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ELECTRICIAN'S TROUBLESHOOTING AND TESTING

POCKET GUIDE

THIRD EDITION

- Expertly diagnose and fix problems on the job
- Assure quality and safety compliance with time-saving charts, tables, and diagrams

H. BROOKE STAUFFER and JOHN E. TRAISTER

Electrician's Troubleshooting and Testing Pocket Guide

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Introduction

Electrical measuring and testing instruments are used in the installation, troubleshooting, and maintenance of electrical systems of all types, particularly in commercial and industrial facilities. Electricians and technicians involved with installing, maintaining, and repairing electrical equipment need a good working knowledge of portable testing instruments and how they are used to diagnose and fix problems in the field.

Most operational problems of electrical equipment and systems involve one of four basic faults:

- Short circuit
- Ground fault
- Open circuit
- Change in electrical value

This guide describes troubleshooting techniques to identify such problems using portable field-testing instruments. Although it covers many types of test equipment, this book emphasizes the use of digital multimeters (DMMs), the most common and versatile electrician's diagnostic tool.

This new third edition of *Electrician's Troubleshooting and Testing Pocket Guide* includes updated information on testing and troubleshooting lighting systems, expanded information on diagnosing power quality problems, and a new chapter on thermographic diagnostic tools.

Scope of This Book

Electrician's Troubleshooting and Testing Pocket Guide covers the use of digital multimeters (DMMs) and other testing equipment to troubleshoot electrical and electronic circuits used for power and control applications. In general, it concentrates on traditional electromechanical and inductive equipment found in commercial and industrial occupancies—motors, transformers, lighting, and power distribution equipment. In general, this guide does not cover testing and troubleshooting of the following types of equipment and systems:

Communications systems. The use of network cable analyzers, optical time domain reflectometers (OTDRs), optical power meters, and other equipment used for testing and troubleshooting communications systems such as telecommunications, computer local area networks (LANs), and outside plant fiber-optic installations are outside the scope of this publication.

Electronic components and systems. This book touches on testing of electronic components such as resistors, small capacitors, and diodes. However, the broad subject of troubleshooting electronic components and circuits using digital multimeters and other portable test equipment is covered in much greater detail in a different McGraw-Hill publication: *Electronic Troubleshooting and Repair Handbook* by Homer L. Davidson (1995; ISBN 0-07-015676-X).

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CHAPTER

1

Analog Test Instruments

Traditional meters used by electricians and technicians for field testing and troubleshooting are analog type. In an analog meter, the magnitude of the property being measured (such as voltage, current, resistance, and illumination) is indicated by a corresponding physical movement of a pointer, needle, or other indicator. Voltage, for example, is shown by the needle of a traditional voltmeter swinging to point at a number on a dial.

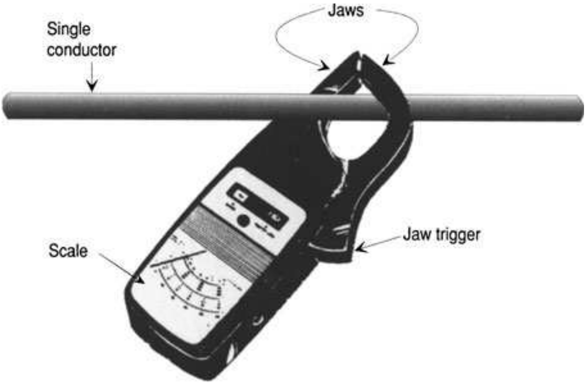
Analog meters are generally limited to a single function. The most common types are ammeters, voltmeters, and resistance testers (frequently called *meggers* in the field, after the name of one of the best-known brands of resistance tester). In some cases the usefulness of traditional analog electrical test instruments can be extended or modified with special adaptors or sensors; some voltmeters, for example, can also be used to measure temperature.

Today, the different types of single-function analog meters have been largely replaced by digital (computerized) meters that combine many measurement functions within a single compact unit. These digital multimeters (DMMs) are now used for most testing, troubleshooting, and maintenance purposes. However, there are still many older analog meters in use, and a working knowledge of these diagnostic tools is useful to electricians and technicians.

This chapter briefly describes the various types of analog electrical meters and instruments, and how they are used. Starting with Chapter 2, the rest of the handbook concentrates primarily on using DMMs.

Ammeters

Figure 1-1 shows a clamp-on ammeter used to measure current in a conductor while the conductor is energized. While exact operating procedures vary with the manufacturer, most operate as follows when measuring current:



1-1 Typical clamp-on-type ammeter.

Step 1. Release the pointer lock.

Step 2. Turn the selector knob until the highest current range appears in the scale window.

Step 3. Press the trigger to open the jaws of the clamp and place them around a single conductor.

Step 4. Release finger pressure on the trigger slowly, keeping an eye on the scale while the jaws close around the conductor. If the pointer jumps abruptly to the upper range of the scale before the jaws are completely closed, the current is too high for the scale selected. Immediately remove the jaws from around the conductor, and use a higher scale.

Never encircle two or more conductors; only encircle one conductor as shown in Figure 1-1. If the pointer moves normally, close the jaws completely and read the current in amperes indicated on the scale.

Accuracy

When using clamp-on ammeters, follow these precautions to obtain accurate readings:

1. Be certain the frequency of the conductor being tested is within the range of the instrument. Most ammeters are calibrated at 70 Hz.
2. Magnetic fields can affect current readings. To minimize this problem, try to avoid using

clamp-on ammeters close to transformers, motors, relays, and contactors.

Ammeter Applications

Ammeters are useful for troubleshooting various electrical components by indicating a change in electrical value. Many examples and troubleshooting charts found throughout this book. But here are two simple examples of ammeter applications.

Three-phase motor

The approximate load on a three-phase motor can be determined while the motor is running. To do this, clamp the ammeter around each of the three-phase conductors, one by one:

- If the ammeter shows the motor is drawing current close to its nameplate reading, this indicates the motor is fully loaded.
- If the ampere reading on each conductor is significantly less, then the motor is not carrying a full load.
- If the current measured with the ammeter is higher than the nameplate, when the motor is running at full speed and rated voltage, then the motor can be assumed to be overloaded.

Electric baseboard heater

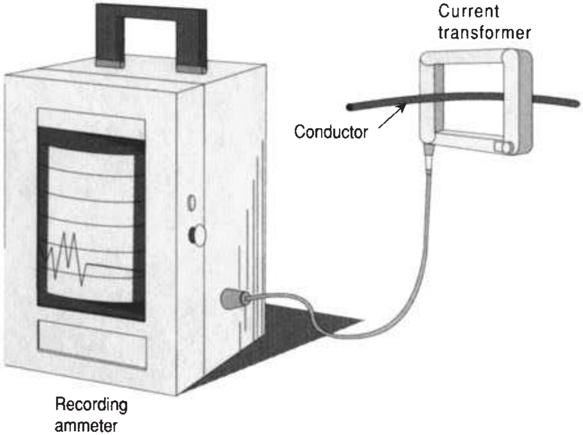
The nameplate will indicate the heater's characteristics. Let's assume that the nameplate indicates a 1000-W, single-phase, two-wire heating element operating at 240 A. If an ammeter reading, which is taken while the heater is operating, shows approximately 4 A of current, this indicates the heater is working properly, because:

$$I = \frac{p}{E} \text{ or } \frac{1000}{240} = 4.16 \text{ A}$$

But an ampere reading much different from 4 A (either higher or lower) indicates some fault in either the heater or the branch circuit supplying it.

Recording Ammeters

A clamp-on ammeter shows instantaneous current, at a moment in time. But often when troubleshooting electrical equipment and systems, it is more useful to have a record of current over a period of time. Figure 1-2 shows a recording ammeter used for this



1-2 Recording ammeter.

purpose. It has a current-sensing element similar to clamp-on ammeters, but produces a chart or graph showing current changes over time.

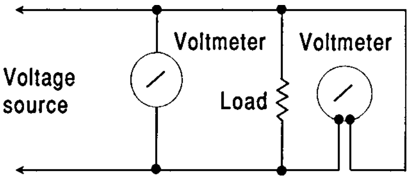
Voltmeters

The unit of electromotive force (EMF) is the volt (V). One volt is the pressure that, if applied to an electrical circuit having a resistance of 1 Ω, produces a current of 1 A.

Connect a voltmeter across the terminals at the place where the voltage is to be measured, as shown in Figure 1-3. Never connect a voltmeter across a circuit with a voltage higher than the rating of the instrument. Doing so can damage the meter, or in extreme cases cause the voltmeter to explode.

DC Circuits

When measuring voltage in a DC circuit, always observe proper polarity. The negative lead of the voltmeter must be connected to the negative terminal of the DC source, and the positive lead to the positive



1-3 Connecting a voltmeter to a circuit.

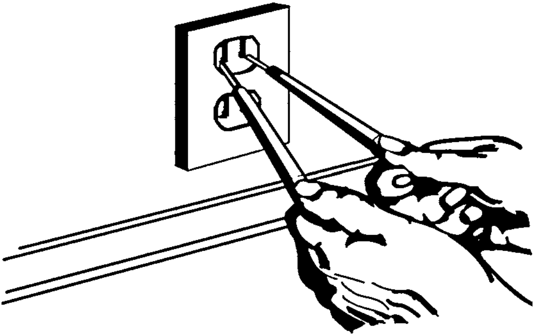
terminal. If the leads are connected to opposite terminals, the needle will move in the reverse direction.

AC Circuits

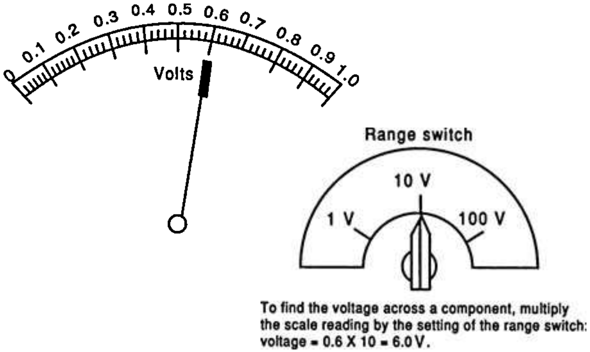
Since voltage constantly reverses polarity in an AC circuit, there is no need to observe polarity when measuring voltage on ac circuits (Figure 1-4).

Voltage Ranges

Many analog voltmeters have two or more voltage ranges that can be read on a common scale, such as 0 to 150 V, 0 to 300 V, and 0 to 600 V (Figure 1-5). When using a multirange voltmeter, always select a higher range than needed to assure that the meter won't be damaged. Then, if the initial reading indicates that a lower scale is needed to obtain a more accurate reading, switch the voltmeter to the next lowest range.



1-4 Checking voltage at a 125-VAC duplex receptacle.



1-5 Multirange, one-scale voltmeter.

One reason that analog voltmeters have multiple ranges is that readings are more accurate on the upper half of the scale. Thus, if they only had a single 0- to 600-V range, lower voltages would be harder to read accurately.

Voltmeter Applications

Voltmeters are used for troubleshooting circuits, circuit tracing, and measuring low resistance. For example, a common cause of electrical problems is low voltage at the supply terminals of equipment; this usually occurs for one or more of the following reasons:

- Undersized conductors
- Overloaded circuits
- Transformer taps set too low

Low-Voltage Test

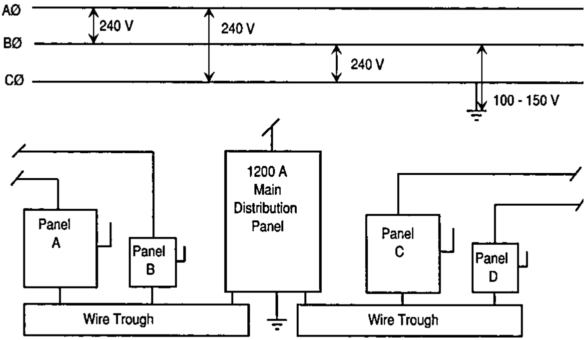
When making a low-voltage test, first take a reading at the service entrance. For example, if the main service is rated 120/240, single-phase, three-wire, the voltage reading between phases (ungrounded conductors) should be 230 to 240 V. If the reading is much lower than 230 V, the electric utility company should be contacted to correct the problem. However, if the reading at the main service is between 230 and 240 V, the next procedure is to check the voltage reading at various outlets throughout the system.

When low-voltage problem is measured on a circuit, leave the voltmeter terminals connected across the line and begin disconnecting all the loads connected to that circuit, one at a time. If the problem disappears after several of the loads have been disconnected, the circuit is probably overloaded (thus causing excessive voltage drop). Steps should be taken to reduce the load on that circuit or else increase conductor wire size to accommodate the load.

Ground Fault

Ground faults are another common problem. Assume that a small industrial plant has a three-phase, three-wire, 240-V, delta-connected service. The service equipment is installed, as shown in Figure 1-6. Under proper operating conditions, the voltmeter should read 240 V between phases (A-B, B-C, and A-C), and approximately 150 V between each phase to ground.

However, if checking with voltmeter indicates that two phases have a voltage of 230 V to ground and the



1-6 Diagram of a small industrial electric service.

third phase is only 50 V to ground, then the phase with the lowest reading (50 V) has a partial ground or ground fault. Follow these steps to correct the ground fault:

Step 1. Connect one voltmeter lead to the grounded enclosure of the main distribution panel and the other to the phase terminal that indicated the ground fault.

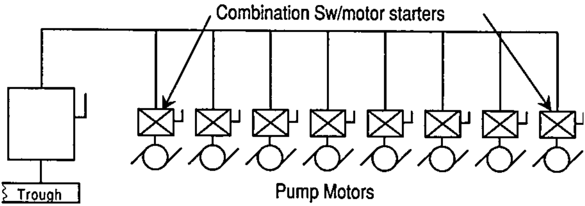
Step 2. Disconnect switch A and check the voltmeter reading. If no change is indicated, disconnect switch B, switch C, and so on, until the voltmeter shows a change (i.e., a reading of approximately 150 V from phase to ground).

Step 3. Assuming the voltmeter indicates this reading when switch D is thrown to the

OFF position, we then know that the ground fault is located somewhere on this circuit.

Step 4. Switch D disconnects the 400-A circuit feeding eight 15-hp motors and connected as shown in Figure 1-7. One voltmeter lead is connected to the grounded housing of switch D and the other lead to one of the phase terminals. The switch is then turned on. Check each phase terminal until the one with the ground fault is located.

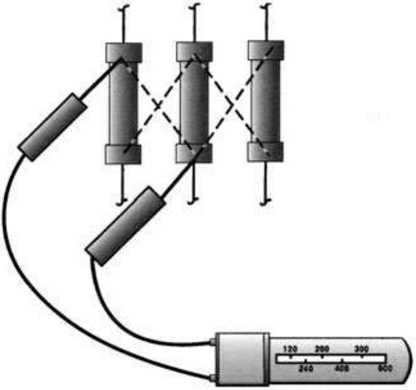
Step 5. Then, one at a time, disconnect the motors from the circuit until the one causing the trouble is found. In other words, when the motor or motor circuit with the ground fault is disconnected, the voltmeter will indicate a normal voltage of approximately 150 V from phase to ground.



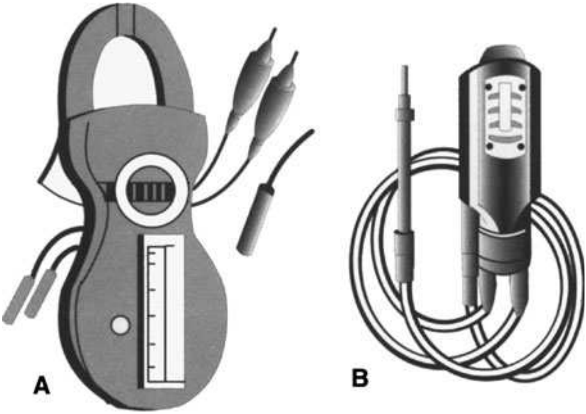
1-7 Wiring diagram for eight 15-hp pump motors fed from a 400-A safety switch.

Step 6. Repair the faulty motor or motor circuit according to standard maintenance procedures. When testing electrical circuits with a voltmeter, it is usually best to begin at the main service equipment. First, test the voltage on the line side to see if the incoming service is "hot"; if it is, then test the main fuses or circuit breakers. Check by testing across diagonally from the line to the load side, as shown in Figure 1-8.

There are various types of analog voltmeters; Figure 1-9 shows two common designs. Meter A is a combination volt-ohm-ammeter with a conventional swinging pointer to indicate the reading; meter B has an audible indicator—similar to the "ting" of an air gauge—and gives only approximate voltage readings.



1-8 **Testing fuses with a voltmeter.**



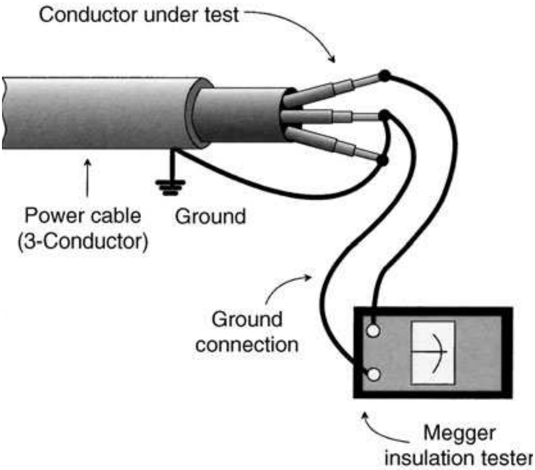
1-9 Common types of voltmeters.

Megohmmeters

The megohmmeter (commonly called a *megger* in the field) is used to measure the resistance of insulation in megohms (thousands of ohms). Test results indicate the presence of dirt, moisture, and insulation deterioration. Megohmmeter instruction manuals provide detailed information about connecting to and testing various types of equipment. The following sections provide general guidance for common types of troubleshooting tests.

Testing Power Cables

Figure 1-10 shows how to test cable insulation using a megger. After both ends of the cable have been



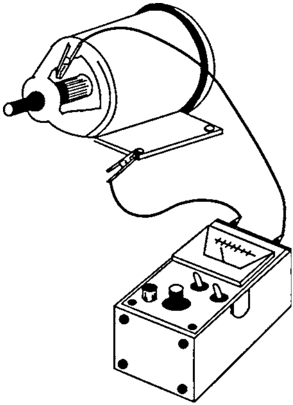
1-10 Testing power cable.

disconnected, test the conductors one at a time, by connecting one of the leads to the conductor under test and connecting the remaining conductors (within the cable) to ground and then to the other (ground) test lead.

Testing DC Motors and Generators

Disconnect a DC motor and a DC generator from its load. Then attach the negative test lead of the megohmmeter to the machine ground and the positive lead to the brush rigging. Measuring the insulation resistance in this manner indicates the overall resistance of all components of the unit.

