Photovoltaic installations
Efficiency and I-V curve

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What to measure - efficiency of the system

How can I know the “quality” of a PV installation? By measuring its efficiency.

The efficiency gives us an overall assessment of the system and how it performs in an easy to understand way, i.e. 0.910 (or 91.0%). This can be:

1. instantaneous
2. data logged
3. efficiency over time (i.e. early basis)

System’s efficiency = DC efficiency (modules) x AC efficiency (inverter)

The efficiency also provides actual data to compare each time the system is tested so that decisions about maintenance/replacement can be made.

Efficiency measurement grants that the modules and the inverter are functioning correctly by checking their parameters while the system is running. There is no need to shut down the plant. Efficiency is measured on a live plant.

When to measure the efficiency of the system?

1. Upon installation. If the system is operating as it was designed, then no further investigation is required and the test data can be used to show that the system was working within the parameters stated by the manufacturers of the panels or within panel specification.
2. Every year. In case the efficiency of the system is decreased by an acceptable value compared to the value measured the year before (usually 0.5% on a yearly basis) no further investigation would be required.
3. Whenever the owner of the system gets a lower return (income) than expected.

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What is the efficiency?

Efficiency is a dimensionless quantity, expressed as a percentage and defined as:

$$\eta(t) = \frac{P_{OUT}(t)}{P_{IN}(t)}$$

Such value is not constant and depends on time. The inverter or the modules may have different efficiencies, depending on the time when measurement is performed. For efficiency measurement, the simultaneity of P_{IN} (t) and P_{OUT} (t) measurements is crucial. Indeed, should you measure P_{IN} at time t1 and P_{OUT} at time t2 you would get P_{IN} (t1) and P_{OUT} (t2) values respectively whose ratio would not provide any meaningful result.

$$\frac{P_{OUT}(t2)}{P_{IN}(t1)} = ???$$

The required simultaneity of measurements brings about some practical problems.

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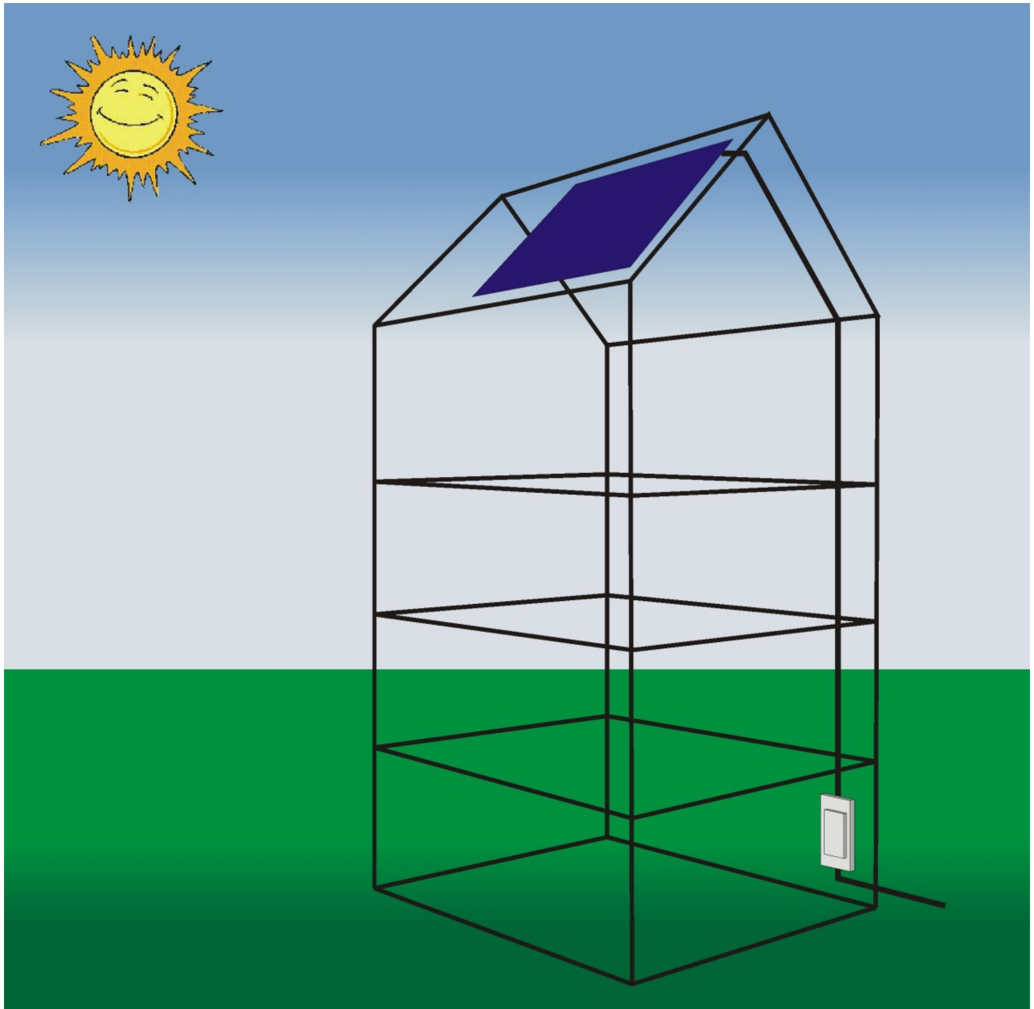
Example – solar roof



In a photovoltaic rooftop installation (solar roof) modules are placed on the roof of the building and the inverter is often in the cellar.

This condition is quite critical since, in order to test the installation, it is necessary to measure

simultaneously

electrical and environmental parameters in places which are very far from each other.

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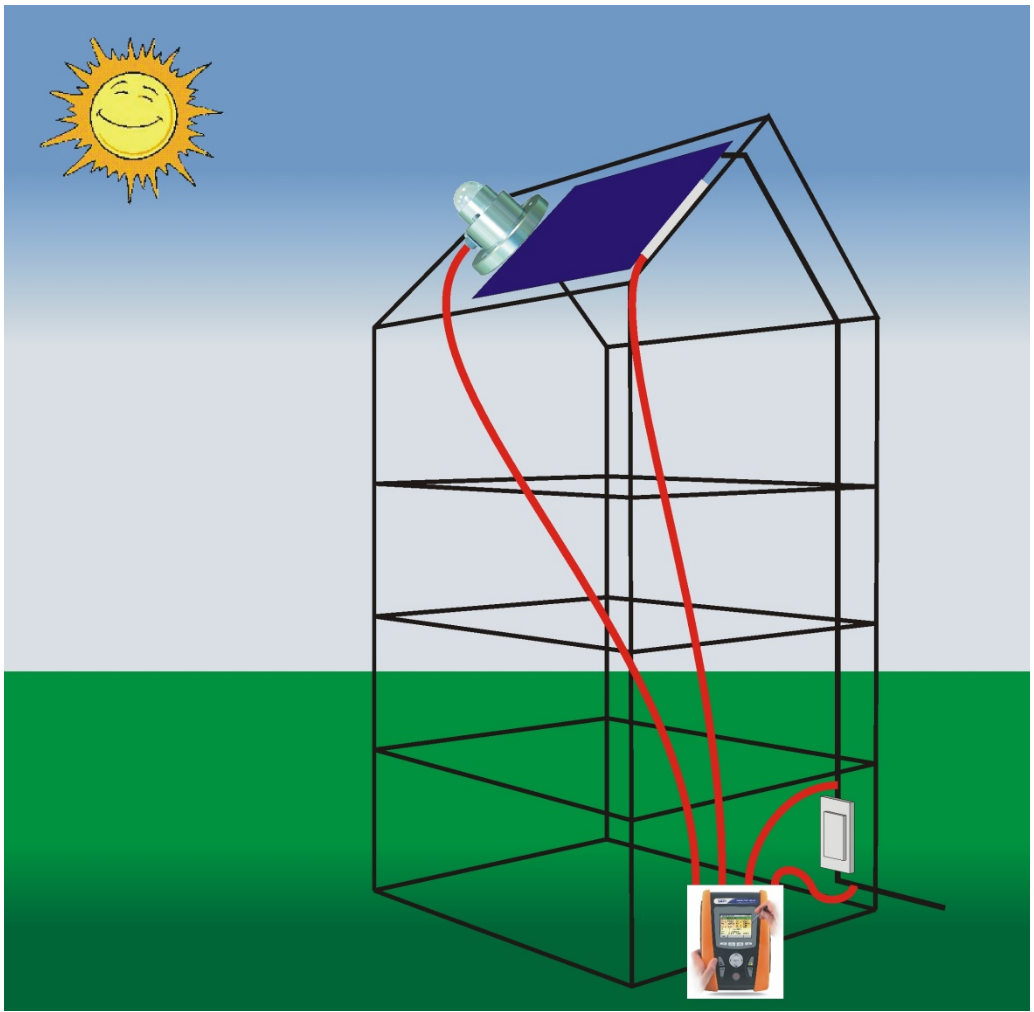
Cable connection



You can connect the measuring instrument to environmental probes using one or more cables. This solution, however, even though simple and cheap, is

uncomfortable, dangerous and inaccurate

Cables go through windows, stairwells, doors causing potential danger to people who can stumble and risk to cut them. Moreover, cables are antennas catching electrical noise possibly even stronger than the signal they are carrying.

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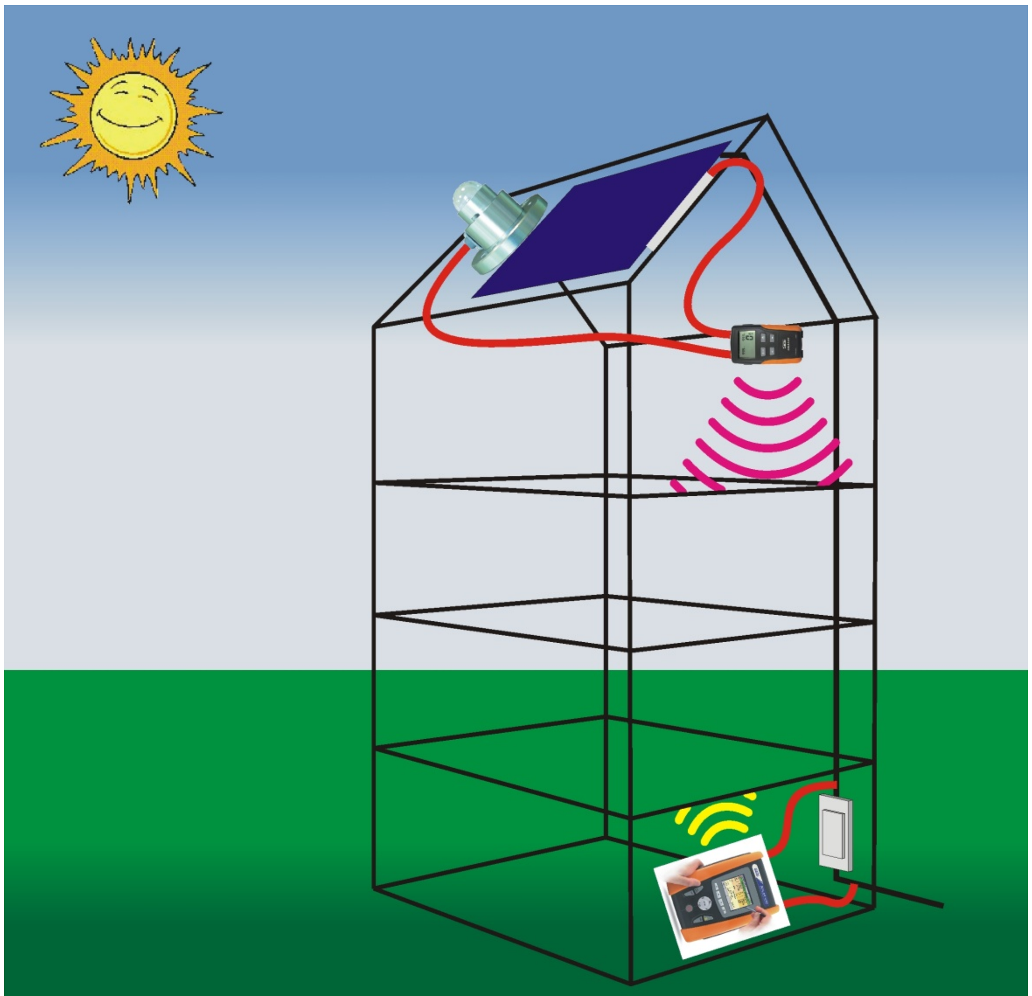
Wireless connection



In such a case you can use a wireless connection. Any type of wireless connection is always certified by

propagation in free field

which is to say free of obstacles. But such a condition is purely theoretical. As a matter of fact the most common conditions are other than "free field". Indeed floors, concrete structures, etc., attenuate signals making communication difficult or even impossible.

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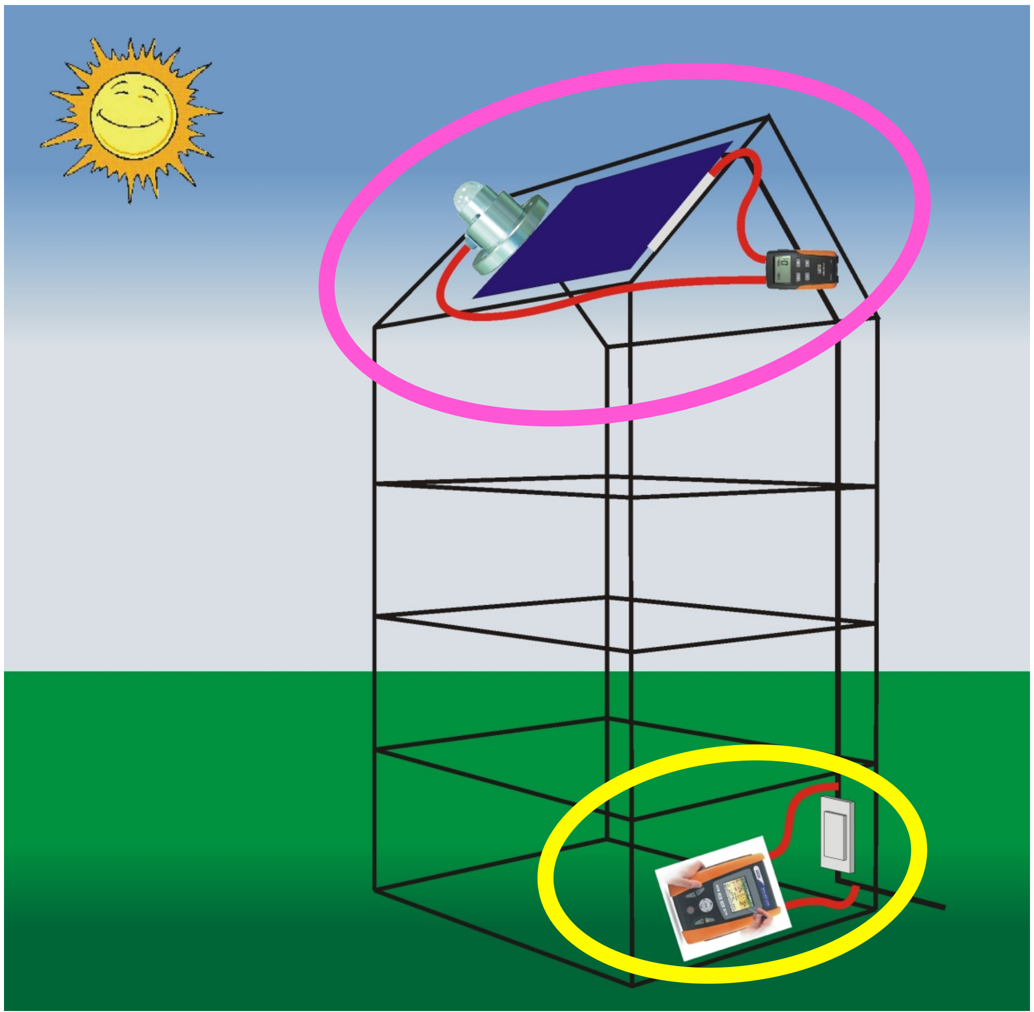
Synchronization



The only viable solution consists in positioning and securing

two independent units

one on the roof for the acquisition of environmental parameters and the other upstream and downstream of the inverter for the acquisition of electrical parameters. Following such a procedure two independent "environments" can be created where measurements are carried out independently from each other.

The synchronization of both units provides the necessary simultaneity of measurements.

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Efficiency and I-V curve

Efficiency recording – SOLAR300N

HT has developed **SOLAR300N**, a tester capable of measuring and recording the efficiency of PV systems:

- through the remote unit SOLAR-02 all environmental parameters: irradiance, module temperature and environment temperature,
- DC voltage, current and power
- AC voltage, current, power factor (cosφ) and power (single- or three-phase installations)

SOLAR300N logs these quantities allowing:

- analysis of installation performance over time
- installation testing even without the physical presence of the professional

Furthermore **SOLAR300N** is a full EN 50160 power quality analyzer.

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Efficiency and I-V curve

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Efficiency recording – SOLAR I-Ve

HT has developed **SOLARI-Ve**, a tester capable of tracing the I-V curve and measuring and recording the efficiency of PV systems. **SOLARI-Ve** measures:

- through the remote unit SOLAR-02 all environmental parameters: irradiance, module temperature and environment temperature,
- DC voltage, current and power,
- AC voltage, current, power factor (cosφ) and power (single-phase installations).

SOLARI-Ve logs these quantities allowing:

- analysis of installation performance over time,
- installation testing even without the physical presence of the professional.

Furthermore **SOLARI-Ve** is a full I-V curve tracer for systems with nominal voltage up to 1,500V.

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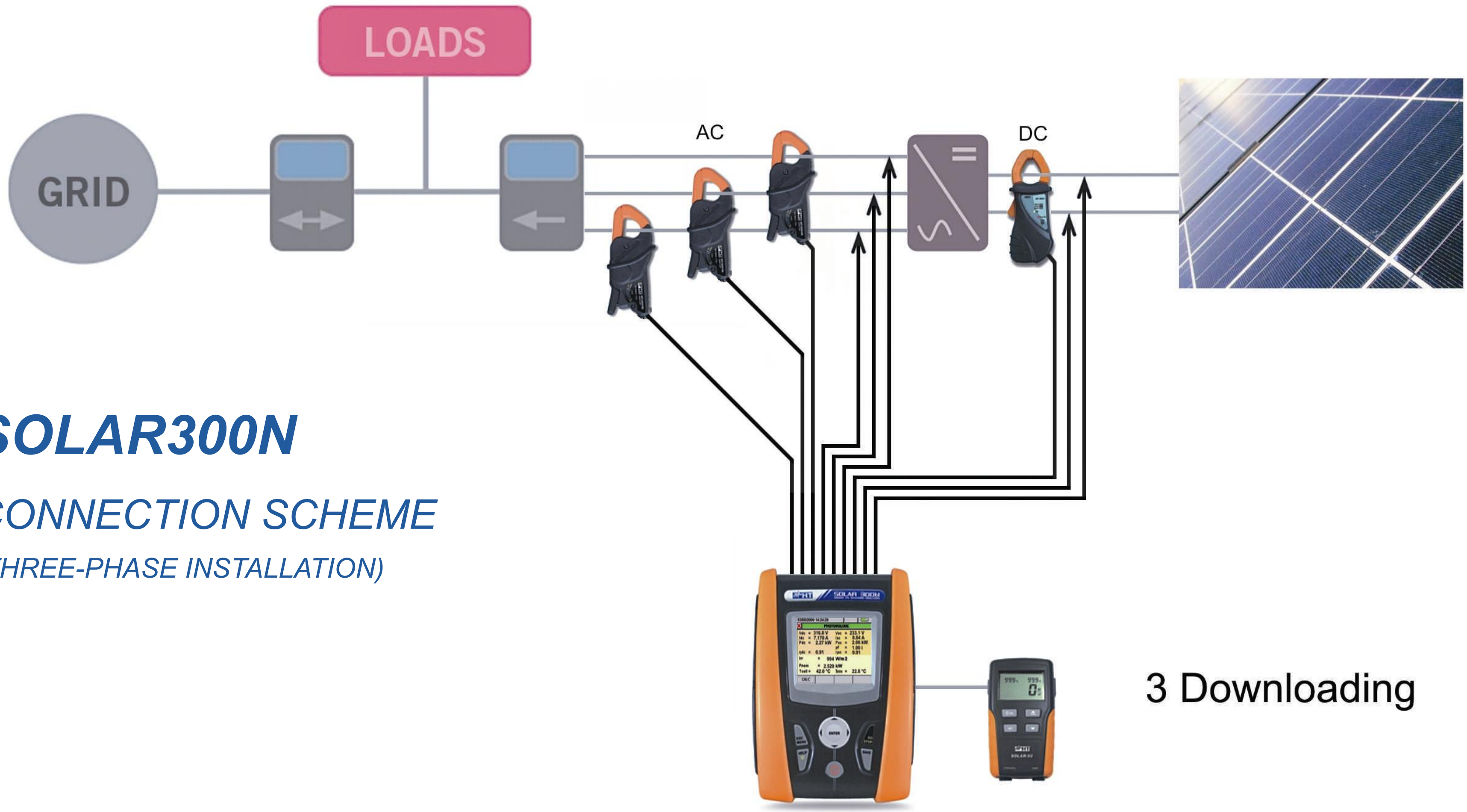
Efficiency and I-V curve

How to connect SOLAR300N and SOLAR-02



SOLAR300N

CONNECTION SCHEME

(THREE-PHASE INSTALLATION)

3 Downloading

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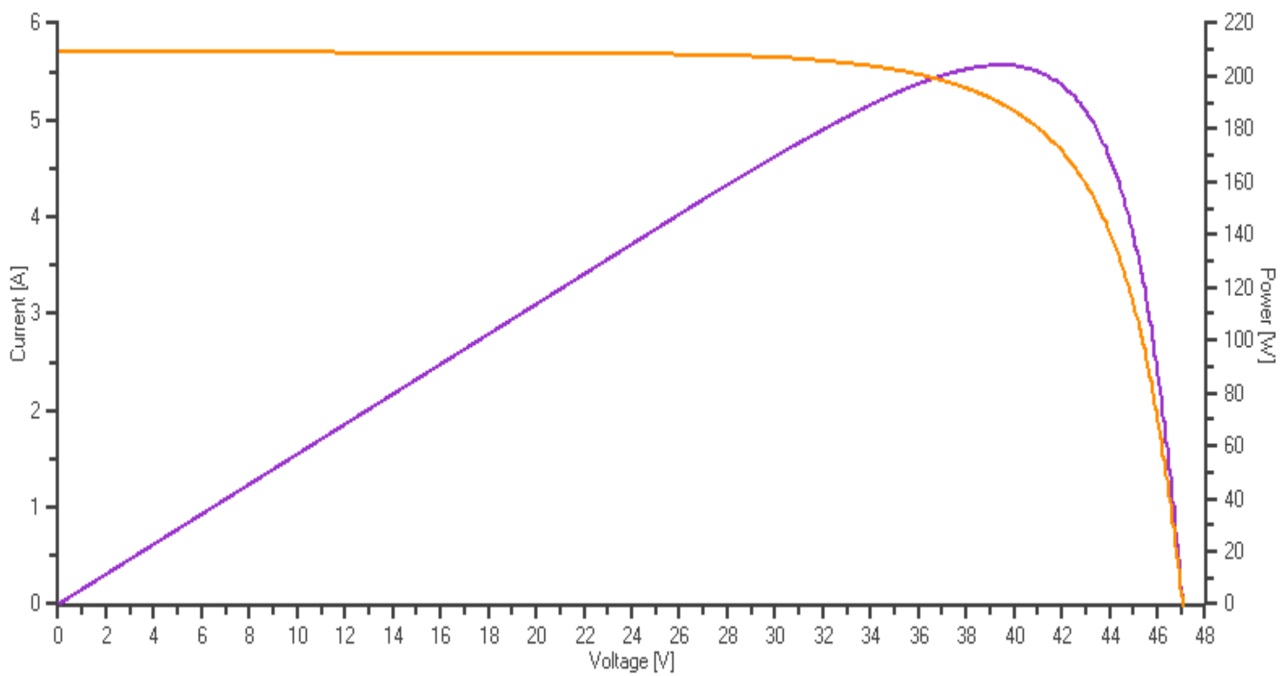
Is the efficiency lower than prospected?

During the installation life some cells may get spoilt, thus compromising the performance of the modules and, consequently, of the whole string.

Improper packaging, careless loading/transport/unloading, stiletto effect on modules horizontally packed, etc. can lead to underperforming cracked panels.

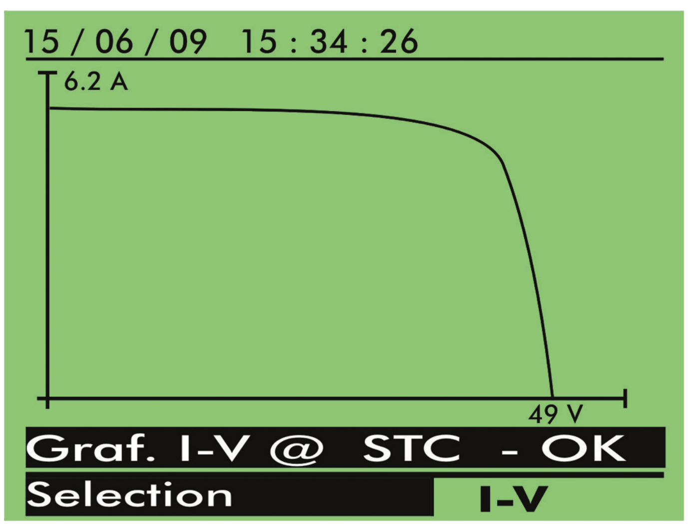
How to prevent a cracked module to be installed? How to spot a cracked module within the already-installed array? By measuring the I-V curve to compare it to the characteristics stated by the manufacturer.

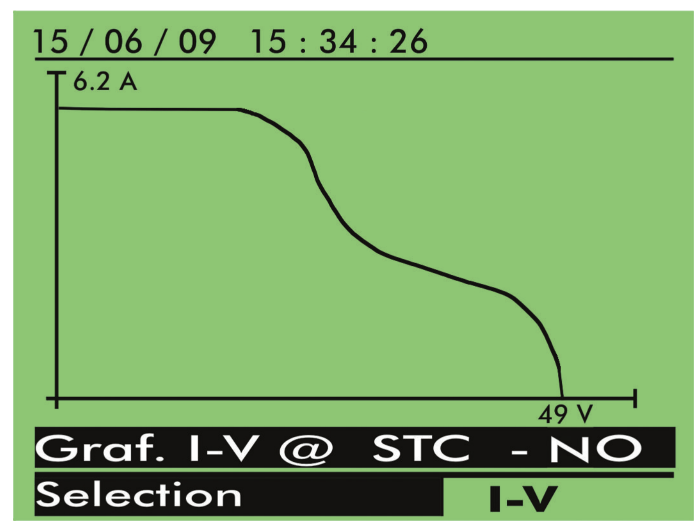


V_{OC} and I_{SC} Vs. I-V curve

The V_{OC} and the I_{SC} are the extremes of the I-V curve, providing not enough information to understand if the module under test was working properly or not.

IEC 60891 “Photovoltaic devices – Procedures for temperature and irradiation corrections to measured I-V characteristics” (which all HT instruments are conform to) provides formulas for data extrapolation from OPC to STC for data comparison to the nominal performance of the modules, as provided by their manufacturer.





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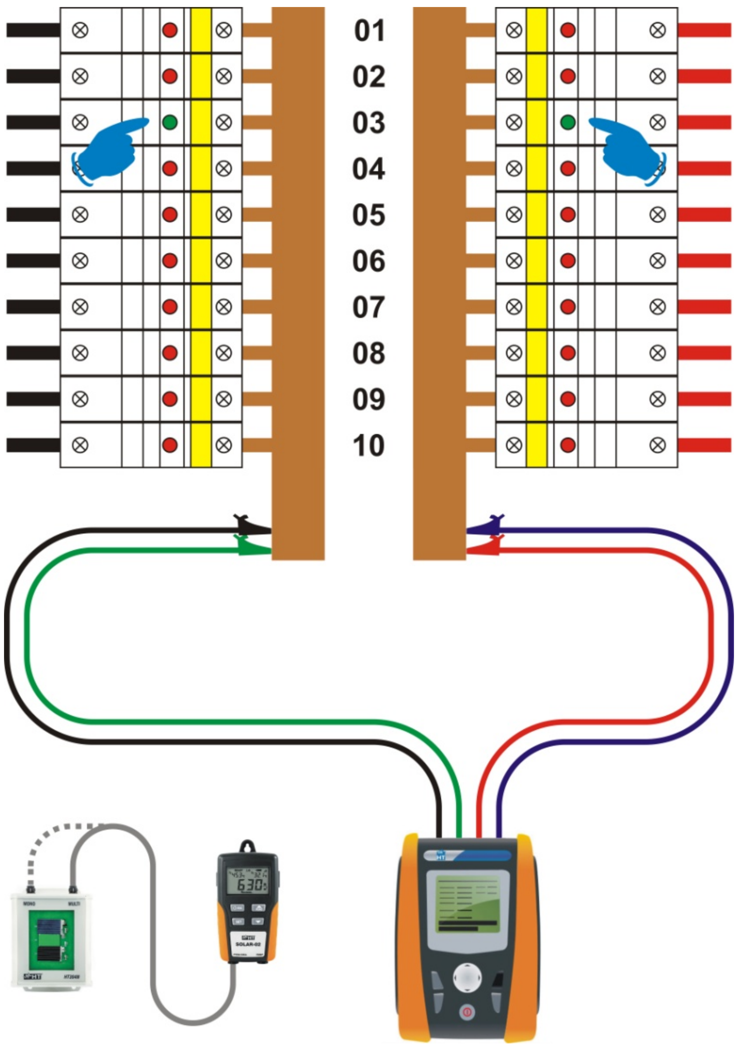
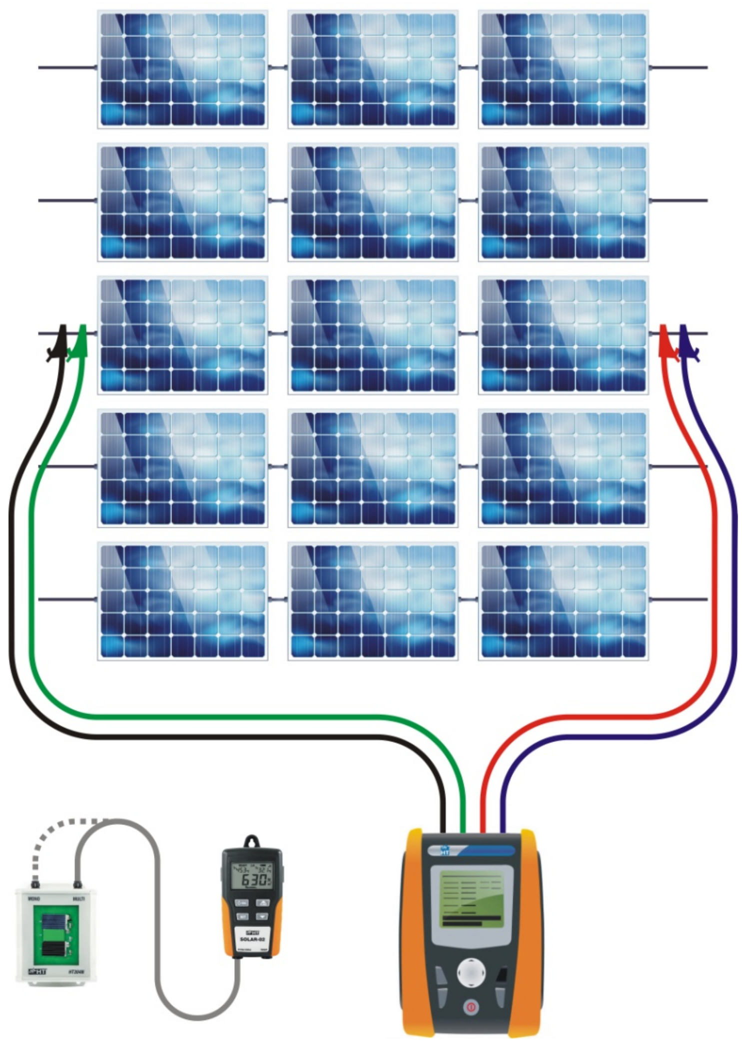
Short in time? Auto I-V curve tracing procedure



