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On the Connectivity of PV Panels to the Grid – Monitoring Systems

Ali Rachini, Iman Mougharbel*[‡], Hadi Y. Kanaan**, Stathis Tselepsis, J. Nicoletatos, Evangelos Rikos***

* Electrical Department, Faculty of Engineering, Lebanese University, Hadath - Lebanon
**Electrical Department, Faculty of Engineering, St. Joseph University, Mar-Roukoz - Lebanon
*** Centre of Renewable Energy Sources and Saving (CRESS) in Pikermi, Athena, Greece

[‡] Corresponding Author; Imad MOUGHARBEL, Lebanese University, Faculty of Engineering, Campus Rafic Hariri, Hadath – Lebanon, P.O. Box 17-5091: Tel: +961 3 315373, Fax: +961 5 463470 , e-mail: AliRachiini@hotmail.com, imadmoug@ul.edu.lb, hadi.kanaan@fi.usj.edu.lb, stselep@cres.gr, inicol@cres.gr, vrikos@cres.gr

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Abstract- A photovoltaic system connected to the grid is continuously monitored in order to evaluate the performance and the efficiency of conversion. The monitoring system detects abnormal operations and power fluctuation in order to execute appropriate tasks. It gives the possibility to optimize control laws and to implement interconnection strategies. Moreover, it is used to evaluate the cost effectiveness of solar energy penetration. Therefore, a database is formed of measured values on parameters that affect the system operation. It is continuously updated in order to improve accuracy of results and to take real time decisions. This study suggests a presentation method of these parameters' values in order to directly deduce the performance and detect abnormal operations. Measurements are performed in the Centre of Renewable Energy Sources and Saving (CRESS) in Pikermi, Athena, Greece.

Keywords- PV panels; grid-connect; monitoring systems; renewable energy; distributed generation.

1. Introduction

Nowadays, photovoltaic solar panels is becoming accepted as an important mean of power generation. And, the production rate will reach tens of gigawatts in the next 40-50 years. Within the category of renewable energies and compared to wind conversion, this Photovoltaic (PV) conversion approach is silent, modular, easily transportable and quickly installed. Power can be generated where it is required without the need of long transmission lines. Actually, terrestrial applications of photovoltaic panels provide auxiliary means of power generation. Also, there are installations in locations where other means of electricity supply would be as costly as photovoltaic panels. Moreover, this kind of installation provides important social benefits to rural communities throughout the world.

Although its penetration is limited because of its high capital cost and low efficiency, ongoing research is continuously lowering these barriers and the use of PV electrical sources is increasing. Research on distributed electrical resources connected to the grid is the major issue for installing mega Watts of PV farms and for increasing its use. Continuously monitoring these installations is a very important matter because it gives feedback information on how to improve the connectivity performance, how to increase the production and how to optimize control strategies. This study concerns an efficient way of presenting and analyzing acquired data collected on a PV system installed at the Centre of Renewable Energy Sources and Saving (CRESS) in Pikermi, Athena, Greece. This work was developed in the frame of the RESSOL-MEDBUILG project that has provided a two-months training program at CRESS. In the next section, this paper starts with a general presentation on the connectivity of PV panels to the grid. In the third section, it shows how such systems are monitored focusing on the parameters that affect the production and the performance. The fourth section describes the system on which measurements have been collected and describes the constituted database. The last section introduces a method of presenting and analyzing measured values. The paper ends with a conclusion on future works.

2. Major Characteristics of PV Grid connected Systems

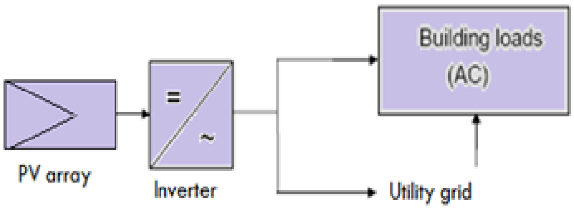

Fig. 1. Schematic diagram of grid- connected photovoltaic system [4]

Stand-alone and grid-connected are the two main PV system configurations. This study concerns only the second configuration that is used to feed electricity into the grid distribution system and/or to power loads which can also be fed from the grid. Many studies have characterized in deep detail PV grid-connected systems. This section presents a brief reminder about major parameters to be considered. Figure 1 shows that the main function to be assured is the conversion from dc to ac through an inverter. These inverters are connected directly to the grid. For a safety reason, the inverter should turnoff automatically in case of power outage. The integration of PV systems to electricity networks is covered by the IEEE 1547 and the UL 1741 standards [1,2,3]. Power quality, power regulation and safety are main issues of these standards. Norms related to power quality present specifications related to the following parameters:

- Harmonics that produce distortions in the voltage and current waveforms.
- Power factor and dc injection that are mainly affected by inverters and converters structures and control methods.
- Voltage flicker that is due to transient interactions between the converters and the grid.
- Radio frequency interference that is caused by high switching frequencies of the converters.

