Electrical Testing Standards Guide

Megger

Insulation Resistance Testing in PV Systems

Introduction

Insulation Resistance Testing Overview

Megohm or insulation resistance (IR) tests validate the insulating properties of conductors used in electrical installations. The test measures the insulation's resistance to current flow. A conductor with good insulation will have high resistance, and poor insulation will have low resistance through the insulation. No insulation is perfect, but the goal of the test is to quantify the insulation's resistance value and provide data that validates the insulation's health.

Insulation resistance testing is a non-destructive test procedure and does not cause harm to the conductors. The test measures the insulation resistance between the conductors and ground. The PV industry commonly uses the test before energizing the cables during project commissioning, during regularly scheduled maintenance, and as a tool for diagnosing system performance issues, especially ground faults.

Running an insulation resistance test will put higher than usual voltage on a conductor. The tool will also inject a small amount of current into the conductor during the test. If the insulation is compromised, the current will "leak" out, and the tool will use Ohm's law to determine the insulation's resistance. This higher test voltage amplifies any existing insulation damage. This small amount of current that the megohmmeter measures allows operators to identify poor conductors before they become a safety hazard. The most commonly used testers in the PV industry are handheld units that can test up to 2,500 Vdc.

When running an insulation resistance test on a compromised conductor, more current will leak out, and the tool will record a low resistance value. To pass International Electrotechnical Commission (IEC) standards for insulation resistance testing, PV systems with an open circuit voltage rating greater than 120 Vdc must have an insulation resistance greater than 1 MΩ.

"Megger" Defined

The term "Megger" is often used in the field to describe the insulation resistance test. The company Megger was the first to create an insulation resistance tester in 1889, and the brand name has become synonymous with the test. Throughout this document, we will refer to the generic test name to avoid any confusion between the test and the company.

Insulation resistance testing on PV circuits is an important aspect of commissioning and O&M procedures.

Testing Through PV Modules

Conducting insulation resistance tests through PV modules should be carefully approached. In short, consult the module manufacturer before performing such tests. The test is non-destructive and should not exceed the modules' voltage rating. To maintain the module warranty, only perform the test per manufacturer instructions.

Interpreting the results of IR tests through modules can be difficult as well. As this guide discusses, temperature and humidity impact resistance measurements. In addition, the amount of glass in the modules tested will impact the leakage current and, therefore, can yield erroneous results. Testing through modules requires greater attention to detail and documentation of environmental conditions.

Verifying the insulation resistance for conductors within a PV array is essential to any commissioning and operations and maintenance (O&M) procedure. Testing insulation is standard in the traditional electrical industry and applies to PV installations. The overall concept is the same for PV systems as for conventional electrical systems: technicians must verify the conductors' insulation is not damaged. Shock hazards and fire risks will be present if the insulator protecting the current-carrying conductors is damaged. Therefore, regularly testing the insulation helps reduce risks and reactive maintenance.

What Makes Insulation Go Bad?

During the initial installation, a reasonable expectation exists that the conductors installed have insulation in excellent condition. Of course, manufacturing defects and installation errors can occur, so technicians must test brand-new conductors.

Environmental exposure can result in conductor degradation.

Degraded or damaged conductors can result in faults that introduce fire and shock hazards in PV installations.

Over time, several issues can cause the deterioration of the conductors' insulation. PV installations commonly have conductors associated with the PV modules and home runs installed outside raceways and protective conduits. Manufacturers list conductors for use in these applications. But exposure to the elements can cause the conductors to fail. In addition, exposed conductors are subject to damage from wildlife, chafing on racking systems, movement from tracking arrays, and build-up of dirt. All of these conditions can lead to the reduction of a conductor's insulation.

Ultimately, failed insulation will manifest as a ground fault. This hazardous condition can result in shock or fires. Consistently checking the health of a PV system's conductors helps reduce the risk associated with ground faults.

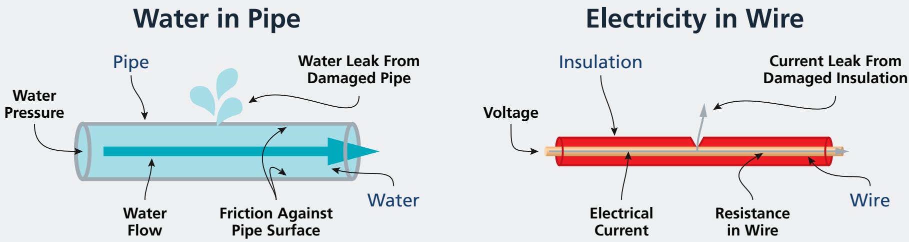
Sometimes, the drop in insulation resistance is sudden, as when a rodent chews through a conductor. However, the loss of resistance can occur gradually, giving plenty of warning if checked regularly. Performing the test periodically, typically annually, allows the operator to plan out any equipment replacements, resulting in a lower overall cost.

Typical insulation resistance test instrument and associated leads.

What is an IR Tester?

An insulation tester is a high-range resistance meter (ohmmeter) with a built-in direct-current generator. This meter utilizes both current and voltage coils, enabling actual ohms to be read directly, independent of the actual voltage applied. This method is non-destructive; that is, it does not cause insulation deterioration.

The battery-powered tool injects a dc voltage (typically 1,000 Vdc or more) on the conductor under test. A complete circuit occurs if a compromised conductor touches anything bonded to earth, like a racking system. The IR tester uses Ohm's law to calculate the insulation resistance from the known voltage and current. The digital display tells the technician the insulation resistance for that conductor.



Insulation Resistance Testing Concepts

Using water flowing in pipes is an excellent way to help visualize the electrical concepts associated with IR testing. Insulators act as the pipe in a water system, keeping the electrons contained and providing them with their intended path. As with a damaged pipe, if the insulation around a conductor is damaged, current can flow along an undesirable path. The figure above illustrates this concept.

