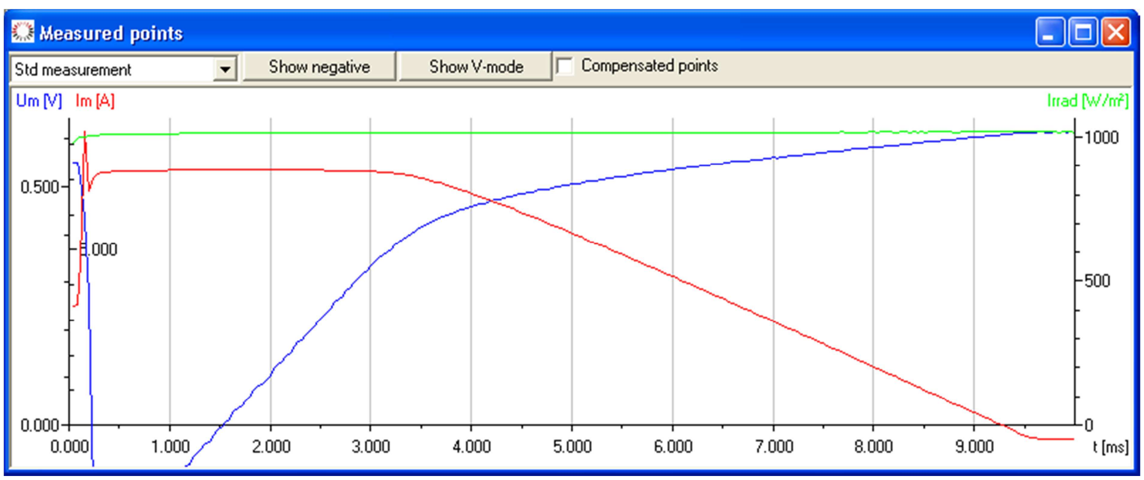
PASAN
MEASUREMENT SYSTEMS

Training Manual

Module: Calibration



SunSim 3b/3c

Part-No.: Osc_020101
Version (Date): beta_16.10.2011

A member of Meyer Burger Group

PASAN S.A.
Rue Jaquet-Droz 8 / CH-2000 Neuchâtel
Phone +41 (0) 32 391 16 16
service@pasan.ch / www.pasan.ch

Table of Contents

1 Learning Objectives

The trainee will understand the principles of the calibration of the SunSim 3c/3b. By using a reference module he is able to calibrate the module tester. The trainee furthermore holds the knowledge that he needs to monitor the system and validate the calibration.

1.1 Requirements

The trainee needs to know the basics of how to operate the SPROD/SLAB software. He needs to have knowledge of how to:

- Create a measurement mode
- Create a monitor cell
- Create a module recipe
- Set up a classification
- Evaluate a measurement
- Understand the measurement cycle

Further the trainee will take over the responsibility for the calibration and therefore should have a sound knowledge of general measurement principles.

2 Security

Never open the lamp housing while the power cable is still connected to the lamp. Risk of sever eye injury and electrocution. High voltage inside.

Never open the flash generator cabinet. Risk of electrocution. High voltage inside.

Never touch the contactors for the module while a measurement is taking place. Risk of electrocution . High voltage can be applied during the measurement.

Never look towards the flash lamp while a flash can occur. Risk of eye injury.

Always switch off the flash generator cabinet when approaching the lightning side of the flash lamp closer than the distance that you have between the module and the flash lamp (SunSim 3c →5.5m, SunSim 3b →8m). Risk of severe eye injury.

3 Calibration

The calibration process of the Pasan SunSimulator can be distinguished into four parts. The calibration of the light uniformity and the e – load are done by the Pasan service engineer resp. the Pasan metrology department, whereas the irradiance and the software calibration need to be done on a regular basis (this will be defined later) and therefore the following instructions form an essential part of our training on the Pasan equipment.