Grounding configurations and island operation are the main issues in safety concerns. An islanding status occurs when the grid doesn't provide power any more. In this case, the inverter should shut down automatically. This operation should happen not later than a time specified in the norms. If grounding design doesn't follow required standards, undesirable damaging phase to ground voltages may occur before islanded status is reached.

Regulation of the voltage at the point of common coupling PCC (point where the solar system is connected to the grid) is an important matter that is also considered in norms related to distributed resources. Voltage regulators are connected to the PCC in order to prevent variation and unbalancing phenomenon. If these regulators are not conveniently specified, undesirable transient voltages may be produced mainly when the PV system is subjected to fluctuations.

3. Monitoring a PV system connected to the grid

A monitoring system on a PV source connected to the grid provides the following:

- Feedback on the operative status: it is produced through a simple observed LED on the inverter or through a display panel with multiple kinds of operative information or through an interactive control panel.
- System evaluation: a system may have been financed on the basis of its output. Therefore, it is important to continuously compare the measured output to the system claims.
- Performance verification: acquired data is analysed with all necessary details in order to reflect the system performance [5].

Three of the parameters mentioned in the IEC standard 61724 may be used to define the overall system performance with respect to the energy production [6,7], solar resource, and overall effect of system losses. These parameters are the daily final PV system yield (Y_F), the daily reference yield (Y_R), and the performance ratio (Pr). They are expressed as follow:

$$Y_F=E_{PV}/P_0 \text{ (kWh/kWp .d)} \quad (1)$$

$$Y_R=H_T/G_{STC} \text{ (kWh/kWp .d)} \quad (2)$$

$$Pr = Y_F/Y_R \text{ .(dimensionless)} \quad (3)$$

where:

P_0 is the peak power of DC PV panels (kWp).

E_{PV} is the energy to grid (kWh)

H_T is the mean daily irradiance in array plane (kWh/m^2.d)

G_{STC} is the reference irradiance at Standard Testing Conditions (STC) (Insolation = 1 kW/m^2).

The monitoring system that is presented in this paper considers also parameters that are not included in the IEC standard 61724. They are useful in order to know the permeability of the data and the working temperature of the systems. These parameters are:

- Availability of data: in normal operation the DAS (Data Acquisition System of CRESS), acquires 102 measurements per day during 17 hours. The acquired data could be lost if for example the PC is shutdown or if the DAS is inoperative. In this case, the number of saved measurements will be less than 102 and the availability value is less than one. (Availability of data = daily number of saved measurements /102).

- Availability of the inverter: the inverter is considered available when the plane irradiance of PV modules is above a reference level (40W/m^2), and the power on the inverter output is different than zero. The daily availability is defined by the ratio: Nac / N_{40} (Nac is the daily number of measurements with a measured ac power on the inverter different than zero, N_{40} is the daily number of measurements giving a plane irradiance above 40 W/m^2. The level 40 W/m^2 is the reference under which the inverter shutoff. Disabling the monitoring system during night would alleviate the DAS and the inverter operations and would not affect the monitoring results.

- Module temperature: it is the mean daily temperature of the panels (^{0}C), during hours of operation (17 hours per day).

4. The monitored system at CRESS

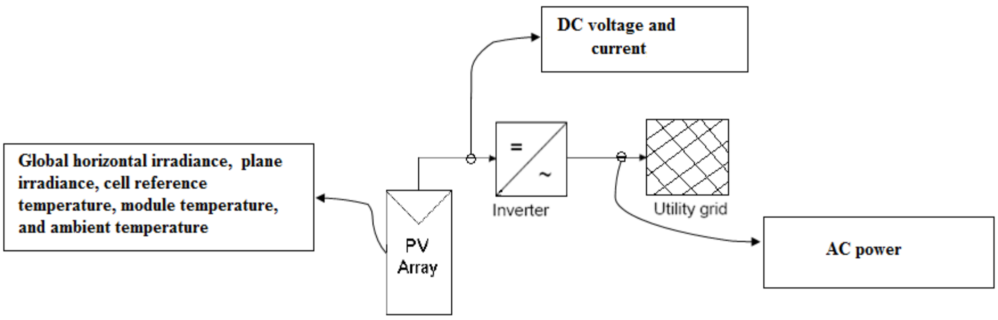

Fig. 2. Levels of measurements acquired by the DAS

Laminated PV modules constitute the PV panel of the concerned system. It is formed with an array of 64 modules of 105Wp each, grouped in 4 sub-arrays of 16 modules each. Modules are serially connected and give a total power of 1680Wp. The panel is mounted on a metallic structure installed with a tilt angle of 45^0 and an offset angle of 0^0. Two single phase inverters of 2.0kW are connected between two phases each are used for grid connectivity, each one converts the power generated by 2 sub-arrays. The dc/dc converter with a rated input of 600V is regulated on its output in order to provide the maximum power to the grid by means of an MPPT integrated algorithm.

The DAS is formed of a PC based data logger, a pyranometer for the measurement of global horizontal irradiance, a calibrated reference PV module for plane irradiance measurements, an ambient air temperature sensor, a sensor to measure the PV module temperature and electrical measurement equipment to acquire voltage, current, power and energy of the PV array on the DC and on the AC sides. Figure 2 shows at what level each measurement is acquired. A more detailed description of this DAS is presented in [8].

Using Matlab and Excel, the acquired data is presented in form of tables, charts and graphs. The DAS saves acquired data as ".text" files according to one file per day. A program selects in these daily files the information related to a specific period given by the user. The system performance is deduced from the yield values. In order to directly evaluate the performance, a program calculates the daily final and reference yield. It is presented with the daily profile of the AC power generation in terms of the plane irradiance. Also it presents the performance in terms of ambient and modules Temperature, availability of data and solar irradiation. Due to this presentation of analysed data, it is possible to directly detect abnormal operations of the PV system.

5. Monitoring results and analysis

The following results are obtained from measured parameters on the CRES system during the period between June 8 and June 14, 2010.

The bar chart in figure 3 represents a comparison between the reference yield, and the final yield. It permits to evaluate the performance ratio by doing the relative difference between the two bars for each day. This value depends mainly on irradiance that is also acquired in order to check if there is a problem in the system. An abnormal operation is considered when irradiance is high and performance is low. A good performance ratio should be around 80% or higher. This performance can’t reach 100% because of losses in the cabling and in the converters.

Figure 4 is a comparative representation between plane irradiance and power transmitted to the grid. This representation is related to a period of time measured in hours, days, weeks or even months. Normally, the power output is proportional to the solar irradiance, if the system operation is normal, the two curves must have the same shape with proportions between maxima and minima.

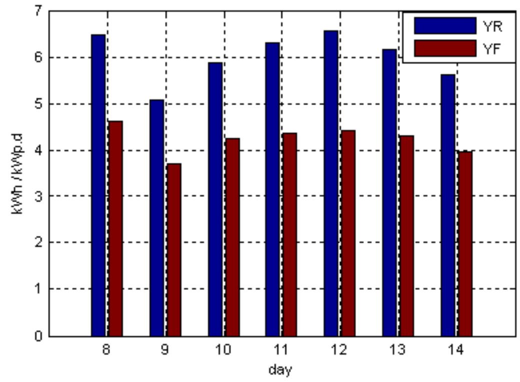

Fig. 3. Final yield (YF) and reference yield (YR) between June 8 and June 14, 2010

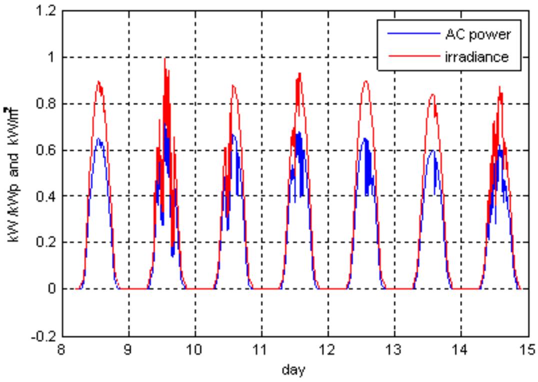

Fig. 4. AC power and plane irradiance CRES-5 (8-14 June 2010)

Referring to figure 5, the average daily values are presented for the performance ratio Pr, the mean of the PV module temperature in degree Celsius (^{0}C), the mean PV module plane irradiance per day and the availability of the inverter.

