltage drops significantly, below 9 volts, this is an indication of a shorted cell within the battery; replace the battery.

Bad controls

A bad control device is not as common as low battery voltage. If you have good battery voltage, you will need to progress in the troubleshooting process. You can start from the starter motor and work your way back. Using your wiring diagrams and the circuit description, follow the path of current and find which control is malfunctioning.

Bad wires

Bad wires are less common than bad controls but can cause an open in the circuit. This will cause the circuit not to operate correctly. When checking the wiring, look for anything that is burnt or loose. If you have large bundles, disconnect the battery and isolate them. Then use an ohmmeter to check for continuity. Check for corrosion. If a battery cable has a large amount of corrosion in it, it will cause a large amount of resistance and not allow current to flow from the battery. Just remember to apply the troubleshooting principles and they will lead you to find the malfunction.

Battery-charging alternators

If the battery-charging system is not working correctly, it may not be immediately evident. One indication is if your battery-charging ammeter is reading in a discharged state. If not equipped with one, simply apply your voltmeter to the output leads on the battery-charging alternator. You should be reading the specified voltage that the manufacturer has prescribed. If the alternator is adjustable, ensure that the adjustments are correct. If they are correct, you will need to check the rectifier and voltage regulator. On most new systems, these are integrated and cannot be repaired so you will need to replace the entire alternator.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

209. Battery maintenance

1. What type of mixture are the spongy lead negative plates and lead peroxide positive plates of a lead-acid cell immersed in?

2. What types of batteries are sealed making it impossible to service the electrolyte?

3. How much does the specific gravity of a lead acid battery electrolyte change with temperature?

4. If the level of a lead acid battery is low, what should you add to the electrolyte to return it to the proper level?

210. Troubleshooting electrical systems

1. What are the steps in the troubleshooting process?

2. What are the electrical malfunction symptoms for an open?

3. What are the electrical malfunction symptoms of a direct short?

4. What are the electrical malfunction symptoms of a cross short?

5. What are the electrical malfunction symptoms of a shorted control?

6. What are the electrical malfunction symptoms of a ground?

7. What are the electrical malfunction symptoms of a low power condition?

8. What is the best way to diagnose a shorted cell in a battery?

Answers to Self-Test Questions

206

1. Changes electrical energy into mechanical energy to rotate the engine for startup.
2. First, it moves the mechanical drive to engage the pinion gear into the flywheel. Second, it closes a set of contacts to energize the starter motor once the pinion gear is meshed with the flywheel.

207

1. The crank relay contacts close providing a path of current flow to the starter solenoid.
2. Voltage regulator.

208

1. Inspect the starter solenoid terminals for corrosion, inspect the starter and starter solenoid for signs of damage and security of mounting bolts, and look for discoloration or other signs of overheating of the starter motor and starter solenoid.
2. Disconnect the negative cable from the battery terminal and tag and disconnect the electrical leads from the starter motor.
3. You may damage the battery and other electrical component.
4. You can damage the battery.
5. Disconnect the negative battery cable before working on the battery-charging alternator.

209

1. A diluted solution of 30 percent sulfuric acid and 70 percent distilled water.
2. (1) Maintenance free.
   (2) Absorbent glass mat.
   (3) Gel cell.
3. .004 for every 10 degrees in temperature change.
4. Distilled water.

210

1. (1) Perform an operational check.
   (2) Analyze the malfunction.
   (3) Locate the malfunction.
   (4) Perform corrective action.
   (5) Perform an operational check.
2. (1) Circuit is inoperative.
   (2) Protective device does not activate.
   (3) Indicator lamps do not illuminate.
3. (1) An inoperative circuit.
   (2) The protective device actuated.
4. (1) Two or more independent circuits operate from one control device.
   (2) The protective device may or may not actuate.
5. (1) The circuit continues to operate with the control device in the OFF position.
   (2) The protective device does not actuate.
6. (1) The circuit is inoperative.
   (2) An actuated protective device.
7. Sluggish electric motor, lights that are burning dim, or relays that are chattering.
8. Use a battery load tester.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

44. (206) Typical electrical system engines use what voltage batteries to provide power to start and operate the engine?
    a. 6 or 12.
    b. 12 or 24.
    c. 18 or 32.
    d. 24 or 36.

45. (206) Which electrical system component performs two functions—one mechanical and one electrical?
    a. Pinion gear.
    b. Starter motor.
    c. Starter solenoid.
    d. Mechanical linkage.

46. (206) Which component is the stationary conductor on the battery-charging alternator?
    a. Rotor.
    b. Stator.
    c. Commutater.
    d. Rectifier assembly.

47. (206) How many diodes are used in the rectifier of a battery-charging alternator?
    a. 1.
    b. 3.
    c. 6.
    d. 12.

48. (207) What causes the crank relay coil to de-energize causing the starter solenoid to de-energize?
    a. Overrun clutch.
    b. Speed switch closing.
    c. Crank relay speed sensor.
    d. Speed switch opening.

49. (208) Why do you make sure to reconnect the electrical leads to the appropriate lugs to match the polarity of the battery?
    a. It does not matter which leads you connect.
    b. To make sure that starter solenoid engages.
    c. To avoid damage to the battery and other electrical components.
    d. To keep the engine from spinning backwards.

50. (208) If you adjust a battery-charging alternator too high, the
    a. battery will not charge.
    b. battery will be damaged.
    c. battery will discharge the extra to ground.
    d. voltage regulator will overheat and stop working.

51. (208) If you adjust a battery charging alternator too low, the
    a. battery will not reach full charge.
    b. battery will store voltage until it reaches full charge.
    c. voltage regulator will compensate and provide the correct voltage.
    d. battery will be damaged.

52. (209) What is the specific gravity of a fully charged lead-acid cell at 80 degrees?
    a. 1.256.
    b. 1.280.
    c. 1.350.
    d. 1.560.

53. (209) In addition to elbow length rubber gloves and a rubber apron, what other safety equipment *must* you wear when working on batteries?
    a. Ear muffs.
    b. Ventilator.
    c. Face shield.
    d. Steel-toed boots.

54. (209) The specific gravity of battery electrolyte changes
    a. .004 for every 10 degrees in temperature change.
    b. .008 for every 25 degrees in temperature change.
    c. .027 for every 5 degrees in temperature change.
    d. .125 for every 2 degrees in temperature change.

55. (209) Visually check the electrolyte level in each cell of a battery. If the level is low, fill the cell to the proper level using
    a. tap water.
    b. sulfuric acid.
    c. distilled water.
    d. potassium acid.

56. (209) What is the *first* step you take when replacing a battery?
    a. Disconnect the positive terminal.
    b. Disconnect the negative terminal.
    c. Remove the hold down clamp.
    d. Remove connecting cables if multiple batteries are used.

57. (209) When replacing a battery, which step helps prevent corrosion?
    a. Ensure battery terminals are seated and tightened.
    b. Ensure battery hold down clamp in secured.
    c. Ensure positive terminal is put on first.
    d. Ensure the negative terminal is put on last.

58. (210) What is the *first* step in the troubleshooting process?
    a. Analyze the malfunction.
    b. Locate the malfunction.
    c. Perform an operational check.
    d. Ensure the equipment is in proper working order.

59. (210) Which electrical malfunction do positive and negative conductors making direct contact cause?
    a. An open.
    b. A cross short.
    c. A direct short.
    d. A low-power condition.

60. (210) Which electrical malfunction is caused by the contacts of a switch or relay being welded closed?
    a. An open.
    b. A cross short.
    c. A shorted control.
    d. A low-power condition.

61. (210) Which electrical malfunction has the same symptoms as a direct short?
    a. Ground.
    b. Cross short.
    c. Shorted control.
    d. Low-power condition.

62. (210) What is the *primary* reason for engines failing to start?
    a. Bad control.
    b. Loose wire.
    c. Low battery voltage.
    d. Bad starter.

63. (210) One indication that a direct current (DC) charging system is *not* working correctly is the battery-charging
    a. ammeter is reading in a discharged state.
    b. ammeter is reading in a charging state.
    c. ammeter is reading zero.
    d. voltmeter is reading 14 volts, direct current (VDC) in a 12 VDC system.

Please read the unit menu for unit 3 and continue ➔

Unit 3. Alternators, Controls, and Protective Devices

TO PRODUCE VOLTAGE, some form of energy must be used to bring about the reaction of electrons. The basic sources of energy used are light, magnetism, thermal, and chemical action. Although all of these sources of energy provide some practical sources of power, coverage here is limited to the producer of the majority of our power—magnetism. In this unit, you will learn how alternators produce electricity and how to maintain the alternators. We also discuss control and protective devices for generators. We start with how to produce electricity.

3–1. Magnetism, Construction Features, and Theory of Operation

When producing electricity, you need a magnetic field, conductors, and relative motion. If you remove any of these, you will not produce electrical power. This section describes each of these requirements and how they fit together to produce reliable power.

211. Magnetism and power generation

The first aspect we will delve into is magnetism and the basic needs to produce power. You must understand these principles before you can learn how an alternator works. In this lesson, you will learn about basic magnetism, the different types of magnets, and the basic production of electricity.

Magnetic terms

Let's look at the basic terms that explain what a magnet is. These items work together with each other to create a material with great ability. We depend on magnets daily for a number of things we take for granted.

Magnet

A magnet is a material or substance that has the ability to attract pieces of iron, steel, or other magnetic materials. Magnetism gets its name from the iron oxide mineral *magnetite*.

Magnetic poles

Every magnet has two distinct poles—a north pole and a south pole, which are located at each end of the magnet. This is where the magnetism has the greatest strength; therefore, the magnet will attract better at the poles.

Magnetic lines of force

The magnetic lines of force are invisible lines of magnetic force that exist between the poles. Each of the lines is independent and never cross each other. The lines of force of a magnet pass from the north pole, make a complete circuit through the surrounding medium, and return to the south pole. From there, they pass through the magnet to the north pole again. Because of this, there are more lines of force at the poles of a magnet. This is what causes the strongest magnetism at the poles.

Residual magnetism

Residual magnetism is the small amount of magnetism that remains in an item after removing the magnetic field. We often find these characteristics in an electromagnet, which you will read about shortly.

Types of magnets

There are different types of magnets we see in the power production career field. Each type has its strengths and weaknesses depending on the application. The paragraphs below describe permanent and temporary magnet characteristics and benefits.

Permanent magnets

Alloys of metals usually make up permanent magnets. An alloy of aluminum, nickel, and cobalt make up one very good type of permanent magnet. One of the accepted theories about magnets (theory of magnetism) is each atom in a material is a tiny magnet with definite north and south poles, shown in figure 3–1. When the material is in its natural state, the poles of these tiny magnets point in all directions. The non-magnetized portion of figure 3–1 shows this. When this material becomes magnetized, the tiny atomic magnets line up so that their north poles all point in the same direction. The south poles point in the opposite direction. This causes the material to have a strong north pole at one end and an equally strong south pole at the opposite end. The completely magnetized portion of figure 3–1 shows this. The most common place this type of magnetism occurs is in a permanent magnet voltage regulator.

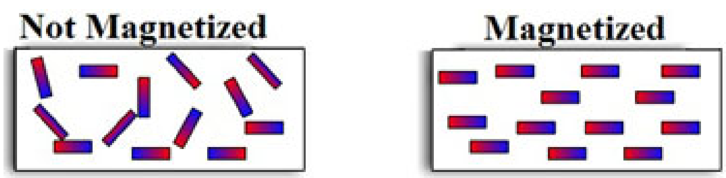


Figure 3–1. Theory of magnetism.

Permanent magnets are made in various shapes, as shown in figure 3–2. Each type of permanent magnet has advantages and disadvantages. Choose a magnet based on the task at hand. This allows you to find the type of magnet that best fits your needs.

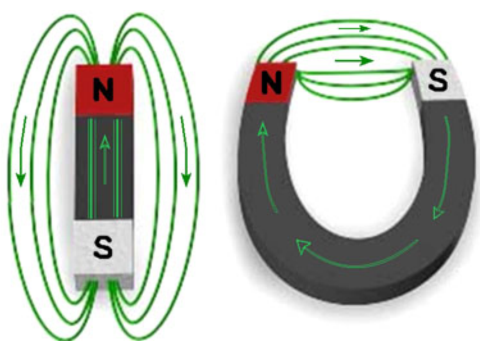


Figure 3–2. Types of permanent magnets.

Temporary magnets

Temporary magnets operate in the same way as permanent magnets except that they become magnetized and demagnetized very easily. In most cases, soft iron makes up these magnets. You can magnetize these magnets simply by placing them in the magnetic field of a permanent magnet or an electromagnet. One of the problems is this type of magnet loses its magnetism very quickly after you remove it from the magnetizing influence. You use these temporary magnets in the operation of electrical motors, generators, relay switches, and other devices.

Electromagnets

Electromagnets are another source of magnetism. As you know, when a current flows through a conductor, a magnetic field builds around the conductor. You can determine the direction of the field by knowing the direction of current flow, as shown in figure 3–3. Since you don't keep a compass readily handy, you can use the right-hand rule for conductors. This is where you take your right hand, with the thumb extended, and wrap it around the conductor. The key to this is to point your thumb in the direction of conventional current flow. Once you have done this, your fingers point in the direction of the magnetic field flow (fig. 3–4). The left hand rule can be used if you point the thumb in the direction of electron flow. The strength of the electrical current determines the strength of the magnetic field.

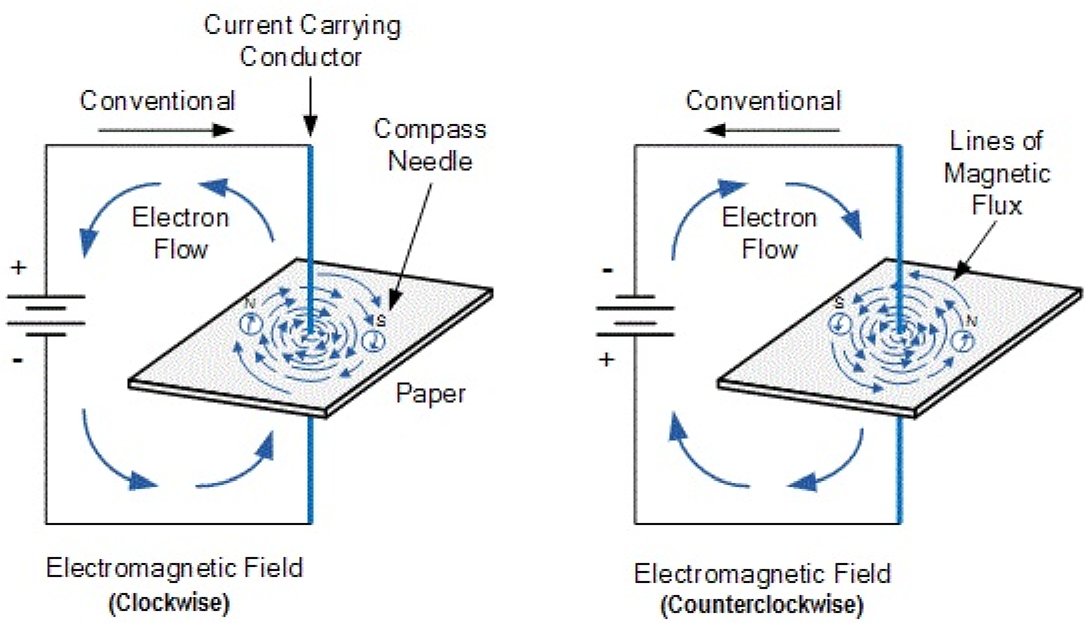


Figure 3–3. Direction of magnetic field around conductors indicated by compasses.

Figure 3–4. Right hand rule.

If you need to increase the amount of magnetism, you can make the wire into a coil, as shown in figures 3–5 and 3–6. You can further strengthen the magnetic field by winding the wire around an iron core (fig. 3–7). This is the type of magnet you use most in the operation of an electrical generator.

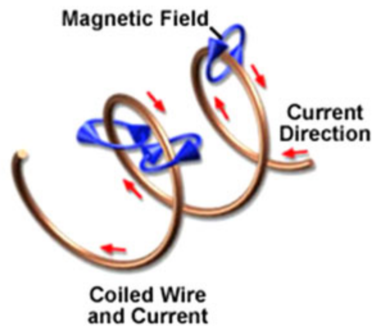


Figure 3–5. Magnetic field around a coil.

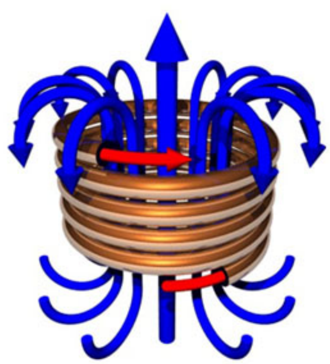


Figure 3–6. Magnetic field around a coil.

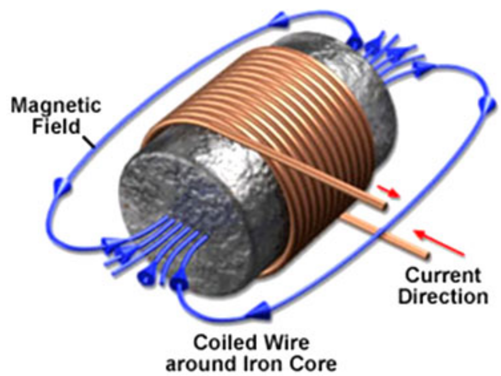


Figure 3–7. Magnetic field around an iron coil.

