STANDARDS AND REGULATIONS FOR THE DESIGN, CONSTRUCTION AND CHECKS OF AN ELECTRICAL SYSTEM

2024

HT INSTRUMENTS

FOR 40 YEARS WE HAVE BEEN TRACING THE LINES OF SUCCESS

INDEX

STANDARDS AND REGULATIONS FOR THE DESIGN, CONSTRUCTION, AND CHECKS OF AN ELECTRICAL SYSTEM

Why is there a publication concerning the standards?

Simply because they are the **main path** that HT Italia's designers and research group follow to **create devices that are always in line with the regulatory dictates and their evolution**.

The most important part of our production has a single direction: first of all, to **create** intrinsically **safe equipment**, intended in turn to **guarantee safety** and **full adherence** to the provisions of the **International Committees**.

Why do we like to return to the subject of Standards?

For two reasons.

The **first** because **we know them well**, we have **studied** them, we have confronted them, we have made them our own.

The **second** reason is much simpler, we try to **make their interpretation easier**, striving, as far as possible, to communicate a basic concept: **building systems according to STANDARDS means creating safe systems**.

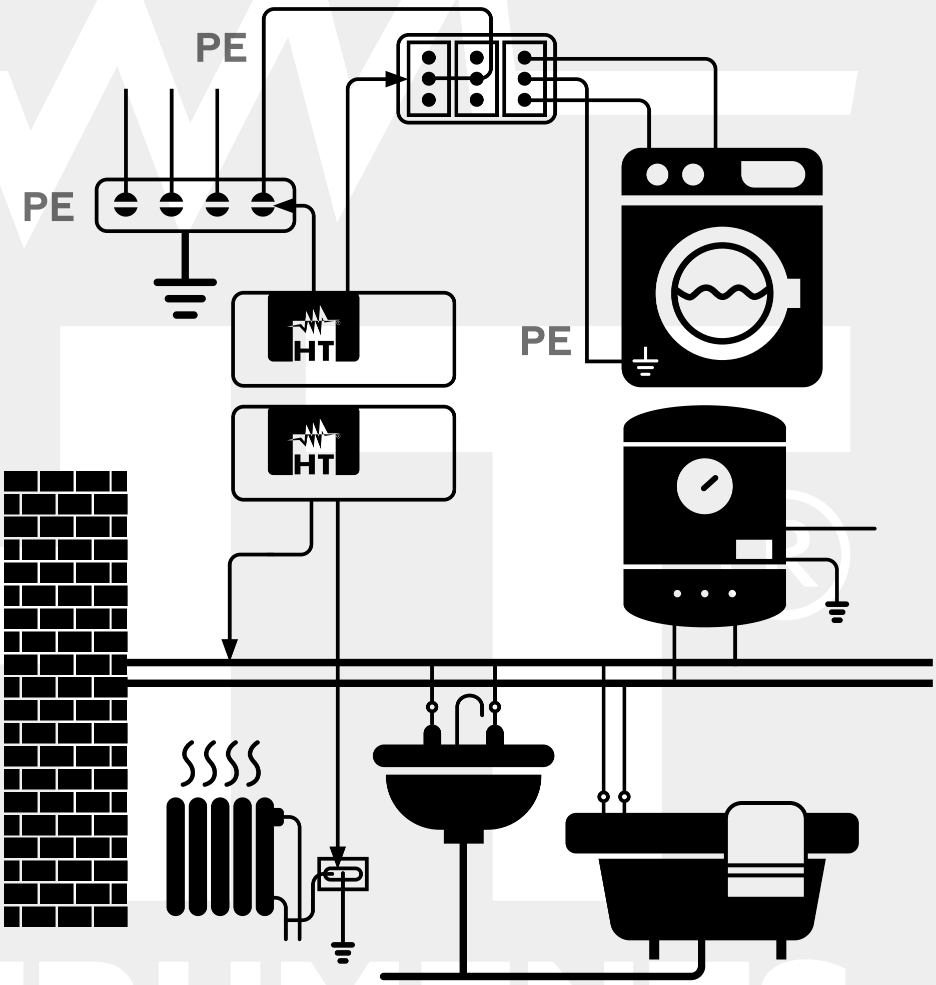
Safety is not a light bulb that turns on at the push of a button, **it is an invisible factor** that, if **not complied with**, can **cause damage** that is then difficult to remedy.

P Continuity test of protective conductors

In order to verify the continuity of protective conductors, the IEC 64-8 standard requires the use of a measuring instrument capable of performing the test with a current greater than or equal to 200mA. The purpose of the test is not to measure the resistance, but to evaluate the existence or otherwise of electrical continuity between the equipotential node and all points of the system where there is an earth connection (plug sockets, earth terminals of Class I equipment and extraneous grounds).

Why is it important to carry it out?
In the event of a fault of an equipment connected to a socket that is not adequately connected to the equipotential earth node, the user is exposed to a risk of electric shock, simply by coming into contact with the casing which is not normally live (indirect contact).

Parts of the system to check



R Measurement of the insulation resistance

Testing of the insulation resistance or of the correct insulation of an electrical system makes it possible to identify any wiring errors or any damage to parts of the system itself. The test must be carried out in the absence of voltage and with all loads and any arresters suitably disconnected. Table 6.1 of the IEC 64-8/6 standard indicates the DC test voltage as a function of the nominal voltage of the circuit, also indicating the minimum insulation resistance expressed in MOHM.

Table 6.1 - Minimum isolation resistance values

Nominal voltage of the circuit V	Test voltage in DC V	Minimum insulation resistance MΩ
SELV and PELV	250	≥ 0.5
Up to 500 V, including FELV	500	≥ 1
More than 500 V	1000	≥ 1

Why is it important to carry it out?

To ensure an insulation barrier between the protective conductor and the active conductors, there must be no contact between the two. The insulation measuring instrument generates a test voltage to safely check for a fault.

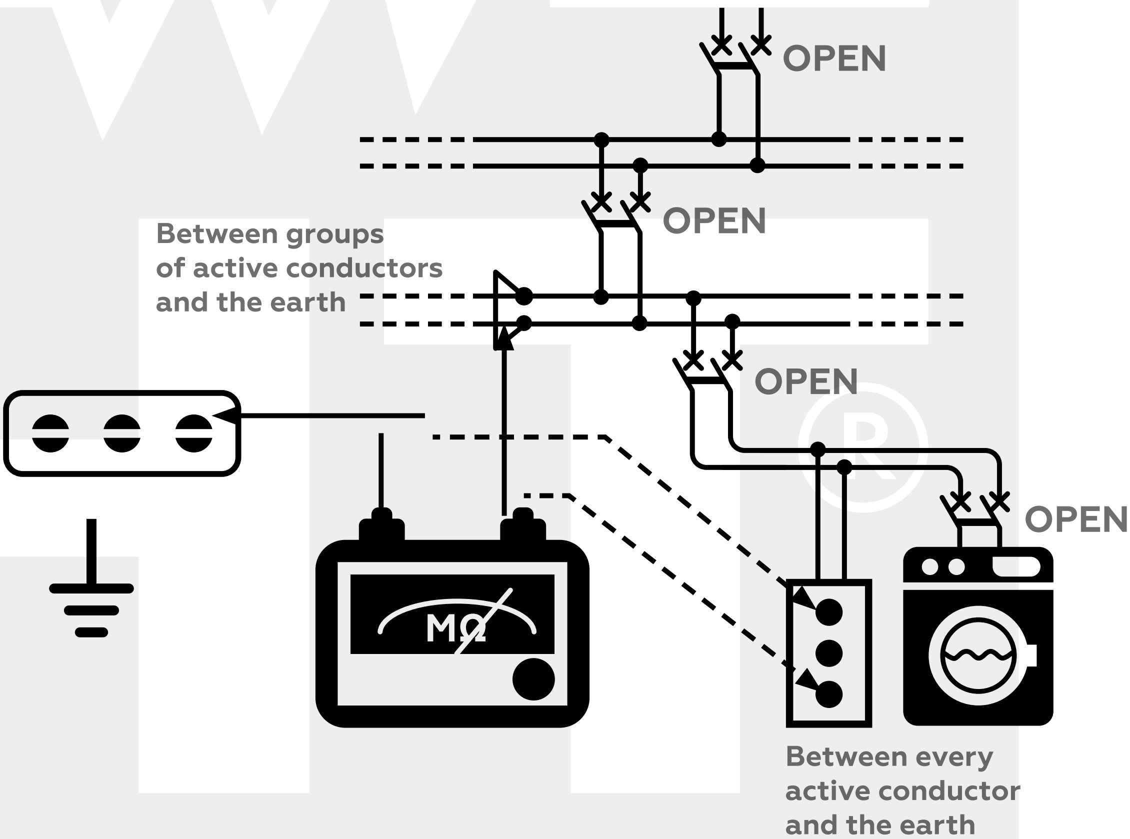


Fig. 1.2.13: Measurement of system insulation resistance.

A Testing to confirm the effectiveness of the automatic disconnection of the power supply

The purpose of this measurement is to check the coordination of differential protections in **TT systems**, to check circuit breaker or fuse protections **in TN systems**, and to check the first fault current **in IT systems**.

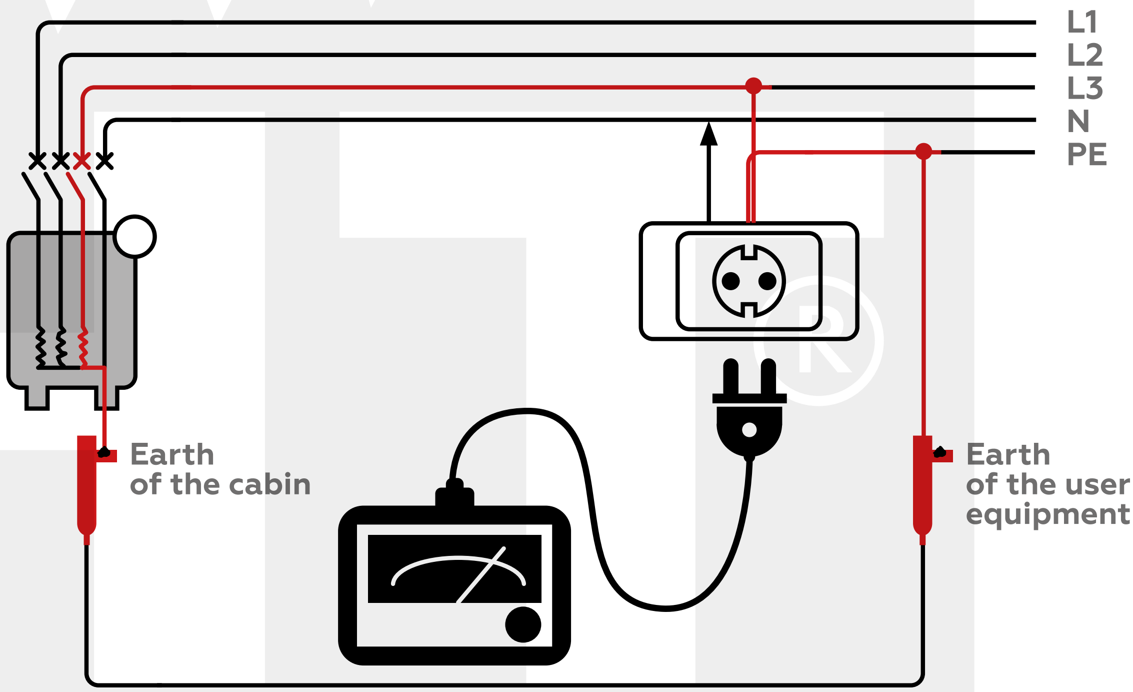
S TT SYSTEMS

In TT systems, the resistance of the ER earth resistance earth rod to which the grounds are connected must be checked, with the addition of checking the characteristic and efficiency of the differential device. The IEC 64-8 standard allows two methods of testing the earth resistance, divided into the "voltamperometric method" and the "fault circuit resistance method", while for the verification of the effectiveness of the automatic disconnection of the power supply (RCD), the measurement of the tripping time of the protection is provided which, with a fault current equal to its nominal tripping current Idn, it must take place within the limits set out in Table 1.

Table 1 - Tripping times for general differentials

Type	$I_{\Delta n}$ (A)	Tripping times (s) for I_Δ equal to:		
		$I_{\Delta n}$	$2\ I_{\Delta n}$	$5\ I_{\Delta n}$
AC	any	0.3	0.15	0.04
A*	≤ 0.01 A	$2\ I_{\Delta n}$	$4\ I_{\Delta n}$	$10\ I_{\Delta n}$
		0.3	0.15	0.04
A*	≥ 0.03 A	$1.4\ I_{\Delta n}$	$2.8\ I_{\Delta n}$	$7\ I_{\Delta n}$
		0.3	0.15	0.04
B/B+	any	$2\ I_{\Delta n}$	$4\ I_{\Delta n}$	$10\ I_{\Delta n}$
		0.3	0.15	0.04

(*): l type F differentials can be tested like type A.



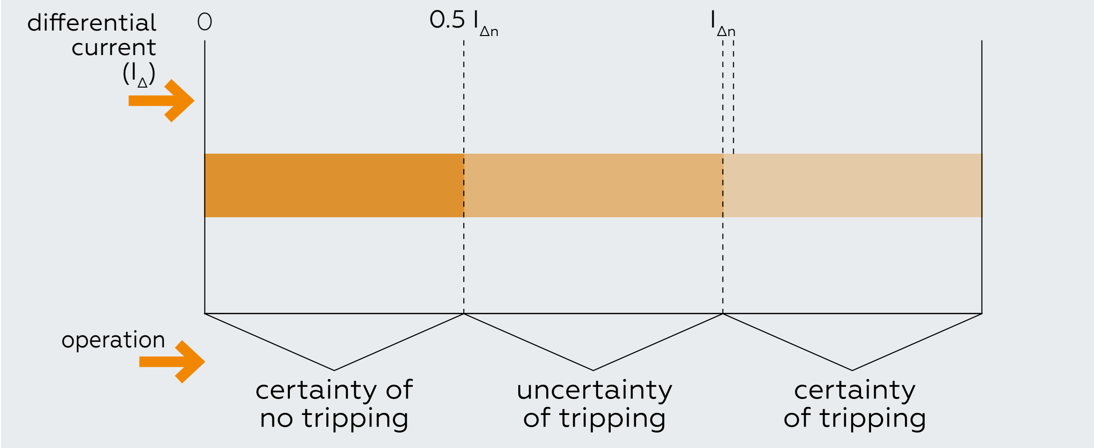
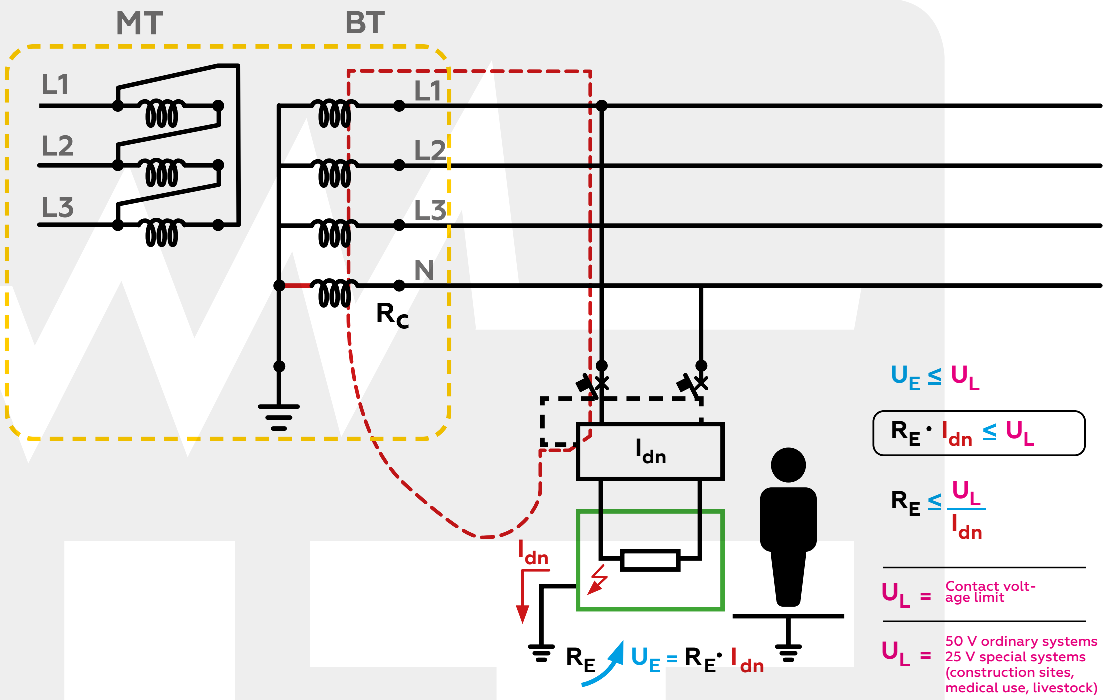


Fig. 3: Correct behaviour of a differential switch in relation to the differential current value that is manifested in line.