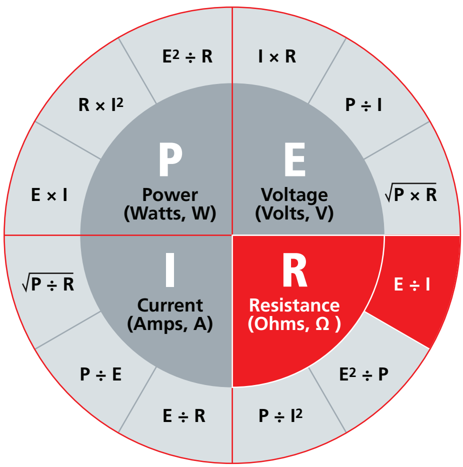
In the water analogy, voltage is equivalent to water pressure, the current is the water flow, and resistance is the force working against both the current and water flow. In our electrical systems, insulators must have a very high resistance to current. When undamaged, they do an excellent job of maintaining current along the intended path. Just as a damaged pipe will leak water, a damaged conductor can "leak" electrons, creating a dangerous situation.

During an IR test, Ohm's Law is used to help determine the actual resistance in the insulation and help technicians and system owners determine the status and health of the insulation. Ohm's Law is expressed this way in equation form:

Ohm's Law & Power Law

$E = I \times R$

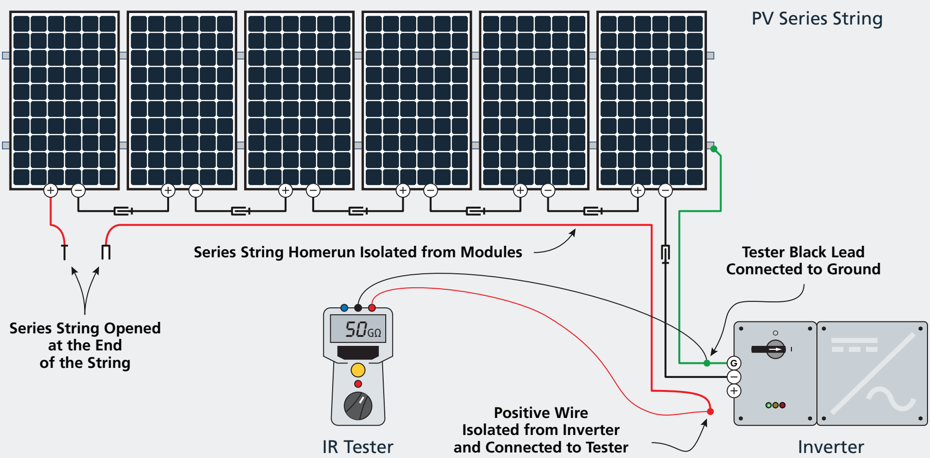
- E = Voltage in Volts
- I = Current in Amperes
- R = Resistance in Ohms



$R = E \div I$

While Ohm's Law is typically represented as E (Volts) = I (Amps) × R (Ohms), in insulation resistance testing applications we rearrange the formula to solve for Resistance as R (Ohms) = E (Volts) ÷ I (Amps).

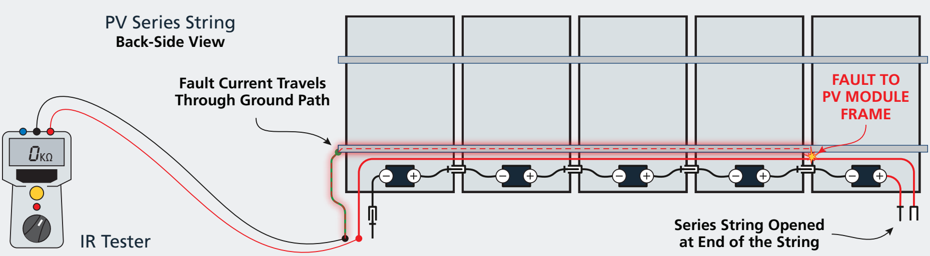
IR Tester in Conjunction with a PV Array



An IR test will place a voltage and a small current on the conductors under test. The tool then uses Ohm's law to calculate the resistance. A good insulator will have substantial resistance, often in the gigaohms (1,000,000,000 - one billion ohms). The discussion about the specific ohm readings will be covered in more detail later.

Performing the test requires connecting one lead from the tester to the conductor under test and the second lead to any system component bonded to the earth. This connection to the earth can be the racking system or equipment grounding conductor (EGC) in PV systems. Damaged insulation will complete a circuit with the metal bonded to earth. The IR meter will read that current through the lead and return a value to the display. If the insulation is damaged enough, the meter may not be able to complete the test, and an error will be displayed. This document includes further information on the testing in the step-by-step instructions.

A Faulted Conductor & Resulting Current Flow During a Test



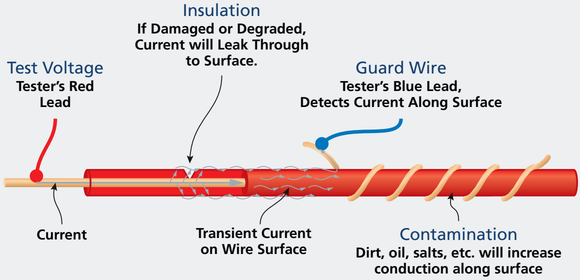
A conductive material wraps around the conductor, and the tool detects surface leakage when connected to an IR tester's guard terminal.

Surface Leakage

Note, however, that no insulation is perfect (that is, it cannot have infinite resistance), so some electricity does flow along the insulation or through it to ground. Such a current may only be a millionth of an ampere (one microampere), but it is the basis of insulation testing equipment. This is a phenomenon known as surface leakage.

