

# Design of a Multiparameter Acquisition System for Photovoltaic Panels

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*Abstract:* - This work represents an effective method of energy prediction that would be produced by photovoltaic systems and a valid tool of their characterization. The prediction of the energy produced by a photovoltaic system is generally made through software which uses algorithms which describe the trend of the efficiency of the panels depending on the temperature, the radiation and, in more sophisticated cases, depending on the incident spectrum features. These algorithms use empiric coefficients which often depend on the special device and they are hard measurable and controllable. So the degree of reliability of the prediction of a given software can be high for a certain number of devices and can be low for other panel typologies according to the algorithms used and to the accuracy which coefficients were obtained with. Therefore we tried to plan and implement a measurement system for all the photovoltaic panel typologies, using a panel test laboratory and giving the possibility of studying the behaviour in real conditions of working of various device typologies, in climatic situations like those of Lecce city (Italy). This method can be extended to every typology of photovoltaic panel installed in any place.

*Keywords:* - Photovoltaic panel, pyranometer, radiation measurement, point tracking, solar radiation power.

## 1 Rationale

The aim of this work is to plan, to realize and to test a multiparameter system of measurement for data collection of four different photovoltaic panel typologies (monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium sulphide) either under the hardware viewpoint or software one. In this way it is possible to verify the behaviour in real operating conditions of various typologies of photovoltaic panels, in climatic situations like those of Lecce where the laboratory is located. It is interesting to underline the analysis concerning the four panels, performed during daytime. Although the aforementioned analysis referred to a very limited sample of measurements, it is very important to see the behaviour of the four panels, in terms of power with respect to the main values: radiation and temperature.

Through the analysis of the monitored data we can study the response in radiation and in temperature of different devices, trying to evaluate

the most suitable typology for the local climatic situation which produces the biggest amount of energy. The method will be furthermore shown in terms of power matrixes, useful tool for photovoltaic system energy and for panel characterization.

## 2 Measurement architecture

A measurement architecture platform has been realized (fig.1). It consists of different sub-units capable of making the monitoring of the climatic conditions like temperature, luminous intensity, wind speed, current values that the photovoltaic cell delivers in response to the voltage input induced by the luminous radiation, and the maximum power points are necessary for the analysis of photovoltaic panel yield.

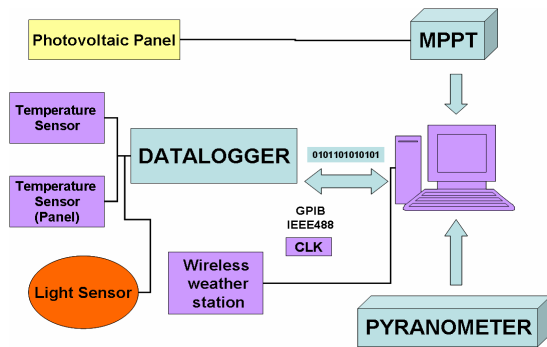


Fig. 1 Measurement chain scheme.

The data storage unity is represented by datalogger Agilent 34970 (Data Acquisition/Switch Unit) which sensors of temperature and luminous intensity are attached to. The data transduced and conditioned by suitable circuits integrated in the rear interfacing panels (multiplexers), are digitized and sent to the second fundamental component, the CPU, which have the purpose to manage the whole measurement chain, through the used software: LabView. The interfacing takes place through GPIB IEEE-488 cable. Another component present in this chain is represented by MPPT (Maximum Power Point Tracker), tool suitable for the tracking of optimum voltage and current values. In fact, It is indispensable to be able to find the maximum power point and order to analyze the performance of the photovoltaic panels; the interfacing of this device takes place through RS485 cable, that agrees to the described standard.

To equip the realization of the aforementioned measurement chain, a weather wireless station is also inserted, that allows to complete the data collection, with environmental parameters like rate of damps, wind speed and other factors; these parameters, not tight necessary, are however, very useful for understanding if and as the same ones can affect the efficiency of the photovoltaic panels. It is necessary to consider that the described architecture in fig. 1 is relative to the presence of a single photovoltaic panel. Actually, the realized work concerns the data acquisition for four photovoltaic panels. The whole system is realized in the Department of Innovating Engineering compound (University of Salento). In particular, the photovoltaic panels, pyranometer, thermo resistors and MPPT are located on the rooftop of compound as indicated in fig 2.