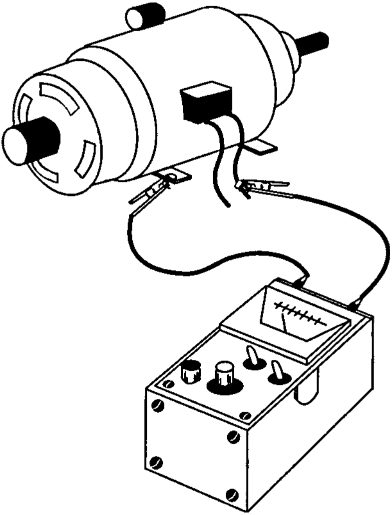
To measure the insulation resistance of the field or armature alone, either remove the brushes or lift them free of the commutator ring and support the brushes using a suitable insulator. Connect one test lead to the frame ground and the other to one of the brushes. Insulation resistance of the field alone will then be indicated, as shown in Figure 1-11. With the brushes still removed from the commutator ring, connect one of the megger test leads to one of the segments of the commutator and the other to the frame ground. The insulating resistance of the armature alone will then be indicated. This test may be repeated for all segments of the commutator.



1-11 **Megger connections for testing DC motors and generators.**

Testing AC Motors

To test an AC motor, first disconnect the motor from its power source, either by using the switch or by disconnecting the wiring at the motor terminals. If the switch is used, remember that the insulation resistances of the connecting wire, switch panel, and contacts will all be measured at the same time. Connect the positive megger lead to one of the motor lines and the negative test lead to the frame of the motor, as shown in Figure 1-12. Compare meter readings to the established insulation resistance minimums.



1-12 Method of testing an AC motor.

Testing Circuit Breakers

Disconnect the circuit breaker from the line and connect the megger black lead to the frame or ground. Check the insulation resistance of each terminal to ground by connecting the red (positive) lead to each terminal in turn and making the measurements.

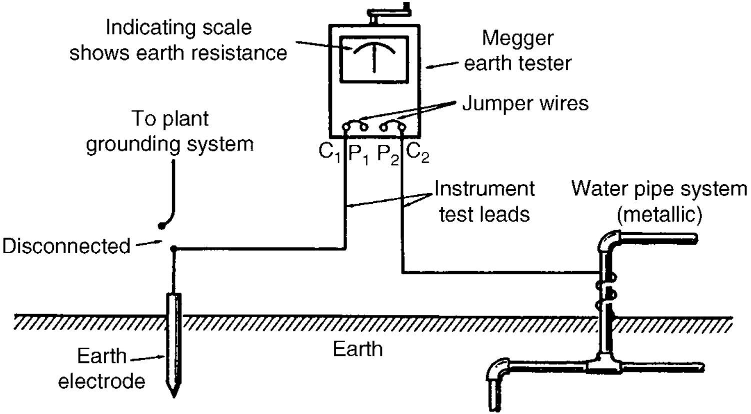
Next, open the breaker and measure the insulation resistance between terminals by putting one lead on one terminal and the other on the second for a two-terminal breaker; for a three-pole breaker, check among poles 1-2, 2-3, and 1-3.

Testing Safety Switches and Switchgear

Completely disconnect from line and relay wiring before testing. When testing manually operated switches, measure the insulation resistance from ground to terminals and between terminals. When testing electrically operated switches check the insulation resistance of the coil or coils and contacts. For coils, connect one megger lead to one of the coil leads and the other to ground. Next, test between the coil lead and core iron or solenoid element.

Testing Ground Resistance

Figure 1-13 shows the simplest method for testing the resistance of earth. The direct or two-terminal test consists of connecting terminals P1 and C1 of the megohmmeter to the ground under test, and terminals P2 and C2 to an all-metal underground water-piping system. If the water piping covers a large area, its resistance should be very low (only be



1-13 **Direct method of earth-resistance testing.**

a fraction of an ohm). Thus, the megohmmeter reading will be that of the earth or grounding electrode being tested.

Miscellaneous Testing Instruments

Ammeters, voltmeters, and megohmmeters are the most common analog devices used for field testing and troubleshooting applications. However, several other specialized types of test instruments should be mentioned briefly.

Frequency Meter

Frequency is the number of cycles completed each second by a given AC voltage, usually expressed in hertz (Hz); 1 Hz = 1 cycle per second.

The frequency meter is used with AC power-producing devices like generators to ensure that the correct frequency is being produced. Failure to produce the correct frequency can result in overheating and component damage.

Power Factor Meter

Power factor is the ratio of the true power (volt-amperes) to apparent power (watts), and it depends on the phase difference between current and voltage.

Three-phase power factor meters are installed in switchboards. Many utilities charge large commercial and industrial users a penalty if power factor falls below 90 percent; so these users try to maintain high power factor at all times. A high power factor provides better voltage regulation and stability.

Tachometers

A tachometer is a device that indicates or records the speed of rotating equipment (motors and generators) in revolutions per minute (rpm). There are several different types:

Vibrating-reed Tachometer

This instrument is simply held against the motor, turbine, pump, compressor, or other rotating equipment, and the speed is shown by the vibration of a steel reed, which is tuned to a certain standard speed.

Photo Tachometer

This instrument aims a light at the rotating shaft on which there is a contrasting color such as a mark, a chalk line, or a light-reflective strip or tape. The rotational speed in rpm is read from an indicating scale. Photo tachometers are especially useful on relatively inaccessible rotational equipment such as motors, fans, grinding wheels, and other similar machines where it is difficult, if not impossible, to make contact with the rotational unit.

Electric Tachometer

This consists of a small generator that is belted or geared to the equipment whose speed is to be measured. The voltage produced in the generator varies directly with the rotational speed of the generator. Since this speed is directly proportional to the speed of the machine under test, the amount of the generated voltage is a measure of the speed.

Footcandle Meter

A footcandle meter consists of a photosensitive element and a meter that indicates the average illumination of a room or other space in footcandles. Typical footcandle meters can read light intensity from 1 to 500 footcandles or more.

To use the footcandle meter, first remove the cover. Hold the meter in a position so the cell is facing toward the light source and at the level of the work plane where the illumination is required. The shadow of your body should not be allowed to fall on the cell during tests. A number of such tests at various points in a room or area will give the average illumination level in footcandles. Readings are taken directly from the meter scale.

Electrical Thermometers

For the measurement of temperatures, there are three basic types of electrical thermometers.

1. **Resistance thermometers** operate on the principle that the resistance of a metal varies in direct proportion to its temperature. They are normally used for temperatures up to approximately 1500°F.

2. **Thermocouples** operate on the principle that a difference in temperature in different metals generates a voltage, and are used for measuring temperatures up to about 3000°F.

3. **Radiation pyrometers and optical pyrometers** are generally used for temperatures above 3000°F. They combine the principle of the

thermocouple with the effect of radiation of heat and light.

Phase-Sequence Indicator

A common phase-sequence indicator is designed for use in conjunction with any multimeter that can measure AC voltage. Most can be used on circuits with line voltages up to 550 VAC, provided the instrument used with the indicator has a rating this high.

To use the phase-sequence indicator, set the multimeter to the proper voltage range. This can be determined (if it is not known) by measuring the line voltage before connecting the phase-sequence indicator. Next, connect the two black leads of the indicator to the voltage test leads of the meter. Connect the red, yellow, and black adapter leads to the circuit in any order and check the meter for a voltage reading.

If the meter reading is higher than the original circuit voltage measured, then the phase sequence is black-yellow-red. If the meter reading is lower than the original circuit voltage measured, then the phase sequence is red-yellow-black. If the reading is the same as the first reading, then one phase is open.

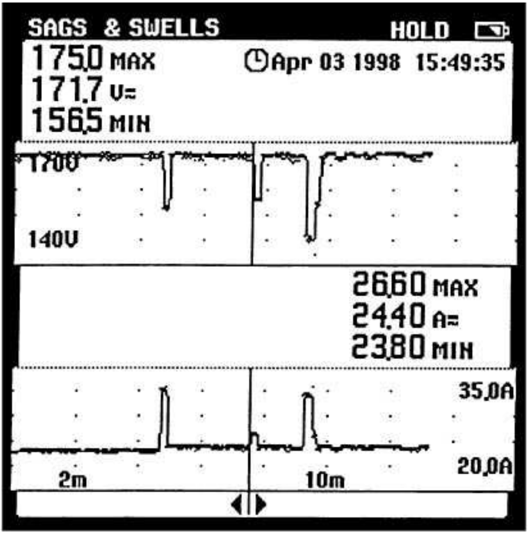
Cable-Length Meters

Cable-length meters measure the length and condition of a cable by sending a signal down the cable and then reading the signal that is reflected back. These instruments are also called time-domain reflectometers (TDRs). A similar instrument used to measure the length of fiber optic cables is called an optical time-domain reflectometer (ODTR).

Power Quality Analyzers

Power quality analyzers are portable test instruments similar in construction to the digital multimeters described in greater detail in Chapter 2. However, unlike DMMs, which typically measure only one property of electrical circuits at a time, power quality analyzers have dual probes that allow both voltage and current to be measured simultaneously. Power quality analyzers can also measure frequency and harmonics.

The results of these readings are displayed graphically, as shown in Figure 1-14. The ability to measure



1-14 **Power quality analyzer display showing voltage on top, current on bottom, and time stamp at upper right.**

and display multiple circuit characteristics at the same time is useful in troubleshooting power quality problems in power distribution systems. This subject is covered more fully in Chapter 9.

CHAPTER
2

Digital Multimeters

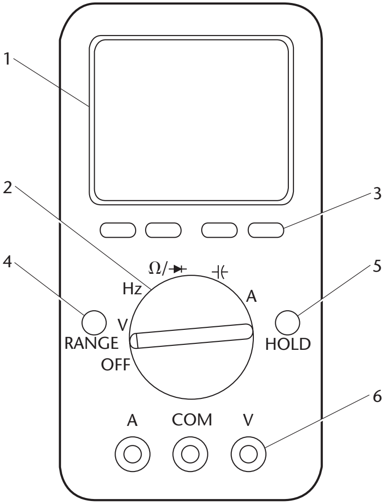
The five core functions of handheld meters are measuring AC and DC voltage, AC and DC current, and resistance. Digital multimeters (DMMs) containing microprocessors perform these functions, but their built-in computing power allows them to offer other capabilities as well:

- Greater accuracy
- Better displays
- Accessory adapters for taking additional types of measurements
- Data-handling capabilities

Figure 2-1 shows a typical DMM. The range of features, options, and accessories offered on DMMs varies widely from one brand and model to the next. The most important are summarized in the next sections.

Greater Accuracy

The accuracy of DMM readings is typically from 0.5 to 0.1 percent, and results can be displayed to two or three decimal places. While this level of accuracy is not always needed for field troubleshooting of electromechanical



1 LCD display with numerical readout.
2 Measurement function knob.
3 Soft-keys—Use with measurement function knob to select measurements.
4 Range button—Use to set measurement range.
5 Hold button—Use to freeze display.
6 Input connectors.

Note: Some DMMs have a separate function knob setting and/or input connector for A/mA..

2-1 Digital multimeter (DMM).

equipment, it can be useful in applications involving electronic circuits.

Better Displays

Digital multimeter displays show numerals and graphical patterns (such as waveforms) rather than swinging needles. Displays are large enough to read from a distance, and some can display two or more items simultaneously, such as voltage and frequency.

Most DMMs have a liquid-crystal diode display that expresses readings in contrasting shades of gray. Many models also have a backlighting switch for taking readings under poorly lighted areas. Maximum display readouts are always one digit less than the marked range. For example, the 200-Ω resistance range reads between 0.0 and 199.9 Ω (Figure 2-3). If higher resistance is present, "OL" or "1" (overlimit or out-of-range indication) shows in the display. When this happens, the rotary switch should be rotated to a higher range.

Hold, Freeze, or Capture Mode

On many DMMs, pressing a "hold" button freezes a reading on the display screen so that the meter can be taken to a more convenient area for viewing. This feature is particularly useful in tight spaces with poor visibility, or when it isn't convenient to read the display at the same time you're taking a measurement on a circuit or piece of electrical equipment.

Construction and Convenience Features

Most DMMs have a shock-resistant heavy-duty case with a belt holster, and a tilt stand for placing on flat surfaces such as a table. Many also have handles that allow them to be hung at eye level, an advantage in many troubleshooting applications where space is tight. DMMs are very rugged and can last for years of trouble-free operation under heavy-duty use.

Many units can operate with the same 9 V battery for 2000 to 3000 hours because the solid-state circuits and LCD display have a very low current drain. Some models constantly display a battery status icon on the screen. In other models, a “Lo Bat” warning appears or the decimal point in the digital display blinks when the battery is nearing its end of life.

Function Selection

DMMs have a dial or rotary switch that lets you select basic measurement functions (such as voltage, current, resistance, frequency, and temperature). Higher-priced DMMs also have either four or eight “soft keys.” These are push buttons whose function depends upon the type of measurement selected.

When the dial is rotated to select a basic measurement function, such as current, some or all of these soft keys may become active. When this happens, the purpose of that key is displayed at the bottom of the LCD display (i.e., just above the soft keys). For some measurement functions, not all soft keys will be active.

Inputs and Test Leads

Most DMMs have three test jacks or inputs: voltage (V), current (A), and common or return (COM). The inputs marked V and A are normally colored red, as are the various test leads that plug into them. The common input, which is used for all measurement functions, is normally colored black, as is the common test lead that plugs into it.

NOTE: Some units also have a fourth separate input for current measurements in the milliampere (mA) or microampere (µA) range.

Accessories

DMM manufacturers offer a wide array of accessories that both extend measurement ranges and allow the instrument to be used for additional types of measurements, including:

- Power
- Power factor
- Energy (kWh)
- Harmonics
- Temperature (single probe, and dual probe for differential)
- Light intensity
- Relative humidity
- Carbon monoxide (CO)
- Airflow

General Instructions for Using Digital Multimeters

Because exact capabilities and features of different DMMs vary, it is important to read the manufacturer's manual supplied with the unit. The following procedures apply to DMMs generally.

Measuring Voltage

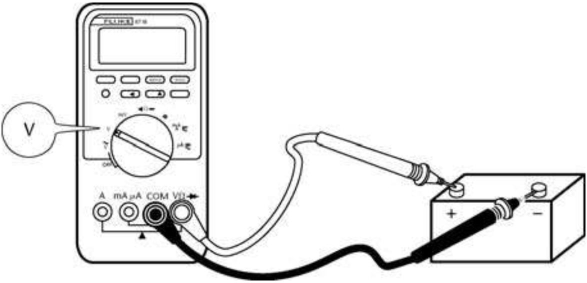
Select a voltage measurement range. Connect test leads to the V and COM inputs. Place the DMM in parallel with the voltage source and load to measure voltage (Figure 2-2). Never place the meter in series with the circuit when measuring voltage.

Measuring Current

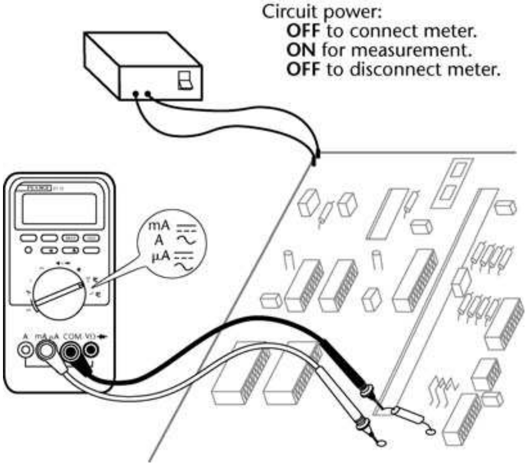
Select a current measurement range. Connect test leads to the A and COM inputs. Place the DMM in series with the voltage source and load to measure current. Never place the meter across (in parallel with) the circuit when measuring amperes. The current in solid-state circuits such as printed circuit boards is measured in milliamperes (mA) or microamperes (µA) (Figure 2-3).

Measuring Resistance

Select resistance test (Ω). Plug the red test lead into the voltage (V) input and the black lead into the common (COM) input. Place the probe tips across the suspected resistor or leaky component. A good resistor should read within plus or minus 10 percent of its rating.



2-2 **Measuring voltage.**

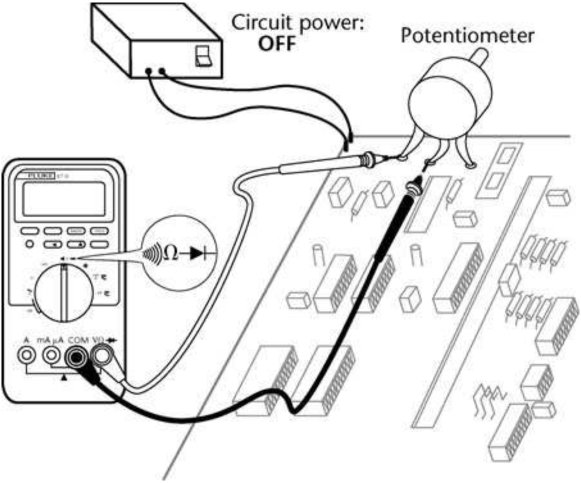


2-3 **Measuring current.**

Thus, a sound 330-Ω resistor would register between 300 and 360 Ω (suspect a burned resistor if the reading is less than 300 Ω). It may be necessary to isolate the resistor or other component from the circuit to get an accurate reading (Figure 2-4).

Testing Continuity

Select resistance test (Ω). Connect test leads to the V and COM inputs. Some DMMs sound a constant tone or noise when making continuity and diode tests. A constant tone indicates proper continuity. No tone (or a broken, stop-start sound) indicates an open circuit, intermittent faults, or loose connections (Figure 2-5).



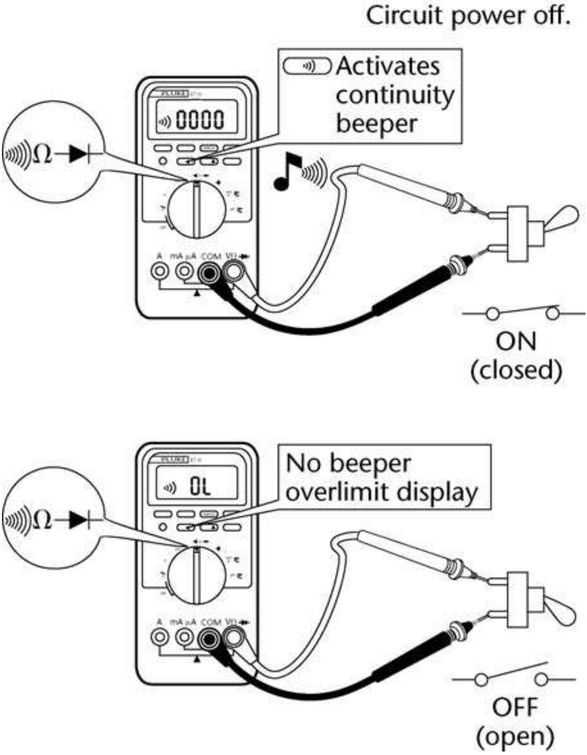
2-4 **Measuring resistance.**

Measuring Capacitance

Select capacitance measurement (⊣⊢). Connect test leads to the V and COM inputs. Capacitors should be isolated from the circuit to provide accurate DMM measurements (Figure 2-6). Discharge large filter capacitors before attempting to measure them.