3.1 Uniformity

For a quality measurement it is essential to have an uniform distribution of the light over the pv – module that is being tested. Pasan guarantees that the relative deviation of the irradiance over the maximum test area (2mx2m for a SunSim3c, 3mx3m for a SunSim3b) lies below ±1%. During the installation of the equipment, the Pasan engineer will adjust the orientation of the module holder resp. the light box to an optimum. The uniform distribution of the light is due to the design of the light box (uniformity mask) and the design of the tunnel/tower. Furthermore it depends on the orientation of the light box to the module holder. Whenever the orientation of the module holder is changed, or the tunnel/tower has moved or the fixation of the light box has been altered there will be the need to check resp. to adjust the uniformity. To check the uniformity, a Pasan reference panel, consisting of one encapsulated cell is measured on 64 evenly distributed spots over the testing area. The measured Isc which is proportional to the irradiance is marked on a map and the relative deviation calculated. According to the gradient that is shown on the map, the orientation between the light box and the module holder is altered.

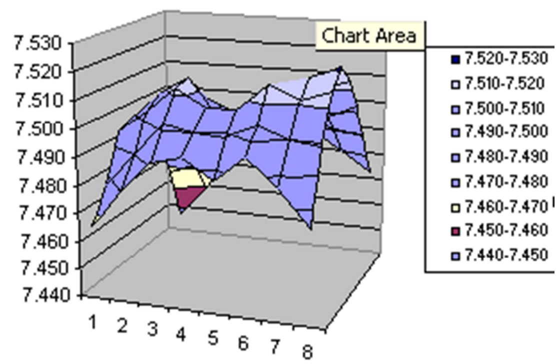


Fig 1: Uniformity map

If above conditions apply, then the light uniformity of the SunSim will remain within the specifications during its lifetime. An exchange of the flash tubes will NOT demand any adjustment! During the Site Acceptance Test (SAT) the uniform light distribution will be proved by our service engineer or our local representative.

3.2 Measurement cards

We advice for an annual calibration of the measurement cards BV 67-3 and BV 66-4. This can only be done at our calibration laboratory. Contact us via service.admin@pasan.ch 2-3 months before the calibration is due. If you are located outside Europe, please do this via your responsible service center. Pasan will send you a lending set with calibration certificate that you will use while you turn in your set for re-calibration. Once we have checked and re-calibrated your cards, we will send them back to you and will provide an incertitude report.

3.3 Irradiance adjustment

In most cases the SunSim will be used to obtain measurement results that are computed to Standard Test Conditions (STC).

These are:

- Device under test is (DUT) at 25°C
- The spectrum of the light is AM 1.5
- The irradiance is 1000 W/m2

3.3.1 Stable irradiance

You want to have the irradiance stable and at 1000W/m2 during your measurement. There are three software settings that have an influence on the irradiance:

- the flash capacitance load
- the irradiance adjust factor
- the monitor cell sensitivity

Flash capacitance load:

This setting can be accessed via: Menu→Config→Setup and determines to which final voltage the capacitor banks in the flash generator will be loaded. 100% corresponds to 800V. Typical values range between 80% and 94%. This value needs to be increased, if the irradiance starts dropping towards the end of the measurement time of 10ms (behaviour when the tubes get older). This you can check by having a look at the graph (Fig 3) and the value (Fig 4) window.

After an exchange of flash tubes the flash capacitance load is decreased again.

It is advised to monitor the irradiance and if necessary to perform an adjustment of this parameter. In the machine settings Fig 2: you can force an error message by setting a limit for the accepted deviation over the irradiance points that fall in the range between the Isc and Voc points. This can support your manual monitoring of the system.