Fig. 2: The four panels used in the project.

### 3 Equipment and instrumentation.

In this paragraph all subunits are described in a concisely way.

#### 3.1 Datalogger Agilent 34970A.

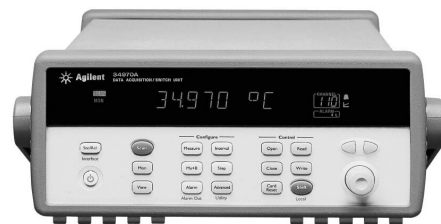


Fig. 3 Frontal panel Agilent 34970A.

Datalogger is used for the collection and the conversion of the output signals in voltage signal which can be converted, conditioned inside the DMM (fig.3), in voltage signal used by an intelligible unity.

### 3.2 Thermo resistors PT100.



Fig. 4: Thermo resistor PT100.

Thermo resistors base their operation on thermo-resistive effect for which the metal resistor positively changes according to change of temperature. In developing our system, four PT100 are used (fig.4), one for every panel, and fixed through a special scotch tape.

### 3.3 Pyranometer CM11.



Fig. 5: Pyranometer CM11.

Pyranometer CM11 (fig.5) is a tool which is used to measure the luminous radiation (Watt/m<sup>2</sup>) on a flat surface, resulting from the direct solar radiation and the diffuse solar radiation.

### 3.4 Weather WS2305 station.



Fig. 6 Weather WS2305 station.

The weather WS2305 station (fig.6) has some wireless sensors which transmit the data by

radiowaves. It is equipped of rain gauge, anemometer, direction of the wind, temperature tracking (indoor and outdoor), damps (indoor and outdoor), barometer, and radio-controlled clock.

### 3.5 MPPT 3000.



Fig. 7: MPPT 3000.



Fig. 8 Location of 4 MPPT.

MPPT (Maximum Power Point Tracker) is an electronic system that operates on the photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that “physically moves” the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power [1]. Additional power harvested from the modules is, then, made available as increased battery charge current. MPPT can be used in conjunction with a mechanical tracking system, but the two systems are completely different. The MPPT3000 are mounted and connected to the panels, as shown in fig. 7 and fig. 8.

### 4 Panels comparison.

In order to perform the experiment on the observation of the environmental features in which the photovoltaic panels work, it was necessary to implement a specific tool based on LabVIEW software. The technical data of every used panel are shown in table I.

Table I – Technical data of used panels

	Si Mono	Si Poli	Si Amorfo	CdS
Max Power (mpp)	55.0 W	70.0 W	64.0 W	n.d.
Current Max Power (I <sub>mpp</sub> )	3.00 A	4.14 A	3.88 A	n.d.
Voltage Max Power (V <sub>mpp</sub> )	18.0 V	16.9 V	16.5 V	n.d.
Short Circuit Current (I <sub>sc</sub> )	3.2 A	4.35 A	4.8 A	n.d.
Open Circuit Voltage (V <sub>oc</sub> )	22.0 V	21.5 V	23.8 V	n.d.
Area (A <sub>m</sub> )	0.41 m <sup>2</sup>	0.51 m <sup>2</sup>	0.92 m <sup>2</sup>	0.65 m <sup>2</sup>

Since outside conditions, especially temperature and radiation, determine a remarkable moving of real MPP with respect to MPP measured in laboratory, the analysis has been conducted by analyzing the behaviour of MPP of every panel and the various sizes which affect it [2] [3].

#### 4.1 Radiation comparisons .

The first comparison that is made on the performance of the four panels, regards the change of MPP with respect to the radiation. The fig. 9 shows the trend of the curves concerning these parameters.

Fig. 9 Trend of MPP depending on the radiation.

