SCOPE: This section provides an overview of rectifier operation and discusses rectifier inspection, troubleshooting and maintenance.

INTRODUCTION

- The most common type of power supply used for impressed current CP is a transformer/rectifier, commonly referred to simply as a rectifier. The most common source of DC power for an impressed current CP system is a transformer-rectifier, often called a rectifier. A rectifier converts the AC power supply voltage to the required output voltage and then converts it to DC. Where AC power is economically available, rectifiers have clear economic and operating advantages over other power sources.

- Rectifiers are either supplied in ventilated cases to allow convective air cooling or are immersed in transformer oil. Rectifiers are normally powered by an AC power system.

- The rectifier input is an AC voltage from the commercial electrical power grid or an engine-generator. A transformer with tap adjustments in the secondary side provides a method to reduce and adjust the output voltage level and to isolate the DC circuit from the input power system. A rectifying circuit next converts the adjusted AC voltage to produce a DC voltage output.

- The basic units of a rectifier consist of:
  - AC supply
  - Circuit breaker
  - Transformer
  - Rectifying elements
  - Meters
  - DC output terminals

Knowledge Objectives

- Understand the fundamental concepts of rectifier operation.
- Understand the process of routine rectifier inspections, troubleshooting, and maintenance inspection.
• Fuses*

• Surge protection*

* depending on unit

• Figure 1 shows typical industrial rectifiers.

![Industrial rectifiers](image1.png)

**FIGURE 1** Industrial rectifiers.

**Circuit Breakers**

• The primary function of a circuit breaker is to provide protection to the rectifier components from current surges or overload. A secondary function is to act as an AC disconnect when working on the face of the panel.

• CAUTION: Circuit breaker contacts can “weld” together and not open when the lever is in the tripped position. Confirm that power is off by measurement before proceeding.

• Circuit breakers are normally installed in the AC supply with the trip lever exposed on the rectifier panel. In a 115 V\text{AC} supply a single
rectifier in the “hot” line is installed but with 230 V\textsubscript{AC} or higher a dual breaker with linked trip levers are used with a breaker in each line. Three-phase units will have a breaker in each of the three lines with linked trip levers.

- There are three types of circuit breakers, which are described below.

**Thermal Breakers**

- These breakers have a bimetallic element that carries current. An excessive amount of current will heat the element, causing the two metals to expand but at different expansion rates since they are selected for their different temperature coefficients (Figure 2). The element is then pulled to one side, thus breaking the connection. The element must cool before it can be reset.

- The thermal breaker is dependent on the ambient temperature allowing more current in a cold environment or less current in a hot environment to pass before opening.

**Magnetic Breaker**

- The magnetic breaker consists of an iron core surrounded by a coil of wire acting as an electromagnet. When the current increases beyond the rating, the magnetic field created will cause the core to pull a trip lever toward it, thus causing an open circuit (Figure 3). Under high
current surges the breaker will trip immediately and is considered the most suitable for CP rectifiers.

FIGURE 3 Magnetic breaker mechanisms.

Thermal Magnetic Breakers

- The thermal magnetic breaker is similar to a thermal breaker except that it has a magnetic plate attached to the element to increase the speed in tripping the circuit (Figure 4). A large surge of current creates a magnetic field around the plate that in turn is attracted to another plate, thus tripping the circuit before the element itself reacts due to overheating.
• Although faster than the thermal breaker, the thermal magnetic breaker has a slower reaction time to the magnetic breaker and can be used where an interrupter continues to trip the breaker.

**Transformer**

• The purpose of a transformer is to either “step up” or “step down” an AC supply voltage. It could also be used as an isolation transformer at the same voltage. Depending on the design of the transformer, it can provide an adjustable range of secondary AC voltages.

• The transformer consists of an iron core with two sets of wires coiled around it. One coil, the primary windings, is connected to the primary AC voltage supply and the alternating magnetic field induces an AC voltage in the second coil or the secondary windings through this magnetic couple (Figure 5).