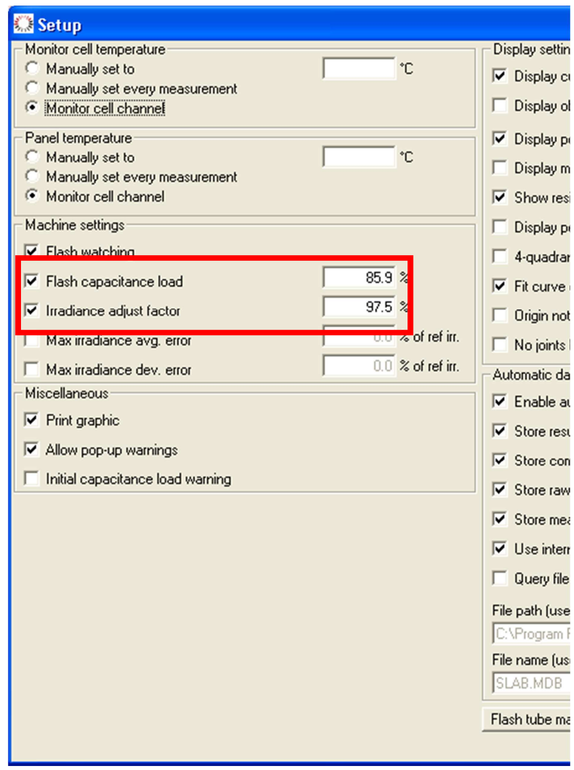


Fig 2: Machine settings

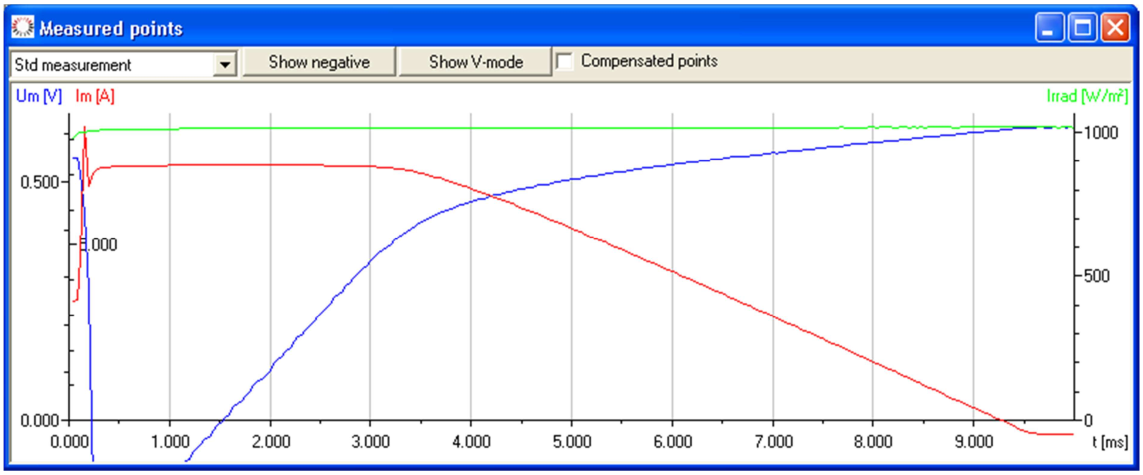


Fig 3: Graph window of the raw measurement points over time. Green – irradiance, red – current, blue – voltage

List of measured points

Std measurement

Point []	Vimp [V]	Vread [V]	Iread [A]	Irrad [W/m²]	Ucomp [V]	Icomp [A]	Pcomp [W]
36	-1.184	-0.038	7.158	997	-0.038	7.179	-0.273
37	-1.175	-0.028	7.158	997	-0.028	7.179	-0.200
38	-1.165	-0.028	7.158	997	-0.028	7.179	-0.200
39	-1.156	-0.013	7.163	997	-0.013	7.184	-0.095
40	-1.146	-0.009	7.163	998	-0.009	7.177	-0.063
41	-1.137	0.007	7.158	998	0.007	7.172	0.053
42	-1.128	0.018	7.163	998	0.018	7.177	0.126
43	-1.118	0.019	7.158	998	0.019	7.172	0.137

Fig 4: Values window. Vread, Iread, Irrad (marked red)

Irradiance adjust factor

This setting can be accessed via: Menu→Config→Setup and holds the value for the gain of the irradiance regulation loop. In the control theory this is the multiplier, the I element of the control loop. The value that is set for the irradiance adjust factor (Fig 2) is proportional to the avg. irradiance which is displayed in the values box on the main window (Fig 5).