It is actually more useful to analyze the graphic of panel efficiency trend depending on the radiation, because, every panel has its own features that change from a panel to another (see fig.10).

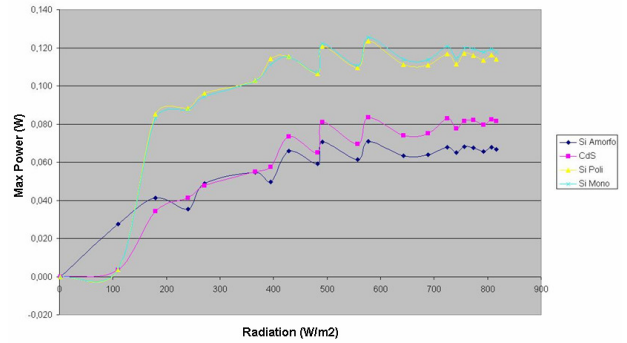


Fig. 10 Trend of the efficiency depending on the radiation

In the monocrystalline and polycrystalline silicon panels, it is well known that the efficiency lightly increases when the radiation raising, while sensitively decreases when the radiation gets down under the 200 W/m<sup>2</sup>.

This behaviour reverses himself in case of amorphous silicon panel, in which the efficiency also remains high under 200 W/m<sup>2</sup> and lightly decreases for high radiation values. The trend of the panel in cadmium sulphide is very similar to the monocrystalline silicon and shows, once more, the reliability of the collecting data [4].

#### 4.2 Comparisons on the temperature.

Another parameter of influence on the panel efficiency is represented by the temperature of the photovoltaic cells. Fig 11 and fig. 12 show the trend of MPP depending on the cell temperature, respectively in case of the monocrystalline silicon and the polycrystalline silicon.

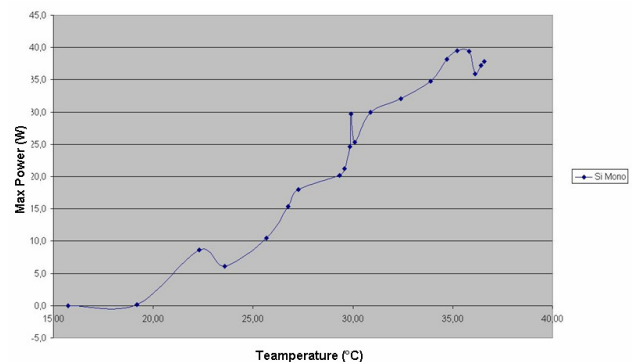


Fig. 11 Trend of MPP depending on the cell temperature (monocrystalline silicon).

The fig. 13 shows the trend of the function MPP - cell temperature, in case of cds-based panel.

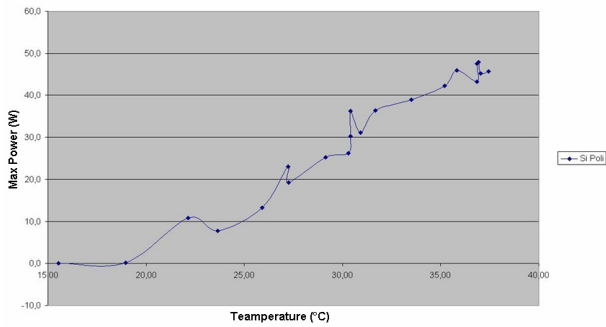


Fig. 12: Trend of MPP depending on the cell temperature (polycrystalline silicon)

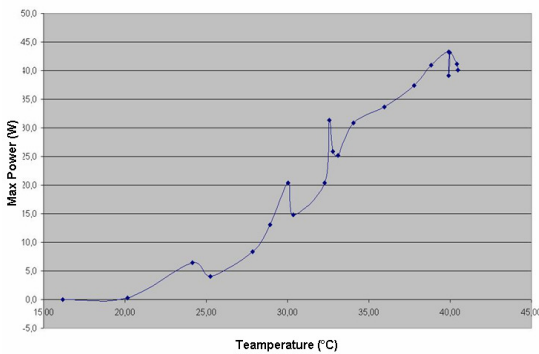


Fig. 13: Trend of MPP depending on the cell temperature (cadmium sulphide).