A guard terminal will account for this surface leakage, as shown below. The guard terminal can measure the current on the conductor's surface(s) and account for that in the final resistance measurement. This current is measured by installing a temporary conductive path on the conductors under measurement. The third terminal of the IR tester is then connected to this conductor to complete the measurement. This feature is discussed in greater detail later in this guide.

Surface Leakage



Surface leakage is a common IR test phenomenon. The extent of surface leakage is a function of multiple factors, including contamination on the conductor surface. A guard terminal can isolate the surface leakage and return an accurate insulation resistance value.

Environmental Impacts on IR Testing

Compensating for Temperature & Humidity

Using a megohmmeter, or an IR tester, allows technicians to place a numerical value on the resistance and better understand the conductors' health. This section will discuss the most significant environmental factors that impact the readings.

The technician running the tests must record the environmental conditions during testing. The data collected are recorded and compared to future data sets. If the environmental conditions from one reading to the next are significantly different, inaccurate conclusions may be drawn from the results.

Effect of Temperature on Insulation Resistance

The resistance of insulating materials decreases with an increase in temperature. Therefore technicians must record the ambient temperature at the time of the recording. This data helps inform the insulation resistance analysis.

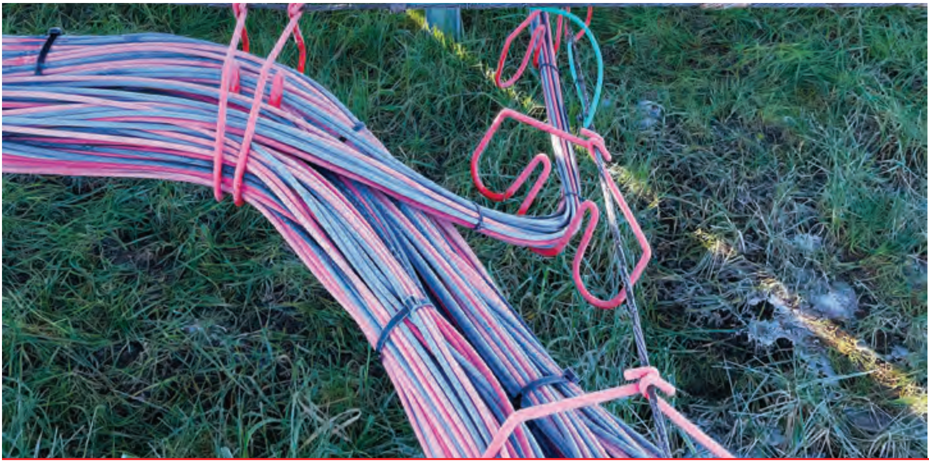
To make reliable comparisons between readings, correct the readings to a base temperature, such as 20°C. Alternatively, take all readings at approximately the same temperature. The second option isn't always viable. Therefore applying correction factors is typically required.

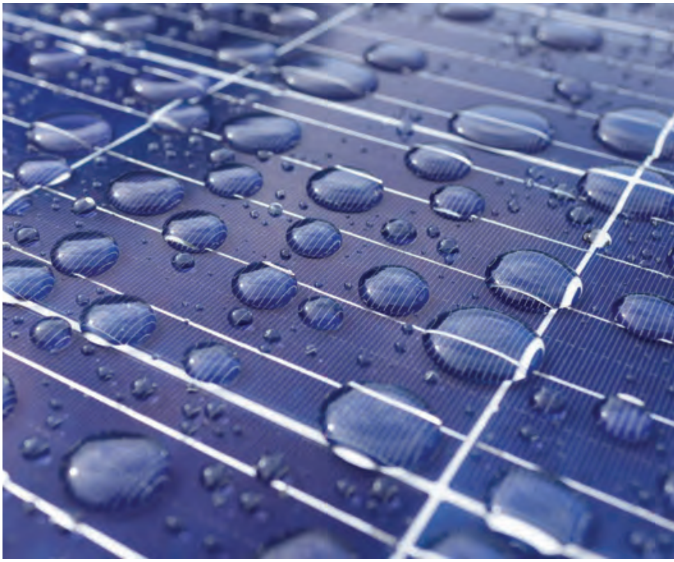
One temperature rule that can be applied consistently:

- **For every 10°C increase in temperature, halve the resistance.**
- **For every 10°C decrease, double the resistance.**

For example, a two-megohm (2 MΩ) resistance at 20°C reduces to 0.5 megohms (0.5 MΩ) at 40°C. Conversely, the resistance would be four megohms (4 MΩ) at 10°C. The critical component for the technician is to notate the temperature during the test so the analysis is conducted accurately.

Frosty wiring in the shadow of a PV array on a cold morning. The resulting resistance doubles for every 10°C below a 20°C base.





Humidity and moisture content on the equipment under test will impact the IR test results.

Effects of Humidity on Insulation Resistance

The humidity will affect insulation resistance measurements. Higher humidity will generally cause the insulation resistance to test lower than it would when dry. Humidity is not as easy as temperature to correct for. Therefore, a best practice is for the technician to document the humidity at the time of the test. Ideally, subsequent tests are taken in similar conditions to help evaluate the results. Technicians should note the environmental conditions as the day progresses. Changes in temperature and humidity throughout a single day will return varying results that may confuse if not recorded.

Studies show, however, that dew will form in the cracks and crevices of insulation before it is visibly evident on the surface. Dew-point measurements will give you a clue as to whether such invisible conditions might exist, altering the test results. The IEC has a section of additional recommended testing for a “wet test” under specific scenarios. When intermittent ground faults appear, especially after rain, running the IR test in these humid or wet conditions can help identify problems. The ground fault testing chapter details this further.