By doing a cross multiplication (rule of three) you set this value so you get an avg. irradiance of 1000W/m2.

As a compensation will be done to the reference irradiance and the relation between irradiance and current is very proportional in this range the final error will be small. But nevertheless, adjust this if you are outside 1000W/m2 ± 3W/m2.

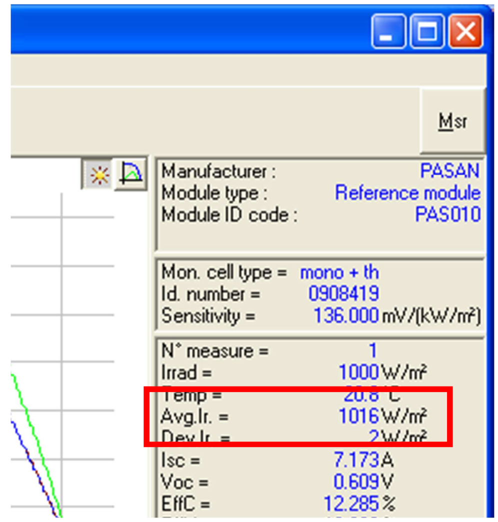


Fig 5: The avg. irradiance measured

Monitor cell sensitivity

The monitor cell (MC) sensitivity marks the set point for the control loop. The sensitivity of the MC is set in the software and can be accessed via Menu→Config→Monitor Cells.

You can create different instances of monitor cells.

The sensitivity setting has direct influence on the power of the flashing light. If that value is measured by the measurement card, then it is assumed, that we receive 1000W/m2. For example, if you use a low value for the sensitivity of the MC, less irradiance needs to be emitted so that this voltage can be measured by the e – load (a voltage drop over a shunt resistance on the MC). If you increase the value, more light needs to be emitted in order to get that set point. Changing the sensitivity value will therefore have direct and proportional influence on the current you will measure on your DUT. This you can best observe by monitoring the data point(s) for Iread when Vread becomes zero (Fig 7).

3.4 Reference panel

A solar panel is referred to as a reference panel, if the measurement results for this panel are already known.

These characteristic values (Isc,Voc,Mpp) can be entered in the reference panel recipe.

The source of these values can be different and some more trustworthy than others. The highest certainty on the values of the reference panel you get, if it was tested by an accredited institute and when the measurement results are stated in a calibration report together with their uncertainty. Such modules are commonly called "golden" reference panels. Furthermore the calibration certificate states at which temperature and which irradiance these values were obtained. In most cases they provide the measurement results at STC, i.e. at 25°C and 1000 W/m2. If a golden reference panel is used to calibrate the SunSim and a second module with yet unknown values is then flashed and measured with those exactly same settings as the reference panel before, then a "silver" reference panel is created. A copy can never be as good as the original and therefore the uncertainty of the results of a silver reference will always be higher than the one of a golden reference.

It is a common practice to get the golden references validated/recalibrated by an institute once a year. When creating a silver module you always calibrate with the golden module that fits closest. A close fit is defined by the following order: (decreasing importance)

- Used cell technology (the spectral response is different, poly or mono)
- Cell manufacturer, cell size, type etc.(spectral response)
- Number of cells in parallel (can change the measurement channel)
- Number of cells in serie (might change the measurement channel)
- Glass, back sheet (spectral response)
- Contact type (series resistance)

3.5 Calibration process

The closer the testing conditions are to the STC the less post processing and compensation needs to be done to the measurement data. This will minimize the overall measurement error. So when performing a calibration you need to:

- have the DUT as close to 25°C possible and use an IR sensor to measure the temperature. (if this is not possible and you have a delta T >4°C to 25°C, recalculate the reference Isc given in the measurement report of the institute to your actual temperature using the known alpha factor for this reference DUT)
- know about its temperature compensation coefficients
- trust the given values (Isc,Voc,Mpp) for the reference panel
- adjust the irradiance in order to absorb 1000W/m2 with your DUT
- have a stabilised irradiance already at the first datapoints that are used to calculate the IV - curve

The SunSim will be calibrated, so that its measurement results will fit the known characteristic values of a reference panel. After having set up the reference panel parameters in a way, that a quality measurement can be performed, the irradiance is adjusted to the extend, that the reference receives true1000W/m2.

