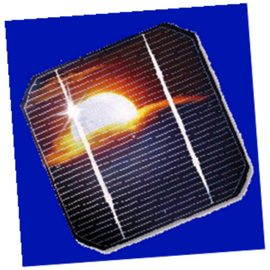

Determining the parameters of solar cell

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Measurement environments

- in the lab;
    1. Measurements under illumination;
    2. Measurements in the dark ;
- in natural light conditions;

Methodological analysis

- The fitting procedure, using either the one or the two diodes model;
- The Analytical Five Point Method;
- The Simple Conductance Technique;
- The Conductance Optimization Method;
- The approximation equation and fitting procedure;
- Etc….
- The methods for determining the series resistance and not only:
    1. Method of slope at the (V_{oc},0) point;
    2. The two characteristics method;
    3. The area method;
    4. Maximum power point method;
    5. The simplified method of the maximum point;
    6. Method of Quanxi Jia and Anderson;
    7. Ideal one-dimensional Case;
    8. Method of the two-diode solar cell model;
    9. A static method;
    10. The generalized area method
    11. Etc….

The main parameters for measuring solar cells performance

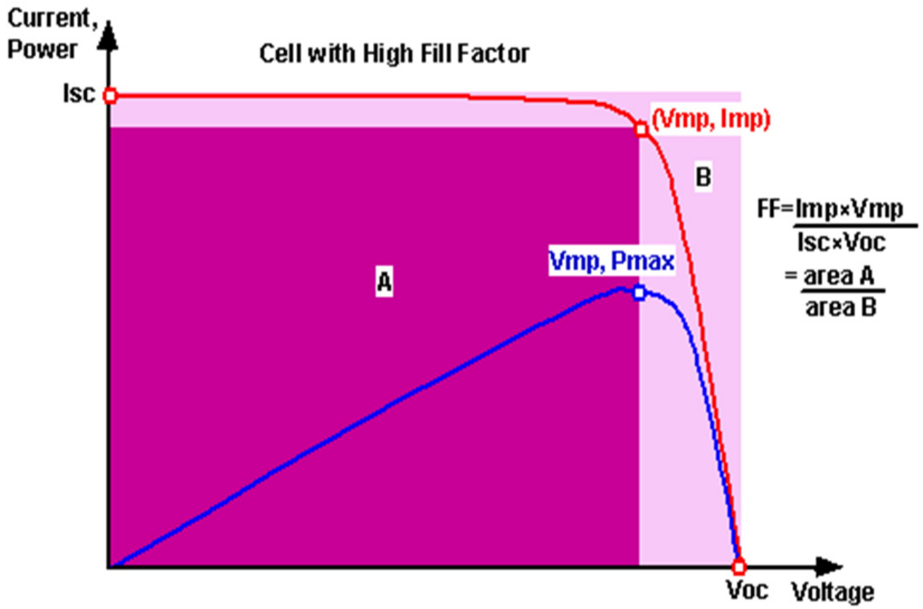
- I_{sc}-short circuit current;

The short circuit current (Isc), is the current which is generated by the solar cell if it is connected to a low impedance forcing the voltage across the device to V = 0.

- V_{oc}-open circuit voltage;

The open circuit voltage (Voc), i.e. the voltage which builds up across the cell as long as its terminals are kept on high impedance forcing the electrical current to I = 0. This quantity is related to the bandgap of the semiconductor used.

$$V_{oc} = \frac{kT}{q}\ln\left(\frac{I_{ph}}{I_o} + 1\right)$$



- FF- fill factor;

The fill factor (FF) corresponding to the ratio of the power which can need be generated by the solar cell (under maximum power conditions i.e. when it is connected to a suitable charge) to the product of Voc*Isc This factor is related to the curvature of the I-V characteristics.

$$FF = \frac{P_m}{V_{oc} \times I_{sc}}$$

- Cell efficiency;

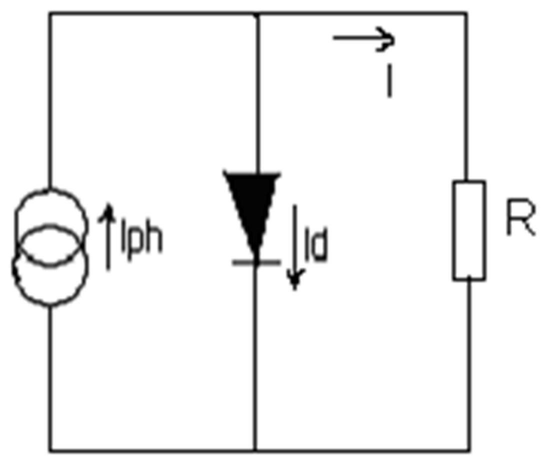
The cell efficiency can be determined from these three external parameters and from the area of the cell

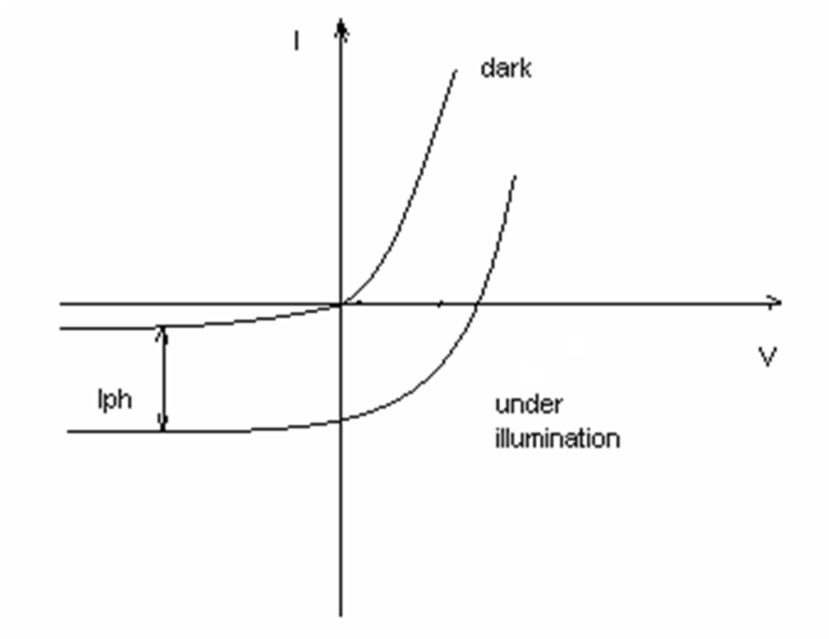
$$\eta = \frac{P_m}{P_{in}} = \frac{V_{oc} \times I_{sc} \times FF}{incident \quad solar \quad power}$$

Equivalent circuits

- the static regime;
- the dynamic regime (alternative)

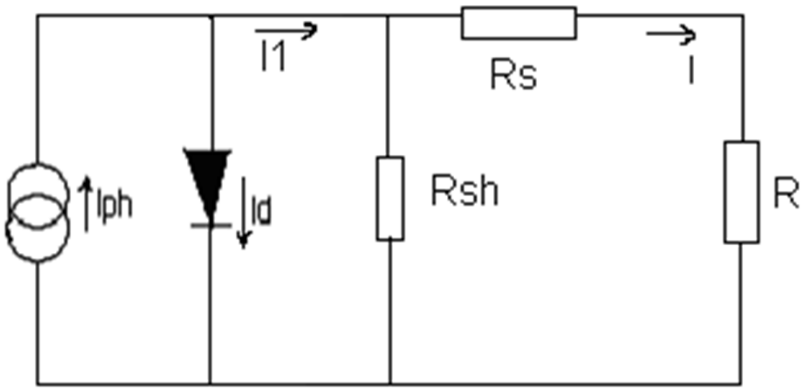
The simplest equivalent circuit





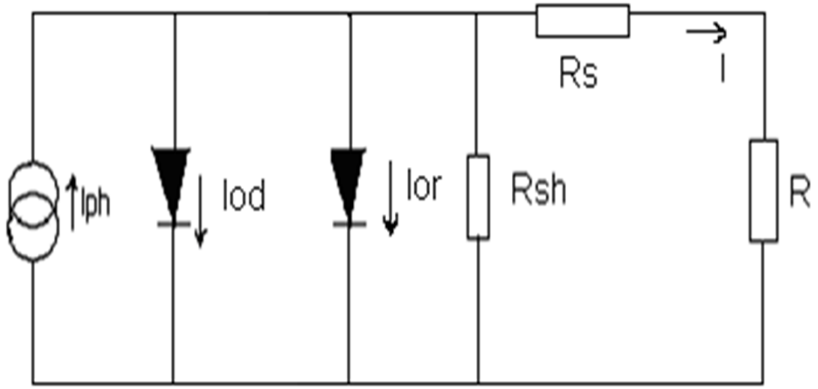
$$I = I_{ph} - I_o\left[\exp\left(\frac{qV}{kT}\right) - 1\right]$$

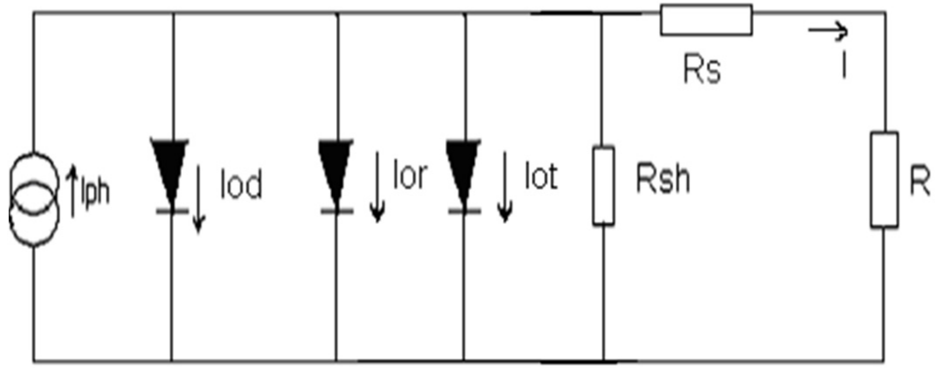
The equivalent circuit with R_s and R_{sh}



$$I = I_{ph} - I_o\left(\exp\left(\frac{q(V + IR_s)}{kT}\right) - 1\right) - \frac{V + IR_s}{R_{sh}}$$

The complex equivalent circuit





$$I = I_{ph} - I_{od}\left(\exp\left(\frac{q(V + IR_s)}{m_1 kT}\right) - 1\right) - I_{or}\left(\exp\left(\frac{q(V + IR_s)}{m_2 kT}\right)\right) -$$

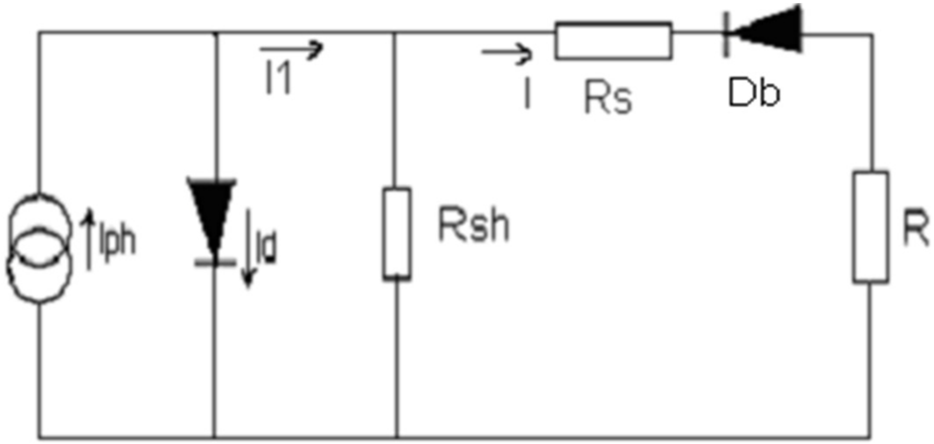
$$- \frac{V + IR_s}{R_{sh}}$$

$$I = I_{ph} - I_{od}\left(\exp\left(\frac{q(V + IR_s)}{m_1 kT}\right) - 1\right) - I_{or}\left(\exp\left(\frac{q(V + IR_s)}{m_2 kT}\right) - 1\right) -$$

$$- I_{ot}\left(\exp\left(\frac{V + IR_s}{m_3 kT}\right) - 1\right) - \frac{V + IR_s}{R_{sh}}$$

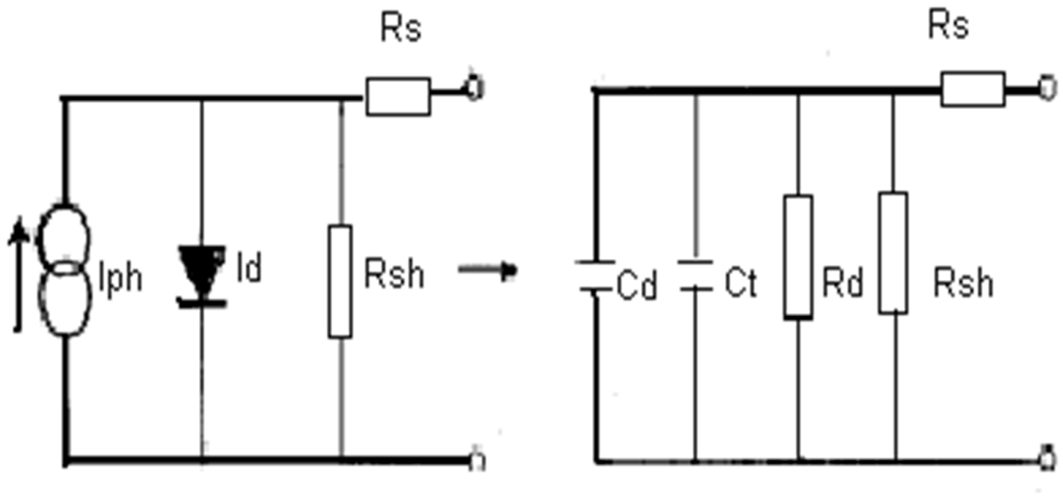
The equivalent circuit for the CdTe cell

Whereas for the silicon cells it was shown that it is useful to take into consideration the second diode as well in the model describing the currents mechanisms in the cells, in case of thin film cells (heterojunctions) this only has a small influence, which can thus be neglected (Gottschalg, 1997). But the standard one diode model cannot completely describe the CdTe(thin film) cells.



- For a CdTe cell the back contact must be taken into consideration, here being formed a metal-intrinsic-semiconductor junction opposed to the main junction. This contact is manifested by two effects:
- the roll over effect – the I-V characteristic is saturated close to the open circuit voltage for low operating conditions;
- the cross over effect –I-V curves in the dark and under illumination are intersected, thus the super positioning principle being contradicted.
- The cell behavior is influenced by the Schottky diode only at small temperatures. As it doesn't belong to the active junction it will only play the role of a resistance which will be added at the series resistance of the cell.