Laws of magnetism

There are a few things we know about magnetism. These always hold true, so we call them the laws of magnetism (fig. 3–8). They are:

- Like poles repel each other.
- Unlike poles attract each other.
- Attractive forces increase as the distance between the unlike poles of magnets decrease.

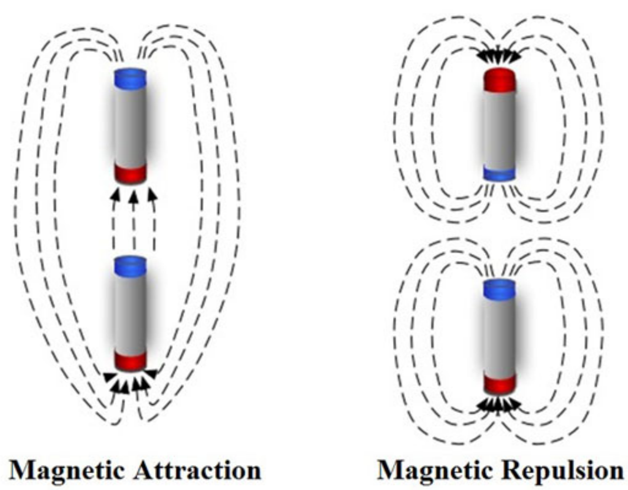


Figure 3–8. Laws of magnetism.

Generation of alternating current

The generation of alternating current (AC) requires three things—a magnetic field, conductors, and relative motion. Since you now know all about magnetism and conductors, you can put them together and add some motion.

When the north pole of the magnet is at zero degrees, there are no magnetic lines of force cutting the conductor; therefore, no voltage is present (fig. 3–9).

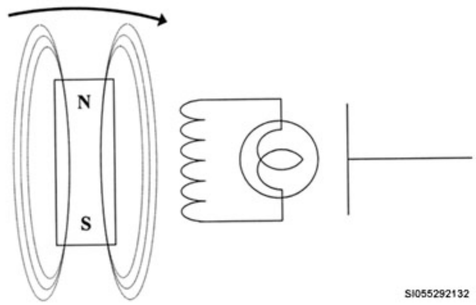


Figure 3–9. Beginning of AC generation.

As the north pole of the magnet begins to move and reach 45 degrees, the magnetic lines of force begin to cut across the conductor causing the voltage to build. The rotation of the magnet continues as it reaches 90 degrees. This is where the greatest number of magnetic lines of force cut the conductor causing the voltage to peak, as shown in figure 3–10.

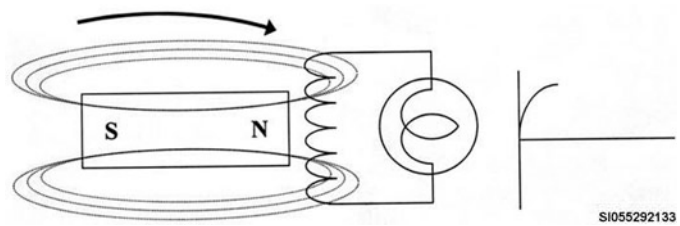


Figure 3–10. AC generation cycle at 90 degrees.

The north pole of the magnet continues on until it reaches 135 degrees. This position has less of the magnetic lines of force cut the conductor causing the voltage to decrease. The rotation of the magnet continues on as it reaches 180 degrees. This is where there are no magnetic lines of force cutting the conductor. Therefore there is no voltage present, as shown in figure 3–11.

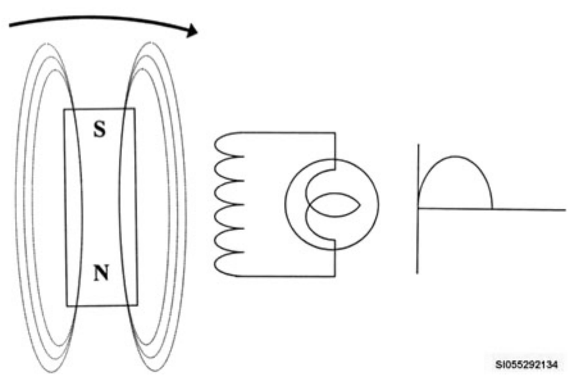


Figure 3–11. AC generation cycle at 180 degrees.

As the rotation of the north pole of the magnet reaches 225 degrees, the magnetic lines of force begin to cut the conductor again. This time the lines of force move in the opposite direction. This causes the voltage to build in the opposite direction. As the north pole of the magnet reaches 270 degrees, the greatest number of magnetic lines of force cut the conductor. Again, the lines of force move in the opposite direction so the voltage peaks in the opposite direction (fig. 3–12).

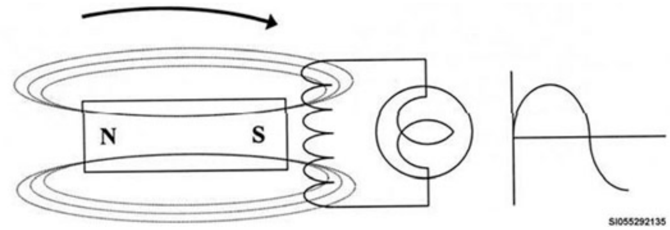


Figure 3–12. AC generation cycle at 270 degrees.

As the north pole of the magnet rotates to reach 315 degrees, less of the magnetic lines of force cut the conductor causing the voltage to decrease in the opposite direction. With the rotation of the north pole of the magnet reaching 360 degrees, there are no magnetic lines of force cutting the conductor; therefore, there is no voltage present, as shown in figure 3–13. Notice the magnet is at the same point where you started. This completes one cycle, and everything starts all over again.

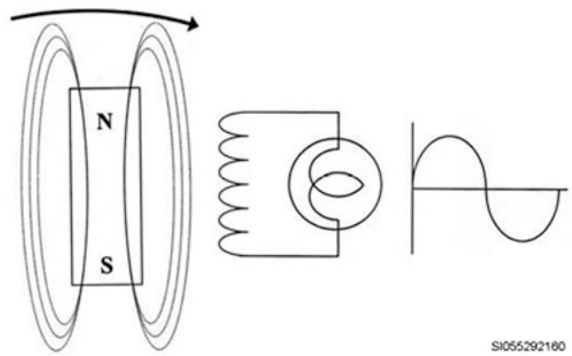


Figure 3–13. AC generation cycle at 360 degrees.

Remember, it takes three things to create AC voltage—magnetism, conductors, and relative motion. Without one of these, no voltage is produced, and your primary job will fail. You must completely understand this process to be able to perform maintenance.

212. Exciters, alternators, and voltage regulator components

The AC production cycle you just read about was very simplified. There are many components necessary to produce a controllable AC output. The key word is *controllable*. This is because having electricity at the wrong level is as bad as having no electricity at all. The three major components described in this lesson are the exciter, alternator, and voltage regulator. As you read this lesson, keep in mind the three requirements to produce voltage—magnetism, conductor, and relative motion.

Exciters

An exciter is a device that provides the alternator electricity needed to produce the electricity used to operate equipment. The difference between the alternator and exciter is the type of electricity at the output. The alternator produces AC while the exciter produces direct current (DC). In order to understand exciters, it’s important for you to know its components, as described below.

Field windings

The exciter, shown in the bottom of figure 3–14, has stationary field windings that provide the magnetic field to produce electricity. The windings are coils of wire wrapped around a soft iron core. A small DC signal provides the current necessary to establish the magnetic field. The soft iron core usually holds some residual magnetism. This allows the exciter to build up a voltage output before the DC signal establishes the magnetic field.

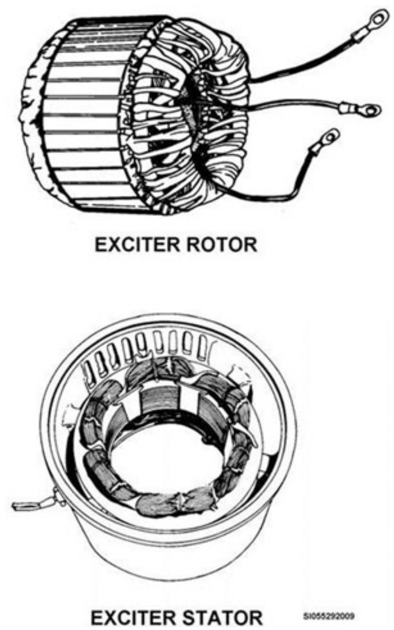


Figure 3–14. Three-phase AC exciter.

Armature

The armature, shown in the top of figure 3–14, is the rotating conductor of the exciter. The armature provides both the conductor and relative motion you need to produce voltage. Manufacturers arrange these conductors so the output is a three-phase wye configuration. This configuration provides the alternator with a smoother signal for its magnetic field.

Rectifier

The rectifier includes six diodes and a surge suppressor mounted on a fan connected to the main shaft. This is the same shaft that holds the alternator and exciter rotors. The diodes make up a three-phase bridge rectifier like you read about in unit 1. These diodes connect to the output of the armature with three in forward bias and three in reverse bias, as shown in figure 3–15. This allows the three-phase signal to reach the alternator windings connected to the rectifier output.

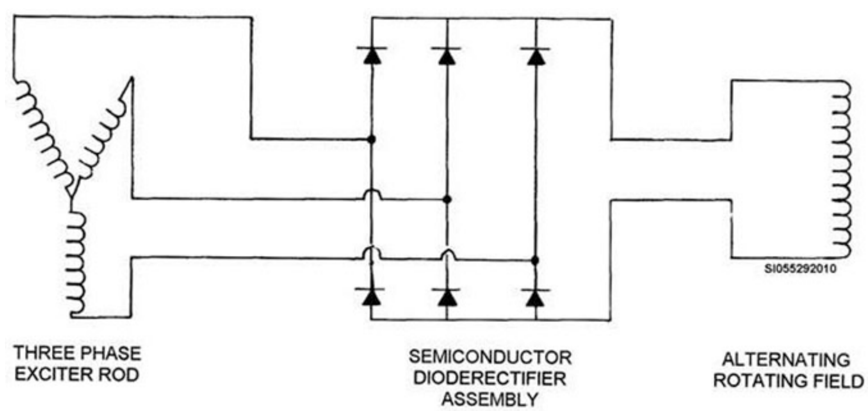


Figure 3–15. Rotating components and circuits.

This takes the three-phase AC output produced by the field windings and armature and changes it into a relatively smooth DC signal. Since the rectifier is part of the exciter, we consider the exciter output to be DC.

Alternators

Alternators provide power to customers to use to operate electronic equipment. This output must be stable and reliable to prevent damaging the equipment connected to it. This is especially true in today's world of high tech electronics. This type of equipment is extremely sensitive and you must provide steady power to it. The basic components are very similar to the ones in the exciter.

Rotor assembly

The rotor assembly is a device that provides the magnetic field necessary to produce electricity. As the name implies, the rotor is the rotating portion of the alternator. It consists of a shaft, field windings, interpoles, and damping windings.

Shaft

The shaft holds all of the rotating components on the alternator. This includes the field windings and damping windings, as well as the armature and rectifier of the exciter. This shaft bolts to the engine that provides the rotation. The shaft also holds cooling vanes to circulate cooling air through the alternator assembly.

Field windings

The field windings provide the main magnetic field to produce electrical power. This magnetic field rotates as the shaft rotates to create the relative motion needed to produce electricity. These windings are coils of wire wrapped around a pole piece. The pole piece, typically made of soft iron to enhance the magnetic field, mounts to the shaft. These windings are laminated to separate the individual wires and protect them from corrosion. This also helps conduct the magnetic field when current passes through the wire.

Interpoles

Interpoles and windings offer a slight magnetic force that aligns the main magnetic field so it remains most effective. Remember, magnetic lines of force never cross each other; if you introduce a magnetic field near another magnetic field, they move to allow the new magnetic field to exist. Placing small magnetic fields at key locations keeps the main magnetic field focused in the right direction and prevents any distortion.

Damping windings

Damping windings are copper bars connected to the end of the rotor. They help the generator maintain a stable voltage under varying load conditions. The damper rings around the rotor assembly connect the damper windings of all pole pieces into one continuous damping circuit. These windings do not cut through the magnetic fields under normal conditions. If the alternator begins to change speed, the damping windings then cut through the magnetic fields. This causes them to oppose speed changes by increasing or decreasing counter torque necessary to oppose the change.

Stator assembly

The stator consists of a frame and the conductors. These conductors remain stationary. These conductors are coils of wire wrapped around a series of bars. This provides the conductor with more material to produce electricity. Manufacturers arrange the conductors in several configurations, which we will discuss in more details a little later in this unit. The stator is where the output of the alternator comes from. The frame connects to the frame of the engine and protects all of the internal components.

Voltage regulator

A small part of the alternator output current goes to the voltage regulator, which changes it to DC to send back to the exciter. The voltage regulator varies the current to the exciter field to maintain a steady alternator output voltage under varying load conditions. The voltage regulator mounts externally to the exciter sending the current to the stationary field windings. There are two basic types of voltage regulators you work with in the power production field—self-exciting and permanent magnet.

Self-exciting voltage regulators

Self-exciting voltage regulators use a soft iron core at the exciter to create the initial voltage in the alternator. This iron core stores a little bit of the magnetism produced during normal operation. We refer to this as residual magnetism. As the voltage in the alternator builds up, the regulator increases the voltage, which increases the magnetic field to the exciter, thus increasing the alternator's output voltage. Once the voltage is at the preset level, the regulator adjusts the voltage to maintain the output of the alternator at a constant level. This is the type of regulator that you will find on many of the commercial grade generators that you work with.

Permanent magnetic voltage regulator

The permanent magnetic voltage regulator works much the same way as the self-exciting regulator. The biggest difference is that it uses a permanent magnet instead of a soft iron core. The magnetism builds up the voltage during start up. Once the regulator gets power, it increases the voltage to the coil and increases the magnetism, thus increasing the voltage output. Once the output voltage of the alternator reaches the preset level, it then controls the voltage to maintain it at a constant level. You can find this regulator on some of the newer generators on the market, such as the BEAR Power Unit.

Each of these components is an equally important part of the production of AC voltage. You now know the principles to produce voltage and the components that do the job. It is also important for you to know exactly how these components work together to produce AC voltage.

213. Operation

You know the production of AC current requires three things—a magnetic field, conductors, and relative motion. You also know how these work together to generate the AC current. You now know the components that make up an alternator. Let's take a look at these components and determine what each part does to produce stable and controllable electrical power.

Basic operating principles

As you get started, the alternator sits motionless (no output voltage from the alternator). Follow the diagram in figure 3–16 as you read through the next few paragraphs. As the alternator begins to rotate, the power generation system starts to come to life. Most exciters use soft iron cores that retain residual magnetism. This small magnetic field extends across the conductors of the armature. As the alternator rotates, you now have relative motion to go with the magnetism and conductors. This induces a small voltage onto the armature.

This induced voltage moves to the rectified assembly changing the three-phase AC signal into DC. This DC signal then moves to the main windings on the alternator rotor. The current moving through the windings creates a magnetic field. The rotating magnetic field cuts across the stationary conductors, inducing voltage at the stator conductors. This voltage is a three-phase AC output for the alternator to provide the customer power.

Since you started with a small residual magnetism, the output voltage is also small. Part of the output voltage enters the voltage regulator. The voltage regulator senses the output voltage is low and provides an increased amount of current to the exciter windings. This increase in current enters the field windings creating a stronger magnetic field. The stronger magnetic field creates more voltage induced at the armature.

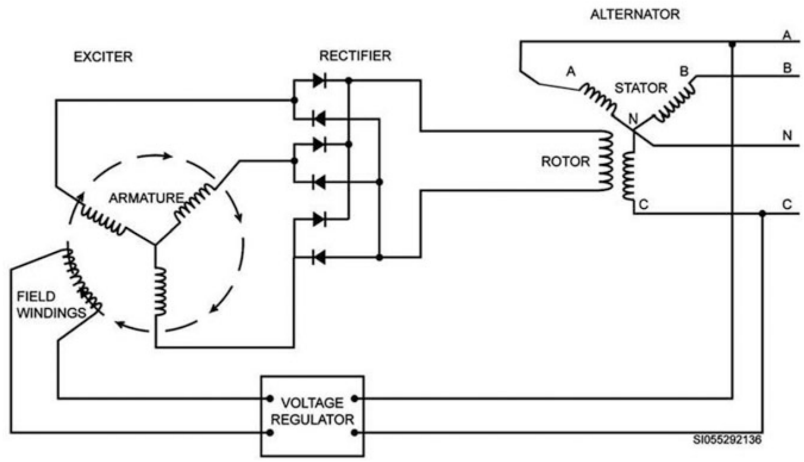


Figure 3–16. Alternator diagram.

The increased armature voltage changes into DC and moves into the main windings of the rotor. This increase in current causes an increased magnetic field. The increased magnetic field induces more voltage on the stator conductors to increase the output voltage of the alternator. Some of the output voltage returns to the voltage regulator to determine the voltage value.

This cycle continues until the output voltage of the alternator reaches the predetermined level. Once this happens, the voltage regulator will maintain the current supplied to the exciter field windings at steady levels to hold the voltage steady.

Alternators using permanent magnet generators for exciters

Many exciters use the output voltage of the alternator for both a reference and for supplied current for field excitation. However, some only use the alternator output for reference only and use what is a called a permanent magnet generator (PMG) for excitation current. The PMG consists of a rare earth magnet and provides a deep pool of energy (fig. 3–17).