As explained in 3.3.1, the irradiance is proportional to the Isc and the values of the golden reference panel are guaranteed to be obtained at STC. We can now change the monitor cell sensitivity. The sensitivity is set to a value, so that the same Isc can be measured as the one given by the reference. Then it can be assumed, that the reference absorbs 1000W/m2 of light. This calibration is referred to as “the physical calibration on Isc by setting the monitor cell sensitivity”.

The physical calibration is then followed by a software calibration. Calibration factors are calculated and the raw measurement values scaled by these factors. This can be done by a calibration wizard. This step can also be regarded as the fine tuning of the calibration.

Remark:

The adjustment on the irradiance via changing the sensitivity of the MC is necessary, because the spectrum of the Xenon-flash-tubes is different than the spectrum of the sun at 1.5AM. Also and depending very much on the cell technology, poly and mono crystalline cells have different sensitivities to different spectral bands of the sun light. This is, why it is necessary to set the irradiance according to the different capability of the cells to absorb the generated light.

3.6 Calibration procedure

- Set up the measurement recipe for a reference panel so that a quality measurement is obtained.
- Check the machine settings (flash capacitance load, irradiance adjust factor) so that the avg. irradiance will be at 1000W/m2

- Control, that for the measurement points where Vread crosses from negative to positive the irradiance is already stable (1000W/m2 ± 3W/m2). To achieve this you might need to decrease the start scanning voltage and/or set a trigger delay. Using the trigger delay setting is the better practice.
- If you set a trigger delay, make sure to also decrease the “Sample number” in the measurement mode (that you are using) to the extend that the “Single flash measurement duration” + “Trigger delay” is not longer than 10ms. Also control, that T compensated results is activated and Irradiance compensation IEC 60-891 is selected.

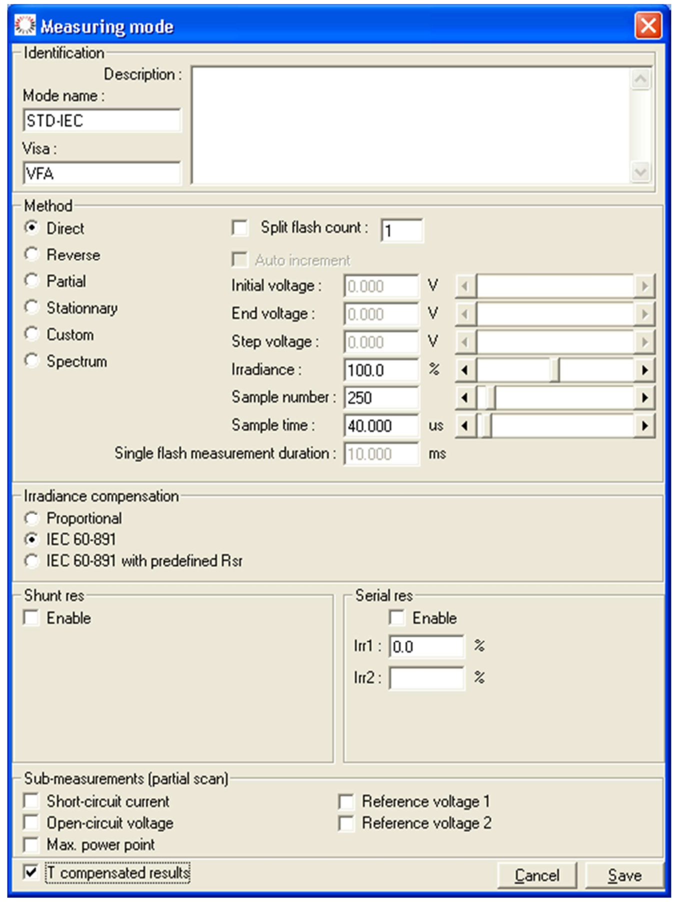
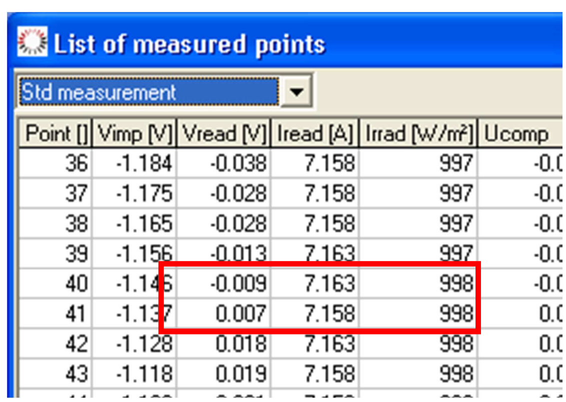