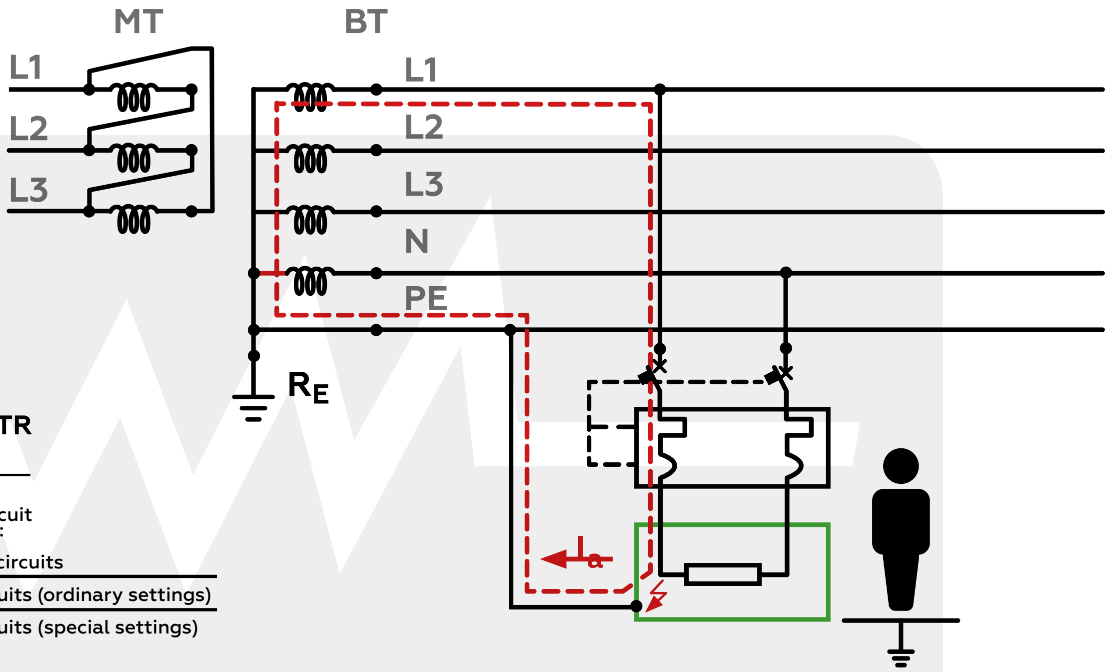


Why is it important to carry it out?

In the event of an earth fault of a piece of equipment, the ground of which is not normally live, the latter could be induced to a potential danger for the user who happens to touch it. By verifying the perfect efficiency of both the earthing system and the residual current device, we are sure that once the fault current exceeds the nominal current value of the differential, it will intervene by protecting the user from the contact voltage before it becomes dangerous (>50V).

S TN SYSTEMS

In TN systems, the standard requires the measurement of the impedance of the fault loop and the verification of the tripping characteristic of the associated protection device (circuit breaker, fuse, RCD). In this type of system, the grounds are connected via the protective conductor to the neutral in the cabin. Once the impedance value of the fault circuit has been obtained and the nominal voltage of the phase and earth system is known, the minimum presumed fault current must be calculated and compared with the characteristic of the protection used in the system, in order to verify its compliance with the tripping times required by table 41A.



$$Z_S \cdot I_a \leq U_0$$

$$Z_S = Z_L + Z_{PE} + Z_{TR}$$

Fault loop impedance

I_a = Current that causes circuit breaker tripping within:

5 s	distribution circuits
0.4 s	terminal circuits (ordinary settings)
0.2 s	terminal circuits (special settings)

Z_S = Fault loop impedance

Z_L = Phase conductor impedance

Z_{PE} = Earth conductor impedance

Z_{TR} = Transformer secondary impedance

Why is it important to carry it out?

Let us take as an example an operator within an industry who is working on a production machine. The current generated between the ground and the point of fault must be sufficient to trigger the circuit breaker or fuse protection according to the values prescribed by table 41A of the standard below. This will ensure that the operator is protected from exposure to a potential hazard in the event of a fault.

Table 41A - Maximum interruption times for TN systems

System	50 V < U_0 ≤ 120 V [s]		120 V < U_0 ≤ 230 V [s]		230 V < U_0 ≤ 400 V [s]		U_0 > 400 V [s]	
	AC	DC	AC	DC	AC	DC	AC	DC
TN	0.8	Note 3	0.4	5	0.2	0.4	0.1	0.1

U_0 is the voltage rating to ground in AC or DC.

Note 1: For voltages that are within the tolerance band specified in the IEC 8-6 standard, the interruption times corresponding to the nominal voltage apply.
Note 2: For intermediate voltage values, the next higher value from Table 41A is chosen.
Note 3: Interruption may be required for reasons other than those related to protection against electrical contacts.
Note 4: When the requirement of this article is met by the use of differential current protection devices, the cut-off times in this Table refer to residual current currents that are presumed to be significantly higher than the residual current rating of the RCD (typically 5 I_{dn}).

S IT SYSTEMS

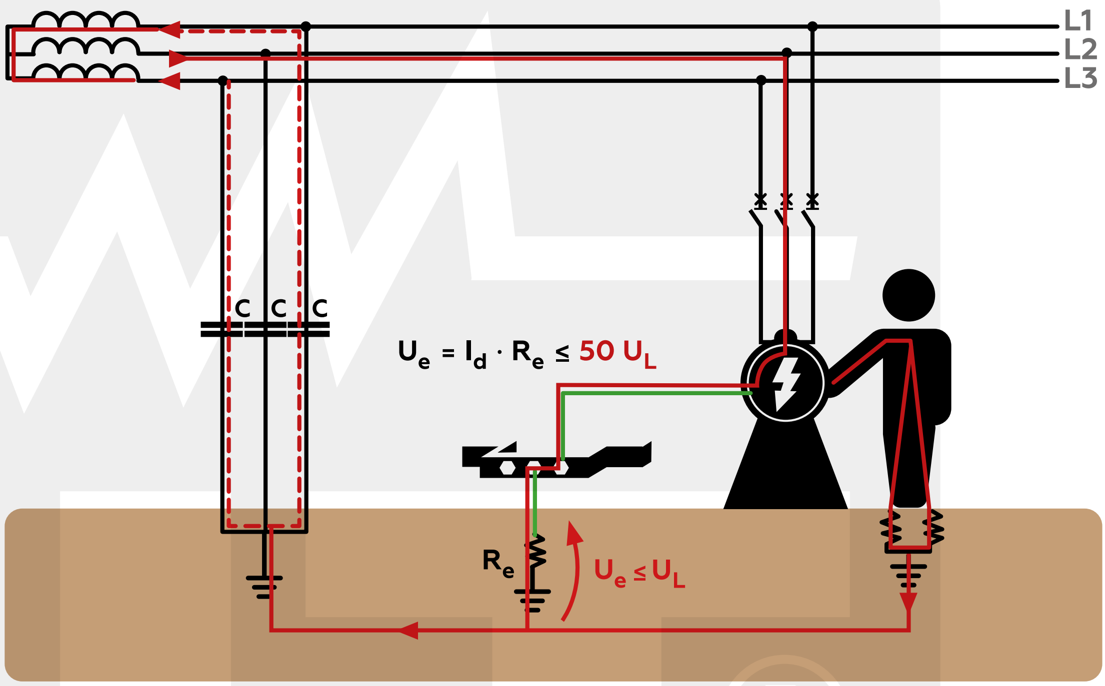
In IT systems where continuity of service is required, such as in a hospital environment, the standard does not require the automatic disconnection of the circuit in the event of a first fault as long as the contact voltage remains within 50VAC (25V local group 2). This condition can be verified by measuring the first fault current Id between a line conductor and a ground. The first fault current will close through the parasitic capacitances of the two phases not involved in the system fault. It is mandatory that IT systems are equipped with an insulation controller in order to constantly monitor the value of the insulation resistance Rf.
There are two measurements to be carried out: verification of the first fault current Id and measurement of the earth resistance Re (voltamperometric method). The condition for which the value of the contact voltage (i.e., the product between the earth resistance and the first fault current) is less than 50Vac must be verified.

U_e = Contact voltage

I_d = First fault current

R_e = Earth resistance

U_L = Contact voltage limit



Why is it important to carry it out?
In IT systems, in the event of a first ground fault, the insulation controller will signal the presence of the fault by continuously monitoring the fault resistance value Rf which must not fall below the threshold of 50kΩ (in accordance with its product standard IEC61557-8). For this reason, it is very important to verify both the correct sizing of the earth resistance and the operation of the insulation controller: the insulation controller will signal (visually and/or acoustically) the presence of low insulation, but the circulation of fault current will be very low (typically the earth resistance in IT systems is in the order of a few hundred Ohms) and will not require the automatic disconnection of the power supply, ensuring continuity of service.

R Earth resistance with the voltamperometric method

This measurement is necessary to know the value of the earth resistance and determine the contact voltage of a system, in order to verify the coordination of the protections in the event of a ground fault.
In IT systems, this measurement is used to identify the resistance value of the earth rod, and together with the fault current measurement, to determine whether in the event of a first fault the contact voltage will remain such that there is no danger to users, thus ensuring continuity of service.
In TT systems, particularly in urban contexts where it is difficult to practice this test mode, the standard allows the verification of earth resistance with the fault loop method.
Finally, in TN systems in which the user is also the owner of the transformer substation, this measurement is necessary to verify whether the resistance value detected, as a function of the fault current and the time to eliminate the fault declared by the Distributor, guarantees in the event of a ground fault, a contact voltage within the limits defined by IEC EN 50222 (IEC 99-3), this avoids the need for pitch and contact measurements.

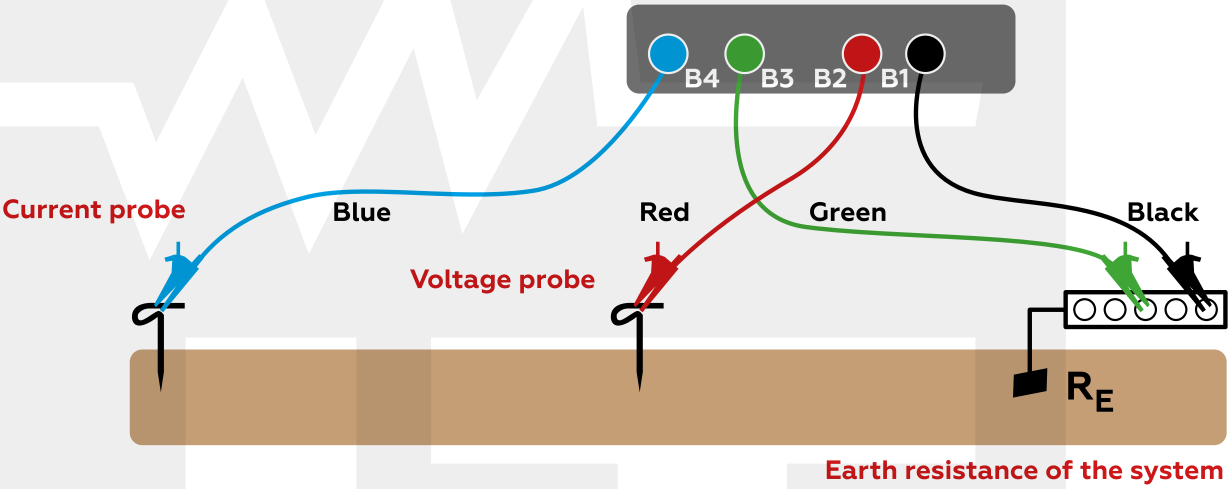


Fig. 28: Measurement of the 3-wire earth resistance

R Earth resistance of the individual earth rods

In ring earth networks composed of several earth rods (minimum two), if the latter are accessible, it is possible to carry out the measurement on the individual earth rods by means of a double toroid clamp, capable of inducing a potential in the ring and reading the circulating current, thus obtaining the resistance of the single earth rod in the hypothesis that the mutual influence is negligible, i.e., with the individual earth rods placed at a sufficient distance from each other, so that they do not influence one another during the measurement.

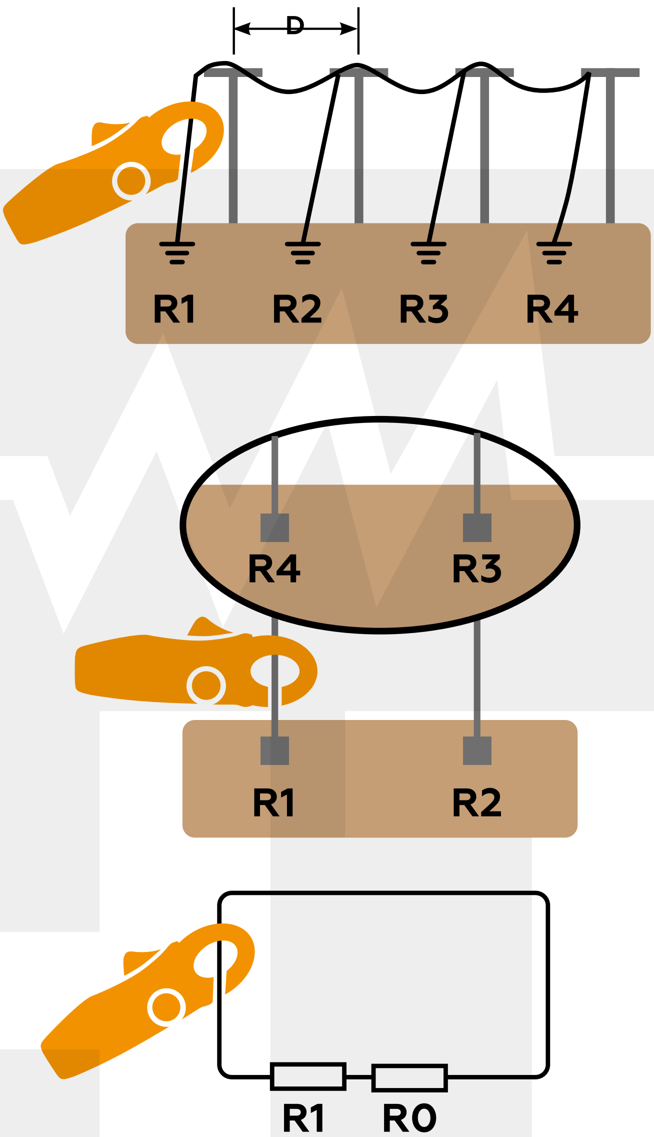
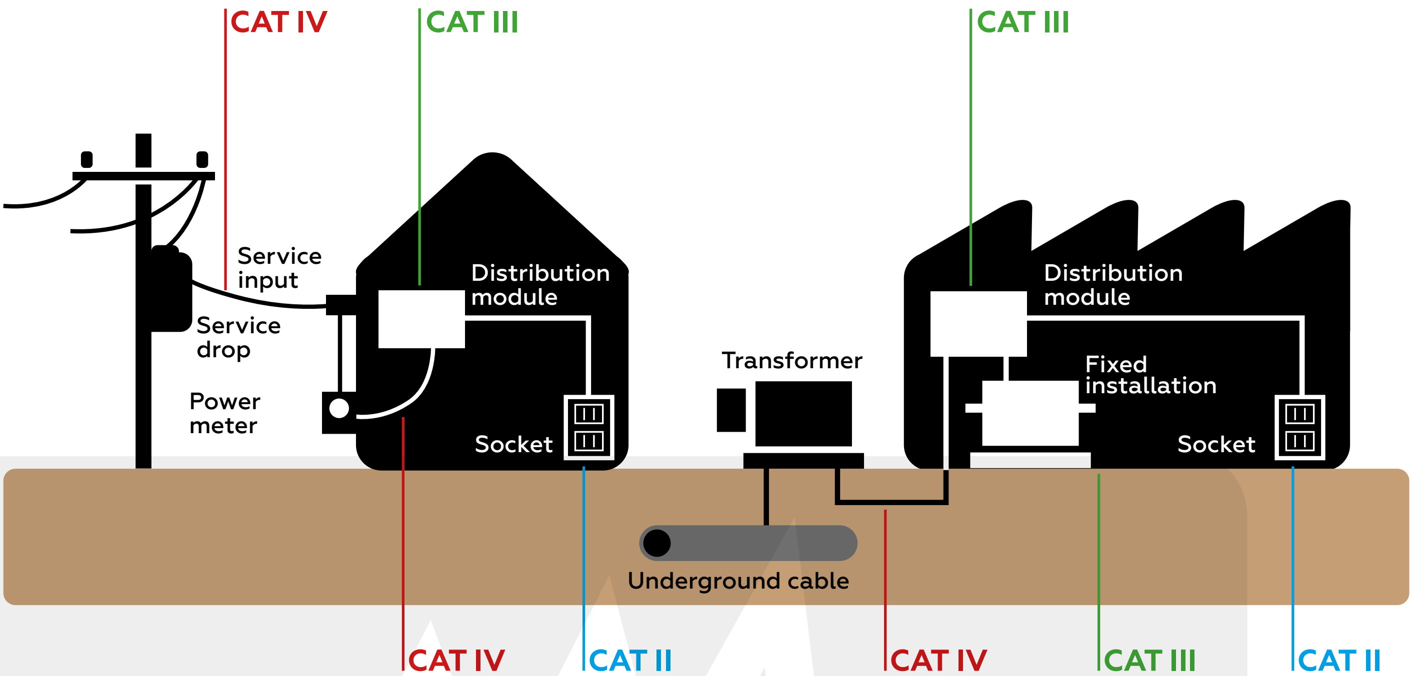


Fig. 9: Connection of the instrument to a multi-earth rod system.

Why is it important to carry it out?

Because in the event of a fault to ground, the correct sizing of the earth resistance of a system guarantees the correct intervention of the protections against indirect contacts, avoiding the risk of electrocution.

R Overvoltage category



The standard "IEC EN 60664-1: Insulation coordination for equipment within low-voltage supply systems. Part 1 - Principles, requirements and tests" in paragraph 4.3.2 "Equipment energised directly from the mains supply" reads:

Circuits are divided into the following measurement categories:

- **Measurement category IV** is for measurements performed at the source of the low-voltage installation. Examples are electricity meters and measurements on primary overcurrent protection devices and ripple control units.

- **Measurement category III** is for measurements performed in installations within buildings. Examples are measurements on distribution modules, circuit breakers, wiring, including cables, bus-bars, junction boxes, switches, socket-outlets in the fixed installation, and equipment for industrial use and some other equipment, for example, stationary motors with permanent connection to a fixed installation.

- **Measurement category II** is for measurements performed on circuits directly connected to the low voltage installation. Examples are measurements on household appliances, portable tools and similar equipment.

- **Measurement category I** is for measurements performed on circuits not directly connected to the MAINS.

