INTRODUCTION

A troubleshooting procedure consists of systematic testing designed to identify and correct a problem. Technicians must gather information and utilize tests to identify problems and develop appropriate solutions. Following established troubleshooting procedures ensures that problems are identified and quickly corrected to minimize equipment and production downtime. Consistent practices also generate consistent measurements for more accurate comparison and tracking over time.

For accurate low-resistance measurements when using a DMM, insulation multimeter, or megohmmeter, the resistance of the test leads is subtracted from the total resistance. Typical test lead resistance is between 0.2 Ω and 0.5 Ω.

TROUBLESHOOTING OF ELECTRIC MOTORS

Insulation resistance testing is performed when troubleshooting electric motors and related equipment. IEEE Standard 43-2000, Recommended Practice for Testing Insulation Resistance of Rotating Machines, recommends the insulation test voltage to apply, based on winding rating, and minimum acceptable values for electric motor windings. The IEEE also provides typical guidelines for DC voltage to be applied during an insulation resistance test.

In order to obtain meaningful insulation resistance measurements, the technician should carefully examine the system under test. The best results are achieved when the following conditions are met:

- The system or equipment is taken out of service and disconnected from all other circuits, switches, capacitors, overcurrent protection devices, and circuit breakers. Ensure that the measurements are not affected by leakage current through switches and overcurrent protective devices.
- The temperature of the conductor is above the dew point of the ambient air. When this is not the case, a moisture coating will form on the insulation surface, and, in some cases will be absorbed by the material.
- The surface of the conductor is free of hydrocarbons and other foreign matter that can become conductive in humid conditions.
- Applied voltage is not higher than the system capacity. When testing low-voltage systems, too much voltage can overstress or damage insulation.
- The system under test has been completely discharged to the ground. The grounding discharge time should be about five times the testing charge time.
The effect of temperature is considered. Since insulation resistance is inversely proportional to insulation temperature (resistance goes down as temperature goes up), the recorded readings are altered by changes in the temperature of the insulating material. It is recommended that tests be performed at a standard conductor temperature of 68°F (20°C).

When comparing readings to 68°F base temperature, double the resistance for every 18°F (10°C) above 68°F or halve the resistance for every 18°F below 68°F in temperature. For example, a 1 MΩ resistance at 104°F (40°C) will translate to 4 MΩ resistance at 68°F (20°C).

To measure the temperature of motor windings, use a noncontact temperature probe connected to a digital multimeter (DMM) or an infrared thermometer. See Figure 3-1.

Several different types of insulation resistance tests are performed when troubleshooting electric motors. These tests include an insulation spot test, a dielectric absorption test, and an insulation step voltage test.

**Insulation Spot Test**

An *insulation spot test* is an insulation resistance test that can be used to verify the condition of the insulation over the life of the motor. See Figure 3-2.

A spot test should be performed at regular intervals (every six months, for example) to track the changes in insulation integrity. The test should also be performed after a motor is serviced. The test measurement data can be recorded on a test graph over time.

To perform an insulation spot test, apply the following procedure:

1. Connect a megohmmeter to measure the resistance of each winding lead to ground. Record the readings after 60 sec.
2. Discharge the motor windings.

Although insulating materials in practical use can be solid, liquid, or gas, resistance measurements generally refer to solid insulation. Factors that affect insulation resistance measurements are the nonuniformity of the material, the time period the sample is energized, the magnitude and polarity of the voltage, the time required for the charge to build, material decay, and specimen contour.
Figure 3-1. To measure the temperature of motor windings, use a noncontact temperature probe connected to a DMM or an infrared thermometer.
Interpret the results of the test graph to determine the condition of the insulation. See Figure 3-3. Point A represents the motor insulation condition when the motor was placed in service. Point B represents the effects of aging, contamination, etc., on the motor insulation. Point C represents motor insulation failure. Point D represents the motor insulation condition after being rewound. Record the lowest meter reading on an insulation spot test graph if all readings are above the minimum acceptable resistance. Service the motor if a reading does not meet the minimum acceptable resistance. The lowest reading is used because a motor is only as good as its weakest point.

Figure 3-2. An insulation spot test is a test that checks motor insulation over the life of the motor.
Dielectric Absorption Test

A dielectric absorption test is an insulation resistance test that checks the absorption characteristics of wet or contaminated insulation. The test is performed over a 10 min period. See Figure 3-4.

To perform a dielectric absorption test, apply the following procedure:

1. Connect a megohmmeter to measure the resistance of each winding lead to ground. Record the lowest meter reading on a dielectric absorption test graph if all readings are above the minimum acceptable resistance. Record the readings every 10 sec for the first minute and every minute thereafter for 10 min.
2. Discharge the motor windings.
Interpret the results of the test graph to determine the condition of the insulation. See Figure 3-5. The slope of the curve indicates the condition of the insulation. Good insulation (curve A) indicates a continual increase in resistance. Moist or cracked insulation (curve B) shows a relatively constant resistance. Service the motor if a reading does not meet the minimum acceptable resistance.