The behaviour in temperature of CdS panel can be considered like the crystalline one. In the amorphous silicon panels, up to a certain temperature value, the power grow to increase by same temperature, in quite linear way (see fig. 14). The missed decrease of the efficiency to rise of the cell temperature can be explained in terms of "annealing effect" and spectrum answer changes [5] [6] [7].

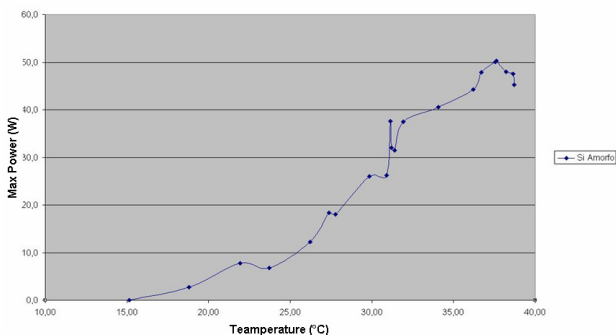


Fig. 14: Trend of MPP depending on the cell temperature (amorphous silicon).

## 5 Power matrixes.

The chain of measurement, described in fig. 1, represents a concrete tool to develop the matrix method. The matrix method is a simple system of

predicting energy produced by the photovoltaic panels based on direct measurements made in real operating conditions. The energy produced in a year by a device is obtained simply by multiplying the elements of power matrix  $P=\{P(G_i,T_a)\}$  by the elements of the matrix of the climatic events  $N=\{N(G_i,T_a)\}$  and adding the elements of the resultant matrix:

$$E = \sum_{G_i,T_a} P(G_i,T_a) N(G_i,T_a) \text{ [kWh/year]} \quad (1)$$

The P power matrix describes the power produced by a special device depending on the incident radiation on the panel plan ( $G_i$ ) and on the room temperature ( $T_a$ ). The elements  $P(G_i,T_a)$  of the P matrix are obtained through the average of the powers produced by a panel during a year of monitoring for every single climatic situation ( $G_i, T_a$ ):

$$P(G_i,T_a) = 1/N \left( \sum_{i=1,N} P_i(G_i,T_a) \right) \quad (2)$$

Each power  $P(G_i,T_a)$  is obtained multiplying  $I_{mpp}$  and  $V_{mpp}$  measured in the climatic situation ( $G_i, T_a$ ). At the end, the matrix is "filtered" excluding the points obtained by an average on less than 3 measurements ( $N < 3$ ; rare events) or measurements with excessive standard error ( $StDev/Avg > 20\%$ ; measurement errors). The matrix of the climatic events N counts the number of times that in a year it verifies a determinate climatic event ( $G_i,T_a$ ). This can be obtained through the hourly data of radiation and temperature obtained from standard software like METEONORM, or through the direct acquisition of ( $G_i,T_a$ ) by a climatic station in the installation site. In this last case, it is necessary, however, to normalize the matrix by dividing it for the number of acquisitions made in an hour.

The procedure for the matrix creation consists in a separated interpolation of the current  $I_m(G_i,T_a)$  and the voltage  $V_m(G_i,T_a)$  obtained by the measurements. The power matrix is yielded by multiplying the current matrix by the voltage one.

The equations are described below:

$$I_m = I_{m,STC} \cdot G_i / 1000 \cdot [1 + \alpha_{Im} \cdot (\Delta T \cdot G_i / 1000 + T_a - 25)] \quad (3)$$

$$V_m = V_{m,STC} + C_0 \cdot \ln(G_i/1000) + C_1 \cdot (\ln(G_i/1000))^2 + \beta_{Vm} \cdot (\Delta T \cdot G_i/1000 + T_a - 25) \quad (4)$$

where:

- $I_{m,STC}$  current at maximum power point at STC condition,
- $\alpha_{Im}$  coefficient of temperature of  $I_m$  to  $1000W/m^2$ ,
- $\Delta T$  difference of  $T_{cell}-T_a$  temperature to  $1000W/m^2$  and working of the panel at the maximum power point,
- $V_{m,STC}$  voltage at maximum power point at STC condition,
- $C_0$  and  $C_1$  parameters of panel,
- $\beta_{Vm}$  coefficient of temperature of  $V_m$  to  $1000W/m^2$ ,
- $T_a$  room temperature,
- $G_i$  incident radiation on the panel.