Fig 6: Measurement Mode

- Perform a flash and note down the value for **Iread** that you get at the measurement point where **Vread** crosses from negative to positive values. Also note down the current sensitivity of the monitor cell (**SENSold**).
- Calculate the new sensitivity (**SENSnew**) of the monitor cell, so that Iread of the next flash will correspond to the known Isc (**Iref**) of your reference. Calculate by using the formula that describes this proportional relation: **SENSnew=Iref·SENSold/Iread**



Point []	Vimp [V]	Vread [V]	Iread [A]	Irrad [W/m²]	Ucomp
36	-1.184	-0.038	7.158	997	-0.(
37	-1.175	-0.028	7.158	997	-0.(
38	-1.165	-0.028	7.158	997	-0.(
39	-1.156	-0.013	7.163	997	-0.(
40	-1.146	-0.009	7.163	998	-0.(
41	-1.137	0.007	7.158	998	0.(
42	-1.128	0.018	7.163	998	0.(
43	-1.118	0.019	7.158	998	0.(

Fig 7: Iread at Vread=0 (choose the mean of the two values)

- Enter this new sensitivity for the monitor cell you are using in the Monitor Cell list.
- Perform a second flash to validate your calculation

The physical calibration of the irradiance by setting the monitor cell sensitivity is now done.

Now the calibration wizard can be used to tune the calibration by calculating calibration factors. Compensated data points for the current and the voltage will be calculated by computing the raw values with these factors.

3.7 Calibration Wizard

A description more in detail can also be found in the Software User Manual.

The calibration wizard (Fig 9) is a tool that supports the user in calculating and setting the software calibration factors for Isc, Voc and Mpp. It furthermore will record the history of the calibration of a reference panel and will display the measurement results and mark the error between the measured and the reference value. When a measurement of a reference panel is performed, that calibration wizard window will automatically pop up.

If this is not the case, then close the software, go to the installation directory and open the software PCONF. In case the computation of the calibration factors is not selected, do so and save and exit.

