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Application Note – Ground fault location in PV systems

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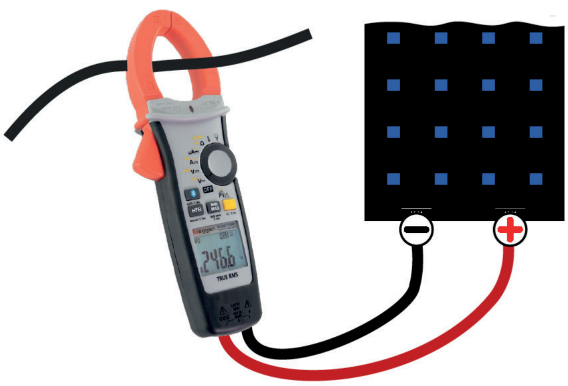
Importance of testing ground faults in PV systems

Every electrical installation need testing to ensure that it's safe to use and to operate. Inspection and testing are, therefore, essential to protect lives and a line of defence against electrical accidents.

Solar Power Plants can produce high DC voltage, and shocks from DC sources are particularly dangerous and connections to their components to earth can impact several risks like, electric shock to people in the surrounding areas, fire under fault conditions, transmission of lightning induced surges and the presence of electromagnetic interference.

A safe and convenient way to perform tests, and to avoid conventional methods which involve breaking the circuit to connect a tester, is to use a clamp meter since it is not necessary to break into a circuit. Some tests can be carried out without taking the panels out of service, and the risk of shock is also greatly reduced.



A Bluetooth® capability let you remotely store and monitor measurements and perform tests while keeping your electrical safe distance from arc fault hazards, air to ground, or air to phase discharges.

Using Bluetooth® connection, the DCM1500S streams measured values in real time via the Megger Link App to a smartphone or tablet, and the MIT430/2 and MIT2500 download stored data on a computer via the Megger Download Manager.

The DCM1500S fully meets the requirements of IEC 61010 for CAT III 1,000 V and CAT IV 600 V applications. It is capable of measuring voltages up to 1,500 V AC and up to 2,000 V DC, as well as currents up to 1500 A in AC and DC. It also has an MC4PV plug for direct voltage measurement from solar panels, as well as standard test leads.

In the other side, the MIT430/2 and MIT2500 CATIV 600 V testers, are handheld tough and lightweight testers with a test voltage up to 2,500 Vdc, measuring resistance up to 200 GΩ.

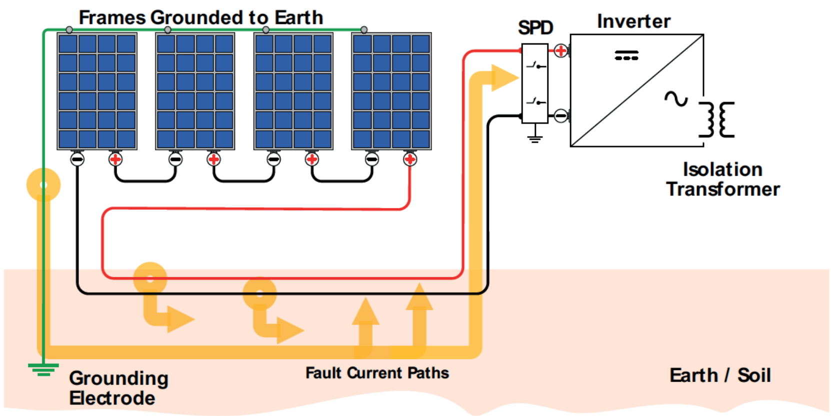
Connections to earth in PV systems

There are two basic types of connection to earth, and it is where more earth leakage can occur.

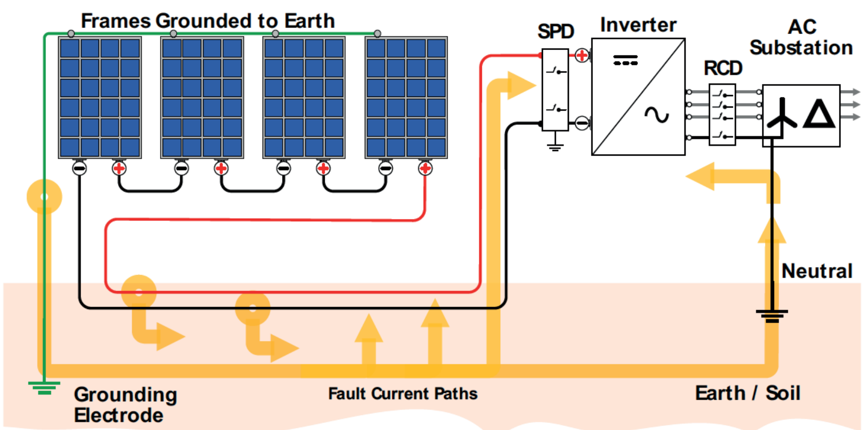
Floating systems

Floating System or Equipment earthing, is an ungrounded system that connect non-current carrying conductive parts to ground, such as PV module frames, structures, enclosures, racks, junction boxes, conduit, and any other metallic components.

Many installations will utilise class II modules, class II DC cables & connectors and be connected to the mains using an inverter with an isolation transformer. This method permits the array frame to be left floating. It is important to understand that accidental earth leakage can be present from faulty equipment or damaged insulation.



Floating Isolated PV System



Floating Non-isolated PV System

Floating systems require specially listed inverters with array fault detection capability, and require wiring protection, disconnecting devices, overcurrent protection, and ground-fault protection in both ungrounded array DC conductors.

Earth System

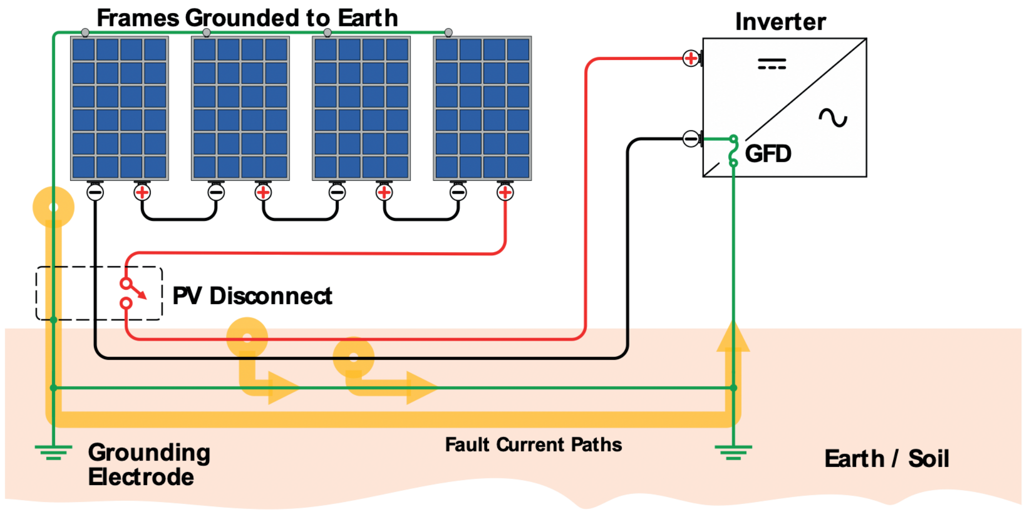
Earth systems or system grounding is a system that connect a current-carrying conductor in an electrical system to ground, or earth potential.

An array output cable or conductor earthing is connected to earth. In this case a bonding to earth is made to any of the live DC current conductors. Here planned earth leakage occurs as consequence of the design of the equipment.

PV systems by default should be equipment earthed, and in the great majority should also be equipped with a system grounding.

In earth systems, when a ground-fault condition is detected by current flow in a grounded conductor and grounding electrode, the circuit is opened, and the inverter displays a ground-fault alarm. The connection between the grounded conductor and grounding electrode system is normally made through the ground-fault protection device.

It is important to note that lightning strikes can also cause damage either from a direct or a nearby strike and surges may be induced on the PV array conductors or the AC cables.



Earth PV System / Grounded PV System

Testing for ground faults location

Inspections and testing of PV systems need to be performed regularly to ensure that remain in a safe and functional during the operative lifetime.

It is important to have access to initial records and measurements of the system from the initial commissioning, including any changes in components or modifications. Initial records can help to compare system changes and to identify problems that require a preventive or corrective service.

There are six common tests conducted on PV systems.

Visual Inspection

This inspection is beneficial to identify incomplete installation details and validate compliance with local applicable standard requirements. It aims to identify any physical damage, modification or degradation of equipment from the effects of environmental conditions, extreme temperatures, dust, corrosion, moisture, as well as damage caused by rodents and nesting animals.

Continuity Testing

This test verifies that appropriate bonding exists to the earthing systems between PV module frames, structures, conductors, connections and other terminations in de-energized circuits.

Verify that the earth electrode conductor is continuous and the viability of any irreversible splices, welds or other connections are made using accepted methods, as well as validating the connection of the earth electrode conductor to the earth electrode.

Also testing continuity bonding in metal cable trays, enclosures, frames, fittings, and other components serving as equipment earthing conductors. Electrical continuity can be loss due to inadequate mechanical installation.Testing electrical continuity between the grounded PV array source circuit and output circuit conductors to the earth electrode conductor, especially when equipment is removed for maintenance or replacement.

Polarity Testing

This test proves the correct polarity for PV DC circuits, and proper terminations for DC utilization equipment, by measuring the voltage on energized circuits, prior to closing disconnects and operating the system.

This test should be validated on the PV modules, PV source circuits, PV output circuits, Disconnecting means, Battery and charge controller circuits, Inverter input terminations and Electrical loads

It is important to test the polarity of every source circuit and the entire PV power source before connecting to any DC equipment. Reversing the polarity of an array connection to a battery can lead to serious accidents on the equipment and lives.

Voltage and Current Testing

These tests verify that the PV array and system are operating within the expected commissioning and equipment manufacturing specifications, by testing voltage and current in the DC and AC circuits of the PV system before closing disconnects and start any system operations.

This test verifies AC voltage and phasing at the utility supply, inverter AC terminals and disconnects. It also tests DC voltage and correct polarity for the PV array source and output circuits and at DC disconnects.

When it applies, also test DC voltages and correct polarities on batteries, battery chargers and controllers.

Open-Circuit Voltage Testing

This test can also be used to prove correct polarity of the PV array source. The open circuit voltage (Voc) tests require suitable testers capable of standing AC and DC voltages over 600 V.

Testing multiple strings can show differences in voltage values within 5% between each PV strings array Inappropriate array cabling, damaged PV modules or bypass diodes can be an indication of lower voltagesbeing tested. These values can also be affected the by temperature and irradiation at the time of the testing,and therefore voltages can change in a range of 2.5% for every 10 C change in module temperature.

To identify faulty strings, verify the Open Voltage of all the strings. Divide the voltage of one of the good stringsby the number of modules in series to determine the module voltage. For example, Voc = 500 V; 10 modules in series; Voc per module = 500 V   10 modules = 50 Vdc per module.

Modules in most PV source circuits are in series; therefore, the earth fault location can be based on the voltage of the faulted string. For example, measuring on a faulted string, Vocf = 400 V; 400 V   50 Vdc per module = 8 modules; fault location may be 8 modules back from the high voltage (output) side of the string.

Short-Circuit Current Testing

This test is performed on PV string source circuits to confirm a correct operation of the system. This short circuit current (Isc) test requires testers capable of standing DC currents of over 10 A, as well as utilizing suitable shorting devices to perform a test safely.

The Short-circuit current of a PV array is proportional to the solar irradiance on the system. This type of tests should be done briefly and under clear sky conditions and the PV modules are free of dust or shades. Testing multiple strings should show acceptable differences within 5% between each PV strings array.

Insulation Resistance testing

This test identifies faults within PV arrays and system circuits, and detects any degradation and faults in wiring insulation, as well as the integrity of cabling and equipment.

Insulation resistance is verified by applying a constant test voltage to a conductor and measuring the current flow between deenergized system conductors or between a conductor and earth.

A conductor with high insulating quality will normally measure higher resistance values. Leakage currents can increase the risk of electrical shocks, damaging the system and exposing risks on lives. Improper or deteriorated installations, as well as many adverse environmental factors, sunlight, moisture, nesting animals and insects, mechanical impacts and vibrations, are common reasons on the deterioration to the wiring insulation.

As the voltages applied on the test range from 50 Vdc to 5000 Vdc, all circuits must be isolated from each other for testing and discharged before and after performing the test. Earthing or bonding connections need to be left connected, while surge suppression equipment must be removed from all the circuits, and make sure there is reliable electrical and mechanical contact between the test leads and the circuits under test, as some connections may require some grinding or filing.

This test can be carried out in two ways:

- Between the positive DC conductor and earth, and between the negative DC conductor and earth.
- Between the shorted positive and negative DC conductors and earth. This test requires suitable shorting devices to perform a test safely.

In ungrounded or floating systems, where modules and structures are not provided with metallic support structures or frames with a bonded connection to earth, this test should be verified between array cables and earth, and between array cables and frame.

For PV system with operating voltages higher than 120 V, an acceptable insulation resistance of 1 MΩ or higher is considered acceptable, while in PV systems with operating voltages lower than 120 V, minimum acceptable insulation resistance values of 0.5 MΩ are considered acceptable. If one or more readings shows a resistance that is 1/10th or less than acceptable conductors, this may be an indication of a damaged conductor or module.

Earth leakage current testing

If the systems are equipped with RCDs or RCBOs, this test will allow to detect tripping problems, which can be related to an oversensitive RCD or RCBO.

This test verifies if the protective devices operate at a lower current than the specified by the system design or device manufacturer. These devices monitor the current flowing in the line conductors and comparing this with the return current in the neutral conductor. If there is a difference that exceeds the sensitivity setting, in mA rating, of the device, it will trip and open the circuit.

The test is performed where live and neutral conductors are accessible, and at connected equipment, and it measures the earth leakage current using a clamp meter. The clamp meter is clamped round the line and neutral conductors only, and it will measure the difference between the line and neutral currents, which is the earth leakage current. Environmental conditions, and the type of cabling used in the system can affect the performance of the device and the measurements during the test.

Testing separate PV system arrays can help in identifying earthing leakage problems. Also, by discarding whether the leakage is intentional or unintentional, as a result of a fault, then a further location and corrective action will be required.

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Abbreviations

DC	Direct current
AC	Alternating current
PV systems	Photovoltaic systems
Class II	Symbolises a double insulated electrical appliance, which has been designed in such a way that it does not require a safety connection to electrical earth (ground). Applies to portable tools and plug-connected equipment not permanently connected to the mains.
CAT III	This category refers to measurements on hard-wired equipment in fixed installations, distribution boards, and circuit breakers. Measurement category III is for equipment connected between the consumer unit and the electrical outlets.
CAT IV	This category refers to origin of installation or utility level measurements on primary over-current protection devices and on ripple control units. Measurement category IV is for equipment connected between the origin of the lowvoltage mains supply outside the building and the consumer unit.
MC4PV Plug	Type of single contact connector commonly used for connecting solar panels.
Voc	Open circuit voltage
Vdc	Voltage direct current
Vocf	Open circuit voltage on a faulted string
Isc	Short circuit current
A	Ampere (the unit)
I	Electric current (the symbol)
mA	milliampere
V	Volt (the unit)
V	Electric voltage (the symbol)
MΩ	Megaohm
GΩ	Gigaohm
SPD	Surge protective devices
RCD	Residual current devices
RCBOs	Residual current circuit breakers with overcurrent protection

Further reading and references

Practical Guide to electrical installation testing for BS7671:2018. Mark Hadley, Product Manager Megger Instruments Limited, Richard Wardak, Product Champion Megger Instruments Limited

Requirements for Electrical Installations BS7671:2018. IET, The Institution of Engineering and Technology

IEC 62446, this standard not only specifies minimum testing and inspection requirements on installed systems, but also, how those inspection and test results are documented and supplied

Photovoltaics in Buildings. Guide to the installation of PV systems. 2nd Edition, DTI, the department for Enterprise

Field Guide for Testing Existing Photovoltaic Systems for Ground Faults and Installing Equipment to Mitigate Fire Hazards. NREL, The National Renewable Energy Laboratory

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