**FIGURE 4** Thermal magnetic breaker mechanisms.

**FIGURE 5** Transformer schematic.
• The secondary windings can be tapped at intervals that change the number of windings and proportionally change the secondary AC voltage. By moving “taps,” the number of windings changes with a corresponding change in voltage. This is the approach taken in most constant voltage rectifiers.

Rectifying Circuits

Bridge Circuits

• Rectifiers are available for either single-phase or three-phase input power (see Figure 6). Single-phase rectifiers are available in half-wave (1 diode), center-tapped (2 diodes), and full-wave (4 diodes) bridges.

![Figure 6: Single-phase bridge rectifier circuit.](image)

• Three-phase rectifiers are available in wye (3 diodes) or full-wave (6 diodes) with full-wave bridges (shown in Figure 7) being the most commonly used. Three-phase units are more efficient than single-phase units, but the initial investment costs are higher. The actual operating efficiency depends on the specific output of the unit. The type of power available and the economic comparison of overall costs are the primary considerations in selecting a single-phase or three-phase rectifier.  

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Modern rectifiers employ either selenium or silicon diodes to provide the rectifying action. Diodes are electrical devices that allow current to pass in one direction but block current in the opposite direction.

Rectifying elements are made of either selenium-coated plates or silicon diodes. In a selenium stack, steel, nickel, or aluminum plates are coated with selenium rectifier crystals. Plates are arranged in "stacks," with the number and size of plates being determined by the voltage and current output capacity of the rectifier.

Significant facts about selenium stacks are:

- Selenium diodes are often called “self-healing,” that is, damaged areas become nonconductive and the stack continues to operate. However, the efficiency of the stack decreases.
Selenium stacks can tolerate current overloads up to 10 times rated capacity for a few minutes.

Aging occurs due to heating, resulting in reduced output voltage.

Overheating occurs if the AC voltage exceeds the stack rating.

Breakdown of the selenium coating and overheating due to transient voltages (e.g., lightning) can occur.

Insulation breakdown of the insulating tube around the mounting stud due to transient voltages can occur.

Corrosion due to salt, acids, hydrogen sulfide (H₂S), or other chemicals can damage selenium stacks.

Physical damage to the coating can occur due to overtightening or overheating due to undertightening of the contact washers during assembly.

Significant facts about silicon diodes are:

Silicon diodes consist of a wafer sliced from a pure single crystal of silicon. The wafer is hermetically sealed inside a metal case with a threaded stud on one end and a wire connector on the other.

Silicon diodes are more efficient than selenium stacks and do not age.

The silicon diode must be attached to a heat sink since they heat up quickly.

Silicon diodes are more sensitive to current surges and can be quickly destroyed by any current overload. Diodes should have a high peak inverse voltage rating (1,000 V).

Silicon diodes fail completely rather than slowly like selenium stacks.

Although the standard transformer-rectifier is by far the most common power supply used for impressed current CP systems due to economics, variations of the standard transformer-rectifier are
available such as silicon-controlled rectifiers, switching-mode rectifiers, and pulse-type rectifiers.

Operational Modes

- The common rectifier operation modes include:

- Constant Voltage: The DC voltage at the terminals remains constant for all current outputs up to the rated maximum rectifier current.

- Constant Current: The current output remains constant over a wide range of circuit resistances up to the maximum rated output voltage.

- Constant Potential: The current and voltage output vary to maintain a pre-selected structure potential.

Other Rectifier Components

Filters

- Efficiency filters are used to decrease the AC ripple of the DC output, which decreases the operating cost of the rectifier. Filters are most often used on single-phase bridge and center tap rectifiers. Filters consist of chokes, capacitors, or a combination of capacitors and chokes.

Surge Protection

- Surge protection is used to protect the rectifier from lightning.

Interrupters

- Built-in interrupters can be supplied with the rectifier to allow cycling the unit on and off for testing purposes.

Warning Devices and Signal Lights

- These are used to alert personnel to operating malfunctions of the unit. They will not provide information on irregularities with the CP system other than what is occurring within the rectifier itself.
Remote Monitoring

- Devices can be installed to monitor current, voltage, and structure potential from a remote location. Some of these devices can be used to control the output.

Adjustments of AC and DC

- As described above, constant voltage rectifiers are usually adjusted by changing the transformer tap settings. These adjustments change the AC voltage supplied to the rectifier stacks. The adjustment taps are found on the front panel of the unit and consist of shorting bars for coarse and fine adjustment. The rectifier MUST be turned off at the breaker before any taps are changed. A lock out/tag out procedure is also recommended. Changes should be made one step at a time.

- The general procedure to change taps is to increase the fine tap one setting making certain that the connections are tight. Turn on the unit and measure the DC output voltage and current. If not satisfactory increase the fine taps again and repeat the process. When the fine taps have reached the maximum, lower it to the first setting and increase the coarse taps one setting. Continue in this manner until the desired output is reached. To lower the output, the reverse procedure is used except that a major reduction may be in order if the reason to reduce the taps is because the circuit breaker tripped.

- Potential control and constant current rectifiers are controlled using a potentiometer adjustment found on the controlling circuit board. On potential control rectifiers, this adjustment controls the structure-to-reference potential, which controls the output voltage and current. Transformer tap setting bars are often also found on potential control and constant current rectifiers as another control on the DC voltage.

- Detailed procedures for adjustment of a rectifier are covered in Module 4, Section 6.
RECTIFIER INSPECTION AND TESTING

- CP rectifiers or other impressed current power source must be inspected at certain intervals each calendar year to ensure that they are operating properly. Through the use of a multimeter and proper reference electrode, measurements can be obtained at an existing CP rectifier or other impressed current power source to document operation.

- **CAUTION:** Only qualified personnel are to test and work on a rectifier. Safety is of the utmost importance when working on an electrical device.

- Note the precautions discussed in Module 2, Safety.

- Determine if the rectifier or any associated electrical equipment is in an electrically hazardous area. Do not open any explosion-proof junction boxes unless otherwise qualified and then only if the circuits are turned off and locked out/tagged out.

- Do not work on or remove any rectifier component without first turning the upstream power off and locking/tagging out.

- When first approaching the rectifier, confirm that the case is not electrically “hot” either by taking an AC voltage-to-ground measurement or with a voltage alert device.

- On first opening the rectifier, identify any exposed terminals that will have a voltage and take measures to protect yourself from them.

Module 2, Safety also contains additional safety precautions when working with rectifiers.
FIGURE 8 Typical lock out/tag out kit.

- It is important to ensure that the power source in an impressed current system, such as a rectifier, remains operational and that the CP system is connected with proper polarity.

The negative (−) terminal of the power source must be connected to the structure and the positive (+) terminal must be connected to the anode bed (see Figure 9).

- The proper connection of a rectifier is CRITICAL and if done improperly can result in catastrophic damage to the structure that is supposed to be protected, resulting in loss of product, structural damage, property damage, environmental damage, or loss of life.

- Often the CP cables are either not identified or are incorrectly identified. It is therefore mandatory to verify the proper connection polarity. This can be accomplished by measuring the structure-to-electrolyte potential near the power source both before and after the source is activated. A shift in potential in the electronegative direction with the power source energized confirms the correct polarity. For this test the cable connected to the negative terminal of the rectifier should not be used as the test lead for the structure-to-electrolyte potential measurement.

- When connecting a rectifier to an AC power supply, the AC supply circuit should be dedicated and separately fused. The rectifier should never share an AC circuit with normally interruptible facilities such as lighting and pumps.

- The voltage and current output of the power source should be monitored regularly to ensure that the unit remains operational. Basic rectifier operational data include:
  - AC input voltage
  - DC output voltage and DC output current
• Tap settings and/or potential set point (if constant potential) or current set point (if constant current)

• Anode-to-structure resistance

![Diagram of typical rectifier connections]

**FIGURE 9** Typical rectifier connections.

**ROUTINE RECTIFIER INSPECTION**

• Rectifiers should be inspected for proper operation. When a rectifier is found to be non-operational, it requires immediate attention. Information related to AC input voltage, fuses, and condition are important to note as well as the following items:

  • AC on cabinet
  • Loss of AC
  • Efficiency of stacks—lightning damage
  • Spider webs
- Tightness of connections and heat generation
- Negative and positive verification
- Troubleshooting
- Repair or replace defective rectifier components
- Adjustment of rectifier

When performing an inspection, previous rectifier inspection reports should be obtained and available for comparison. The inspector should also obtain the following information:

- Manufacturer
- Company identification number or company rectifier number and nameplate data including:
  - Rated DC output voltage and current
  - Primary AC input voltage

Access to the rectifier should be documented, in writing, including any obstructions that may have been encountered. The condition of gates, fencing, or guards protecting the rectifier and the rectifier enclosure should be inspected for obvious damage. Deficiencies and corrective actions taken should be documented and any abnormal conditions reported. Examples of abnormal conditions that may occur or may exist during a routine rectifier inspection include, but are not limited to, the following:

- Test measurements obtained with this task indicate a more negative reading with the rectifier “off” than “on.”
- Reversed structure and anode lead connections were made at the rectifier output terminals.
- Structure-to-soil measurements obtained with this task are found to be significantly different when compared using two different structure connections.
• Voltage measurements obtained with this task are found to be opposite of expected values.

• At least once each year (usually at the time of the annual corrosion survey), rectifiers should be thoroughly and systematically inspected. Special attention should be given to the following items:

• Clean and tighten all current-carrying connections.

• Clean all vent screens and remove any obstructions.

• Remove any insect or animal nests and plug entry points.

• Check indicating meters for accuracy by comparing with calibrated portable instruments.

• Replace any wire with cracked or deteriorated insulation.

• Check all protective devices (circuit breakers, fuses, or lightning arrestors) for evidence of damage.

• Carefully inspect for evidence of excessive heating.

• For oil immersed units, check the color and level of oil. Change oil if rectifier components cannot be seen beneath the oil.
Rectifier Voltage and Current Output Readings

- **Rectifier Voltage (see Figure 10):** When taking a rectifier voltage reading the meter should be set to volts.

![Figure 10 Rectifier voltage reading.](image)

- **Rectifier Current Output (see Figure 11):** To determine current output of the rectifier you will be taking a mV reading across the rectifier shunt. Set your meter to the mV scale and the meter leads to the shunt-reading terminals. What is the direction of current? Use the leads and the polarity (positive or negative) of the reading to determine.
When measuring current using a shunt, any shorting straps connected across the shunt to protect it from lightning damage must be removed to obtain a valid reading.

If the meter reading reads positive (+), the current direction is from the red lead (volt terminal of meter) to the black lead (com terminal of meter).

If the meter reading reads negative (–) current is moving in the opposite direction. How is this important when determining the critical nature of the bond? If there is an established bond, there should be some indication of current; if not, this is an abnormal condition.

Always use extreme caution when working on or near electrically energized equipment. Read the manufacturer’s safety instructions before performing any work on a rectifier, and read and follow all documented company safety procedures.

Examples of abnormal conditions that may occur or may exist during rectifier measurements include:

- Excessive heat
- Burning “electrical smell”
MODULE 4 CATHODIC PROTECTION
Section 4 INSPECTION AND MAINTENANCE OF CATHODIC PROTECTION RECTIFIERS

- Energized cabinet
- No case ground
- A slide-in rectifier that is not properly bolted to frame
- No voltage and/or current output
- Improperly supported rectifier
- Incorrect connection of structure lead and/or anode lead
- Loose mechanical connections
- Significant change in either voltage and/or amperage readings compared to historical operation
- Damage caused by animal, insect, or reptile habitation
- Excessive dirt, dust, or spider webs to a level where operation of the rectifier is abnormal
- Operating conditions (voltage output or amperage output) above or below unit design operating parameters

RECTIFIER TROUBLESHOOTING

Output Problems

- A good maintenance program can often detect potential rectifier failures beforehand, allowing scheduled repair before an actual outage. Even with the best of maintenance programs, however, failures do occur. Often basic step-by-step troubleshooting techniques can determine the cause of the outage. For the following discussions, only standard single-phase, manual adjustment type rectifiers are considered.
• When checking rectifier outputs on a routine basis, there are four basic cases of symptoms requiring investigation: zero current and voltage outputs, zero current output with unchanged output voltage, significant current change with unchanged voltage, or significant changes in both voltage and current outputs.

Zero Current and Voltage Outputs

• For the case of zero output for both current and voltage, either there is no input power to the unit or an open circuit within the rectifier is indicated. First, determine if input AC voltage is present. If not, the problem is external to the rectifier. If AC voltage is present at the input terminals, an open circuit exists within the rectifier. However, the open circuit may be due to a tripped circuit breaker at the rectifier input.

• The component causing the open circuit can be located by realizing that the rectifier voltage must exist across the open circuit element. If it is determined that the input circuit breaker has tripped, a high current or overload has occurred. This high current could have been a temporary problem, perhaps due to a lightning surge, or a permanent short circuit. The best method of proceeding is to reduce the voltage output tap to a low level and reset the circuit breaker. If the circuit breaker does not trip again, the problem was probably temporary and full output voltage can be restored. If the circuit breaker does trip, a permanent short circuit is indicated.

• The sequence of short circuit location based on a circuit breaker tripping is shown in Figure 12.
To determine if the short circuit is external to the rectifier, turn off the AC power supply, disconnect one of the DC output connection leads and reset the breaker. If the short circuit is external to the rectifier, the circuit breaker will not trip. If the short circuit is internal to the rectifier, the circuit breaker will again trip. Next, the best approach involves isolating the problem to a particular section of the rectifier by beginning at the input terminals and adding one component at a time to the circuit until the circuit breaker trips. The short circuit must be the last component connected when the circuit breaker trips. For example, the transformer can be connected to the input circuit breaker with the tap adjustment bars removed.

Zero Current Output with Unchanged Voltage Output

If the DC voltage output of the rectifier is relatively unchanged but the current output is zero, an open output circuit is indicated. This could be caused by:
• Open fuse in the output circuit. If an open fuse in the output circuit is found, either a high temporary current surge or a short exists (or has existed) in the output circuit.

• Faulty connections

• An open positive or negative lead cable

• Failed anodes

**Significant Current Change with Unchanged Voltage**

• If the DC current output significantly changes with no change in the output voltage, the output circuit resistance has changed. If the current output has significantly increased, a lower circuit resistance is indicated. This could be due to system additions, shorts to other underground structures, or major coating damage. If the current output significantly decreased, a higher circuit resistance is indicated. Some of the possible causes might include installation of inline isolators, anode deterioration, discontinuity due to disconnection of a system component, or gas blockage. Seasonal variations in soil conditions, such as drying or frost, can also increase the current resistance.

**Significant Changes in Both Voltage and Current Outputs**

• Sometimes both the voltage and current outputs will decrease significantly. If the voltage and current outputs are approximately one-half of the normal values, the most probable cause is partial failure of the rectifier stacks (“half waving”). If the rectifier stacks are found to be operating properly, the transformer should be investigated for possible winding-to-winding shorts.

• The existing rectifier operational data should be compared to prior data from when the rectifier was known to be operating properly. If abnormal data is obtained, then troubleshooting procedures need to be used.

• If the anode-to-structure resistance is normal, then the problem is with the rectifier.
• If the anode-to-structure resistance is not normal, the problem could be outside the rectifier.

• Open circuit and short circuit failure modes can occur on all impressed current systems. Usually a short circuit condition will cause either the rectifier breaker or AC supply breaker to trip. In many instances, the power source fuses are also blown. The short circuit can appear either within the rectifier or external to the power supply.

• The following conditions can cause internal short circuits:
  
  • Failed diode(s)
  
  • Contact in transformer windings
  
  • Contact between positive circuit and the rectifier cabinet or negative circuit
  
  • Spark-gap type lightning arrestors failed in the shorted condition
  
  • External short circuits can occur due to any metallic contact between the positive and negative circuits. Inadvertent contact between the anode or its low resistivity backfill and the structure is the most common type of external short circuit.

• When confronted with a possible short circuit, disconnect all external positive and negative cables at the rectifier before re-energizing the rectifier. If the rectifier operates normally upon re-energizing, then the short is external to the unit, providing the short reappears when the cables are reconnected. Some rectifier units can be operated in the shorted condition when on the lowest AC tap setting. This facilitates troubleshooting to find the defective component. A pipe or cable locator connected between the positive and negative cables at the rectifier can also be used to pinpoint an external short circuit. Disconnecting the components in sequence starting at the output of the unit and working back toward the transformer is a relatively convenient method of locating the shorted component.

• Open circuits can appear within the power source or external to it. The open circuit condition is characterized by a zero current output. If the open circuit is external to the rectifier then the voltage output will
appear at the terminals of the rectifier. If the open circuit is internal, then the voltage will appear across the internal component with open circuit. Common causes of internal open circuits include the following:

- Failed diode(s)
- Broken cables
- Open connections
- Failed or weak breaker
- Blown fuse(s)

External open circuits generally involve broken or corroded cables, although on occasion, the groundbed may be consumed.

Circuit Diagrams

- Each rectifier should be supplied with its own specific circuit diagram that can be consulted to establish the electronic configuration of the unit. This is a code requirement in some areas.

Electrical Damage

- Note that when testing, visual inspection must be performed with the rectifier off and AC power disconnected and locked out.

- Electrical damage, such as from lightning or power surges, might be diagnosed by looking at and smelling the rectifier components. Electrical damage often shows as burnt, melted, or charred marks or the smell of burnt insulation may be present. If any of these are observed, electrical tests using a voltmeter and ohmmeter should be performed to see if the component is functioning. Electrically overstressed components will be hot to the touch.

Filters

- Filters are used to improve efficiency and for noise interference control. They consist of capacitors and chokes. If the choke is
suspected to be defective, it can be removed from the circuit with a heavy jumper placed across the choke leads.

- Capacitors usually fail by shorting. The capacitors should be fused. If the fuse is blown, replace it and turn on the rectifier. If the fuse blows again, the capacitor is defective and should be replaced.

**Detection of Cable Breaks**

- Wire connections within the rectifier can become disconnected or loose (e.g., broken solder joint, burned connection, pulled spade lug). These can be checked with a multimeter or gentle pull at the connection. *Note: Turn off and lock out rectifier before testing.*

- Broken cables outside the rectifier are also a possibility. Causes of external cable breaks include: construction damage, broken bond connection to the structure, broken anode connection, or broken anode wire due to exposure of the metallic wire to the electrolyte at a fault in the insulation.

**Testing Transformers**

- If AC voltage is present to the primary but not the secondary, check to see whether there is an audible hum coming from the transformer. If so, the primary is operating, but the secondary is probably open. Check the above conclusions by electrically isolating the transformer and checking the DC resistance of the windings with an ohmmeter. The secondary should have generally less than 1 $\Omega$ resistance while the primary should have 1 to 10 $\Omega$ resistance.

- If either value is high, the winding is effectively an open circuit and the transformer will have to be replaced.

- Use an AC voltmeter to see if voltage is applied to the stacks. If AC voltage is present, the stacks may be open circuited and should be checked with an ohmmeter. Check the leads between stacks if multiple stacks are used. On silicon stacks, remove each diode and check individually with a diode checker for forward and reverse bias. A bad silicon diode is either open or shorted.
If there is no output voltage or current, the breaker or fuse might be blown. Reduce the output slightly if due to a steady overload. Check for a possible short circuit in some component. Isolate the component and replace or repair.