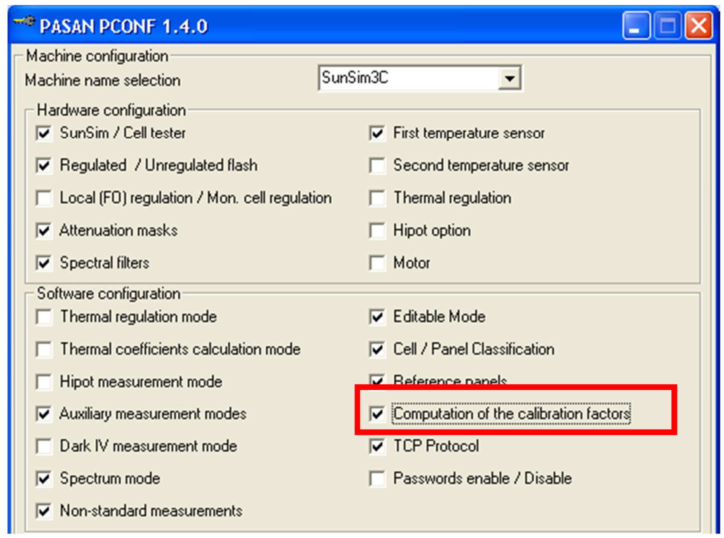


Fig 8: Select computation of the calibration factors

When now a measurement is made, the calibration wizard window will pop up (Fig 9). If you don't need it you just close it. The window is divided into two areas, one that holds the history of the calibration and the other one that displays the calibration results.

Each one of the three reference values Isc, Voc and Mpp is compared with the actual measurement result. The calibration factor that was used for the current measurement is also shown as well as the proposed new calibration factor.

I order to save and to use the proposed new calibration factors, it is necessary to enter your initial in the field Visa and to confirm this with "Enter". Only then the field Change calibration factors will be highlighted. You select this field and choose "Validate". Now a second measurement needs to be made to validate the new calibration factors. If the shown error (either on Isc, Voc or Mpp) remains above 0.2%, then repeat the above step. In some cases if the difference between the new calibration factors and the old ones is too high, the wizard will need two goes to exactly calculate the new factors.

3.8 Linking the module to a reference panel

It is possible to inherit the calibration factors of a reference panel and to then also use them for the measurements done with a module from the modules list. It is however important, that some of the settings of your module from the modules list correspond to those of the reference that you plan to link to. These are the settings that have direct influence on the voltage ramp and the measurement scale (Absolute max. voltage, Start scanning voltage, Absolute max. current, Trigger delay). The operation to perform this link is simple.

In the module recipe you double click on the entry for “Reference panel”. The list of the reference panels will pop up. You select the reference panel and confirm by the button “Use”. Now the name of the reference panel that you selected is displayed in your Module parameter window and the same calibration factors will be applied to this module.

3.9 The measurement

- Select the module you want to flash from the module list
- Select the corresponding Monitor cell from the Monitor cell list. It is the same one you used to perform the calibration on the reference panel that you linked your module to.
- Select the measurement mode

4 Validation of the Calibration

It is a good practise to use a classification also for the reference panel. The advantage is, that you will immediately notice when the measurement falls out of those limits that you defined in its single class. If this is the case, then you will be warned by red letters in the calibration wizard window. If your measurement falls into your defined class, then the reading will be in green letters.