As a part of your maintenance records, it’s a good idea to note the humidity, even if just a qualitative “humid” or “dry,” and whether it was above or below ambient temperatures at the time of testing. When testing any vital equipment, consistently record the ambient wet and dry bulb temperatures, and you can easily calculate dew-point and humidity (percent relative or absolute) later.

Types of IR Tests

Appropriate Testing for PV Systems

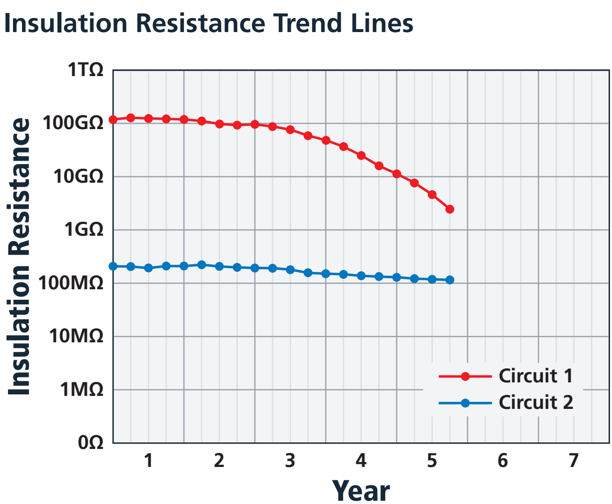
IR testers can perform multiple specific tests. PV systems will typically use the short-time test described in this guide. Other components like transformers and motors may require other IR tests. For a complete list of tests and applications, please refer to "A Stitch In Time," a comprehensive guide on insulation resistance published by Megger.

Short-Time or Spot-Reading Test

In this method, you simply connect the IR instrument to the apparatus to be tested and operate it for a short, specific period (60 seconds is recommended). The tester will inject the desired voltage into the item under test. The tool will calculate the insulation resistance based on the current flow in the circuit created.

A measurement less than the IEC standard will dictate replacement, regardless of when the test is conducted. Presuming a passing test, your first spot reading on equipment in your plant, with no prior tests, can be only a rough guide on how good or bad the insulation is. As detailed in this guide, documenting the results and comparing future readings is essential to determine if insulation is failing.

Recording readings periodically give you a better basis for judging the insulation condition. Any persistent downward trend is usually a fair warning of trouble ahead, even though the readings may be higher than the suggested minimum safe values. Equally valid, if your periodic readings are consistent, they may be okay when greater than the recommended minimum values. The figure below's curves show typical insulation resistance behavior under varying plant operating conditions.



Trend lines help identify the condition of a conductor's insulation resistance. Sharp consistent loss of insulation resistance indicates problems, even when the reading remains above minimum allowable levels.

Driving Forces for IR Testing

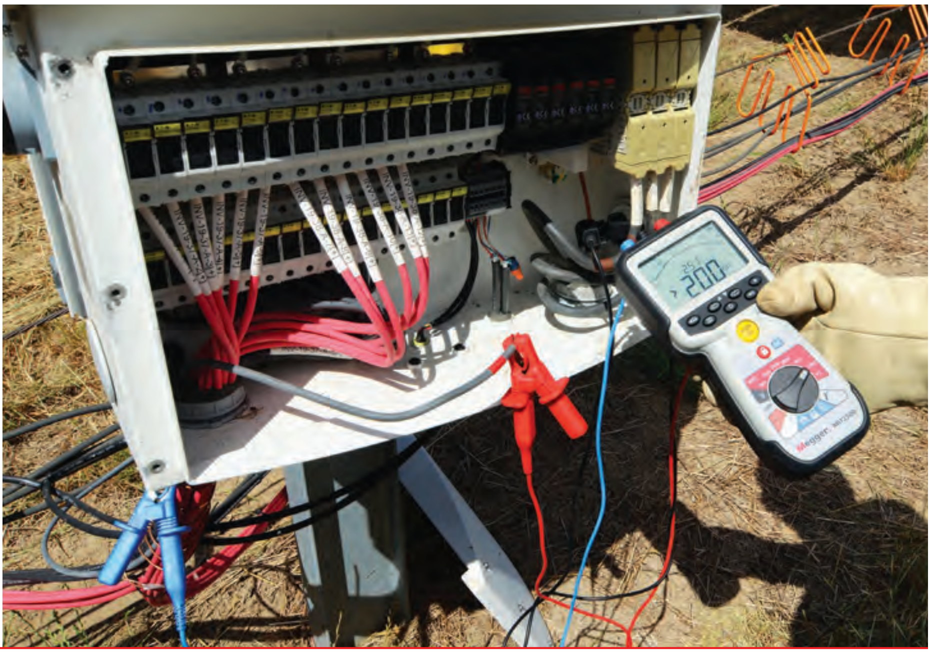
In a PV installation, especially for large commercial or utility-scale arrays, conductor insulation can quickly become compromised without you even realizing it. Those damaged wires can cause ground faults, presenting electrical shock and fire hazards. Without testing, identifying, and repairing compromised wires in the system, your team may have to deal with the costly service calls, repairs, personnel injuries, and liability claims for property damaged by fires and shock that are likely to happen.

Insulation resistance testing should be a part of standard PV system quality control checks, both at the point of commissioning and during routine operations and maintenance service calls. Still, only some PV contractors implement this at the necessary level. Integrating IR testing into annual service calls will help reduce the risks associated with failed conductors.

Codes & Standards

The International Electrotechnical Commission (IEC) has published the international standard IEC 62446, which details the information and documentation to complete before customer hand-off. The standard includes using insulation resistance testing as a protocol for safety and commissioning standards. While not required by all US jurisdictions, many large-scale contractors are adopting the IEC 62446 and supplemental guides such as SunSpec Alliance's "Commissioning for PV Performance" to ensure safety and avoid costs and liabilities.