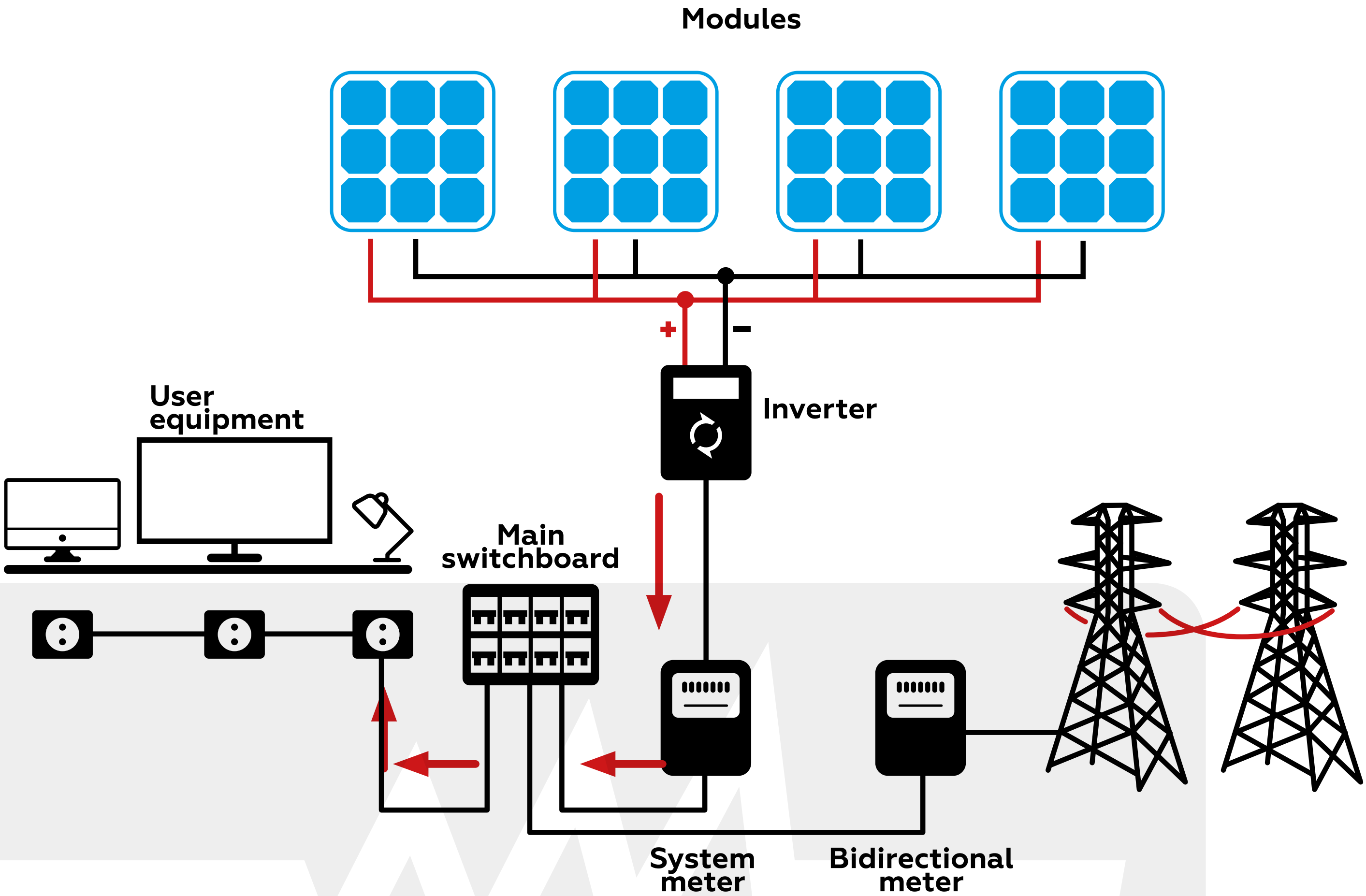
F Photovoltaic

The reference guide in Italy for the design, construction and management of photovoltaic generation systems is IEC 82-25 part 1, which in its latest edition (2022-08), no longer indicates any checking and control methods, recalling only what is prescribed by the IEC EN 62446-1 standard (Documentation, commissioning and periodic checks of photovoltaic systems).
In turn, IEC EN 62446-1 does not impose a periodicity of tests and distinguishes between two test categories: category 1 (basic tests) and category 2 (in-depth tests). The level of checking is not mandatory and it is generally at the discretion of the client which category to request from the technician.

Category 1 AC side IEC 64-8/6 ((the standard refers to the tests of IEC 64-8/6):
1. Continuity of earthing conductors and/or equipotential connection if present
2. Measurement of the insulation resistance to earth of active conductors
3. If TT system, check RCD and earth resistance
4. If TN system, fault loop impedance
5. If IT system, measure the first fault current and the earth resistance

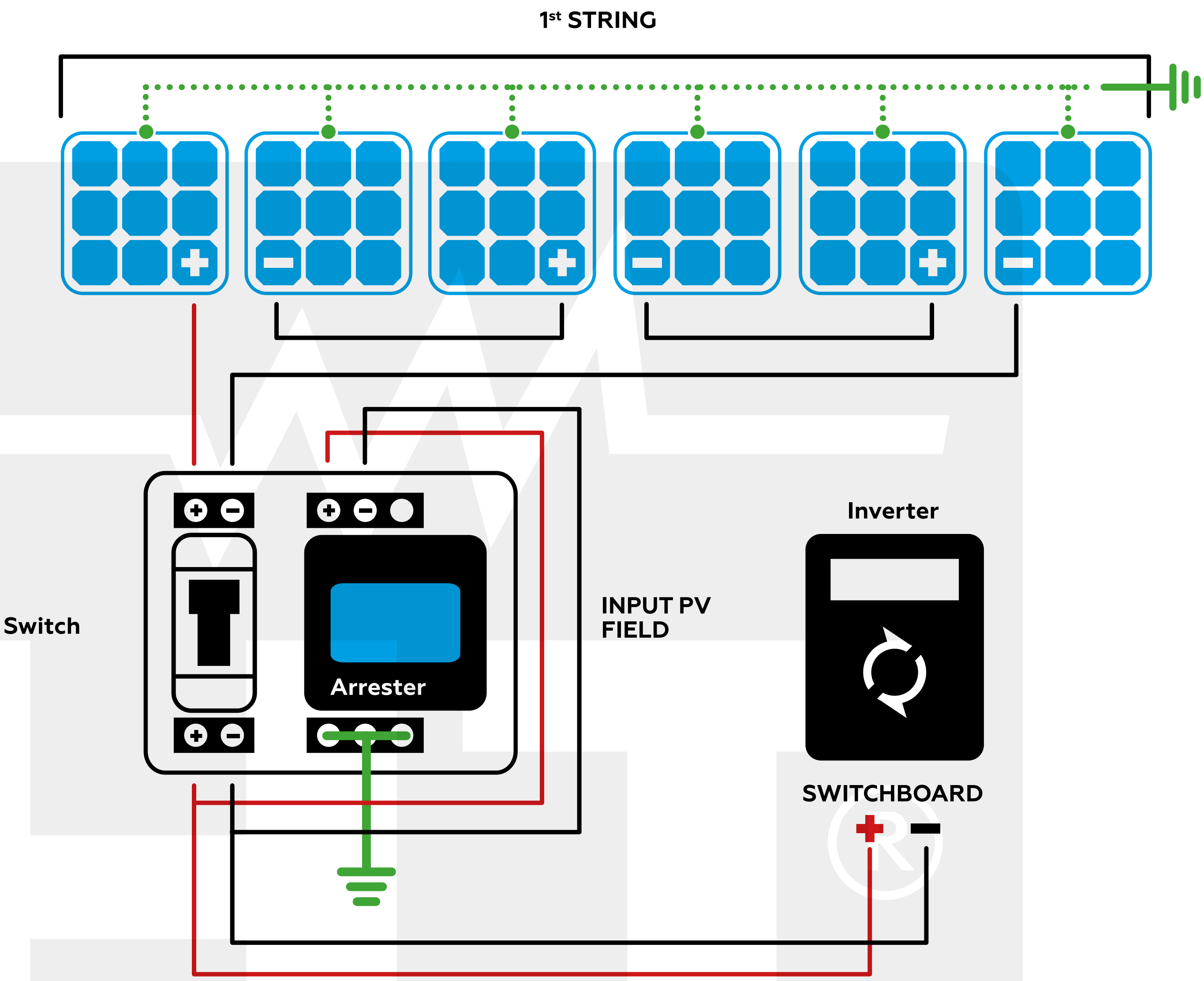
Category 1 DC side:
1. Continuity of earthing conductors and/or equipotential connection if present
2. Polarity test
3. Measurement of the open circuit voltage Voc
4. Measurement of short-circuit or Isc operating current
5. Functional test (measurement of string current using an amperometric clamp)
6. Measurement of the insulation resistance of DC circuits

Category 2:
In addition to the Category 1 checks to be carried out, the following is envisaged:
1. Measurement of the I-V curve
2. Thermographic survey


Modules
+
−
Inverter
User equipment
Main switchboard
System meter
Bidirectional meter

F Photovoltaic systems: continuity of protective conductors in DC circuits (category 1)

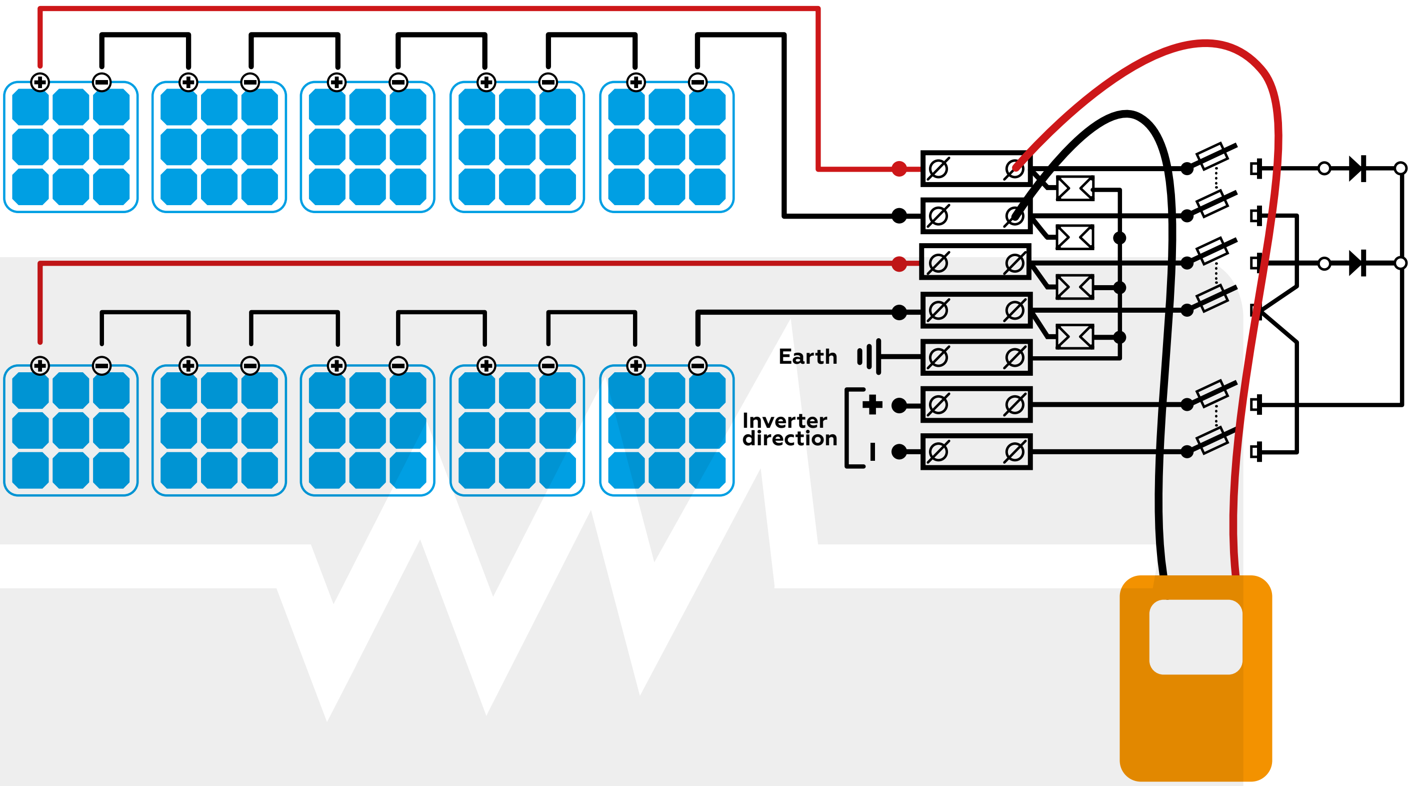
If there are grounding conductors and/or equipotential connection (e.g., equipotential connections of the row of modules) on the DC side on all those conductors and, if possible, also toward the main earth collector, electrical continuity should be checked. The standard only requires the use of instrumentation compliant with IEC 61557-1, -4, therefore with a test current >200mA.



Why is it important to carry it out?
The verification of the ground connection of the module structures or of the modules themselves (if provided), suitably assisted by the installation of SPDs on the DC side, guarantees protection in the event of atmospheric discharges as well as the correct operation of the insulation controller generally installed on the inverter.

F Polarity test (category 1)

The polarity in all DC cables must be checked using a suitable measuring instrument. The purpose is to verify the correct identification of the cables and the correct connection to the system devices and junction panels (verification of the correct connection of the strings).



Why is it important to carry it out?
The check of the polarity of the strings is essential to ensure both the correct operation of the system and to avoid, for example, through the inversion of a string, the sum of two string voltages.

F Photovoltaic system: Open circuit voltage Voc (category 1)

The open circuit voltage of a string must be measured with a suitable measuring instrument before closing any circuit breakers or circuits. The purpose of this measurement is to verify the correct number of modules within the string and consequently the correct open circuit voltage value of the module or series.

In conditions of stable irradiation, the standard suggests as a preferable verification method, the verification of the voltage of a single module (from a data sheet or alternatively by measurement) by multiplying it by the number of modules that make up the string in order to obtain the expected string voltage. At this point, the string voltage is measured and should generally not deviate by more than 5% from the calculated value.

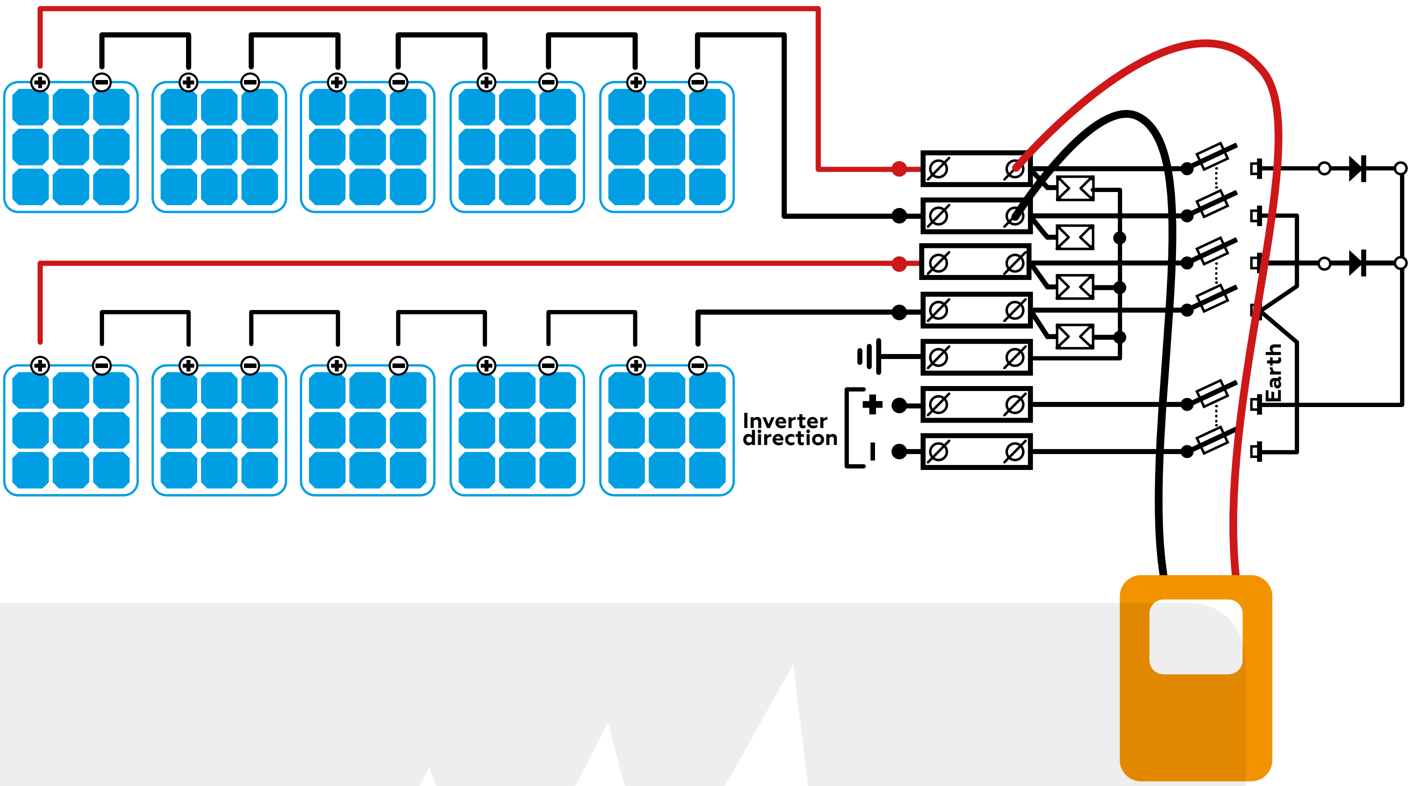
In the case of systems with several identical strings and in stable irradiation conditions, the voltages between the strings can be compared, always taking as a reference a maximum deviation of 5% between the voltage of the various strings.

In the case of unstable irradiation, the standard indicates that one can proceed in one of the following ways:

1) the check is postponed; (economically unprofitable)

2) the check is carried out using several voltmeters with similar characteristics while keeping one voltmeter on a reference string; more people are needed to do a "simple" job, which is economically unprofitable)

3) the check is carried out by measuring the open circuit string voltages and correcting them with the measured values of solar irradiance on the plane of the modules (most appropriate mode).



Why is it important to carry it out?

The verification of the open circuit voltage makes it possible to verify, before commissioning the system, that the voltage of a string is equal to what was expected or to the sum of the nominal voltages of the modules, allowing any connection errors to be quickly identified.

F Photovoltaic system: Measurement of the short circuit current ISC (category 1)

The realisation and interruption of the string short-circuit current is a potentially hazardous test and must be measured with suitable equipment. The short circuit on the string being tested can be obtained by:

Option 1: A temporary short-circuit cable connected to a circuit-breaking or disconnecting device already present in the string circuit.

Option 2: A device or instrument capable of short circuiting the string temporarily introduced into the test circuit.

Option 3: Use of a short-circuit break-off test box, i.e., a proper circuit-breaking device that can be temporarily inserted into the circuit to create a switched short circuit.

NOTE: In any case, this device must be rated higher than the open-circuit voltage and short-circuit current of the string being tested.

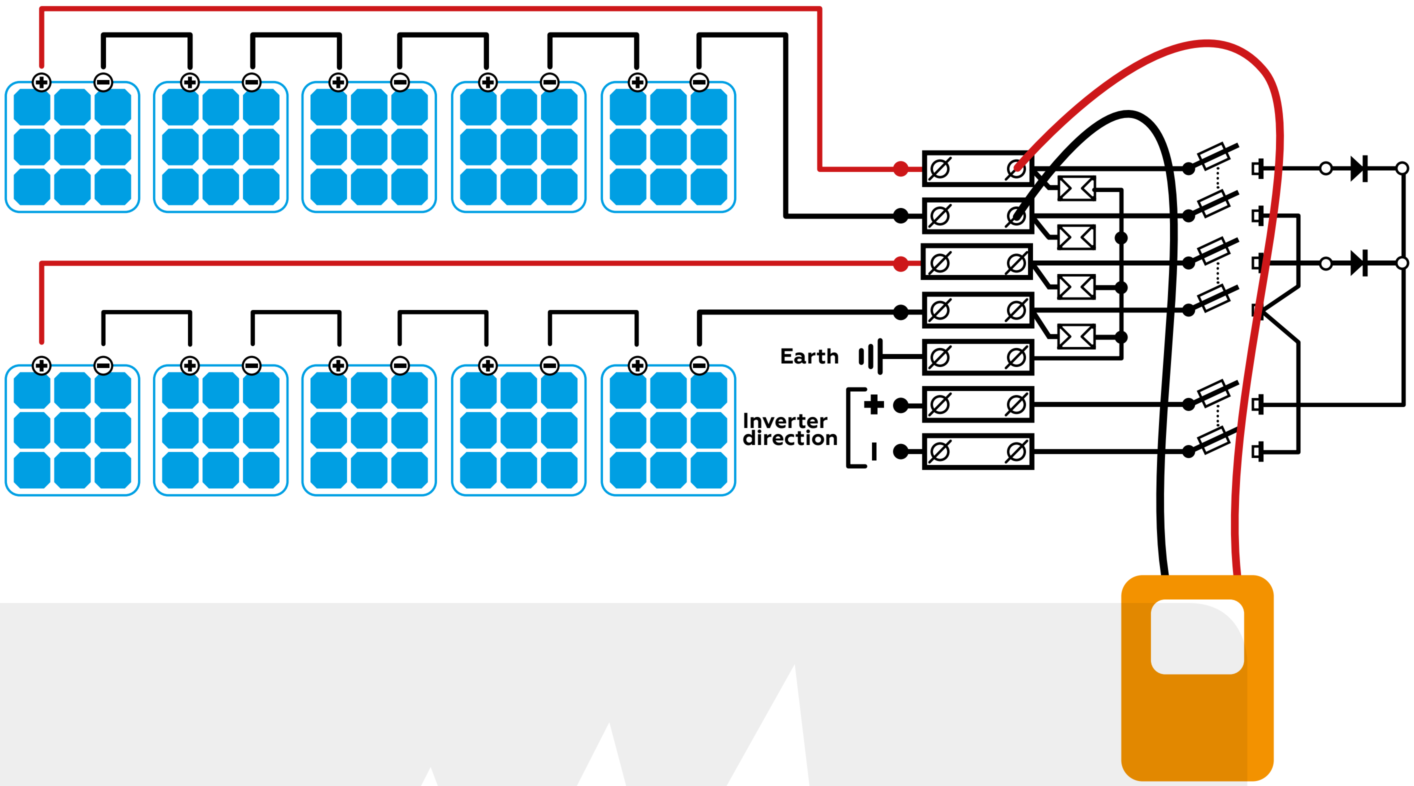
The measured values must be compared with the expected values. In the case of systems with several identical strings and under stable irradiance conditions, the currents between the strings can be compared. The values obtained should be "almost" equal (a typical value declared by the manufacturer is 5% for stable irradiation conditions).

In the case of unstable irradiation, the standard indicates that one can proceed in one of the following ways:

1) the check is postponed; (economically unprofitable)

2) the check is carried out using several amperometers with similar characteristics while keeping one amperometer on a reference string; more people are needed to do a "simple" job(which is economically unprofitable)

3) the check is carried out by measuring the current of the strings and correcting them with the measured values of solar irradiance on the plane of the modules (most appropriate mode).



Why is it important to carry it out?

The verification of the short-circuit current makes it possible to identify the correct connection and operation of the modules, being able to compare the results with what the manufacturer has declared.

F Photovoltaic system: Functional test (category 1)

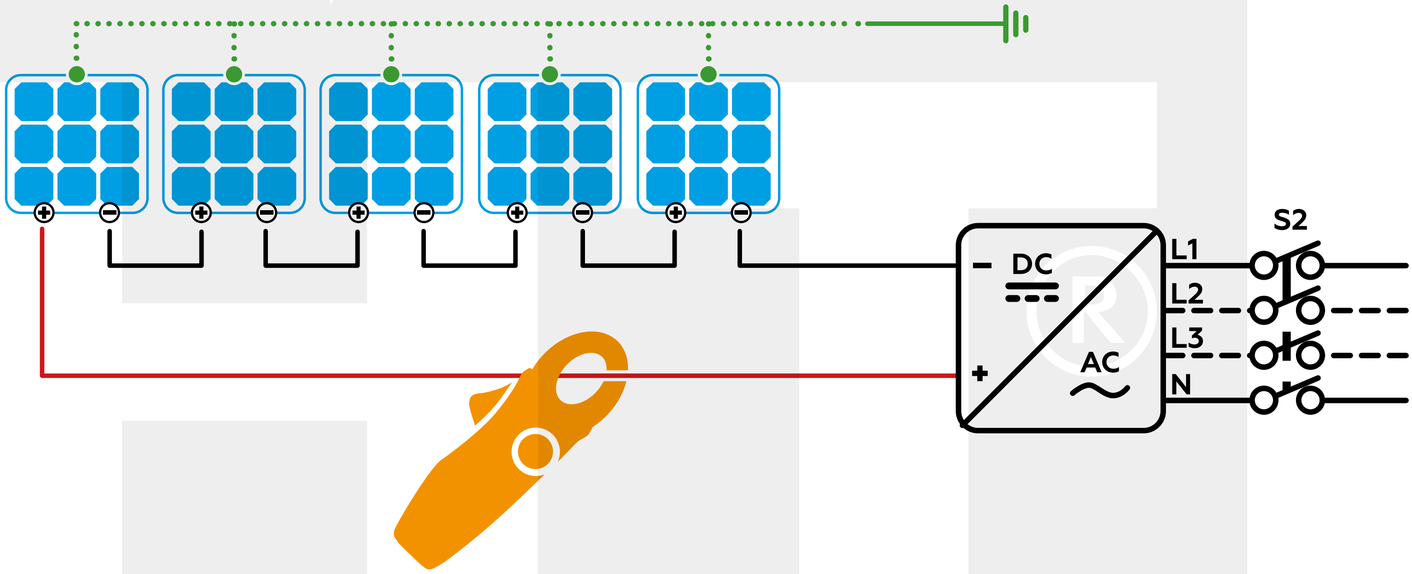
With the system switched and in the normal mode of operation (tracking the point of maximum power by the inverters) the current from each string of modules must be measured using an amperometric clamp, placed around the string cable.
In the case of systems with several identical strings and under stable irradiance conditions, the currents between the strings can be compared. The values obtained should be “almost” equal (a typical value declared by the manufacturer is 5% for stable irradiation conditions).
In the case of unstable irradiation, the standard indicates that one of the following methods can be carried out:
In the case of **unstable irradiation**, the standard indicates that one can proceed in one of the following ways:

1) the check is postponed (economically unprofitable)

2) the check is carried out using several amperometers with similar characteristics while keeping one amperometer on a reference string; (more people are needed to do a “simple” job, which is economically unprofitable)

3) the check is carried out by measuring the current of the strings and correcting them with the measured values of solar irradiance on the plane of the modules (correct)

4) A test of the I-V curve can be carried out (correct).



Why is it important to carry it out?
The functional tests make it possible to verify whether the MPPT current is in line with what the manufacturer has declared.

F Photovoltaic system: testing of the insulation resistance of a string of PV modules (category 1)

DC circuits of PV module strings are active during the day and, unlike a conventional AC circuit, cannot be disconnected prior to this test.

The standard allows two test modes:

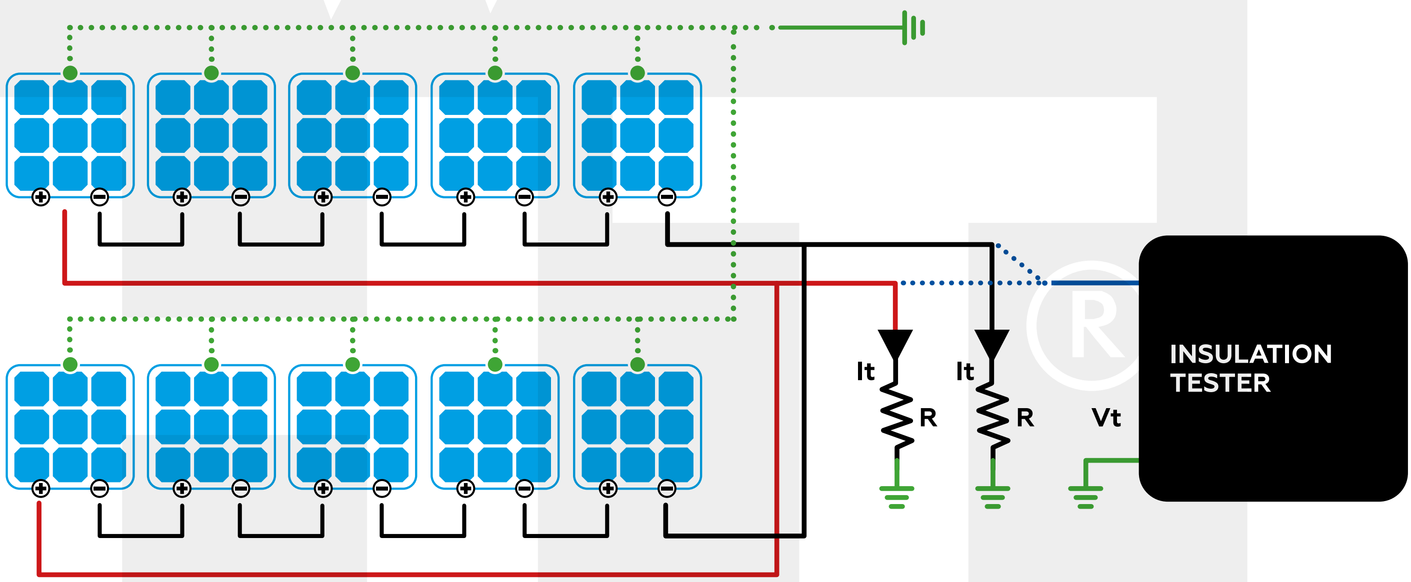
METHOD 1 - Test between the negative pole of the row of modules and the earth followed by a test between the positive pole of the row of modules and the earth.

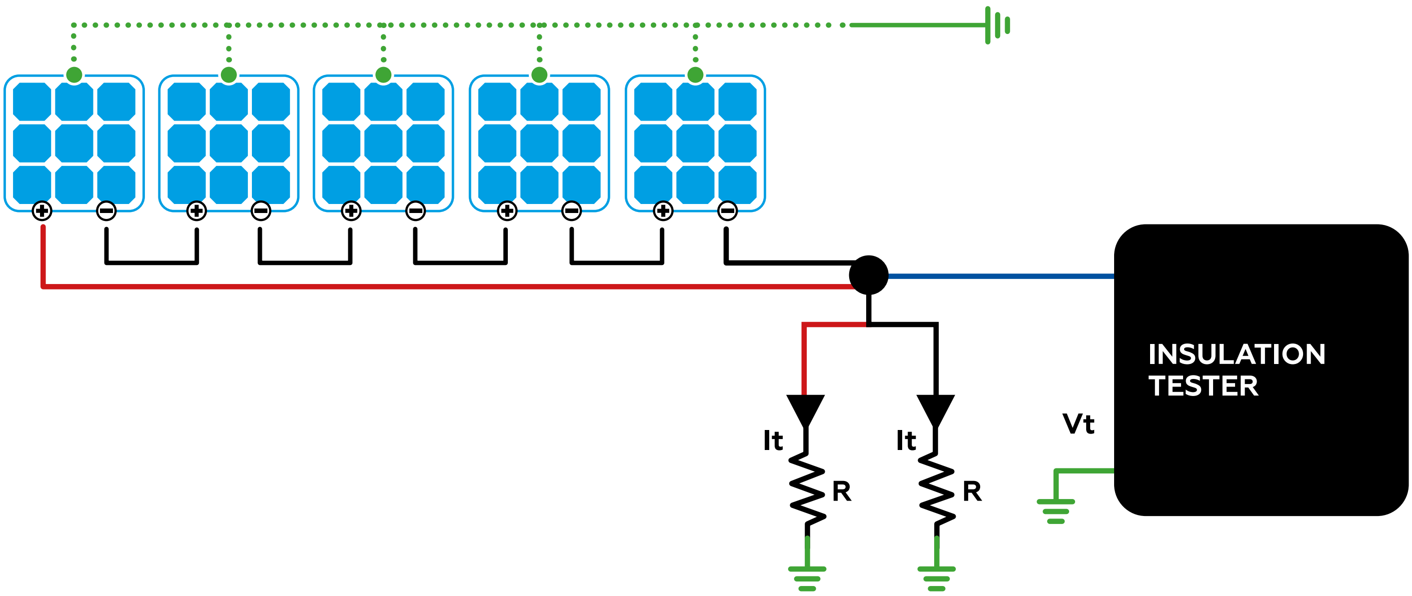
METHOD 2 - Test between the earth and the positive and negative poles of the fault of short-circuited modules.

Voltage of the system (V_{oc} (stc) x 1.25) V	Test voltage V	Minimum insulation resistance MΩ
< 120	250	0.5
from 120 to 500	500	1
> 500	1000	1

Table of allowed minimum values

Measurements must be made in DC using suitable test instruments (IEC61557-1, -2) capable of providing the expected voltages with a current rating of 1mA.





Why is it important to carry it out?
Insulation tests allow one to correctly identify the presence of a problem on one or more modules or connections (especially in particular environmental conditions such as humidity). In this case, poor insulation almost always coincides with a system shutdown, as inverters typically stop due to poor insulation for values below 200k Ohms. Proper isolation diagnostics therefore allow one to minimise system downtime.

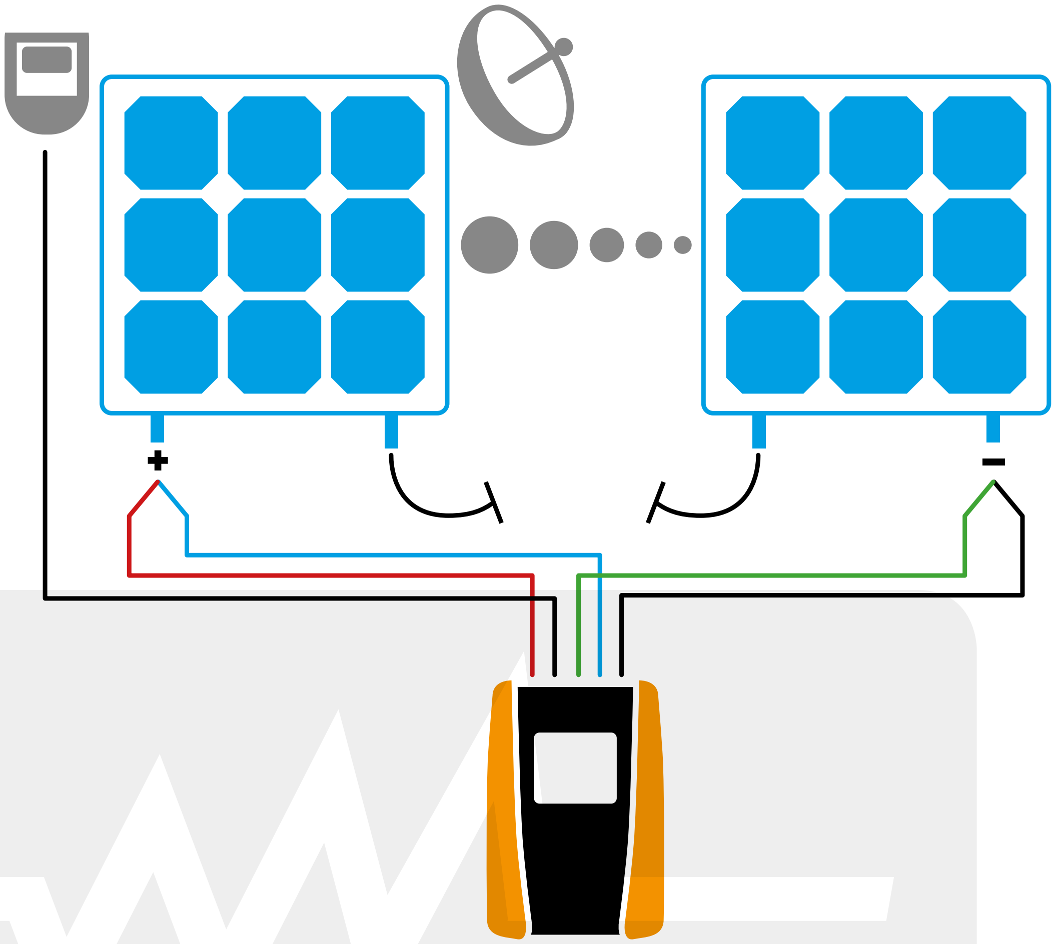
F Photovoltaic system: measurement of the I-V curve (category 2)

During the life of the system, it can happen that some cells have a fault, compromising the performance of the module and, consequently, of the entire string. It should be remembered that the operating curve of the string is determined by the curve of the worst of the modules that make up the string itself. Any damaged cells further reduce the performance of the module and string, increasing mismatching losses.