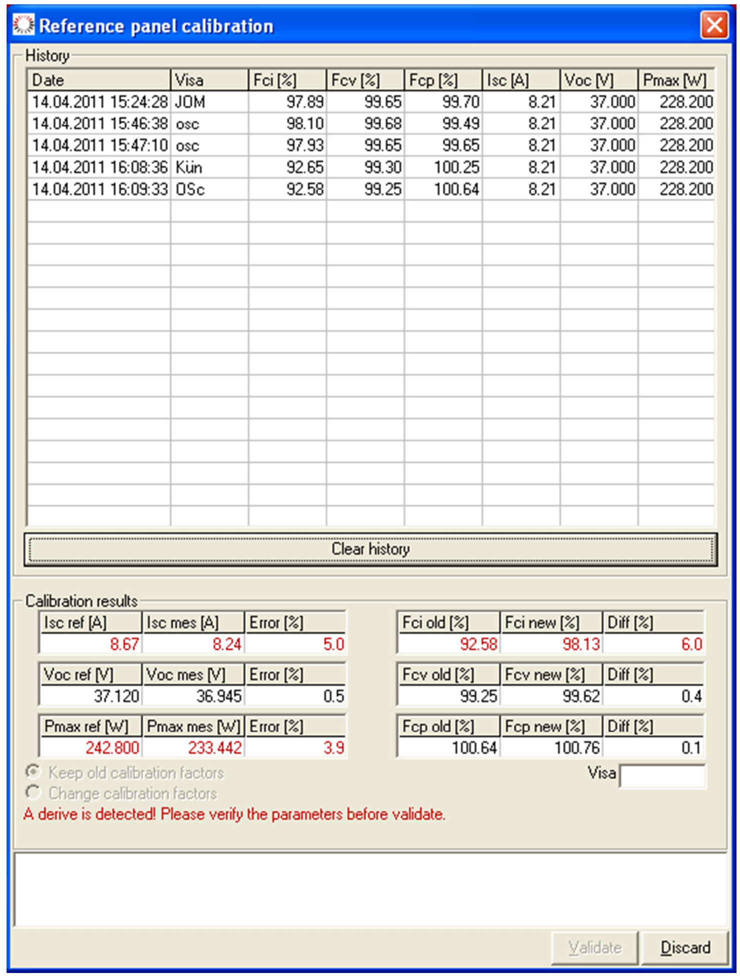


Fig 9: Calibration wizard, the reference values for Isc, Voc and Pmax as well as the measured values are displayed and the error calculated. The old and proposed calibration factors are also shown.

Typically you check if Isc, Voc, Mpp is within a range of ± 1% of your reference values (Fig 10).

You will want to check your reference panel on a regular basis, we advise to do this at least once a day. Most manufacturers do this at the beginning of each shift or after every x flash. For this test you don't want to use the golden module, because the risk is quiet high, that it can get damaged by the constant handling. For this routine test you use the silver module.

4.1 Re-Calibration

Monitor the history of your reference panels. If you notice a drift in the calibration factors, it can indicate, that your reference lost some of its power due to exposure to light and aging. It can also indicate worn out contacts or a monitor cell or filters in the light box that are never cleaned and continuously become more and more dirty.

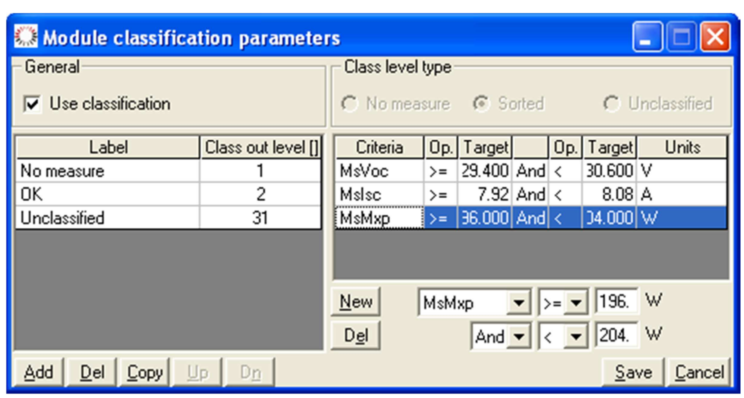


Fig 10: Classification of the reference within 1% margins

You can limit the aging of your golden module by storing it in a dark place. And its best to store it close to your desired testing temperature. (25°C optimal)

If you don't use it for the routine check you also prevent, that its contacts get worn out.

The silver reference however is

handled more often, it will age faster and its contacts are stressed more. This is why you want to remake your silver reference on a regular basis, say every three months or if heavily used more often, or if the monitoring of the calibration factors give you an indication.

Recalibrating with the golden module

You are advised to recalibrate with the golden module after an exchange of the flash tubes. The reason therefore: each set of flash tubes has a slightly different spectrum. The recalibration you perform as mentioned above - by first adjusting the sensitivity of the monitor cell and then by running the calibration wizard.

You also want to recalibrate the system when you exchange the connectors to your module because this goes hand in hand with a change of the overall series resistance in the measurement loop. Whenever you insert new measurement cards in the e-load you will also consider a recalibration. Whenever a change is done to the measurement chain:

light box – tunnel – monitor cell – e-load –connectors, verify your calibration!!

Get your golden module recalibrated by an institute once a year or if you suspect it could have been damaged. Don't save on this one.

Don't only have one golden module. Each module type that you manufacture should have a corresponding golden reference.

Remarks: