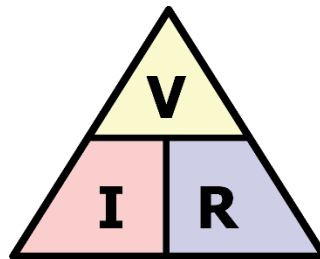


## Insulation Testing Training - Reference Guide

### 1. What is Insulation Resistance testing?

Insulation resistance testing is a diagnostic method used to assess the **condition of electrical insulation** between conductive elements in electrical equipment such as motors, transformers, cables and other insulated current carrying components. The goal of this testing method is to detect **deterioration and contamination** that could lead to unsafe **leakage currents**, equipment malfunction, or failure.



$$R(\Omega) = V \div I$$

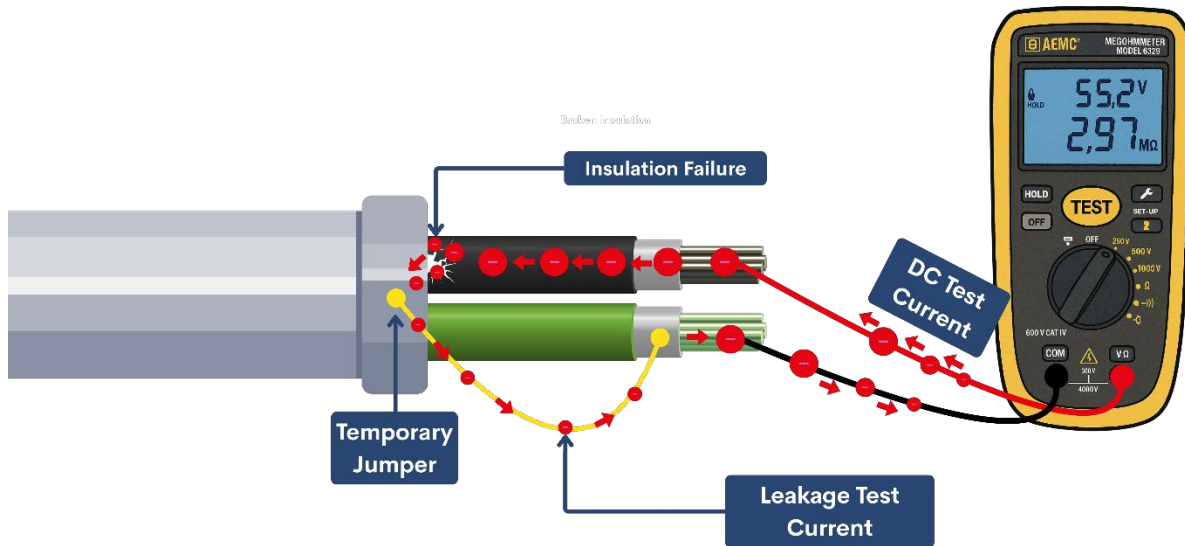
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### 2. How is insulation resistance measured?

The test works by applying a known **DC voltage** across the insulation and measuring the resulting current flow. Using **Ohm's Law** ( $R = V/I$ ), the **resistance** is then calculated. High resistance values (in the **mega-ohm** to **tera-ohm** range) suggest good insulation, while low values may indicate **contamination, moisture, or aging** issues.

To visualize this, consider the insulation as the wall of a **pipe**, **voltage** as the **pressure** pushing water through the pipe, and **current** as the **water flow**. If the pipe (insulation) is intact, very little water (current) leaks through. However, if the pipe wall has holes or is thin, more water will leak—just as more current will flow through degraded insulation. This analogy helps explain why high resistance indicates better insulation.

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### 3. What is a Megohmmeter?