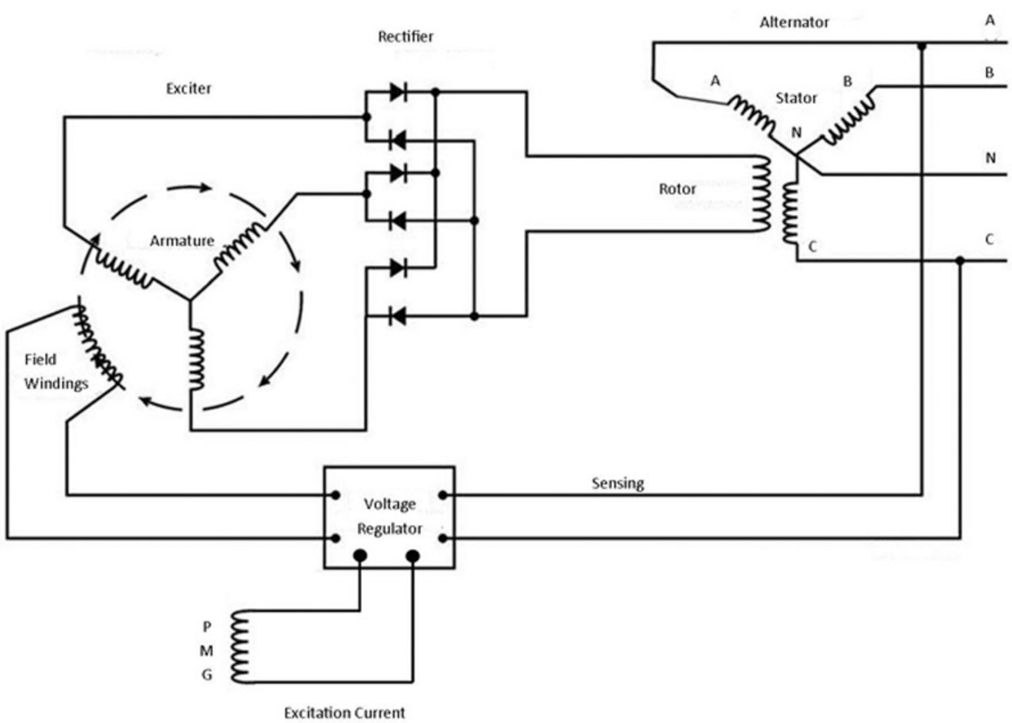


Figure 3–17. Alternator with PMG diagram.

Operating principles for changes in voltage

Once the alternator reaches operating speed and operating voltage levels, the voltage regulator monitors the voltage output of the alternator to keep it steady. If the voltage level begins to drop, the voltage regulator senses the lower than normal level and increases the current to the exciter field windings. This increase in current to the winding causes the magnetic field to get stronger. This causes the amount of voltage induced at the armature to increase. The increased voltage changes to DC at the rectifier and moves on to the rotor main windings. This causes an increase in current making the magnetic field stronger. This induces more voltage at the stator conductor increasing the alternator output.

If the output voltage of the alternator gets high, the voltage regulator senses a higher than normal voltage. It then decreases the current flow to the exciter field windings. This weakens the magnetic field decreasing the induced voltage at the armature. This decrease in voltage changes to DC and moves into the rotor main windings. This causes a decrease in the current flow through the windings decreasing the strength of the magnetic field. The stator conductor has less voltage induced into it decreasing the output voltage of the alternator.

Making manual adjustments to the alternator voltage levels

The voltage regulator has an adjustment attached to it. This allows you to make small adjustments to the output voltage of the alternator. What you are really adjusting is the reference voltage; the voltage regulator compares the output voltage level. This makes the voltage regulator read the output voltage as high or low and make an adjustment to the current applied to the exciter field windings.

If the output voltage level is too high, turn the voltage adjustment down. This lowers the reference voltage making the voltage regulator read the output voltage as too high. This makes the current level applied to the exciter field windings decrease lowering the magnetic field and decreasing the voltage level induced at the armature. This lower level of voltage goes through the rectifier changing it to DC and moves on to the rotor. The decreased level of current in the main windings decreases the magnetic field to decrease the voltage induced at the stator conductor. This decreases the output voltage of the alternator.

If the voltage level is too low, adjust the voltage by turning the voltage adjustment up. This tells the voltage regulator the output voltage is too low. The voltage regulator again compares the reference and output voltages and makes adjustments to the magnetic fields opposite of what was described above to increase the voltage induced in the stator conductor. This increases the output voltage of the alternator.

The operation of an alternator is relatively easy to understand. Each component performs its job providing the self-sufficient means to produce AC voltage. All it needs is the relative motion typically provided by a diesel engine.

214. Configurations

The configuration of an alternator shows how the manufacturers make the connections for the output. This determines the type of customer you can use this generator for. Each of our customers has needs you must meet. You must consider if the facility is single phase or three phase, is an industrial area or an office area, and how large the load they need. This will vary from place to place. This is why you need different configurations of a generator. In this lesson, you will learn about the different types of alternator configurations and what you use them for.

Single-phase alternator

A single-phase alternator is the simplest type. Notice the schematic wiring diagram of the single-phase alternator in figure 3–18. The alternator consists of a rotating magnetic field and a single set of stator coils; therefore, there will be a single output voltage induced by the magnetic field. The sine wave in the diagram shows that the rotor revolves through one full rotation and produces one cycle of

AC. Since there are no overlapping cycles produced by the alternator, the voltage output has only single-phase connection point. We refer to this as a single-phase alternator.

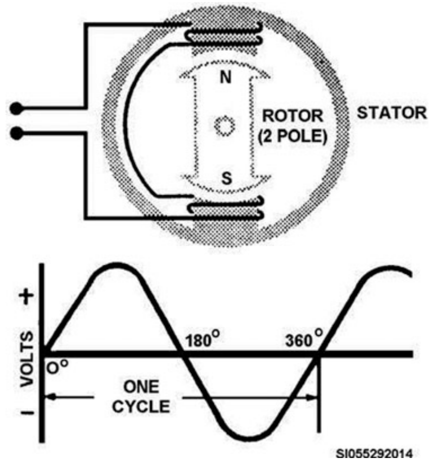


Figure 3–18. Single-phase alternator.

Three-phase alternator

The three-phase alternator also has a rotating magnetic field and stationary coils. The difference between the single-phase alternator and a three-phase alternator is how many outputs it has. The three-phase alternator (fig. 3–19) has three sets of stator windings (phase A, B, and C). Manufacturers place these windings at equal distances from each other. Since the alternator works over 360 degrees and there are three different phases, they sit 120 degrees apart. These are independent windings and do not depend on each other. Each of the sets of windings produces an independent sine wave (fig. 3–19). As the rotor makes one rotation, it produces three independent sign waves. The sign waves, like the stator coils, are 120 degrees apart.

The output of the three-phase alternator operates almost all electrical equipment in the Air Force. This is the reason you almost always use the three-phase alternator in electrical power production. While you use the output of this alternator to operate three-phase equipment, you often use it to operate single-phase equipment at the same time. You can do this from each of the phases or from a combination of any two of the phases. Three-phase alternators are configured in one of two ways—wye or delta.

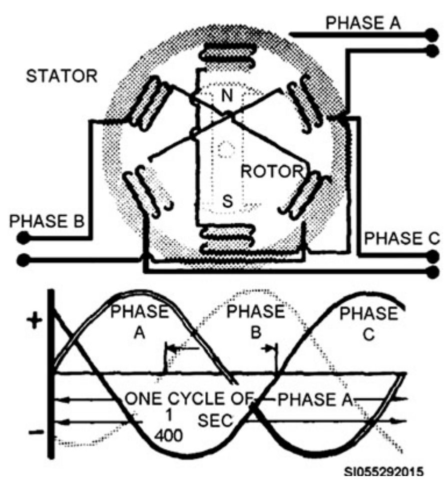


Figure 3–19. Three-phase alternator.

Wye

You can easily identify wye connect alternators, shown in figure 3–20, because their coils look like a big Y. Notice there are three legs that all connect in the middle, which gives you the ability to connect in four places to this configuration. These connection points are each of the three legs and the center connection point. Depending on the connection you make, you can get two different values of voltage. If you connect something to two of the legs, you get two of the stator coils in the circuit. If you connect between the center point and one of the legs, you get only one stator coil in the circuit. You have the ability to connect three-phase equipment to the generator as well as simple single-phase lighting circuits.

The connection points at the end of the legs are called phase connections. This is because the three coils are our three phases (A, B, and C). The center connection is the neutral because it is common to all three phases. The voltage values between these different connection points vary.

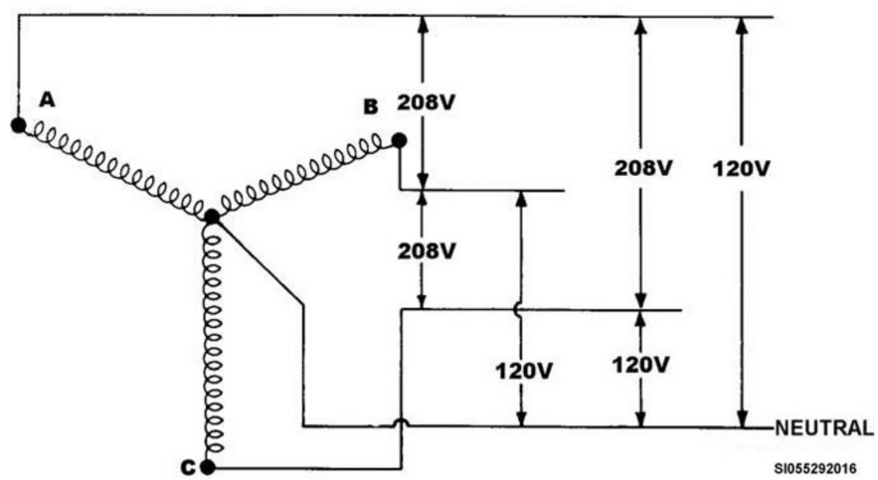


Figure 3–20. Wye connection.

The voltage between any phase and neutral is equal to the alternator phase voltage or 120 volts in this illustration. We refer to this as *phase voltage* because it measures the voltage of one phase. You would think the voltage between two phases would double since there are twice as many phases in the circuit. This is not true. The voltage between any two of these phase lines is approximately 208 volts. This is because the phases are 120 degrees apart so the increase is not twice as big. We refer to this as *line voltage* because it is the voltage used in electrical transmission lines. The line voltage is 1.73 times more than the phase voltage.

There are two different types of wye alternators. The manufacturer can choose to make the alternator set for a single set of voltages or reconnectable for multiple sets of voltages. The way you determine this is the number of connecting wires coming out of the alternator. If the alternator has four wires, the manufacturer sets it up for a single set of voltages. Often, the alternator comes with 12 wires. You can reconfigure it for multiple sets of voltages because the alternator is adaptable for different customers. Specify this when you order new generators.

Delta

You can also easily identify the delta connected alternator, shown in figure 3–21, because it resembles the Greek letter Δ. Notice it has three connection points, one at the end of each of the phases. This is quite different than the wye connection. The three phases are still A, B, and C, but there is no neutral that is common to all three phases.

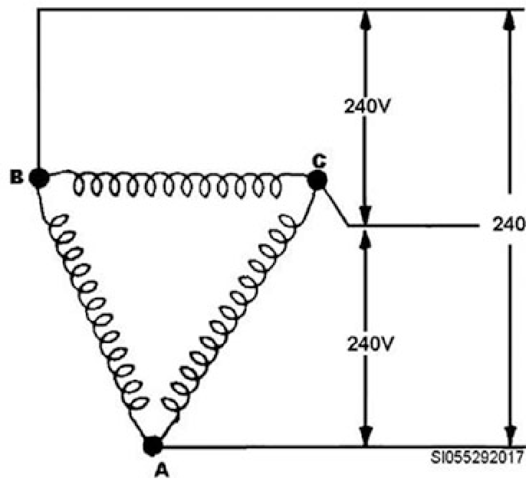


Figure 3–21. Delta connection.

When you look at the voltage output of the delta connected alternator, you find the three connection points. No matter which of the three ways you make a connection, you only cross one stator coil; therefore, there will only be one output voltage. The voltage, shown in figure 3–21, is 240V.

We will find delta connected alternators used with large, three-phase equipment of the industrial nature heavy industry. We also find delta connected alternators used to power transmission power lines sending electricity over long distances. We use this because of the tremendous cost savings of not having to run a fourth power line.

Whether the alternator uses a single- or three-phase connection, the output must remain steady to provide the customer with the power necessary to complete the mission. The voltage level must be correct and steady to power sensitive equipment. The frequency must also be precise to allow the equipment to operate properly.

215. Maintenance

This lesson contains maintenance instructions that are necessary for you to maintain dependable, continuous operation of the exciter and alternator. How you perform periodic maintenance is a major factor contributing to trouble-free equipment operation of your equipment.

Inspection of alternator components

From time to time there are inspections that you must accomplish to the alternator and its components. Some of these are periodic in nature and others will result from a fault in the operation of a generator.

Rotating rectifier testing

As discussed before, the rectifier takes the AC input of the exciter and changes it to DC in order to excite the magnetic field within the alternator field. As with all tasks, consult the proper technical order or manufacturer’s manual when performing all maintenance tasks. We will concentrate on a MEP 806B assembly in this example.

- Shut down the generator set and allow the generator to cool to ambient temperature.
- Open the BATTERY ACCESS door and disconnect the negative battery cable.
- Remove the rear housing panel.
- Remove the end bell cover plates.

NOTE: It will be necessary to bar (turn) the engine in order to position a specific area of the rotating rectifier at one of the end bell access holes. Use the center bolt on the harmonic balancer to turn the engine.

- Tag the main rotor and diode leads and remove the nuts (fig. 3–22), lockwashers (15), and leads from the terminal bolts (2).

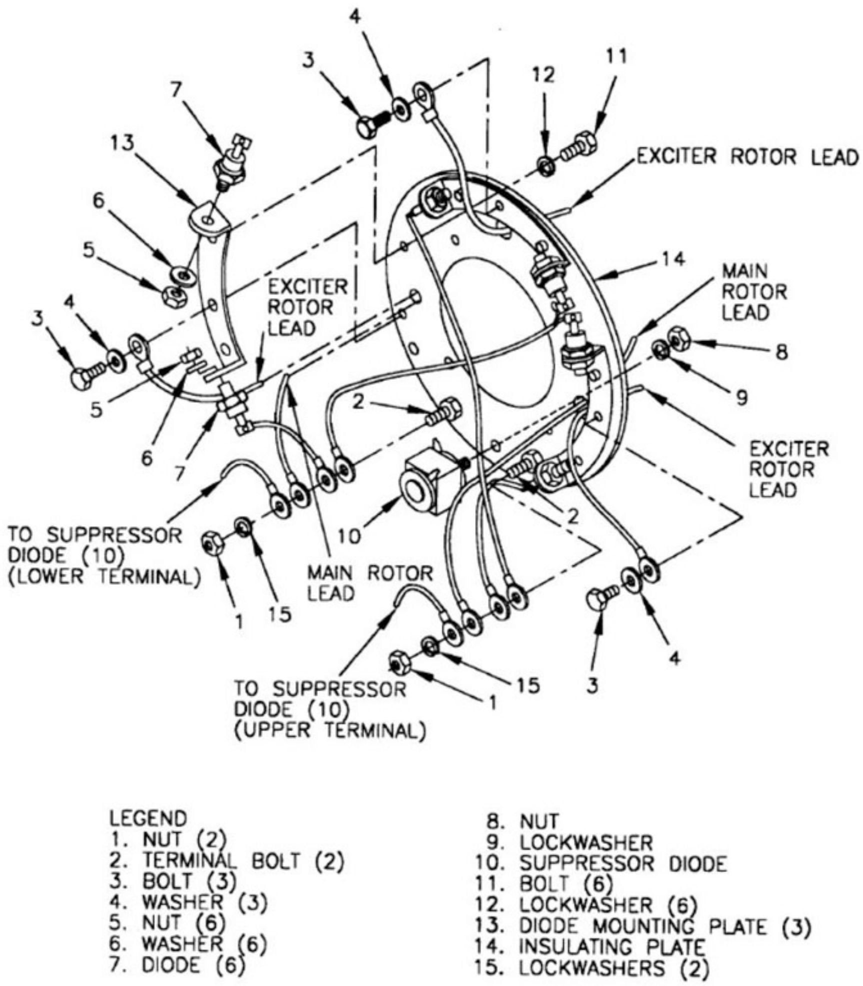


Figure 3–22. Rectifier assembly.

- Tag the exciter rotor leads, and remove the bolts (3), washers (4), and leads from rectifier mounting plate (13).
- Set the multimeter for ohms, and connect the positive lead to one side and negative lead to other side of each diode.
- Record the multimeter reading for each diode.
- Repeat the step with multimeter leads reversed.
- Resistance (ohms) readings should show continuity in one direction and no continuity in the reversed direction. If readings show continuity or no continuity in both directions, the diode is defective and must be replaced. Continuity in both direction indicate a shorted diode.
- Install the exciter rotor leads, washers (4), and bolts (3) on rectifier mounting plate (13). Remove the tags.
- Install the diode and main rotor leads, lockwashers (15), and nuts (1) on the rotating rectifier terminals.
- Install the end bell cover plates.
- Install the rear housing panel.