Measuring Frequency

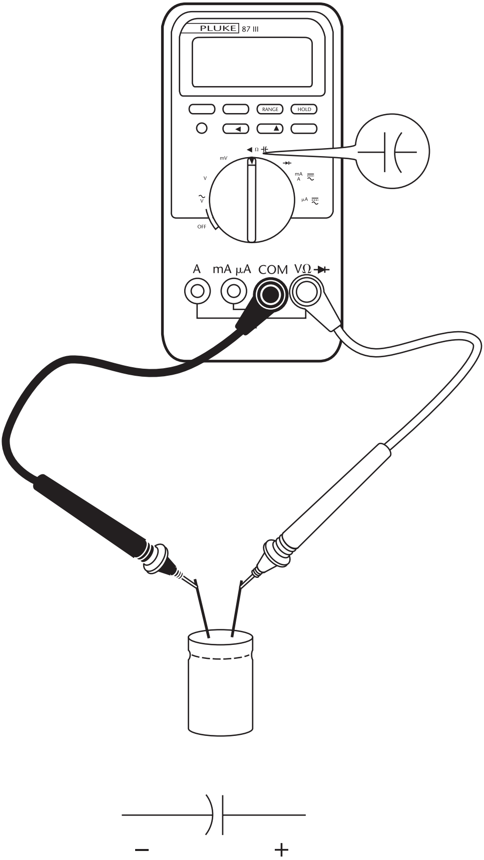
Select frequency measurement (Hz). Connect test leads to the V and COM inputs. As with other DMM measurements, start at the highest band and switch down to the correct frequency range.



2-5 **Testing for continuity.**

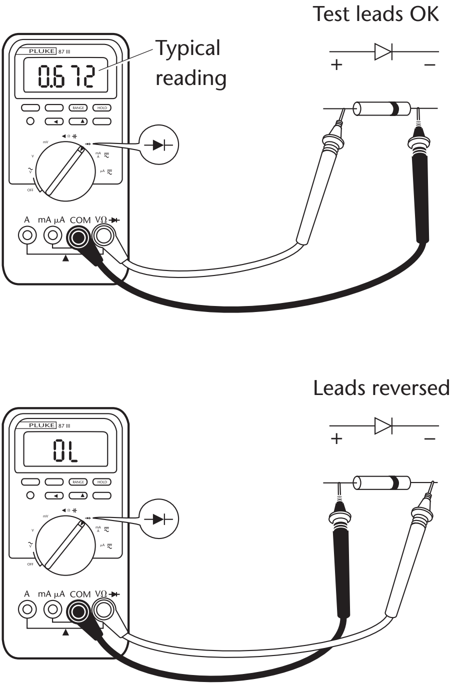
Testing Diodes

Select diode test (→|–). Connect test leads to the V and COM inputs. Some DMMs have an audible tone for the



2-6 **Measuring capacitance.**

diode test. Touch the red probe to the anode and the black test probe to the cathode terminal of the diode. The cathode may be marked with a black or white line at one end of the diode (Figure 2-7). A normal silicon diode reading will indicate only an overlimit measurement (OL or 1) if the test leads are reversed.



2-7 **Testing diodes.**

Digital Multimeter Safety Features

Hand-held test meters should never be connected to any electrical equipment or system operating at a voltage that exceeds the meter's rating. While this is an important safety precaution when using any meter, it is even more important with DMMs.

Digital meters are more sensitive than older analog models to transient overvoltages caused by nearby lightning strikes, utility switching, motor starting, and capacitor switching. High-voltage transients can damage the electronic circuitry inside DMMs, and in severe cases cause meters to explode.

DMMs have internal fuses that function to protect the test instrument (and the person using it) from harm when taking readings on systems of higher voltage or current rating than the DMM.

However, it is still extremely important never to try to take a reading on a system whose voltage or current is higher than the rating of the DMM itself.

Underwriters Laboratories Inc. has established safety ratings for DMMs. UL standard 3111-1 defines four energy-rating categories for test and measurement equipment, with CAT IV offering the highest level of protection.

CAT IV covers utility connections and all outdoor conductors (because of lightning hazards). Examples include service entrance equipment, watt-hour meters, and switchboards/switchgears.

CAT III covers power distribution equipment within buildings and similar structures. This includes panelboards, feeders, busways, motors, and lighting.

CAT II covers single-phase, receptacle-connected loads located more than 10 m from a CAT III power source or more than 20 m from a CAT IV source.

CAT I covers electronic and low-energy equipment.

DMMs are certified to these four categories by UL and other independent testing laboratories. The certification level is marked directly on the DMMs, and often included in advertising for them. Higher-rated meters can safely be used for lower-level measurement functions.

IMPORTANT

The category number of a DMM is more important than its voltage rating when determining the degree of protection that it provides. In other words, a CAT III, 600 V meter offers better protection against high-energy transients than a CAT II, 1000 V meter.

General Safety Precautions for Using Digital Multimeters

- When schematic drawings, building plans, or other documentation is available, check for expected ranges of voltage, current, resistance, and other properties before taking measurements with the DMM. Rotate the function switch to the appropriate range.
- If the appropriate range for a given mea-

surement is not known, start at the highest scale for voltage, current, and so on. Select progressively lower ranges until the measurement falls within the correct range.

- If the overlimit display (OL or 1) comes on, turn to a higher measurement scale.
- Remove test leads from the circuit or device being tested when changing the measurement range.
- Resistance and diode measurements should only be taken in de-energized circuits.
- Discharge all capacitors before taking capacitance readings with a DMM.

CHAPTER

3

Troubleshooting Basics

Much of the work performed by electricians and technicians involves the repair and maintenance of electrical equipment and systems. To maintain such systems at peak performance, workers must have a good knowledge of what is commonly referred to as troubleshooting—the ability to determine the cause of a malfunction and then correct it.

Troubleshooting covers a wide range of problems, from small jobs such as finding a short circuit or ground fault in a home appliance to tracing out defects in a complex industrial installation. The basic principles used are the same in either case. Troubleshooting requires a thorough knowledge of electrical theory and testing equipment, combined with a systematic and methodical approach to finding and diagnosing problems.

The following general tips and principles are intended to help define the troubleshooting process. Specific types of electrical equipment and systems are described in later chapters of this book.

Think Before Acting

Study the problem thoroughly, and ask yourself these questions:

- What were the warning signs preceding the trouble?
- What previous repair and maintenance work has been done?
- Has similar trouble occurred before?
- If the circuit, component, or piece of equipment still operates, is it safe to continue operation before further testing?

The answers to these questions can usually be obtained by:

- Questioning the owner or operator of the equipment.
- Taking time to think the problem through.
- Looking for additional symptoms.
- Consulting troubleshooting charts.
- Checking the simplest things first.
- Referring to repair and maintenance records.
- Checking with calibrated instruments.
- Double-checking all conclusions before beginning any repair on the equipment or circuit components.

The source of many problems is not one part alone, but the relationship of one part to another. For instance, a tripped circuit breaker may be reset to restart a piece of equipment, but what caused the breaker to trip in the first place? It could have been caused by a vibrating "hot" conductor momentarily coming into contact with a ground, or a loose connection could eventually cause overheating, or any number of other causes.

Too often, electrically operated equipment is completely disassembled in search of the cause of a certain complaint, and all evidence is destroyed during disassembly operations. Check again to be certain an easy solution to the problem has not been overlooked.

Find and Correct the Cause of Trouble

After an electrical failure has been corrected in any type of electrical circuit or piece of equipment, be sure to locate and correct the cause so the same failure will not be repeated. Further investigation may reveal other faulty components. Also be aware that although troubleshooting charts and procedures greatly help in diagnosing malfunctions, they can never be complete; there are too many variations and solutions for a given problem.

Note:

Always check the easiest and obvious things first; following this simple rule will save time and trouble.

To solve electrical problems consistently, you must first understand the basic parts of electrical circuits, how they function, and for what purpose. If you know that a particular part is not performing its job, then the cause of the malfunction must be within this part or series of parts.

Intermittent Faults

Finding and diagnosing intermittent faults, where a short, open, or other problem occurs only temporarily, or only under certain conditions, is always a difficult troubleshooting problem. Two features found on most DMMs can help with identifying intermittent faults.

Continuity capture mode

This feature is useful for finding intermittent connections with small gauge wires and wiring bundles, and even intermittent relay contact. To check for intermittent opens, place the leads across the normally closed or shorted connection and select Continuity Capture mode on the DMM. Wiggle the wire(s) and heat the connection with a heat gun, or cool it with circuit cooler to make the intermittent open appear. When the open is captured (as short as 250 μs), the display shows a transition from open to a short.

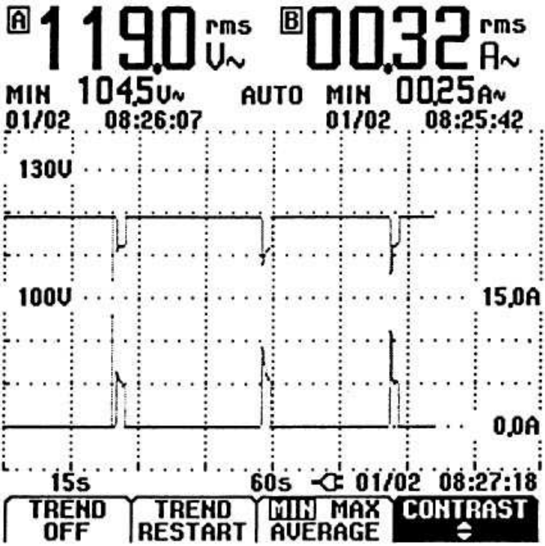
Intermittent shorts can be found the same way, by connecting to a normally open circuit and using the wiggling and heating/cooling techniques to capture the short. The only difference is that the transition lines will go from the bottom of the display to the top.

Recording mode

Sometimes intermittent faults cannot be successfully induced while observing the DMM display. Some higher-end units have a recording mode with a date and time stamp. This type of DMM can be left connected to a circuit or piece of electrical equipment for an extended period of time to record the occurrence of an intermittent fault. The date and time of occurrence may provide clues that allow the electrician or technician to trace the cause of the fault (Figure 3-1).

Working Safely Is Critical

Electrical troubleshooting is inherently hazardous. The hazards of working with electricity include shock and electrocution, fire, and arc-blast injuries.



3-1 Recording DMM display.

Arc-blast is a high energy "explosion" that can occur when something happens such as accidentally shorting across transformer terminals or the bus bars in a panelboard—for example, by dropping a metal screwdriver.

NFPA 70E-2004, *Standard for Electrical Safety in the Workplace,* is the governing standard for protection against electrical hazards in the workplace. Troubleshooting is particularly hazardous, because electricians and technicians are often working on energized ("live") equipment and systems.

In addition to electrical hazards, testing and maintenance work also involves other dangers such as falling from roofs and ladders, and accidents with power tools. Entire books have been written about electrical safety. This section summarizes essential safety precautions when performing troubleshooting on electrical equipment and systems. It is based on the safety rules of NFPA 70E.

Qualified persons

Article 100 of the National Electrical Code defines a *qualified person* as "One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training on the hazards involved." NFPA 70E uses the same definition.

To help prevent accidents and injuries, only *qualified persons* meeting this definition should perform electrical troubleshooting work. Untrained, unqualified, persons should never be allowed to do electrical testing and maintenance.

Personal protective equipment

Troubleshooting often involves testing of energized circuits and equipment. Because of the dangers, NFPA 70E defines electrical testing as a hazardous task that should only be performed wearing appropriate personal protective equipment (PPE). The minimum PPE for electrical troubleshooting work is as follows:

- Long-sleeved shirt and pants of natural fibers, such as cotton or wool. Don't wear synthetic fabrics such as polyester or nylon, which can melt and catch fire in case of an electrical arc-blast.
- Steel-toed boots.
- Only plastic hard hats should be worn for electrical work.
- Safety goggles or glasses.
- Work gloves.

In addition, don't wear metal jewelry such as rings, wristwatches, chains, and earrings when working around electrical circuits and equipment. Gold and silver are excellent conductors of electricity.

Working on energized equipment such as panelboards and motor control centers with the covers off is particularly hazardous. A short-circuit or faulty circuit breaker in an energized panelboard could result in an arc-blast, causing severe burns and other injuries to the workers involved. NFPA 70E requires the following additional PPE when performing "switching operations" on live electrical equipment:

- Fire-rated (FR) clothing.
- FR flash jackets or suits with hoods over the FR clothing.
- Arc-rated face shields.
- Hearing protection.
- Voltage-rated gloves.
- Voltage-rated tools.

PPE is a complex subject. The correct PPE needed depends upon the type of work being done, the operating voltage, and the available fault current. For complete information about this subject, see NFPA 70E-2004, *Standard for Electrical Safety in the Workplace*.

Avoid working "live"

Electrical testing must often be performed on energized circuits and equipment. But the safest technique for doing tasks such as repairing and replacing faulty components is to turn the power off. PPE isn't needed when there are no electrical hazards to protect against. So, the simplest safety rule for electrical maintenance work is—*Don't work live!*

Lockout/tagout

When electrical systems are de-energized to perform maintenance work safely, precautions must be taken to insure that circuits are not accidentally turned back on while the work is going on.

Lockout/tagout is the preferred method of controlling energy sources to minimize hazards to personnel. The details are complex, and beyond the scope of this book. But every company should have an official lockout/tagout procedure, which should always be followed when electrical circuits are de-energized during construction or maintenance work. For more information, refer to NFPA 70E, Annex G "Sample Lockout/Tagout Procedure."

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CHAPTER

4

Troubleshooting Dry-Type Transformers

Dry-type transformers are a part of most electrical installations. They range in size from small doorbell transformers to three-phase 25-kVA units installed in electrical closets (Figure 4-1) to large, free-standing units rated at several hundred kVA (Figure 4-2). Electricians must know how to test for and diagnose problems that develop in transformers—especially in the smaller, dry-type power-supply or control transformers.

Open Circuit

If one of the windings in a transformer develops a break or "open" condition, no current can flow and therefore, the transformer will not deliver any output. The symptom of an open-circuited transformer is that the circuits, which derive power from the transformer, are de-energized or "dead." Use an AC voltmeter or DMM to check across the transformer output terminals, as shown in Figure 4-3. A reading of 0 V indicates an open circuit.

Then take a voltage reading across the input terminals. If voltage is present, this indicates that one

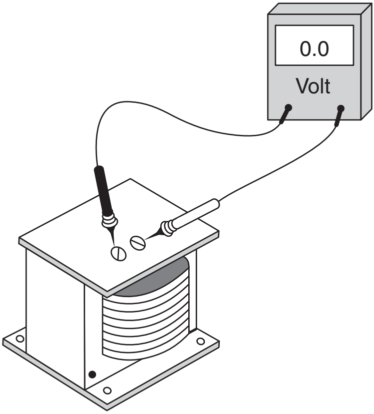
4-1 Dry-type transformer (25-kVA, three-phase). *(Courtesy of Square D Company.)*

of the transformer windings is open. However, if there is no voltage reading on the input terminals either, then the open must be somewhere else on the line side of the circuit; possibly a disconnect switch is open.

4-2 Dry-type transformer (300-kVA, three-phase). *(Courtesy of Square D Company.)*

WARNING!

Make absolutely certain that your testing instruments are designed for the job and are calibrated for the correct voltage. Never test the primary side of any transformer over 600 V unless you are qualified, have the correct high-voltage testing instruments, and the test is made under the proper supervision.



4-3 Checking for an open circuit in a transformer.

However, if voltage is present on the line or primary side and no voltage is on the secondary or load side, open the switch to de-energize the circuit, and place a warning tag (tag-out and lock) on this switch so that it is not inadvertently closed again while someone is working on the circuit. Disconnect all of the transformer primary and secondary leads and check each winding in the transformer for continuity (a continuous circuit), as indicated by a resistance reading taken with an ohmmeter.

Continuity is indicated by a relatively low resistance reading on control transformers, while an open winding will be indicated by an infinite resistance reading (OL or 1). In most cases, such small transformers will have to be replaced, unless of course the break is accessible and can be repaired.

Ground Fault

Sometimes a few turns in the secondary winding of a transformer experience a partial short, which in turn causes a voltage drop across the secondary. The usual symptom of this condition is transformer overheating caused by large circulating currents flowing in the shorted windings.

The easiest way to check this condition is with a voltmeter. Take a reading on the line or primary side of the transformer first to make certain normal voltage is present. Then take a reading on the secondary side. If the transformer has a partial short or ground fault, the secondary voltage reading will be lower than normal.

Replace the faulty transformer with a new one and again take a reading on the secondary. If the voltage reading is now normal and the circuit operates satisfactorily, leave the replacement transformer in the circuit, and either discard or repair the original transformer.

Complete Short

Occasionally a transformer winding becomes completely shorted. In most cases, this activates the overcurrent-protective device (circuit breaker or fuse) and de-energizes the circuit. But in some cases, the transformer may continue trying to operate with excessive overheating—due to the very large circulating current. This heat will often melt the insulation inside the transformer, which is easily detected by the odor. Also, there will be no voltage output across the shorted winding and the secondary circuit supplied by that winding will be dead.

The short may be in the external secondary circuit or it may be in the transformer's winding. To determine its location, disconnect the secondary circuit from the winding and take a reading with a voltmeter. If the voltage is normal with the external circuit disconnected, then the problem is in the external circuit. However, if the voltage reading is still zero across the secondary leads, the transformer is shorted and must be replaced.

Grounded Windings

Insulation breakdown is quite common in older transformers—especially those that have been overloaded. At some point, insulation breaks or deteriorates and bare conductors become exposed. The exposed wire often comes into contact with the transformer housing and grounds the winding.

If a winding develops a ground, and a point in the external circuit connected to this winding is also grounded, part of the winding will be shorted out. The symptoms are overheating, usually detected by feel or smell, and a low voltage reading as indicated on a voltmeter scale. In most cases, transformers with this condition must be replaced.

A megohmmeter is used to test for this condition. Disconnect the leads from both the primary and secondary windings. Tests can then be performed on either winding by connecting the megger negative test lead to an associated ground and the positive test lead to the winding to be measured.