Each PV module is subject to an inexorable deterioration in performance (typically guaranteed by the manufacturer within 10..20% out of 15.. 20 years).

It is therefore advisable to periodically check that the aforementioned "guarantee" is respected and it is therefore advisable to periodically check the efficiency of the PV modules of the system in order to immediately identify situations of distress.
With the I-V feature of the module, the manufacturer provides a real identity card of the module (providing information related to short-circuit current, open circuit voltage and power generation). It is therefore sufficient to measure the I-V characteristic of the installed modules and compare what has been obtained with the characteristic declared by the manufacturer.

What does the standard say?
IEC 62446 provides for some precautions necessary for the correct detection of the I-V curve:
• Irradiance on the plane of the modules at least 400W/m2 (preferably >600-700 W/m2).
• Measurements carried out in incident radiation conditions orthogonal (as much as possible) with respect to the plane of the modules.
• String being tested sectioned and connected to the I-V curve test device.
• Test instrument suitably programmed with the characteristics of the modules declared by the manufacturer.
• Irradiance meter associated with the I-V curve instrument mounted in the same plane as the modules and having the same technology as the row of modules being tested or adequately corrected for technology differences.
• Instrument that calculates temperature corrections (recommended) or alternatively if one uses a thermal probe for the cell, it should be attached to the rear of the module and to the centre of a cell that is in turn in the centre of the module.



At the end of the test, the maximum value of the measured power must be compared with the nominal value (on the data plate) of the row of modules being tested. The measured value should be within the tolerance values indicated for the power of the modules being tested (together with a tolerance for the accuracy of the I-V curve test of the equipment). For systems with multiple identical strings and where stable irradiance conditions exist, the curves of the individual (overlapping) strings must be compared. The curves should be equal (typically within 5% for stable irradiance conditions).
Manufacturers normally declare values at STC i.e., 1000W/m2, 25°C, AM 1.5, which are difficult to reproduce in the field. It is therefore essential that the instrument is able to translate the conditions detected in the OPC field to the STC conditions. The IEC/EN60891 standard describes, by means of appropriate equations, the procedure for transferring data from OPC to STC.

Why is it important to carry it out?
The I-V curve check makes it possible, in the event of poor performance of a system, to verify if one or more modules of the same are affected by problems and/or excessive deterioration compared to what is declared by the manufacturer, and in this case to be able to intervene promptly by replacing the damaged parts of the system.

F Photovoltaic systems: thermographic checks (category 2)

The purpose of thermographic measurements is to detect unusual temperature changes in the operation of PV modules in the field. Thermal imaging can be used to identify problems within modules and/or the row of modules, such as reverse-biased cells, branch diode faults, welding faults, weak connections, and other conditions that lead to localised high-temperature operation.

OPERATING INSTRUCTIONS

- String of modules in normal operating mode (inverter maximum power point tracker).
- Irradiance on the plane of the row greater than 400 W/m², preferably > 600 W/m² to ensure that there is sufficient current and to bring out temperature differences.
- Stable sky conditions.
- Depending on the construction/configuration of the module mounting, check which side of the module is most significant for the purpose of measurement (normally the glass front, as glass has a higher thermal conductivity which makes temperature variations more evident).
- Pay special attention to blocking diodes, junction boxes, electrical connections, or any specifically identified problem of the row of modules that shows a visible temperature difference from the immediate surrounding area.
- Be careful not to cast shadows on the area under examination.

RESULTS

The temperature difference between the localised overheat point and that of the normally operating module row is critical. It investigates thermal anomalies through visual examinations or electrical tests (e.g., measurement of the I-V curve).

Why is it important to carry it out?

Thermographic checks allow us to have a first wake-up call regarding the problems of the photovoltaic modules. In case of thermal discrepancies on the surface of the modules, it is possible to intervene directly on the string/module involved by performing specific electrical tests aimed at identifying the problem with certainty.

Q Switchboards and machines

Standard 61439 consists of 8 parts as follows:

61439-0: It is a guide on how to draw up the switchboard specification

61439-1: It includes all the general rules that apply to all switchboards

61439-2: Power switchgear

61439-3: Distribution panels accessible to untrained people

61439-4: Construction site switchboards

61439-5: Public network distribution panels

61439-6: Bus-bar systems

61439-7: Switchboards for specific applications

The instrumental checks to be performed are detailed in part 1 of the standard.

IEC EN 61439-1 must always be applied in conjunction with the product-specific standard.
Example of Product-specific standards cited:
• IEC EN 61439; -2; -3; -4; -5; -6
• IEC EN 60204-1
The plate/declaration of the switchboard must read: "Conforms to IEC 61439-1 and IEC61439-x" (the first part may be implied).

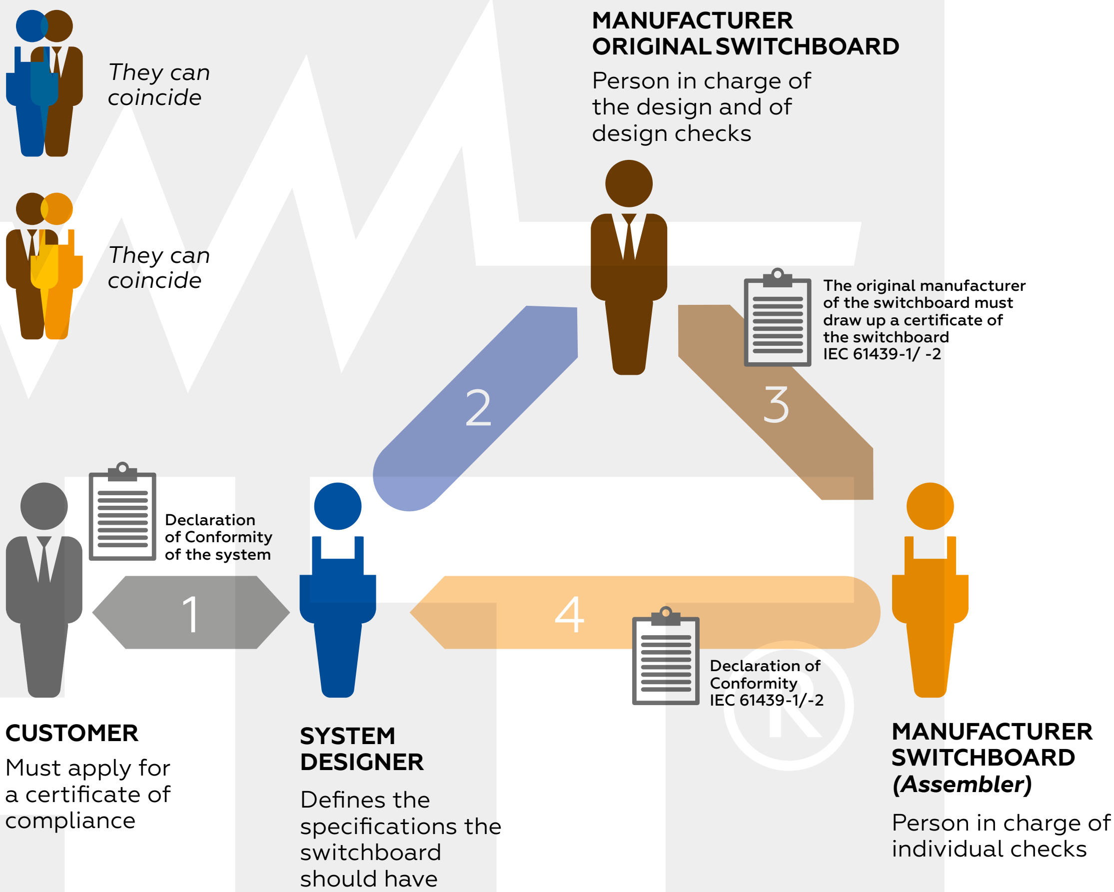
Field of application:
The standard applies to SWITCHBOARDS:
- designed, built and checked in a single exemplar
- completely standardised and built in serial production

Definition of switchboard (Art. 3.1.3 IEC EN 61439-1)
Combination of one or more low-voltage protection and switchgear devices, with any control, measurement, signalling, protection and regulation devices with all internal electrical and mechanical interconnections, including structural support elements.
The standard considers a switchboard as a standard component of the system such as a switch or socket, even if it consists of the assembly of several devices and must therefore comply with the respective product standard.

Responsibility for the original switchboard manufacturer and assembler:
Given that the two figures (very often) can coincide, individual responsibilities are distinguished as follows:

Person in charge of the design
• designing the desired switchboard/line of switchboards;
• checking "some" prototypes of that switchboard/line of switchboards to demonstrate compliance with the mandatory requirements of the Standard;
• possibly deriving from the tests other outfittings through calculation or further evaluations or measurements and add further outfittings obtained without tests but with "design rules"
• finally, collecting all the above information and disseminating it: either to the original manufacturer of the switchboard so that it can be made, or to the end customer so that it can be used correctly and to carry out suitable checks/maintenance.

IEC EN 61439: OBSERVATIONS



The Assembler will be responsible for:
• (topographical) assembly of the components in accordance with the instructions provided
• carrying out individual checks (testing) on each switchboard made
• certifying the switchboard (issuance of the declaration of conformity).

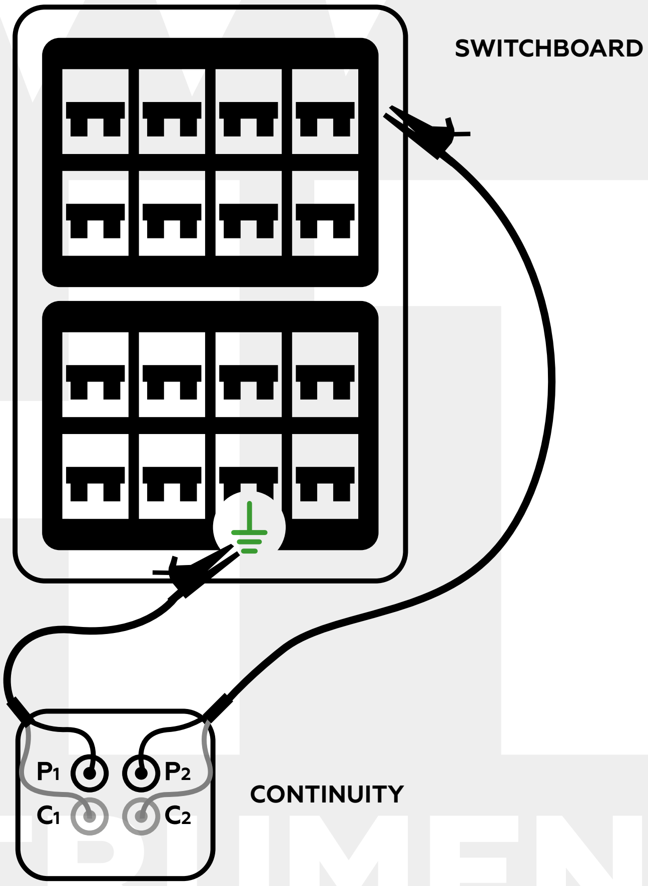
DESIGN CHECKS

The design checks, carried out by the original manufacturer of the switchboard, are aimed at verifying some prototypes of that switchboard/ line of switchboards in order to demonstrate compliance with the mandatory requirements of the Standard; They are also used to collect all the necessary information and disseminate it to the assembler so that he can carry it out, or (in the case of a "custom" switchboard to the end customer so that he can use it correctly and carry out appropriate checks/ maintenance).

To ascertain the conformity of the switchboard, the standard admits 3 equivalent alternatives:
1) checks with test
2) checks with calculations
3) checks with design rules (design deductions, etc.))

For the check with tests, in particular, it is possible to apply checks by electrical instrumentation for the following tests:

Effective continuity of earthing between the grounds of the switchboard and the ground bar.
Check that the different grounds of the switchboard are actually connected to the terminal for the incoming external protective conductor and that the resistance of the circuit does not exceed 0.1 Ohm. The test must be performed using a resistance measuring instrument capable of circulating at least 10 A (AC or DC).



Operating Instructions

- Test all protective and equipotential conductors
- Test time not spec. (typically 2 s)
- It must always be R<0.1 Ohm
- Preferably with a 4-terminal instrument (no need for cable compensation)

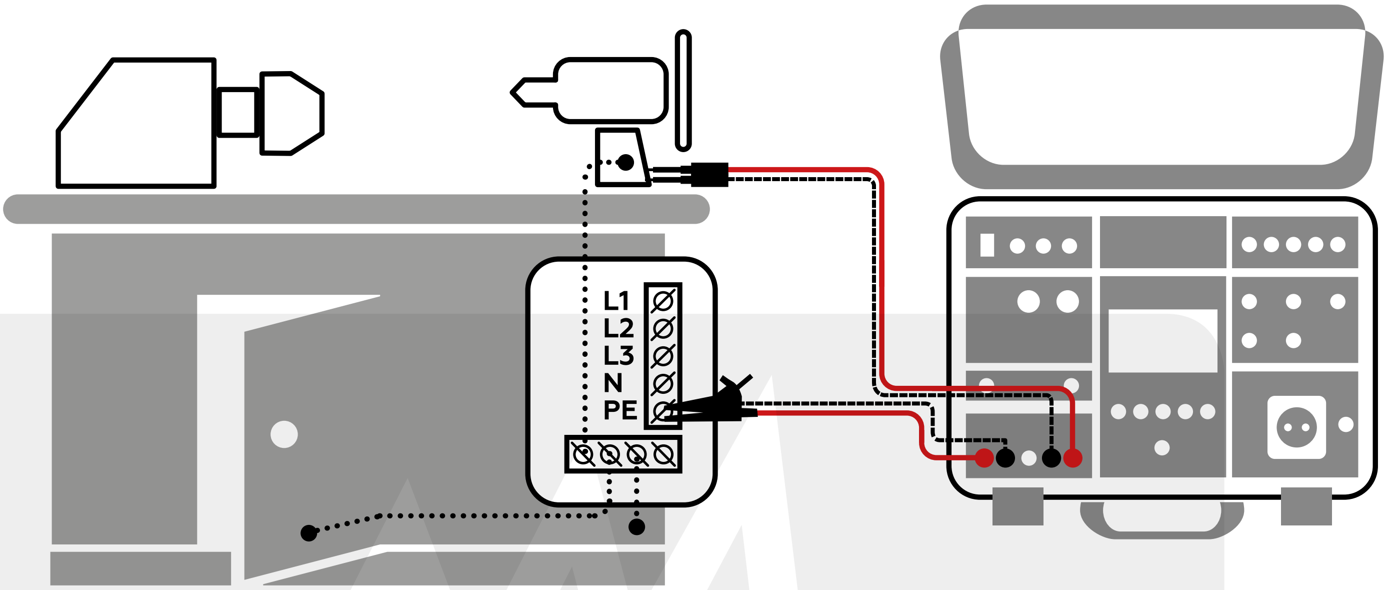


Fig. 27: Connection of the measuring terminals in RPE-4WIRE function.

Why is it important to carry it out?

In the event of a fault with the consequent tensioning of some parts normally out of voltage (e.g. the switchboard door), the continuity tests of the protective conductor allow the protections to be tripped against indirect contacts in the system, avoiding the risk of electrocution.

Withstand voltage at industrial frequency

The instrument used must meet the following requirements:
Source Frequency 50 Hz, Inom 100 mA, Icc 200 mA (IEC 61180-2).

The main, auxiliary, and control circuits, which are connected to the main circuit, shall be subjected to the test voltage in accordance with Table 8.

Auxiliary and control circuits, both AC and DC that are NOT connected to the main circuit, shall be subjected to the test voltage in accordance with Table 9.

Table 8 - Withstand voltage at operating frequency for main circuits		
Nominal voltage of insulation U_i (between the phases in VAC or DC) V	Dielectric test voltage in AC effective value V	Dielectric test voltage [b] in DC V
$U_i \leq 60$	1000	1415
$60 < U_i \leq 300$	1500	2120
$300 < U_i \leq 690$	1890	2670
$690 < U_i \leq 800$	2000	2830
$800 < U_i \leq 1000$	2200	3110
$1000 < U_i \leq 1500$[a]	-	3820

a: Only for DC
b: The test voltages are based on 6.1.3.4.1, fifth paragraph, of IEC 60664-1.

Table 9 - Withstand voltage at operating frequency for auxiliary and control circuits	
Nominal voltage of insulation U_i (between the phases) V	Dialectric test voltage in AC effective value V
$U_i \leq 12$	250
$12 < U_i \leq 60$	500
$60 < U_i$	Please see Tab.8

Operating Instructions:
• All main and auxiliary circuits must be tested
• Voltage generator connected between Earth and active Conductors connected together
• Voltage Ramp 50%... 100% Vtest
• Hold for 60 s

The test is passed if there are no disruptive discharges.

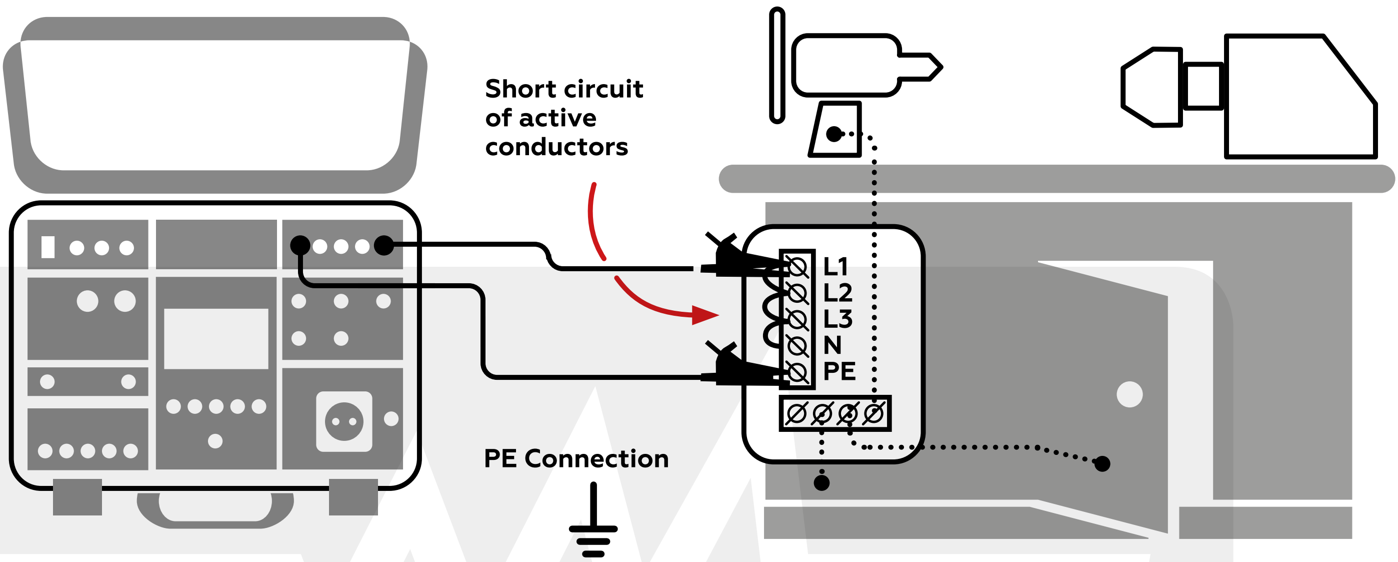


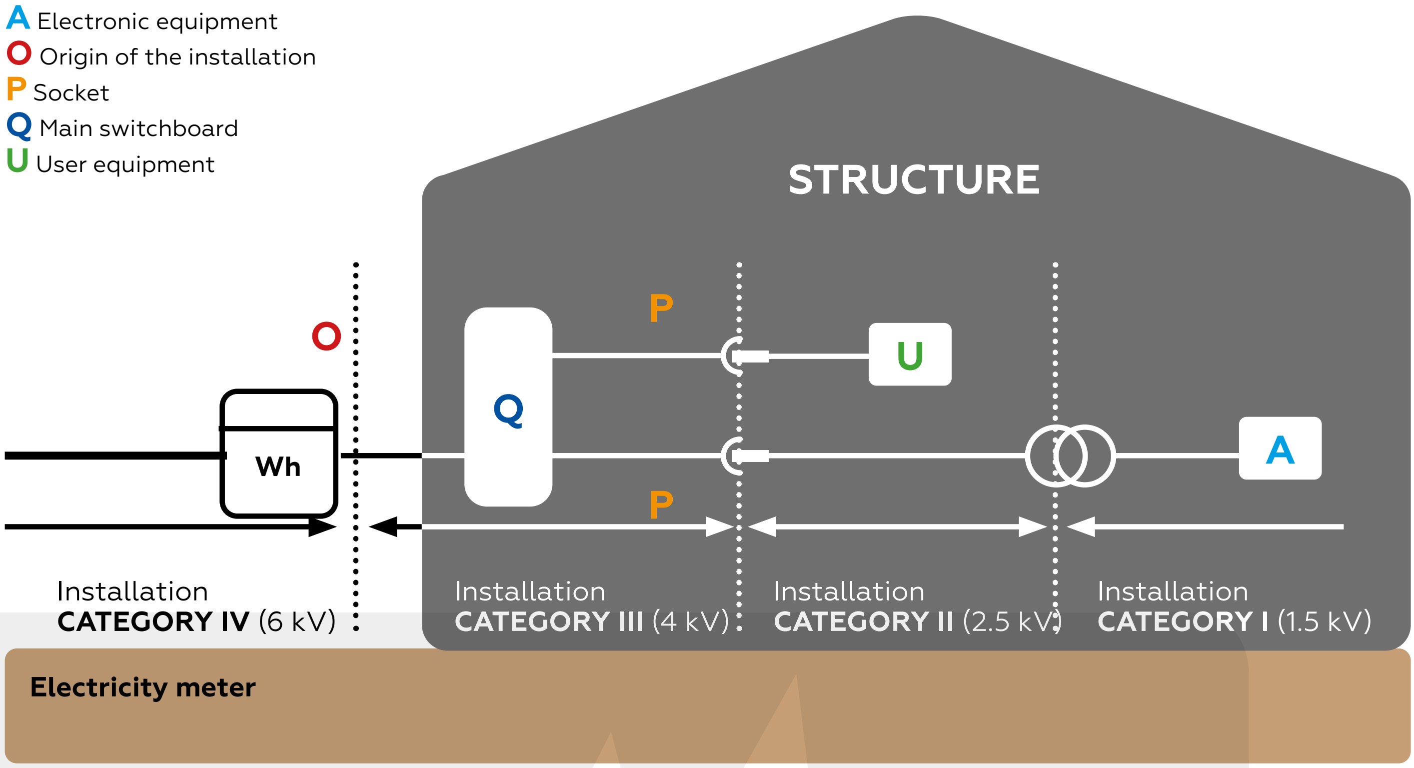
Fig. 39: Connection of terminals for DIELECTRIC measurement.

Why is it important to carry it out?
This test makes it possible to verify that both the power and auxiliary connections are correct with respect to the protective conductor. It also allows one to check the correct insulation of all the components of the switchboard according to the voltage toward earth of the switchboard.

TEST OF IMPULSE WITHSTAND

In place of the impulse withstand test, which would require the use of a surge generator capable of generating a series of 5 impulses with reversed polarity equal to 1.2/50us, the original manufacturer may perform, at its discretion, an equivalent AC voltage test. The required characteristics of the instrument (freq, Inom and Icc) are the same as those required in the test of withstand voltage at industrial frequency.

Step:
• Define the overvoltage category in which the switchboard will be installed (see figure 1 below).
• Refer to table G1 and according to the phase/ground voltage of the switchboard and its overvoltage category, identify the value of the impulse voltage.
• Then check Table 10 for the corresponding AC voltage value to be applied during the test.



The main, auxiliary and control circuits, which are connected to the main circuit, shall be subjected to the test voltage in accordance with Annex G and Table 10 of the standard.

Table G.1 - Correspondence between the nominal voltage of the power supply system and the nominal impulse withstand voltage of the equipment

Maximum value of operational nominal voltage toward earth in AC effective value or in DC V	Nominal voltage of the power supply system (≤ of the nominal insulating voltage of the equipment) V				Preferential values of the nominal impulse withstand voltage (1.2/50 µs) at 2000m kV			
					Overvoltage category			
					IV	III	II	I
	AC eff. value	AC eff. value	AC eff. value or DC	AC eff. value or DC	Level at the origin of the system (service entry)	Distribution circuits level	Load level (household appliances, equipment)	Particularly protected level
50	-	-	12.5, 24, 25, 30, 42, 48	-	1.5	0.8	0.5	0.33
100	66/115	66	60	-	2.5	1.5	0.8	0.5
150	120/208 127/220	115, 120, 127	110, 120	220-110, 240-120	4	2.5	1.5	0.8
300	220/380 230/400 240/415 260/440 277/480	220, 230 240, 260 270	220	440-220	6	4	2.5	1.5
600	347/600 380/660 400/690 415/720 480/830	347, 380, 400, 415, 440, 480, 500, 577, 600	480	960-480	8	6	4	2.5
1000	-	660, 690, 720, 830, 1000	1000	-	12	8	6	4

Tab. 10 - Impulse withstand voltage										
Impulse with-stand nominal voltage U_{imp} kV	Test voltages and corresponding altitudes during the test									
	$U_{1,2/50}$, AC (peak value) and DC kV					Effective value in AC kV				
	Sea level	200 m	500 m	1000 m	2000m	Sea level	200 m	500 m	1000 m	2000m
2.5	2.95	2.8	2.8	2.7	2.5	2.1	2.0	2.0	1.9	1.8
4.0	4.8	4.8	4.7	4.4	4.0	3.4	3.4	3.3	3.1	2.8
6.0	7.3	7.2	7.0	6.7	6.0	5.1	5.1	5.0	4.7	4.2
8.0	9.8	9.6	9.3	9.0	8.0	6.9	6.8	6.6	6.4	5.7
12.0	14.8	14.5	13.3	13.3	12.0	10.5	10.3	9.9	9.4	8.5

Operating Instructions

- All main and auxiliary circuits must be tested
- No Voltage ramp
- Hold for 5 cycles (100ms at f=50Hz)
- There must be no discharges.

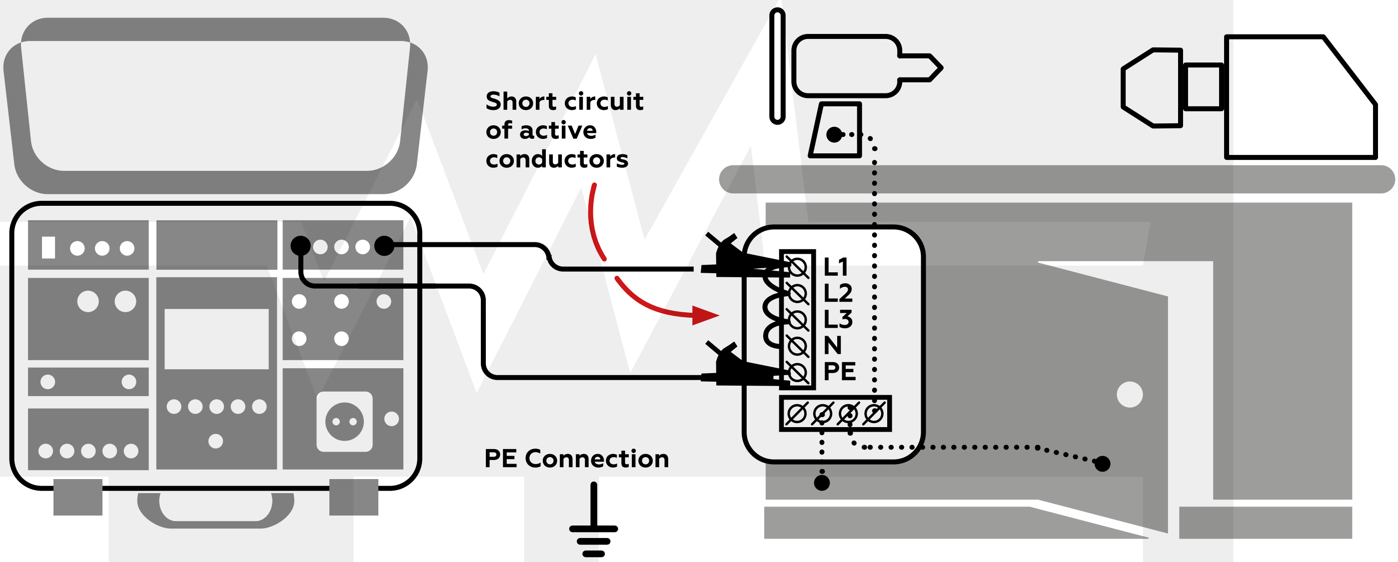


Fig. 39: Connection of terminals for DIELECTRIC measurement.

Why is it important to carry it out?

This test makes it possible to verify that both the power and auxiliary connections are correct. It also allows one to check the correct insulation of all the components of the switchboard according to the overvoltage in which they are installed.

Additional test for casing in insulating material

For casing in insulating material, an additional dielectric test shall be performed by applying the AC test voltage between:
- a sheet of metal placed on the outside of the casing
- the active parts and grounds, located within the SWITCHBOARD.

For this additional test, the test voltage must be equal to 1.5 times the values indicated in Tab. 8.

Nominal voltage of insulation U_i (between the phases in VAC or DC) V	Dielectric test voltage in AC effective value V	Dielectric test voltage [b] in DC V
$U_i \leq 60$	1000	1415
$60 < U_i \leq 300$	1500	2120
$300 < U_i \leq 690$	1890	2670
$690 < U_i \leq 800$	2000	2830
$800 < U_i \leq 1000$	2200	3110
$1000 < U_i \leq 1500^a$	-	3820

a: Only for DC
b: The test voltages are based on 6.1.3.4.1, fifth paragraph, of IEC 60664-1.

If switchboard 230/400 V → Volt. 1890 x 1.5 = 2835 V

Why is it important to carry it out?

This test makes it possible to verify the goodness of the insulation offered by the material used for the casing, ensuring in the event of a ground fault that it cannot induce a dangerous potential.

INDIVIDUAL CHECKS

The purpose of individual checks is to identify defects in materials and workmanship and to ensure that the assembled switchboard is working properly. They are carried out on each SWITCHBOARD, and the SWITCHBOARD MANUFACTURER must determine whether individual checks are carried out during and/or after assembly. Individual checks must confirm that the design checks are properly verified.

Checks Provided for:

- Insulation clearance distances
- Surface insulation distances
- Withstand voltage at operating frequency
- Impulse withstand voltage

CLEARANCE AND SURFACE DISTANCES

The prescribed measures in relation to surface insulation clearance distances must be subject to visual examination.

If it is not sufficient by means of a visual examination, the verification must be carried out:

• with a physical distance measurement

OR

• with an impulse withstand voltage test (or equivalent).

NOTE: the considerations and voltage levels applied in the impulse withstand test apply for design checks (see page 33).

Withstand voltage at industrial frequency

A withstand voltage at operating frequency test must be performed on all circuits, but compared to the design check with a duration reduced to 1 s.

This test should NOT be performed on auxiliary circuits if:

• they are protected by a short-circuit protection device rated <= 16 A

• an electrical function test has already been carried out at the nominal operating voltage for which the auxiliary circuits are designed.

NOTE: The voltage levels applied in the withstand voltage at operating frequency apply.

NOTE: In place of the withstand voltage at operating frequency test, for switchboards with nominal input protection up to 630 A, the insulation resistance test can be performed using an insulation measuring instrument with a voltage of at least 500 V DC. In this case, the test shall be deemed to have been passed if the insulation resistance between the circuits and the grounds is at least 1M Ω for each circuit.

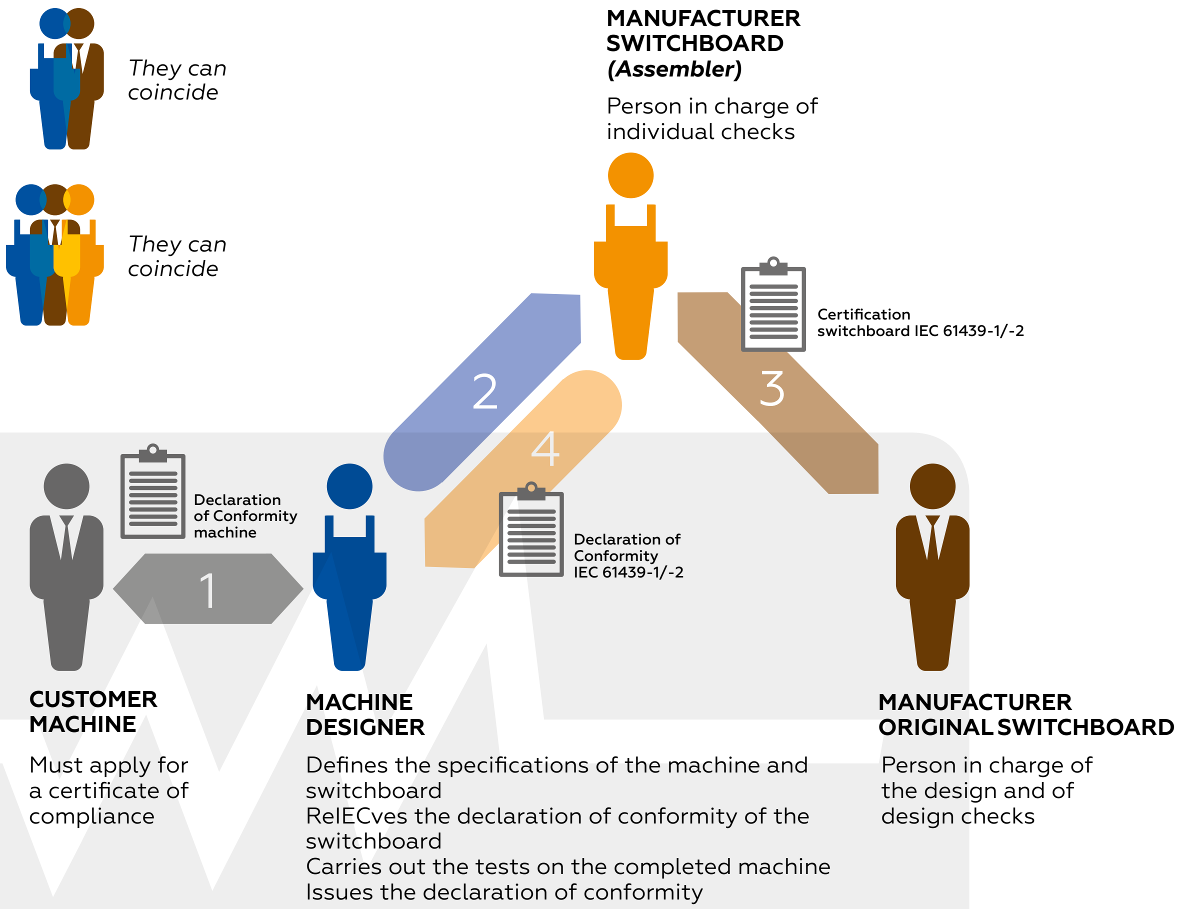
NOTE: check the insulation between short-circuited active conductors and ground (as for design checks).

Impulse withstand voltage
In place of the impulse withstand test, which would require the use of a surge generator capable of generating a series of 5 impulses with reversed polarity equal to 1.2/50us, the original manufacturer may perform, at its discretion, an equivalent AC voltage test. The required characteristics of the instrument (freq, Inom and Icc) are the same as those required in the test of withstand voltage at industrial frequency.

NOTE: the considerations and voltage levels applied in the impulse withstand test apply for design checks (see page 33).

Q Switchboards and machines

EN 60204: OBSERVATIONS



The machinery's switchboard is a component of the machinery itself and should be certified with the IEC 61439-1 + IEC 60204-1 standard.

Checks provided for:

Protection against indirect contacts	Continuity of the protective conductor. Results compatible with length, section and material of the conductors.
	Automatic disconnection of the power supply: TT Systems: IEC 60364- 6 (IEC 84/8-6) TN Systems: IEC 60364- 6 (IEC 84/8-6)
Insulation measurement	Test carried out with test voltage 500V DC
Withstand voltage test at unknown frequency	Test carried out with test voltage 1000V VAC
Measurement of residual voltage	Plug or discharge testing of internal capacities with 1s and 5s cut-off times

PROTECTION AGAINST INDIRECT CONTACTS - TT SYSTEMS

In this case, the checks to be carried out are the same as for the electrical systems, therefore, in accordance with IEC 64-8/6, it is necessary to carry out:

- Verification of the continuity of the equipotential protection circuit.
- Verification that the residual current protection is tripped.
- Measurement or specification of earth resistance.

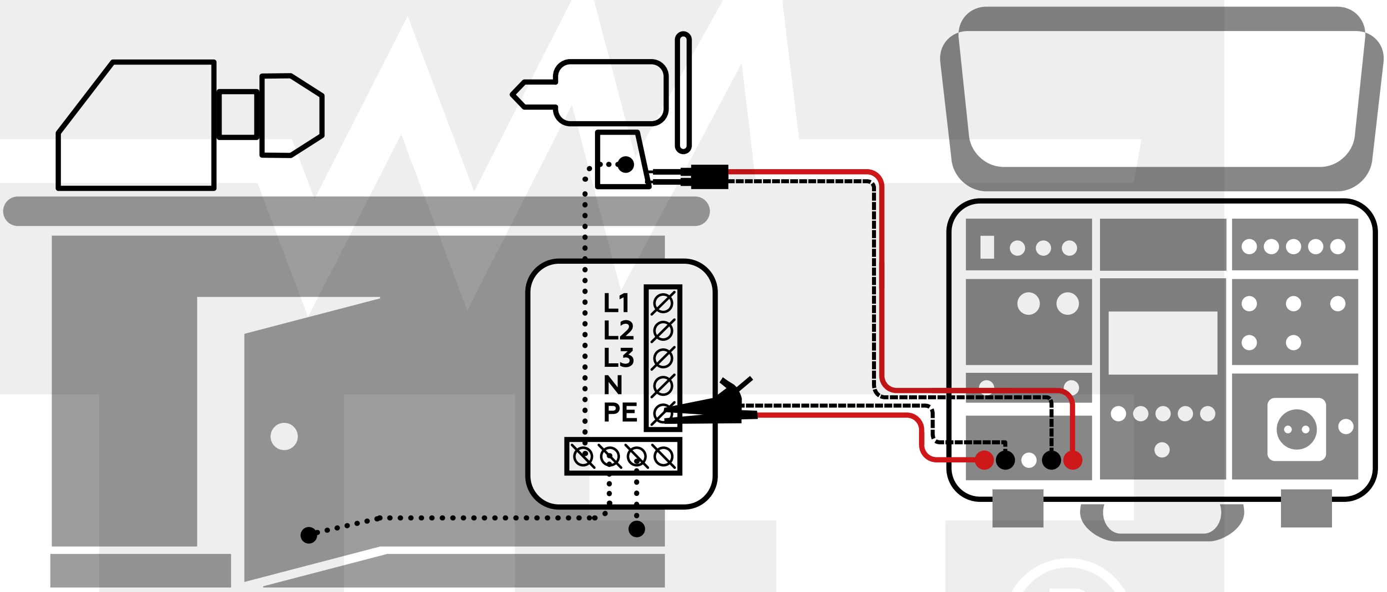
EQUIPOTENTIAL PROTECTION CIRCUIT CONTINUITY - TT/TN SYSTEMS

The standard requires one to measure the resistance of all protective and equipotential conductors with respect to the PE terminal of the machine:
• Test current between 0.2A and 10A with maximum open circuit voltage of 24V AC or DC
• No test time is specified (typically a test time >2s is sufficient).

Unlike the continuity test on the switchboards, the standard does not impose a limit, but states that the results must be compatible with the length, cross-section and material of the conductors.

This means that we can use an instrument that allows us to enter the characteristics of our conductor or alternatively, based on our own experience, establish a reasonable resistance limit keeping in mind R = ρ * L/s where rho is the resistivity of the conductive material, L is its length and s is its cross-section.

Operating instructions:



A 4-wire connection is recommended, so that there is no need to compensate the test cables.

It is necessary to test all ground connections against the PE terminal of the machine (on large diameter cable sections or very small length cables, it is preferable to use higher test current values in order to achieve higher resolution).

TESTING TO CONFIRM THE EFFECTIVENESS OF THE AUTOMATIC DISCONNECTION OF THE POWER SUPPLY

As for the checks on IEC 64-8/6 electrical systems, check:
• Global earth resistance
• That the residual current protection is tripped

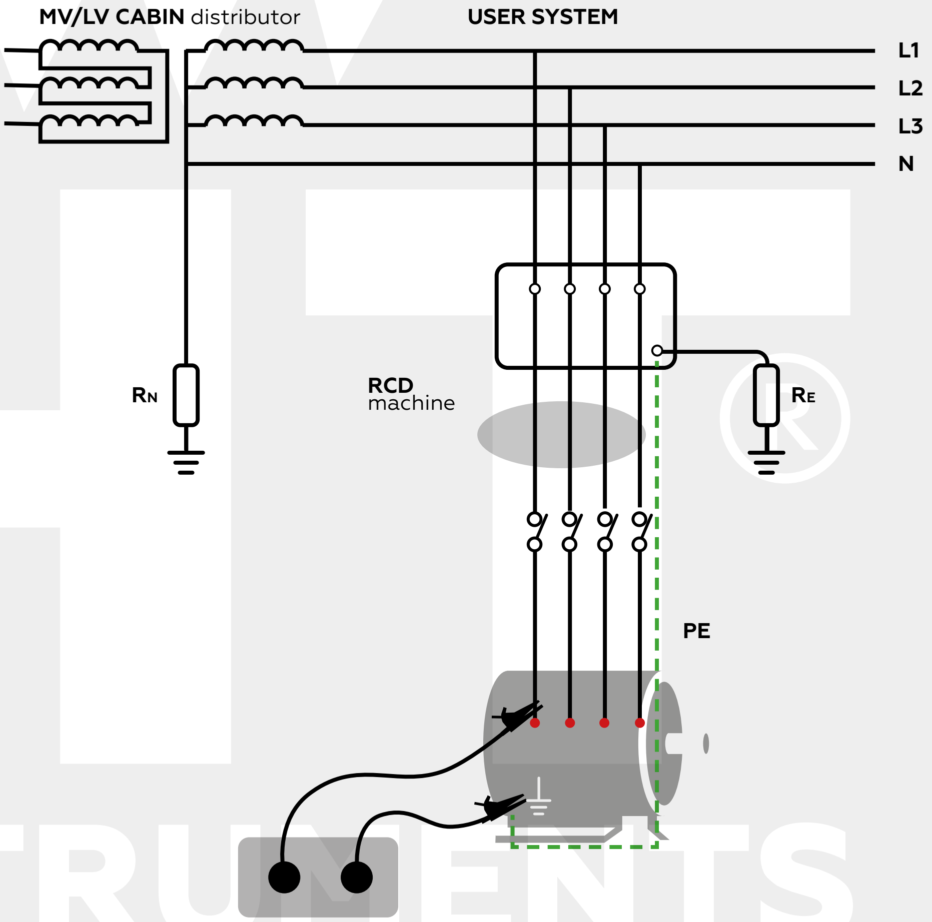
Protection from indirect contacts must be guaranteed by means of a differential protection device, suitably sized according to the characteristics of the machine (e.g., according to the presence of EMI filters) and according to the characteristics of the electrical installation system.

EARTH RESISTANCE

INTRODUCTION: It is important to note that the following check, in particular, must be carried out on the machine installed in the plant where it will operate. Since the measurement of earth resistance is closely linked to the earthing system of the building in which the machine will be installed, a test in a different installation (e.g., in the manufacturer's workshop) would therefore be of little significance. It will be the manufacturer's responsibility to declare what the maximum value of earth resistance allowed for the installation of the machine is. This is done by connecting downstream of the differential protection and measuring earth resistance using the fault loop method.

OPERATING INSTRUCTIONS

• Power up the machine.
• The instrument is connected immediately downstream of the differential and the measurement is made.
• It is verified if the result guarantees the coordination of the protections, i.e. Re*Idn≤Ut where Re is the earth resistance, Idn is the rated tripping current of the differential and Ut is the maximum contact voltage (50V).



Why is it important to carry it out?

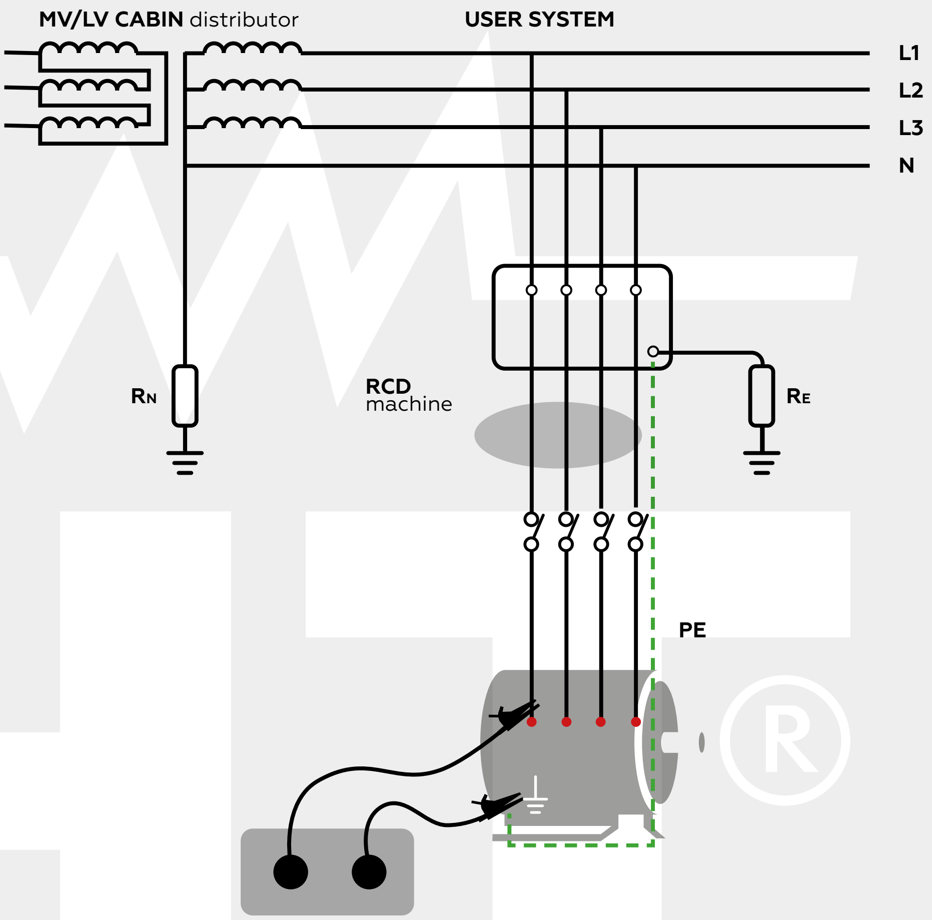
When it comes to a machine installed in a third-party system, it is essential to know the earth resistance value of the system in order to verify that, in the event of a ground fault, the conditions are in place for the differential protection of the machine to intervene within the reference times (300ms for generic RCDs at Idn x1).

VERIFICATION OF THE DIFFERENTIAL PROTECTION

The RCD is connected downstream of the differential protection and the efficiency of the RCD is checked with a suitable instrument capable of circulating the nominal current of the same with the correct waveform (A, AC, F, B, B+) and at the same time able to monitor the contact voltage Ut.

OPERATING INSTRUCTIONS

- Power up the machine
- The instrument is connected immediately downstream of the differential, the measurement is made and the tripping time is recorded.



Why is it important to carry it out?

In the event of a ground fault of the machine in question, the ground of which is not normally live, the latter could be induced to a potential danger for the operator who happens to use it. By verifying the perfect efficiency of both the earthing system and the residual current device, we are sure that once the fault current exceeds the nominal current value of the differential, it will intervene by protecting the user from the contact voltage before it becomes dangerous (>50V).

PROTECTION AGAINST INDIRECT CONTACTS - TN SYSTEMS

As for the checks on IEC 64-8/6 electrical systems, check:

• Fault loop impedance and check of protection coordination

Protection against indirect contacts must be ensured by means of an overcurrent protection device (circuit breaker or fuse) that cuts off the power supply to the circuit or equipment in the event of a fault between an active part and a protective ground or conductor within a duration of no more than 0.4s (if Uo = 230V).

Uo [V]	Max interruption duration [s]
120	0.8
230	0.4
277	0.4
400	0.2
> 400	0.1
Uo = AC rated voltage to ground	

This requirement is fulfilled if the following condition is met:
Zs x Ia ≤ Uo or **Ia ≤Uo / Zs**
Zs = Fault loop impedance
Ia = current that causes the device to trip within the specified time
Uo = AC rated voltage to ground
(Uo / Zs) = assumed minimum short-circuit current

OPERATING INSTRUCTIONS

INTRODUCTION: It is important to note that the following check, in particular, must be carried out on the machine installed in the plant where it will operate. Since the impedance measurement is closely linked to the power supply line, a test in a different installation (e.g., in the manufacturer's workshop) would therefore be of little significance. It will be the manufacturer's responsibility to declare what the maximum line impedance allowed for the installation of the machine is.

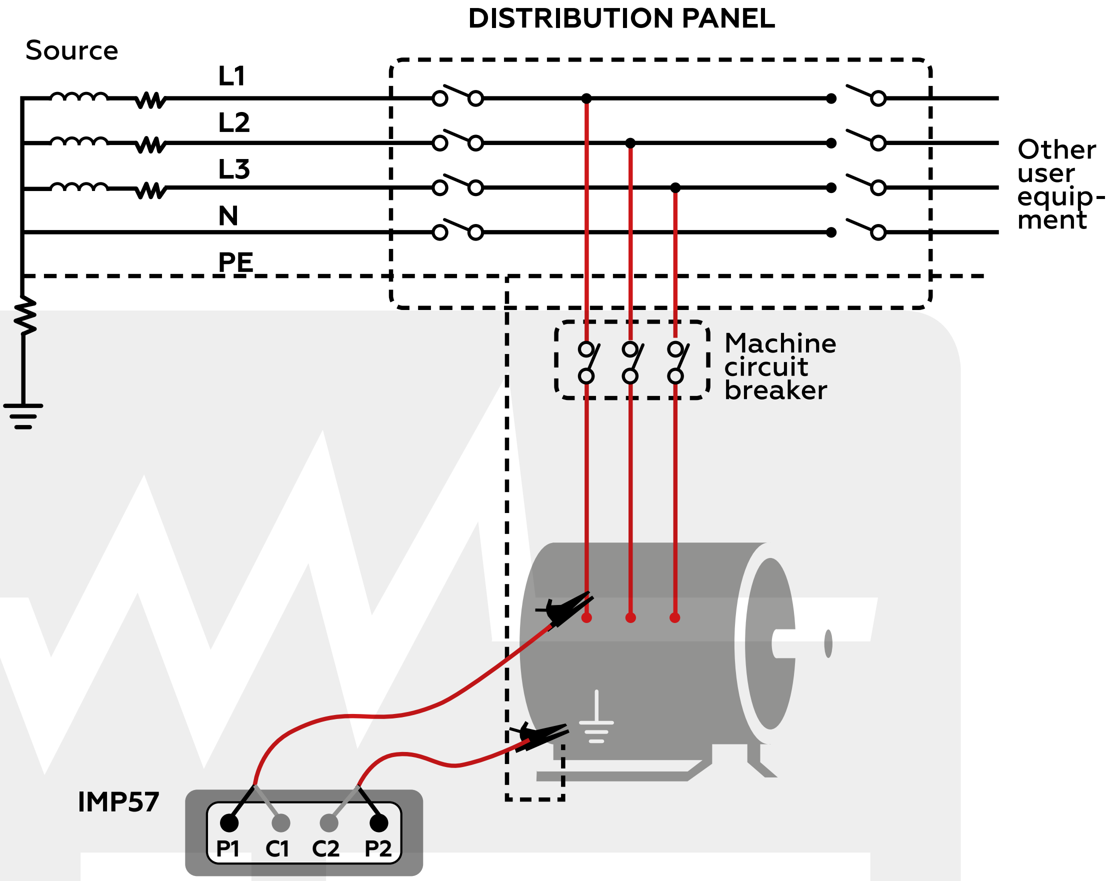
• Power up the machine

• Plug in the measuring instrument at the furthest point from the protective device (worst case) and measure the impedance Phase Earth

• Minimum short-circuit current (vs worst case) is calculated in accordance with IEC EN 60909-0

• Compare the value obtained with **Ia**

Depending on the tripping characteristic of the protection (e.g., the circuit breaker curve) it can be determined whether, in the event of a ground fault, the short-circuit current that will circulate (at the point furthest from the power source --> and therefore with a higher impedance) will be sufficient to trigger the protection in the maximum time established by the standard (e.g. 0.4s for Uo=230V).



Example: assuming that the machine is protected at the input by a 32 A circuit breaker with curve C (characteristic protection tripping between 5 and 10 In), if the calculated current Ia will be >10In or >320A the test will be considered OK, while for a lower value the protection, in the event of a fault, may not be tripped.

Why is it important to carry it out?

Taking as an example the operator who is working on the machine, in the event of a fault, the current that is generated between the ground and the point of fault, must be sufficient to trip the circuit breaker or fuse protection according to the values prescribed by the standard (typically 0.4s for Uo=230V). This will ensure that the operator is protected from exposure to a potential hazard in the event of a fault.

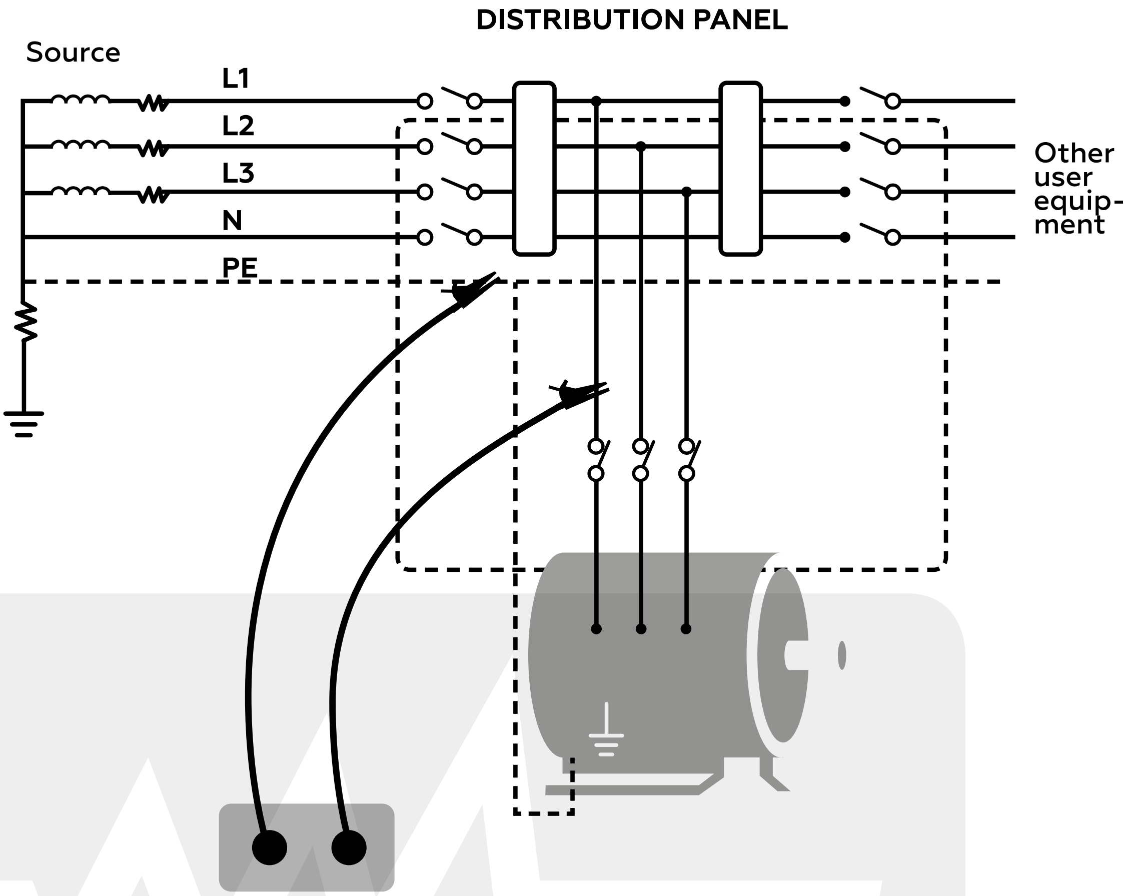
VERIFICATION OF INSULATION - TT/TN SYSTEMS

The standard prescribes that the insulation resistance between the conductors of the power circuit (L1, L2, L3, N) and the equipotential protection circuit must be measured with a test voltage of 500VDC and the measured value must not be less than 1 MOhm.

OPERATING INSTRUCTIONS

- Machine disconnected from the power supply.
- Disconnect internal parts of the same that could be damaged by the test voltage (e.g., electronic parts, PLCs, etc.).
- Connect the instrument between the equipotential protection circuit and the short-circuited conductors of the power circuit.
- The test can be carried out on individual sections of the complete electrical installation.

The measured value must be greater than 1 MOhm.



Why is it important to carry it out?

The insulation measurement guarantees both the correctness of the wiring and the goodness of the insulations.

Unlike the dielectric strength measurement, it is a non-destructive DC measurement, the purpose of which is not to verify the seal of an insulation and its possible fault, but to "quantify" how great this insulation value is. The standard requires a minimum value of 1 MOhm, but typically values of tens or hundreds of MOhm can be measured, which typically increase as the duration of the test increases.

Voltage tests

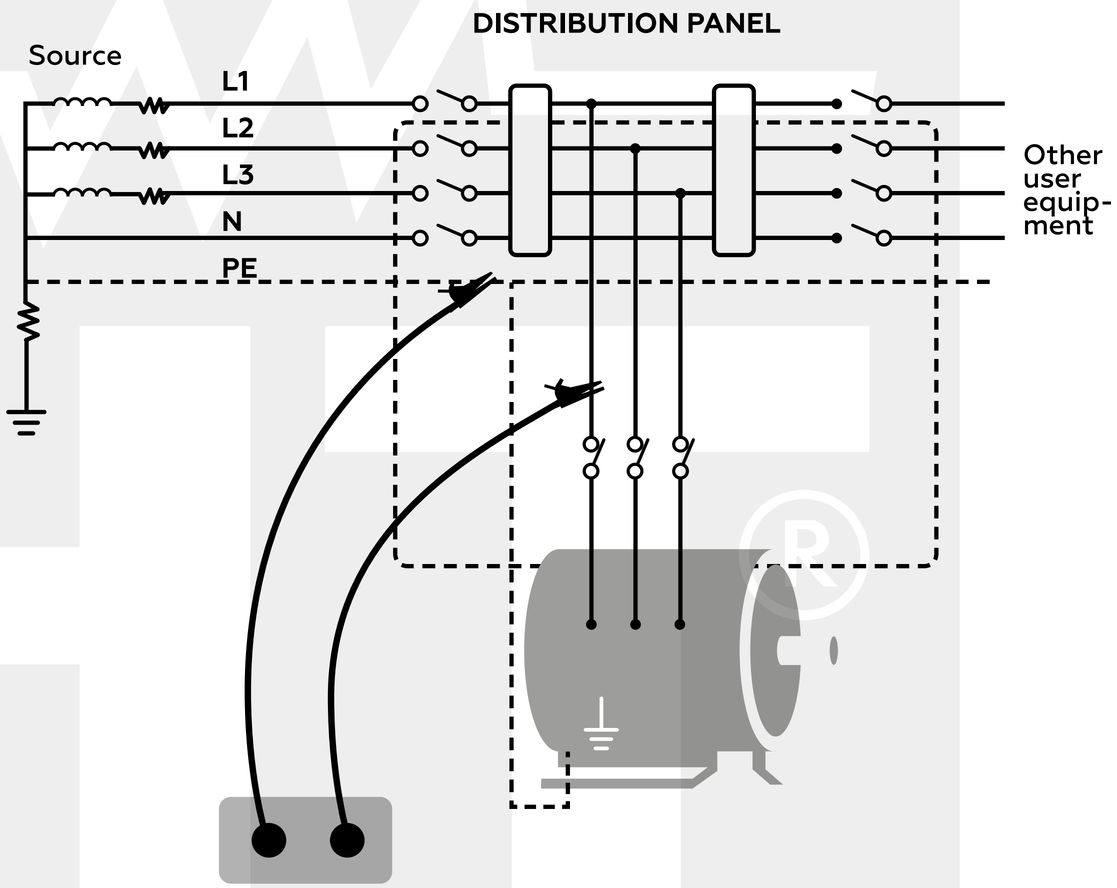
The standard requires to perform a voltage test (dielectric rigidity) with instrumentation compliant with IEC 61180-2 (Source 50 or 60Hz, Inom>100mA, Icc>200mA) at the operating frequency (50 or 60Hz).

The test must be performed at 2x nominal operating voltage or 1000V, whichever is greater.
Components and devices that do not have nominal characteristics such as to withstand the test voltage must be disconnected during the test.
Components and devices that have been voltage tested in accordance with their product standards may be disconnected during the test.

The requirements are complied with if there are no disruptive discharges.

OPERATING INSTRUCTIONS

- Machinery not supplied with power.
- Connect the instrument between the potential protective circuit and the short-circuited conductors of the power circuit.
- Test voltage for 1s applied.
- No discharges must occur.



Check residual voltage

The Legislation prescribes: "active parts that maintain a residual voltage > 60V after power failure (typically internal capacities) must be discharged within 5s after power failure, taking care that the discharge characteristic does not disturb the operation of the machine.

In the case of plugs or similar devices, the extraction of which would result in exposure to contact with conductive parts, the discharge time shall not exceed 1s."

OPERATING INSTRUCTIONS

• Machine, initially powered under working conditions.
• Disconnect the machine from the power supply by checking that the voltage on the internal parts or plugs drops below 60V within the specified time limits (5s for permanently connected machines or 1s for plugs).

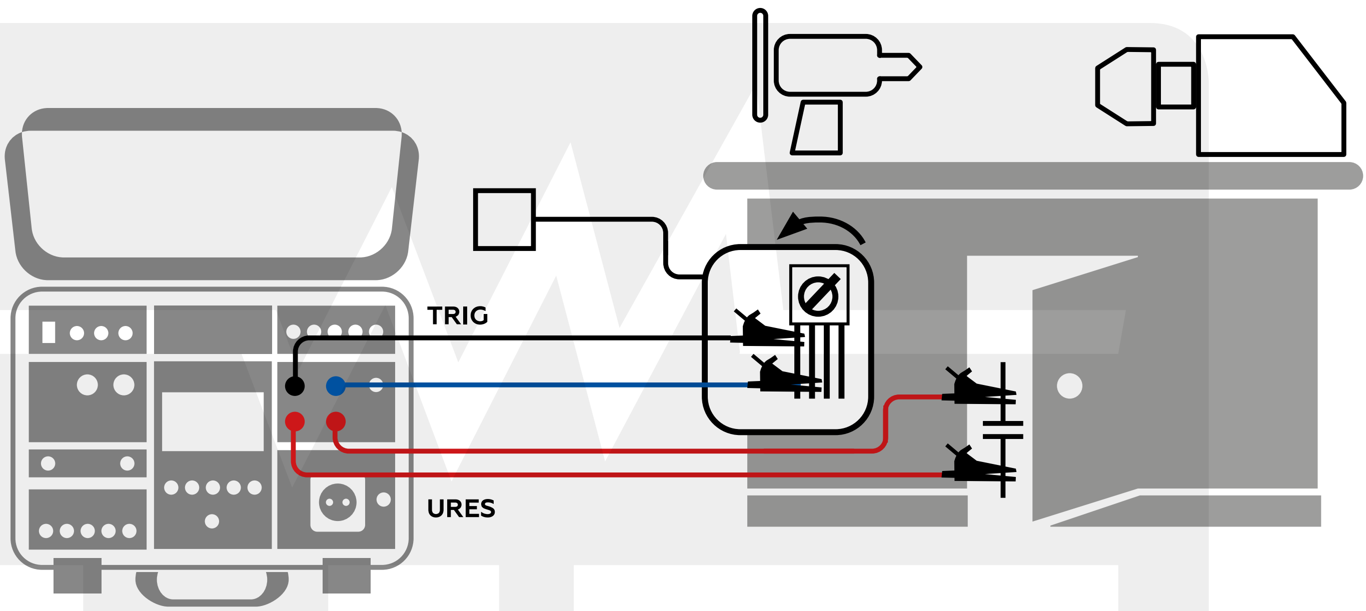


Fig. 59: Connection for URES INT measurement on permanently connected machines.

When the specified discharge characteristic may interfere with the proper operation of the equipment, a durable warning shall be placed, drawing attention to the hazards and indicating the delay required before the enclosure can be opened; it shall be placed in an easily visible position or in the immediate vicinity of the enclosure containing the capacities.

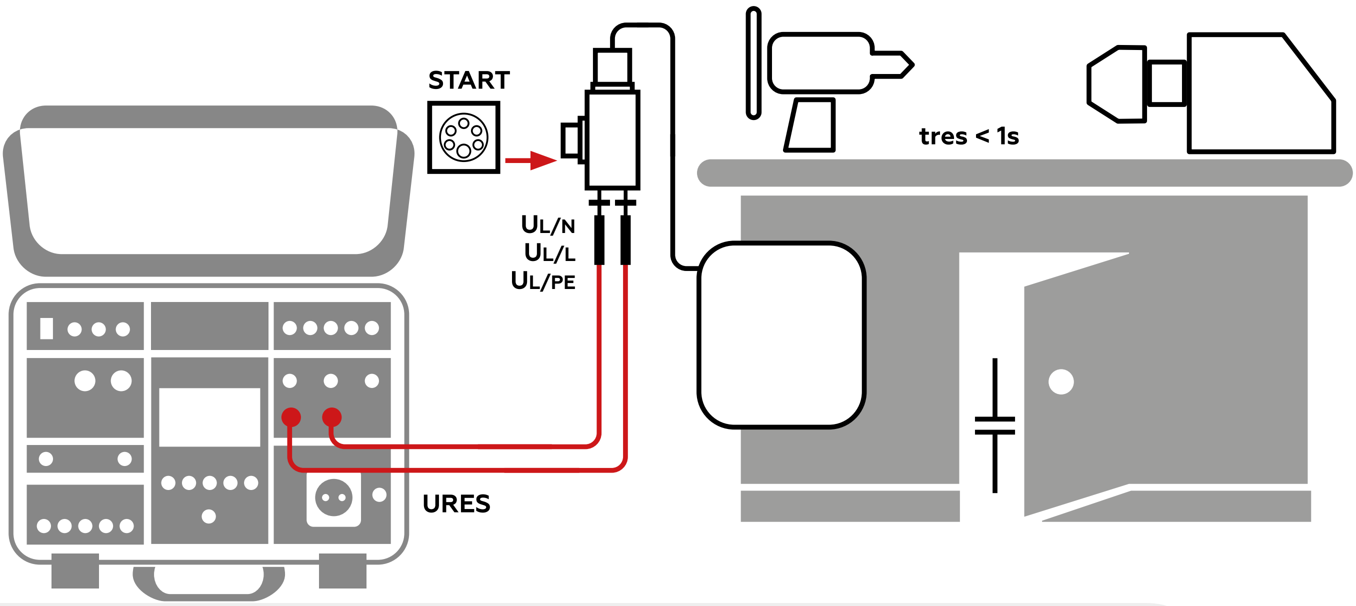


Fig. 60: Connection of measuring terminals in URES PLUG measurement.

In the case of plugs or similar devices, the extraction of which would expose conductors (e.g., plugs) to contact and the discharge time must not exceed 1 s.
Otherwise, these conductors must be protected against direct contact with a degree of protection of at least IP2X or IPXXB. If a discharge time of 1 s or a degree of protection of at least IP2X or IPXXB cannot be achieved, additional interrupting devices or a suitable warning device (e.g., a warning suitable to withstand the ambient conditions of the installation) must be provided.

Why is it important to carry it out?
This test makes it possible to identify a possible electrical hazard on parts accessible by the operator even when the machine is disconnected, possibly being able to undertake the appropriate operations (for example, by affixing danger plates and waiting before accessing the active parts).

E Quality of supply of electricity

The purpose of the EN50160 standard is to define and describe the characteristics of the supply voltage regarding the frequency, amplitude, waveform and symmetry of line voltages. These parameters are subject to change during the normal operation of a power system as a result of load changes, disturbances generated by certain equipment, and the occurrence of faults that are primarily caused by external events. Some of the phenomena that affect the voltage are particularly unpredictable, which makes it very difficult to give defined useful values relative to the corresponding characteristics. An analysis is therefore necessary in order to identify all the phenomena of disturbance of the mains voltage in time and intensity.

MAINS FREQUENCY

Average Frequency value (obtained as an average of the values over 10 sec):

- for interconnected systems:
  50Hz ± 1% during 95% of the values recorded in a week
  50Hz + 4%, -6% during 100% of the values recorded in a week

- for island power systems:
  50Hz ± 2% during 95% of the values recorded in a week
  50Hz ± 15% during 100% of the values recorded in a week

VOLTAGE VARIATION

Excluding voltage interruptions (obtained as an average of values measured over 10 minutes), the voltage value must be within the following limits:

- Vnom ± 10% during 95% of any week's values (V1 95%, V2 95%, V3 95%)
- Vnom + 10%, Vnom - 15% during 100% of the values of any week (V1 100%, V2 100%, V3 100%)

DYSSYMMETRY

U2 (Ratio of Inverse to Direct Sequence) ≤ 2% during 95% of the values of any week

FLICKER

PLT (Long Term Flicker severity) ≤ 1 during 95% of any week's values.

TOTAL DISTORTION (THD%)

Obtained as the sum of the Voltage Harmonics:
THDv% ≤ 8% during 95% of the recorded values of any given week.

VOLTAGE HARMONICS

Vh% ≤ VhLIM during 95% of the recorded values of any week.

Odd Harmonics				Even Harmonics	
Not multiples of 3		Multiples of 3			
Order	Max % Value	Order	Max % Value	Order	Max % Value
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.5	6..24	0.5
13	3	21	0.5		
17	2				
19	1.5				
23	1.5				
25	1.5				

Limits value (VhLIM%) for voltage harmonics (Vh%)

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