In order to analyse this representation, first of all the inverter availability is to be checked. Most of inverters are provided with a tripping protection unit that disconnects the system when overheat or overload occur. That is why it is important to check the temperature with the inverter availability. The case of figure 5 shows that the inverter is 100% available during the concerned period. The second issue is to verify how the performance ratio Pr changes with irradiance Irra. If Pr is low although Irra is high, it means that a saturation or abnormal phenomenon has occurred. This is the case of day 12 in figure 5 which is due to the relatively small size of the inverter nominal power compared to the nominal DC power of the PV array.

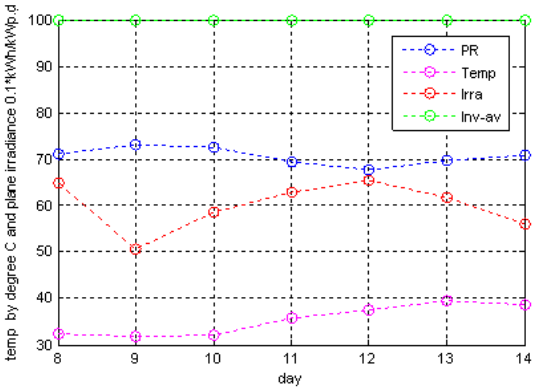

Fig. 5. Performance (PR) variation in terms of the daily variation (8-14 June 2010) of the temperature (Temp), the plane irradiance (Irra) and the availability of the inverter (Inv-av).

The other set of results representation shows relations between parameters. They are obtained by gathering information from the database and produce statistical calculations. Figure 6 represents the performance ratio with different mean PV module temperature. Values are considered during one month (May 2010). It is clear that the performance ratio decreases with the increase of the mean temperature.

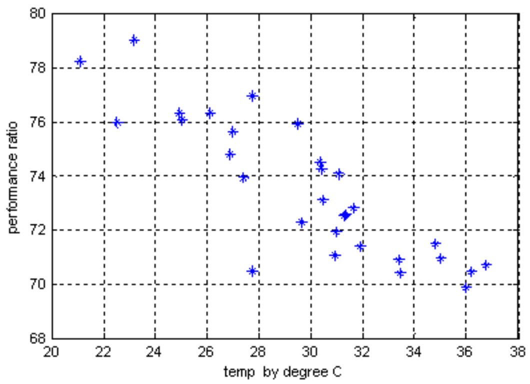

Fig. 6. Performance ratios versus mean PV module Temperature

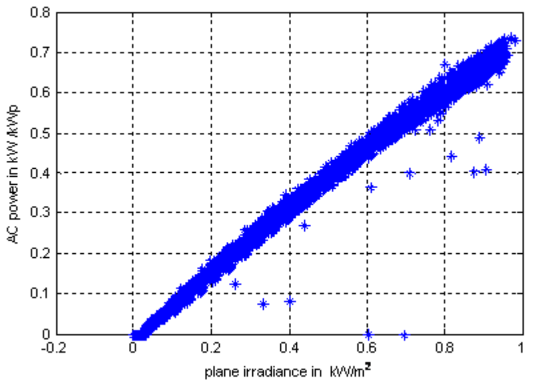

Fig. 7. AC power versus the PV plane irradiance.

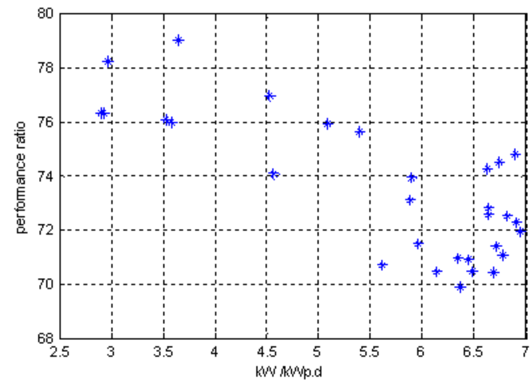

Fig. 8. Performance ratio versus reference yield (DC energy).

Figure 7 represents the generated AC power in terms of the irradiance for a same temperature during the month of May 2010. It shows that the AC power generation increases linearly with the PV plane irradiance.

Figure 8 represents the performance ratio versus the reference yield (DC energy). It is clear that the performance decreases with the increase of the reference yield at a given ambient temperature.

6. Conclusion

This study has shown the importance of continuously monitoring a grid connected PV system. The acquired data is stored in a data base, it is analysed and presented. One set of these presentations give parameters values in terms of time, the other set gives the relation between these parameters. Due to the presentation forms that are suggested in this paper, it would be possible to directly deduce about the operative status of the system, its performance and its capacity. Future works will be done on the implementation of controllers that makes the system reach its maximum performance in all conditions. This will be done due to the real time measurement of parameters and also due to information gatherd in a database.

Acknowledgements

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