Insulation resistance should then be measured between the windings themselves, by connecting one test lead to the primary and the second test lead to the secondary.

The troubleshooting chart in Figure 4-4 covers the most common dry-type transformer problems.

Malfunction	Probable Cause
Overheating.	Continuous overload; wrong external connections; poor ventilation; high surrounding air temperatures.
	High input voltage.
	Clogged air ducts or inadequate ventilation.
Reduced to zero voltage.	Short turns; loose connections to transformer terminal board.
Excess secondary voltage.	Input voltage high; dirt accumulations on primary terminal board.
High conductor loss.	Overload; terminal boards not on identical tap position.
Coil distortion.	Coils short-circuited.

4-4 Troubleshooting chart for dry-type transformers.

Malfunction	Probable Cause
Insulation failure.	Continuous overloads; dirt accumulations on coils; mechanical damage in handling; lightning surge.
	Very high core temperature due to high input voltage or low frequency.
Breakers or fuses open.	Short circuit; overload.
Excessive cable heating.	Improperly bolted connection.
High voltage to ground.	Usually a static charge condition.
Vibration and noise.	Low frequency; high-input voltage; core clamps loosened in shipment or handling; loose hardware on enclosure; location.
High exciting current.	Low frequency; high input voltage; shorted turns (windings).
High core loss.	Low frequency; high input voltage.
Smoke.	Insulation failure.
Burned insulation.	Lightning surge; switching or line disturbance; broken bushings.

4-4 Troubleshooting chart for dry-type transformers. *(Continued)*

CHAPTER

5

Troubleshooting Luminaires (Lighting Fixtures)

The National Electrical Code (Article 100) defines *luminaire* as follows:

> ***Luminaire***. *A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and ballast (where applicable), and to connect the lamps to the power supply.*

A typical commercial, industrial, or institutional building contains hundreds or even thousands of luminaires. For this reason, troubleshooting luminaires is an important part of the typical maintenance electrician's work. This chapter covers the three most common types of lighting used in commercial, industrial, and institutional applications:

- Fluorescent luminaires
- Incandescent luminaires
- High-intensity discharge (HID) luminaires

Troubleshooting Fluorescent Luminaires

Fluorescent lamps are electrical discharge lighting sources. Current flows in an arc through a glass tube filled with mercury vapor between contacts called *cathodes* at each end of the tubular lamp. The inside of the tube is coated with a powder called *phosphor* that glows when excited by ultraviolet radiation, producing visible light.

Fluorescent lamps require an auxiliary component called a *ballast* to operate. The ballast performs two functions:

1. It produces a jolt of high voltage to vaporize the mercury inside the lamp and start the arc from one end to the other.
2. Once a lamp is started, the ballast limits current to the lower value needed for proper operation.

There are many different types of fluorescent lamps and ballasts. Older types of ballasts known as *core-and-coil* are still widely used, but electronic ballasts are also common.

Almost all fluorescent luminaires installed in modern construction use *rapid start* and *instant start* lamps. An older type of *preheat* fluorescent lamp uses a separate component called a *starter* to heat the lamp cathodes before the arc is struck. Preheat lamps and fixtures are rarely used in modern commercial lighting systems, and they are not included in this troubleshooting guide.

The troubleshooting chart (Figure 5-1) lists faults, probable causes, and corrective action to take while troubleshooting fluorescent luminaires.

Troubleshooting Incandescent Luminaires (Including Tungsten-Halogen)

Although fluorescent and HID luminaires are now used for most area lighting applications in commercial, industrial, and institutional facilities, incandescent luminaires are still widely used for decorative and accent lighting.

- Traditional incandescent lamps are made in thousands of different types and colors from a fraction of a watt to over 10 kW each, though the types most commonly used for general lighting applications are rated between 40 and 200 W (Figure 5-2). Traditional incandescent produce light by means of a filament heated to incandescence (white glow) in a vacuum.
- Tungsten-halogen lamps (also known as quartz-halogen and quartz-iodide) use a lamp-within-a-lamp design (Figure 5-3). The inner quartz envelope is filled with iodine vapor, which retards evaporation of the tungsten filament and thus prolongs lamp life. Tungsten-halogen lamps aren't physically interchangeable with other types of incandescent lamps and require special luminaires.

Symptoms	Probable Cause	Action or Items to Check
Blinking on and off, along with shimmering effect during lighted period.	Normal end of lamp life, emission material on electrode depleted.	Replace lamp.
Blinking of relatively new lamps.	Incorrect or defective starter. Loose circuit contact.	Seat lamp securely; indicator bumps should be directly over socket slot. Check if lamp holders are rigidly mounted and properly spaced; tighten all connections.

5-1 Troubleshooting chart for fluorescent luminaires.

Symptoms	Probable Cause	Action or Items to Check
Blinking with two-lamp ballasts. One lamp starts and one end of the other may blink on and off without starting; eventually both lamps may start.	Cold drafts hitting lamp. Starter leads improperly wired.	Enclose or protect lamp. Check wiring diagram on ballast and reconnect leads correctly or interchange lamp holders at one end of fixture.

5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
No starting effort, or slow starting.	Open circuit in electrodes or air leak in lamp.	Check lamps in another fixture; if no fluorescent end glow exists, replace them.

5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Slow starting of rapid start type lamps during conditions of high humidity.	Dust or dirt on lamps overcomes effect of silicone coating.	Wash lamps in water containing mild detergent. Rinse lamps with clean water to prevent film from depositing on bulb.
Very short lamp life accompanied by severe end blackening on lamps.	Electrode not being heated.	Check for poor contact between lamp pins and socket. Check for open circuit — loose socket contacts or break in line.

5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Very short lamp life accompanied by severe end blackening on lamps.	Loose circuit contact causing on-off blink.	Be sure the lamp holders are rigidly mounted and that the lamp is securely seated; check the circuit wiring.
	Voltage too low or too high.	Check the line voltage and be sure it is within the range on the ballast nameplate.

5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Very short lamp life accompanied by severe end blackening on lamps.	In series instant start ballasts, one lamp burned out and the other burning dimly. If the burned out lamp is not replaced, the dim lamp will burn out shortly.	Replace the burned out lamp immediately.
	Series instant start ballasts, both lamps out, only one lamp may be defective.	Check both lamps to determine which is defective; reinstall good lamp.

5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Very short lamp life accompanied by severe end blackening on lamps.	Ballast not within specifications or wrong ballast being used.	Use CBM certified ballast of correct rating for lamp size.
	Improper ballast equipment of DC sources.	Check ballast equipment.
Dense blackening at one or both ends, extending 2 to 3 in. from base.	Normal end of lamp life.	Replace lamp.

5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Dense blackening at one or both ends, extending 2 to 3 in. from base.	With rapid start lamps, accompanied by short life—poor contact between lamp pins and socket.	Check for proper socket spacing or poor socket construction not providing proper wiping of pins when lamp is installed.
Blackening generally within 1 in. of ends.	Mercury deposit.	Should evaporate as lamp is operated.

5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Blackening early in life.	Too low or too high voltage.	Check the line voltage to be certain it is within the range shown on the ballast nameplate.
	Loose circuit contact causing on-off blink.	Be sure the lamp holders are rigidly mounted and the lamp is securely seated; check circuit wiring.

5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Blackening early in life.	Ballast not within specifications or wrong ballast being used.	Use CBM certified ballast of correct rating for lamp size.
Dense spot — black about ½ in. wide, extending about halfway around lamp, centering about 1 in. from the base.	Normal sign of age in service. If early in life, indicates excessive lamp starting or high operating current.	Check for off rating or ballast or unusually high-current voltage. Ballast may be improperly designed.

5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Rings — brownish ring at one end or both, about 2 in. from base.	This may develop on some lamps during operation.	Will not affect the lamp performance.
Dark streaks lengthwise on tube.	Globules of mercury condensed on lower part of tube.	The lower half of the tube is cooler than the upper half; by rotating the tube 180° these mercury globules should evaporate due to the increased warmth.

5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Pronounced swirling, spiraling, or fluttering of arc stream.	May occur in new lamps.	Should season out in normal operation.
	Ballast not within specifications or wrong ballast used.	Use CBM certified ballasts of correct rating for lamp size.

5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Pronounced swirling, spiraling, or fluttering of arc stream.	High-voltage starting.	Check voltage and correct, if possible. If condition persists, replace lamp.
Radio interference.	Line radiation and line feedback.	Apply radio-interference filter at lamp or fixture.

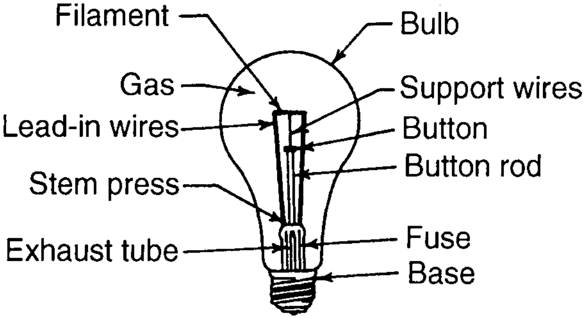
5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Noise: humming sound that may be steady or come and go.	Internal variation in ballast.	Tighten fixture louvers, such as glass, side panels. If ballast continues to be noisy, replace it.
	Overheated ballast.	Prolonged blinking of lamp tends to heat ballast; replace ballast.
Decreased light output.	Cold drafts hitting lamp.	Enclose or protect lamp. Improve ventilation of fixture.

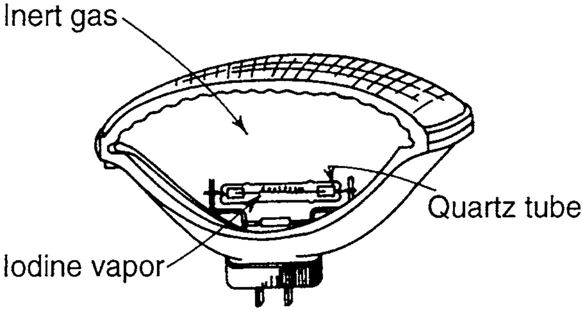
5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Decreased light output.	Low temperature.	Enclose the lamp.
	Low circuit voltage.	Check voltage and correct if possible.
	Dust or dirt on lamp, fixture, walls, or ceilings.	Clean.
Lamps operate at unequal brightness.	Low circuit voltage on two-lamp lead-lag ballasts.	Check voltage and correct if possible. Possibly defective ballast.

5-1 Troubleshooting chart for fluorescent luminaires. *(Continued)*



5-2 Basic components of an incandescent lamp.



5-3 Basic components of a tungsten-halogen lamp.

The troubleshooting charts to follow (Figure 5-4) cover the most commonly encountered problems with incandescent luminaires.

Troubleshooting HID Luminaires

High-intensity discharge (HID) lamp is a generic term for lamps that have arc tubes and are supplied by ballasts. HID lamp types include mercury vapor, metal halide, and high-pressure sodium. Low-pressure sodium lamps aren't actually HID, but use ballasts and resemble HID lamps in other ways.

The troubleshooting chart in Figure 5-5 lists troubleshooting techniques for HID luminaires.

Symptoms	Probable Cause	Action or Items to Check
Lamp not burning, but apparently okay.	Lamp loose.	Tighten in socket.
	Loose or broken connections.	Secure terminals.
		Repair wiring.
Lamp burns dim.	Low voltage.	Match lamp rating to line voltage.
		Increase line voltage.
Short lamp life.	High voltage.	Match lamp rating to line voltage.
	Bulb cracked due to mechanical shock.	Replace lamp.
		Make sure that water does not drip on bulb.

5-4 Troubleshooting chart for incandescent luminaires.

Symptoms	Probable Cause	Action or Items to Check
Short lamp life.	Overheating due to too-large lamp.	Replace with lamp of size for which luminaire is rated.
	Excessive vibration.	Use shock absorbing device.
Lamp breakage.	Water contacts lamp bulb.	Use enclosed, vaportight luminaire if water spray is present.
		Seal joint where conduit stem enters luminaire.
	Bulb touches luminaire.	Use correct size of lamp.
		Straighten socket.

5-4 Troubleshooting chart for incandescent luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Lamp fails to start or glows feebly.	Lamp has reached end of life.	Replace lamp.
	Lamp was too hot from previous operation.	Relight when lamp has cooled.
	Lamp loose.	Tighten in socket.
		If solder has melted or base eyelet is badly pitted, check for poor contact or defective socket.
	Low temperature.	Make sure that the ballast has adequate voltage to start the lamp at the lowest ambient temperature.

5-5 Troubleshooting chart for HID luminaires.

Symptoms	Probable Cause	Action or Items to Check
Lamp fails to start or glows feebly.	Low voltage.	Check open-circuit voltage at socket or ballast tap if incorrectly matched to supply voltage.
		Increase line voltage if necessary.
		Look for wiring fault or poor connections.
Low light output.	Lamp is near end of life.	Replace lamp.
	Low voltage.	Check line voltage and ballast tap selected.
	Wiring fault.	Check wiring and connections.

5-5 Troubleshooting chart for HID luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Low light output.	Wrong ballast.	Be sure that ballast is right for the lamp.
	Low ballast output.	Check to see if ballast delivers proper starting current.
	Excessive draft.	Protect single-tube lamps from excessive drafts.
	Dirty, corroded, or inadequate fixture.	Clean, polish, or replace fixture.
	Wrong burning position.	Some fixtures are designed for operation only with their bases up or down. Observe correct burning position.

5-5 Troubleshooting chart for HID luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Lamps go out frequently for several minutes at a time.	Voltage dips.	Separate lighting circuit from heavy power circuits.
		Provide voltage regulator.
		Use ballast affording greater protection against voltage dips, such as a regulated output ballast.
	Wiring fault.	Check wiring.
		Tighten connections.
	Frequent power interruptions.	Consult utility company.
	Wrong ballast.	Install correct ballast.

5-5 Troubleshooting chart for HID luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Outer bulb color abnormally greenish or yellowish. Internal parts oxidized.	Lamp is worn out from exceptionally long service, so that arc tube has discolored.	Replace lamp.
	Outer bulb seal destroyed.	Replace lamp.
	Dirt or dust.	Wipe bulb carefully so as not to scratch surface. Clean fixture.
Annoying stroboscopic effect.	Cyclic flicker.	Connect fixtures in a staggered arrangement on a three-phase supply.
		Use a two-lamp lead-lag ballast.

5-5 Troubleshooting chart for HID luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Radio interference.	Circuit components.	Check circuit, as lamp itself generally creates no radio interference, and standard ballast, usually suppress any line re-radiation.
		If individual lamp ballasts are not used, it may be necessary to add a small capacitor across the lamp.
Noisy ballast.	Cyclic vibration.	Tighten ballast cover.

5-5 Troubleshooting chart for HID luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Noisy ballast.	Cyclic vibration.	Replace ballast.
Sunburn or suntan.	Exposure to rays of lamp without outer bulb or prolonged exposure at very short distance from lamp.	Replace lamps that lack an outer bulb.
		Turn lights out when working near them or cover exposed parts of body.
		Use enclosed fixtures.
Lamp won't enter fixture.	Fixture opening too small or socket off-center.	Relocate socket or try a socket extender if change in position of light center is not critical.
	Damaged base.	Replace base. Check for rough handling.

5-5 Troubleshooting chart for HID luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Lamp won't enter fixture.	Crooked base.	Check base-bulb alignment. If more than 3° in any direction, lamp may be defective.
Overcurrent devices open when lamps are started.	High transient current of very short duration. Usually caused by ballast or circuit components.	Use time-delay fused or thermal-magnetic type circuit breakers.
Lamp breakage or cracks in outer bulb.	Shipping damage or mishandling.	Check carrier and workers handling bulbs.
	Water drips on hot bulb.	Check for leaks or for condensation in fixture.
	Poorly sealed fixtures breathe in moist air.	Use enclosed vapor-tight fixture.

5-5 Troubleshooting chart for HID luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Lamp breakage.	Bulb touches fixture, edge of sockets, metallic bulb changer, heat conductor, or heat insulator during insertion or operation.	Straighten or adjust socket.
		Use socket extender to provide ample clearance.
		Remove metallic or other element touching bulb.
		Use weather duty lamps.
	Bulb cracked through mechanical shock.	Replace lamp.
		Do not allow bulbs to bump against each other.
Arc tube swollen, cracked, or broken.	Overwattage operation.	Check ballast and socket wiring.

5-5 Troubleshooting chart for HID luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Ends of arc tube split apart or internal wires melted.	Excessive current or voltage due to operation without ballast or else lightning damage.	Check ballast and socket wiring.
		Check for possibility of lightning damage.
		Check for very high voltage applied to a hot lamp, even momentarily, resulting in discharge in outer tube.

5-5 Troubleshooting chart for HID luminaires. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Loose base.	Abnormal operation or defective lamp.	Check for operation beyond published temperature limits.
		Check if basing cement was severely disturbed prior to or within first 10 hours of operation.
Rattle.	Piece of loose glass or cement.	Lamps having this condition should not be considered defective if they are otherwise satisfactory.
Blackening of inner arc tube.	Long service.	Replace lamp if lamp output is too low.

5-5 Troubleshooting chart for HID luminaires. *(Continued)*

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CHAPTER

6

Troubleshooting Electric Motors

Electric motors operate on the principle of electromagnetic induction. An electric motor has a stationary magnet, or stator, with windings connected to the supply conductors, and a rotating magnet. There is no electrical connection between the stator and rotor. The magnetic field produced in the stator windings induces a voltage in the rotor.

When an electric motor malfunctions, the stator (stationary) windings are often defective, and must be repaired or replaced. Stator problems are usually caused by one or more of the following:

- Worn bearings
- Moisture
- Overloading
- Poor insulation
- Single-phase operation of a three-phase motor

Troubleshooting Motors

To detect defects in electric motors, the windings are normally tested for ground faults, opens, shorts, and reverses. The exact method of performing these tests depends on the type of motor being serviced. However, regardless of the motor type, a knowledge of some important terms is necessary to properly troubleshoot motors:

Ground: A winding becomes grounded when it makes an electrical contact with the iron frame of the motor. The usual causes of grounds include bolts securing the end plates coming into contact with the winding; wires press against laminations at the corners of the slots; or the centrifugal switch becoming grounded to the end plate.

Open circuits: Loose or dirty connections, as well as a broken wire, can cause an open circuit in an electric motor.

Shorts: If two or more turns of a winding contact each other, the result is an electrical short circuit. This condition may develop in a new winding if the winding is tight and pounding is necessary to place the wires in position. In other cases, excessive heat caused by overloads degrades the insulation and causes a short. A short circuit is often detected by observing smoke from the windings as the motor operates, or if the motor draws excessive current at no load.