A polarization index is the ratio of the insulation resistance of a machine winding calculated by using values obtained from a 10 min measurement divided by a 1 min measurement. The polarization index is an indication of the condition of the insulation. A low polarization index (typically 1.5 or lower) indicates excessive moisture or contamination. Different insulation classes will have different minimum acceptable polarization index values. See Figure 3-6. Insulation classes are based on the continuous operating temperature of the application. For example, Class A insulation has a maximum operating temperature of 212°F, Class B, 248°F, Class F, 293°F, and Class H, 329°F.
For example, if the 1 min reading of Class B insulation is 80 MΩ and the 10 min reading is 90 MΩ, the polarization index is 1.125 (90 MΩ ÷ 80 MΩ = 1.125). The polarization index is lower than the minimum accepted values because the insulation contains excessive moisture or contamination.

**Insulation Step Voltage Test**

An *insulation step voltage test* is a test that creates electrical stress on internal insulation cracks to reveal aging or damage not found during other motor insulation tests. This test is done by testing the insulation at two or more voltages and comparing the results. The insulation step voltage
test is performed only after an insulation spot test. See Figure 3-7.

To perform an insulation step voltage test, apply the following procedure:

1. Set the megohmmeter to 500 V and connect to measure the resistance of each winding lead to ground. Take each resistance reading after 60 sec. Record the lowest reading.
2. Place the meter lead on the winding that has the lowest reading.
3. Increase the megohmmeter setting by increments of 500 V starting at 1000 V and ending at the high-end voltage for a range of motors within the system. Record each reading after 60 sec.
4. Discharge the motor windings.

Interpret the results of the test to determine the condition of the insulation. See Figure 3-8. The resistance of good insulation that is thoroughly dry

**Figure 3-7.** An insulation step voltage test is a test that creates electrical stress on internal insulation cracks to reveal aging or damage not found during other motor insulation tests.
(curve A) remains approximately the same at different voltage levels. The resistance of deteriorated insulation (curve B) decreases substantially at different voltage levels.

The larger the insulation surface, the lower the insulation resistance. The greater the supply voltage to the motor, the thicker the insulation requirements. A 50 HP, 230 V motor requires the same insulation as a 1 HP, 230 V motor.

**Caution:** A megohmmeter uses very high voltages during insulation resistance testing (up to 5000 V). Always follow recommended procedures and safety rules. After performing insulation resistance tests with a megohmmeter, connect the device being tested to ground through a 5 kW, 5 W resistor if the megohmmeter does not include a discharge function.

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**TROUBLESHOOTING CABLE AND WIRE INSTALLATIONS**

When troubleshooting cable and wire installations, they should be disconnected from panels and machinery to keep them isolated. The conductors should be tested against each other and against ground. See Figure 3-9.

Cables and wires should be tested and maintained on a three-year cycle at a minimum. Insulation resistance tests should be performed more frequently for those systems that show deterioration of insulation material. When performing insulation tests on wire and cable, apply the following procedure:

1. Inspect exposed sections of cables and wires for physical damage. Replace or repair sections that exhibit damage.

![Figure 3-8. Insulation step voltage test measurement data is recorded on a test graph over time.](image-url)
2. Inspect cables and wires for proper grounding, cable support, and termination. Terminate those sections that are not properly terminated.

3. If cables and wires are properly terminated, verify that neutrals and grounds are properly terminated for operation of protective devices.

4. Perform an insulation resistance test on each conductor in the cable. Apply 1000 VDC for 1 min (one-minute insulation resistance test) to low voltage cables (1 kV or less) and use a megohmmeter, or insulation multimeter (IMM) to measure the insulation resistance. (Use a hipot tester to perform a DC hipot test on cables ranging from 1 kV to 69 kV.)

**Low-Voltage Cables**

A cable length test should be performed on newly installed low-voltage cables. Knowing the actual length of low-voltage cables is required because low-voltage cables, like all conductors, have resistance that reduces the amount of power passing through them. The greater the length of a cable, the greater the power reduction (attenuation) created by the cable. Because the signals are transmitted at low power, any reduction in power caused by a cable must be kept to a minimum.