Completing IR testing is key to meeting the IEC 62446 requirements.



EC 62446 includes testing requirements for dry and wet IR testing. Dry IR testing is the standard protocol and, as the name suggests, is completed when the PV equipment is dry. IEC recommends a wet test if the dry IR tests are inconclusive or faults persist. The different methods for completing the tests are included later in this guide.

The American Society for Testing and Materials (ASTM) has several testing standards for PV systems. Specifically for IR testing, ASTM has published methods for dry and wet testing of PV modules and arrays.

The National Fire Protection Association (NFPA) publishes several codes and standards, including NFPA 70, National Electrical Code, and NFPA 70B, Standard for Electrical Equipment Maintenance. Two items of note for NFPA 70B, one is the 2023 version updated the document to a standard. In previous versions, it was a recommended practice manual. This upgrade means it can be enforceable once adopted by an authority having jurisdiction (AHJ). The second item to note is including PV systems in the 2023 version.

The applicable standards for the various agencies are listed below.

Applicable Standards for Various Agencies

Dry Testing	Wet Testing
IEC 62446 Section 6.7 (2016)	IEC 62446 Section 8.3 (2016)
IEC 60364 Section 6.4.3 (2016)	ASTM E1802-12 (2018)
ASTM E1462-12 (2018)	ASTM E2047-10 (2019)
NFPA 70B Section 30.4.5 (2023)	

Confirm Proper Installation at Project Commissioning

Performing IR tests at the time of commissioning is typically a required activity during commissioning before official hand-off to the site owner. Regardless of the contractual necessity, performing these tests provides the commissioning against and system owners valuable information before the handoff.

Insulation resistance testing should be part of standard best practices for all PV systems' quality and safety control checks. Many solar installations require detailed testing and verifications per the IEC 62446 international standard. Benefits include:

- **Ensure proper conductor installation before energizing system**
- **Establish a baseline for future test results**
- **Verification before installation to catch manufacturing defects**

Standard Operations & Maintenance (O&M) Plans

While there are cases where the drop in insulation resistance can be sudden, such as when equipment is flooded, or conductors are damaged, it usually drops gradually, giving plenty of warning if tested periodically. These regular checks permit planned reconditioning before service failure or a shock condition, helping to predict and prevent electrical equipment breakdown.

Without a regular testing program, all failures will come as a surprise – unplanned, inconvenient, and quite possibly costly in time and resources and, therefore, money to rectify. If advanced insulation degradation goes undetected, there is an increased possibility of injury, electrically induced fires, reduction in equipment lifetimes, and the array can face unscheduled and expensive downtime.

Troubleshooting

Failure to identify ground faults causes significant delays and financial losses. Typical IR testers have a variety of functions, including measuring voltage, resistance, and continuity. However, their primary function is as an insulation resistance tester identifying hazardous faults due to compromised wires. This test can be incorporated into troubleshooting when ground faults are present. The ground fault troubleshooting section includes detailed instructions on this process..

Identifying faults in the field reduces losses and potential hazards to technicians.

Safety Considerations

Technician Safety During Testing

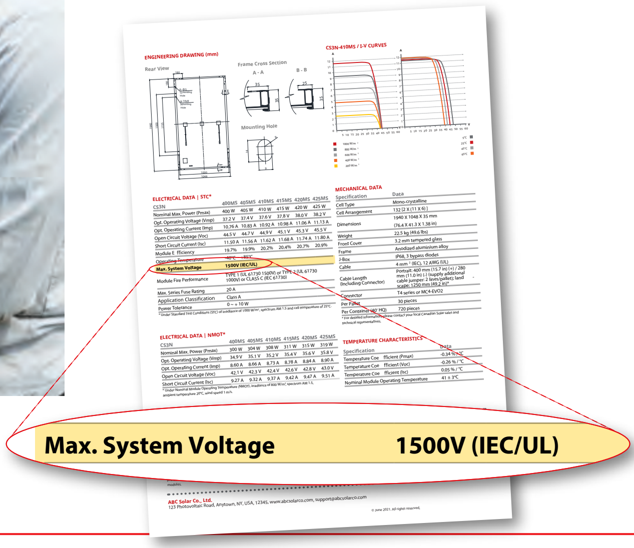
Insulation resistance tests place a high voltage and low current on the components under test. The test technicians must maintain a safe working environment for themselves and others working on the electrical system. All technicians using the tools must be trained appropriately and understand the hazards before performing tests.

In PV systems, technicians must isolate all power electronics and surge protection devices from the circuit under test. Failure to isolate these components can result in damage. Technicians that wish to perform the insulation resistance test through the PV modules must obtain approval from the module manufacturer. To avoid damage, the test voltages applied should remain less than or equal to any PV module voltage rating.

Before performing tests, the working area must be appropriately identified and isolated. All technicians on site must be notified of the tests so they do not inadvertently come in contact with any components under test.

Technicians must use proper personal protective equipment (PPE). At a minimum, high-voltage gloves and safety glasses must be worn when performing tests. Based on the test requirements, the insulation resistance testers will place a voltage on the equipment, introducing a shock hazard. If a fault is present, the test voltage and a small current can be on the equipment and conductors bonded to the earth.

Technicians must wear proper PPE based on the hazards present.



IR testing should not exceed the listing agency's maximum voltage rating.

Step-By-Step Instructions for PV Circuits

Performing IR tests within a PV array is similar to other electrical circuits, but there are key differences. Proper planning and understanding the required methods will ensure the tests are performed safely and correctly.

Before arriving at the site, identify all circuits for testing. While testing, use a site map and sequential operation to maintain proper record-keeping. Collecting data within the tools will expedite the process, but technicians must be aware of the data collected and verify that the measured circuits match the plans. The technician will need a handheld megohmmeter to perform the tests, high voltage safety gloves, and safety glasses as minimum PPE.

1. Document Environmental Conditions

This is a crucial step to establish accurate trendlines. The environmental conditions will impact the test results. Properly accounting for the environmental conditions will better inform the data collected and the conductors' health. Document the ambient temperature, humidity, and irradiance for future reference. Technicians can use the temperature and humidity values to normalize the data collected for analysis in trend lines.

Take note of the environmental conditions at the time of your testing, as they can affect the results. The technician should record the conditions observed, such as time, date, temperature, humidity, and the condition of the equipment being tested (wet, dry, etc.). This documentation will be necessary when comparing against future test results to better evaluate the conductors' condition.

Document environmental conditions for proper analysis.

2. Shutdown & LOTO

Place all solar equipment (inverters, dc disconnects, combiner boxes, etc.) in the open (off) position and use lockout tagout (LOTO) methods to maintain a safe working environment. When testing PV circuits, isolate the conductors from the modules to remove the voltage.

Verify all voltage and current values are at expected levels before moving to the next step. PV modules will produce voltage whenever there is ambient light present. Therefore, until modules are isolated, the supply side of all PV circuits will still have voltage present even when the connected equipment is in the open (off) position. The load side of the terminals may also have voltage present depending on the exact configuration of equipment.

Before opening any touch-safe fuse holders, use a multimeter capable of measuring dc current on all PV dc circuits. Faults in the wiring or miswired PV modules can result in current on conductors, even when the disconnects are in the open position. Pulling touch-safe fuse holders in these scenarios will expose the technician to shock and fire hazards.

Verify open circuit voltage conditions from the PV array when equipment is turned off.

Use a clamp meter to read current prior to opening touch-safe fuse holder or PV quick connects. Current values must be zero prior to opening these components.

3. Isolate All Power Electronics

Isolate all power electronics – inverters, module-level power electronics (MLPE), surge suppression, overcurrent devices, and modules should all be isolated unless the manufacturer approves beforehand.

The IR tester will place a voltage on the circuit. Therefore any components, especially electronics, must be isolated from the circuit. Consult module manufacturers before performing an IR test through any modules. Therefore, PV modules should be isolated from the circuit before performing IR testing unless approved. In addition, IR testers will typically go into a safe mode and not operate if a voltage is present on the circuit. As PV modules will produce voltage when expensed to sunlight, proper placement in the circuit is critical when performing a test through the modules.

Power electronics must be isolated from the test circuit. Pull-out fuse holders can be used for isolation.

4. PV Circuit Tests: Connect the IR Tester Leads

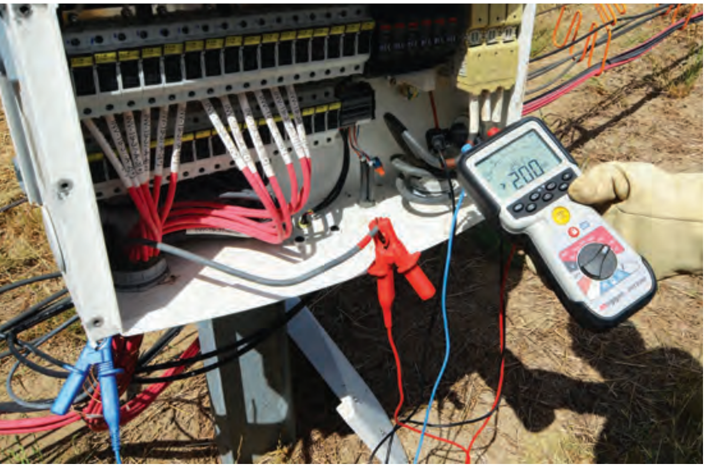
For PV source circuits, leads can be connected at the combiner box or the termination point in the inverter provided the equipment is appropriately isolated. With the PV side of the source-circuit isolated, the IR tester's positive lead can be connected to the termination point of the homerun. The negative lead of the tester must be connected to a grounded surface, typically the ground bus in the equipment.

The IR tester can also test inverter output conductors. Conductors must be isolated from both the inverter and the overcurrent device on the opposite end of the circuit. The tests for these ac conductors can then be performed as described below.

5. Set the IR Tester to the Desired Voltage Test Level

Select the appropriate testing voltage, which should be a minimum of 1,000 Vdc for systems operating at an open circuit voltage greater than 500 Vdc per IEC standards. Next, select the duration you'd like to run your tests for by using the fixed time test feature on the tester to ensure consistent and accurate results. For PV systems, a one-minute test will allow the tool to reach equilibrium and display accurate readings.

Note IEC 62446 limits the test voltage to 1,000 Vdc. Systems operating above 1,000 Vdc should be tested to their nominal operating voltage at a minimum. For ground-mounted PV arrays, this is typically 1,500 Vdc.



Connect the IR tester to the conductor to be tested and a metallic component such as the racking system bonded to earth.

6. Test the Connected Circuit

Test the connected circuit using the timed test setting and record the resistance value.

Once your electronics are isolated, the test leads are connected, and voltage and time values are input into the instrument, you can run your test by pressing and releasing the "Test" button. The on-screen timer will count down while the test occurs, and the final resistance measurement will be displayed once the test is complete. The onboard display will also clearly indicate whether the test passes or fails.

Per IEC standards, the minimum insulation resistance is a function of the system and test voltage as seen in the table on the following page.

Test Voltage & Minimum Resistance

System Voltage[1] (VDC)	Test Voltage[2] (VDC)	Minimum Resistance (MΩ)
<120	250	0.5
120 – 240	500	1.0
>500 VDC	1000 VDC	1.0 MΩ

1. System Voltages are: Voc (at STC) x 1.25. 2. Test voltages based on PV system open circuit voltages per IEC 62446.

The minimum passing resistance is one megaohm (MΩ) which is relatively small. Many commissioning and maintenance protocols from system owners and financiers dictate a minimum resistance value of 100 MΩ. This value is derived from the ANSI/NETA ATS-2017 Table 100 requirements.