The chart in Figure 6-1 lists tools and equipment used in maintenance and troubleshooting of electric motors. The following sections describe common causes of motor malfunctions.

Grounded Coils

A grounded coil in a motor winding typically causes repeated tripping of the circuit breaker. Follow these steps to test for a grounded coil using a continuity tester:

1. Open and lock out the disconnecting means, to insure the motor is de-energized.
2. Place one test lead on the frame of the motor and the other in turn on each of the

Tools or Equipment	Application
Multimeters, voltmeters, ohmmeters, clamp-on ammeters, wattmeters, clamp-on power factor meter.	Measure circuit voltage, resistance, current and power. Useful for circuit tracing and troubleshooting.
Transistorized stethoscope.	Detect faulty rotating machinery bearings and leaky valves.
Tachometer.	Check rotating machinery speeds.

6-1 Tools for electric motor maintenance.

Tools or Equipment	Application
Recording meters, instruments.	Provide permanent record of voltage, current, power, temperature, etc., on charts for analytic study.
Insulation resistance tester, thermometer, psychrometer.	Test and monitor insulation resistance; use thermometer and psychrometer for temperature-humidity correction.
Portable oil dielectric tester; portable oil filter.	Test OCB, transformer oil, or other insulating oils. Recondition used oil.
Air gap feeler gauges.	Check motor or generator air gap between rotor and stator.
Cleaning solvent.	Removes grease or dirt from motor windings or other electrical parts.

6-1 Tools for electric motor maintenance.
(Continued)

Tools or Equipment	Application
Hand stones (rough, medium, fine), grinding rig, canvas strip.	Grinding, smoothing, and finishing commutators or slip rings.
Spring tension scale.	Checks brush pressure on DC motor commutators or on AC motor skip rings; tests electrical contact pressure on relays, starters, or contactors.
Magnifying glass, binoculars.	Use magnifying glass to examine brushes, commutators, or small electrical contacts or parts; binoculars allow close inspection of remote or high-voltage parts.
Motor rotation tester.	Checks direction of motor rotation before connection.

6-1 Tools for electric motor maintenance.

(Continued)

ungrounded (power) conductor supplying the motor. If there is a grounded coil at any point in the winding, the lamp of the continuity tester will light, or the meter display will indicate *infinity*.

3. For a three-phase motor, test each phase separately, after disconnecting the star or delta connection.

4. Sometimes moisture on old insulation around the coils causes a high-resistance ground that is difficult to detect with a test lamp. A megger can be used to detect such faults.

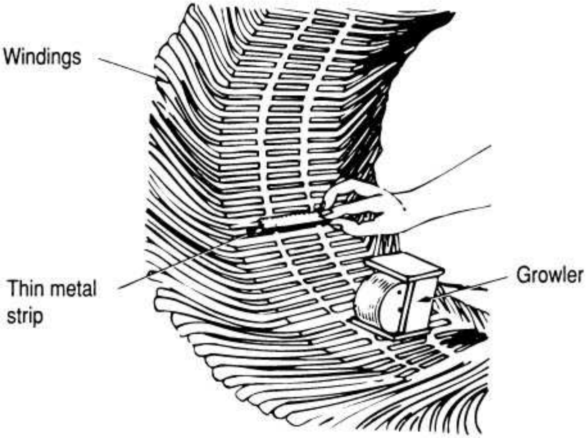
5. Test the armature windings and commutator for grounds in a similar manner.

6. On some motors, the brush holders are grounded to the end plate. Before the armature is tested for grounds, lift the brushes away from the commutator.

Shorted Coils

Shorted turns within coils are usually the result of failure of the insulation on the wires, caused by oil, moisture, and the like. One inexpensive way of locating a shorted coil is by the use of a growler and a thin piece of steel, as shown in Figure 6-2.

1. Place the growler in the core as shown, with the thin piece of steel at the distance of one coil span from the center of the growler.



6-2 Growler used to test a stator of an AC motor.

2. Test the coils by moving the growler around the bore of the stator and always keeping the steel strip the same distance away from it.

3. If any coil has one or more shorted turns, the piece of steel will vibrate very rapidly and cause a loud humming noise. By locating the two slots over which the steel vibrates, both sides of the shorted coil can be found.

4. Sometimes one coil or a complete coil group becomes short-circuited at the end connections. The test for this fault is the same as that for a shorted coil.

Open Circuit

1. When one or more coils become open-circuited by a break in the turns or a poor connection at the end, they can be tested with a continuity tester as previously explained. If this test is made at the ends of each winding, an open can be detected by the lamp failing to light. Remove the insulation from the pole-group connections, and test each group separately.

2. An open circuit in the starting winding may be difficult to locate, since the problem may be in the centrifugal switch instead of the winding itself. In fact, the centrifugal switch is more likely to cause trouble than the winding since parts become worn, defective, and more likely, dirty. Insufficient pressure of the rotating part of centrifugal switches against the stationary part will prevent the contacts from closing and thereby produce an open circuit.

Reversed Coil Connections

Reversed connections cause current to flow through coils in the wrong direction. This causes disturbance of the magnetic circuit, which results in excessive noise and vibration.

The fault can be located by the use of a magnetic compass and a direct current power source, as follows:

1. Adjust to send about one-fourth to one-sixth of the full-load current through the winding,

with the DC leads placed on the start and finish of one phase.

2. If the winding is a three-phase, star-connected, winding this is at the start of one phase and the star point. If the winding is delta-connected, disconnect the delta point and test each phase separately.

3. Place a compass on the inside of the stator and test each coil group in that phase. If the phase is connected correctly, the needle of the compass will reverse definitely as it is moved from one coil group to another. However, if any one of the coils is reversed, the reversed coil will build up a field in the direction opposite to the others, thus causing a neutralizing effect that is indicated by the compass needle refusing to point definitely to that group. If there are only two coils per group, there will be no indication if one of them is reversed, as that group will be completely neutralized.

4. When an entire coil group is reversed, current flows in the wrong direction in that whole group. The test for this fault is the same as that for reversed coils. Magnetize the winding with DC, and when the compass needle is passed around the coil group, it should alternately indicate North-South, North-South, and so on.

Reversed Phase

Sometimes in a three-phase winding a complete phase is reversed by either having taken the starts from the wrong coils or connecting one of the windings in the wrong relation to the others when making the star or delta connections.

Delta connection: In a delta-connected winding, disconnect any one of the points where the phases are connected together and pass current through the three windings in series. Place a compass on the inside of the stator and test each coil group by slowly moving the compass one complete revolution around the stator. The reversals of the needle in moving the compass one revolution around the stator should be three times the number of poles in the winding.

Wye connection: In a star- or wye-connected winding, connect the three starts together and place them on one DC lead. Then connect the other DC lead and star point, thus passing the current through all three windings in parallel. Test with a compass in the same way as the delta winding. The result should then be the same, or the reversals of the needle in making one revolution around the stator should again be three times the number of poles in the winding.

These tests for reversed phases apply to full-pitch windings only. If the winding is fractional-pitch, a careful visual check should be made to determine whether there is a reversed phase or mistake in connecting the star or delta connections.

Troubleshooting Split-Phase Motors

If a split-phase motor fails to start, the trouble may be due to one or more of the following faults:

- Tight or "frozen" bearings
- Worn bearings, allowing the rotor to drag on the stator
- Bent rotor shaft
- One or both bearings out of alignment
- Open circuit in either starting or running windings
- Defective centrifugal switch
- Improper connections in either winding
- Grounds in either winding or both
- Shorts between the two windings

Tight or worn bearings: Tight or worn bearings may be due to the lubricating system failing, or when new bearings are installed, they may run hot if the shaft is not kept well oiled. If the bearings are worn to such an extent that they allow the rotor to drag on the stator, this will usually prevent the rotor from starting. The inside of the stator laminations will be worn bright where they are rubbed by the rotor. When this condition exists, it can generally be easily detected by close observation of the stator field and rotor surface when the rotor is removed.

Bent shaft and bearings out of alignment: A bent rotor shaft will usually cause the rotor to bind in a certain position but then run freely until it comes back to the same position again. Test for a bent shaft by placing the rotor between centers on a lathe and turning the rotor slowly while a tool or marker is held in the tool post close to the surface of the rotor. If the rotor wobbles, it is an indication of a bent shaft. Bearings out of alignment are usually caused by uneven tightening of the end-shield plates. When placing end shields or brackets on a motor, tighten the bolts alternately, first drawing up two bolts, which are diametrically opposite.

Open circuits and defective centrifugal switches: Open circuits in either the starting or running winding will prevent the motor from starting. This fault can be detected by testing in series with the start and finish of each winding with a test lamp or ohmmeter.

A defective centrifugal switch is generally caused by dirt, grit, or some other foreign matter getting into the switch. The switch should be thoroughly cleaned with a degreasing solution and then inspected for weak or broken springs.

If the winding is on the rotor, the brushes sometimes stick in the holders and fail to make good contact with the slip rings. This causes sparking at the brushes. There will probably also be a certain place where the rotor will not start until it is moved far enough for the brush to make contact on the ring. The brush holders should be cleaned and the brushes carefully fitted so they move more freely with a minimum of friction between the brush and the holders.

Reversed connections and grounds: Reversed connections are caused by improperly connecting a coil or group of coils. The wrong connections can be found and corrected by making a careful check on the connections and reconnecting those that are found at fault. The compass test with a DC power source can also be used for locating reversed coils. Test the starting and running windings separately, exciting only one winding at a time, with direct current. The compass should show alternate poles around the winding.

The operation of a motor that has a ground in the winding will depend on where the ground is and whether or not the frame is grounded. If the frame is grounded, then when the ground occurs in the winding, it will usually blow a fuse or trip the overcurrent protective device.

A test for grounds can be made with a test lamp or continuity tester. One test lead should be placed on the frame and the other on a lead to the winding. If there is no ground, the lamp will not light, nor will any deflection be present when a meter is used. If the lamp does light or the meter shows continuity, it indicates a ground is present—due to a defect somewhere in the motor's insulation.

Short circuits: Short circuits between any two windings can be detected by the use of a test lamp or continuity tester. Place one of the test leads on one wire of the starting winding and the other test lead on the wire of the running winding. If these windings are properly insulated from each other, the lamp should not light.

If it does, it is a certain indication that a short or ground fault exists between the windings. Such a condition will usually cause part of the starting winding to burn out. The starting winding is always wound on top of the running winding, so a defective starting winding can be conveniently removed and replaced without disturbing the running winding.

Identifying Motors

Electric motors with no identification (no nameplate or lead tags) must often be maintained and repaired. Follow these steps to determine an unknown motor's characteristics, based on the NEMA Standard method of motor identification. First, sketch the coils to form a wye. Identify one outside coil end with the number one (1), and then draw a decreasing spiral and number each coil end in sequence as shown in Figure 6-3.

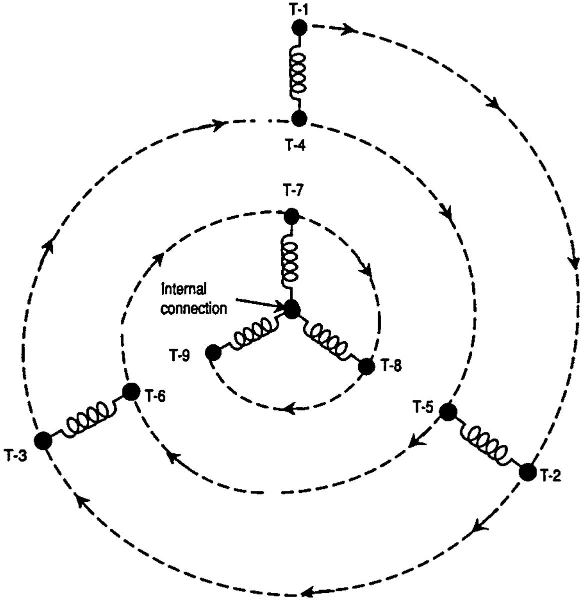
Using a DMM, ohmmeter, or continuity tester, the individual circuits can then be identified as follows:

Step 1. Connect one probe of the tester to any lead, and check for continuity to each of the other eight leads. A reading from only one other lead indicates one of the two-wire circuits. A reading to two other leads indicates the three-wire circuit that makes up the internal wye connection.

Step 2. Continue checking and isolating leads until all four circuits have been located.

Tag the wires of the three lead circuits T-7, T-8, and T-9 in any order. The other leads should be temporarily marked T-1 and T-4 for one circuit, T-2 and T-5 for the second circuit, and T-3 and T-6 for the third and final circuit.

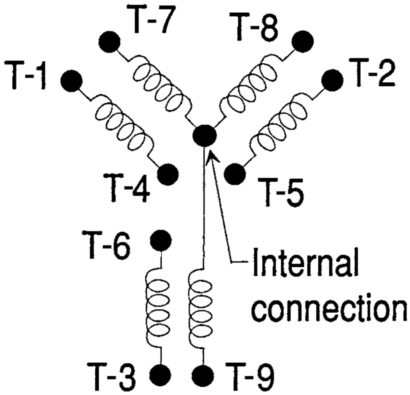
The following test voltages are for the most common dual-voltage range of 230/460 V. For



6-3 Identify one outside coil and then draw a decreasing spiral and number each coil.

other motor ranges, the voltages listed should be changed in proportion to the motor rating.

As all the coils are physically mounted in slots on the same motor frame, the coils will act almost like the primary and secondary coils of a transformer. Figure 6-4 shows a simplified electrical arrangement of the coils. Depending on which coil group power is applied to, the



6-4 Simplified electrical arrangement of wye-wound motor coils.

resulting voltage readings will be additive, subtractive, balanced, or unbalanced depending on physical location with regard to the coils themselves.

Step 3. The motor may be started on 230 V by connecting leads T-7, T-8, and T-9 to the three-phase source. If the motor is too large to be connected directly to the line, the voltage should be reduced by using a reduced voltage starter or other suitable means.

Step 4. Start the motor with no load connected and bring up to normal speed.

Step 5. With the motor running, a voltage will be induced in each of the open two-wire circuits that were tagged T-1 and T-4, T-2 and T-5, and T-3 and T-6. With a voltmeter, check the voltage reading of each circuit. The voltage should be approximately 125 to 130 V and should be the same on each circuit.

Step 6. With the motor still running, carefully connect the lead that was temporarily marked T-4 with the T-7 and line lead.

Read the voltage between T-1 and T-8 and also between T-1 and T-9. If both readings are of the same value and are approximately 330 to 340 V, leads T-1 and T-4 may be disconnected and permanently marked T-1 and T-4.

Step 7. If the two voltage readings are of the same value and are approximately 125 to 130 V, disconnect and interchange leads. If the test calls for equal voltages of 125 to130 V and the reading is only 80 to 90 V, this is acceptable as long as the voltage readings are nearly equal. T-1 and T-4 and mark permanently (original T-1 changed to T-4 and original T-4 changed to T-1).

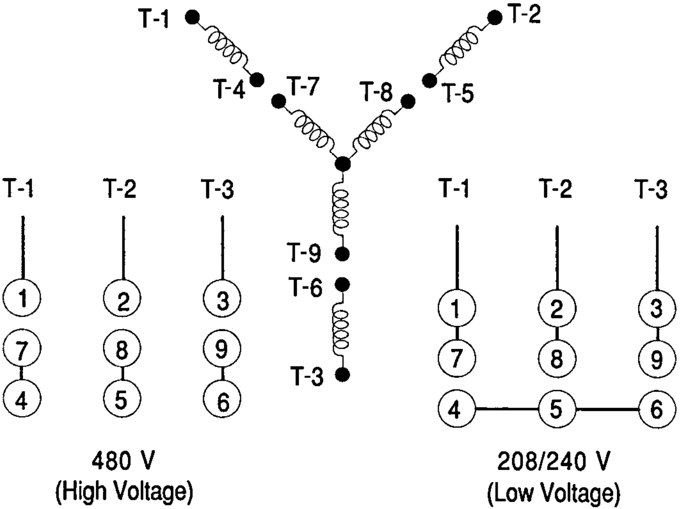
Note

The voltages referred to during the testing are only for reference and will vary greatly from motor to motor, depending on size, design, and manufacturer.

Step 8. If readings between T-1 and T-8 and between T-1 and T-9 are of unequal values, disconnect T-4 from T-7 and reconnect T-4 to the junction of T-8 and line.

Step 9. Measure the voltage now between T-1 and T-7 and also between T-1 and T-9. If the voltages are equal and approximately 330 to 340 V, tag T-1 is permanently marked T-2 and T-4 is marked T-5 and disconnected. If the readings taken are equal but are approximately 125 to 130 V, leads T-1 and T-4 are disconnected, interchanged, and marked T-2 and T-5 (T-1 changed to T-5, and T-4 changed to T-2). If both voltage readings are different, T-4 lead is disconnected from T-8 and moved to T-9. Voltage readings are taken again (between T-1 and T-7 and T-1 and T-8) and the leads permanently marked T-3 and T-6 when equal readings of approximately 330 to 340 V are obtained.

Step 10. Follow the same procedure for the other two circuits that were temporarily marked T-2 and T-5 and T-3 and T-6, until a position is found where both voltage readings are equal and approximately 330 to 340 V and the tags change to correspond to the standard lead markings as shown in Figure 6-5.



6-5 NEMA Standard lead markings for dual-voltage, wye-wound motors.

Step 11. Once all leads have been properly and permanently tagged, leads T-4, T-5, and T-6 are connected together and voltage readings are taken between T-1, T-2, and T-3. The voltages should be equal and approximately 230 V.

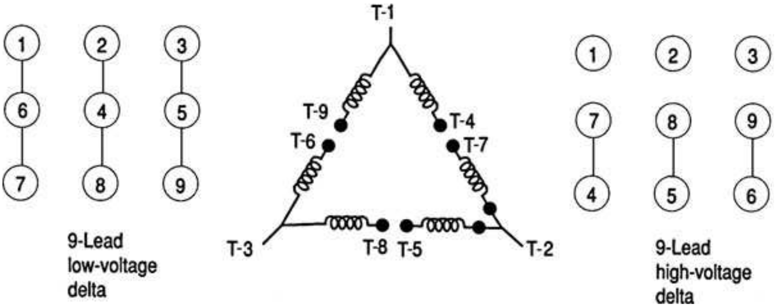
Step 12. As an additional check, the motor is shut down and leads T-7, T-8, and T-9 are disconnected, and leads T-1, T-2, and T-3 are connected to the line.

Connect T-1 to the line lead T-7 was connected to, T-2 to the same line as T-8 was previously connected to, and T-3 to the same lead that T-9 was connected to. With T-4, T-5, and T-6 still connected together to form a wye connection, the motor can again be started without a load. If all lead markings are correct, the motor rotation with leads T-1, T-2, and T-3 connected will be the same as when T-7, T-8, and T-9 were connected.