Passing from the equivalent circuit in static regime to dynamic

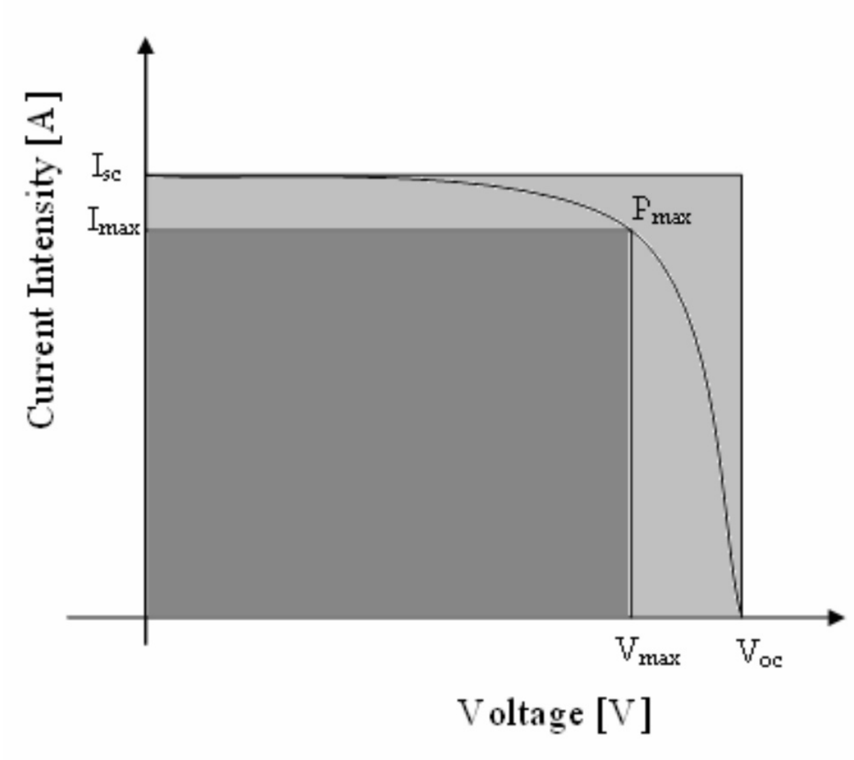


The equivalent circuit from fig. is obtained by replacing the diode with its diffusion capacity C_d, the barrier capacity C_t and the dynamic resistance in parallel with the shunt resistance

- Why about raising I-V characteristic of solar cells?
  - The I-V characteristic is one of the most important methods of determining and studying the parameters of solar cells
- Comparisons
  - Autolab
  - Capacitor
  - MOSFET
- Conclusions

THE I-V CHARACTERISTIC OF SOLAR CELLS

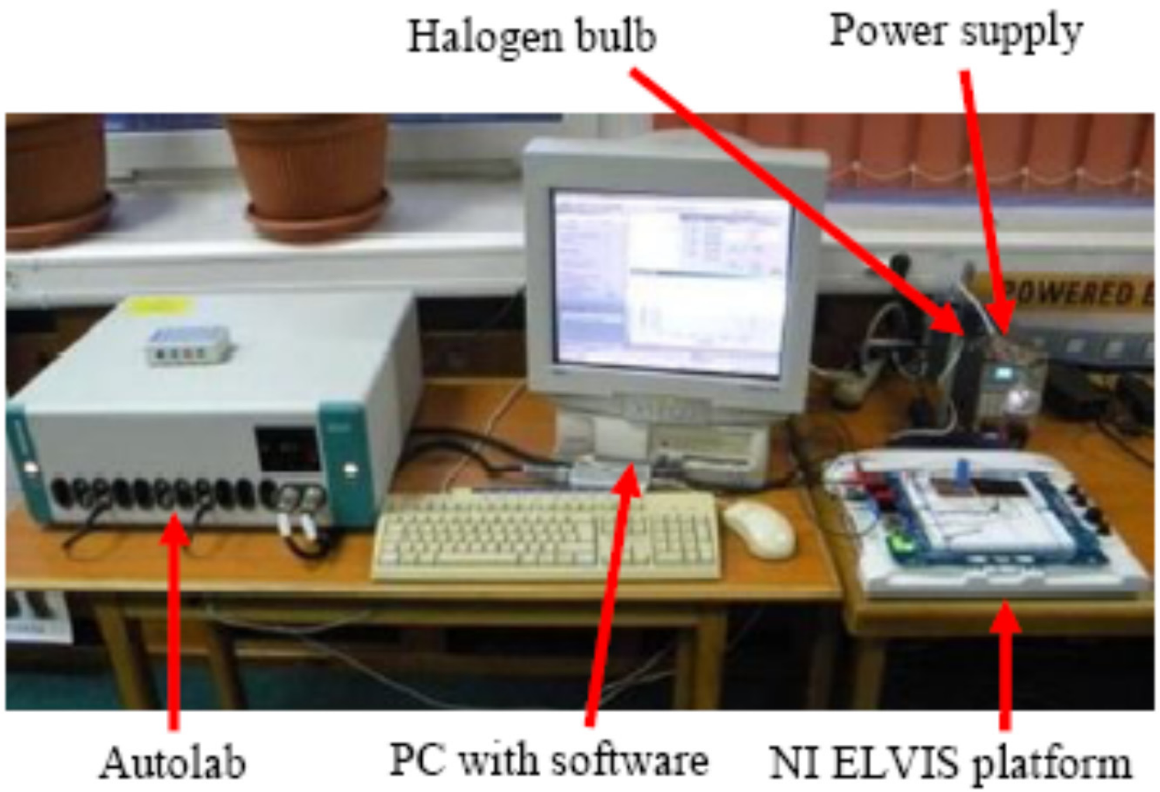
- Determining the solar cell parameters is important for industrial considerations as well as for scientific research.
- It can be performed using various methods. One of the most widely implemented is the use of the current- voltage characteristic, I-V, under illumination or in the darkness.



TECHNIQUES OF RAISING THE I-V CHARACTERISTIC OF SOLAR CELLS

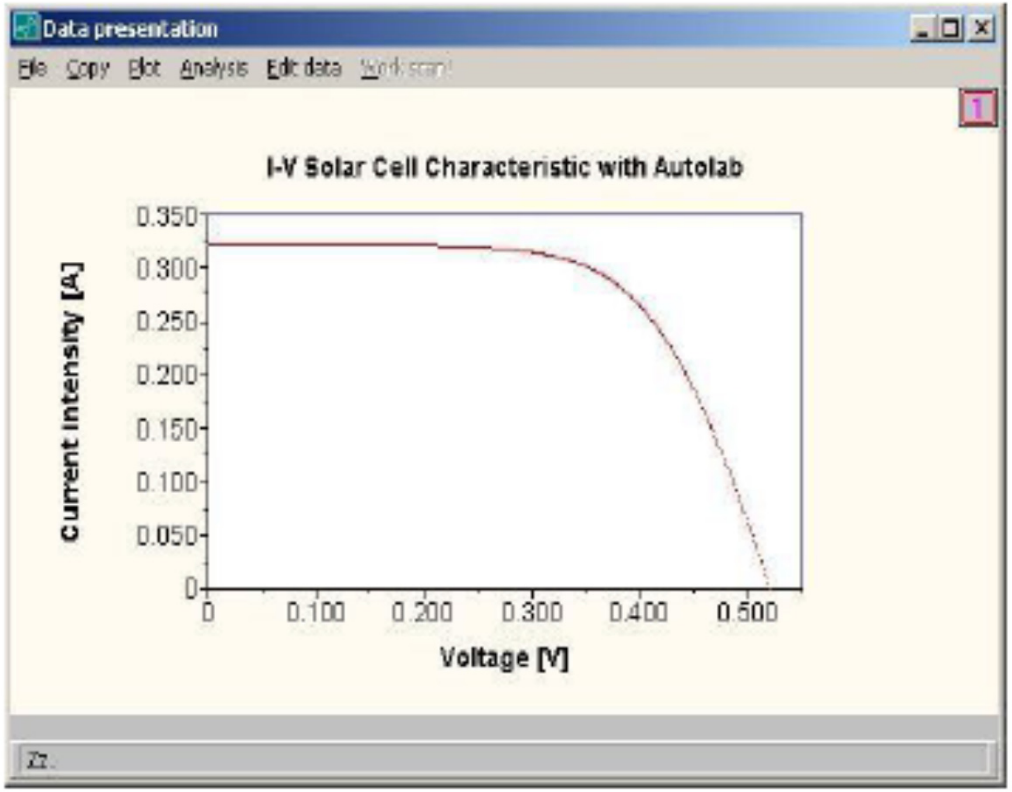
– Autolab –used as a electronic load
– Capacitor
– MOSFET

The system configurations



The electronic load

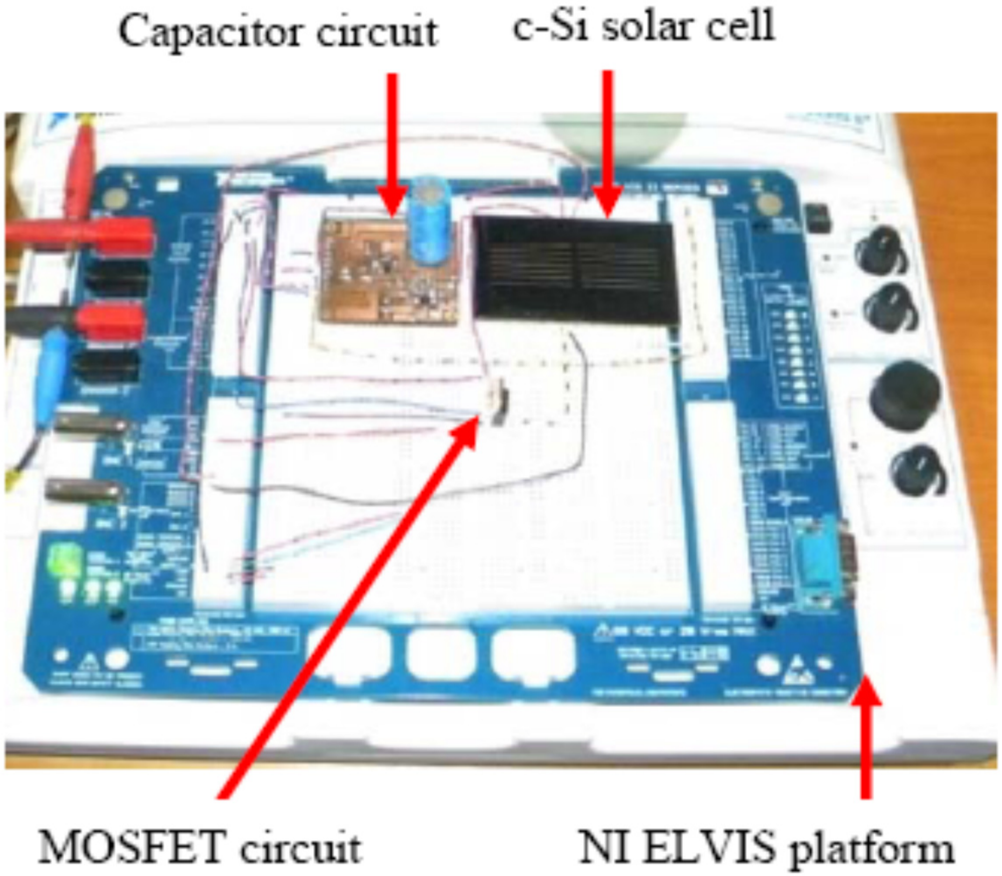
- The raising of the I-V characteristic of the solar cell using the electronic load was realized with the Autolab, used on the mode “Potentiostat”.
- The points (V,I) were acquisitioned using the method Cyclic voltammetry.
- The number of points (V,I) measured was 990, and the duration of measurements was 30 s. The I-V characteristic for the c-Si solar cell is presented in the figure.
- The advantage of this technique lies in the possibility to start the characteristic from the voltage of zero volts.



NI ELVIS setup

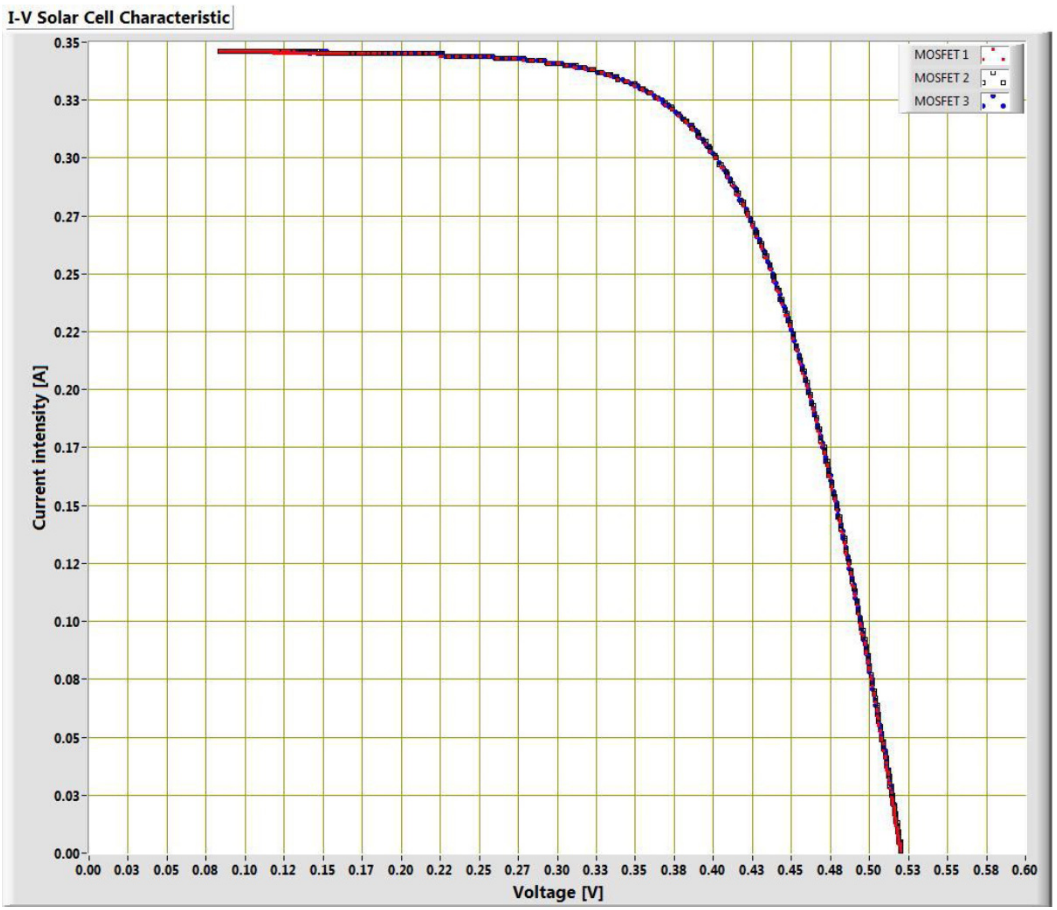
NI ELVIS II a real “music” “from the past” to “the future” in engineering research and education !

NI Educational Laboratory Virtual Instrumentation Suite



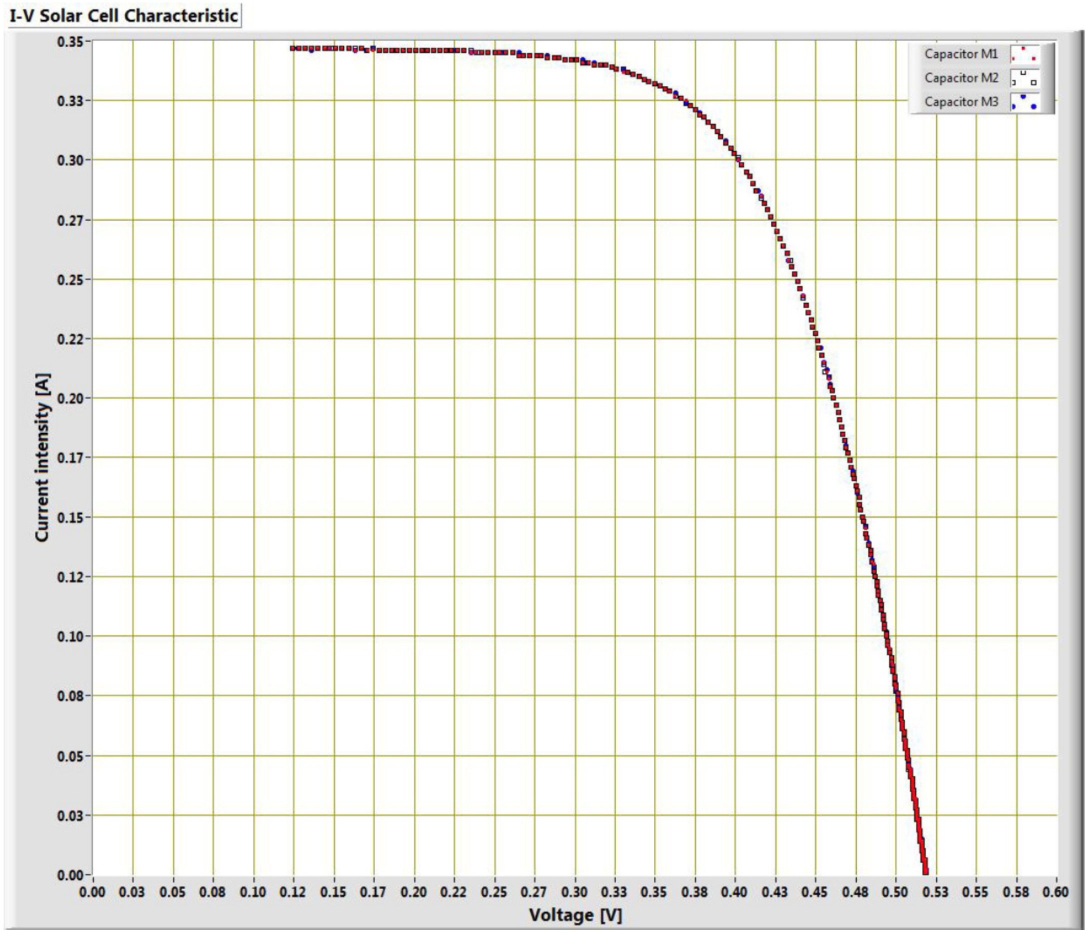
The solar cell I-V characteristic raised with MOSFET

- The raising of the I-V characteristic with the MOSFET technique was realized by using a simple circuit.
- For the command of the transistor MOSFET a triangular 1 Hz signal was generated with the module Function Generator of the NI ELVIS platform.
- The signals (both voltages) were measured on the channels AI_0 and AI_1.
- The amplitude of the signal was chosen so that the transistor works on the linear portion and covers completely the cell characteristic. The MOSFET transistor plays the role of a variable resistance.