If the breaker trips occasionally for an unknown reason, the problem could be:

- Temporary overload due to soil moisture changes
- Line voltage surges or wrong line voltage connections
- Intermittent short circuits. Isolate the component. Check for loose connections or brackets. (Check with ohmmeter while moving components—with POWER OFF.)
- Thermal breaker may be affected by sun’s heat—install shield or shade
- No AC line voltage. Check with voltmeter. Check the service to the rectifier or check for the following:
  - Open circuit in some component or connection
  - Defective meters or meter switches
  - Defective transformer

**Testing Diodes**

To check the diode bias, use the multimeter operated in the diode check mode (Figure 13). A functional diode will typically display a voltage from 0.3 V to 0.9 V in the forward bias; positive lead to anode, negative lead to cathode. In the reverse bias condition—positive lead to cathode and negative lead to anode—a functional diode will display “OL” (overload or out of limits).
For shorted diodes, the meter will display some low voltage value in both forward and reverse bias configuration. In the case of an open-circuit diode, the meter will display “OL” in both forward and reverse bias.

To correctly verify diode operation, at least one lead must be disconnected from the circuit. Diodes cannot be properly checked while in the circuit or with the power on.

Diodes can be tested in a rectifier after it is turned off (locked out) after disconnecting the secondary taps and the DC cables. Each tap and each DC output terminal then represents a connection to a diode. Check the manufacturer’s schematic diagram to confirm how the connections are made. Proceed with the diode test described in Figure 14.
Check diode with power off and at least one lead disconnected from the circuit. Test in forward and reverse bias.

**FIGURE 14** Diode check.

**Troubleshooting Rectifier Bond Connections**

- Through the use of a multimeter, obtain both AC and DC measurements to troubleshoot rectifier electrical connections and to confirm or identify components that may not be operating correctly or incorrectly. Done correctly, personnel should not have to go “behind” the front panel board to obtain any electrical measurements. Significant electrical safety hazards exist “behind” the front panel board and only personnel who are properly trained should work “behind” the front panel board.

- Most rectifier troubles are simple and do not require extensive detailed troubleshooting procedures. Most common problems are: blown fuses, faulty meter, loose terminals, open groundbed leads, and lightning damage. These troubles are usually found by a simple visual examination of the rectifier.

- For more difficult troubles, it is usually better to systematically isolate the rectifier components until the defective part is found.

- Abnormal conditions that may occur or may exist while troubleshooting a rectifier include, but are not limited to the following:
  - Excessive heat
  - Burning “electrical smell”
• Energized cabinet
• No case ground
• A slide-in rectifier that is not properly bolted to frame
• No voltage and/or current output
• Improperly supported rectifier
• Incorrect connection of structure lead and/or anode lead
• Loose mechanical connections
• Significant change in either voltage and/or amperage readings compared to historical operation
• Damage or habitation by animals or insects
• Excessive dirt, dust, or spider webs to a level where operation of the rectifier is abnormal
• Operating conditions (voltage output or amperage output) above unit design operating parameters
• Rectifier circuit breakers or AC breakers found “tripped” or “trip” on any attempt to re-start the rectifier unit.
• Detailed procedures for troubleshooting rectifier electrical connections on the front panel of a rectifier are provided in Section 8.

**Repair or Replace Defective Rectifier Components**

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• Detailed procedures for repairing and replacing defective rectifier components are provided in Module 4, Section 6.

• It is extremely important to recognize that electrical hazards exist when working behind the front panel or AC breaker box. Exercise caution utilizing proper lock and tag out procedures. All test leads must be of a type considered insulated. Remove all metallic objects from hands and wrist such as rings, watches, or id-bracelets. Do not work in wet conditions or wet ground without taking proper precautions to ensure safety such as using rubberized boots or utilizing a rubber mat.