The motor is now ready for service and is connected in series for high voltage or parallel for low as indicated by the NEMA Standard connections shown in Figure 6-6.

Three-Phase Delta-Wound Motors

Most dual-voltage, delta-wound motors also have nine leads, as indicated in Figure 6-6, but there are only three circuits of three leads each. Use continuity tests to find the three coil groups, as was done for the



6-6 NEMA Standard lead markings for dual-voltage, delta-wound motors.

wye-wound motor. Once the coil groups are located and isolated, make further resistance checks to locate the common wire in each coil group. A DMM, Wheatstone bridge, or other sensitive device may be needed, since the resistance of some delta-wound motors is very low.

Each coil group consists of two coils tied together with three leads brought out to the motor junction or terminal box. Reading the resistance carefully between each of the three leads shows that the readings from one of the leads to each of the other two leads will be the same (equal), but the resistance reading between those two leads will be double the previous readings; Figure 6-7 illustrates the technique:

Step 1. The common lead found in the first coil group is permanently marked T-1, and the other two leads temporarily marked T-4 and T-9. The common lead of the next coil group is found and permanently marked T-2 and the other leads temporarily marked T-5 and T-7. The common lead of the last coil group is located and marked T-3 with the other leads being temporarily marked T-6 and T-8.

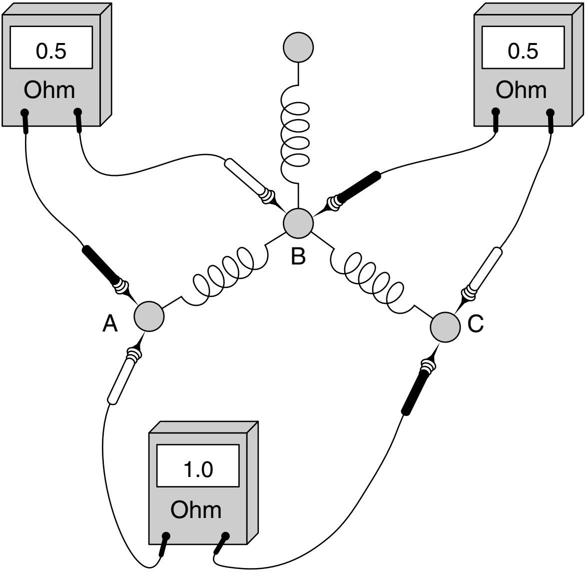
Note

This procedure may not work on some wye-connected motors with concentric coils.

Step 2. After the leads have been marked, connect the motor to a 230-V three-phase line using leads T-1, T-4, and T-9. Lead T-7 is connected to line and T-4, and the motor is started with no load connected. Voltage readings are taken between T-1 and T-2. If the voltage is approximately 460 V, the markings are correct and may be permanently marked.

Step 3. If the voltage reading is 400 V or less, interchange T-5 and T-7 *or* T-4 and T-9 and read the voltage again. If the voltage is approximately 230 V, interchange *both* T-5 with T-7 and T-4 with T-9. The readings should now be approximately 460 V between leads T-1 and T-2. The leads connected together now are actually T-4 and T-7 and are marked permanently. The remaining lead in each group can now be marked T-9 and T-5, as indicated by Figure 6-7.

Step 4. Connect one of the leads of the last coil group (not T-3) to T-9. If the reading is approximately 460 V between T-1 and T-3, permanently mark this lead T-6. If the reading is 400 V or less, interchange T-6 and T-8. A reading now of 460 V should exist between T-1 and T-3. T-6 is changed to T-8 and marked permanently and temporary T-8 is changed to T-6.



6-7 Using DMM to test motor leads.

If all leads are now correctly marked, equal readings of approximately 460 V can be obtained between leads T-1, T-2, and T-3.

Step 5. To double-check these markings, shut off the motor and reconnect it using T-2, T-5, and T-7. Connect T-2 to the same line lead as T-1, connect T-5 where T-4 was, and connect T-7 where T-9 was previously connected. When started, the motor should rotate the same direction as before.

Step 6. Stop the motor and connect leads T-3, T-6, and T-8 to the line leads previously connected to T-2, T-5, and T-7, respectively, and when the motor is started it should still rotate in the same direction. The motor is now ready for service and is connected in series for high or parallel for low voltage as indicated by the NEMA Standard connections shown in Figure 6-6.

Record Keeping

Accurate records are an important element of an effective motor maintenance program. Records on each motor should include the following, at a minimum:

- Complete description, including age and nameplate data.
- Location and application, updates when motors are transferred to different areas or used for different purposes.
- Notations of scheduled preventive maintenance and previous repair work performed.
- Location of duplicate or interchangeable motors.

Troubleshooting Charts

The troubleshooting chart (Figure 6-8) lists common motor problems along with their causes and remedies.

Symptoms	Probable Cause	Action or Items to Check
Oil leakage from overflow plugs.	Cracked or broken overflow plug.	Replace the plug.
	Plug cover not tight.	Tighten plug or furnish gasket.
Motor dirty.	Ventilation blocked, end windings filled with fine dust or lint.	Clean motor will run 10° to 30°C cooler. Dust may be cement, sawdust, rock dust, grain dust, coal dust, and the like. Dismantle entire motor and clean all windings and parts.

6-8 Troubleshooting chart for electric motors.

Symptoms	Probable Cause	Action or Items to Check
Motor dirty.	Rotor winding clogged.	Clean, grind, and undercut commutator. Clean and treat windings with good insulating varnish.
	Bearing and brackets coated inside.	Dust and wash with cleaning solvent.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor wet.	Subject to dripping.	Wipe motor and dry by circulating heated air through motor. Install drip or canopy type covers over motor for protection.
	Submerged in flood waters.	Dismantle and clean parts. Bake windings in oven at 105°C for 24 hours or until resistance to ground is sufficient. First make sure commutator bushing is drained of water.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor fails to start.	Circuit not complete.	Switch open, leads broken.
	Brushes not down on commutator.	Held up by brush springs, need replacement. Brushes worn out.
	Brushes stuck in holders.	Remove and sand, clean up brush boxes.
	Armature locked by frozen bearings in motor or main drive.	Remove brackets and replace bearings, or recondition old bearings if inspection makes possible.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor fails to start.	Power may be off.	Check line connections to starter with light. Check contacts in starter.
Motor starts, then stops and reverses direction of rotation.	Shunt and series fields are bucking each other.	Reconnect either the shunt or series field so as to correct the polarity. Then connect armature leads for desired direction of rotation. The fields can be tried separately to determine the direction of rotation individually.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor does not come up to rated speed.	Overload.	Check bearing to see if in good condition with correct lubrication. Check driven load for excessive load or friction.
Motor does not come up to rated speed.	Starting resistance not all out.	Check starter to see if mechanically and electrically incorrect.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor does not come up to rated speed.	Voltage low.	Measure voltage with meter and check with motor nameplate.
	Short circuit in armature windings or between bars.	For shorted armature inspect commutator for blackened bars and burned adjacent bars. Inspect windings for burned coils or wedges.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor does not come up to rated speed.	Starting heavy load with very weak field.	Check full field relay and possibilities of full field setting of the field rheostat.
	Motor off neutral.	Check for factory setting of brush rigging or test motor for true neutral setting.
	Motor cold.	Increase load on motor so as to increase its temperature, or add field rheostat to set speed.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor runs too fast.	Voltage above rated.	Correct voltage or get recommended change in air gap from manufacturer.
	Load too light.	Increase load or install fixed resistance in armature circuit.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor runs too fast.	Series coil reversed.	Reconnect coil leads in reverse.
	Series field coil shorted.	Install new or repaired coil.
	Neutral setting shifted off neutral.	Reset neutral by checking factory setting mark or testing for neutral.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor runs too fast.	Motor ventilation restricted, causing hot shunt field.	Hot field is high in resistance; check causes for hot field in order to restore normal shunt field current.
Motor gaining speed steadily and increasing load does not slow it down.	Unstable speed load regulation.	Inspect motor to see if off neutral. If series field has a shunt around the series circuit that can be removed, check series field to determine shorted turns.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor gaining speed steadily and increasing load does not slow it down.	Reversed field coil shunt or series.	Test with compass and reconnect coil.
	Too strong a commutating pole or commutating pole air gap too small.	Check with factory for recommended change in coils or air gap.
Motor runs too slow continuously.	Voltage below rated.	Check voltage and correct to value on nameplate.
	Motor operates cold.	Motor may run 20% slow due to light load. Install smaller motor.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor runs too slow continuously.	Overload.	Check bearings of motors and the drive to see if in good condition. Check for excessive friction in drive.
	Neutral setting shifted.	Check for factory setting of brush rigging or test for true neutral setting.
	Armature has shorted coils or commutator bars.	Remove armature to repair shop and put in first class condition.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor overheats or runs hot.	Overloaded and draws 25 to 50% more current than rated.	Reduce load by reducing speed or gearing in the drive or loading in the drive.
	Voltage above rated.	Motor runs drive above rated speed requiring excessive hp. Reduce voltage to nameplate rating.
	Inadequately ventilated.	Location of motor should be changed.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor overheats or runs hot.	Draws excessive current due to shorted coil.	Repair armature coils or install new coil.
	Grounds in armature such as two grounds which constitute a short.	Locate grounds and repair or rewind with new set of coils.
	Armature rubs pole faces due to off-center rotor causing friction and excessive current.	Check brackets or pedestals to center rotor and determine condition of bearing wear for bearing replacement.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Hot armature.	Core hot in one spot indicating shorted punching and high iron loss.	Sometimes full slot metal wedges have been used for balancing. These should be removed and other means of balancing investigated.
	Brush tension too high.	Limit pressure to 2 to 2½ psi. Check brush density and limit to density recommended by the brush manufacturer.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Hot armature.	Punching uninsulated. Punching has been turned or band grooves machined in the core. Machined slots.	No-load running of motor will indicate hot core and drawing high no-load armature current. Replace core and rewind armature. If necessary to add band grooves grind into core. Check temperature on core with thermometer; not to exceed 90°C.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Hot commutator.	Brushes off neutral.	Reset neutral.
	Brush grade too abrasive.	Get recommendation from manufacturer.
	Shorted bars.	Investigate commutator mica and undercutting, and repair.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Hot commutator.	Inadequate ventilation.	Check as for hot motor.
Hot fields.	Voltage too high.	Check with meter and thermometer and correct voltage to nameplate value.
	Shorted turns or grounded turns.	Repair or replace with new coil.
	Resistance of each coil not the same.	Check each individual coil for equal resistance within 10% and if one coil is too low replace coil.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Hot fields.	Inadequate ventilation.	Check as for hot motor.
	Coil not large enough to radiate its loss wattage.	Coils should be replaced if room is available in motor.
Motor vibrates, indicating unbalance.	Armature out of balance.	Remove and statically balance or balance in dynamic balancing machine.
	Misalignment.	Realign motor and drive.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor vibrates, indicating unbalance.	Loose or eccentric pulley.	Tighten pulley on shaft or correct eccentric pulley.
	Belt or chain whip.	Adjust belt tension.
	Mismating of gear and pinion.	Recut, realign, or replace parts.
	Unbalance in coupling.	Rebalance coupling.
	Bent shaft.	Replace or straighten shaft.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor vibrates, indicating unbalance.	Foundation inadequate.	Stiffen mounting place members.
	Motor loosely mounted.	Tighten holding-down bolts.
	Motor feet uneven.	Add shims under foot pads to mount each foot tight.
Motor sparks at brushes or does not commutate.	Neutral setting not true neutral.	Check and set on factory setting or test for true neutral.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor sparks at brushes or does not commutate.	Commutator rough.	Grind and roll edge of each bar.
	Commutator eccentric.	Turn, grind, and roll, commutator.
	Mica high—not undercut.	Undercut mica.
	Commutating pole strength too great causing over-compensation or strength too weak indicating under compensation.	Check with manufacturer for correct change in air gap or new coils for the commutating coils.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor sparks at brushes or does not commutate.	Shorted commutating pole turns.	Repair coils or install new coils.
	Shorted armature coils on commutator bars.	Repair armature.
	Open-circuited coils.	Repair armature.
	Poor soldered connection to commutator bars.	Resolder with proper solder alloy.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor sparks at brushes or does not commutate.	High bar or loose bar in commutator at high speeds.	Inspect commutator nut or bolts and retighten and grind commutator face.
	Brush grade wrong type. Brush pressure too light, current density excessive, brushes stuck in holders. Brush shunts loose.	Inspect brushes and replace as necessary.
	Brushes chatter due to dirty film on commutator.	Resurface commutator face and check for change in brushes.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor sparks at brushes or does not commutate.	Vibration.	Eliminate cause of vibration by checking mounting and balance of rotor.
Brush wear excessive.	Brushes too soft.	Blow dust from motor and replace brushes with grade recommended by manufacturer.
	Commutator rough.	Grind commutator face.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Brush wear excessive.	Off neutral setting.	Recheck factory neutral or test for true neutral.
	Abrasive dust in ventilating air.	Reface brushes and correct condition by protecting motor.
	Brush tension excessive.	Adjust spring pressure not to exceed 2 to 2½ psi.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Brush wear excessive.	Electrical wear due to loss of film on commutator face.	Resurface brush faces and commutator face. Check for change in brush grade.
	Threading and grooving.	Resurface brush faces and commutator face. Check for change in brush grade.
	Oil or grease from atmosphere or bearings.	Correct oil condition and surface brush faces and commutator.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor noisy.	Brush singing.	Check brush angle and commutator coating, resurface commutator.
	Brush chatter.	Resurface commutator and brush face.
	Motor loosely mounted.	Tighten foundation bolts.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor noisy.	Foundation hollow and acts as sounding board.	Coat underside with sound-proofing material.
	Strained frame.	Shim motor feet for equal mounting.
	Armature punching loose.	Replace core on armature.
	Armature rubs pole faces.	Recenter by replacing bearings or relocating brackets or pedestals.
	Magnetic hum.	Refer to manufacturer.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor noisy.	Belt slap or pounding.	Check condition of belt and adjust belt tension.
	Excessive current load.	May not cause overheating but check chart for correction of shorted or grounded coils.
	Mechanical vibration.	Check chart for causes of vibration.
	Noisy bearings.	Check alignment, loading of bearings, and lubrication.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor stalls.	Wrong application.	Change type or size. Consult manufacturer.
	Overloaded motor.	Reduce load.
	Low motor voltage.	See that nameplate voltage is maintained.
	Open circuit.	Check fuse, circuit breaker, overload relay, starter, and pushbuttons.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor stalls.	Incorrect control resistance of wound rotor.	Check control sequence. Replace broken resistors. Repair open circuits.
Motor connected but does not start.	One phase open.	Reconnect open phase.
	Motor may be overloaded.	Reduce load.
	Rotor defective.	Look for broken bars or rings.
	Poor stator coil connection.	Remove end bells.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor runs and then dies down.	Power failure.	Check for loose connections to line, to fuses, and to control.
Motor does not come up to speed.	Not applied properly.	Consult supplier for proper type.
	Voltage too low at motor terminals because of line drop.	Use higher-voltage transformer tap or reduce load.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor does not come up to speed.	If wound rotor, improper control operation of secondary resistance.	Correct secondary control.
	Starting load too high.	Check load motor is supposed to carry at start.
	Low pull-in torque of synchronous motor.	Change rotor starting resistance or change rotor design.
	Check that all brushes are riding on rings.	Check secondary connections.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor does not come up to speed.	Broken rotor bars.	Look for cracks near the rings. A new rotor may be required as repairs are usually temporary.
	Open primary circuit.	Locate fault with testing device and repair.
Motor takes too long to accelerate.	Excess loading.	Reduce load.
	Poor circuit.	Check for excessive voltage drop.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor takes too long to accelerate.	Defective squirrel-cage rotor.	Replace with new rotor.
	Applied voltage too low.	Get power company to increase voltage tap.
Wrong rotation.	Wrong sequence of phase.	Reverse connections of motor or at switchboard.
Motor overheats while running under load.	Check for overload.	Reduce load.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor overheats while running under load.	Wrong blowers or air shields, may be clogged with dirt and prevent proper ventilation of motor.	Good ventilation is indicated by a continuous stream of air leaving the motor. If not, check manufacturer.
	Motor may have one phase open.	Check to make sure that all leads are well connected.
	Grounded coil.	Locate and repair.
	Unbalanced terminal voltage.	Check for faulty leads, connections, and transformers.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor overheats while running under load.	Shorted stator coil.	Repair and then check wattmeter reading.
	Voltage too high or low.	Check terminals of motor with voltmeter.
	Rotor rubs stator bore.	If not poor machining, replace worn bearings.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor vibrates after corrections have been made.	Motor misaligned.	Realign motor and drive.
	Weak foundations.	Strengthen base.
	Coupling out of balance.	Balance coupling.
	Driven equipment unbalanced.	Rebalance driven equipment.
	Defective ball bearing.	Replace bearing.
	Bearings not in line.	Line up properly.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Motor vibrates afer corrections have been made.	Balancing weights shifted.	Rebalance rotor.
	Wound rotor coils replaced.	Rebalance rotor.
	Polyphase motor running single phase.	Check for open circuit.
	Excessive end play.	Adjust bearing or add washer.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Unbalanced line current on polyphase motors during normal operation.	Unequal terminal voltages.	Check leads and connections.
	Single-phase operation.	Check for open contacts.
	Poor rotor contacts in control wound-rotor resistance.	Check control devices.
	Brushes not in proper position in wound rotor.	Ensure that brushes are properly seated and shunts in good condition.

6-8 Troubleshooting chart for electric motors. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Scraping noise.	Fan rubbing air shield.	Remove interference.
	Fan striking insulation.	Clear fan.
	Loose on bedplate.	Tighten holding bolts.
Magnetic noise.	Air gap not uniform.	Check and correct bracket fits or bearing.
	Loose bearings.	Correct or renew.
	Rotor unbalance.	Rebalance.

6-8 Troubleshooting chart for electric motors. *(Continued)*

CHAPTER
7

Troubleshooting Motor Bearings

Alternating-current motors account for a high percentage of electrical repair work. A high proportion of failures are caused by faulty bearings. Sleeve and ball bearing failure can occur in both newer and older motors; but sealed motor bearings are much less prone to failure.

Types of Bearings

There are many types of motor bearings, with ball bearings being the most common. There are several different types of ball bearings used in motors:

- Open
- Single shielded
- Double shielded
- Sealed
- Double row and other special types

Open bearings, as the name implies, are open construction and must be installed in a sealed housing. These bearings are less apt to cause churning of grease, and for this reason are used mostly on large motors.