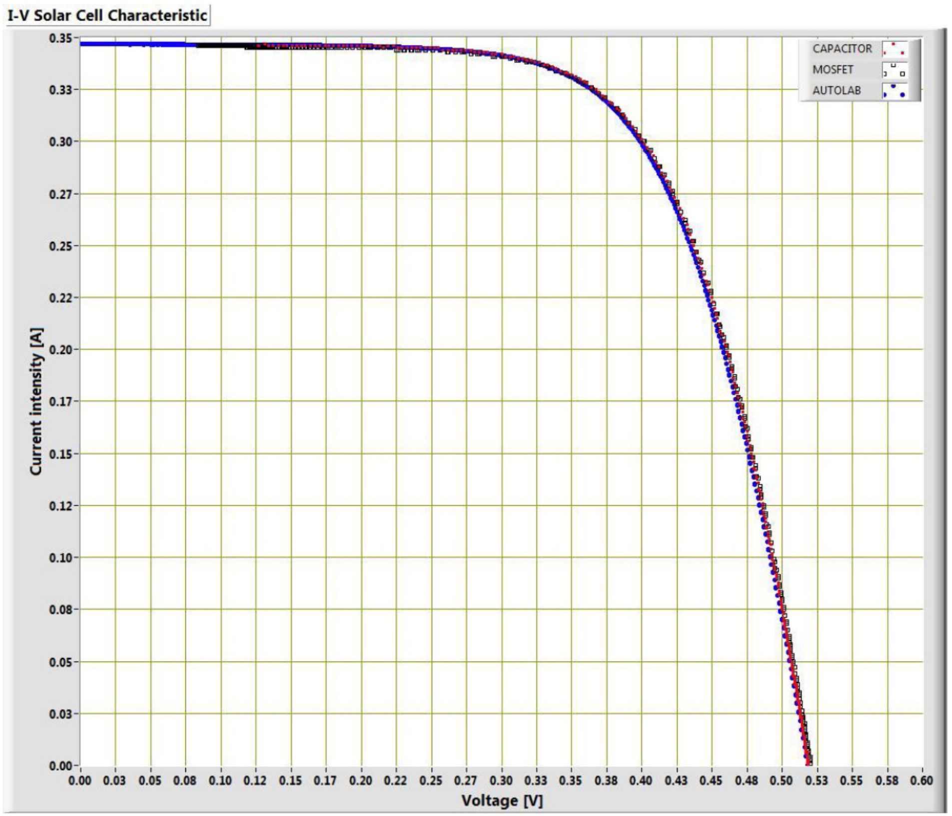
The capacitor method

- The principle of this technique consists of: acquisitioning the values for the current (the voltage drop is measured on the resistor) and for the voltage on the capacitor charging cycle.
- The capacitor starts to charge when the cell is connected to it.
- The capacitor is charged starting from the short circuit current (I_{sc}) until the cell reaches the open circuit voltage (V_{oc}).



The comparison

1. It is observed that for the MOSFET and capacitor techniques, the characteristic doesn’t start from the zero value for voltage. A part of the characteristic is thus lost.
2. This is due to the internal resistances of the used MOSFET and solid state relay and the resistance on which the voltage drop is measured to determine the current generated by the cell.
3. The smaller the resistance used for the current measurement is, the fewer points are lost from the characteristic.



The comparison

- The advantages presented by the MOSFET and the capacitor techniques are:
  - a much smaller time to raise the characteristic in comparison to the one needed in the electronic load technique;
  - the large number of points (V,I) that can be acquisitioned in a very short time, facilitating a very good fitting;
  - the cell parameters remain constant throughout the measurement;
  - the cost is very low for both methods.

Conclusions

- By raising the I-V characteristics on the same graph, a good matching is observed between the three characteristics.
- It can be concluded that for the raising of the characteristic much cheaper devices can be used than the electronic load that have the advantage of a small duration of raising the solar cell characteristic and they can also be used for high power.
- Thus, portable devices can be designed on the basis of these techniques of solar cells characterization that allow the checking of the panels or arrays at the mounting place, not necessarily in the lab.
- From measurements it was observed that any resistance that is added to the circuit translates the I-V characteristic towards the left.
- From this perspective, in the raising of the I-V characteristics of the solar cells, it is necessary to consider the minimizing of the supplementary resistances introduced in the circuit (the internal resistances of the components under use, the connection wires' resistances and the contacts…)

The Analytical Five Point Method

The method consists of determining the cell parameters by using: Voc, Isc, Im, Vm, R_{so}, R_{sho}

$$R_{sh} = R_{sho} = -\left(\frac{dV}{dI}\right)_{I = I_{sc}}$$

$$B = \ln\left(I_{sc} - \frac{V_m}{R_{sho}} - I_m\right) - \ln\left(I_{sc} - \frac{V_{oc}}{R_{sh}}\right)$$

$$m' = \frac{A}{V_T\left(B + C\right)}$$

$$C = \frac{I_m}{I_{sc} - \frac{V_{oc}}{R_{sho}}}$$

$$A = V_m + R_{so} I_m - V_{oc}$$

$$m = 10m'$$

$$I_o = \left(I_{sc} - \frac{V_{oc}}{R_{sh}} \right) \exp\left(- \frac{V_{oc}}{m' V_T} \right)$$

$$R_{so} = -\left(\frac{dV}{dI} \right)_{V=V_{oc}}$$

$$R_s = R_{so} - \frac{m' V_T}{I_o} exp\left(- \frac{V_{oc}}{m' V_T} \right)$$

$$I_{ph} = I_{sc} \left(1 + \frac{R_s}{R_{sh}} \right) + I_o \left(\exp\left(\frac{I_{sc} R_s}{m' V_T} \right) - 1 \right)$$

R_{s0} and R_{sh0} are obtained from the measured characteristic by a simple linear fit

An approximation equation

- As the fitting of the I-V characteristic is more accurate and easier the less parameters must be determined, an approximate equation can be found, and it gives good results. Thus the reverse saturation current is eliminated.

$$V = -IR_s + \frac{1}{\Lambda}\ln\left\{\frac{I_{sc} - I}{I_0} + 1\right\}$$, where $$\Lambda = \frac{q}{mkT}$$

$$I_0 = \frac{I_{sc}}{\exp(\Lambda V_{oc}) - 1}$$

$$V = -IR_s + \frac{1}{\Lambda}\ln\left\{\left[\frac{I_{sc} - I}{I_{sc}}\right]\exp(\Lambda V_{oc}) + 1\right\}$$

exp(ΛVoc) x exp(-ΛVoc)=1

$$V = V_{oc} - IR_s + \frac{1}{\Lambda}\ln\left\{\frac{I_{sc} - I}{I_{sc}} + \exp\left(-\Lambda V_{oc}\right)\right\}$$

For short circuit condition,(I = Isc) in equation, we get V < 0 and in order to impose V = 0, a coefficient B will be added to equation

$$V = V_{oc} - IR_s + \frac{1}{\Lambda}\ln\left\{\frac{I_{sc} - I}{I_{sc}} + B\exp\left(-\Lambda V_{oc}\right)\right\}$$

$$0 = V_{oc} - I_{sc}R_s + \frac{1}{\Lambda}\ln\left\{B\exp\left(-\Lambda V_{oc}\right)\right\}, \qquad B = \exp\left(\Lambda I_{sc}R_s\right)$$

$$V = V_{oc} - IR_s + \frac{1}{\Lambda}\ln\left\{\frac{I_{sc} - I}{I_{sc}} + \exp\left[\Lambda\left(I_{sc}R_s - V_{oc}\right)\right]\right\}$$

The Simple Conductance Technique

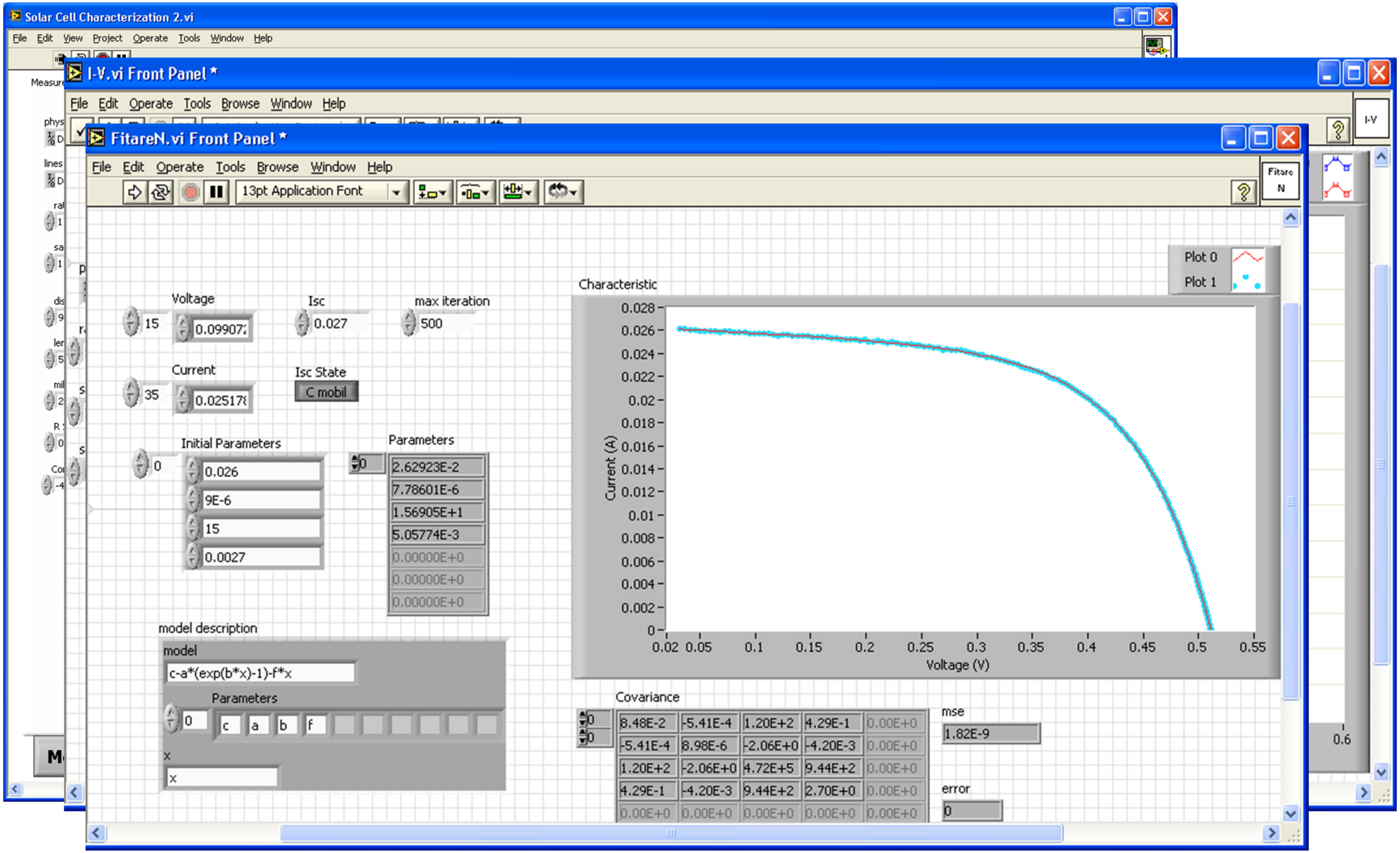
$$I = I_{ph} - I_0\left(\exp\left(\frac{q(V + IR_s)}{mkT}\right) - 1\right)$$

$$G = -\frac{q}{mkT}(1 + R_s G) I_0 \exp\left(\frac{q(V + IR_s)}{mkT}\right)$$

$$G = -\frac{q}{mkT}(1 + R_s G)(I_{ph} - I)$$

$$\frac{G}{I_{ph} - I} = -\frac{q}{mkT}(1 + R_s G)$$

It is based on the Werner method which has been adapted for solar cells and used to determine the solar cell parameters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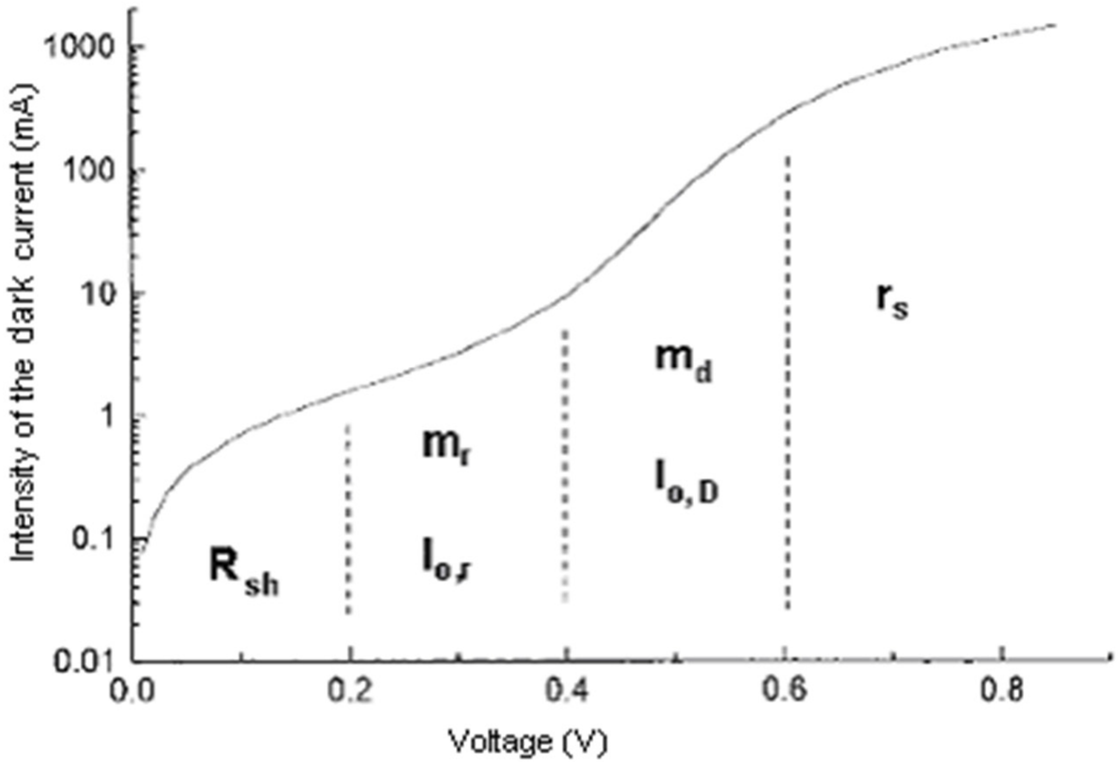
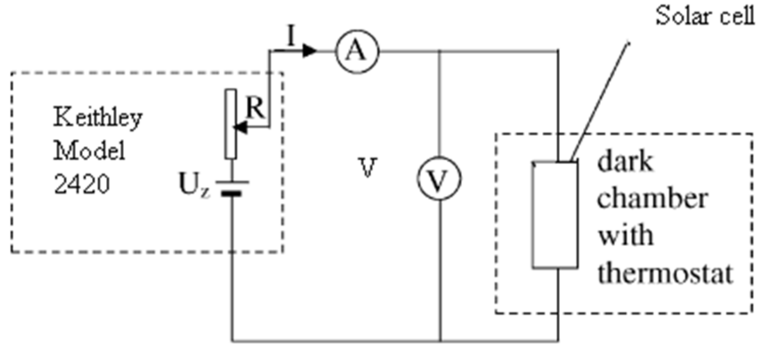
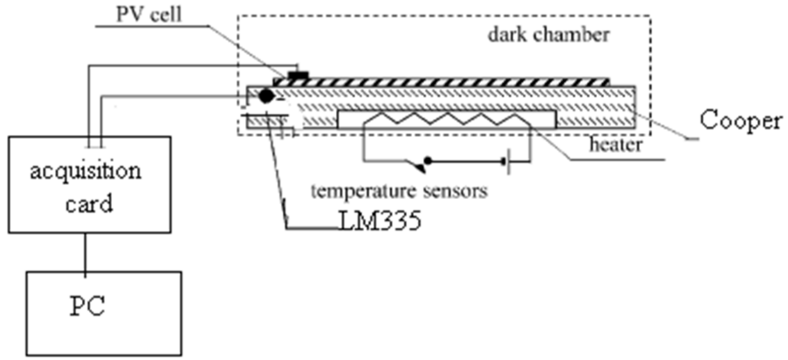
Semi-log I-V characteristic for solar cell under dark condition



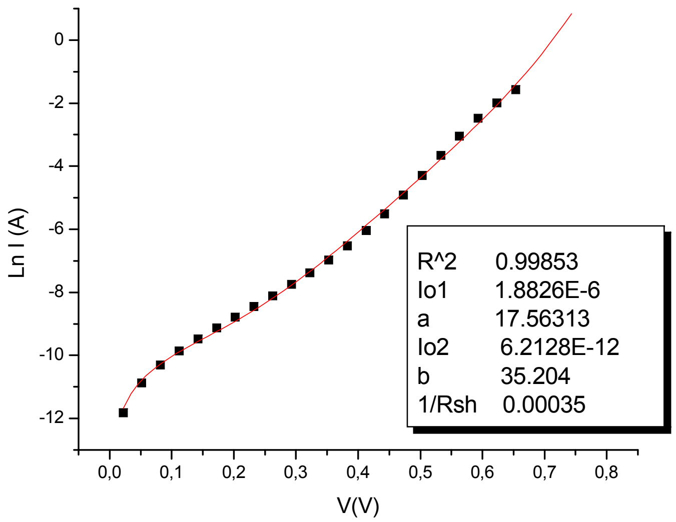
The experimental set up for I-V dark measurement

- a dark chamber;
- the solar cell;
- Keithley Model 2420, High Current Source Meter or Autolab PGSTAT30 ;
- data acquisition board NI 6036E;
- a copper thermostat with a heater;
- a sensor LM 335 for temperature measurement.
- PC.