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*Cable length testers measure the length of cables and also indicate the distance to a cable fault by accessing the end of a cable with two or more conductors.*
**TROUBLESHOOTING ELECTRICAL SWITCHGEAR AND SWITCHBOARDS**

Electrical switchgear and switchboards are freestanding assemblies of metal-enclosed sections containing circuit breakers and/or fused disconnect switches. They also contain bus bars, cable termination points, backup protection devices, and various forms of controls and instrumentation. Switchgear or switchboards are used to distribute utility power via busways to transformers, panelboards, and motor starters. See Figure 3-10. An assembly may be part of a load center, substation, or distribution board.

Switchgear and related assemblies should be tested and maintained at a minimum of once a year. Inspections should be performed more frequently if equipment is in an environment that has excessive dirt or moisture. Per plant procedures and manufacturers recommendations, the best

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**Figure 3-10.** Switchgear or switchboards are used to distribute utility power via busways to transformers, panelboards, and motor starters.
results are achieved when the following actions are applied:

- Inspect electrical sections of switchgear for damage. Repair or replace damaged sections.
- Inspect all bus connections for high resistance by using an insulation multimeter. Repair or replace sections that are not in compliance.
- Inspect insulation material for physical damage or contaminated surfaces. Clean or repair any insulation that is not in compliance.
- Perform insulation resistance tests on each bus section, phase-to-phase, and phase-to-ground by using a megohmmeter or insulation multimeter. Typical switchgear insulation resistance values range from 50 MΩ to 20,000 MΩ. Insulation resistance values that are less than the equipment manufacturer’s recommended minimum resistance value should be investigated for additional problems.
- Always perform tests on deenergized equipment.

**TROUBLESHOOTING MISCELLANEOUS ELECTRICAL DEVICES**

Miscellaneous equipment includes such equipment as portable electrical devices, double-insulated tools, extension cords, transformers, and any electrical device that receives power through a separate power conductor. Insulation resistance testing is performed on such equipment as part of regular maintenance programs as well as for standard OSHA and NEC® compliance.

Although standard insulation resistance specifications can be applied when troubleshooting most motors and other electrical devices, certain situations require higher resistance specifications to be applied. Most stated specifications list the maximum amount of acceptable leakage current and not the actual resistance. For example, a 3-wire handheld electrical appliance or tool must be insulated enough to allow no more than 0.75 mA (0.00075 A) of leakage current to flow through the exposed parts to ground.

Typical resistance values are one-third higher than the 1 MΩ per 1 kV industry standard. Medical equipment and electrical devices rated as “double-insulated” have much higher insulation ratings than ordinary equipment. Miscellaneous equipment includes two-prong Category II power cord devices, three-prong Category I power cord devices, and dry-type transformers.

**Insulation resistance values vary with temperature and the amount of moisture in the insulation. The temperature and humidity should be recorded at the time the insulation test readings are taken.**

Two-Prong Category II Power Cord Devices

A two-prong Category II power cord device is a device that has only two conductors extending from it, one hot and one neutral. Two-prong devices do not have a third ground (green wire) prong on the power cord. Certain two-prong devices are classified as double-insulated.

A double-insulated device is an electrical product designed so that a single ground fault cannot cause a dangerous
electrical shock through any exposed sections of the product that could come in contact with an electrician. Double-insulated devices include not only the standard insulation used on conductors but also extra insulating material between the energized parts of the device and the parts that can be contacted.

When troubleshooting these devices for insulation resistance, leakage current is measured from the exposed metal parts to ground. See Figure 3-11. To test a two-prong Category II power cord device for insulation resistance, apply the following procedures:

1. If the device has no exposed metal, wrap metal foil on the exposed plastic parts (such as the handles). The metal foil simulates a wet hand contacting the electrical device.
2. Ensure that the electrical device being tested is not plugged into a power source.
3. Connect the ground test lead to the metal foil wrap on the tool under test.
4. Connect the voltage test lead to the neutral (larger) blade on the tool’s power cord.
5. Use the insulation resistance tester to supply the test voltage.
6. Measure the amount of leakage current in mA and record the readings. Typical specified maximum leakage current for a double-insulated, two-prong Category II device is typically 0.25 mA (0.00025 A).

When leakage current exceeds the specified limit, a three-prong power cord must be used. The ground (green) wire is added to carry the leakage current to ground by providing a low impedance (resistance) path from all non-current-carrying parts to earth ground. Equipment used in the medical field will have an even lower acceptable maximum leakage current limit.

### Three-Prong Category I Power Cord Devices

A three-prong Category I power cord device is a device that has three conductors extending from it, one hot, one neutral, and one ground. Any leakage current will flow through the ground (green) conductor back to ground during normal operation. The ground conductor prevents the exposed metal parts of the electrical device from becoming energized to the point of causing an electrical shock. See Figure 3-12. To test a three-prong Category I power cord device for insulation resistance, apply the following procedure:

1. Ensure that the electrical device being tested is not plugged into a power source.
2. Connect the ground test lead to a metal portion of the equipment under test, such as a motor housing.
3. Connect the voltage test lead to the neutral (larger) blade on the tool’s power cord.
4. Measure the amount of leakage current in mA and record the readings.

The more power a load requires, the larger the amount of current flow. For example, a 10 HP motor draws approximately 28 A when wired for 230 V. A 20 HP motor draws approximately 54 A when wired for 230 V.
Figure 3-11. A two-prong Category II power cord device has only two conductors extending from the device, one hot and one neutral, and does not have a third ground prong on the power cord.
THREE-PRONG CATEGORY I POWER CORD DEVICES

1. ELECTRICAL DEVICE THREE-PRONG POWER CORD NOT PLUGGED INTO POWER SOURCE

2. CONNECT GROUND TEST LEAD TO METAL PORTION OF EQUIPMENT UNDER TEST

3. CONNECT VOLTAGE TEST LEAD TO NEUTRAL PRONG

4. MEASURE AMOUNT OF LEAKAGE CURRENT AND RECORD READING (3.5 mA MAXIMUM LEAKAGE CURRENT ALLOWED)

Figure 3-12. A three-prong Category I power cord device has three conductors extending from the device, one hot, one neutral, and one ground (green wire).
The typical specified maximum leakage current for a three-prong category I device is typically 0.75 mA (0.00075 A) for handheld electrical devices such as disc grinders, and 3.5 mA (0.0035 A) for non-handheld electrical devices such as floor buffers, electric motors, small drill presses, and air compressors.

A reference multimeter can be used to take resistance measurements from $2 \, \Omega$ to $20 \, M\Omega$, as well as more accurate voltage, current, and temperature measurements than a standard handheld meter.

An IMM set to measure resistance can be used to check for open circuits in coils, short circuits between primary and secondary coils, or coils shorted to the core without power applied to the transformer. See Figure 3-13.

**Open Circuits in Coils.** The resistance of each coil is checked with a DMM. The winding is open and the transformer is bad if any of the coils show an infinite resistance reading. Note that very low resistance readings do not indicate a short, but rather the resistance of the wire.

**Short Circuits between Primary and Secondary Coils.** A check for short circuits should be made between the primary and secondary coils of the transformer. Checking for short circuits between the primary and secondary coils should be performed with a megohmmeter.
Figure 3-13. An IMM set to measure resistance can be used to check for open circuits in coils. When testing for short circuits between primary and secondary coils, or for coils shorted to the core without power applied to the transformer, use the insulation test function of the IMM.
**Coils Shorted to Core.** A resistance check is made from each transformer coil to the core of the transformer. All coils should show an infinite resistance reading to the core. The transformer should not be used if a resistance is shown between any coil and the core.

**Transformer Maintenance.** Transformer manufacturers provide recommended maintenance procedures and schedules for their equipment, but the actual performance of a specific transformer should determine the frequency of the maintenance and troubleshooting to be performed.

The majority of transformer failures are caused by poor maintenance. Transformers should be tested and maintenance performed at least once annually. When performing insulation resistance tests on dry-type transformers, apply the following procedures:

1. Visually inspect for physical damage: cracked insulation, defective wiring, tightness of connections, and dirt/moisture on the coil.
2. Verify proper core and equipment grounding.
3. Use a megohmmeter or insulation multimeter to perform insulation resistance tests on winding to winding or windings to ground. Perform insulation resistance tests for each winding.

Typical transformer insulation resistance values range from 500 MΩ to 25,000 MΩ. See Figure 3-14. Insulation resistance test readings for transformer windings should be within 1% of adjacent windings.

<table>
<thead>
<tr>
<th>Transformer Coil Rating*</th>
<th>Minimum Test Voltage†</th>
<th>Minimum Insulation Resistance‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 600</td>
<td>1000</td>
<td>500</td>
</tr>
<tr>
<td>601 - 5000</td>
<td>2500</td>
<td>5000</td>
</tr>
<tr>
<td>5001 - 15,000</td>
<td>5000</td>
<td>25,000</td>
</tr>
</tbody>
</table>

* in VAC  † in VDC  ‡ in MΩ  

**Figure 3-14.** Typical transformer insulation resistance values range from 500 MΩ to 25,000 MΩ.

When inspecting small (600 V or less) dry-type transformers, apply the following procedures:

1. Visually inspect for physical damage: cracked insulation, defective wiring, tightness of connections, and dirt/moisture on the coil.
2. Verify proper core and equipment grounding.
3. Clean the unit prior to making any tests.
4. Use a megohmmeter or insulation multimeter to perform insulation resistance tests on winding to winding or windings to ground. Perform insulation resistance tests for each winding.

To help prevent electrical problems that cause equipment damage, neutral conductors should be the same size as, or larger than, hot conductors.