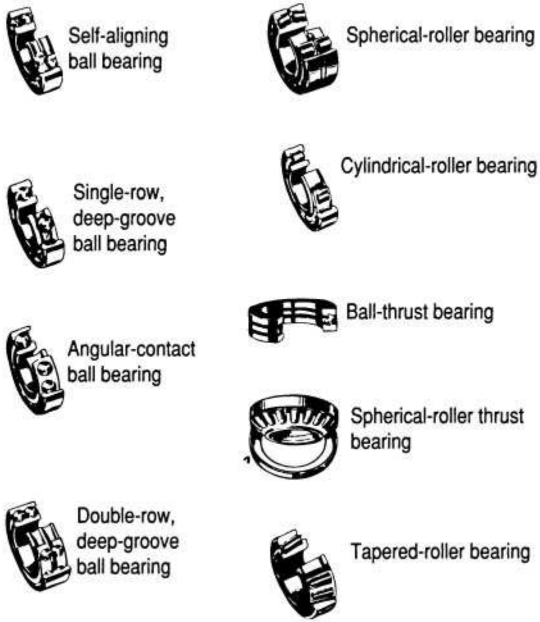
Single-shielded bearings have a shield on one side to exclude grease from the motor windings.

Double-shielded bearings have a shield on both sides of the bearing. This type of bearing is less susceptible to contamination, requires no maintenance, and does not require regreasing. It is normally used on small- or medium-size motors.

Each bearing type has characteristics which make it the best choice for a certain application. Replacement should be made with the same type bearings. The following list of functions provide a basic understanding of bearing application, a guide to analysis of bearing troubles due to misapplication, and emphasize the importance of proper replacement.

Figure 7-1 shows several types of bearings used in electric motors. The following is a brief description of each:

Self-aligning ball bearings: Self-aligning ball bearings are used for radial loads and moderate thrust loads in either direction. This ball bearing, has two rows of balls rolling on the spherical surface of the outer ring, compensates for angular misalignment resulting from errors in mounting, shaft deflection, and distortion of the foundation. It is impossible for this bearing to exert any bending influence on the shaft—an important consideration in high-speed applications requiring extreme accuracy.



7-1 Various bearing types.

Single-row, deep-groove ball bearings: The single-row, deep-groove ball bearing will sustain, in addition to radial load, a substantial thrust load in either direction, even at very high speeds. This advantage results from the intimate contact existing between the balls and the deep, continuous groove in each ring. When using this type of bearing, careful alignment between the shaft and housing is essential. This bearing is also available with seals and shields, which exclude dirt and retain lubricant.

Angular-contact ball bearings: The angular-contact ball bearing supports a heavy thrust load in one direction, sometimes combined with a moderate radial load. A steep contact angle, assuring the highest thrust capacity and axial rigidity, is obtained by a high thrust-supporting shoulder on the inner ring and a similar high shoulder on the opposite side of the outer ring.

Double-row, deep-groove ball bearings: The double-row, deep-groove ball bearing has a lower axial displacement than the single-row design, substantial thrust capacity in either direction, and high radial capacity due to the two rows of balls.

Spherical-roller bearings: The spherical-roller bearing has maximum capacity, due to the number, size, and shape of the rollers, and the accuracy with which they are guided. Since the bearing is inherently self-aligning, angular misalignment between the shaft and housing has no detrimental effect, and the full capacity is always available for useful work.

Cylindrical-roller bearings: This type of bearing has high radial capacity and provides accurate guiding of the rollers, resulting in low friction that permits operation at high speed. The double-row type is particularly suitable for machine-tool spindles.

Ball-thrust bearings: The ball-thrust bearing is designed for thrust load in one direction only. The load line through the balls is parallel to the axis of the shaft, resulting in high-thrust capacity and minimum-axial deflection.

Spherical-roller thrust bearings: The spherical-roller thrust bearing is designed to carry heavy thrust loads, or combined loads, which are predominantly thrust. This bearing has a single row of rollers that roll on a spherical outer race with full self-alignment. The cage, centered by an inner ring sleeve, is constructed so that lubricant is pumped directly against the inner ring's unusually high guide flange.

Tapered-roller bearings: Since the axes of its rollers and raceways form an angle with the shaft axis, the tapered-roller bearing is especially suitable for carrying radial and axial loads acting simultaneously. A bearing of this type usually must be adjusted toward another bearing capable of carrying thrust loads in the opposite direction. Tapered-roller bearings are separable; their cones (inner rings) with rollers and their cups (outer rings) are mounted separately.

The do's and don'ts for ball-bearing assembly, maintenance, inspection, and lubrication are shown in Figure 7-2.

Frequency of Lubrication

Frequency of motor lubrication depends not only on the type of bearing but also on the motor application.

Small- and medium-size motors equipped with ball bearings (except sealed bearings) are greased every 3 to 6 years if the motor duty is normal. Severe applications (high temperature, wet or dirty locations, or corrosive atmospheres), may require more frequent lubrication.

DO's

DO work with clean tools, in clean surroundings.

DO remove all outside dirt from housing before exposing bearing.

DO treat a used bearing as carefully as a new one.

DO use clean solvents and flushing oils.

DO lay bearings out on clean paper or cloth.

DO protect disassembled bearings from dirt and moisture.

DO use clean, lint-free rags to wipe bearings.

DO keep bearings wrapped in oil-proof paper when not in use.

DO clean outside of housing before replacing bearings.

DO keep bearing lubricants clean when applying and cover containers when not in use.

DO be sure shaft size is within specified tolerances recommended for the bearing.

DO store bearings in original unopened cartons in a dry place.

DO use a clean, short-bristle brush with firmly embedded bristles to remove dirt, scale, or chips.

7-2 Do's and don'ts for ball-bearing assembly, maintenance, and lubrication.

DO's (*Cont.*)

DO be certain that, when installed, the bearing is square with and held firmly against the shaft shoulder.

DO follow lubricating instructions supplied with the machinery. Use only grease where grease is specified; use only oil where oil is specified. Be sure to use the exact kind of lubricant called for.

DO handle grease with clean paddles or grease runs. Store grease in clean containers. Keep grease containers covered.

DON'Ts

DON'T work under the handicap of poor tools, rough benches, or dirty surroundings.

DON'T use dirty, brittle, or chipped tools.

DON'T handle bearings with dirty, moist hands.

DON'T spin uncleaned bearings.

DON'T spin any bearings with compressed air.

DON'T use same container for cleaning and final rinse of bearings.

DON'T scratch or nick bearing surfaces.

7-2 Do's and don'ts for ball-bearing assembly, maintenance, and lubrication. *(Continued)*

DON'Ts *(Cont.)*

DON'T remove grease or oil from new bearings.

DON'T use incorrect kind or amount of lubricant.

DON'T use a bearing as a gauge to check either the housing bore or the shaft fit.

DON'T install a bearing on a shaft that shows excessive wear.

DON'T open a carton until the bearing is ready for installation.

DON'T judge the condition of a bearing until after it has been cleaned.

DON'T pound directly on a bearing or ring, when installing, as this may cause damage to shaft and bearing.

DON'T overfill when lubricating. Excess grease and oil will ooze out of the overfilled housings past seals and closures, collect dirt, and cause trouble. Too much lubricant will also cause overheating, particularly where bearings operate at high speeds.

DON'T permit any machine to stand inoperative for months without turning it over periodically. This prevents moisture which may condense in a standing bearing from causing corrosion.

7-2 Do's and don'ts for ball-bearing assembly, maintenance, and lubrication. *(Continued)*

Lubrication in sleeve bearings should be changed at least once a year. When the motor duty is severe or the oil appears dirty, it should be changed more frequently.

Lubrication Procedure

Cleanliness and using the proper lubricant are critically important when lubricating motors. Follow this procedure:

1. Wipe the bearing housing, grease gun, and fittings clean.
2. Take care to keep dirt out of the bearing when greasing.
3. Next, remove the relief plug from the bottom of the bearing housing. This prevents excessive pressure from building up inside the bearing housing during greasing.
4. Add grease, with the motor running if possible, until it begins to flow from the relief hole. Let the motor run 5 to 10 minutes to expel excess grease. Replace the relief plug and clean the bearing housing.
5. Avoid over-greasing. When too much grease is forced into a bearing, churning of the lubricant occurs, resulting in high temperature and eventual bearing failure.
6. On motors that don't have relief holes, apply grease sparingly. If possible, disassemble the

motor and repack the bearing housing with the proper amount of grease. During this procedure, always maintain strict cleanliness.

Testing Bearings

Two of the most effective tests are what might be called the "feel" test and the "sound" test. Perform the "feel" test while the motor is running; if the bearing housing feels overly hot to the touch, it is probably malfunctioning.

During the "sound" test, listen for foreign noises coming from the motor. Also, one end of a steel rod (about 3 ft long and 1.2 in. in diameter) may be placed on the bearing housing while the other end is held against the ear. The rod then acts as an amplifier, transmitting unusual sounds such as thumping or grinding, which indicate a failing bearing. Special listening devices, such as a transistorized stethoscope, can also be used for the purpose.

The troubleshooting chart in Figure 7-3 lists the most common problems with motor bearings.

Symptoms	Probable Cause	Action or Items to Check
Hot bearings—general.	Bent or sprung shaft.	Straighten or replace shaft.
	Excessive belt pull.	Decrease belt tension.
	Pulley too far away.	Move pulley closer to bearing.
	Pulley diameter too small.	Use larger pulleys.
	Misalignment.	Realign drive.

7-3 Troubleshooting chart for motor bearings.

Symptoms	Probable Cause	Action or Items to Check
Hot bearings—sleeve.	Oil grooving in bearing obstructed by dirt.	Remove bracket or pedestal with bearing and clean oil grooves and bearing housing; renew oil.
	Bent or damaged oil rings.	Repair or replace oil rings.
	Oil too heavy.	Use a recommended lighter oil.
	Oil too light.	Use a recommended heavier oil.

7-3 Troubleshooting chart for motor bearings. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Hot bearings—sleeve.	Insufficient oil.	Fill reservoir to proper level in overflow plug with motor at rest.
	Too much end thrust.	Reduce thrust induced by driven machine or supply external means to carry thrust.
	Badly worn bearing.	Replace bearing.

7-3 Troubleshooting chart for motor bearings. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Hot bearings—ball.	Insufficient grease.	Replace bearing.
	Lubricant deteriorated or contaminated.	Remove old grease, wash bearings thoroughly in kerosene, and replace with new grease.
	Excess lubricant.	Reduce quantity of grease. Bearing should not be more than half filled.

7-3 Troubleshooting chart for motor bearings. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Hot bearings—ball.	Heat from hot motor or external source.	Protect bearing by reducing motor temperature.
	Overloaded bearing.	Check alignment, side thrust, and end thrust.
	Broken ball or rough races.	Replace bearing; first clean housing thoroughly.

7-3 Troubleshooting chart for motor bearings. *(Continued)*

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CHAPTER

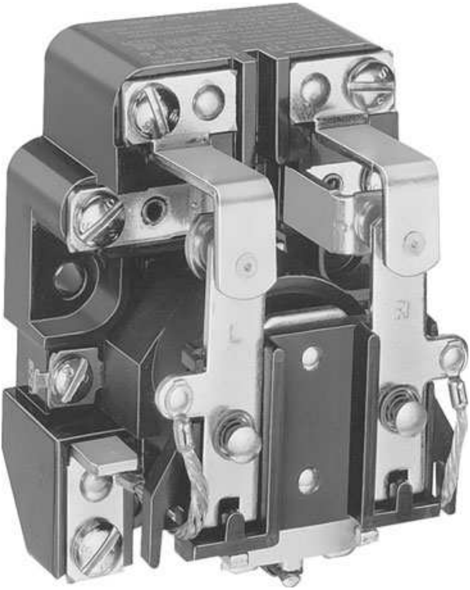
8

Troubleshooting Relays and Contactors

A relay is an electromagnetic or solid-state device used in control circuits of magnetic motor starters, heaters, solenoids, timers, and other devices. They are frequently used for remote control applications. Relays are manufactured in a number of different configurations, in both mechanical and solid-state designs. Figure 8-1 shows a type of relay often used to control small, single-phase motors and other light loads such as heaters or pilot lights.

Contactors are electromagnetic devices similar in construction and operation to relays, but designed to handle much higher currents (Figure 8-2) involved in applications such as switching large banks of stadium lights on and off.

Figure 8-3 describes troubleshooting procedures for relays and contactors.



8-1 Single-pole, single-throw (SPST) relay rated 30 A, 600 V. *(Courtesy of Schneider Electric Company.)*

8-2 NEMA size 1 contactor rated 10HP, 575 V.
(Courtesy of Schneider Electric Company.)

Symptoms	Probable Cause	Action or Items to Check
Failure to pull in.	Either no voltage or low voltage at coil terminals.	Open fuse or circuit breaker, open line switch, or break in wiring.
		Line voltage below normal.
		Overload relay open or set too low.
		Tripping toggle (nonautomatic breakers) fouled.
		Control level or start button in OFF position.

8-3 Contactor and relay troubleshooting chart.

Symptoms	Probable Cause	Action or Items to Check
Failure to pull in.	Either no voltage or low voltage at coil terminals.	Pull-in circuit open, shorted, or grounded.
		Contacts in protective or controlling circuit open or one of their pigtail connections broken.
	Operating coil open or grounded.	Inspect and test coil.
	Loose or disconnected coil lead wire.	Inspect and correct.

8-3 Contactor and relay troubleshooting chart. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Failure to pull in.	Excessive magnet gap, improper alignment.	Inspect and correct.
	Armature obstructed or gumming deposits between armature and pole face.	Inspect and correct.
	Binding caused by deformed or gummy hinge.	Replace or degrease.
	Excessive armature spring force.	Lessen spring force.

8-3 Contactor and relay troubleshooting chart. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Failure to pull in.	Normally closed contacts welded together.	Replace contacts.
Failure of equipment to start with contactor closed.	One contact not closing.	Replace set of contacts.
	Contacts burned.	Use emery cloth to lightly burnish or replace.
	Contact pigtail connection broken.	Replace.

8-3 Contactor and relay troubleshooting chart. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Failure to drop out.	Operating coil is energized.	Contacts in controlling or protective tripping circuits closed, shorted, or shunted.
		Tripping devices defective; such as overload tripping toggles do not strike release, undervoltage relay plunger stuck or out of adjustment, defective stop button, or defective time-delay escape mechanism (closed air vent).

8-3 Contactor and relay troubleshooting chart. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Failure to drop out.	Operating coil is energized.	Current following unintentional path due to grounds, defective insulation, pencil markings, moisture, or lacquer chipped off relay's base.
	Residual magnetism excessive, due to armature closed tightly against pole face.	Adjust or replace.

8-3 Contactor and relay troubleshooting chart. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Failure to drop out.	Armature obstructed or gumming deposits between armature and pole face.	Clear and clean.
	Binding caused by deformed or gummy hinge.	Replace or degrease.
	Contact pressure spring or armature spring too weak or improperly adjusted.	Replace or adjust.
	Improper mounting position (upside down).	Mount correctly.

8-3 Contactor and relay troubleshooting chart. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Failure to drop out.	Normally opened contacts welded together.	Replace contacts.
Time delay relays operate too fast.	Escapement mechanism faulty.	Air escapes too freely due to holes in bellows or open air vent.
		Worn dashpot plunger, or dashpot oil too thin.
	Nonmagnetic shim in air gap too large or armature spring too strong.	Adjust or replace.
	Magnets out of adjustment.	Adjust.

8-3 Contactor and relay troubleshooting chart. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Contacts pitted or discolored.	Contacts overheated from overload.	Reduce load and replace contacts.
	Contacts not fitted properly.	Refit.
	Barriers broken from rough usage or breakers closing with too much force.	Replace barriers; check for high voltage.
	Wiping action of contacts on closing is insufficient.	Correct.

8-3 Contactor and relay troubleshooting chart. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Contacts pitted or discolored.	Exposure to weather, dripping water, salt air, or vibration.	Use suitable NEMA enclosure type.
Excessive chatter or hum.	Vibration of surrounding devices communicated to relay.	Arrange differently.
	Relay receiving contradictory signals.	Correct.
	Bouncing of controlling or protective contacts.	Correct.

8-3 Contactor and relay troubleshooting chart. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Excessive chatter or hum.	Line voltage fluctuating or insufficient.	Consider using buck-and-boost transformers.
	Excessive coil circuit resistance.	Lessen resistance.
	Armature spring or contact pressure spring too strong.	Lessen.
	Excessive coil voltage drop on closing.	Correct.
	Improper antifreeze pin location.	Locate in correct position.

8-3 Contactor and relay troubleshooting chart. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Excessive chatter or hum.	Free movement of armature hindered due to deformed parts or dirt.	Clean and replace appropriate parts.
Excessive coil temperature.	Excessive current or voltage.	Reduce load or adjust taps on transformer.
	Short circuit in coil.	Replace coil.
	Excessive eddy current and hysteresis.	Correct.
	High room temperature.	Replace with properly rated relay.

8-3 Contactor and relay troubleshooting chart. *(Continued)*

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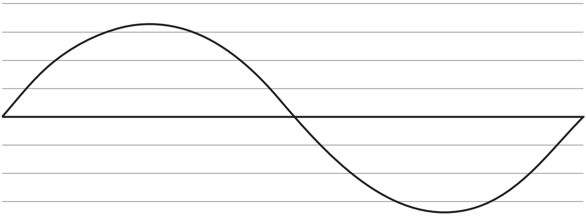
CHAPTER
9

Troubleshooting Power Quality Problems

A power quality problem is any change of voltage, current, or frequency that results in failure or reduced performance of end-user equipment. In real-life electrical power systems, voltages and currents are generally not the pure 60-Hz sine waves shown in textbooks (Figure 9-1). Instead, the waveform is typically distorted by voltage transients, harmonics, and other phenomena (Figure 9-2). These waveforms can be displayed on the screens of power monitors and other instruments to diagnose power quality problems. Power quality problems can be caused by many factors:

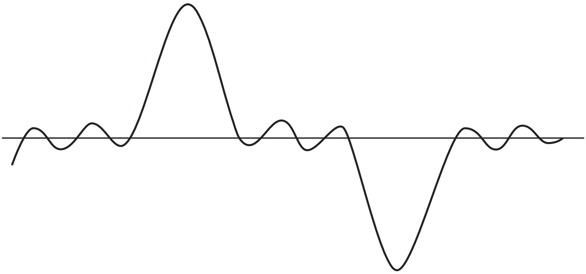
- Voltage levels (steady state) and voltage stability (surges and sags)
- Current balance (phase loading)
- Harmonics
- Power factor
- Grounding
- Overheated terminals and connections
- Faulty or marginal circuit breakers



9-1 Ideal sine waveform representing voltage or current.