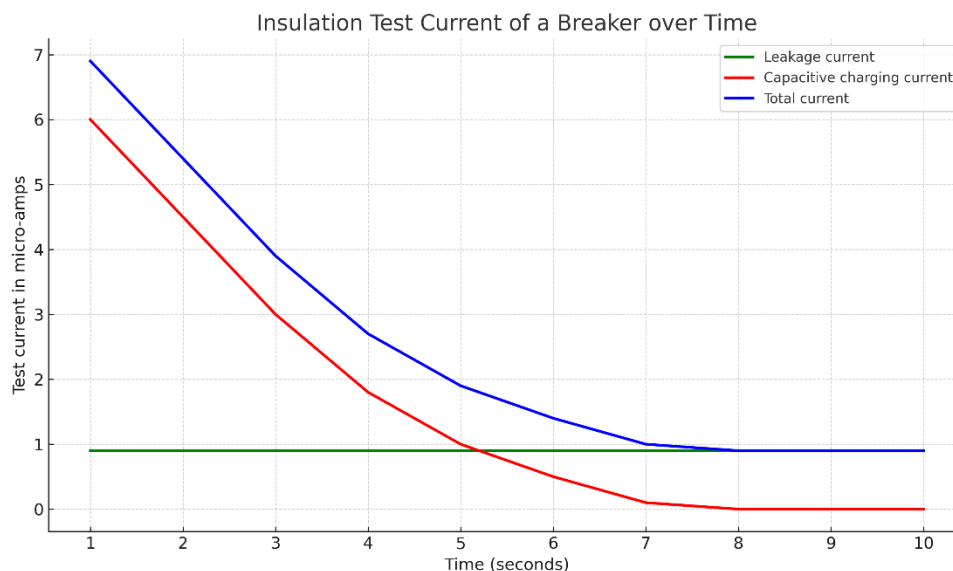
A **Megohmmeter** is an electrical testing instrument that applies a high DC voltage (ranging typically from 100 V to 15,000 V) to an electrical component or system to measure its **insulation resistance** typically **mega-ohms (MΩ)**, **giga-ohms (GΩ)**, or **tera-ohms (TΩ)**.

#### Megohmmeter Principal of Operation

- A megohmmeter applies a user defined high-voltage DC source between two conductors (or between a conductor and ground).
  - The instrument measures the resulting leakage current and calculates the resistance using Ohm's Law.
  - Resistance readings provide insight into insulation contamination from moisture, carbon tracking, dirt, or deterioration.
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## 4. Why is the length of time important for insulation resistance testing?

Time plays a crucial role in insulation resistance (IR) testing because the current flowing through insulation materials varies significantly after voltage is applied. This time-dependent behavior is due to the interplay of three currents: **capacitive charging, absorption, and leakage current**. As voltage is applied, capacitive current spikes and quickly dissipates, followed by the slower-decaying absorption current as molecular dipoles align within the insulation. Only after these transient effects settle can a meaningful insulation resistance value be observed—especially in larger equipment where this can take several minutes. Insulation materials—such as thermoplastics (like PVC or polyethylene), thermosetting resins (like epoxy-mica), and rubber compounds—all exhibit these time-dependent behaviors to varying degrees depending on their molecular structure and moisture content. Epoxy-mica, for example, has better long-term stability and lower absorption current compared to older asphalt-mica types. Without allowing sufficient time for these currents to stabilize, resistance readings may be misleading, potentially obscuring developing faults. This underscores the importance of timed tests like the 1-minute and 10-minute readings used in Polarization Index (PI) calculations. Moreover, since insulation resistance is highly sensitive to temperature, especially for materials like thermoplastics, temperature correction or standardization is essential to ensure comparability across time and test conditions.



## 5. What types of tests are run with a Megohmmeter? (Test methods explained)

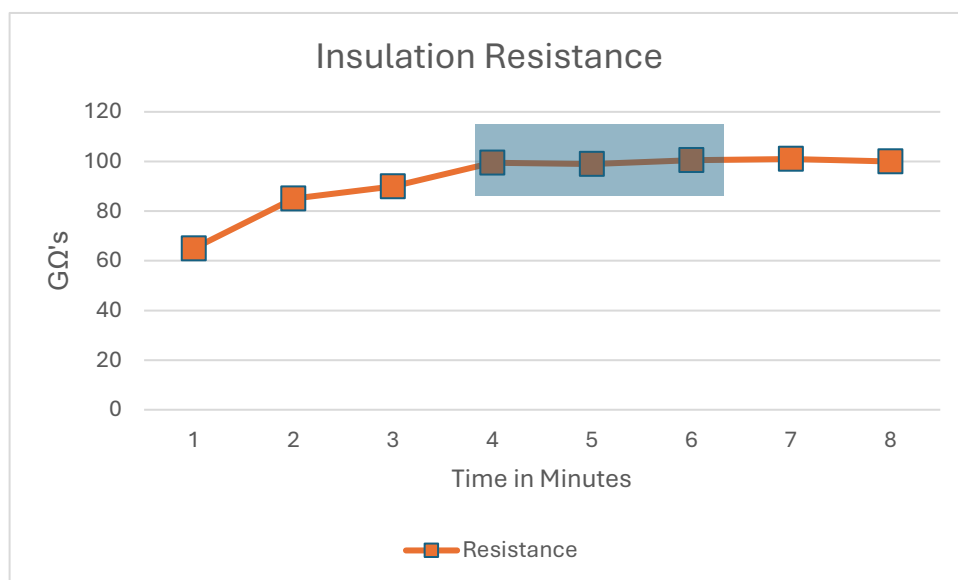
### Spot Testing (Short-Time Readings)

Spot testing is the simplest method, where a test voltage is applied for a brief, fixed period (typically 30 or 60 seconds), and the insulation resistance is read at the end of this interval. This test method is best used during emergency outages to locate failure modes. The measurement value should not be considered a comprehensive analysis of the insulation's resistance, nor should it be logged for historical analysis. Temperature of the device under test as well as ambient humidity should be corrected for when analyzing this value.