Maintenance professionals have used the one-megohm rule for years to establish the allowable lower limit for insulation resistance. The rule may be stated:

Insulation resistance should be approximately one megohm for each 1,000 V of operating voltage, with a minimum of one megohm.

For example, a PV array rated at 1,500 Vdc should have a minimum insulation resistance of 1.5 megohms. In practice, megohm readings normally exceed this minimum value in new equipment or when insulation is in good condition.

Per IEC 62446, PV conductors are acceptable if insulation resistance exceeds 1 MΩ. Some testers can register resistances up to 200 GΩ, so the values may broadly vary between readings. So learning how to evaluate those varying passing results is essential. For example, a 5 MΩ result is passing, but what if the very next conductor results in 500 MΩ resistance? Is that first conductor 100 times less resistant? Should this cause concern? A good rule of thumb, especially when commissioning new equipment, is that a measurement above 100 MΩ is a reliable indicator of good performance. While a measurement below 100 MΩ, even if above the IEC standard 1 MΩ, is something to keep an eye on. With subsequent interval testing, flagging conductors in this range is an excellent way to catch issues. A result of less than 1 MΩ always indicates that immediate attention and replacement are needed to avoid safety hazards.

Note that a common mistake in the field is to be alarmed by a 1 GΩ reading, mistaking it for a for 1 MΩ reading. Pay close attention to the readings and the clear pass or fail result on your tester's screen.

Continued on page 22

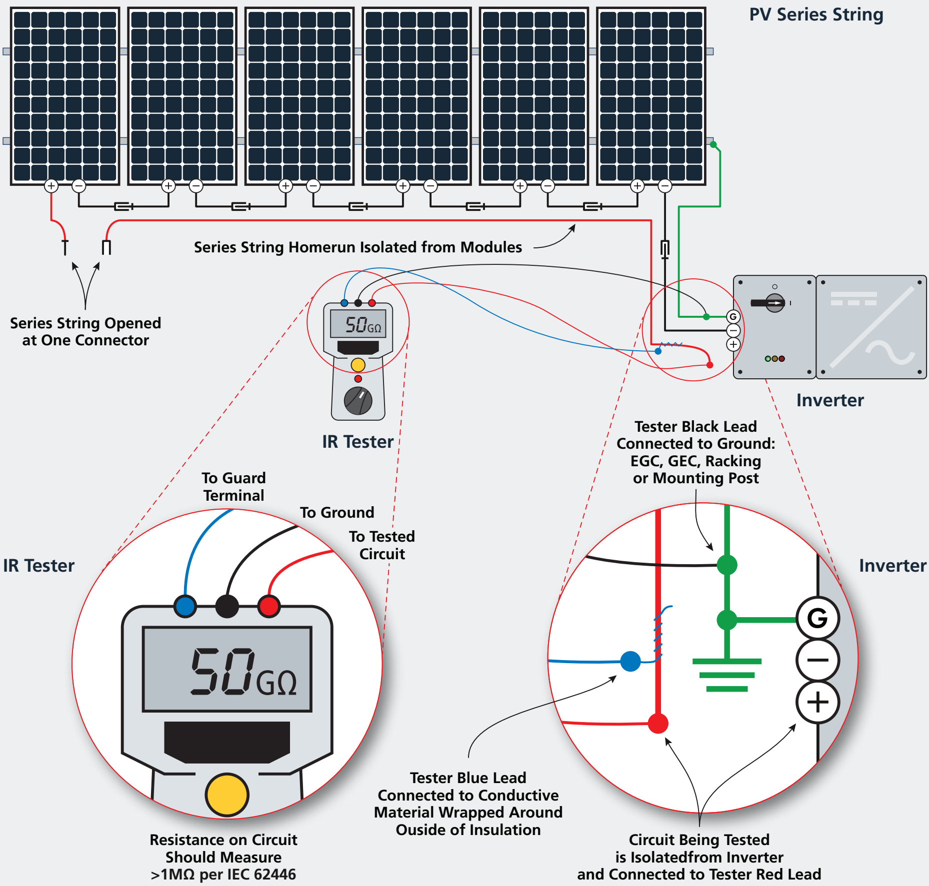
Use of a Guard Terminal

Using an Integrated Guard Terminal

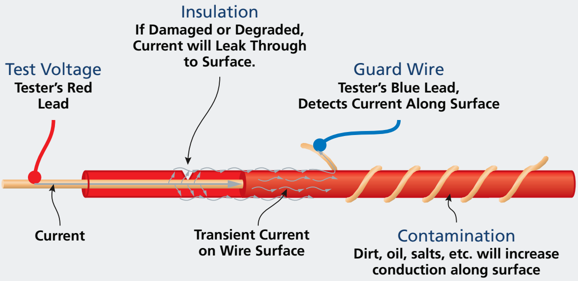
During solar commissioning or maintenance checks, it is essential to use an IR tester to test the integrity of the conductors in your PV array. An insulation resistance test measures two components; current leakage through the insulation and current leakage over the insulation material. The current leaking through the insulation, without the surface leakage, is the accurate measure of the safety and quality of the conductors and insulation you're testing.

Using a handheld IR tester with a guard terminal eliminates, or significantly reduces, the effect of surface leakage on the test results. Common environmental conditions such as high humidity, dirt, grease, or other natural contaminants affect the amount of surface leakage, causing unreliable test results. Rooftop and ground-mounted solar arrays often have exposed

Insulation Resistance Testing with Guard Terminal



Guard Wire on a Conductor



Surface leakage is a common IR test phenomenon. The extent of surface leakage is a function of multiple factors, including contamination on the conductor surface. A guard terminal can isolate the surface leakage and return an accurate insulation resistance value.

Utilizing a guard terminal eliminates the surface leakage component during an IR test. Conductors exposed to the elements may have a higher surface leakage component and tests without a guard terminal may result in inaccurate measurements.

conductors, frequently over long distances. This can result in more contaminants, and without the guard terminal, tests will give a falsely low resistance value. Inaccurate testing can lead to the needless replacement of costly conductors that may not even need to be replaced.

To use the guard terminal, wrap a conductive material around the PV circuit conductor under test and then connect the guard terminal lead to the bare conductor.

Keep in mind that it is nearly impossible to qualify varying test results without using the guard terminal to eliminate the surface leakage contribution. Conducting the test without the guard terminal and then immediately repeating the test with the guard terminal will help qualify the impacts of surface leakage under the existing conditions. Suppose the comparison between the results with and without the guard terminal reveals surface leakage to be minimal. If environmental conditions haven't changed, you may avoid using the guard terminal on nearby conductors. Run your test with and without the guard terminal again as environmental conditions change; for example, between morning and afternoon testing.

7. Record Results

The results should be recorded and stored for future reference. Subsequent readings collected should be stored in the same master file to develop a trendline. This information can then be analyzed and used to help determine when proactive maintenance for conductors is required.

Gathering Data

	A	B	C	D	E	F	G	H
1	TEST NUMBER	TEST TYPE	TIMED INS R	TIMED INS LEAK	TIMED INS V	INS	INS LEAK	INS V
2	1	Timed Insulation	92.7	0.0273	2510			
3	2	Capacitance						
4	3	Insulation				12.5	0.0383	496
5	4	Insulation				14.1	0.0183	414
6	5	Insulation				0.33	1.36	452
7	6	Insulation				0.52	1.31	673
8	7	Insulation				3.83	0.204	748
9	8	Insulation				0.5	1.31	642
10	9	Insulation				3.04	0.334	1022
11	10	Insulation				4.97	0.205	1024
12	11	Insulation				0.62	1.23	709
13	12	Insulation				4.63	0.2	901
14	13	Insulation				1.19	0.733	970
15	14	Insulation				3.82	0.267	1023
16	15	Timed Insulation	231	0.0044	1017			
17	16	Timed Insulation	>200000	0	1017			
18	17	Timed Insulation	0.051	1.43	73			
19	18	Timed Insulation	0.15	1.4	204			
20	19	Timed Insulation	77.9	0.0131	1018			

Data from the IR tests must be collected and verified for analysis. Utilizing tools that integrate data recording in the tool or a connected smart device is recommended.

8. Evaluate Results in the Field

Upon completing the test, the technician should take a moment to evaluate the results before moving to the next circuit. Incorrect tool setup or user error can provide incorrect data that leads to confusion for anyone evaluating the data later. Technicians should consider the results in real-time. Comparing consecutive tests can help the technician decide if the results align with expectations. Results that are below the passing threshold should be immediately flagged. Dramatically different results from one test to the next should be reevaluated and rerun as necessary.

Technicians need to verify readings in real time. Any results below the minimum or dramatically different from previous tests should be investigated while on site.

9. Creating & Evaluating Trend Lines

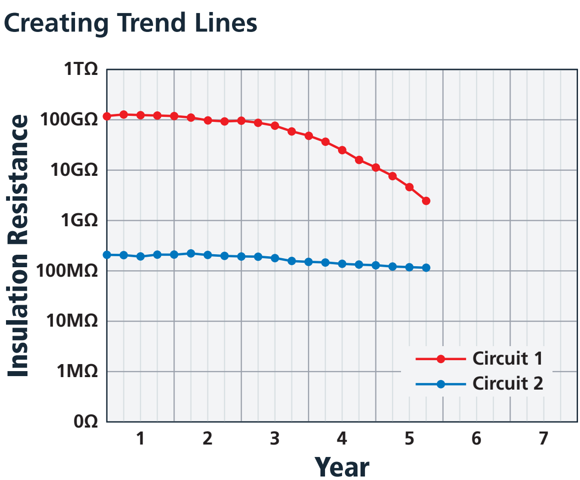
Comparing trends in your test results over time is essential to finding changes in the integrity of your wires. Watching trends is why testing should occur before energizing and at periodic maintenance intervals. The time between maintenance intervals may vary depending on your system owner or operator guidelines. Regardless of the time between intervals, finding trends in the same conductor test results will be the best way to catch degrading wires before they become problematic.

A conductor with an initial high insulation resistance may degrade rapidly, indicating required replacement. Conversely, a conductor may have a lower but acceptable resistance value that holds steady over time. So the lower resistance alone does not indicate poor insulation or the necessity for replacement.

During commissioning and maintenance checks, running many insulation resistance tests with your IR tester on source-circuit conductors in a PV array is common. A test fails when insulation resistance is below 1 MΩ per IEC standards for grid-tied PV systems. But beyond a pass or fail, the first test can only be a rough guide on how good or bad the insulation is.

However, many factors cause the readings to vary widely. Different meters, equipment, humidity, temperature, length, and the insulation's age can all affect your test results. To qualify your results, it is important to note the environmental conditions when testing. Testing your conductors with and without the guard terminal included with your tester is a great way to determine if conditions are causing surface leakage.

In addition, analyzing trends between readings comparatively with periodic testing is the best way to judge the insulation condition. Be sure to run your periodic tests the same way, each time, with the same test connections and voltage applied for the same amount of time.



Trend lines are an important aspect of the IR test. Rapid reductions in insulation resistance may go unnoticed without consistent readings.

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