EmaZys Technologies®

Z200 PV Analyzer User Manual

January 21, 2019

Z200 PV Analyzer User Manual

Written by EmaZys

January 21, 2019

Contents

1 Nomenclature

1.1 Warning signs

Please note that the manual uses the following safety instructions. The safety instructions should be followed carefully. Failure to do so may cause personal injury or irreparable damage to the equipment.

	WARNING. Personal injury / death. A situation of use of a technical nature or the like which may cause injury or death
	WARNING. Personal injury / death. Risk of electrical shock.
	CAUTION. Damage to the machine or accessory. A situation of use of a technical nature or the like, which can cause damage to the machine or accessories.
	NOTICE. Important information. A situation of use of a technical nature or the like, which is very important.

1.2 Tips and recommendations

Please note that the manual uses the following information instruction.

	INFORMATION. Provides useful tips and recommendations and provides information on how to use the product efficiently and without interruptions.

2 Limited warranty and limitation of warranty

Each EmaZys product is warranted to be free from defects in material and workmanship under normal use and service. The warranty period is one year and begins on the date of shipment. Parts, product repairs, and services are warranted for 90 days. This warranty extends only to the original buyer or end-user customer of a EmaZys authorized reseller, and does not apply to fuses, disposable batteries, or to any product which, in EmaZys's opinion, has been misused, altered, neglected, contaminated, or damaged by accident or abnormal conditions of operation or handling. EmaZys warrants that software will operate substantially in accordance with its functional specifications for 90 days and that it has been properly recorded on non-defective EmaZys does not warrant that software will be error free or operate without interruption.
EmaZys authorized resellers shall extend this warranty on new and unused products to end-user customers only but have no authority to extend a greater or different warranty on behalf of EmaZys. Warranty support is available only if product is purchased through a EmaZys authorized sales outlet or Buyer has paid the applicable international price. EmaZys reserves the right to invoice Buyer for importation costs of repair/replacement parts when product purchased in one country is submitted for repair in another country.
EmaZys's warranty obligation is limited, at EmaZys's option, to refund of the purchase price, free of charge repair, or replacement of a defective product which is returned to a EmaZys authorized service center within the warranty period.
To obtain warranty service, contact EmaZys service center on E-mail:
sales@emazys.com to obtain return authorization information, then send the product to the service center, with a description of the difficulty, postage and insurance prepaid (FOB Destination). EmaZys assumes no risk for damage in transit. Following warranty repair, the product will be returned to Buyer, transportation prepaid (FOB Destination). If EmaZys determines that failure was caused by neglect, misuse, contamination, alteration, accident, or abnormal condition of operation or handling, including over-voltage failures caused by use outside the products specified rating, or normal wear and tear of mechanical components, EmaZys will provide an estimate of repair costs and obtain authorization before commencing the work. Following repair, the product will be returned to the Buyer transportation prepaid and the Buyer will be billed for the repair and return transportation charges (FOB Shipping Point).
THIS WARRANTY IS BUYER'S SOLE AND EXCLUSIVE REMEDY AND IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. EMAZYS SHALL NOT BE LIABLE FOR ANY SPECIAL, INDIRECT, INCIDENTAL, OR CONSEQUENTIAL DAMAGES OR LOSSES, INCLUDING LOSS OF DATA, ARISING FROM ANY CAUSE OR THEORY.
Since some countries or states do not allow limitation of the term of an implied warranty, or exclusion or limitation of incidental or consequential damages, the limitations and exclusions of this warranty may not apply to every buyer. If any provision of this Warranty is held invalid or unenforceable by a court or other decision-maker of competent jurisdiction, such holding will not affect the validity or enforceability of any other provision.

2.1 Warranty disclaimer

PV Analyzer Z200 is warranted for 12 months from the reception. The warranty does not cover the battery. There is no warranty on the device, if you use other cables than the supplied. The warranty will be invalid if the product is damaged due to any of the following:

- Neglect to follow the User Manual
- Use of the product for purposes for which it was not intended
- Natural wear
- Incorrect fitting
- Mechanical or technical alterations
- Use of unauthorized spare parts

3 Unpacking and commissioning

3.1 Scope of delivery

The PV Analyzer Z200 is delivered in a cardboard box.

> INFORMATION.
> If you use knives or sharp objects when unpacking, please observe great care.

After unpacking, make sure that you have received all parts ordered. Accessories and special items may have been ordered as well, so please check with your purchase order and invoice, that nothing is missing. If you have not received all parts, please contact EmaZys or your local distributor.

Z200 PV Analyzer std. kit
Z200 PV Analyzer, RRC2054 Battery, RRC-SMB-MBC Standard Battery Charger, Banana-Croc. GND testing lead, Banana-MC4 PV+ testing lead, Banana-MC4 PV- testing lead. Note: The picture shows the std. Z200 PV Analyzer testing kit. A range of different accessories can be supplied from EmaZys - please go to https://emazys.com and see what we can offer. We recommend to also buy and use the tone pickup, when ordering the Z200 PV Analyzer kit. The tone pickup will enable more fault localisation functionality in your instrument. Below is a photo of the tone pickup.

3.2 Commissioning

3.2.1 Battery

Prior to start-up please check that the RRC2054 battery is fully charged. The battery can be charged using the charger that comes with the instrument. See battery specifications in the "Technical data" section.

3.2.2 Control interface

The control interface is separated from the main instrument box in a wireless manner, and you may use a smart device with WiFi transceiver, with an internet browser as controller device. The front panel itself only includes instrument status LEDs, the ON-OFF/WAKE UP button, battery acces, and WiFi antenna.

3.2.3 Cables

Connect the supplied cables to the instrument. The red wire is connected to the Red (+) connection socket, the black wire is connected to the Black (-) connection socket and the Yellow/Green wire is connected to GND. Different solar PV modules may use different connectors, than supplied with the Z200 PV Analyzer std. kit. If you need other types of adaptors, please contact EmaZys or your local distributor.

	Make sure to connect the inputs correctly on the Z200. (Cables are all colored accordingly).

	WARNING. Personal injury /death. Make sure cables used to connect the instrument to photovoltaic modules and strings are CAT III, 1000V compliant.
	WARNING. Personal injury / death. Risk of electrical shock.
	CAUTION. Damage to the machine or accessory. It is not recommended to use cables other than the supplied. The instrument's warranty is no longer valid if other types of cables are used,

4 Safety

Before carrying out measurements with PV Analyzer Z200, you must ensure that:

- there is sufficient space to operate the instrument
- the necessary tools are present on the site
- the operator has a general knowledge of PV modules (photovoltaic modules) and is trained to work in high voltage environments
- the instrument is correctly connected
- the instrument and the measurement cables are in good condition. Check that the cables are not cracked or damaged in any way.