- Connect the negative battery cable to battery, and close the BATTERY ACCESS door.

Replacing

Now that you have tested the diodes on the rectifier, you will now learn how to replace them.

Removal

- Remove the end bell and main bearing.
- Remove the nuts (fig. 3–22) and lockwashers (15) securing the main rotor leads and rotating the rectifier diode leads to terminal bolts (2). Tag and remove the leads.
- Remove the bolts (3) and washers (4) securing the exciter rotor leads to rotating rectifier plate (13). Tag and remove the leads.
- Remove the bolts (18, figure 3–22), lockwashers (19), and rotating rectifier (20) from the rotor assembly (23).

Replacing and repairing

- Unsolder the electrical lead from the diode (7) (fig. 3–22) to be removed.
- Remove the nut (5), lockwasher (6), and diode (7) from the rotating rectifier plate (13) through the access hole in the end bell.
- Run a bead of thermal-electrical contact compound around the base of diode (7) prior to installing. Do not coat the threads.
- Insert the diode (7) through the generator end bell access hole, and install on the rotating rectifier plate (13) with lockwasher (6) and nut (5). Torque the nut to 28-30 inch-pounds (3.16-3.38 Nm).
- Using a soldering iron and solder, solder the electrical lead to diode (7). Install the end bell top cover and louvered covers.
- Install the rear housing panel.

Installation

- Install the rotating rectifier (20) (fig. 3–22), lockwashers (19), and bolts (18) on the rotor assembly (23).
- Install the exciter rotor leads, washers (4) (fig. 3–22), and bolts (3) on the rotating rectifier plate (13).
- Install the main rotor leads and rotating rectifier diode leads, lockwashers (15), and nuts (1) on the terminal bolts (2).
- Install the end bell and main bearing.
- Install the rear housing panel.
- Connect the negative battery cable to battery, and close the BATTERY ACCESS door.

Inspecting alternator windings

The windings are the coils of wire that make up the alternator and exciter fields. As with all tasks, consult the proper technical order or manufacturer's manual when performing all maintenance tasks. We will concentrate on a MEP 806B assembly in this example.

Rotor assembly

The rotor assembly houses all of the rotating pieces of an alternator. Testing it requires attention to detail along with some math.

Testing

- Shut down the generator set, and allow the generator to cool to ambient temperature.

- Open the BATTERY ACCESS door and disconnect the negative battery cable.
- Remove the rear housing panel.
- Remove the end bell top cover and louvered covers.
- Remove the lockwashers securing the main rotor leads to the terminal bolts.
- Tag and remove the leads.

NOTE: It will be necessary to bar (turn) the engine in order to position a specific area of the rotating rectifier at one of the end bell access holes. Use the center bolt on the harmonic balancer to turn the engine.

- Set the multimeter for ohms, and connect between the disconnected main rotor leads. The multimeter reading should be as shown below:

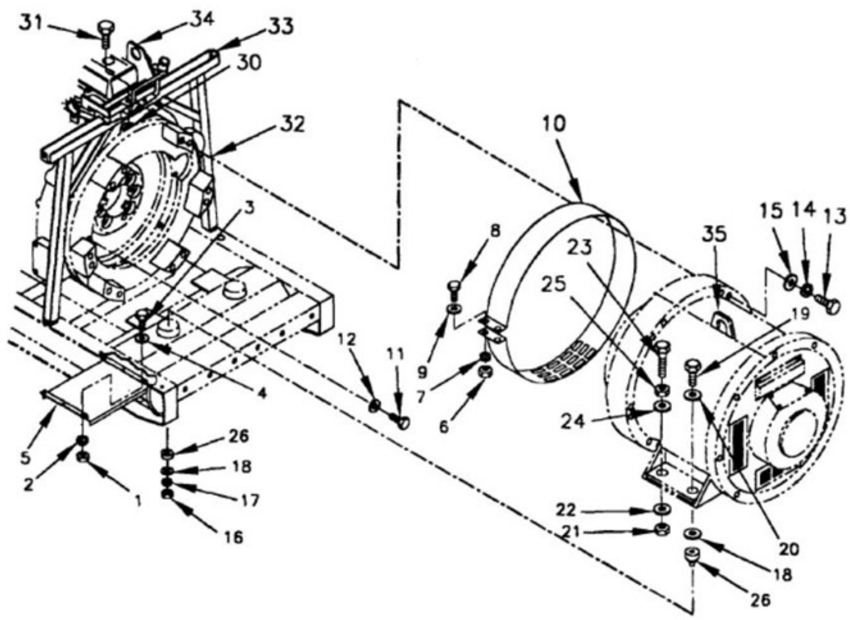
Component	Resistance
Generator Rotor	Between 24.85 & 33.61 ohms
Generator Stator	Between .202 & .274 ohms

- A reading other than the above indicates shorted or open windings, and the main rotor must be replaced.
- Connect the multimeter between each main rotor lead and rotor shaft, in turn.
- A multimeter reading of less than infinity indicates a defective ground insulation, and the main rotor must be replaced.
- Install securing main rotor leads and rotating rectifier diode leads, lockwashers, and bolts on the terminal bolt.
- Install the end bell top cover and louvered covers.
- Install the rear housing panel.
- Connect the negative battery cable to the battery, and close the BATTERY ACCESS door.

Removal

In order to remove the rotor assembly, you must first remove the entire alternator. As always, use the proper TO or manufacturer’s manual when completing this task.

- Shut down the generator set.
- Open the BATTERY ACCESS door and disconnect the negative battery cable.
- Remove the output box assembly.
- Remove the rear housing section.
- Remove the load output terminal board.
- Remove the rear forklift guide.
- Loosen the nut (fig. 3–23), adjust the bolt to contact the support frame, and tighten the nut.
- Remove the nuts (fig. 3–23), lockwashers, bolts, washers, and rear forklift guide from the skid base.



LEGEND

1. NUT (6)	19. BOLT (2)
2. LOCKWASHER (6)	20. BELLEVILLE WASHER (2)
3. BOLT (6)	21. JAMNUT (2)
4. WASHER (6)	22. WASHER (2)
5. REAR FORKLIFT GUIDE	23. BOLT (2)
6. NUT (2)	24. WASHER (2)
7. LOCKWASHER (2)	25. JAMNUT (2)
8. SCREW (2)	26. SHOCK MOUNT (2)
9. WASHER (2)	27. NOT USED
10. BAND COVER	28. NOT USED
11. SELF-LOCKING BOLT (8)	29. NOT USED
12. WASHER (8)	30. NOT USED
13. BOLT (12)	31. JAMNUT
14. LOCKWASHER (12)	32. BOLT
15. WASHER (12)	33. CONTACT SUPPORT FRAME
16. LOCKNUT (2)	34. LIFTING BRACKET
17. WASHER (2)	35. LIFTING EYE
18. SNUBBING WASHER (4)	

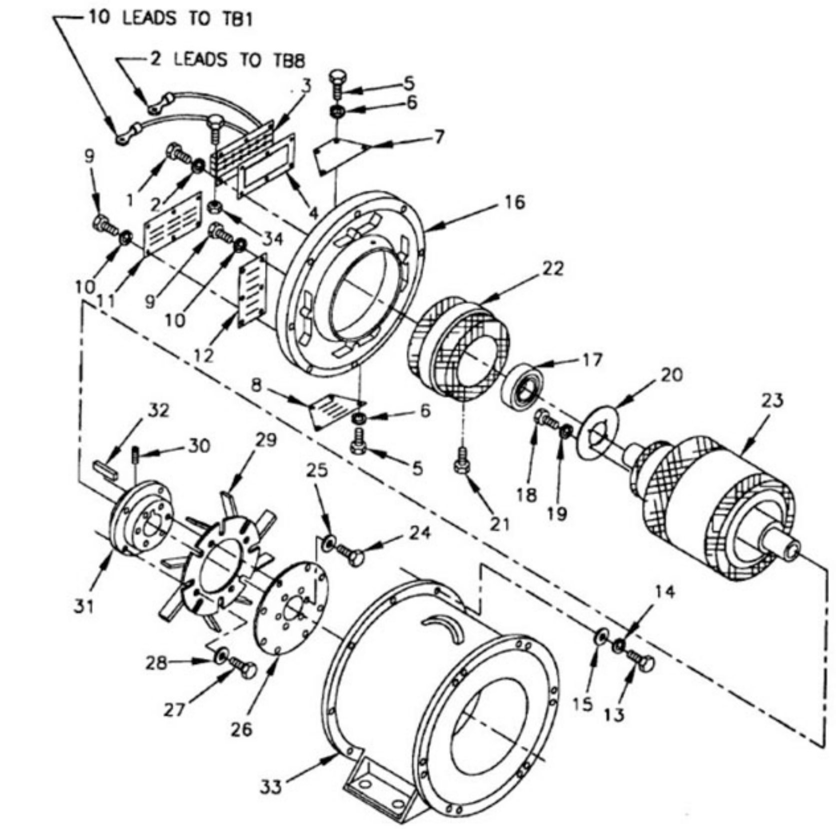
Figure 3–23. Alternator assembly removal.

WARNING: Rated capacity of the overhead hoist should be rated for the proper weight. Using a hoist with less capacity could result in equipment damage, personal injury, or death.

- Attach the lifting harness to the overhead hoist and the generator lifting eye. Take up the slack.
- Remove the nuts, lockwashers, screws, washers, and band cover from the generator case.
- Remove the bolts and washers securing the generator drive disc to the engine flywheel.
- Remove the bolts, lockwashers, and washers securing the generator to the engine flywheel housing.
- Remove the nuts, washers, snubbing washers, bolts, and Belleville washers securing the generator to the skid base.
- Lift the generator slowly from the skid base, ensuring that the engine flywheel housing adapter and generator separate smoothly avoiding any undue stress.
- Remove the generator shock mounts from the skid base.
- Remove the nuts, washers, bolts, and washers from the generator mounts.

Now that the alternator assembly has been removed, it is time to remove the rotor.

- Remove the bolts (fig. 3–24), washers, and drive discs from the drive hub.



LEGEND
1. BOLT (7)
2. LOCKWASHER (6)
3. CLAMP ASSEMBLY
4. GASKET
5. BOLT (8)
6. LOCKWASHER (8)
7. COVER
8. COVER
9. BOLT (18)
10. LOCKWASHER (18)
11. AIR INTAKE SCREEN
12. LOUVERED COVER
13. BOLT (8)
14. LOCKWASHER (8)
15. WASHER (8)
16. END BELL
17. BEARING
18. BOLT (4)
19. LOCKWASHER (4)
20. ROTATING RECTIFIER
21. BOLT
22. EXCITER STATOR
23. ROTOR ASSEMBLY
24. BOLT (6)
25. WASHER (6)
26. DRIVE DISC
27. BOLT (4)
28. BELLVILLE WASHER (4)
29. FAN
30. SETSCREW
31. DRIVE HUB
32. KEY
33. GENERATOR HOUSING
34. NUT

Figure 3–24. Alternator assembly.

- Remove the bolts, lockwashers, and fan from the drive hub.
- Attach a suitable rotor lifting device (fig. 3–25) to the drive hub and overhead hoist.

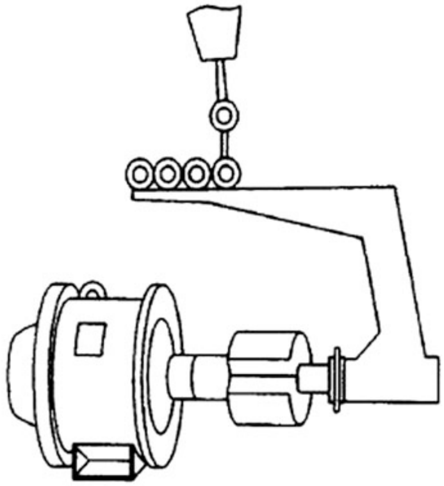


Figure 3–25. Typical rotor assembly lifting device.

- Remove the end bell and main bearing.
- Remove the rotating rectifier.

CAUTION: Take special care when you remove a rotor assembly. Winding damage could result if the rotor is allowed to hit the main stator.

- Carefully remove the rotor assembly and attached components from the main stator and generator housing.

Installation

- Install the rotating rectifier.
- Install the main bearing.

CAUTION: Take special care when you install a rotor assembly. Winding damage could result if the rotor is allowed to hit the main stator.

- Attach a suitable rotor lifting device to the drive hub and overhead hoist as shown in figure 3–25.
- Carefully install the rotor assembly and matched components into the main stator and generator housing.
- Install the end bell and remove the rotor lifting device.
- Install the fan on the drive hub with lockwashers and bolts.

NOTE: Make sure all disc mounting holes at the inner and outer diameter are properly aligned.

- Install drive discs, washers, and bolts on the drive hub. Torque bolts (24) to 35ft-lb (47 Nm).
- Install the generator assembly.

As you can see, this is a very large job requiring special tools and knowledge on the procedures. This type of job is normally done at a depot level shop. As always, use the proper technical order when performing all maintenance.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

211. Magnetism and power generation

1. What are the two distinct poles every magnet has?

2. What are the magnetic lines of force?

3. What materials make up one very good type of permanent magnet?

4. What three things are required for the generation of AC?

5. What happens when the magnetic field is at 90 degrees during the generator of voltage?

6. What happens as the rotation of the north pole of the magnet reaches 225 degrees?

212. Exciters, alternators, and voltage regulator components

1. What is an exciter?

2. What is the armature?

3. What is the rotor assembly?

4. What is the purpose of the interpoles?

5. What is the biggest difference between the self-exciting and permanent magnetic voltage regulator?

213. Operation

1. Why do most exciters use soft iron cores?

2. What happens if the voltage level of an alternator begins to drop?

3. What happens if you turn the voltage adjustment down?

214. Configurations

1. What is the output of a single set of stator coils on an alternator?

2. Since the alternator works over 360 degrees and there are three different phases, how far do they sit?

3. Since there are three legs that all connect in the middle in a wye connected alternator, how many connection points are there?

215. Maintenance

1. What is an indication of a shorted diode?

2. What is used to attach the leads to the diodes?

3. What is used to test the main rotor leads?

4. What do you attach the overhead hoist to when lifting the alternator assembly?

3–2. Generator Controls and Protective Devices

A generator is a device that produces electricity. As you have already read, the engine changes heat energy from combustion into mechanical energy. This mechanical energy drives the alternator. The alternator changes the mechanical energy into electrical energy. This electricity is what we use on a daily basis to accomplish the mission. You must be able to control the voltage and frequency that the alternator produces. This is where the control panel comes into play. It will allow us to control the output of the generator to make it useful to the customer. Protective devices provide the weak link of a circuit that prevents expensive components from damage by high current. This protects the system from problems that you could not repair. It also protects against problems that could destroy other equipment or kill someone. They are an essential part of any circuit.

216. Construction features and theory of operation of generator controls

Control panels consist of a combination of instrumentation and control devices. This combination allows you to set the generator for the operation that you require and monitor it to ensure that everything is satisfactory. Understanding the meter readings and how the controls change the operation is essential to completing the mission.

Control panel meters

Control panel instruments may have one of many types of meter movements depending on their use. No matter what type you use, each meter will have parts for limiting the current that goes through the meter coil. The permanent magnet instruments have very little use in measuring AC. Most of the AC instruments use electromagnets for their operation. This type of meter is very accurate and sensitive and not affected by the change in direction of current flow. Figure 3–26 shows a representation of an electromagnet type AC meter. With current flow in the direction of the arrows, left to right, the indicator will move up the scale. If current flow reverses direction, as in AC, the meter will still move up the scale. Only a reduction or interruption to current flow will cause the meter to move back down the scale. The pointer deflection is proportional to the amount of current flowing through the meter.

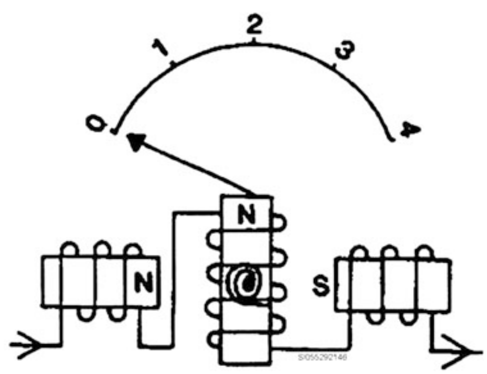


Figure 3–26. Electromagnet-type meter movement.

AC voltmeter

You use a voltmeter to measure the electromotive force (EMF) or potential difference between two points. The voltmeter connects in parallel to the measured device. The voltmeter on the generator set control panel measures the effective value of voltage produced by the alternator. The meter uses a current limiting resistor in series with the meter coils to reduce the current flow to a safe value.

The connections of the voltmeter depend upon the type of alternator used and the voltage requirements. In a WYE connected alternator, you can connect the voltmeter to read either phase-to-phase (line voltage) or phase-to-neutral (phase voltage). If the generator uses a delta connected alternator, you can connect the voltmeter to the phase leads, but if the alternator produces high voltage, you must connect the voltmeter to a potential transformer used to step-down the voltage before applying it to the voltmeter.

To avoid the expense of having a separate voltmeter for each phase of a three-phase alternator, use one voltmeter connected to a selector switch. The selector switch changes the connections between the phase leads of the alternator. Figure 3–27 shows a voltmeter circuit connected to a WYE connected alternator. Switch schematics show the closed contacts of a switch for each switch position. With the selector switch in position 2, contacts 3–4 and 7–8 would be closed and the current would flow as shown by the solid arrows on one alternation and as shown by the broken arrows on the other alternation of AC.

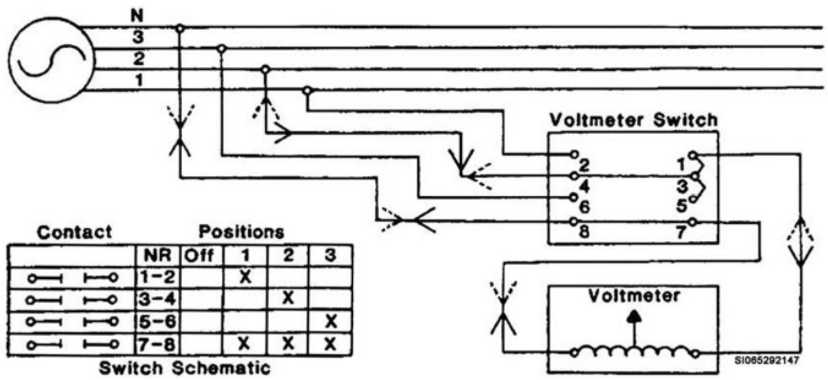


Figure 3–27. Wiring arrangement of voltmeter and selector switch on a WYE.

Figure 3–28 shows a voltmeter and selector switch connected to a Delta connected alternator. With the switch in position 3–1, contacts 1 and 4 are in the closed position and the current flows as shown by the solid and broken arrows for both alternations.

Contact Number	Switch Position		
	3–1	2–3	1–2
1	X		X
2		X	X
3		X	
4	X		

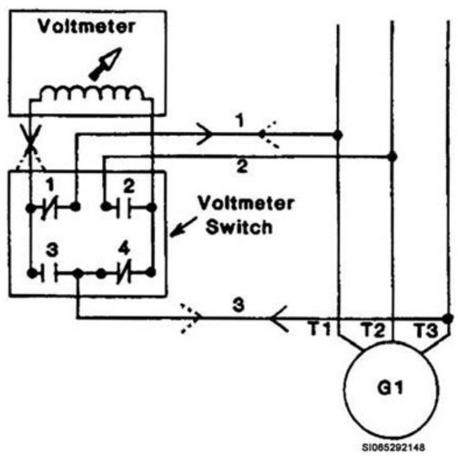


Figure 3–28. Wiring arrangement of voltmeter and selector switch on a Delta connected alternator.

Ammeters

An ammeter is an instrument used to measure current flow in an electrical circuit. The DC ammeter indicates the current output of the exciter, while the AC ammeter indicates the amount of load current for each phase of the alternator. Connect an ammeter in series with the load. To limit the current flow through the electromagnet, the ammeter has a bypass connected in parallel to shunt, or bypass, the electromagnet.

The size of an ammeter would have to be large for us to connect it in series with a load of 350 amperes. For this reason, the AC ammeter on the panel board connects to current transformers to step down the amount of current from the alternator in a ratio of 80 to 1. Manufacturers use a current transformer on each phase of the alternator. The heavy mainline bus serves as the primary, and the open center winding serves as the secondary. Never open the secondary winding while the switchgear is energized due to the very high buildup of voltage.

Ammeter circuits, for the same reason as the voltmeter circuits, have only one ammeter connected to an ammeter switch. Figure 3–29 shows a circuit diagram. This switch schematic shows which contacts of the switch are in the closed position for each switch handle position. The diagram shows the current flow through the switch with the handle in position 1. Also, there is current flow returning to all current transformers, which is a safety precaution to prevent opening the secondary circuit.

Ammeter Switch Positions

Contact	Position 1	Position 2	Position 3
1		X	X
2	X		
3	X		X
4		X	
5	X	X	
6			X

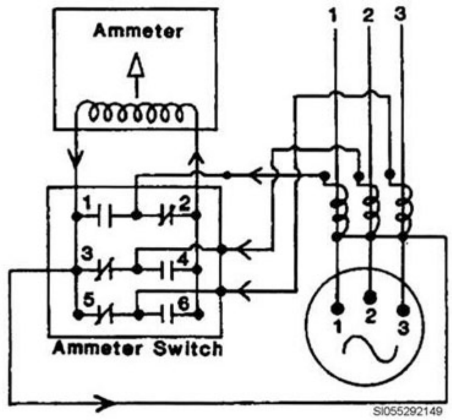


Figure 3–29. Wiring arrangement of ammeter circuit.

Wattmeter

The wattmeter indicates the *true power* load in an AC circuit. True power is that power used by resistive type loads. You find this by multiplying the voltage drop across the resistance times the current flow through the resistance. To show true power, the wattmeter must measure voltage and current at the same time. Wattmeters for generator sets measure in kilowatts. One thousand watts equals one kilowatt.

Three electromagnets, a pointer, and a scale make up the wattmeter, as shown in figure 3–30. Two of the electromagnets do not move and are connected in series with the load to measure the current. Since they measure current, manufacturers connect a shunt resistor in parallel to them. The other electromagnet moves within the magnetic field of the stationary electromagnets.

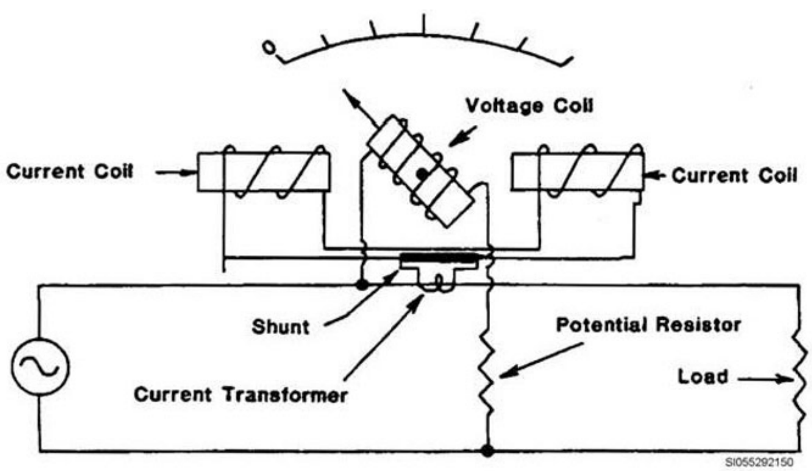


Figure 3–30. Wattmeter construction.

This moveable coil connects in parallel with the load to measure the voltage. Since this is a voltage-measuring coil, a resistor connects in series with the coil. The pointer, attached to the moveable coil, has a deflection that is proportional to the value of the voltage times the current since the force acting upon the coil is the product of the magnetic fields of both the fixed and moveable coils. The polarity of the electromagnets is the same as discussed earlier.

The fixed coils, being current measuring coils, connect to a current transformer. The moveable coil, being a voltage measuring coil, connects to phase leads or a potential transformer. Binding posts, marked negative and positive amps and volts, make the wattmeter. The secondary of the current transformer connects to the amps terminals. When connecting a wattmeter into a circuit, be careful to properly connect the four terminals.

Power factor meter

The power factor is the ratio of *true power* to *apparent power*. The power factor meter shows the percentage of the generator's apparent power used as true power by the resistive load. It will also show the type of load (fig. 3–31) (inductive, capacitive, or resistive) that the generator produces by measuring the phase angle between the voltage and the current. With a purely resistive load, the current and voltage are in phase, and the phase angle is 0.

A capacitive load will cause current to lead voltage. You see this on the power factor meter by a reading on the lead side. An inductive load will cause current to lag voltage. You can read this on the power factor meter by the pointer reading on the lag side. You can also read a resistive load when the power factor meter is reading 100 percent. This is called a *unity power factor*.

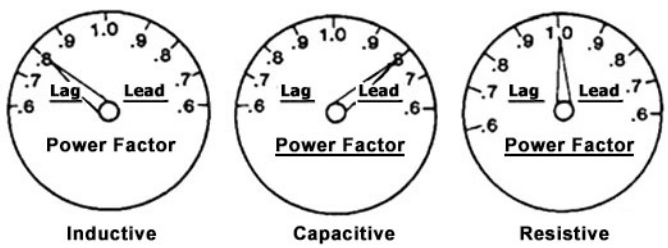


Figure 3–31. Power factor meter indications.

Frequency meter

The frequency meter indicates frequency of AC power in hertz. It indicates the number of cycles per second the generator produces. When anything passes through a series of changes and returns to the starting point to repeat the same series of changes, it is a *cycle*. As you know, an electrical cycle is a complete occurrence of events during 360 electrical degrees.

The frequency of the alternator depends upon two major factors: the number of field poles in the alternator, which you cannot easily change, and the speed of rotation, which you can easily adjust by controlling the speed of the prime mover.

Control panel control devices

After you have observed the meters on the control panel, you must make the appropriate adjustments to the output of the generator with switches and rheostats. You need to understand how each of these devices affects the output of the generator. This allows you to operate a generator at peak efficiency.

Switches

There are many switches located on the control panel. They include the stop-start-run switch, the AC circuit breaker switch (often called the load contactor), the single unit-parallel switch, and the panel light switch, to name a few. Not all control panels use all of these switches. The manufacturer designs each generator for a specific type of operation that will determine the type of switches that you will find on the control panel. These switches provide us with an on-off control of the circuit that the switch is associated with. The name of the switch usually tells us what the switch does. For example, the start-stop-run switch provides us the ability to start and stop the generator. Sometimes, the same switch is called several different names depending on the manufacturer.

Rheostats

Rheostats are devices that provide variable amounts of resistance to provide a circuit with different levels of output. They provide a clean signal that makes it the choice of manufacturers for items that need a precise signal, such as the volume control for televisions and stereos. Generators use rheostats to control the amount of voltage and frequency. This allows you to make minor adjustments to the output voltage and frequency to provide your customer with steady, precise electricity. This is essential in today's world of electronics.

Generator controls include the simple control devices to operate the generator. It also includes the metering systems that allow you to monitor the generator operation to make sure the generator systems are operating at peak efficiency.

217. Control component maintenance

Voltage regulators provide the exciter with the current that creates the magnetic field to produce voltage. It reads the output voltage of the alternator and determines if it is high, low, or at the appropriate level. It will make adjustments to the level of current to the exciter as necessary to maintain the output voltage of the alternator at the set level.

Inspecting voltage regulators

Inspections for all voltage regulators are essentially the same. Inspect them for cleanliness. Dirt accumulation on the voltage regulator can cause it to overheat by restricting airflow around the components. Inspect the mounting hardware for security. Manufacturers sometimes use vibration isolation dampeners. If they are used, inspect them for cracking and deterioration. Inspect the entire voltage regulator wiring for cracks, burns, or frays in the insulation. You must replace any damaged wiring. Inspect all connections for corrosion and clean as required. The connections should be clean and secure. Loose connections anywhere in the voltage regulator circuit can cause intermittent problems that are difficult to locate. Fuses may protect the regulator assembly. Inspect any fuses and fuse holders for security.

Replacing voltage regulators

To replace a voltage regulator, be sure that the one that you have to replace is the correct one. Many regulators can look the same physically but use different electronic components. Disable the generator and tag the control panel. Tag and disconnect all of the wires. Remove the mounting screws and remove the regulator. To install the new regulator, mount it and install the screws. Connect all of the wires. Start the generator, and test it to find out if the regulator is working properly.

Inspecting an exciter

The exciter provides the alternator with the current that is required to produce the magnetic field to generate AC. Manufacturers mount it to the end of the alternator. You must disable the generator and tag the control panel before you begin any maintenance. To inspect it, you will need to remove the inspection ports from the end of the alternator housing. Examine the rotating rectifier assembly for loose, frayed, or burnt wiring and loose mounting of the diodes. Inspect the exciter rotor and stator windings for loose, frayed, or burnt wiring and any other damage. Look for any signs of rubbing between the rotor and stator.

Replacing the exciter

If you find any problems with the exciter, replace it. Start by tagging and removing the wiring from the rectifier assembly. Often, you will find the connections to the diodes soldered. Be sure to use a heat sink when you are unsoldering the diodes. Remove the rectifier assembly. Next, unbolt the rotor assembly and remove it. Next, remove the stator assembly. Install the new exciter by mounting the stator and rotor assemblies. Mount the rectifier assembly, and connect the wiring. If you are soldering the diode's wiring, be sure to use a heat sink so the heat doesn't damage them.

Inspect transformers

Transformers are electrical devices that change the voltage level of alternating current. They operate by using mutual induction to induce a voltage from the primary coil to the secondary coil. The input voltage is applied to the primary coil and the output (load) is connected to the secondary coil. They can be used to step up (increase) or step down (decrease) the voltage. The ratio of turns between the primary and secondary coils are determines this. If the number of turns in the primary coil is greater than the number of turns in the secondary coil, then it is a step down transformer. If the number of turns in the primary coil is less than the number of turns in the secondary coil, then it is a step up transformer. The ratio of turns in the two coils will determine how much the voltage will be increased or decreased. Remember that voltage and current are inversely proportional, so the lower voltage will have higher current and the higher voltage will have a lower current when compared to the other coil.

Replacing transformers

If you find any problems with the transformer, you will need to replace it. Ensure that the circuit is deenergized and tagged. Confirm that there is no power to the transformer using a meter. Tag and remove the electrical leads. Unbolt the transformer and remove it. Install the new transformer and securely mount it. Identify the primary and secondary side of the transformer and connect the wiring.

Inspect control panel components

Generator control panels contain many instruments for observing and controlling generator operation. These components include meters for observing the electrical output of the alternator, gauges for indicating operating condition of prime mover, control and selector switches, adjustment knobs, and indicating lights. These components must be in working order to ensure proper operation of the generator set.

Inspect meters and gauges for physical damage, such as broken glass and bent or missing indicating needles. During operation, the meters and gauges should operate without binding or sticking. You should check the adjustment knobs, if used for voltage and frequency adjustments, to ensure they rotate freely without binding or sticking. A setscrew may secure the knob. Engine vibration could loosen this screw; check for tightness. Switches should move freely and snap into position. Inspect all wiring and connections. Loose connections can cause arcing at the terminals, increased circuit resistance, burnt wiring, and intermittent problems. Replace any components that do not operate correctly. It is extremely important to follow all safety precautions and ensure all power to the control panel is deenergized.

Replace control panel components

Before you remove the defective component, such as a meter, switch, or indicator, obtain a suitable replacement item. Ensure the replacement has the same electrical rating as the original.

1. Disconnect the negative battery terminal from the battery. This will ensure the control panel is deenergized.
2. Prior to removing any wires, tag or label them. This will assist you when you reconnect the wires to the proper terminals.
3. Loosen or remove the terminal screw or nut and remove the wire from the electrical terminal.
4. Remove and replace the component and ensure the component is securely fastened to the control panel.
5. Reconnect the wires to the correct component terminals observing the tags or labels used to identify location before removal.
6. Reconnect the negative battery cable to the battery terminal.
7. Perform an operational check of the generator set and verify replacement component is functional.

Being able to inspect and replace generator control components will allow you keep your system operating. You must also perform the appropriate maintenance to keep the generator operating in peak efficiency.

218. Construction features and theory of operation of protective devices

There are several protective devices that you will work with in the power production field. Each of them does the same basic job of protecting the equipment and the personnel that operate it. You must know how each of the different type of protective devices work. The most common types of protective devices are the circuit breaker, inductive relay, solid-state relay, and fuse.

Circuit breakers

We use a circuit breaker to protect a circuit from overload and short-circuit conditions. The main advantage of a circuit breaker over a fuse is its ability to manually reset to complete the circuit again without removal or replacement. Manufacturers class circuit breakers according to their operation principles: thermal, magnetic, or a combination thermal-magnetic.

A thermal-type circuit breaker has a bimetallic element within the breaker that responds to temperature change. Fusing together two strips of dissimilar metal makes the bimetallic element. Each strip has a different expansion rate when heated. Current flowing through the breaker generates heat. As the current increases, it causes the bimetallic element to bend and act against a latch. Manufacturers adjust the breaker mechanism so when the current flow reaches a set level, the element bends enough to trip the latch. This action opens a set of contacts to break the circuit. Usually we refer to the thermal-type circuit breaker as a *time lag breaker* because the breaker does not open immediately when an overload occurs. The bimetallic element requires a short time (length depends on the size of the overload) to respond to the heat generated by the overload current.

A magnetic-type circuit breaker responds instantaneously when an excess of current flows through the breaker. A small electromagnet actuates the breaker mechanism.

The thermal-magnetic circuit breaker, as the name implies, combines the features of both the thermal and the magnetic types. Of the three, the thermal-magnetic circuit breaker is preferred for general use. A small overload actuates the bimetallic strip to open the circuit on a time delay, while a large overload or short circuit actuates the magnetic trip to open the circuit instantly.

When selecting circuit breakers for circuit protection, consider the total current flow and voltage of the circuit in which you will install the breaker. Manufacturers seal circuit breakers as units and you should make no attempt to adjust the ampere capacity or to repair it. You must remove and replace a defective breaker.

Inductive relay

An inductive relay (fig. 3–32) is an electromagnetic switch constructed of an electromagnet, armature, contacts, and spring. Inductive relays operate on the electromagnetic attraction principle. In essence, an inductive relay is a small electric motor whose armature only pivots through a small portion of a circle or “arc.” This arc is centered on the armature’s own immobilized end. Inductive relays have no intentional time delay in their operation. Manufacturers design a time delay into a relay. In its simplest form, an inductive relay begins to work when its coil energizes. The coil induces a magnetic field in a core. The core moves the armature, and the armature operates a set of contacts. The contacts then open or close a circuit. Let’s look at how each major part works in more detail.

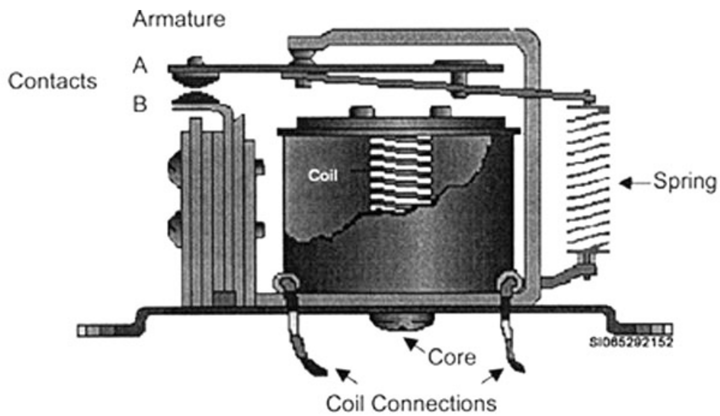


Figure 3–32. Inductive relay.

Electromagnet

The electromagnet is made up of a coil wrapped around a core.

Coil

Coils are rated according to voltage and power handling capabilities. A coil is a length of wire wound around a metallic core. The coil may have many or few windings, of heavy or light wire. The number of wire windings, size of the conductors, and amount of current applied affect the strength of the magnetic force exerted on the armature. Ultimately the strength of the applied magnetic force depends upon the relay's design purpose.

Core

The core is a solid pole usually made of soft iron, though it can be made of almost anything. It will have a coil of wire wrapped around it. The type of core material affects the strength of the magnetic field the core will produce.

Armature

The armature is the relay's only moving part. The armature operates the relay contacts, shown in figure 3–32. The armature is a small metal arm, basically a small lever, immobilized at one end but free to pivot.

Contacts

Contacts open or close the relay secondary circuits. There are two contacts, one moveable and one stationary. The armature mounts the moveable contact, shown in figure 3–32, A. This contact is insulated from the rest of the relay. Manufacturers make these contacts of gold, silver, silver alloys, or platinum alloys, and they are often plated with cadmium or nickel. Relay contacts are rated by maximum current handling capabilities and voltage ratings. These ratings depend upon the types of contact material, size and spacing of the open contacts. It is very important not to exceed contact ratings. Overloaded contacts will arc causing worn and pitted contacts.

Spring

Manufacturers construct the spring of wound spring steel wire or make it like a small leaf spring. Sometimes the armature and the spring are one part. The spring provides a constant restraining force keeping the armature in the normal (deenergized) position, shown in figure 3–32. The term "deenergized" describes a relay without voltage applied to the coil.

Solid-state relay

The solid-state relay (SSR) is a completely self-contained unit. It has no moving parts. Having no moving parts makes SSRs far more reliable than inductive relays. However it also limits them because the time delay and operating values are preset and non-adjustable. SSRs are becoming more and more popular. The SSRs design electrically isolates the control circuit from the load circuit. “Isolation” means the control circuit and load circuits are separate, with *no electrical connection* between them.

During operation, an SSR activates an internal circuit to complete a path through itself. A generator fault circuit applies a predetermined signal to the control circuit operating the SSR. This signal (voltage) causes a light emitting diode (LED) to glow, shown in figure 3–33. The LED’s glow acts upon a light sensitive type of solid-state device, shown in figure 3–34. When light strikes the light sensitive device’s surface, the device’s normally high resistance drops to almost zero. This separation between the LED and the light sensitive device provides electrical isolation between the control circuit and the load circuit. When the light sensitive device’s resistance drops to almost zero, it provides a path for current flow, which activates a third solid-state device. The third solid-state device acts as an electronic switch, which turns current flow on or off in the relay’s secondary circuit.

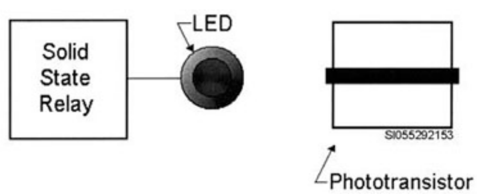


Figure 3–33. LED, with no signal applied.

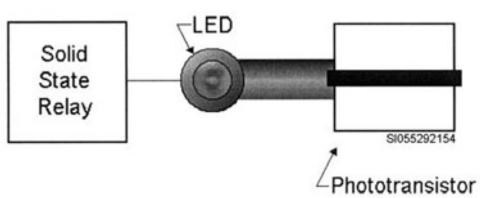


Figure 3–34. LED, with a signal applied, shining on phototransistor.

Fuses

Manufacturers construct fuses from small, fine wire known as the fuse link. This wire is engineered to burn if certain amperages are exceeded. Manufacturers size fuses by their voltage and current capacity—primarily current.

For example, a three-amp fuse burns up and opens the circuit when the current exceeds 3 amps. A load that draws 3 amps or greater will generate sufficient heat in the fuse to melt the fuse link. The time required to melt the fuse link is inversely proportional to the amount of overload; therefore, the higher the overload current, the faster the melting action occurs. When a fuse link melts, you must replace the fuse.

When selecting fuses, consider the total current flow and voltage of the circuit in which you will install the fuse. Since the purpose of the fuse is to protect the circuit, it must be the weakest point in the circuit. Thus, you must use a fuse rated no higher than the lowest-rated component the fuse will protect.

Understanding how the protective devices operate allows you to quickly determine if there is a problem with one. This will also let you quickly reset or replace the component as necessary. These are devices you will find on every circuit you work with.

219. Inspecting and replacing protective devices

You must inspect protective devices on a regular basis. This will help you determine the serviceability of the components. You may be able to find a problem before it shows itself by shutting the circuit down. This will prevent power outages to critical equipment. You also need to understand the requirements for replacing these components.

Inspecting circuit breakers

To perform maintenance on circuit breakers, you need to know their construction and component functions as well as the operating scheme of their electrical circuits. The arrangement, size, and construction of circuit breakers will vary at different installations. This variation should be no problem if you understand how typical circuit breaker components operate.

You can find circuit breakers in circuits that use voltages from 12 to 13,800 volts. Some commercial plants produce even higher voltages. Manufacturers rate circuit breakers according to their interrupting capacity. Interrupting capacity is the amount of current flow across the contacts caused by a collapse of a magnetic field in a circuit when the circuit is broken. Breakers used with 600 volts and lower are usually rated in “root mean squared (RMS) ampere interrupting capacity.” Larger breakers are rated in “kilovolt-amperes (kVA) interrupting capacity.”

Circuit breakers that you will come in contact with are classed as vacuum, or air types. Normally vacuum-type circuit breakers are found on large portable generator sets, such as the MEP–012A. The oil-type circuit-breaker contacts operate in insulating oil.

Air circuit breakers, regardless of manufacturer, will have the same basic assemblies, shown in figure 3–36. These assemblies are the frame, arc chutes (three), poles (three), closing and tripping assembly, and linkage assembly.

Frame assemblies are either welded or bolted. Bolted frame assemblies generally make teardowns for maintenance and inspection easier. Heavier breakers will have rollers or wheels attached for ease of removal and installation.

The arc chute of one particular circuit breaker consists of blowout coils, side plates of insulating material, and arc horns all housed in a jacket of high-dielectric strength. An arc chute surrounds each set of arc (not main) contacts. Its function is to extinguish or quench any arcing that takes place when the breaker opens or closes.

The three-pole assemblies are mounted on the back section of the frame assembly. One set of main contacts mount on each of the poles. These contacts are normally made of silver and tungsten alloy, which helps reduce oxidation. The arcing contacts are attached to the main contacts. These contacts take the brunt of the arcing by closing before and opening after the main contacts.

The closing assembly usually consists of a closing coil or motor and a control switch. Operation of the control switch energizes the closing coil or motor, which closes the circuit breaker. The contacts latch closed against spring tension, and all that is necessary to open the breaker is to unlatch it. A tripping coil unlatches the circuit breaker.

Testing circuit breakers

There are a few ways to test a circuit breaker. The first is checking voltage on the output side of the breaker. You would use a voltmeter to check each phase of the circuit breaker to ensure the proper voltage is present. The second way is to a continuity check. This is accomplished by de-energizing the circuit and checking from the input to the output of each phase. When the breaker is closed, it should have continuity and when it is open the meter should indicate an open circuit.

Removal and replacement of circuit breakers

Before you perform any type of maintenance on any circuit breaker, be sure that the breaker is open and that you disconnect all electrical power, both primary and control. Disable the generator and tag the control panel. Tag and remove all of the wiring leading to the circuit breaker. Unbolt the breaker and remove it from the housing.

Replace the breaker by installing it into the housing and bolting it into place. Connect all of the wiring and remove all of the tags. This will prevent any possibility of the breaker hanging up. Start the generator and test the breaker for proper operation.

Protective relays

The protective relays used in today's generators are typically enclosed, plug-in components. They are often made of clear or opaque plastic. They can also have metal cases. They consist of the relay and a base that it plugs into. To inspect these types of relays, look for damage to the case and base. Make sure the connections on the base are tight and free of corrosion. Plug the relay tightly into the base.

To replace a relay, ensure that there is no power to the circuit. Pull the relay from the base. You may find a relay with hold down screws that holds the relay in place. If you find these, remove them and then remove the relay. Compare the relay to the one that you are going to replace, and make sure it has the same electrical rating and the same style plug. The relay is equipped with a keyway to align the coil and contact pins to the base. Slide the relay into place, ensuring that it is completely installed and tight.

Testing and replacing fuses

Testing and replacing fuses seems like a very simple task on the surface but it has been known to trip-up even the most experienced technician from time to time. One of the most common mistakes made is not isolating the circuit entirely. You can test fuses in an energized circuit, but you must understand what readings to look for. Always replace fuses on a deenergized circuit and with the proper tools. When choosing a replacement fuse, it is essential to consult proper tech data for the appropriate type and electrical rating. Fuses come in all different sizes and types, and to list them all would be a lengthy process. Instead we will focus on the physical acts of testing and replacing fuses.

Set the meter for the correct type of voltage depending on circuit voltage. Measure across the fuse by placing one lead on each end of the fuse. You are reading the difference in potential by reading the fuse this way. Think of the fuse like a wire. What goes in one side of the wire should come out the other side. If 120 volts goes in one end, 120 volts should come out the other end. If there is 120 volts at one end and 120 volts at the other, then 120–120=0 volts. Remember the word *difference* means subtraction. There should not be a difference of potential across the fuse. Any reading other than zero indicates that the fuse may be bad, and further testing is necessary.

To test the fuse with an ohmmeter, deenergize the equipment, and tag the control panel. Verify that the equipment is deenergized with the multimeter. Remove the fuse using fuse pullers. Set the multimeter to read ohms, and place the meter leads on the ends of the fuse. A good fuse should read 0 ohms while a bad fuse should give you a reading of OL (infinity) on the meter. If you determine the fuse is bad, you must replace it.

When you are replacing a fuse, it is essential that the replacement fuse be the same type and has the proper electrical ratings. Consult the applicable technical reference for guidance. It is also a good idea to check the physical condition and test the replacement fuse prior to installing it. Paper cartridge-style fuses can deceive you due to their design. Before installing the fuse, check the condition of the fuse holder or clips. Install the fuse into the fuse holder, and energize the circuit.

Being able to test, inspect, and replace protective devices is necessary because it is designed to be the weakest component so it protects the rest of the circuit and components. When the circuit no longer works, the protective device is the first suspect.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

216. Construction features and theory of operation of controls

1. Why do you often use one voltmeter connected to a selector switch?

2. Why should you never open the secondary winding of a current transformer while the switchgear is energized?

3. What is the change in the relationship of current and voltage in a purely resistive load?

4. What do switches provide for us?

217. Control component maintenance

1. If your generator uses isolation dampeners, what do you inspect them for?

2. What is the first step to replacing an exciter?

3. What will typically secure the adjustment knob?

218. Construction features and theory of operation of protective devices

1. When does a magnetic-type circuit breaker respond to trip?

2. What affects the strength of the magnetic force exerted on the armature?

3. What makes SSRs far more reliable than inductive relays?

4. When selecting fuses, what must you consider as to which fuse to install?

219. Inspecting and replacing protective devices

1. What is the function of an arc chute that surrounds each set of arc (not main) contacts?

2. What does the closing assembly usually contain?

3. What is the relay equipped with to align the coil and contact pins to the base?

Answers to Self-Test Questions

211

1. (1) A north pole.
   (2) A south pole.
2. Invisible lines of magnetic force that exist between the poles.
3. An alloy of aluminum, nickel, and cobalt.
4. (1) A magnetic field.
   (2) Conductors.
   (3) Relative motion.
5. The greatest number of magnetic lines of force cut the conductor causing the voltage to peak.
6. The magnetic lines of force begin to cut the conductor again. This time the lines of force move in the opposite direction.

212

1. A device that provides the alternator electricity needed to produce the electricity you use to operate equipment.
2. The rotating conductor of the exciter.
3. A device that provides the magnetic field necessary to produce electricity.
4. They offer a slight magnetic force that aligns the main magnetic field so it remains most effective.
5. The permanent magnetic voltage regulator uses a permanent magnet; the self-exciting voltage regulator uses a soft iron core.

213

1. Because they retain residual magnetism.
2. The voltage regulator senses the lower than normal level and increases the current to the exciter field windings.
3. This lowers the reference voltage making the voltage regulator read the output voltage level as too high.

214

1. There will be a single output voltage induced by the magnetic field.
2. 120 degrees apart.
3. Four.

215

1. Low reading in both directions.

2. Soldering iron.
3. Multimeter set to ohms.
4. Lifting eye.

216

1. To avoid the expense of having a separate voltmeter for each phase of a three-phase alternator.
2. Because of the very high buildup of voltage.
3. Current and voltage are in phase, and the phase angle is 0.
4. On-off control of the circuit that the switch is associated with.

217

1. Cracking and deterioration.
2. Tagging and removing the wiring from the rectifier assembly.
3. A setscrew.

218

1. Instantaneously when an excess of current flows through the breaker.
2. (1) The number of wire windings.
   (2) The size of the conductors.
   (3) The amount of current applied.
3. They have no moving parts.
4. Total current flow and voltage of the circuit.

219

1. To extinguish or quench any arcing that takes place when the breaker opens or closes.
2. A closing coil or motor and a control switch.
3. Keyway.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

64. (211) Where does a magnet have the *greatest* amount of magnetism?
    a. In the center.
    b. At the north pole.
    c. At the south pole.
    d. At each end of the magnet.

65. (211) What is the small amount of magnetism that remains in an item after removing the magnetic field?
    a. Faint.
    b. Residual.
    c. Reluctant.
    d. Specialized.

66. (212) Which alternator component offers a slight magnetic force that aligns the main magnetic field so it remains *most* effective?
    a. Rotor.
    b. Interpoles.
    c. Voltage regulator.
    d. Damping windings.

67. (212) Which alternator component helps the generator maintain a stable voltage under varying load conditions?
    a. Rotor.
    b. Interpoles.
    c. Stator.
    d. Damping windings.

68. (213) What type of cores do *most* exciters use that retain residual magnetism?
    a. Galvanized.
    b. Soft iron.
    c. Mica.
    d. Air.

69. (213) What does a voltage regulator sense if it decreases the current to the exciter field windings causing the magnetic field to get weaker?
    a. A drop in the load.
    b. A drop in the current.
    c. An increase in the frequency.
    d. An increase in the voltage level.

70. (214) Which type of alternator consists of a rotating magnetic field and a single set of stator coils?
    a. Wye.
    b. Delta.
    c. Three phase.
    d. Single phase.

71. (214) Which alternator configuration has three legs that all connect in the middle?
    a. Wye.
    b. Beta.
    c. Delta.
    d. Gamma.

72. (214) What is the multiplier you use to determine the line voltage if you know the phase voltage?
    a. .707.
    b. 1.73.
    c. 2.00.
    d. 3.14.

73. (214) Which alternator configuration has no neutral that is common to all three phases?
    a. Wye.
    b. Beta.
    c. Delta.
    d. Gamma.

74. (215) In a rotating rectifier test, what does it indicate if a diode has a low reading in both directions?
    a. Open.
    b. Closed.
    c. Shorted.
    d. Reversed.

75. (215) Which test instrument do you use when testing the main rotor leads?
    a. Voltmeter.
    b. Ammeter.
    c. Ground tester.
    d. Multimeter set to ohms.

76. (216) Which component is used with a voltmeter for a three-phase alternator to save money?
    a. Multi-tap transformers.
    b. Multiple pointers.
    c. Cheaper meters.
    d. Selector switch.

77. (216) Which meter indicates the *true power* load in an alternating current (AC) circuit?
    a. Ammeter.
    b. Voltmeter.
    c. Wattmeter.
    d. Power factor meter.

78. (216) On the power factor meter, what will an inductive load cause?
    a. Current and voltage in phase.
    b. Current to lead voltage.
    c. Current to lag voltage.
    d. Will have no effect.

79. (216) What devices provide variable amounts of resistance to provide a circuit with different levels of output?
    a. Rheostats.
    b. Inductors.
    c. Capacitors.
    d. Selector switches.

80. (217) When you inspect the voltage regulator vibration dampeners, look for
    a. cracking and deterioration.
    b. security and discoloration.
    c. lubrication and dry rot.
    d. staining and wear.

81. (217) Where should you look for any signs of rubbing on an exciter?
    a. At the diode ring.
    b. Around the bearing.
    c. Between the rotor and stator.
    d. Where the shaft meets the diode.

82. (217) What color will a transformer turn if it gets too hot?
    a. Bright red.
    b. Dark gray or black.
    c. Lighter than normal.
    d. Shade of yellow or brown.

83. (218) Which type of circuit breaker responds instantaneously when an excess of current flows through the breaker?
    a. Coil.
    b. Heat.
    c. Magnetic.
    d. Secondary trip.

84. (218) Which relay component provides a constant restraining force keeping the armature in the normal (deenergized) position?
    a. Coil.
    b. Spring.
    c. Plunger.
    d. Contact.

85. (218) Which relay component is completely self-contained and has no moving parts?
    a. Capacitive.
    b. Solid-state.
    c. Inductive.
    d. Isolation.

86. (219) The closing assembly of a circuit breaker usually consists of
    a. arc chutes and a tripping coil.
    b. advancing motor and distribution points.
    c. closing coil or motor and a control switch.
    d. closing transformer and adjustable resistors.

87. (219) Which ohmmeter reading indicates that a fuse is good and no further testing is necessary?
    a. Zero.
    b. Infinity.
    c. Below 250 ohms.
    d. Above 500 ohms.

Please read the unit menu for unit 4 and continue ➔

Student Notes

Unit 4. Grounding and Transfer Switches

GROUNDING IS PROBABLY one of the least thought of, but more important, tasks in any career field that deals with electricity. Grounding consists of more than just connecting the generator ground strap to a ground point. In this unit, we cover the different types of grounds and installing and testing grounds. Grounding is largely an electrician's responsibility, but you must still know about it. If you are stationed at a remote site, you may be the sole electrical person or become the second electrician.

4–1. Grounding

Why is grounding so important? Probably the most important aspect is grounding can save your life. In this section, we discuss the types of grounds and the reasons we use grounding.

220. Types and installation

Have you ever walked across a carpeted floor and shocked yourself or someone else? Static electricity causes this shock. It might be fun to zap someone on the back of the ear but imagine the damage that small spark could do to an electronic component in a sophisticated piece of equipment. This is just one reason we ground our equipment and ourselves.

Static electricity

Three things cause static electricity to form. First, it can result from friction between small particles. This means as your feet rub on the carpet, particles rub together to create a charge. Second, it can form from electrostatic induction by a charged object. This is where an object with a charge causes the induction of a charge in another object adjacent to it. Third, it also comes from contact and separation of two substances, one or both of which are nonconductive.

Objects receive a charge when the atoms become ionized. This charge now looks for a path to conduct the charge to ground. Sparks occur when the charge accumulates enough voltage to overcome the resistance, or insulating value, of the surrounding air. The charge then discharges to the ground through the spark. This can be a hazard, being more severe in dry, cold weather than during humid, warm weather. This is because in humid, warm weather, most surfaces have a film of moisture that makes them good conductors. This draws off the static charge before it can get to dangerous levels. Dry, cold weather causes the resistance of objects to increase because of the decrease of moisture. This means the static charge gets much stronger than in hot, humid weather.

Liquid moving through space has the capability to build up a static charge of up to 10,000 volts under proper conditions. It also has the ability to create a spark at about 300 volts. This means the fuel we pump into fuel tanks has this capability. Static charges of only 1,500 volts can ignite gasoline fumes. This means putting fuel into a tank has the capability to ignite itself. This is why it is important to use a grounding system on the fuel system. The grounding system prevents such a thing from happening.

Stationary equipment, like a parked aircraft or other large metal equipment can easily build up high static charges from wind or dust blown over their metallic surface. This equipment can build enough of a charge to severely injure or kill someone. Again, grounding systems provide protection.

Static grounds

Since static electricity and stray currents occur in hazardous areas, we must protect ourselves against them. The usual way to dissipate or reduce unwanted electrical charges in hazardous areas is to provide a continuous electrical path to ground. This provides a path of low resistance, which unwanted charges move off harmlessly, thus neutralizing the difference in electrical potential. The grounding conductor path's resistance can be relatively high and still leave it adequate as a ground, but considerations of mechanical strength and reliability require substantial grounding conductors and connections.

There is no uniformity in the maximum resistance for grounding systems in the various technical orders (TO) and industrial standards. The intent is to have secure, mechanically strong ground systems. Any ground that is adequate for power circuits is more than adequate for protection against static electricity. We discuss specific grounding procedures for different hazardous locations later, but we must connect any effective grounding system to clean, unpainted, metal surfaces.

A static ground is a connection made between a piece of equipment and earth for draining off static electricity charges before it reaches a sparking potential. Typically, static grounding involves connecting large metal objects, such as certain fuel tanks and aircraft, to earth through a ground rod. Static grounding is also necessary on electronic equipment since components of printed circuit boards cannot handle a voltage spike caused by static electricity.

Current Air Force directives pertaining to grounding systems specify 10,000 ohms maximum for all static grounds. It is important to remember that static grounds are not part of an electrical power system.

Equipment grounds

Intentional equipment grounding maintains metallic surfaces at low potentials above ground thereby decreasing the possibility of electric shocks. System grounds and equipment grounds usually interconnect at some point.

Equipment grounding pertains to the interconnecting and connection to earth of all noncurrent-carrying metal parts of an electrical wiring system. This includes equipment connected to the system. We do this so the metal parts people might come into contact with are at or near zero volts with respect to ground.

Equipment grounding must be capable of carrying the maximum ground fault current possible without causing a fire or explosive hazard. The grounding must be able to carry the ground fault current until the circuit protective device clears the fault. One example is the bare copper wire or green-insulated conductor connected to the frame of an electric motor. Connect the equipment ground to an electrical system ground (neutral) only at the service entrance of a building. Do not let the resistance exceed 25 ohms to ground. Another example: When you install a generator at a site, you must ground the generator frame to prevent the frame from becoming a current-carrying device if an electrical wire or cable makes contact with the frame.

Installing equipment grounds

Contrary to popular belief, the earth is a poor conductor. It has a resistivity of about 10 billion times that of copper. This poor conductor is very useful because there is so much of it. You can sink a metal rod, pipe, or plate into the earth and connect a grounding conductor to it. This metal rod, pipe, or plate becomes a grounding electrode. Electrodes are conductors you use to establish electrical contact with a nonmetallic part of a circuit.

The conductors you use to interconnect earth electrodes must be at least 1/0 AWG stranded copper. We do not use fine-stranded copper braid or aluminum wire of any type or size due to corrosion and high inductive reactance. All wires we use in the earth electrode subsystem must be continuous, meaning free of splices or welds.

Ground rods

Ground rods are a good way of grounding equipment. They give a known conductive value and allow for expansion if the required ohms value is not present. When you install ground rods, you can use one of several configurations. One of the configurations is using a ground rod that comes in 3-foot sections that can be coupled for ease of driving them into the ground. The other configuration is to create a star ground.

CAUTION: Before driving any ground rods, make sure you obtain a digging permit to avoid hitting any electrical, water, sewer, or gas lines that may be buried in the area.

Single conductor using a three-piece rod kit

When using the three-piece ground rod kit, select areas close to the generator to reduce the chance of a tripping hazard. In addition, this keeps the total resistance of your ground low because you are able to use a shorter ground conductor. Next, using the ground rod-driving adapter, drive the first ground rod until about 6 inches are showing above ground. Using the ground rod-driving adapter is necessary; without it, you will damage the top of the ground rod making it difficult to place a ground connector on it and making it impossible to screw in another coupler to allow for another ground rod to be installed. At this point, use an earth ground tester to measure the resistance of the ground. If it is to the desired reading, you will install the ground. If not, attach another 3-foot ground rod section and drive it until about 6 inches are showing. Repeat these steps until you obtain the desired resistance reading. Take a reading after you drive in each ground rod so that you will not waste them by using too many.

Star ground

To form a star ground, radiate wires horizontally from a central point shown in figure 4–1. This configuration is particularly useful at mobile sites. If soil conditions permit, terminate the wires with ground rods. The resistance of a star ground is a function of the length and depth of its horizontal conductors. The depth of the horizontal conductors is not as important as in the case of ground rods, but 18 to 36 inches is the minimum in normal soil. The size of the conductors has only a slight effect on resistance. Using longer conductors lowers resistance but increases reactance. The best approach is to increase the number of conductors while you keep their lengths short. Make sure the conductors are straight since curves cause inductance, which reduces the effectiveness of the ground.

Grid electrodes

Grid electrodes consist of buried wires joined together to form a network of squares. The wires in the grids must be securely bonded to each other by welding or brazing at every crossing. The size of the squares varies from one facility to another, but spacing of 1 to 2 feet is common. Grid systems usually extend over the entire area of a facility and may extend some distance beyond. Specific dimensions and fabrication instructions are included in the Air Force Installation Scheme or the Army Engineering Installation Package.

Plate electrodes

Plate electrodes are useful in small areas where grids and ground rods are impractical. The conductance of plate electrodes depends on the total surface area of the plates. Ferrous electrodes (iron or steel) should be at least $^{1}/_{4}$-inch thick, while nonferrous electrodes should be at least 0.06 inch thick. Bury plates 4 to 8 feet below grade. Generally, at least two plates connected in parallel are required to achieve a reasonably low resistance. Plates are not as economical as ground rods.

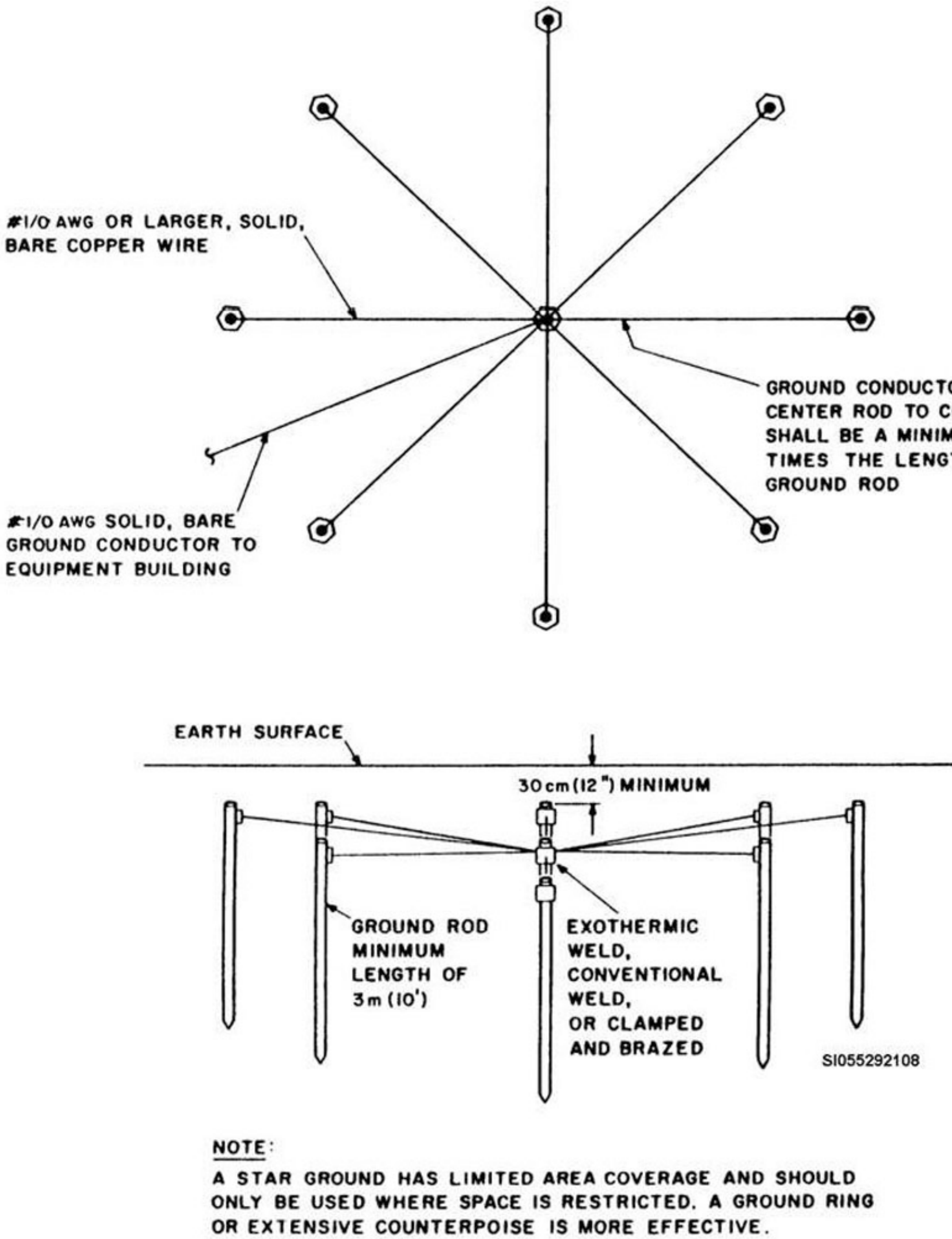


Figure 4–1. Typical star ground and connection.

Horizontal conductor configurations

We use several configurations of horizontal conductors as earth electrodes. These conductors include solid, stranded, or braided wires, cables, straps, or tubes. We can use horizontal conductors alone or in conjunction with ground rods depending on soil conditions. Like grid electrodes, horizontal wires are relatively good conductors at higher frequencies. They are easy to install and can easily be added to existing electrode subsystems.

Ground loop

Form a ground loop by bonding a continuous 1/0 American Wire Gauge (AWG) bare copper wire to ground rods that encircle the facility 2 to 6 feet outside the drip line where the water runs off the roof. Extend the grounding conductors from within the facility beyond the building foundation and bond them to this loop. To install a ground loop, drive the ground rods at intervals of 15 to 25 feet and at a distance of 2 to 6 feet outside the drip line of the building. Bury the cable at least 18 inches and bond it to the rods. After you lay the ground conductors in the trench and bond them to the ground rods, apply a protective sealant. After you have accomplished all bonds and sealed them, refill and tamp all trenches and holes.

Water pipes

One of the best earth electrodes is an electrically continuous network of buried metal water pipes. Whenever such a system is available, use it and bond it to the ground loop at the crossover point. At least 10 feet of electrically continuous pipe is required. Before making a connection, check for the presence of electric current. If there is current, eliminate it before you use the pipes to enhance the earth electrode subsystem. Measure the resistance of water pipe connections before using them. In average soil, a good pipe network has a resistance of less than 3 ohms. Replace or bypass with low impedance bonds any nonconductive portions of pipe, water meters, and insulating joints. Leaded or screw-type joints usually provide low impedance. Joints made of "leadite" or similar cements may have impedances of several hundred ohms—bypass them.

Connect water pipes, well casings, and other incidental electrodes to the earth electrode subsystem with 1/0 AWG solid bare copper wires buried at least 18 inches below the surface. Use conventional or exothermic welds to bond, but you may connect pipe with clamps. After bonding, apply a protective sealant to the wire and then refill and tamp the trench.

221. Bonding and troubleshooting grounds

Now that you know the types of grounds and how to install them, we will go over bonding generators and troubleshooting grounds.

Connecting generator to ground

No matter what type of ground you use, it is important to install the generator to the grounding source properly. There a few things that you must determine before connecting the generator. First, you must know if the generator is a standby or prime power unit. Second, if it is a standby unit, you must know what type of switch connects the generator to load This is important because it will determine if you bond the generator's ground and neutral.

Prime power generation

You will bond the ground and neutral if you are providing prime power. To bond the generator, install the appropriate jumper from the neutral and ground connection on a generator. You do this to provide a path for electricity to ground in the event of a fault.

Standby generation

If the generator is being used as an emergency or standby generator in the event of a power outage, you must determine how it is connected to the load. If either an automatic a manual transfer switch connects it, you will need to check if the neutral is switched.

Switched neutral

If the neutral is switched, you must bond the generator because there is not another available path for fault current that may occur on the neutral conductor. Essentially, this is like operating a prime power unit. See figure 4–2.

Un-switched neutral

If the neutral is not switched, you must remove the generator bonding to eliminate more than one path for fault current, which can cause many electrical system faults. See figure 4–2.

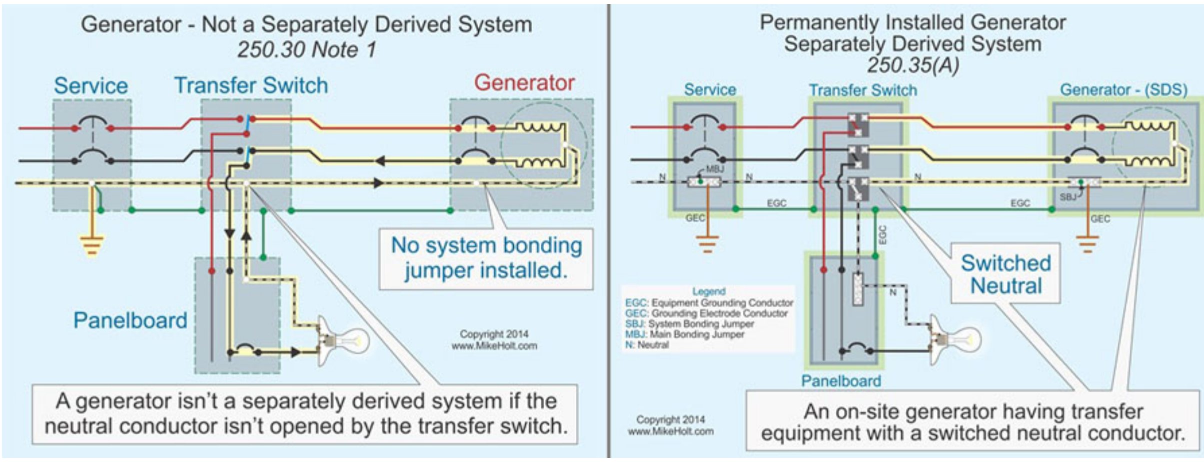


Figure 4–2. Generator bonding.
(Reprinted with permission from Mike Holt Enterprises, Inc.)