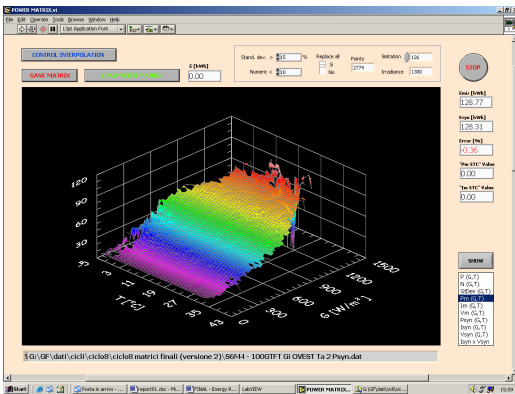


Fig. 15: Power matrix.

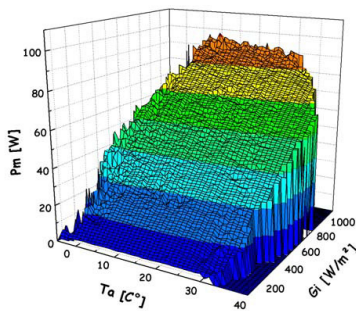


Fig. 16: Power matrix representation.

Fig 15 and fig. 16 depict the power matrix yielded from the developed modeling while fig. 17 illustrates the ideal and real power matrixes got from the implemented modeling.

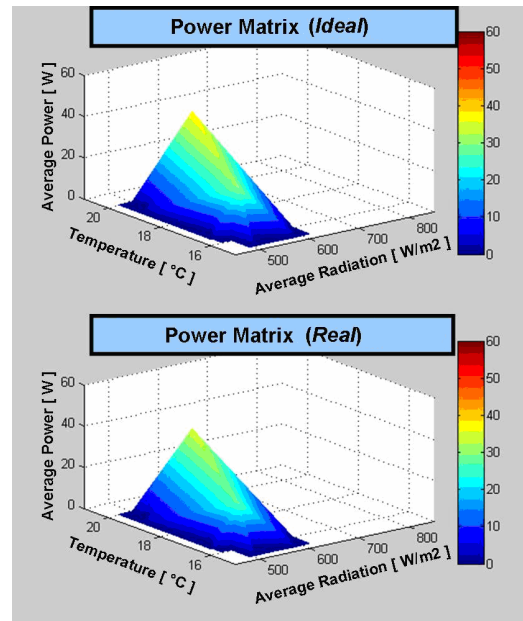


Fig. 17: Ideal and real power matrixes for a photovoltaic panel.

## 6 Conclusions.

Realizing this provisional panel test laboratory [8] [9], we wanted to give the possibility to study the behaviour in real conditions of working of various device typologies, in climatic situations of Lecce. Using two panels in c-Si (mono and poly), a panel in a-Si and one in CdS, tested and analyzed by the LEEE-TISO Laboratory, it was possible to monitor the power produced in MPP and build the power matrixes and the matrix of the climatic events.

Through the analysis of the monitored data it was possible to study the answer in temperature and the answer in radiation of the different devices, trying to evaluate the typology most suitable for the local climatic situation, that is, the typology that produces the biggest amount of energy.

Furthermore, analyzing the differences between the power matrixes obtained with the measured ones in the TISO Laboratory, it was possible to study the effects of the change of spectral output on the different devices.

We are working, together with TISO laboratory, to turn the matrix method into true and real software for the prediction of the energy produced by the photovoltaic systems, including corrective factors in the method which considers the effect of cloud and the other system power losses (mismatch between the panels, losses in the cables and efficiency of inverter).

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