NOTICE.

- The PV Analyzer Z200 and the User Manual are intended for use by adequately trained personnel.
- Before use, the operator must have read the user manual.
- The User manual must be kept near the instrument.

WARNING.

- PV module measurements are performed in high voltage areas. Always use approved safety equipment designed for high voltage installations.
- If subjected to an electrical shock, you must seek medical advice, even if you feel well. Some potentially harmful effects may not occur until several hours after exposure.

CAUTION.

- Exercise caution in use.
- The PV Analyzer Z200 should be used wherever possible in a dry environment.
- The instrument's lid should always be closed during long-term measurements. Make sure to mark up the measuring site.

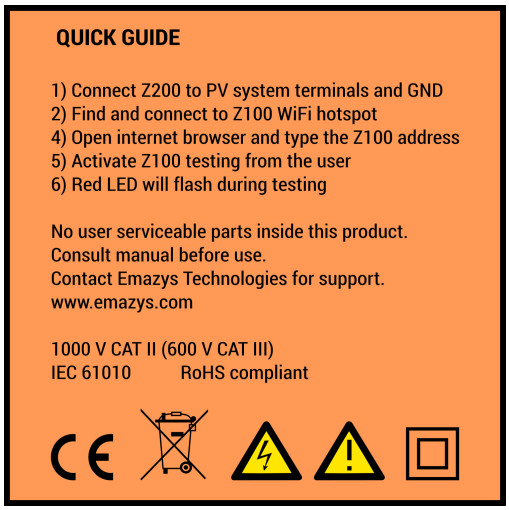
4.1 Instrument self-check

The Z200 also conducts self-check procedures of internal HW components that are critical to the safety of the operator. Self-check procedures are carried out as part of all measurement features and on all involved critical HW components. Failures detected could be temporary (excessive voltages, excessive currents or overheating during measurements) or permanent (e.g. malfunction of a HW component). In both cases, a pop-up window will appear to instruct the operator on how to proceed if a failure occurs. Most often a power OFF/ON cycle will be sufficient to fully analyse and in most cases also clear temporary errors.

4.2 Labelling on instrument

In the lid of the instrument is placed a Quick guide sticker that shows how to get started. You will also find a number symbols for safety etc. Please read and understand these symbols before you start working with the instrument.

	Caution risk of electrical shock
	Risk of personal injury / death
	Waste Electrical and Electronic Equipment Directive
	CE marking - Communautes Europeennes
	Double insulated
RoHS	Restriction of Hazardous Substances



5 Introduction and operation

The PV Analyzer Z200 is a portable and battery powered instrument used to detect and locate faults in strings of series connected photovoltaic modules.

> INFORMATION.
> All Z200 analysis algorithms, assumes that the instrument is connected to a series string of solar PV modules. Correct fault position estimation can hence not be guaranteed, if the Z200 is connected to parallel coupled solar PV module strings.

Specifically, the instrument has the following features and measurement applications:

1. Measure position of a single ground fault in a PV string
2. Measure position of a single disconnect in PV strings
3. PV string impedance curves (health and degradation check)
4. PV string series resistance R_S
5. PV string string open circuit voltage V_{OC}
6. PV string string short circuit current $_{SC}$
7. PV system isolation resistance R_{ISO}
8. PV module voltage
9. PV module bypass diode check
10. PV module shunting resistance (module/cell degradation)
11. Integrated timer for periodic faults
12. Tone generator and tone tracer pickup
13. Build in PDF report generator

The instrument is connected to the string terminals e.g. at the string inverter or combiner box and also to the ground reference for the PV installation.
Once connected and activated, it will perform impedance spectroscopy between any two of the three connected terminals, as well as measure the terminal voltages and currents flowing under various DC loads introduced by the instrument. By combining the results from these various measurements using the on-board computer, critical faults in the system can be defined and positioned.

5.1 Front panel elements

In the illustrations below, you will find a description og each element found on the front panel of the Z200 PV Analyzer. The tables below show sections of the front panel seen in Figure 1.

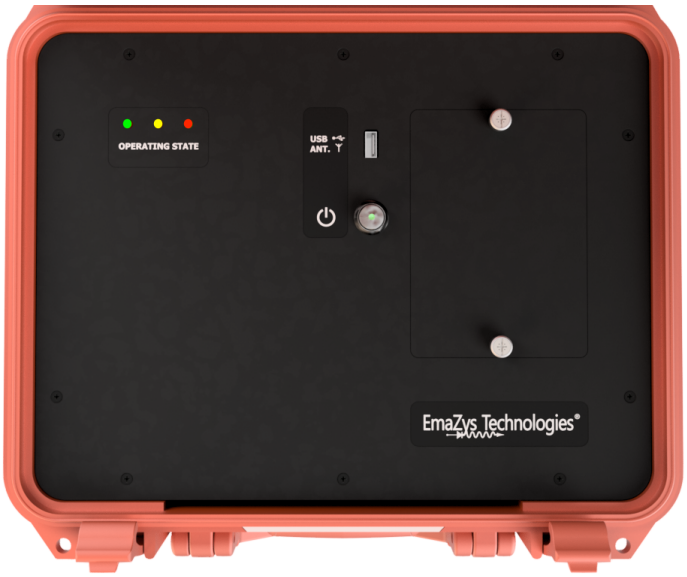
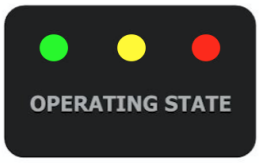


Figure 1: The Z200 PV Analyzer front panel.

	The operating state of the instrument is indicated by 3 colored light emitting diodes (LEDs). The green diode is on when the instrument is turned on. The yellow diode indicates that the WiFi antenna is ready to transmit and receive data. The red LED will in general blink when the instrument is busy with either measurements or analysis

	Placed on the middle of the front panel we find the ON/OFF switch. When the instrument is turned on a small LED in the button will emit green light. The ON/OFF button also controls the "Timer" application. This application is described in detail in the Timer section. The instrument USB antenna is found above the ON/OFF button. **Please never remove this antenna. It is paired to the instrument, and EmaZys support is needed to install a new antenna**.
	The ON/OFF button is in the OFF state, and the instrument is turned off.
	The ON/OFF button is in the ON state, and the instrument is turned on.
	The ON/OFF button is in the WAKE UP state, and the instrument is in the timer mode.
	The Z200 PV Analyzer battery solution is based on a rechargeable RRC 2054 Li-ion battery, that can be reached from the front panel by loosening the two finger screws. The battery cover must be mounted at all times, unless when the battery is being replaced.