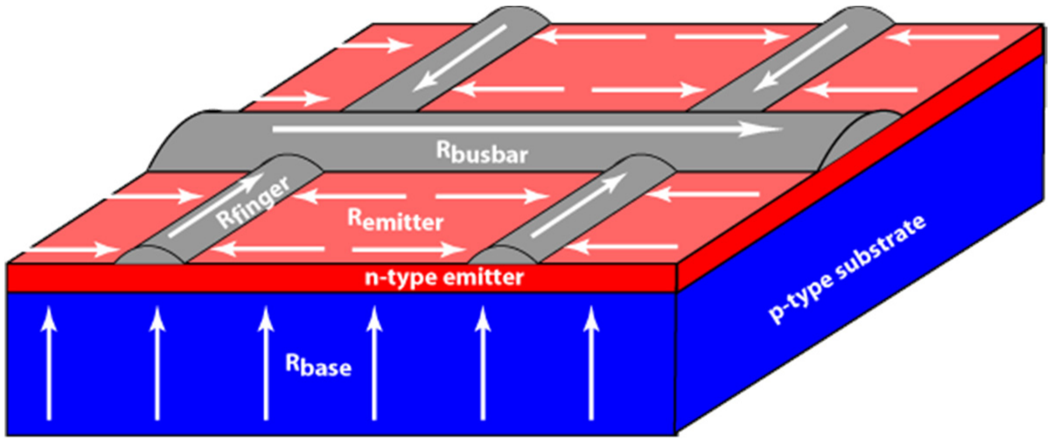


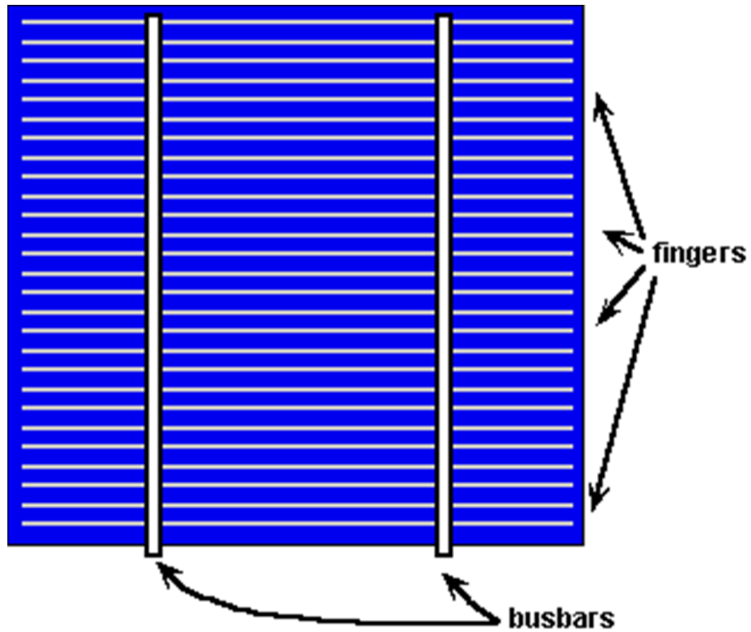
The dark I-V characteristic was raised for the multicrystalline silicon solar cell in forward bias, kept at the temperature of 20^0C. The characteristic was raised by using Autolab PGSTAT30 used as potentiostat.
For the fitting of the dark I-V characteristic obtained the Origin software was used. In the fitting procedure, five independent parameters were used. These parameters are: I_{01} and I_{02} - reverse saturation currents, m_1 and m_2 - ideality factor of the diodes and R_{sh} – shunt resistance.



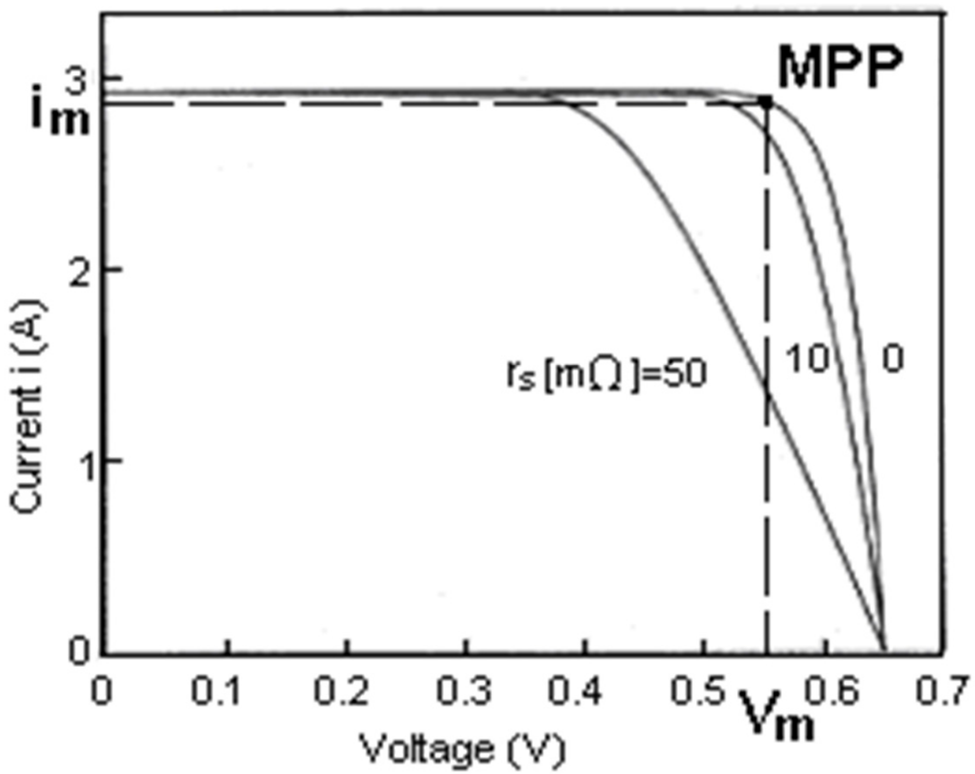
I_{01}(A)	m_1	I_{02}(A)	m_2	R_{sh}(Ω)
1.8826E-6	2.24	6.2128E-12	1.124	2778

The determination of the series resistance





The series resistance in a solar cell is determined by the series resistance of the base, by the resistance of the metal-semiconductor contacts at electrodes and by the resistance of the diffused layer from the illuminated surface of the cell…



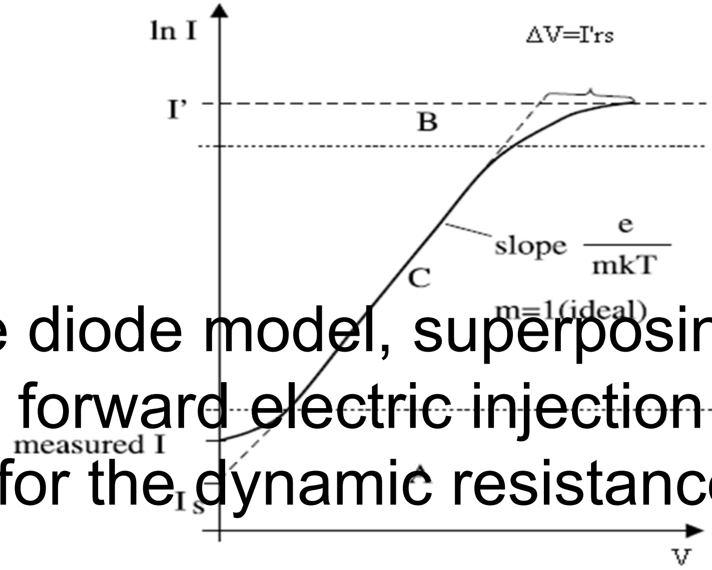
The effect of R_s in the characteristic curve of PV-cell.

The methods for determining the series resistance

- Due to the major effects that the series resistance, Rs, has on the solar cell performance, a series of methods were developed to determine and reduce them.
- The determining of the series resistance can be performed in darkness as well as under illumination.
- Among the most widely used methods there are: a static method and a dynamic method:
  - the method of slope at the (Voc,0) point;
  - the two characteristics method;
  - the maximum power point method;
  - the area method;
  - the generalized area method;
  - the analytical five point method;
  - the method of Quanxi Jia and Anderson
  - the Cotfas method and others.

- Measurements in the dark

1. A static method: Rs can be deduced as the value from the gap on the V axis, between the actual curve and the diffusion line



2. A dynamic method-using the one diode model, superposing a very low amplitude a.c. signal to a forward electric injection , the following expression is obtained for the dynamic resistance:

$$r_d = \left.\frac{dV}{dI}\right|_{I=ct.} = \frac{mkT}{q}\frac{1}{I} - R_s$$

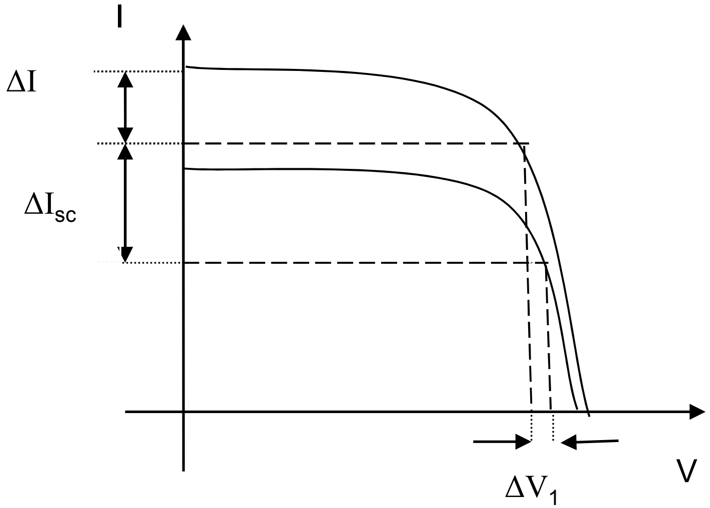
- Measurements under illumination

in this case there are much more methods, in this course only few of them being reminded.

- **Method of slope at the (Voc,0) point-**at constant illumination and using the one diode model Rs is determined from the relation:

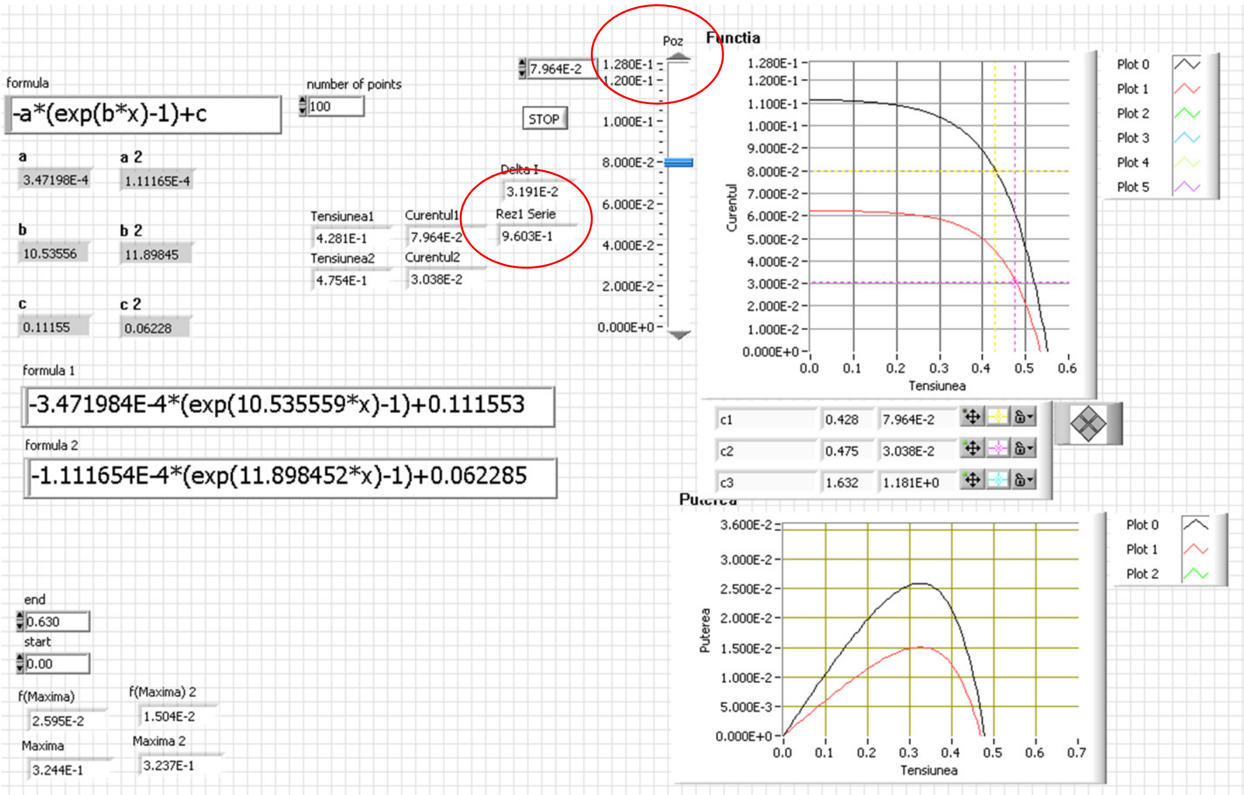
$$R_S = -\frac{dV}{dI}\bigg|_{I=0.} = \frac{mkT}{q}\frac{1}{I_{ph}+I_o}$$

- **The two characteristics method-**is a method that uses two I-V characteristics raised at the same temperature for two illumination levels. The two characteristics are translated one from the other with the quantities ΔIsc and ΔIscRs = ΔV1



$$R_s = \frac{\Delta V_1}{\Delta I_{sc}}$$

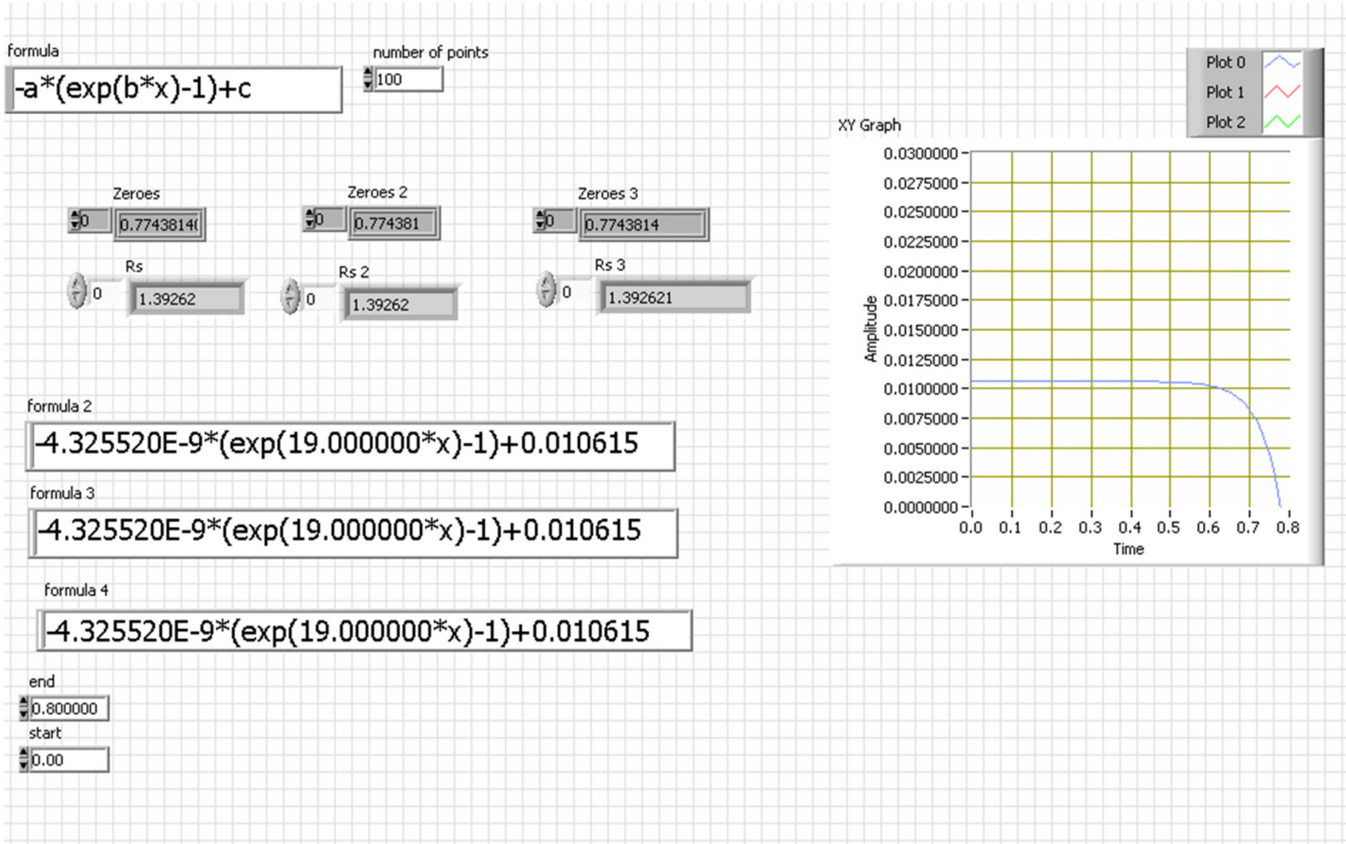
The two characteristics method for c-Si, 3 cm^2



$$R_s = \frac{V_1 - V_2}{\Delta I_{sc}} = \frac{\Delta V}{\Delta I_{sc}}$$

- **The area method**-using equation we shall calculate Rs:

$$R_s = 2\left(\frac{V_{oc}}{I_{sc}} - \frac{A}{I_{sc}^2} - \frac{mkT}{qI_{sc}}\right)$$