Grounds are very reliable if properly maintained. If you are having problems involving grounds, there are a few things to check that usually will solve the problem.

- Ensure that the generator bonding is correct.
- Check for corrosion and loose connections. This can cause corrosion, which can lead to higher resistance.
- Check the security of the grounding rod. If this is loose, it may have become disconnected from the rest of the grounding system.

If the bonding is correct, there is no corrosion or loose connections, and the grounding rod is secure, you may have to add to your current grounding system.

Methods of obtaining better grounds

High soil resistivity makes it difficult to obtain satisfactory low electrode resistance. The table below explains several ways to lower the resistance of the electrode (in order of preference).

Method	Explanation
Ground rod depth	As a ground rod penetrates deeper into the soil, it makes more surface contact with the earth. Also, the deeper soil is more conductive. The deeper the electrode, the less likely is surface moisture content and temperature to affect grounding.
Parallel ground rods	Ground rods driven parallel to each other should have space between them equal to at least the length of the rods. Multiple rods connected by a conductor have a greater ability to equalize potential over the installation area.
Soil replacement	You can significantly lower the resistance of a ground rod by lowering the resistance of the soil immediately surrounding it. The cathodic protection specialists have a good method of doing this. This mixture is better than chemical salts because it lasts much longer. Do the following: Dig a hole 8 to 12 inches in diameter. Center the ground rod in the hole. Mix together 75 percent gypsum, 20 percent bentonite (well driller's mud), and 5 percent sodium sulfate. Prepare enough to fill the hole almost to the top. Place the dry mixture in the hole surrounding the rod to within 6 inches of the top and tamp the mixture down. Finish filling the rest of the hole with earth and tamp it down.

There are many types of devices you can use to ground equipment. The best one may not always be the easiest or most convenient to use. Remember, as you install a ground, you and your coworkers' lives are at stake. Make sure the ground you install meets all of the requirements.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

220. Types and installation

1. What are three things that cause static electricity to form?
2. How much of a static charge can ignite gasoline fumes?
3. Why is it necessary to use the ground rod-driving adapter?
4. Where is a star ground configuration particularly useful?
5. What do grid electrodes consist of?
6. How deep must plate electrodes be buried?

221. Bonding and troubleshooting grounds

1. Why do you bond the generator’s neutral and ground?
2. When are the ground and neutral bonded?
3. What can a loose connection on a generator ground cause?

4–2. Automatic Transfer Switches

With the cost of fuel increasing almost daily, it is virtually impossible to staff a power shop 24 hours a day, but this is not very cost-effective due to the manpower cost involved. So what is the solution to manning generators for critical sites in case of bad weather or a power outage?

Some of the critical sites for Air Force generators are the hospital, communication sites, aircraft navigational sites, and water plants. These sites must have an emergency source of power in case of emergencies to continue the mission. These sites have an automatic transfer switch (ATS) that would start the emergency generator and maintain the site until the condition is corrected. An ATS switches the load from a commercial source to an emergency generator or vice versa, so some manufacturers refer to them as automatic transfer switches. In this section, you learn how to review the construction features, operating principles, and maintenance procedures for the ATS.

222. Components and theory of operation

ATSs provide around-the-clock control for starting and stopping the generator along with the ability to switch from commercial and generator power. This occurs through a series of solid-state monitoring devices.

Controls

An ATS is one giant control. It contains several inputs and outputs which determines when to start the generator and transfer the load.

Commercial power monitoring

Even though many ATS manufacturers use various names to describe their systems, they all work in roughly the same manner. The commercial power monitoring is no exception; there are inputs to a solid-state controller, which is monitoring both the presence and quality of commercial power. The controller is looking at voltage values and frequency. There are predetermined points of where the controller will signal for the start of a generator. On some systems, you make these adjustments at external points on the controller itself. On others, you connect a laptop and make the adjustments by reprogramming the controller. Common adjustments you make are percentage of desired voltages and frequency.

Engine start control

The engine start control is usually an output of the controller itself. These can be either normally open or normally closed set of contacts. The set of contacts you use will depend on the generator you are attempting to start. In the normally open configuration, once commercial power goes out, they will close providing a path to the generator start control, and this will cause the engine to start. When using the normally closed configuration, the circuit will open causing the generator controller to start the engine. There is also a time delay feature. This feature allows for a several second delay from the time the power goes out until the generator starts. This helps eliminate unnecessary startups in the case of a small short power bump.

Generator power monitor

The generator power monitor senses generator voltage and frequency. Once voltage and frequency are within limits, the monitor sends a signal to switch the transfer switch. You can make several adjustments to this monitor including percentage of desired voltage and frequency.

Transfer control

The transfer control sends a signal to the transfer motor to transfer to emergency.

Retransfer control

The retransfer control sends a signal to the transfer motor to retransfer to commercial (normal) power. This control also has a time delay, which is based upon how long commercial power has been back up. Most times this is also adjustable.

Engine shutdown timer

This engine shutdown timer ensures that the generator has time to cool down before it shuts down. Some generators have a built-in time down cooler when they start automatically; you may be able to disable this feature.

Other sensors and controls

On older systems, there may be a time delay relay external to the controller itself. Additionally, there may be inductive relays that perform some of the actions that the solid-state components now perform. These tend to be less reliable because of the large amount of moving parts and the relatively high voltage required to initiate the relays, which can cause arcing over time.

Power supply

In order to run solid-state circuits and other devices, a lower voltage is needed to help reduce arcing on the small paths for electricity.

Transformers

The ATS uses transformers to bring the system voltage down to a usable level. Many manufacturers will use these transformers to obtain 24 volts, alternating current (VAC).

Transfer/retransfer motor

Most transfer/retransfer motors are 24 volts, direct current (VDC) motors because most single-phase AC motors can only rotate in one direction.

Rectifier

Because manufacturers use DC motor for transferring and retransferring, a rectifier must be used to convert incoming AC to DC for the operation of the motor.

Operation

The operation of an ATS relies on a series of events all working together to accomplish the transfer of the load to the generator then back.

Commercial power outage

During a commercial power outage, the commercial power monitoring circuit detects a problem with the incoming commercial power. Once commercial outage drops out of the programmed parameters, it actuates a time delay; this can be from almost immediate to several seconds. At that time, the engine start control sends the appropriate signal to the generator to tell it to start. As the generator is coming up to speed, the generator power monitoring circuit looks for the proper voltage and frequency; once this is obtained, it signals the transfer control. At this point, the transfer control sends a signal to the transfer motor causing it to switch to generator power.

Commercial power returns

As the generator is connected to load the commercial power, the monitoring circuit is constantly monitoring for the return of power. Upon the return of commercial power, the monitoring circuit sends a signal to the retransfer control. The retransfer control starts a timer to ensure that commercial power is steady for the desired amount of time. Once the prescribed amount of time has passed, the retransfer control sends a signal to the motor, and the motor will retransfer the load to commercial. At this point, the engine shut down timer starts counting down. At the end of this period, it sends a signal to the generator telling it to shut down. The engine shuts off, and the ATS goes back to monitoring for power failures.

223. Inspection, maintenance, and installation

As with any equipment maintenance, testing and inspections are necessary to keeping an ATS working. We will now go over these tasks.

Inspection

A thorough visual inspection of the electrical components often reveals minor discrepancies you can correct, which will prevent them from developing into major problems. Check such items as the wiring harness for breaks, worn or cracked insulation, or any signs of rubbing against any metal parts. Check transformers, resistors, relays, and terminals for loose connections, evidence of overheating, cracks, corrosion, or any signs of damage. Inspect other components for obvious damage from overheating, wear, or abuse. If the inspection reveals problems with any component, replace it immediately to ensure continued system reliability.

Testing

You must perform a functional test of the complete emergency power transfer system. This test ensures that the generator set and panel work correctly. You initiate the test by disconnecting (opening disconnect switch) the incoming power source that feeds the transfer switch. The ATS will sense the loss of power and start the generator, transfer to generator power for the duration of the test. To complete the test, restore incoming power to the ATS. The system should automatically retransfer the load back to the normal power source and shut down the generator.

Adjusting

When adjusting an ATS, make sure to consult the manufacturers’ manual. Be very careful when adjusting the ATS, and always make adjustments in small increments.

Drop outs

When you are adjusting the drop out (the percentage or value of when the panel will transfer), you must know what you are powering along with what the actual incoming voltage is. Some places may have a slightly higher or lower voltage. If you have your adjustments too tight, this could cause constant transfers to the generator. In addition, if your load has a very precise requirement, you do not want to cause damage to it by making adjustments that allow for too much voltage variance.

Pick ups

Pick-ups are similar to drop outs. They are simply the percentage or value of when the panel will retransfer back to the normal power source.

Engine start delay

In some instances, you may need the engine start delay set close to zero. Some of these instances could include areas that have a time requirement for being up and running once power goes out. One of these is for weapons storage areas security lighting.

Retransfer time delay

You will rarely make this adjustment; however, if you are in a location where power is very unstable during certain parts of the day you may want the generator to run that entire time.

Engine shutdown delay

As discussed earlier, some generators have built-in shutdown delays. If that is the case, you can set this delay to zero. You can lengthen the delay to ensure that instant power is available if you are in a location where power is very unstable during certain parts of the day.

Troubleshooting

When troubleshooting your ATS, it is important to follow the troubleshooting step discussed earlier. It is even more important to know how your particular ATS works. Use caution because you are working with high voltages, and make sure that you are wearing your appropriate personal protective equipment (PPE).

Replacing components

When replacing ATS components, you must ensure that all power is turned off to the panel. Hazardous voltages are present and can cause death if you come in contact with them. Follow all manufacturers’ manuals and recommendations when replacing components.

Compatibility
When determining your ATS compatibility, you must see if the panel is rated appropriately for application you are using it for.

Location
All electrical systems have ratings based on where they may be used. Is the electrical system going to be used outdoors? Is it going to be in an area where it must be explosion proof? Is the panel going to be exposed to weather where it must be weather tight? If you have any questions, refer to the National Electric Code (NEC) to determine the rating that you must use.

Voltage rating
The panel must be rated for the system voltage. Some manufacturers allow for some modification so refer to the manual to find out if you can change the voltage.

Amperage rating
The panel must be rated for the amperage of the circuit. The rating of the panel must not be less that the output of the generator.

Poles or phases
Ensure that you have the correct amount of poles or phases for application you are using. All new installations must use a switched neutral. When you order a new panel, make sure the neutral is switched.

Installation
When installing an ATS, you must take a few general steps:

- Coordinate an outage for the time it will take to do the job.
- Gather all the materials and tools that you need to complete of the job.
- Do as much pre-work as possible safely before the outage.
- Once the outage starts, work as quickly as you can while adhering to safety and proper work methods.
- Double-check all of your work. In particular, make sure phase rotation is correct and that all connections are tight.
- Once complete, restore commercial power and complete a full test of the system.
- Clean-up the work site and ensure that you return all your material and tools to the appropriate locations.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

222. Components and theory of operation
1. How are adjustments made to commercial power monitoring?

2. What type of contacts are used for the generator start control?

3. What control sends a signal to transfer the load to the generator?

4. What control sends a signal to transfer the load to commercial power?

5. What allows the generator to cool down before shutdown?

223. Inspection, maintenance, and installation

1. How do you perform a functional test of an ATS?

2. When would you adjust the retransfer time delay?

3. When replacing components, what must you do before performing the maintenance?

4. What are four considerations when determining the compatibility of an ATS?

5. When installing an ATS, what must you do once you restore commercial power?

Answers to Self-Test Questions

220

1. (1) It can result from friction between small particles.
   (2) It can form from electrostatic induction by a charged object.
   (3) It also comes from contact and separation of two substances, one or both of which are nonconductive.
2. 1,500 volts.
3. Without it you will damage the top of the ground rod making it difficult to place a ground connector on it and making it impossible to screw in another coupler to allow another ground rod to be installed
4. Mobile sites.
5. Buried wires joined together to form a network of squares.
6. 4 to 8 feet below grade.

221

1. To provide a path for electricity to ground in the event of a fault.
2. (1) Prime power generation.
   (2) Standby with a switched neutral.
3. This can cause corrosion, which can lead to higher resistance.

222

1. External points on the controller itself. On others, this is accomplished through a computer program, where a laptop is connected and the adjustments by reprogramming the controller.
2. Normally open or normally closed set of contacts.
3. Transfer control.
4. Retransfer control.
5. Engine shutdown timer.

223

1. Going to the power source for the transfer panel and opening it.
2. In locations where power is very unstable during certain parts of the day and you want the generator to run that entire time.
3. Ensure that all power is turned off to the panel.
4. (1) Location.
   (2) Voltage rating.
   (3) Amperage rating.
   (4) Poles or phases.
5. A full test of the system.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

88. (220) In what type of weather can a static charge can be most hazardous?
    a. Arid, hot weather.
    b. Dry, cold weather.
    c. Wet, cool weather.
    d. Humid, warm weather.

89. (220) At what voltage can static charges ignite gasoline fumes?
    a. 1,500.
    b. 3,000.
    c. 5,000.
    d. 10,000.

90. (220) What function does a static ground serve?
    a. To connect all noncurrent carrying metal parts of an electrical system to ground.
    b. To provide a path to ground for current from lightning strikes.
    c. To provide a path for electricity to ground in the event of a fault.
    d. To dissipate or reduce unwanted electrical charges in hazardous areas to ground.

91. (220) What function do equipment grounds serve?
    a. To connect all noncurrent carrying metal parts of an electrical system to ground.
    b. To provide a path to ground for current from lightning strikes.
    c. To provide a path for electricity to ground in the event of a fault.
    d. To dissipate or reduce unwanted electrical charges in hazardous areas to ground.

92. (220) When installing a star ground, what is the *best* approach to lower resistance and reactance at the same time?
    a. Use larger conductors.
    b. Increase the number of conductors while keeping their lengths short.
    c. Decreasing the number of conductors but making them longer.
    d. Use small conductors.

93. (220) It is important to use straight conductors when installing grounds because a curved conductor
    a. can increase resistance.
    b. can cause inductance.
    c. cannot be driven into the ground.
    d. can cause capacitance.

94. (220) Before making a ground connection to a water pipe, check for the
    a. tightness of the connector.
    b. presence of electric current.
    c. depth the ground rods is driven.
    d. type of material the soil is made of.

95. (221) The purpose of bonding the generators neutral and ground is to
    a. connect all noncurrent carrying metal parts of an electrical system to ground.
    b. provide a path to ground for current from lightning strikes.
    c. provide a path for electricity to ground in the event of a fault.
    d. dissipate or reduce unwanted electrical charges in hazardous areas to ground.

96. (221) You will bond the the generator's neutral and ground if you are providing
    a. prime power generation and a standby generator with a switch neutral.
    b. prime power generation and a standby generator with an un-switched neutral.
    c. a standby generator with an un-switched neutral only.
    d. prime power generation only.

97. (222) Which automatic transfer switch control sends a signal to transfer the load to generator power?
    a. Retransfer control.
    b. Transfer control.
    c. Engine start control.
    d. Engine shutdown timer.

98. (223) When conducting a visual inspection of an automatic transfer switch, what should you do if you find a problem with a component?
    a. Open work orders to have somebody else replace it.
    b. Tell your supervisor.
    c. Replace it immediately.
    d. Operate it in the manual mode.

99. (223) What automatic transfer switch adjustment could be set to zero if the generator has a built-in shutdown timer?
    a. Engine shutdown delay.
    b. Retransfer time delay
    c. Engine start delay.
    d. Transfer delay.

100. (223) When installing an automatic transfer panel, what do you have to ensure when double-checking your work?
    a. Doing a full system test.
    b. Doing as much pre-work that can be done safely.
    c. Ensuring phase rotation is correct and that all connections are tight.
    d. Cleaning up the work site.

Student Notes

Glossary of Abbreviations and Acronyms

Ω	ohms
μf	microfarads
AC	alternating current
ATS	automatic transfer switch
AWG	American Wire Guage
DC	direct current
E	voltage
EMF	electromotive force
FO	foldout
I	current
kVA	kilovolt-amps
kW	kilowatts
LED	light -emitting diode
MEP	Mobile Electric Power
MW	megawatts
NC	normally closed
NEC	National Electric Code
NO	normally open
Ohms	resistance
OL	infinity
P	power
PMG	permanent magnet generator
PPE	personal protective equipment
R	resistance
RMS	root-mean-square
SSR	solid- state relay
TO	technical order
VA	volt-amps
VDC	volts, direct current

W	watt
X	reactance

Student Notes

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