5.2 WiFi setup and Z200 WiFi basics

You will communicate with the Z200 through a browser window at all times.

1. After turning on the instrument, the internal computer will set up a WiFi hotspot (local wireless network) that can be connected with other WiFi devices, so make sure that WiFi on your preferred smart device (smartphone, tablet or laptop) is enabled.

2. The name of the hotspot access point will be in the form: "Z200-xxxx-xxxx", where x represents unique numbers for every Z200 hotspot. Once you have found the hotspot simply connect using the password: Xoplag10.
3. Open your internet browser (e.g. google Chrome) and type: "z200/" in the URL bar. If you are already connected to the internet by other means, you have to type "192.168.4.1" instead, as this signifies to your device not to look up the Z200 through a DNS server, but only find it within the local WiFi network itself.
4. When using a new browser to access the Z200 for the first time, it might be necessary to enable PopUps for the Z200 homepage, in order to allow it to store PDF reports from your subsequent measurements. This is e.g. done within Chrome by clicking on the "No PopUp" icon, that appears to the right of the URL-address bar AFTER creating the first PDF report (It is only needed the first time you generate a report).
5. Optional: With Chrome it is possible to make a shortcut to the Z200 homepage, so you can open up directly to the Z200 with an icon of its own. Go to the Z200 homepage, and open the menu to the right of the URL address bar and tap on "Add to home Screen".

INSTRUCTION TIP.
At the following URL https://www.youtube.com/emazys a number of instructional videos can be found. Also, www.emazys.com is frequently updated with relevant technical guidance.

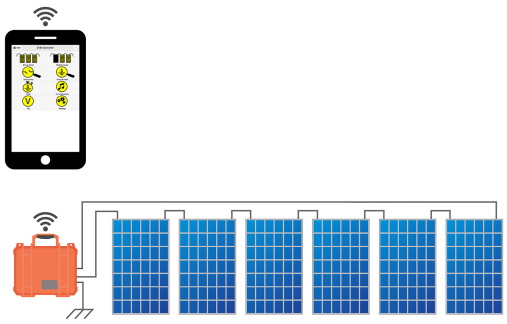


Figure 2: Once the Z200 is correctly connected to the string of photovoltaic modules, it can perform full string analysis controlled from the WiFi connected device.

NOTICE.

1. If the Z200 has been disconnected or turned off, you need to reconnect to the Z200 hotspot.
2. If you get out of reach of the Z200, it may also be necessary to reconnect your device with the Z200, depending on the availability of other nearby networks within reach of your device.

5.3 Requirements for controller devices

The controller device may be a smartphone, a tablet computer or a PC / MAC. It is left to the user to choose his preferred device. In some situations a smartphone may be sufficient, and in other cases when evaluating data, a device with a larger screen may be preferred.

Figure 3: An illustration showing the different options for choice of controller device for the Z200 PV Analyzer. The controller device may be a smartphone, a tablet computer, a PC / MAC or even other unconventional devices.

5.3.1 Recommended internet browsers for controller devices

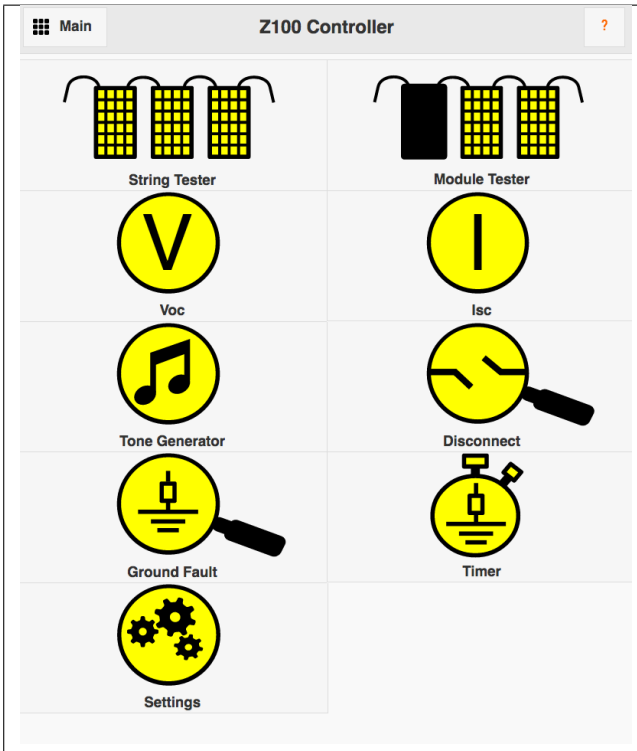
The Z200 PV Analyzer has been optimized for use with the following internet browsers.

	Google Chrome browser
	Apple Safari browser
	Firefox browser

Please note that using other browsers, such as e.g. Microsoft Internet explorer, is not recommended and full functionality can not be guaranteed in such cases.

5.3.2 Appearance of main Graphical User Interface - GUI

Below we see screenshots of the main Graphical User Interface (GUI). The GUI is basically a simple website, hosted on the Z200 PV Analyzer.



Main menu User Interface. This screen will appear in your browser window when connected with the Z200 WiFi hotspot.
1) The **Main** button leads back to this main GUI screen from any other page in the controller interface.
2) The charging state of the battery is seen in the upper middle part of the GUI. In this example we have 44 % capacity left.
3) Press the red question mark at any page in the controller interface, to read a brief summary of the chosen application.

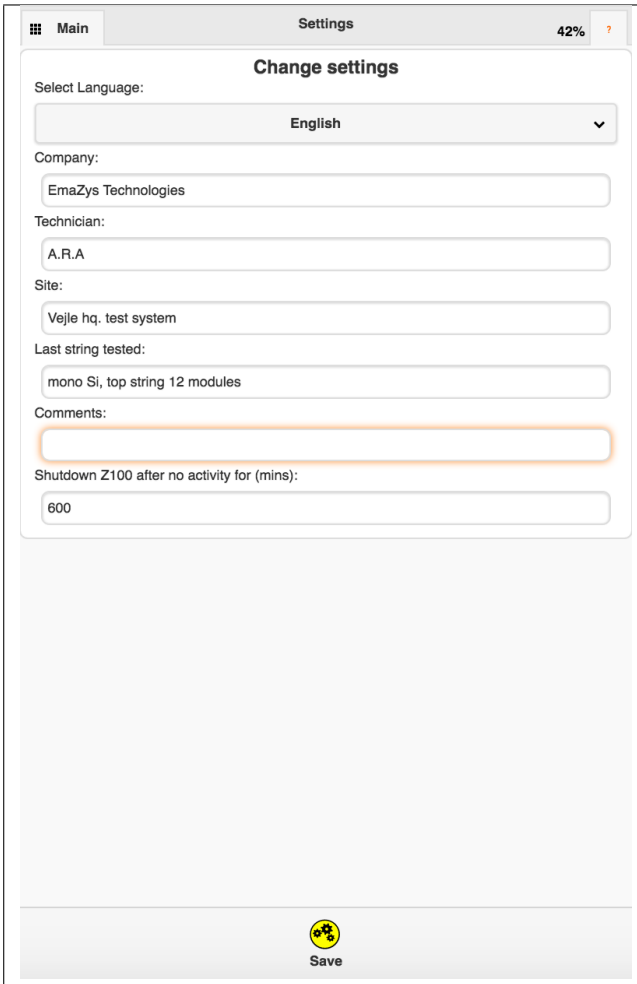
6 Applications and measurements

Some rudimentary control and assessment of the light reaching the string and individual PV modules is necessary. I.e. in order to accurately detect and localize ground faults, and disconnects in cables and connectors, all the modules in the string under test need to be illuminated by at least 100 $\frac{W}{m^2}$. The most accurate results are obtained when the irradiation level is steady throughout your measurement. This is also the case if you want to estimate the overall string series resistance R_S. When checking the health state of module bypass diodes it is also necessary with ambient sunlight intensity at each module of at least 100 $\frac{W}{m^2}$. Please note that testing the health state of the diodes in a specific PV module in the string, requires blocking the sunlight from reaching that module. If R_P of the string or a subset of the string down to individual cells or modules needs to be measured the sunlight needs again to be blocked from reaching the PV cells or modules being tested, however this can be achieved by measuring at nighttime (I.e. R_P of the entire string).

6.1 Settings

APPLICATION.
Settings is used to enter basic information about your company, name of technician, the site you are working on, and other relevant information for documentation purposes. The information entered will go in the PDF report generated by the instrument.

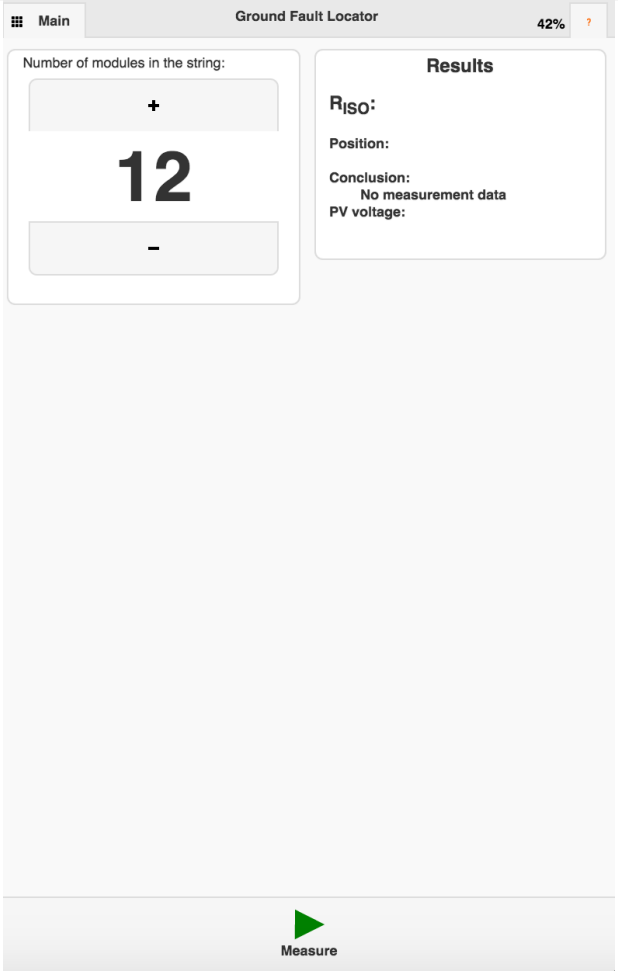
Before starting the actual measurements, it is advised to enter information about the site you are working on. This information will be transferred to the PDF report template found in some other applications e.g. "Ground Fault". The test results from the various measurements, can be transferred into individual PDF reports, which in turn can be downloaded to your preferred device, for documentation purposes.



Select "Settings" in the main menu. Type in your company name, name of technician and site/location. For each measurement report, you have the choice of adding additional information that might be helpful in the subsequent analysis of your results. When the entry is complete, just press "Save". The entered data is then included in the reports made from the various measurements.

6.2 Ground Fault

APPLICATION.
This application is used to measure the isolation of the PV string towards ground. If poor isolation is found, the instrument will attempt to position the fault.



First enter the number of PV modules using the + and - keys. The measurement will take 45-60 seconds. In the Results window the measured R_{ISO} together with the string V_{OC} are returned. After the measurement is done, you can download a PDF report with the results to your device for documentation purposes. Simply press the Generate report button, and follow the instructions in the GUI.

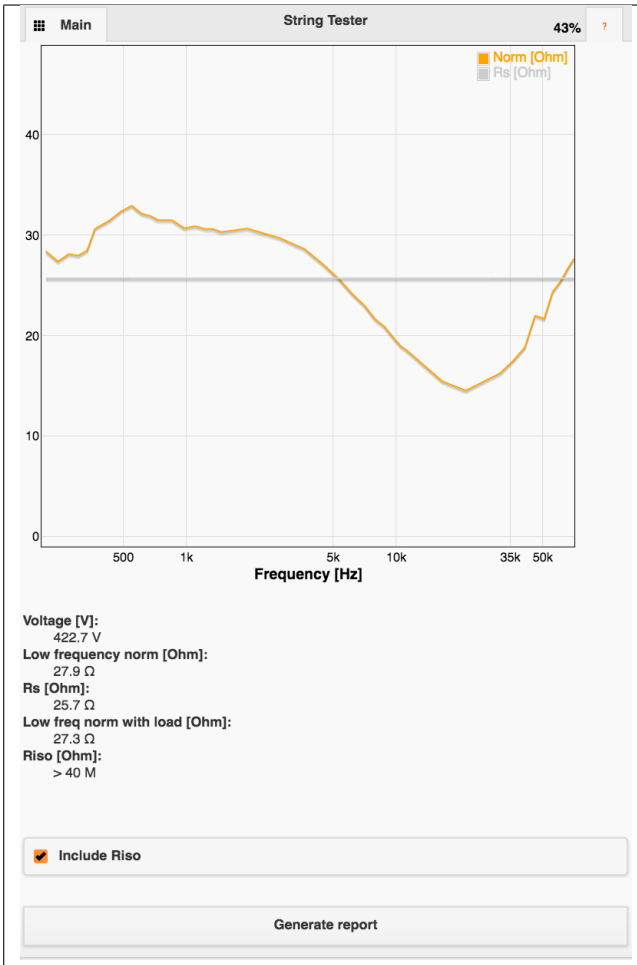
NOTICE.

- Due to the inherent uncertainty of the fault localization method and due to the possibility of multiple or distributed faults, it is highly recommended to verify a fault position by bypassing a given faulty module or cable segment with a known good cable and redo the measurement to ensure good isolation BEFORE repairing the string e.g. replacing a cable segment or PV module.
- It is good practice to verify correct connection of the string to the instrument AND sufficient illumination of modules ($> 100\ \frac{W}{m^2}$) by comparing the measured PV voltage with the expected voltage (Number of modules multiplied by the Voc of each module in the string).
- The measurement analysis assumes that modules in the string are producing evenly. If a fault is not found accurately, it may point to additional or other problems and the user is advised to run a String test.

6.3 String Tester

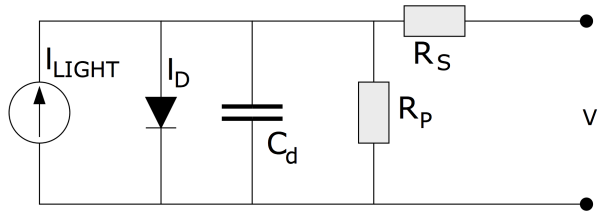
APPLICATION.
The string tester performs a range of impedance measurements. The overall result is an assessment of the health condition of the solar PV module string under test.

The String tester is a diagnostic tool for checking the overall health condition of the PV module string. The basic content of the string test, is to measure an impedance spectrum using the Z200 PV Analyzer pre-programmed measurement routine. The open circuit voltage is also measured, and an optional R_{ISO} measurement may also be included.
The impedance spectrum is recorded by measuring the alternating current flow in the PV module string, when the string is subjected to an alternating voltage test signal, transmitted by the Z200. The impedance is then found by dividing the AC voltage with the AC current, according to *Ohm's law*. The impedance is most often denoted as a complex number, and note that impedance accounts for both ordinary "Ohmic" resistance, as well as reactance i.e. capacitance and inductance. The mathematical theory of impedance spectroscopy, is beyond the scope of this manual, and the reader is referred to textbooks on the subject matter e.g. **Electrochemical Impedance Spectroscopy** by authors Mark E. Orazem, Bernard Tribollet. However, a full understanding of such theory is not a prerequisite to work with the Z200 PV Analyzer.



Connect the instrument to the PV string and press the "Measure" button to collect a spectrum. The measurement will take 30-60 seconds. In the example shown to the right, R_S is 16.9 Ω as is the low frequency norm at a voltage of close to 410V, which indicate a healthy string of 12 x 250 W modules with a decent sun irradiation. With a higher irradiation Rs could go as low as 10 Ω.

The in-depth interpretation of solar PV module impedance spectra requires some knowledge about the physics of a PV string/module. Below is a diagram of a simple so-called three parameter PV string model. It contains the three component parameters R_P the shunting (or parallel) resistance, R_S the series resistance and C_d the diffusion capacitance. The remaining components in the model are the light current generator I_{LIGHT} and shunt diode with current I_D. The current source models the current delivered by the PV string when short-circuited and the diode characteristics determine the open circuit voltage of the string. R_S is the string series resistance that should ideally be close to zero in order to minimize power loss. It is the sum of junction diffusion loss in the PV cells and of all series losses in cables, connectors and bus-bars in the PV modules. An illuminated healthy PV string (with irradiation $> 100\ \frac{W}{m^2}$) will only have an impedance represented by R_S, since the photo diode is fully turned ON by the photovoltaic voltage, and thus effectively shorting C_d and R_P .



Solar module string - equivalent circuit. This model is roughly equivalent to the solar module string, and a basis for understanding the impedance measurement.

1. I_{LIGHT} is the current generated by light on the modules
2. I_D is the diode current
3. C_d is the diffusion capacitance
4. R_P is the parallel (shunting) resistance
5. R_S is the series resistance

R_S should be estimated in the frequency range $f = 100$ Hz to $f = 10$ kHz where the simple model is most accurate (at higher frequencies e.g. effects of cable inductance become a factor and cause the impedance to increase). At EmaZys, a study on more than 500 commercial modules representing various PV cell technologies and sizes, has been conducted. A worst-case relationship concerning the dependence of R_S on I_{SC0} (short- circuit current at 1000 $\frac{W}{m^2}$ irradiation) and V_{OC} (open-circuit voltage) has been

$$R_S < 30\Omega A \cdot \frac{V_{OC}}{100V} \cdot \frac{1000\frac{W}{m^2}}{Irr.} / I_{SC0} \tag{1}$$

Example: Let us see what this means by a concrete example. An operator is in the field conducting measurements on modules having $I_{SC0} = 10$A, string open circuit voltage is 500 V and the irradiation has been measured at 100 $\frac{W}{m^2}$. The R_S on a healthy string should be less than 150 Ω according to the above formula. Let us insert the values an check:

$$R_S < 30\Omega A \cdot \frac{500V}{100V} \cdot \frac{1000\frac{W}{m^2}}{100\frac{W}{m^2}} / 10A$$

$$\Downarrow$$

$$R_S < 30\Omega A \cdot 5 \cdot 10/10A$$

$$\Downarrow$$

$$R_S < \frac{30\Omega A \cdot 5}{1A}$$

$$\Downarrow$$

$$R_S < 150\Omega$$

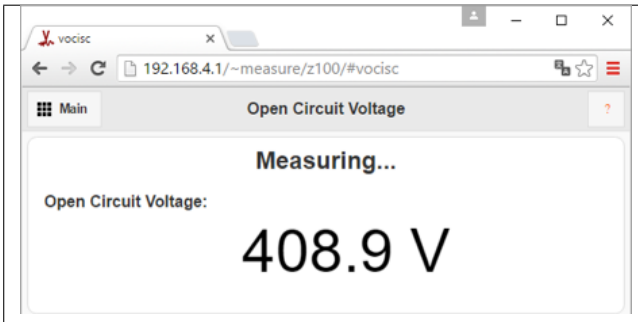
This estimate is generally applicable regardless of technology i.e. it applies to both crystalline and thin film technologies. However, there is significant variation between technologies. For instance, PV modules based on mc-Si cells typically has an R_S value of half of the above estimate or less.
Obviously, when there are many PV strings of similar construction in a test-site it is also possible to find potential outliers by comparison of measurement data. If R_S is found to be too high, it is an indication of a problem e.g. with shading or bad cabling/connectors. If the impedance exceeds 10 kΩ at $f = 100$ Hz, there may be a disconnect in the string e.g. in the form of a bad internal junction, a broken cable or faulty connector. See info box below for tips on how to quickly locate the fault. R_P is the string parallel (shunting) resistance; a value that will be several kΩ per PV module when the solar cells are in a healthy condition. The effect of R_P is only seen in strings that are partially or fully shaded or at nighttime. R_P is estimated at low frequencies where the effect of C_d the diffusion capacitance is minimal.

INFORMATION.

- If R_S is greater than expected, there could be problems internal to one or more modules e.g. with broken bus-bars or corrosion. The operator is encouraged to do a quick baseline measurement in the "Bypass Diode test" function. If the R_S value in this test looks OK, then proceed with the rest of the , which will locate all poor performing modules.
- If R_S remains high in the "baseline" measurement and is above 10 kΩ, then there is probably a disconnect somewhere in the string external to the modules. In this case, the operator is advised to run the "Disconnect" application in order to position the fault.

6.4 V_{OC}

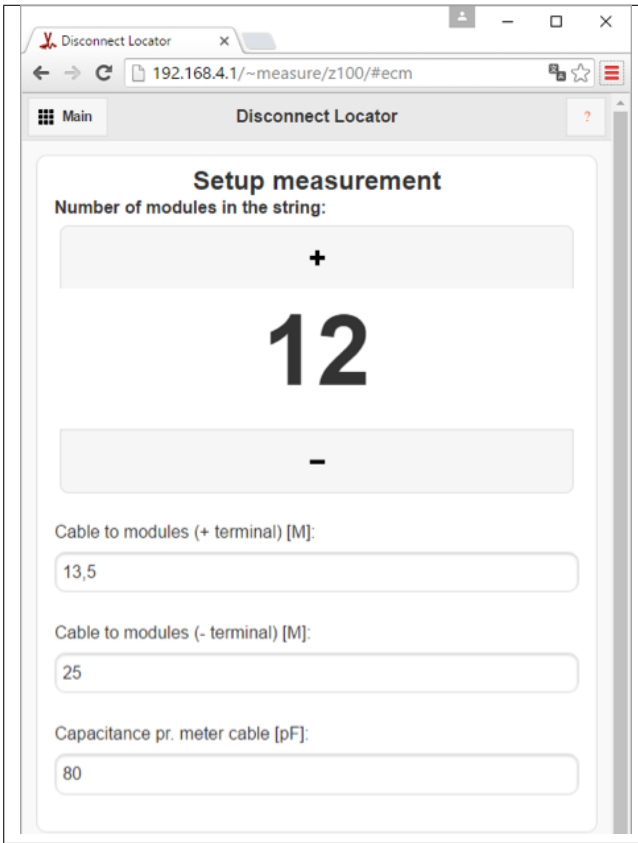
APPLICATION.
The voltmeter is as simple as it appears. The application continuously measure the V_{OC} value at the + and - terminals of the instrument. The value is continuously updated in the user interface



Voltage is shown instantly. In the example to the right almost 410V is measured across 12 x 250 W mc Silicon modules indicating irradiation close to Standard Test Conditions.

6.5 Disconnect

APPLICATION.
The disconnect test is used to measure the position of a disconnect in a string solar PV modules. The instrument will measure the low frequency impedance of the PV string connected. The condition for a PV system disconnect is a string impedance at low frequencies, with a value higher than 10 kΩ.



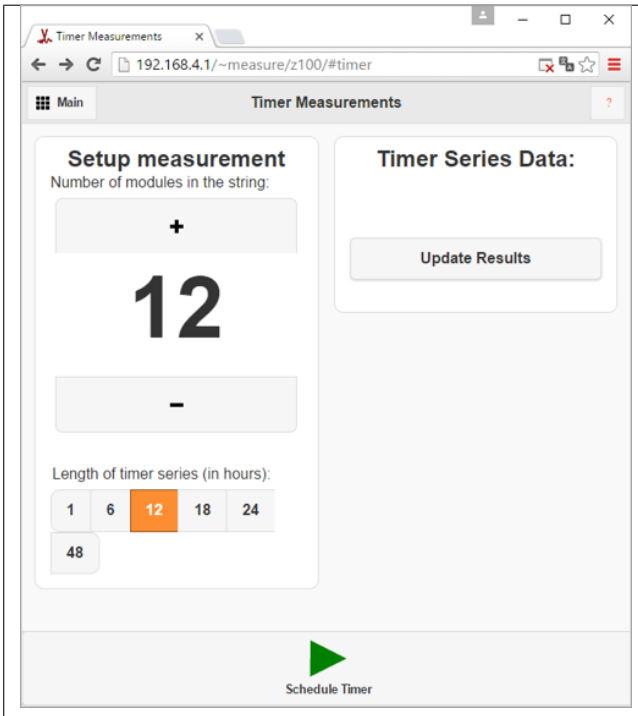
The number of PV modules is adjusted using the + and - buttons Then enter cable length [m] to the positive and the negative string terminal point. Last enter the cable capacitance. Use the default value of 80 pF/m for normal dry weather conditions. Set the value at 120 pF/m in wet and moist environments.

NOTICE.

- Due to the inherent uncertainty of the fault localization method and due to the possibility of multiple faults, it is highly recommended to verify a fault position by bypassing a given faulty module or cable segment with a known good cable and verify string R_S is within range. Typically, a visual inspection of a suspected faulty string element should clearly validate fault position.
- The accuracy of the fault localization is highly dependent on the correct compensation of cable capacitance. If cable lengths and capacitance per unit cable length are unavailable, the user is advised to conduct the measurement close to the string of PV modules, thus omitting most of the cable between the instrument and the solar module string.. This is the reason for the two-step measurement process which allows for a measurement from the positive terminal to ground without the negative terminal being connected and vice versa in terms of the measurement from the negative terminal to ground.
- Cable capacitance can also be measured by disconnecting the cables from the string modules and running the "Disconnect" test which will return the capacitance of both the cable segments. Use this information to insert correct cable information. I.e. the product of cable length and per unit length capacitance should match the measured cable capacitances.

6.6 Timer

APPLICATION.
This application is basically an automatic ground fault test. You can set a timer to perform the ground fault test and thus leave the instrument during testing. This can be an advantage if the ground fault is periodic e.g. if it only shows up in the early morning, but disappears after a few hours of sunlight.



The number of PV modules "N" must be adjusted using the + and - buttons. Select the duration/length of the timer test using the buttons: a ground fault test will be conducted every 15 minutes during the duration of the test . The Schedule Timer button will start the test when pressed. The WiFi antenna will close down during test

When the timer function is active the diode will change colour from bright green to red (WAKE UP state). If the button is pressed in the WAKE UP state, the timer test will be interrupted, and the instrument will wake up to normal operation.

6.7 Module test

APPLICATION.
This application is based on measuring various parameters, when 1 module in a string of modules, is shaded during measurements. This particular approach has the peculiarity that it can reveal latent and complex faults, while still being rather simple to carry out.

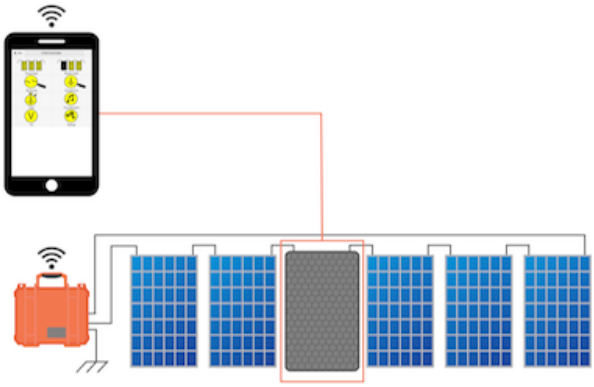


Figure 4: In the illustration we see the general approach to the module test. First a reference spectrum is recorded without any modules shading. Individual solar module are then shaded one by one, while the main measurement parameters are recorded.

The main measured parameters are:

1. **Module voltage estimation**
   The module voltage drop caused by shading modules, one by one, is measured in the string of modules under test. Under normal circumstances, the string voltage drop thus corresponds closely to the voltage of the shaded module. The result of this testing procedure, is an overview of the individual modules voltages in bar diagram form. Modules with a low voltage, relative to the majority of the string modules, may then be identified in a convenient manner.
   If a single module voltage is found to be about 2/3 or 1/3 of the normal open circuit module voltage, the problem could be caused by 1 or even 2 bypass diodes, that are in a short circuit state. Short circuited bypass diodes are often seen as a damage following lightning strikes, but please note that many types of damage could lower the voltage of a solar PV module installed in the field.

2. **Impedance at open circuit condition**
   The low frequency impedance norm, measured in the open circuit state. In the case of fully illuminated modules, the low frequency impedance is normally very low; approximately around the R_S value. A shaded module will however normally show a much raised impedance value, even when it is placed in a string showing a significant voltage. The high impedance appears, since the test signal must travel through the shaded solar cells in the module. The impedance is caused by a phenomenon normally referred to as shunting

resistance (R_{sh} also called parallel resistance R_P), which hinders the flow of return-currents within the solar cell PN junction. In this way a low value of R_{sh} indicates degradation in the module i.e. a condition where generated current is not harvested externally. Especially a gradually falling value of module-R_{sh} toward a string terminal is an indication of Potential Induced Degradation (PID).

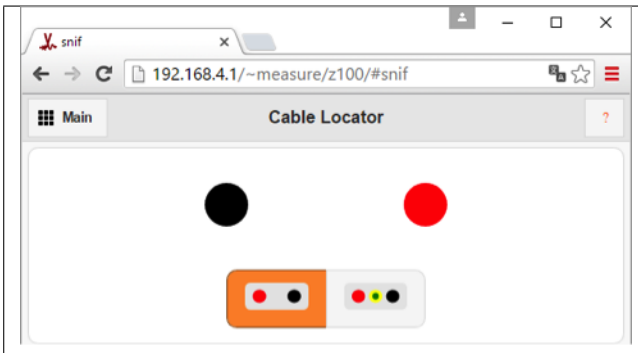
3. **Impedance under operation**
   The low frequency impedance norm, is measured while loading the string with a weak load i.e impedance is measured while a small electric current is allowed to flow in the string. When shading a module, while the instrument is transmitting the test signals (during a current flow) it is thus possible to determine, if the module bypass diodes function as intended. If the diodes do not "open", the instrument will measure a much raised impedance value. The impedance shows up in the measurement, because the test signal must pass shaded solar cells. If the impedance does not change, the current flows in the diodes, and the instrument will conclude that there is no risk.
   The result of the measurement is a Module Risk Factor (MRF), that is assigned to each module. The higher the MRF is for a module, the more likely it is, that electric power will be dissipated in the module in case of longterm shading or internal cell damages. This will in most cases lead to so-called "hot spots" and burn marks, which causes significant irreversible damage to the system.

NOTICE.

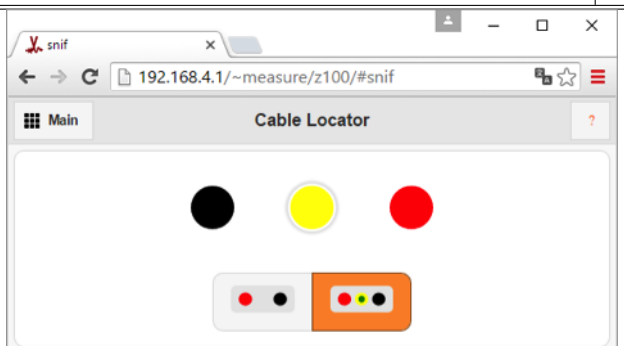
- It has been seen in experiments that the impedance from even adjacent shaded PV cells can vary an order of magnitude. In order to reduce the risk of erroneous measurements it is therefore recommended to use as big a shade as possible i.e. preferably shading the entire module.
- When using the Module test, make sure that the irradiation is not varying. A low irradiation is not problematic, but constantly shifting cloud cover, will to some extend lead to variations in module voltages. If the irradiation changes during testing, make sure to recalibrate as many times as needed, to get the best possible quality of test results.
- The Module test is the most advanced test within the Z200 PV Analyzer range of methods. The method relies on a basic understanding of solar PV module physics, to get the best interpretation of the test result.

6.8 Tone generator and pickup

APPLICATION.
The Z200 is capable of transmitting frequencies that may be picked up and heard as "beep" sounds using a handheld pickup. Such testing allows to determine what string the instrument is connected to, in cases where the mapping of a solar PV system is less than optimal or simply in cases where the system is build by many strings. Disconnections may also be found using the pickup. Simply start the "Tone generator" and use the pickup to detect the transmitted frequencies.



This mode sends out a medium frequency tone between positive and negative terminals.



This mode alternates between high and low frequency between ground and positive, and between ground and negative.

NOTICE.
Important information. If only a partial disconnect exists in the string, it may be difficult to identify the exact position with this method, as the difference in the tones heard will be smaller and smaller the better the remaining connection is.

7 Calibration

It is recommended that PV Analyzer Z200 is calibrated once a year. The instrument must be sent to your local service partner or the manufacturer for calibration.

1. Remove the battery before shipping the instrument
2. The instrument must be securely packed in a suitable cardboard box
3. Shipping back and forth is exclusively at the user's responsibility and cost.

8 Storage and disposal

8.1 Storage

If the PV Analyzer Z200 is taken out of service for a long time, charge and remove the battery.

8.2 Disposal

PV Analyzer Z200 must be returned to EmaZys for correct disposal. Dismount the battery before shipping.

> **!** NOTICE.
> DO NOT try to disassemble the instrument. It must be disposed correctly according to EU regulations

9 Support

If you need support, please contact EmaZys. Go to our website https://emazys.com and find updated contact information e.g. phone numbers. This manual and our website is updated whenever a customer reports a new topic that must be attended. The website also contains various articles with background information and videos to help you.
Please carefully study this manual to unveil the many features and capabilities we put into this instrument. If you still ned support after exploring the materials on your own, please do not hesitate to contact us.

10 Technical data and specifications

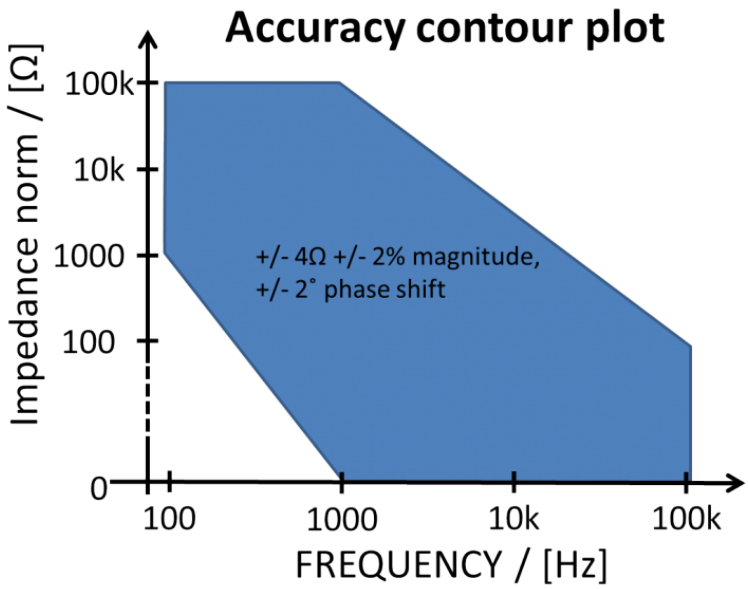


Figure 5: In this graph we see the impedance accuracy contour plot for the Z200 PV Analyzer.

Measurement feature	Z200 PV Analyzer
Frequency coverage	100 Hz to 100 kHz
Frequency accuracy	+/- 2 %
Measurement feature	Z200 PV Analyzer
Frequency drift with temperature (° C to 35 ° C)	>0.1
Measurement of short circuit current I_{SC}	Z200 PV Analyzer
DC current range	0-15 A
Measurement of open circuit voltage V_{OC}	Z200 PV Analyzer
Analysis	Checks for correct polarity and voltage in-range.
Range	0-1000V
Measurement of resistance towards ground R_{ISO}	Z200 PV Analyzer
Range	0 Ω - 40 MΩ
Measurement time	about 60 sec.
Conditions	Irradiation > 100 $\frac{W}{m^2}$ and string V_{OC} > 100V
Precision (stable light conditions)	+/- 50 kΩ +/- 10%
Analysis	Above 40M Ω, R_{ISO} is returned as R_{ISO} > 40M Ω. Below 100kΩ, R_{ISO} is returned as R_{ISO} < 100kΩ
Detection and localization of ground isolation fault R_{ISO}	Z200 PV Analyzer
Threshold for localization of a ground fault	3 MΩ
Localization precision (stable light conditions)	+/- 0.5 PV module
Localization resolution	0.1 PV modules
Conditions	Irradiation > 100 $\frac{W}{m^2}$ String V_{OC} > 100V
Analysis	Fault indicated (with text in user interface) if R_{ISO} <1 MΩ
Detection and localization of series resistance fault external to the PV modules	Z200 PV Analyzer
Localization of singular series fault > 10 kΩ e.g. disconnect	✓(when external to module/solar cells)
Localization precision	+/- 1 PV module
Localization resolution	0.1 PV modules
Conditions	Irradiation > 100 $\frac{W}{m^2}$

Mechanical	
Enclosure	HPRC 2300
External dimensions	external dimension 335x289x155(mm)
Connectors for DUT	3 x case-side mounted shrouded 4mm banana sockets. Rated: 1kV CAT III - 24A
Environmental	
Storage Temperature	-10° C to 55 °C (limited by battery)
Operating Temperature	0 °C to 35 °C (limited by battery)
Operating Altitude	up to 3000 meters
Battery	
Battery model	RCC2054
Technology	Li-Ion, DC 15 V, 3200 mAh, 48.0 Wh
Operating time	8-10 hours
Standby/Sleep time	max. 150 hours in sleep mode
Recharge time	