Interface for determination of series resistance using the area method for CdTe solar cell, having an area of 1 cm^2

• The generalized area method

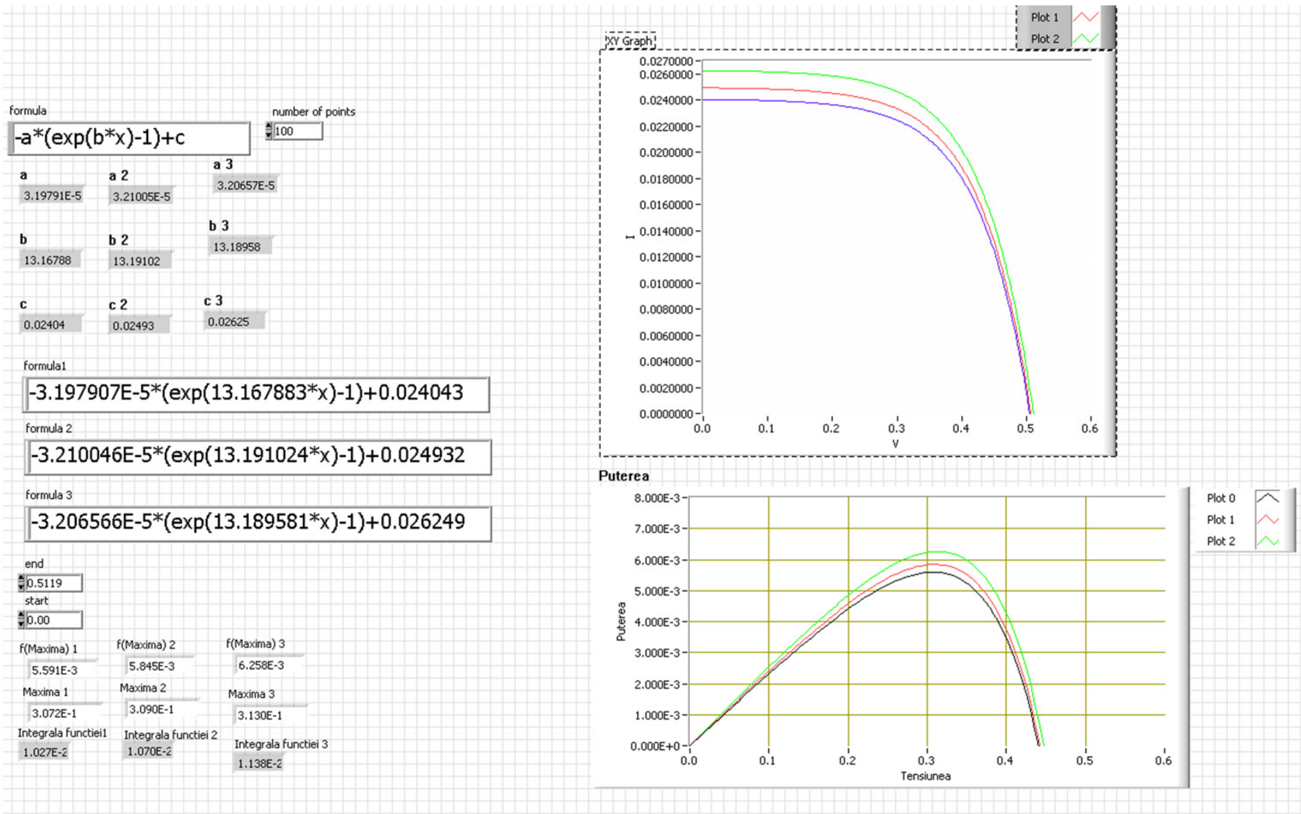
$$\rho_i = \left(\frac{I_{sc}}{2V_{oc}}\right)_i r + \left(\frac{1}{V_{oc}}\right)_i \gamma m + \left(\frac{V_{oc}}{2I_{sc}}\right)_i g - \left(\frac{1}{I_{sc}}\right)_i \gamma g m$$

$$\rho_i = \left(\frac{I_{sc}V_{oc} - A}{I_{sc}V_{oc}}\right)_i$$

$$r = R_s$$

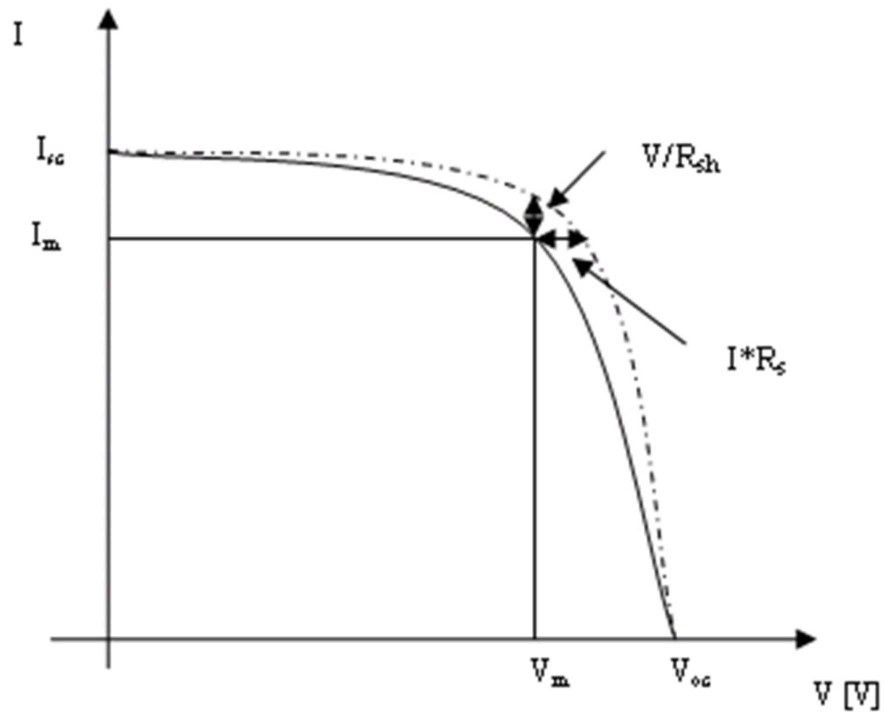
$$\gamma = \frac{kT}{q}$$

$$g = \frac{1}{R_{sh}}$$

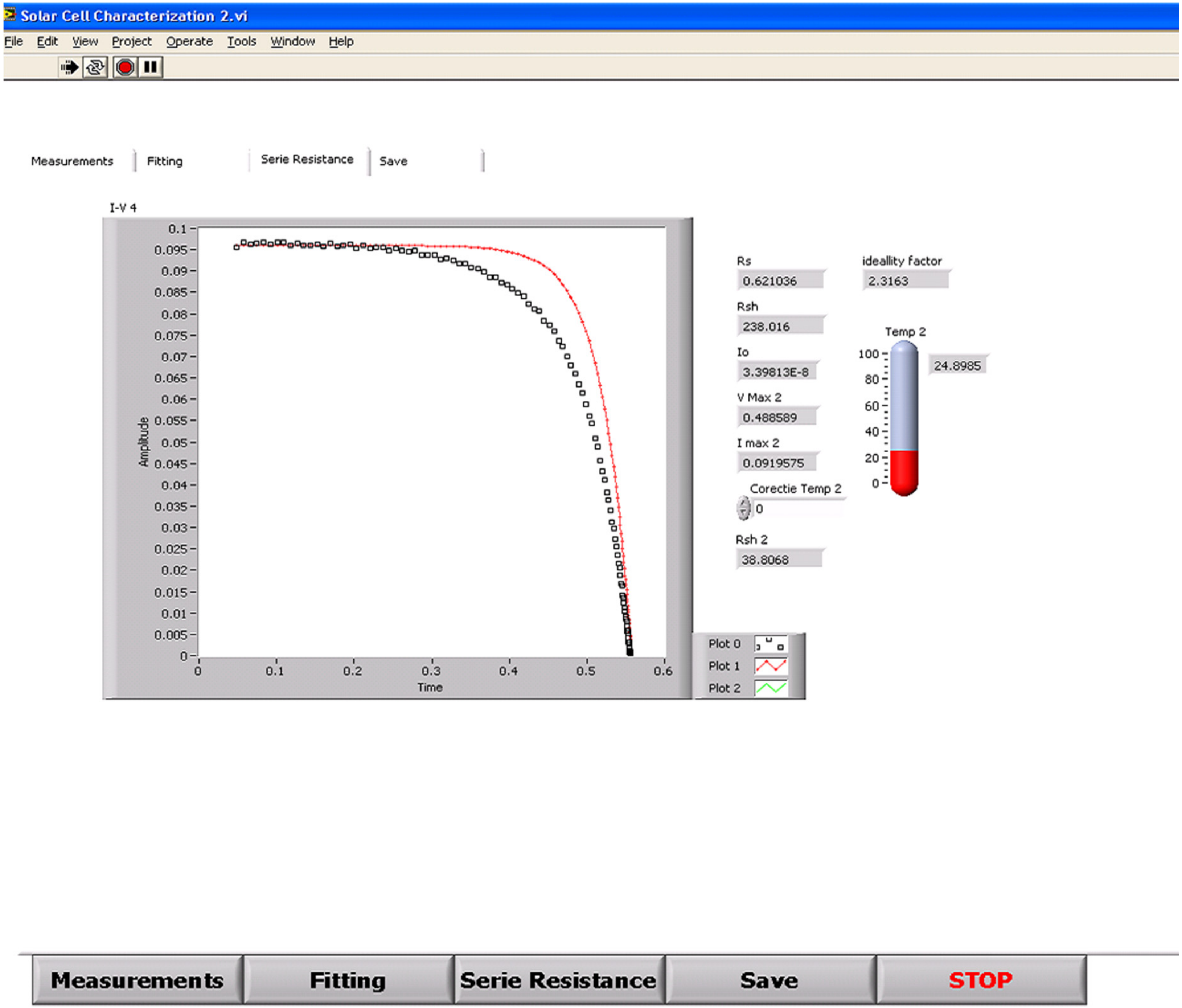


Cotfas method

- The series resistance has as an effect the translation towards the left of the I-V characteristic, and the shunt resistance has as an effect the lowering of the characteristic, (the increase of the slope in the plateau). The translation on the vertical area is given by I*Rs, and on the plateau slope by V/Rsh .



$$R_s = \frac{\Delta V}{I_{\max}} = \frac{V_{ideal} - V_{\max}}{I_{\max}}$$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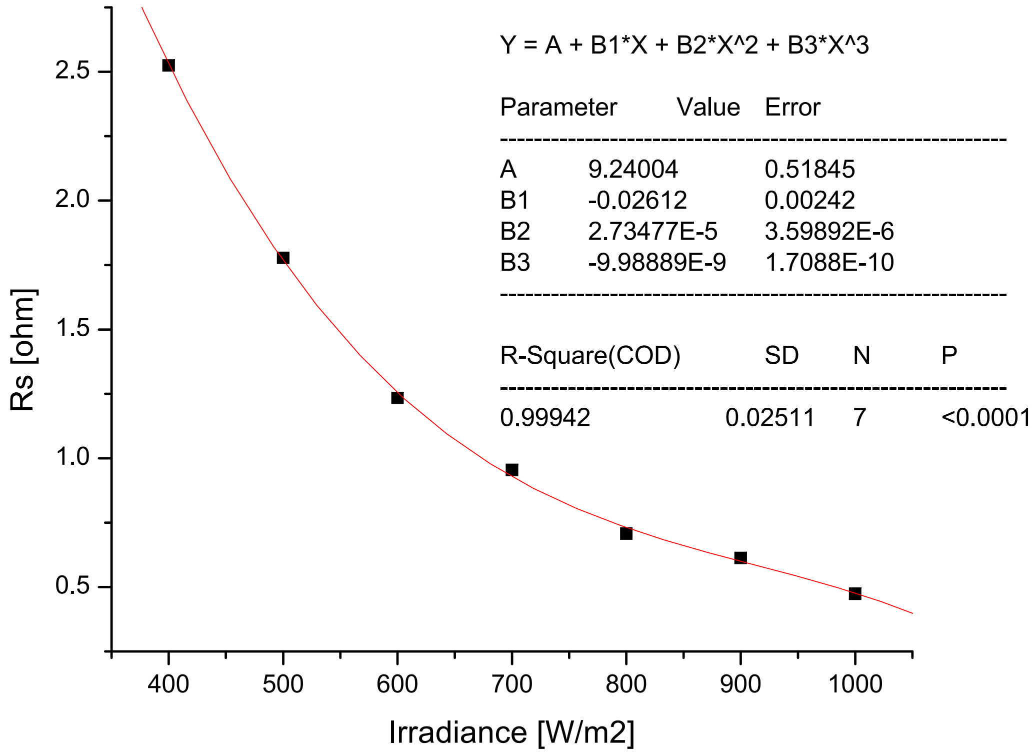
3.39813E-8
V Max 2
0.488589
I max 2
0.0919575
Corectie Temp 2
0
Rsh 2
38.8068
Measurements
Fitting
Serie Resistance
Save
STOP

The dependence of the series resistance on irradiance



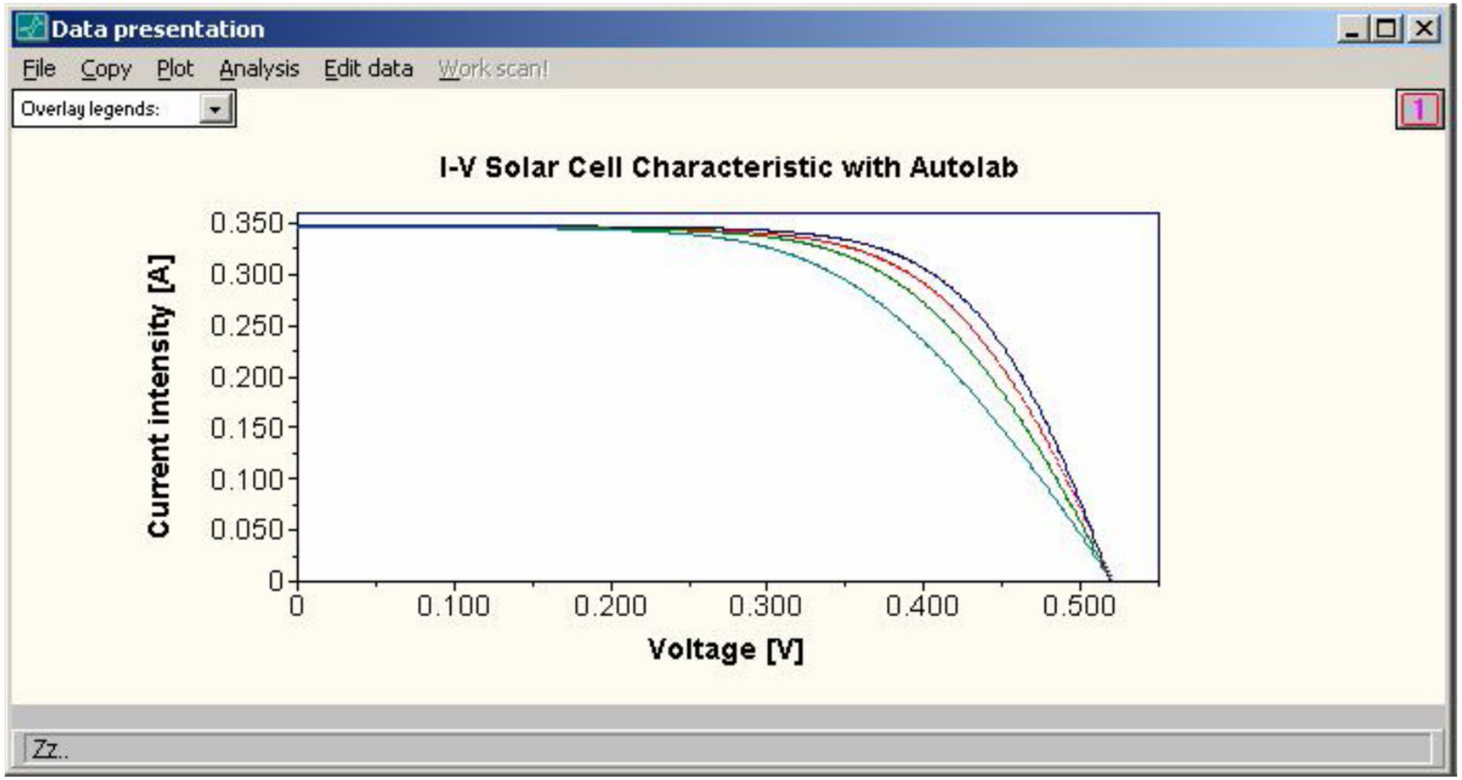
This dependence is fitted with a third degree polynomial. The raise of the series resistance is rapid for small illumination levels, thus explaining the non-linear dependence of the open circuit voltage on the illumination levels.

The new method

- It is observed that in the equation of the mathematical model, besides the series resistance there are other three unknown quantities.
- To find the solutions of the four unknown quantities, a non linear system of four equations will be numerically solved.
- The supplementary equations are obtained by putting in the circuit some resistances bound in series with the series resistance of the cell.
- The values of these resistances were previously measured.
- The system of non linear equations is solved by using a program realized in LabVIEW.

$$I = I_{sc} - I_0\left(\exp\left(\frac{q(V + I(R_s + R_i))}{mkT}\right) - 1\right) - \frac{V + I(R_s + R_i)}{R_{sh}}$$

The new method



- The effect of the resistances added upon the I-V characteristic of the solar cell (the purple curve corresponds to the cell without added resistance, the red curve is for the resistance of 50 mΩ, the green curve for the resistance of 100 mΩ, and the blue one for the resistance of 200 mΩ)

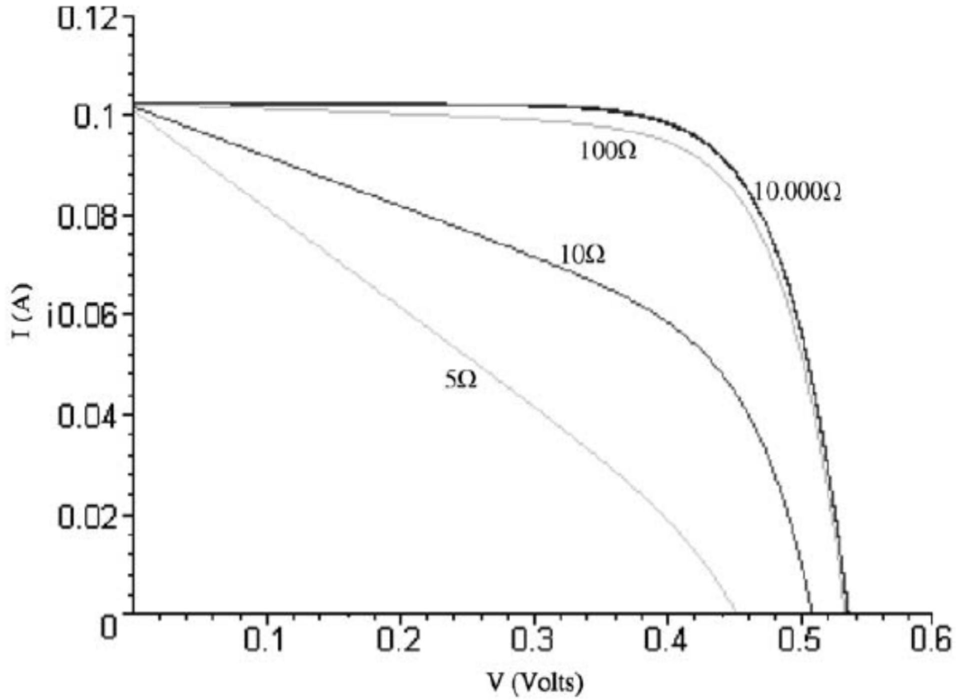
The results

No	Method	The series resistance of the cell [mΩ/cm²]
1	The two characteristics method	23,4 ± 0.2
2	The Cotfas method	23,3 ± 0.3
3	The generalized area method	22,9 ± 0.5
4	The new method	23,5 ± 0.2

- The values obtained for the series resistance of the solar cell are written in Table I. As it can be observed, the values obtained by the four methods are very close.

Conclusions

- A new method to determine the series resistance of the solar cell was developed.
- As the values of the series resistance of the solar cell obtained with the new method are practically equal to those obtained by the already existent methods, the sustainability of the new method is proved. Moreover, the method allows a visualizing of the series resistance variation along the entire characteristic.
- The measurement chain realized is a compact one, easy to use and capable to reduce the undesired resistances in the circuits.
- The LabVIEW soft used is a tool that ensures the data acquisition, as well as quick and easy data processing.



Effect of a decrease in Rsh on the simulated I–V characteristics of a crystalline silicon cell

Method of Quanxi Jia and Anderson

$$R_s = \frac{V_m}{I_m} \cdot \frac{\frac{1}{V_t} \cdot \left(I_{sc} - I_m\right)\left[V_{oc} + V_t\left(1 - \frac{I_m}{I_{SC}}\right)\right] - I_m}{\frac{1}{V_t} \cdot \left(I_{sc} - I_m\right)\left[V_{oc} + V_t\left(1 - \frac{I_m}{I_{SC}}\right)\right] + I_m}$$

$$mV_t = \left(V_m + I_m R_s\right)\ln\left[\left(1 - \frac{I_m}{I_{SC}}\right)\exp\left(\frac{V_{oc}}{I_{sc}}\right) + \frac{I_m R_s}{2V_t} + \frac{I_m}{I_{sc}}\right]$$

Maximum power point method

$$R_s = \frac{V_m}{I_m} - \frac{1}{B(I_L - I_m)}$$

$$B = \frac{[I_m/(I_L - I_m)] + \ln[(I_L - I_m)/I_L]}{2V_m - V_{oc}}$$

$I_L \approx I_{sc}$

A flash lamp method

$$R_s = R_L\left(\frac{V_{oc}}{V_L} - 1\right)$$

Method of the difference between the photogenerated and the short-circuit currents

$$\ln\left(\frac{I_{ph} - I_{sc}}{I_o}\right) = \frac{qI_{sc}R_s}{nKT}$$

The simplified maximum point method

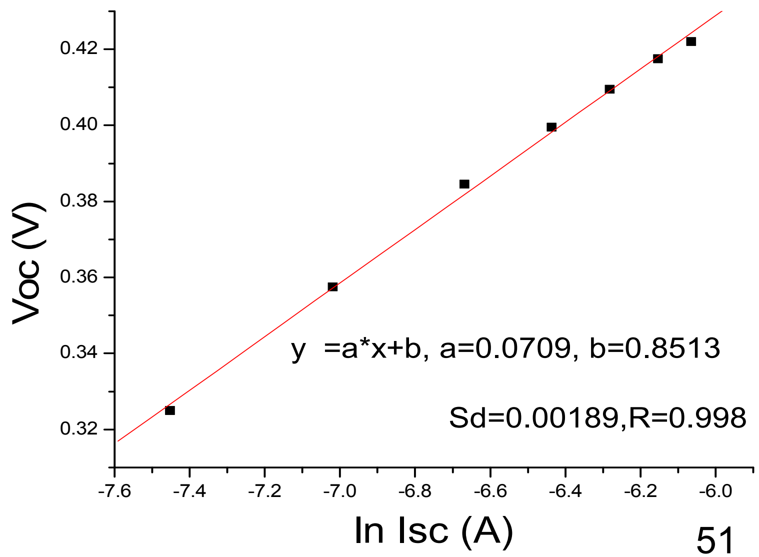
$$R_s = \frac{V_{oc}}{I_{sc}} - \frac{V_m}{I_m}$$

Ideality factor of diode

- The ideality factor, m, is calculated between adjacent pairs of I-V curves by using V_{oc}, I_{sc} pairs.

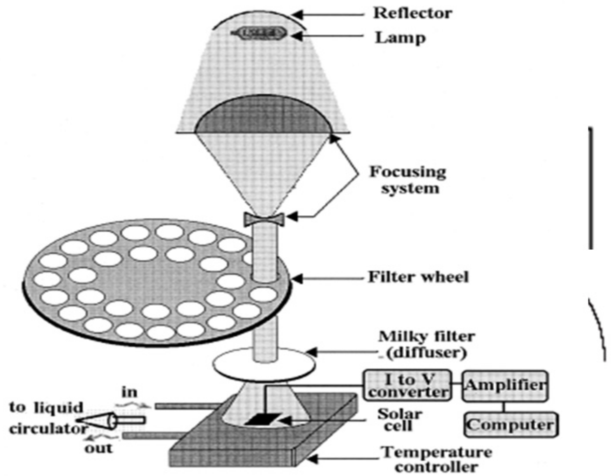
$$m = \frac{V_{oc1} - V_{oc2}}{\frac{KT}{q}\ln\left(\frac{I_{sc1}}{I_{sc2}}\right)}$$

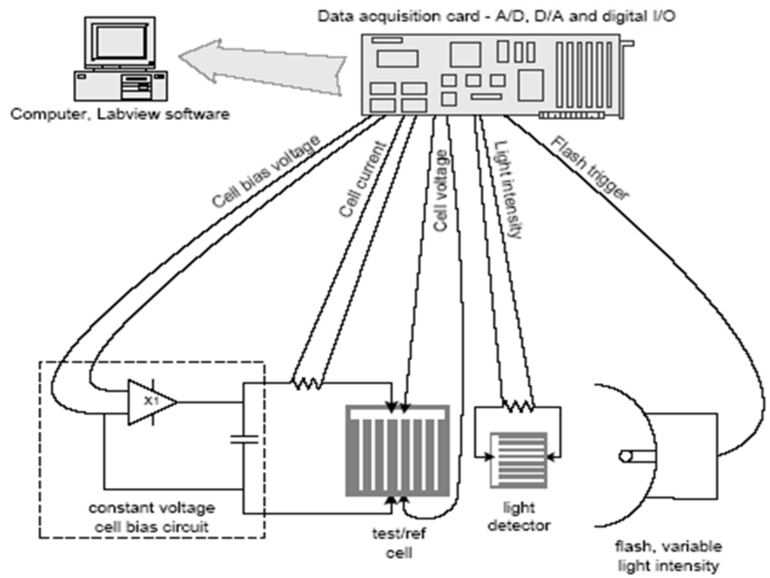
- The equivalent of this method is the raising of the characteristic V_{oc}=V_{oc}(ln I_{sc})



Experimental devices

- Sunalyzer
- The device for spectral and efficiency behavior of solar cell
- The system with the Mod 2420 Source Meter Instrumen
- The constant voltage flash tester
- The natural sunlight used for measurements

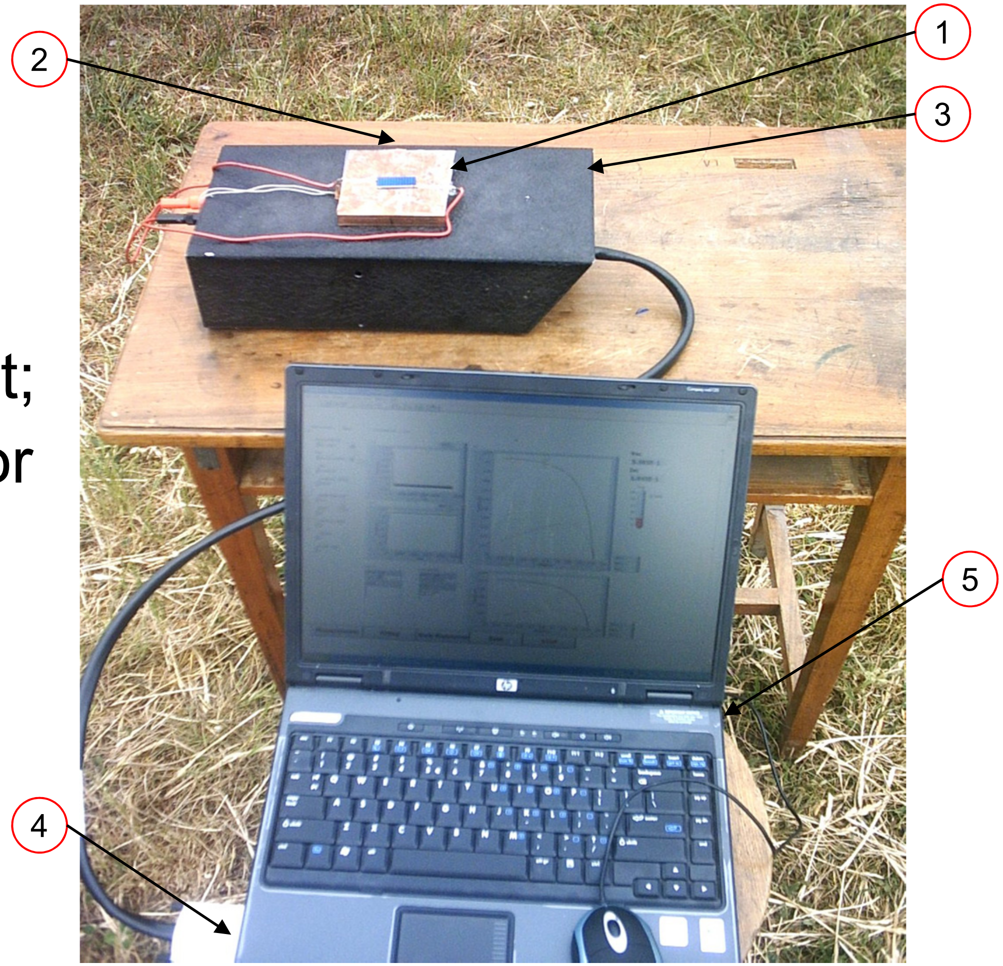




The experimental measurements for solar cell parameters

The system components are:

1. the solar cell;
2. the copper thermostat;
3. the electrical circuit for raising the I-V characteristic;
4. the data acquisition board, NI 6036E;
5. the laptop.



SolarLab, a System for Solar Cells Study

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International Conference
Bridgeport, CT/United States
Remote Engineering & Virtual Instrumentation
REV

The concept

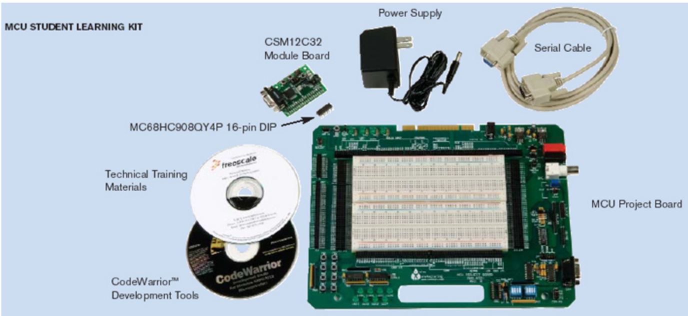
- there are several works in this direction:
  - using the Autolab system from EcoChemie
  - using the Keithley Model 2420 High Current Source Meter, etc.
- very good tools but very expensive and also the implemented facilities are limited

The system

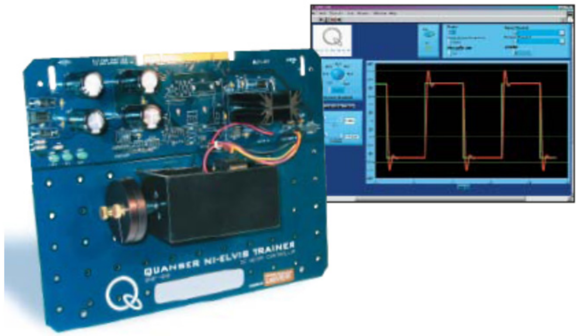
- This paper presents an original tool, SolarLab, tool developed by our team, which is dedicated to lab experiments for students concerning the study of the solar cells.
- The tool consists of designing a board for the NI-ELVIS system along with the adjacent software.

The system – NI-ELVIS

- Using NI-ELVIS system's facilities, several companies have developed add-on boards for NI-ELVIS



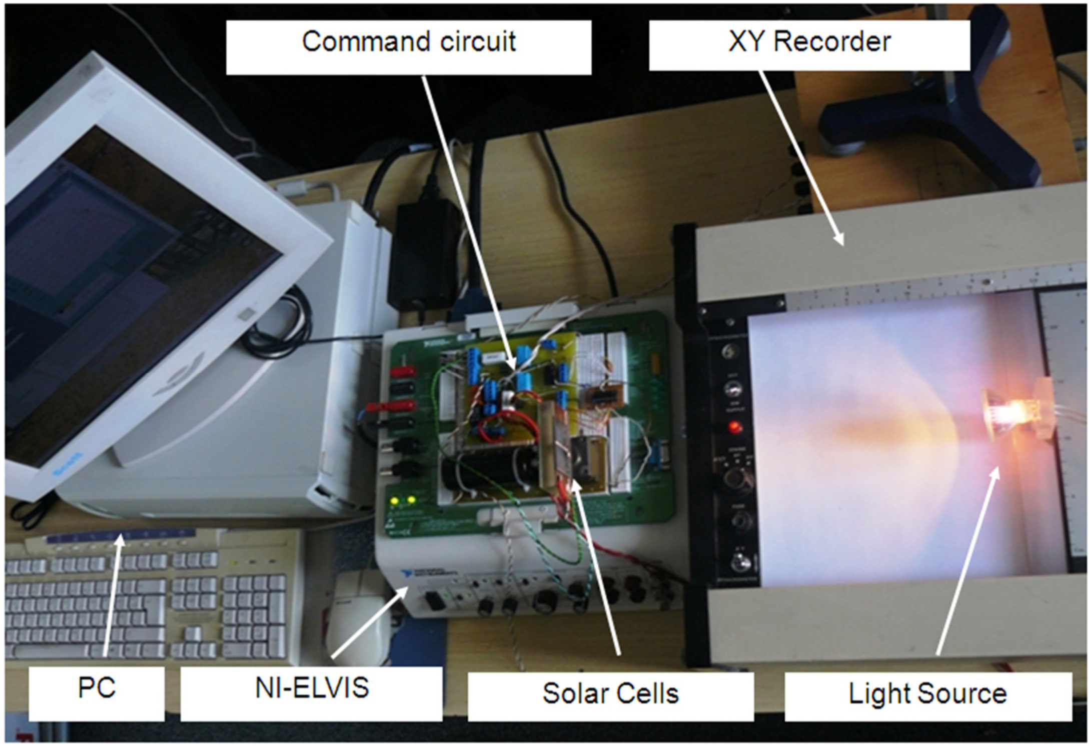
Freescale



QUANSER ENGINEERING

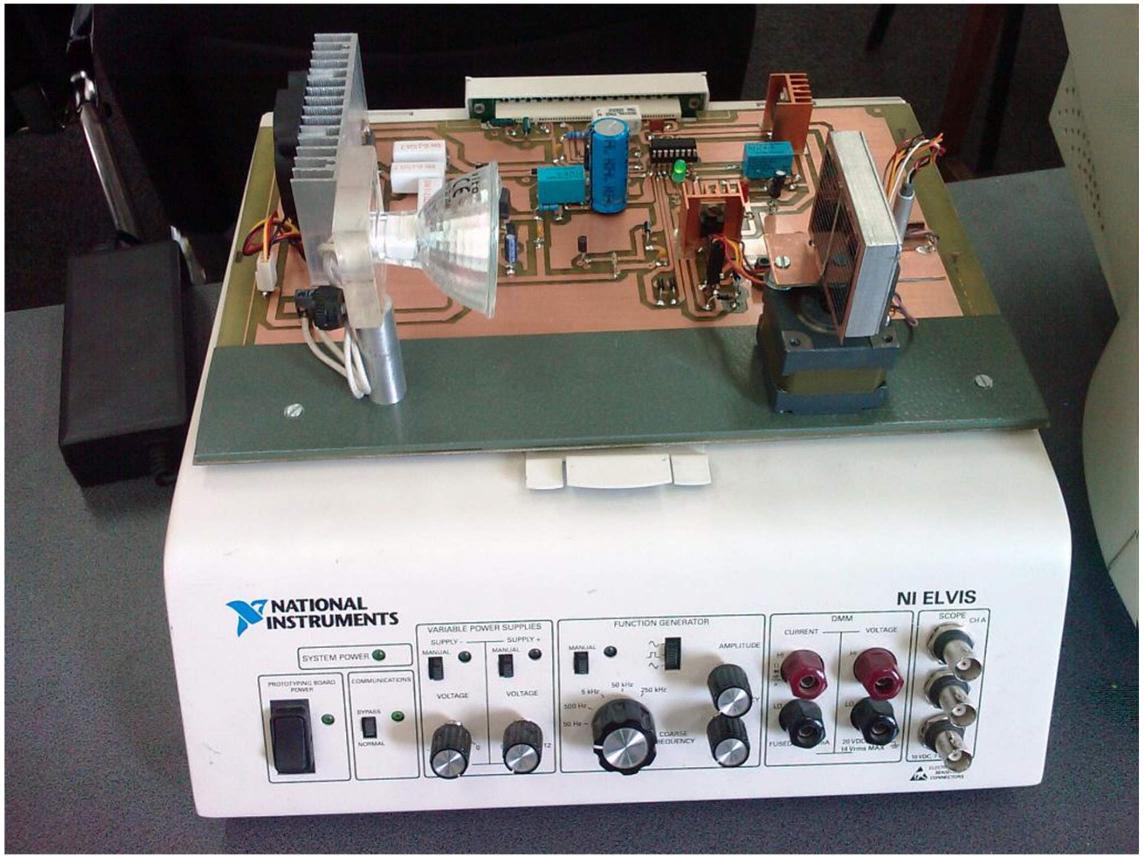
The system – Version 1

- a study system was designed, using all these facilities of the NI-ELVIS system, for solar cells
- the system allowed the raising of the I-V characteristics for solar cells on the basis of the variance of impedance during the charge of a capacitor in a RC circuit (resistor-capacitor)



The system – Version 2

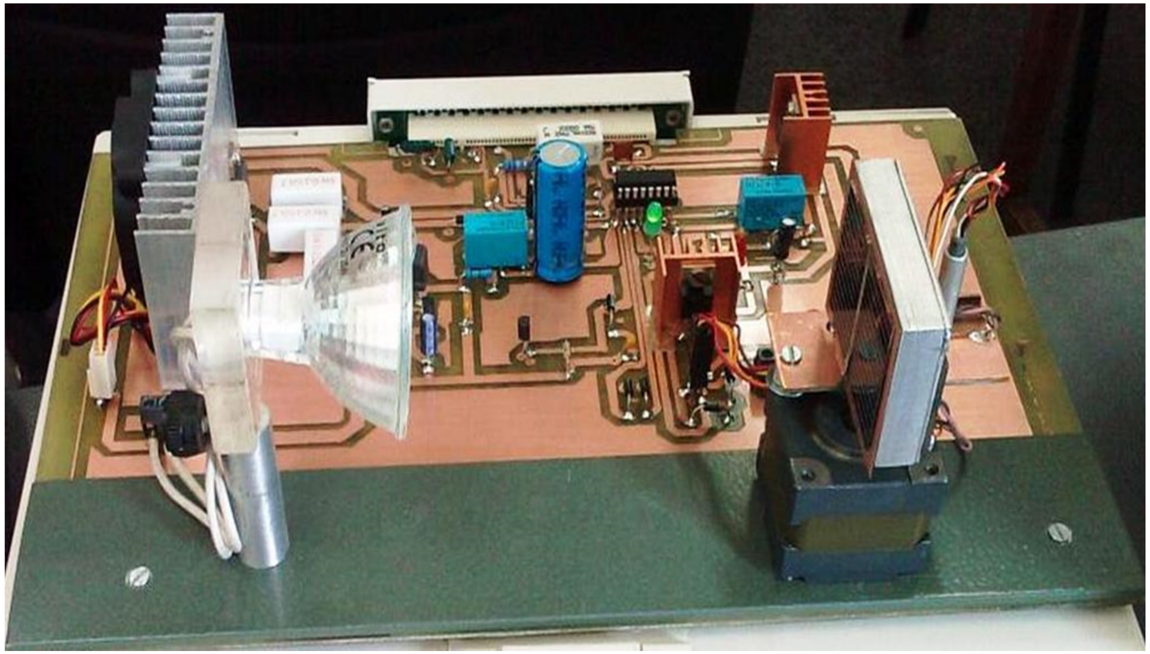
- an original "one board" system was developed, compatible with the NI-ELVIS system (an add-on board for NI-ELVIS)
- this system includes all the necessary instruments to carry out the lab experiments using only one board



The system – Version 2

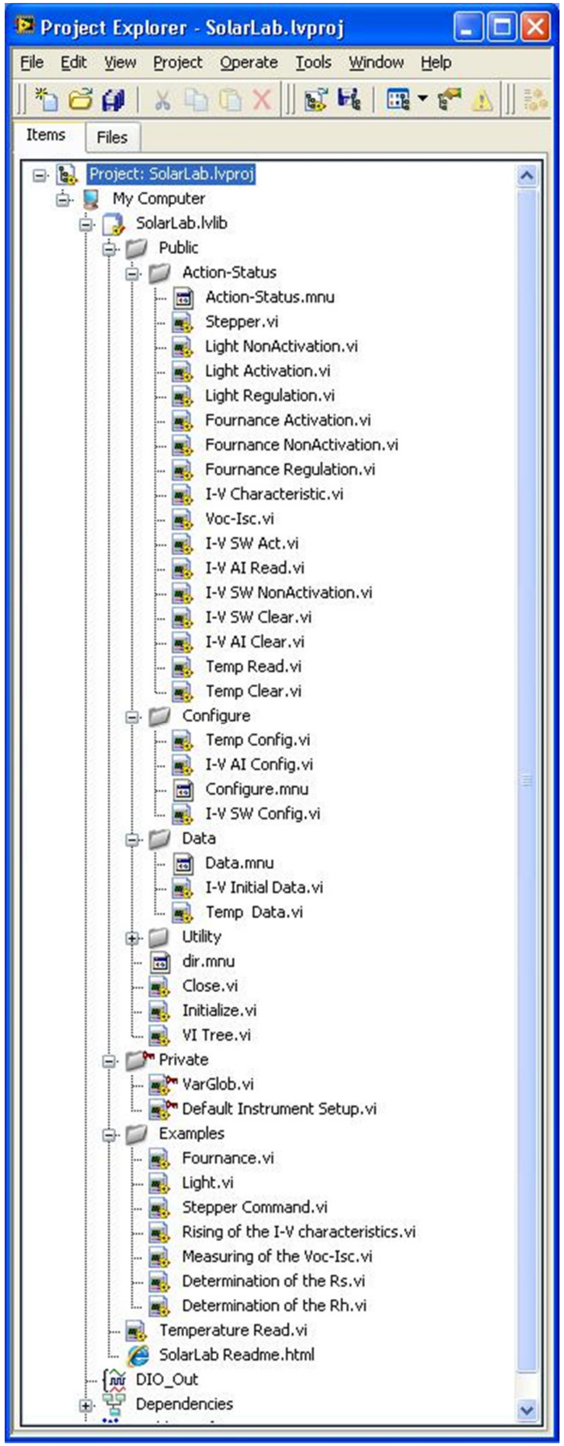
The board is divided into several modules:

– The power module for adjustable alimentation of the light source;
– The command module of the step by step motor to adjust the incidence angle between the light radiation and the surface of the solar cell;
– The module for thermostating of the solar cell;
– The module for raising the I-V characteristic of the solar cell;
– The measuring module for the open circuit voltage and of the short circuit current.



The software

- The software was developed in LabVIEW as a driver project that contains the necessary VIs to control each existent hardware module as well as the VIs needed for the data processing and also examples for the proper implementation of the lab experiments dedicated to solar cells.
- Thus, in the processing part there are VIs dedicated to:
  - Filtering the signals;
  - Fitting the I-V characteristics due to the mathematical relation for the one diode model;
  - Determining the parameters of interest (the open circuit voltage, the short circuit current, the maximum power, the series and shunt resistance, by various methods, the ideality factor, etc.);
  - Data logging.

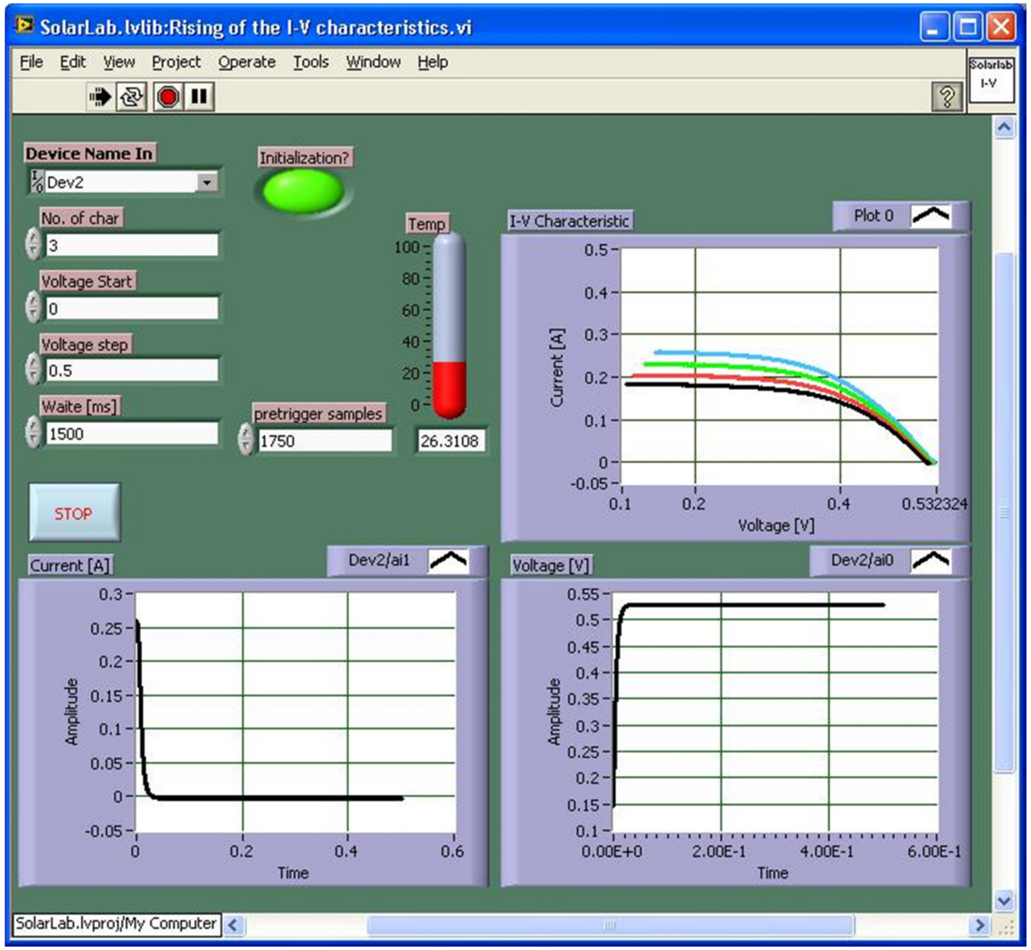


The software

- The lab experiments that can be performed with this system are:
  1. Determination of solar cells parameters using the I-V characteristic;
  2. Determination of the series resistance of the photovoltaic cells using the methods:
     a) The two characteristics method;
     b) The area method;
     c) The generalized area method;
     d) Maximum power point method;
     e) Method of Quanxi Jia and Anderson;
     f) The simplified maximum point method;
     g) The original method.
  3. Determination of the shunt resistance of the photovoltaic cells;
     a) The generalized area method;
     b) The fitting method;
     c) The original method.
  4. Measurement of the solar cell impedance;
  5. Determination of the ideality factor of the diode;
     a) The generalized area method;
     b) Method of Quanxi Jia and Anderson;
     c) The original method.
  6. Study of the solar cell's parameters dependence upon the illumination level;
  7. Study of the solar cell's parameters dependence upon the temperature;
  8. Study of the solar cell's parameters dependence upon the incidence angle of the light radiation.

The applications

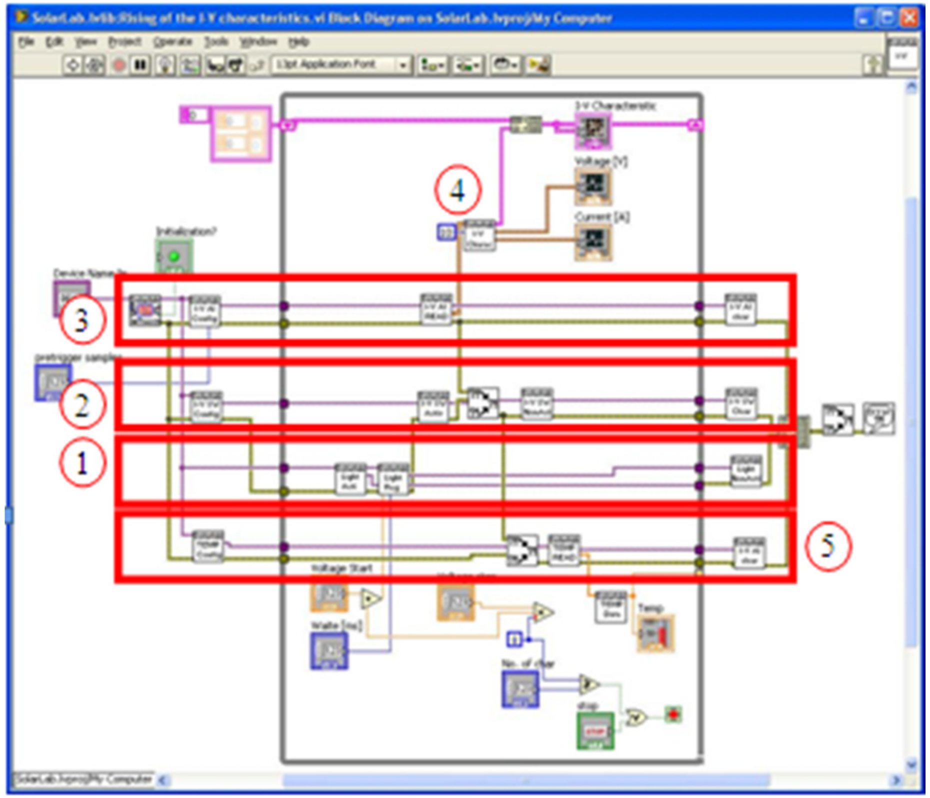
- the application bellow enables the raising of the I-V characteristics for the studied solar cell



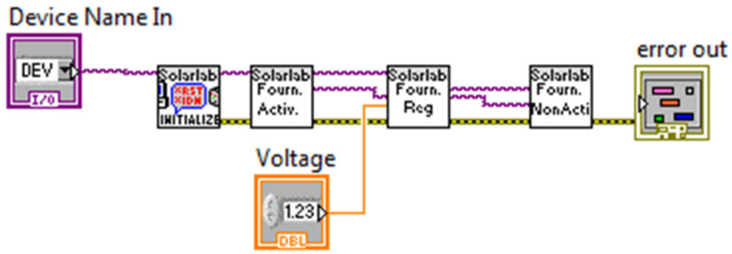
The applications

to raise the I-V characteristic, the below steps must be followed:

1. Switching on the source of light to a certain illumination level adjusted using the analogue output channel AO0.
2. Switching the ADG884 relay at the capacitor charging position from the module for raising the I-V characteristic of the solar cell.
3. Starting the measurement on the analogue input channels AI0 and AI1 in the moment of relay switching.
4. Processing the I-V characteristic.
5. Measuring the work temperature of the solar cell using the LM335 temperature sensor.



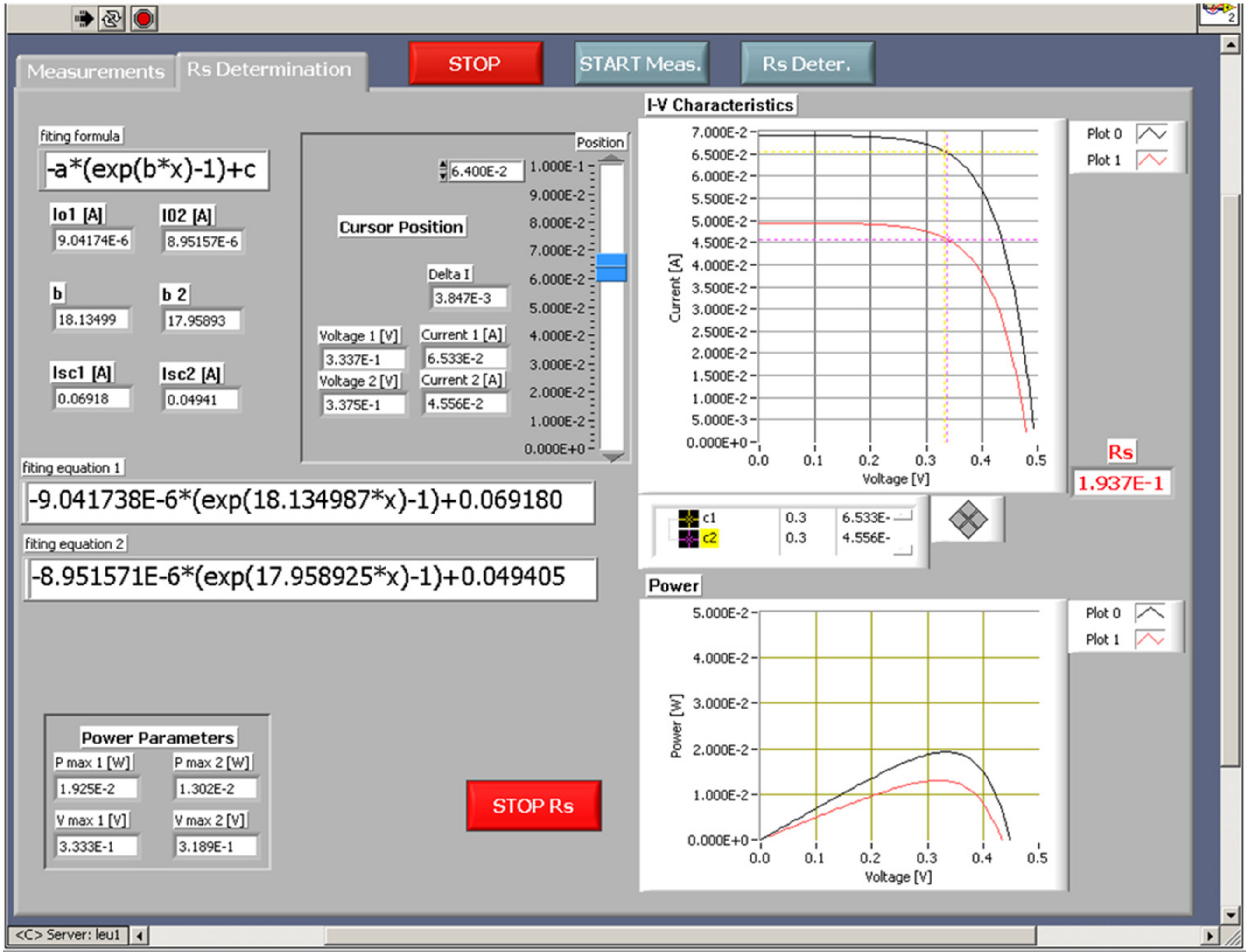
The applications



- By introducing a command line for the furnace one can study the influence of the temperature upon the parameters of interest (especially the open circuit voltage, V_{oc}).
- By using the stepper.vi one can set the angle between the cell and the luminous radiation, so studying the parameter's dependence on this angle.
- The command lines and VIs can be used independently, so studying parameter by parameter or can be used together and through the synchronization between them one can achieve a complex system for investigating the solar cells.

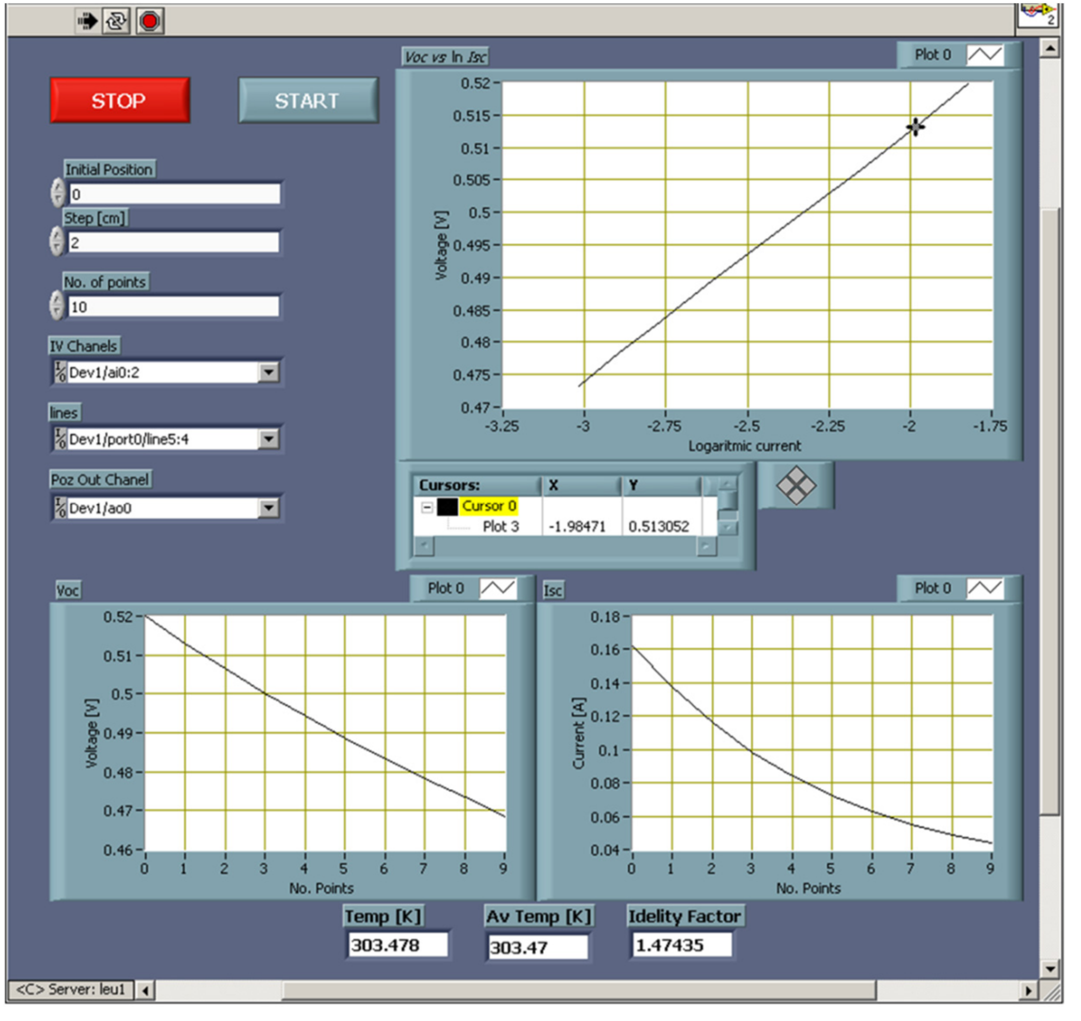
The applications

- Determination of series resitance



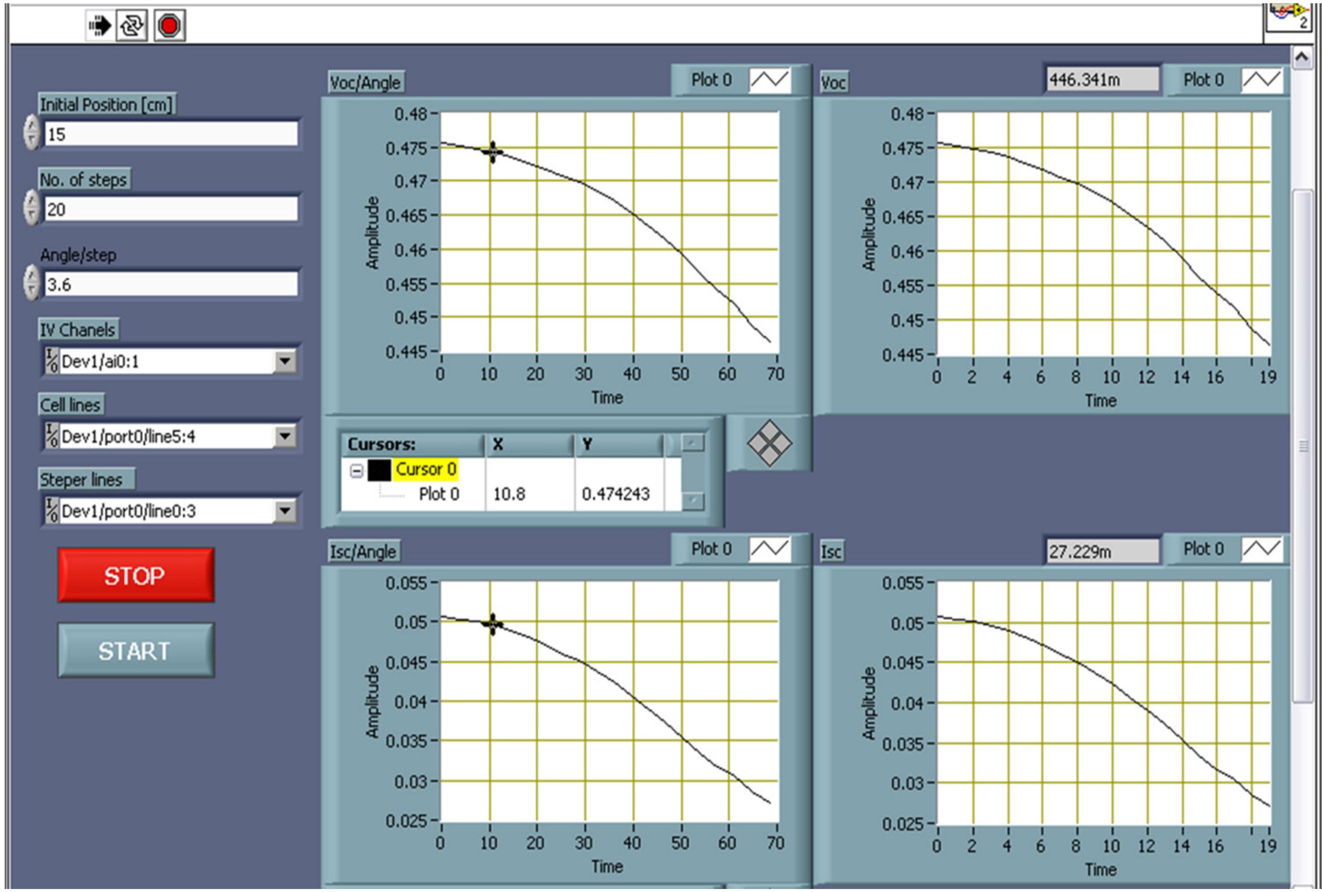
The applications

- Determination of the ideality factor for solar cell



The applications

- The study of dependency of the V_{OC} and I_{SC} parameters on the incidence angle of the light radiation with the cell.



Conclusions

- the understanding and improvement of the performances of the renewable energy sources is compulsory;
- the developing of tools necessary to study these energy sources, at educational as well as at research levels, is of major importance;
- the SolarLab is an unique add-on board for the NI-ELVIS system developed in order to study the solar cells;
- the developed software allows to create eight different experiments using various investigation methods for study of the solar cells parameters;
- using the LabVIEW project VIs associated to the SolarLab board and NI-ELVIS platform a high flexibility of the system is ensured, so new experiments can be created by the user.

References

- Keogh, W. M.: „Accurate performance measurement of silicon solar cells”, PhD. Thesis, 2001
- Chegaar, M. ; Ouennoughi, Z.; Guechi, F.; Langueur, H.: „Determination of Solar Cells Parameters under Illuminated Conditions”, Journal of Electron Devices, Vol. 2, pp. 17-21, 2003
- Stutenbaeumer,U.;Mesfin,B.: „Equivalent model of monocrystalline, polycristalline and amorphous silicon solar cells”, Renewable Energy,Vol. 18, pp 501-512, 1999
- Gottschalg, R.; Elsworth, B.; Infield, D.G.; Kearney, M.J.: „Investigation of the contact of CdTe solar cells”, Centre for Renewable Energy System Technology, London
- Kiran, E.; Inan, D.: „An approximation to solar cell equation for determination of solar cell parameters”, Renewable Energy, vol. 17, pp. 235-241, 1999.
- Bashahu,M.; Habyarimana, A.: „Review and Test of Methods for Determination of the Solar Cell Series Resistance”, Renewable Energy, vol. 6, pp. 128-138,1995
- Kaplanis, S.: „Technology of PV-systems and Applications”, Brasov 2003.
- Aberle ,A. G.; Lauinger, T.; Bowden, S.; Wegener, S.; Betz,G.: „Sunalyzer-a powerful and cost-effective solar cell I-V tester for the photovoltaic community”, Emmerthal
- D. T. Cotfas, P. A. Cotfas, S. Kaplanis, D. Ursutiu, “Results on series and shunt resistances in a c-Si PV cell. Comparison using existing methods and a new one”, Journal of optoelectronics and advanced materials, vol. 10, no. 11, pp. 3124 – 3130, 2008.
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Thank you for your attention!