Monitoring

Recording monitors are typically installed to record power system characteristics over a period of time, such as 24 hours, or 7 days. This long-term monitoring provides information on whether a power quality problem was caused by a one-time random event, or a repetitive recurring event. Often, power quality



9-2 Sine waveform distorted by power quality problems.

problems are not caused by a single event, but by a combination of factors (such as voltage drop, utility transients, harmonics, and improper neutral-to-ground connections).

Power can be monitored at different locations in an electrical power system:

At the load: Placing a monitor at the branch circuit supplying a motor or other piece of utilization equipment analyzes the power quality at the point of use.

At the distribution equipment: Placing a monitor on the feeder to a panelboard or motor control center (MCC) analyzes the power quality in an entire section of a building.

At the service: Placing a monitor at the incoming service conductors to a switchboard or other service equipment analyzes the power quality in an entire building (Figure 9-3). This is where capacitors are typically installed to improve power factor for the reason of avoiding utility penalty charges.

Voltage Levels and Stability

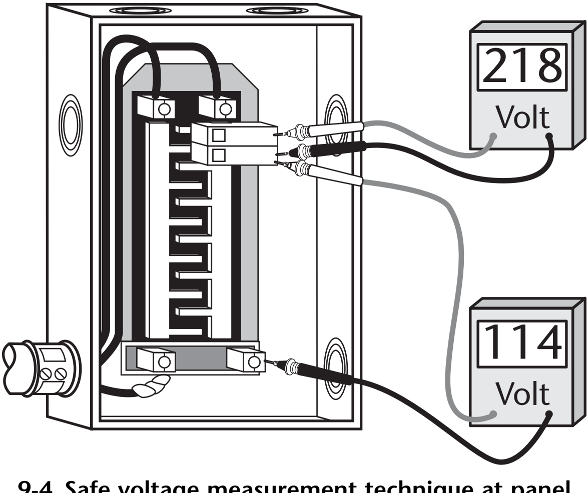
Voltage Levels

Check voltage levels at the main panel terminals and each branch circuit. Voltage at the panel should ideally be 120/208 or 277/480 V, three-phase, four-wire. Voltage at receptacles or utilization equipment may be lower due to voltage drop on branch circuits, but should ideally be no less than 115/200 or 265/460 V.

9-3 Service equipment: main distribution panel.
(Courtesy of Schneider Electric Company.)

For safety, take voltage measurements on the load side of main or branch circuit breakers whenever possible. This precaution helps protect the test instrument and operator from potential fault currents on feeders (Figure 9-4).

Low voltage causes electric motors to run slower than their design speed, incandescent lights to burn dimmer, starting problems for fluorescent and HID lamps, and performance problems for electronic and data devices. Overvoltage causes motors to run faster, shortens incandescent lamp life, and can damage sensitive electronic components.



9-4 Safe voltage measurement technique at panel board.

Most electrical and electronic equipment are designed to tolerate a range of ±10 percent of rated voltage and still operate satisfactorily. However, panelboard voltages in the range of 115/200 or 265/460 V will probably translate into unacceptably low voltages at receptacles or utilization equipment, due to additional voltage drop on the branch circuit conductors.

Common causes of low voltage at the panel are low tap settings at transformers, feeder conductors that are too long or too small, and loose connections. The first condition results in lower supply voltage; the latter two result in higher impedance that increases voltage drop.

Voltage Stability

Voltage sags can be caused by either loads on branch circuits, or elsewhere in the distribution system, including utility-generated sags and brownouts. This is most easily analyzed using an instrument such as a power quality analyzer that measures both voltage and current simultaneously. Take measurements at each branch circuit in the panelboard.

Voltage sag occurring simultaneously with a *current surge* usually indicates a problem downstream of the measurement point. This would be a load-related disturbance on the branch circuit.

Voltage sag occurring simultaneously with a *current sag* usually indicates a problem upstream of the measurement point, originating elsewhere in the distribution system. Typical source-related disturbances include large three-phase motors coming on line (starting) or sags in the utility network.

Current Loading

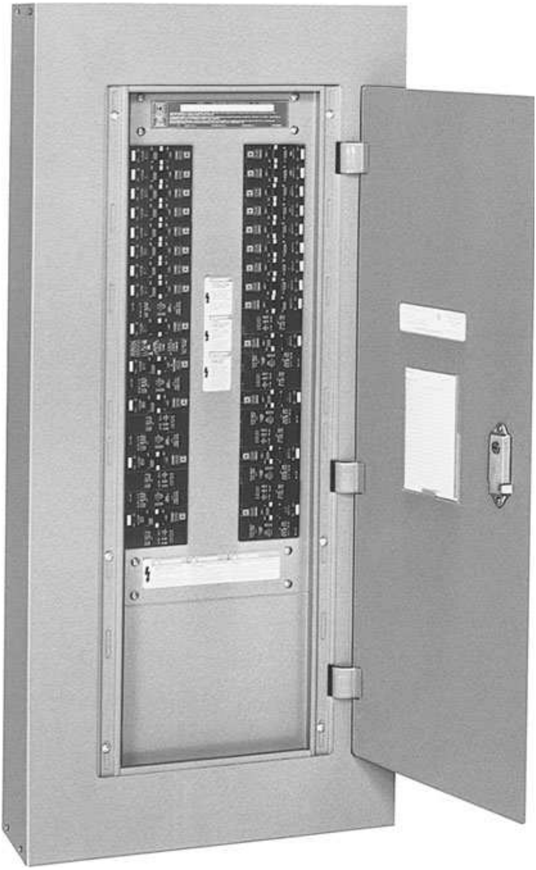
Measure the current on each feeder phase and branch circuit (Figure 9-5). It is important to make these measurements using a true-RMS ammeter or digital multimeter (DMM). Because the combination of fundamental and harmonic currents results in a distorted waveform, a lower-cost average-sensing meter will tend to read low, leading you to assume that circuits are more lightly loaded than they actually are.

Loading on the three phases should be as balanced as possible. Unbalanced current will return on the neutral conductor, which may already be carrying a high load due to harmonics caused by nonlinear loads. In an ideal, balanced, three-phase electrical distribution system, there is little or no load on the neutral.

Neither the panel feeder nor branch circuits should be loaded to the maximum allowable limit (80 percent of the overcurrent device rating, for continuous loads). There should be some spare capacity to allow for harmonic currents.

Harmonics

Harmonics are frequencies that are multiples of the fundamental frequency (120 Hz, 180 Hz, 240 Hz, and so on). High-frequency harmonic currents caused by nonlinear loads such as computers, adjustable speed motor drives, programmable controllers, and fluorescent fixtures with electronic ballasts can cause significant heating in power distribution systems, particularly in grounded (neutral) conductors. Harmonics affect the operation or



9-5 Branch-circuit panelboard. *(Courtesy of Schneider Electric Company.)*

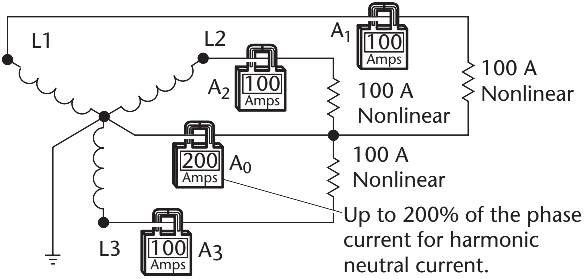
equipment such as motors, transformers, and overheating of neutral conductors.

Triplen Harmonics

Triplen harmonics are the following multiples of the fundamental frequency: 3, 6, 9, 12, and so on. They are very harmful for power quality because triplen harmonic currents can add up in the neutrals of the three-phase power systems, as shown in Figure 9-6. Nonlinear loads include such common electrical equipment as switched-mode power supplies used in computers and their peripherals, and fluorescent or HID fixture ballasts.

Overloaded neutrals are a potential fire hazard because, unlike phase conductors, they are not protected by an overcurrent device. Third harmonics can overload system neutral conductors even when loads have been balanced among the three phases.

For this reason, National Electrical Code 310.15(B)(4)(c) requires that "On a four-wire, three-phase, wye



9-6 Effect of harmonics due to nonlinear loads.

circuit where the major portion of the load consists of nonlinear loads, harmonic currents are present in the neutral conductor; the neutral shall therefore be considered a current-carrying conductor."

In effect, this requires that neutral conductors of such three-phase, four-wire systems be at least the same size as the phase conductors. In practice, neutrals of systems serving a high proportion of nonlinear loads (such as office areas with multiple computers and fluorescent lighting) are sometimes even larger, up to double the size of the associated phase conductors (Figure 9-6).

Multiwire Branch Circuits

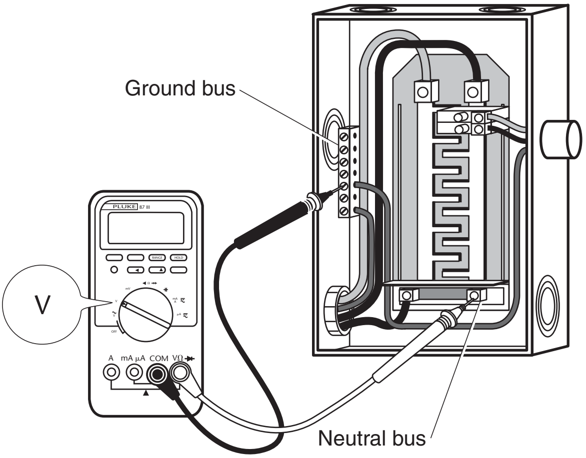
Common neutrals shared by either two or three single-phase branch circuits are subject to the same overloading as neutrals of three-phase panel feeders, due to asymmetrical loading and third harmonics.

Harmonic currents in feeder or branch circuit grounded (neutral) conductors can be measured using a DMM, or by using a probe-type meter to measure the potential from neutral to ground (Figure 9-7).

Grounding

The neutral and grounding electrode conductor should be bonded together only once, at the service entrance or distribution point of a separately derived system. Other neutral-ground connections elsewhere in the system, such as subpanels or receptacle outlets, are a violation of the National Electrical Code.

Unfortunately, improper downstream connections between neutral and grounding conductors are also



9-7 Measuring neutral current.

very common, and they are frequently a source of power quality problems.

When the neutral and grounding electrode conductors are bonded at a subpanel or other location, the ground path becomes a parallel return path for normal load current, and there will be measurable current on the ground.

To determine whether improper connections exist, measure the current on the grounded (neutral) conductor and then on the grounding electrode conductor and look at the ratio between them. For example, if the neutral current is 70 A and the ground current is 2 A, the small ground current probably represents normal leakage. But if the neutral measures 40 A and the green ground measures 20 A, this probably indicates that there are improper neutral-ground connections. The smaller the ratio of neutral-to-ground current, the more likely it is that neutral-ground binds exist.

All neutral-to-ground connections not permitted by the National Electrical Code should be removed. This will improve both safety and power quality.

Overheated Terminals and Connections

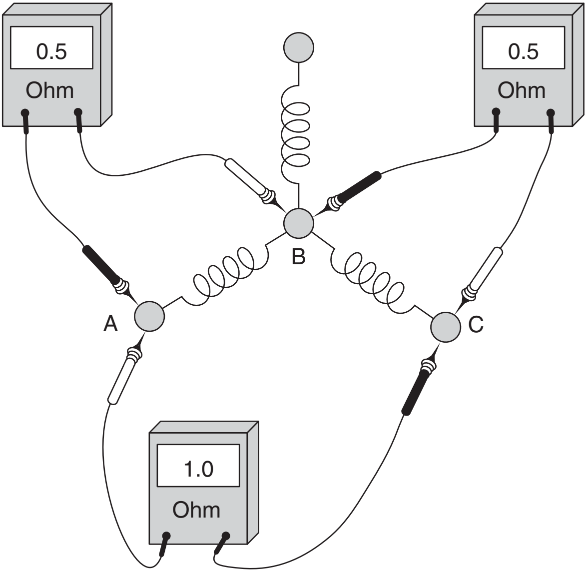
Poor connections and loose terminations increase circuit impedance and thus voltage drop. They can also cause hard-to-diagnose intermittent problems, such as circuits that cycle on and off unpredictably (a loose connection may open when it heats up, and then close again when it cools down).

"Hot spots" indicating possible poor connections and terminations can often be found using thermal scanning, which is discussed further in Chapter 10. Visual inspection may also be useful. A preventive maintenance program of checking and tightening conductor connections on a regular basis can help prevent this type of problem before it occurs.

Circuit Breakers

Although molded-case circuit breakers typically have long service lives, contacts and springs can wear out, particularly when the device has tripped frequently or been used as a switch to turn equipment or circuits on and off. As with other poor connections, marginal breakers increase circuit impedance and voltage drop. Overheating due to their poor internal connections may also lead to "nuisance tripping."

Measure voltage drop across the circuit breaker, from line side to load side, to determine the condition of internal components (see Figure 9-8). If voltage drop exceeds 100 millivolts (mV), the branch circuit breaker should be replaced. Readings in the 35 to



9-8 Measuring voltage drop across circuit breaker.

100 mV range should be noted and those breakers rechecked at regular intervals.

Power Factor

Power factor is a key element of power quality; it is computed as real power (volt-amperes) divided by apparent power (watts). Both electric utilities and facility engineers typically try to maintain power factor as close to unity (1.0) as possible. However, many types of equipment and devices attached to modern electric supply systems cause either a leading or lagging power factor, because impedance causes a phase shift between the voltage and current waveforms. Power factor is a measure of how efficiently a load uses electricity or how much energy is consumed by the load versus how much the utility must provide. Electric utilities frequently levy high penalties on large electricity users (industrial plants, office campuses) that fail to keep power factor above some minimum such as 0.95 power factor.

Impedance

Impedance is at the heart of power factor. Typically, there should be an impedance value of less than 0.5 Ω between the phase and grounded (neutral) conductor, and between the neutral conductor and equipment grounding conductor.

Figure 9-9 summarizes power quality troubleshooting recommendations.

Symptoms	Probable Cause	Action or Items to Check
Low voltage levels at panelboard or service entrance equipment.	Utility supply voltage too low.	Consult utility.
	Transformer tap settings too low.	Use higher voltage taps.
	Loose connection in feeder service conductors.	Check connections.
Voltage sag coincides with current surge, when measured at panelboard.	Downstream load with high inrush current, such as motor(s) or incandescent lighting.	Consider feeding sensitive loads from other circuits or panelboards.
Voltage surge coincides with current decrease, when measured at panelboard.	Upstream source-related disturbance.	Consult utility.

9-9 Troubleshooting chart for power quality problems.

Symptoms	Probable Cause	Action or Items to Check
Significant neutral current on three-phase feeder.	Unbalanced loading on different phases of panelboard.	Balance panelboard.
Current on neutral of three-phase feeder equals or exceeds phase currents.	Harmonics generated by nonlinear loads.	Increase size of feeder neutral conductor.
Current on shared neutral of multiwire branch of circuit equals or exceeds phase currents.	Harmonics generated by nonlinear loads.	Use individual two-wire branch circuits.
Neutral-to-ground potential exceeds 0.5 V.	Neutral-to-ground connections at panels other than service entrance equipment.	Remove improper neutral-to-ground connections.

9-9 Troubleshooting chart for power quality problems. *(Continued)*

Symptoms	Probable Cause	Action or Items to Check
Low voltage levels at receptacles or utilizations equipment.	Long branch circuit runs.	Install oversized conductors to compensate for voltage drops.
	Loose connections in branch circuits.	Check and tighten connections.
Voltage drop across circuit breaker exceeds 100 mV, from load to line side.	Worn circuit breaker contacts and springs.	Replace circuit breaker.

9-9 Troubleshooting chart for power quality problems. *(Continued)*

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CHAPTER
10

Troubleshooting With Infrared Thermography

Infrared thermography (also called thermal scanning) is an important diagnostic tool for troubleshooting electrical equipment and systems. Overheating can be a symptom of many different kinds of problems, and equipment typically goes through a stage where it gives off heat before an actual physical failure occurs. This heat is infrared radiation, in energy wavelengths (invisible to the human eye).

Infrared thermography uses infrared cameras to "see" and measure the thermal energy being emitted by overheated electrical equipment. This information is used to pinpoint electrical problems before failures occur. Infrared cameras, in effect, take photographs of electrical equipment by detecting heat energy rather than visible light. Infrared thermography is used to detect the following general types of electrical maintenance problems:

Poor Connections: Vibration and thermal cycling can cause electrical connections to loosen. Moisture and contamination can corrode connections.

Poor connections cause hot spots that are easily detected using infrared cameras.

Overloaded Conductors: Overloaded electrical conductors typically cause protective devices such as circuit breakers and fuses to operate. When they dont, the overloaded conductors run hotter than usual.

Short Circuits and Ground Faults: Short circuits and ground faults (a short circuit involving an equipment ground) also should cause protective devices to operate. But sometimes the current, while not sufficient operate a circuit breaker or ground fault relay, is sufficient to damage conductor insulation and cause overheating that can ignite a fire.

Harmonics: High-frequency harmonic currents caused by electronic loads such as computers, adjustable speed motor drives, and fluorescent fixtures with electronic ballasts can cause significant heating in power distribution systems, particularly in grounded (neutral) conductors.

Mechanical problems: Problems such as loose couplings and misalignment of motor shafts cause overheating that can be detected by thermal scanning.

The troubleshooting chart in Figure 10-1 lists typical operational problems of electrical equipment that

Symptoms	Probable Cause	Action or Items to Check
Overheated terminal or connection.	Loose or corroded terminal.	Tighten or replace terminal.
	Damaged conductor.	Replace conductor.
Transformer overheats.	Insulation failure.	See Chapter 8.
	Shorted turns in transformer core.	See Chapter 8.
Transformer bushing overheats.	Loose connection.	Tighten or repair connector.
	Internal fault.	See Chapter 8.
Motor overheats.	Misaligned shaft.	See Chapter 10.
	High or low voltage.	See Chapter 10.
	Shorted stator coil.	See Chapter 10.
	Faulty connection.	See Chapter 10.

10-1 Troubleshooting chart for problems identified with thermal scanning.

can be identified using thermal scanning (infrared thermography).

Safety Considerations

Infrared thermography is a noncontact troubleshooting technique. It is typically performed on energized systems operating at full load.

However, while it's not necessary for an infrared camera or electronic thermometer to contact the equipment, in many cases thermal scanning is still hazardous work. This is because it is often performed on energized equipment such as panelboards and switchboards, with the covers removed. A mistake can result in accidental contact with "live" parts and possible electrocution, burns, or arc-flash injuries to the technicians.

For this reason, all thermal scanning work around exposed conductors and equipment must be performed in accordance with NFPA 70E-2004, *Standard for Electrical Safety in the Workplace*—particularly minimum approach distances and proper use of personal protective equipment (PPE).

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