AUTO sequence:

- start,
- acquire,
- store,
- rearm.

speeds the installation test time. The start command is automatically initiated as soon as the string under test is connected and the instrument senses voltage at its inputs.



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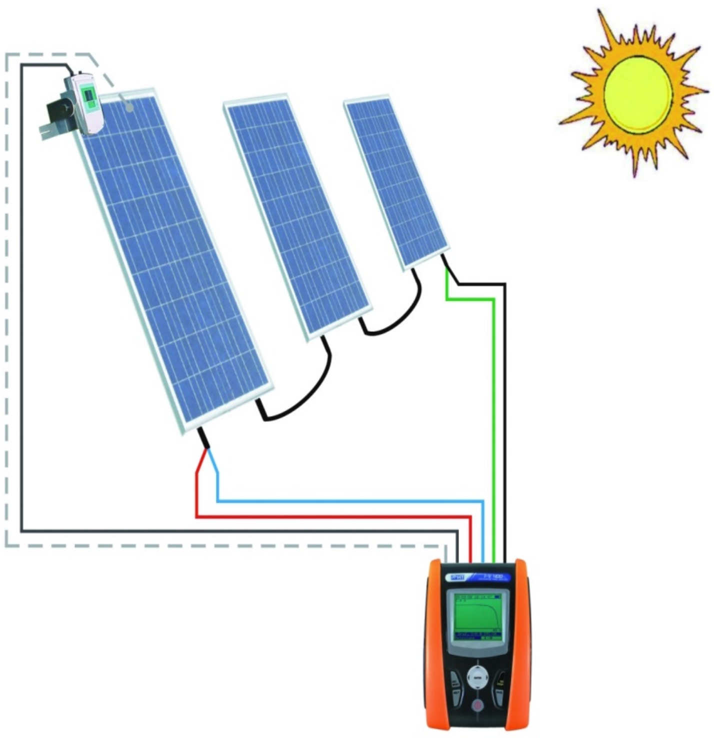
Resistances to compensate? 4-wire technique

What if positive and negative terminals of the string are considerably far each other? How to compensate extensions' resistance and contact resistance? Unfortunately, contact resistance is unpredictable, thus it cannot be compensated.

The solution is the 4-cable measurement technique, keeping voltage and current test circuits separated. In the voltage circuit there is no current flowing, so no voltage drop and no influence on the measure. In the current measuring circuit, the ammeter measuring just the current is not affected by the voltage drop on the parasitic resistances.



The 4-wire technique allows the use of extensions without the need for compensation. In addition, contact resistances and other parasitic values do not play any role, making this technique **the only** one to be considered **fully reliable under any test condition**.

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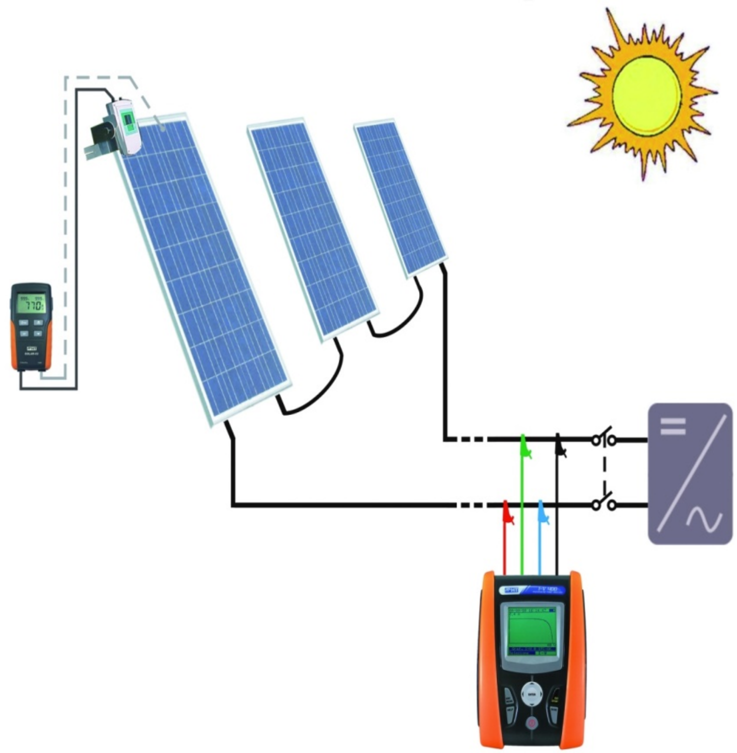
Cables difficult to accede?

In some PV installations, such as roof-top installations, it may be difficult to access the module output cables. An access to the cables at the combiner box or at the inverter's inputs may be the only chance.

In this case the measurement of the I-V characteristic can be achieved by measuring the environmental parameters (irradiation and temperature) through the remote unit SOLAR-02.



The remote unit is positioned next to the photovoltaic modules and connected to the probes for measuring environmental parameters.

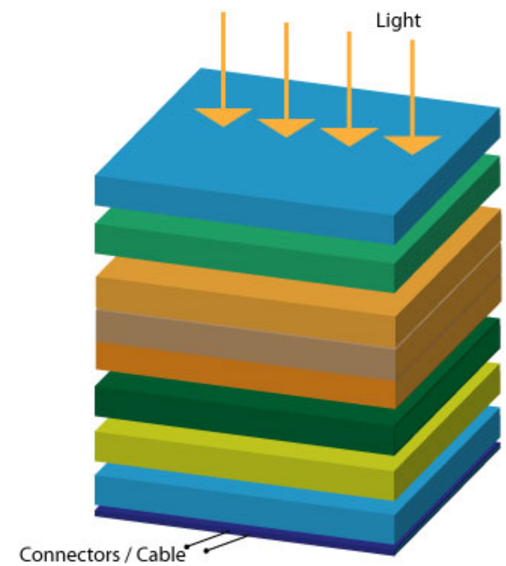
The synchronization between the two units guarantees the necessary contemporaneity of measurements making possible the extrapolation of the I-V curve at STC without using long extensions cords cable.

Temperature measurement via PT probe

A proper temperature measurement plays a key role in the data extrapolation to STC. Modules' output power strongly depends on temperature, usually modules lose 0,5% performance per °C.

Temperature can be measured via a PT probe to be glued to the module's back. A temperature conductive gel would be needed, as well as a system to keep the temperature probe in place and a shield to protect the back side of the PT probe from cooling.

In any case, the PT probe would measure the temperature of the external side of the module's back sheet, that may be lower than the temperature of the junction even by 10-20°C. In fact, the external side of the module's back sheet is cooled by air, while the junction is not. In addition, assuming the temperature of a single spot constant along the module and constant along the string is totally wrong.



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Temperature measurement via IR thermometer

IR temperature measuring would be also wrong, as it would measure the temperature of the front layer, and would be influenced by the reflected temperature.

So, how to measure the temperature?

Let's consider a Big Mac.

Similar to the PV modules, also the Big Mac is made of several layers (bread, cucumber, meat, lettuce, etc.).

As in the Big Mac the temperature of the meat is different than the temperature of the bread, in PV modules the temperature of the plastic back layer is different than the temperature of the junction!

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Temperature measurement via open-circuit voltage

The most reliable (and quick) method to measure the temperature is through the open-circuit voltage. In fact, the open-circuit voltage temperature coefficient β (%/°C) defines the change in panel open-circuit voltage at temperatures other than 25°C. So, by knowing β and the nominal open-circuit voltage (both stated by the manufacturer of the module in its datasheet) and by measuring the open-circuit voltage at operative conditions, it is possible to calculate the temperature of the junction.

This method provides an average temperature value across the module/string under test, that is the right value to consider. Moreover, it is not affected by the inaccuracies of the other methods, since it provides the temperature of the junction, not the temperature of the external layers. This is the easiest method, since the operator does not have to connect any probe or to take any specific measurement. **I-V 400w**, **I-V 500w** and **SOLAR I-Ve** can take the temperature measurement while measuring the I-V curve.

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I-V curve tracing – HT portfolio

HT has developed **I-V 400w**, **I-V 500w** and **SOLAR I-Ve**, testers capable of performing the I-V curve tracing to verify the efficiency of PV modules and strings

- irradiance measurement,
- module(s) temperature measurement,
- **open-circuit voltage Voc measurement**
  I-V 400w up to 1,000V DC
  SOLAR I-Ve and **I-V 500w** up to **1,500V DC**,
- short-circuit current Isc measurement,
- maximum power point voltage Vmpp, current Impp and power Pmax measurement,
- gap to the nominal power @STC DPmax calculation,
- fill factor FF calculation,
- USB and wi-fi connection to PC and smartphones (iOs and Android).

In addition, **SOLAR I-Ve** measures and logs the efficiency of PV systems


Thank
you
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HT85
HT2034
HT2043
6011
6511
HT55
XL421
HT9030
SKYLAB
HT9030
AT2004
HT71