#### Purpose:

This method provides a snapshot of insulation condition. While it is fast and useful for quick checks, the short time duration may not allow for a comprehensive analysis of the insulation for large motors or transformers. Use this method to locate trouble conditions in emergency outages, or to verify the insulation quality of already operating equipment that may not be of significant value.

### Insulation Resistance Profiling (Timed Tests)



While like a spot test, this test method will require a longer time period while a fixed voltage is applied across the insulation under test. Insulation resistance measurements are logged for a specific time period, often during one minute intervals. Should the value remain constant (+/- 10%) for three consecutive periods, the test may be considered complete and the final value is recorded as the insulation resistance of the sample under test. While measurements are *less* effected by temperature and humidity with longer profiling tests, it is recommended that values be corrected using the temperature correction factors.

**Purpose:** Insulation resistance profiling ensures that time is not a limiting factor in the accuracy of the measurement. Repeatability over three consecutive time periods ensures that the applied test current has successfully overcome the capacitive charging and absorption phases, and the measurement is largely dependent on leakage current values. This measurement is best used for comprehensive trend analysis during periodic maintenance testing intervals or acceptance testing post installation. Values should be historically trended over time and remain relatively constant. Slight downward trends are expected as equipment ages, however sharp decreases in insulation resistance values are indicative of potential failures.

### **Ratio Quality Tests – Dielectric Absorption (DAR) and Polarization Index (PI)**

Dielectric Absorption Ratio (DAR) and Polarization Index (PI) are time-based ratio tests used to evaluate the condition of electrical insulation. These tests help reveal issues such as moisture contamination, insulation aging, or physical deterioration that may not be visible with a single-point resistance measurement.

- **DAR (Dielectric Absorption Ratio):**

This test compares the insulation resistance measured at 60 seconds to the value measured at 30 seconds. The formula is:

$$\text{DAR} = R_{60\text{s}} / R_{30\text{s}}$$

A good insulation system will show increasing resistance over time due to the decay of capacitive charging and absorption currents. A **DAR below 1.25** indicates poor insulation, while higher values suggest good condition.

- **PI (Polarization Index):**

The PI is a more robust evaluation, comparing insulation resistance at **10 minutes** to that at **1 minute**:

$$PI = R_{10min} / R_{1min}$$

This test is especially effective for dry-type insulation systems like cables and motors. A PI **less than 2** is generally cause for concern, while values above 4 suggest excellent insulation quality.

PI.Value	Insulation.Condition
< 2	Problem
2 - 4	Good
> 4	Excellent

According to IEEE Std 43-2013, when the 1-minute insulation resistance value ( $IR_1$ ) measured at 40 °C is greater than **5000 MΩ**, the **Polarization Index (PI)** test is **not recommended** as an assessment tool. At such high insulation resistance levels, the total current involved in the measurement becomes extremely small—often in the sub microampere range—making the test highly susceptible to small variations in voltage, humidity, and test setup. These external influences can significantly distort the PI ratio, rendering it ambiguous or misleading for evaluating insulation condition.

In such cases, the insulation system is in excellent condition, and further trending using PI is unnecessary. Instead, focus should shift to maintaining the high IR value and watching for any sudden changes over time.

**Purpose:** Ratio tests serve to simplify the insulation resistance testing process by providing rigid time and result values. These test procedures are often specified by the manufacturers of transformer and motors to ensure constancy among installers and technicians of their devices. However, as noted, there are still limitations to these test methods that may render them less effective than resistance profiling test methods.

## 6. How should different types of equipment be tested?

When performing insulation resistance (IR) testing, it's critical to understand that the nature of the equipment under test significantly influences both the method and interpretation of results. For example, the approach to testing devices like circuit breakers and conductors differs markedly from that used for motors or transformers, due to their construction and insulation configurations.

### **Circuit Breakers and Conductors (resistive devices)**

Circuit breakers and associated bus conductors typically have solid insulation and short conductor lengths, resulting in low capacitance. IR testing these types of devices primarily serves as a go/no-go check for contamination, moisture ingress, or tracking paths across insulation surfaces. Since these systems don't store significant charge, readings stabilize quickly, and short-time (e.g., 1-minute) tests are often sufficient. It's also common to test breakers both in the open and closed positions, and phase-to-phase as well as phase-to-ground, with grounded reference points for untested conductors to prevent floating voltages.

### **Long Conductor Runs**

When performing insulation resistance (IR) testing on long conductor runs—such as extended cable circuits or feeder lines—special considerations are required due to their inherent capacitive characteristics. As cable length increases, so does the total capacitance of the system, which impacts both the charging current at the beginning of a test and the stabilization time required to obtain accurate resistance readings. This can lead to deceptively low insulation resistance values if measurements are taken too early. As noted in IEEE 400, the charging current dominates the initial test response, especially in cables with high capacitance like shielded power cables. Therefore, it is essential to allow sufficient time for the transient capacitive effects to subside, which is why polarization index (PI) or time-resistance testing methods are often preferred for long runs over single-point spot tests.

Additionally, testers should ensure proper grounding of all phases not under test and at both cable ends to avoid floating voltages or unsafe conditions. Using a megohmmeter with guard terminals can help eliminate surface leakage currents that become more prominent over long exposed distances. Accurate testing of long runs must also consider temperature correction and insulation type to interpret results meaningfully. Overall, careful setup,

extended measurement duration, and temperature correction are key to valid and safe insulation resistance testing of long conductors.

### Transformers

Transformers have complex insulation systems involving winding-to-ground and winding-to-winding insulation. These systems often include oil or resin insulation, and exhibit high dielectric absorption due to their larger mass and surface area. This means their IR readings increase with time as polarization currents settle. For this reason, time-resistance tests like PI (Polarization Index) and insulation profiling are particularly meaningful. A low PI value could indicate absorbed moisture or contamination in windings or insulation layers, even if the 1-minute resistance is high.

### Motors, Generators (Rotating Machinery)

Motors, especially larger form wound types, present a combination of windings and laminated iron cores, which again introduce significant capacitance and absorption effects. The IR test procedure involves isolating individual windings (e.g., stator or field) and applying voltage to assess insulation condition. Like transformers, trending IR values over time and using PI values are important in predictive maintenance. Motors are also more sensitive to contamination (e.g., carbon dust, moisture), and a drop in P.I. ratios or trending resistances over time can help detect early-stage insulation failure.

**Summary Table of IR Testing Considerations**

Equipment.Type	Insulation.Type	Primary.IR. Test.Method	Notes
Circuit.Breakers	Solid (air, resin, mica)	Spot Test (1-minute)	Quick readings, both open/closed, phase-to-phase and to ground.
Conductors-Cables	Solid/polymeric	Spot Test + Profile (if long)	Shielding matters, longer lengths require absorption considerations.



Transformers	Solid + Oil (or resin)	IR Profile or PI	Polarization effects significant; IR increases over 10 min.
Motors—Generators	Varnish-insulated windings	IR Profile or PI	Track winding degradation over time; sensitive to surface moisture.

By tailoring IR testing approaches to the unique insulation and electrical structure of each apparatus, maintenance personnel can more accurately diagnose conditions and plan remediation before catastrophic failures occur.

## 7. How are insulation resistance values used?

Insulation resistance (IR) testing serves two distinct purposes: **troubleshooting** and **trending**, each with unique goals and application methods.

When used for **troubleshooting**, IR testing is a quick, reactive diagnostic tool to determine if a motor, cable, or other component has experienced insulation failure. For example, if a motor on a production line suddenly fails, a spot test—typically a 30- or 60-second voltage application—can quickly indicate if the problem lies in the motor windings or possibly in the conductors supplying it. A very low resistance reading may suggest a direct short or severe moisture ingress, pointing toward immediate repair or replacement. However, this one-time test offers limited insight into the *cause or progression* of the failure.

Conversely, IR testing used for **trending** is a proactive, preventive maintenance strategy. Periodic measurements taken under consistent environmental and procedural conditions (especially temperature and humidity) allow maintenance teams to observe the *deterioration rate* of insulation systems over time. Even if an IR value remains above a minimum threshold, a downward trend across months or years may reveal aging, contamination, or early-stage moisture ingress—issues that can be addressed before catastrophic failure occurs. This approach is especially valuable for critical assets where unplanned downtime would be costly.

Ultimately, while troubleshooting offers immediate fault isolation, trending provides long-term condition monitoring. The effectiveness of either method depends on understanding both the nature of the equipment and the underlying insulation system—whether it's

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thermoplastic, thermoset, or resin-rich—and ensuring consistent test conditions for accurate interpretation

Glossary of Terms: