OUTDOOR PV MODULE PERFORMANCE COMPARISON AT TWO DIFFERENT LOCATIONS

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ABSTRACT

The paper presents the results of a two years outdoor monitoring campaign that has been carried out on the same polycrystalline photovoltaic module at two different locations in Europe: the SUPSI-ISAAC outdoor facility in Lugano, Switzerland, from April 2006 till May 2007, and the outdoor ESTER facility in Rome, from April 2008 till May 2009. Since the same module has been tested in two places using the same testing electronic unit (MPPT 3000), the device performance differences can mainly be ascribed to the different local environmental conditions. A detailed characterization of the climatic conditions in Lugano and Rome for the periods of interest have been performed and the PV module performance comparison has been carried out in terms of module efficiency, module yield (Y) and Performance Ratio (PR). No evident influence of the PV module different mounting and monitoring management has been observed on the module performance. The PR monthly trend is mainly due to the temperature influence on the module behaviour, with lower values during summer months; for the same reason, the higher temperatures experienced in Rome penalize the performance. The monthly PR appears higher for Lugano than for Rome apart from the April 07-09 case where the performance in Rome has been higher. A 3% maximum PR deviation between the two sites has been registered during the autumn months.

INTRODUCTION

Renewable energy production by solar energy conversion is having a high impulse in recent days due to the attention paid by various governments in Europe and overseas. Many industries are focused on the production of photovoltaic modules claiming high performance and high reliability of their products. Sometimes this performances are not reached when the devices are exposed to the real environment, at different locations and with different configurations. It is important, therefore, to evaluate the real behaviour of such modules in outdoor conditions through reliable and accurate measurements to give indications to the costumer about the choice of the right device for his specific application.

In Europe, there are well established laboratories that are doing research on the performances of PV modules of well consolidated technologies as well as new emerging ones. Among them, the SUPSI-ISAAC Institute in Lugano, active since 1991, is one of the leading groups in the field of outdoor monitoring [1, 2]. More recently an outdoor monitoring facility, called ESTER, for testing of PV modules of various technologies has been built at the University of Tor Vergata and it is part of the laboratories of the CHOSE (Centre for Hybrid and Organic Solar Energy), a centre funded in 2006 by the Lazio region with the objective of give impulse to the photovoltaic in Italy and especially to develop and industrialize the Dye Sensitized Solar cells (DSC) as a new generation of photovoltaic technology. A close collaboration has been started between the two groups. A polycrystalline PV module by Kyocera model KC125GHT-2 has been donated by SUPSI to ESTER and a validation procedure for the new Italian laboratory has been performed with the device [3]. The module has been mounted on the ESTER stand since January 2008 and data of more than one year of operation at this location are now available.

The paper presents the results of a comparison campaign of the same module exposed to the outdoor environment in Lugano, Switzerland and Rome, Italy.

EXPERIMENTAL

In this section a brief description of the two outdoor facilities will be done. Details on the test conditions of the module at the two locations will be given.

ESTER Facility

The station is located on the roof top of the Engineering building of the University of Rome Tor Vergata (41.8556° latitude North, 12.6233° longitude East) and it consists of two units: a meteorological station (active since 2003), that provides high quality data of solar radiation at ground and of microclimatic parameters, and a monitoring station for photovoltaic devices recently added. An overview of ESTER is shown in Fig. 1. The meteorological unit can separately measure direct, diffuse, reflected and global solar radiation at ground. It is equipped with a Kipp&Zonen 2AP sun tracker that supports a shaded ventilated pyranometer for diffuse radiation measurements and a pyrheliometer for direct radiation measurements; global and reflected irradiances are measured by two pyranometers mounted on a dedicated plate.

Fig. 1. View of the ESTER facility at the University of Rome Tor Vergata.

A Campbell Scientific CR10X data logger collects radiation data every minute only during diurnal period, while weather data are collected all day long and minimum, maximum and average of each variable are given every minute and on both hourly and daily basis.

The PV monitoring station consists of a fixed stand that is oriented toward South and whose tilt angle can be varied from 25° to 75°. The structure has two frames that can be tilted separately so that different inclinations can be tested simultaneously primarily when the sun is at midday. The stand can host up to six PV modules and is fully instrumented with an in plane pyranometer, reference cells for mono, poly and amorphous silicon technologies, PT100 sensors for modules temperature measurements, ambient temperature sensor and sonic anemometer. A sun tracker can host up to two PV modules of large size. Also the sun tracker is equipped with sonic anemometer, in-plane pyranometer, reference cells and PT100 for PV modules temperature measurements. Each PV module under test is continuously monitored by a MPPT 3000 provided by SUPSI. Maximum current and voltage are measured every minute together with all the environmental parameters; every 10 minutes a complete I-V curve is retrieved for each PV module. Data are collected by a Campbell Scientific CR1000 data logger via RS485. More details on the station architecture can be found in [4] and [5].

The KC125GHT-2 module has been mounted on the fixed stand since January 2008. As it can be seen from figure 1, the module is open rack mounted with no lateral obstructions. Each month the frame tilt angle has been varied to get the maximum energy for the period and to allow the module to be at normal incidence ± 5° at noon.

ISAAC Facility

Since 1991 the ISAAC laboratory, has been carrying out independent tests on single PV modules. With the regular publication of the results, the laboratory wants to deliver to the end user some information about PV module quality and reliability in terms of power, energy output and stability. The general procedure [2, 6] consists in the measurement of the energy output and STC power of max. 18 randomly selected module types (two modules for each type) exposed outdoors under real operating conditions for a period of 15 months.

Fig. 2. View of the SUPSI-ISAAC facility in Lugano.

Two modules of each type are open-rack mounted (Fig. 2), tilted at 45° and -4° south of azimuth at the institutes roof at Lugano (46.03° latitude North, 8.96° longitude East, 373m altitude). Each module is equipped with a Maximum Power Point Tracker (MPPT 3000) specially developed by SUPSI-ISAAC adapted to its voltage and current range to optimize measurement accuracy. The module temperature is measured with a PT100 fixed on the back of the module. The test stand consist of three pyranometer and different reference cells to monitor the in-plane irradiance. The meteorological data as global and diffuse horizontal irradiance, wind speed and ambient temperature as well as the module performance data are recorded by HP data logger with a resolution of one minute. The investigated Module was measured in the period from April 2006 to May 2007.

RESULTS

Great attention has to be paid when comparing PV modules performance and energy production data, coming from different datasets. Since for energy calculation, the datasets are integrated over time, different observation time intervals produce different results.

ISAAC and ESTER datasets have been carefully analyzed and filtered using the same screening analysis [7]. Data with in plane irradiance lower than 20 W/m^2 have been discarded. Shadowing have been recognized and eliminated from the sets together with outliers and data out of physical range. ESTER has experienced a system failure in August 2009 so that only one day could be considered, after filtration. ISAAC had also a larger system failure in May 2006 with 16 days missed and some smaller failures distributed over the year. Moreover Lugano is regularly performing indoor measurements under standard test conditions of all modules to monitor its stability over time. After filtering Rome presents 335 useful days while Lugano could use 320 days for the analysis.

The first approach to the data analysis consisted on the climatic characterization of the two sites.

Comparison of the PV module performance at the two sites have been performed through the module yield (Y) and Performance Ratio (PR) evaluation.

Climatic Characterization

A deep analysis of the weather data (filtered data) for the two sites has been carried out focusing on irradiance availability and ambient temperature trends. The irradiance resource potential for the two locations has been evaluated in

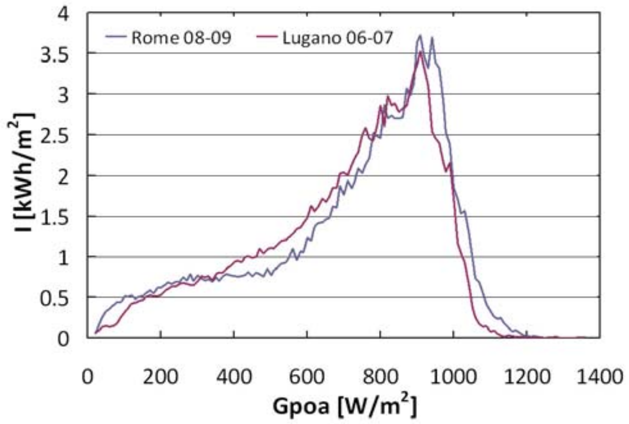

Fig. 3. Frequency distribution of incoming energy for the two site.

terms of frequency distribution of the incoming energy and of the Cloud Ratio.

The Cloud Ratio (CR) is defined as the ratio of the horizontal diffuse irradiance over the global horizontal irradiance and it gives an indication of the cloud coverage. It ranges from 0 to 1 with 0 meaning very clear sky and 1 meaning overcast sky. For this application, CR has been calculated for data taken every minute and the CR range has been divided in 5 classes. For each of the classes the data frequency has been evaluated. To compare the two datasets the frequency distribution has been normalized to the total data amount of each datasets.

Fig. 3 shows the frequency distribution of the solar energy. In plane irradiance (G_{poa}) has been binned into 10 W/m^2 intervals and for each interval the solar irradiation (I) has been calculated. The graph shows a higher energy availability for Lugano in the range 300-800 W/m^2 while Rome shows higher incoming energy in the range 900-1200 W/m^2. The annual incoming energy in Rome was 1.33 MWh/m^2 (335 days) and 1.30 MWh/m^2 (320 days) in Lugano. Fig. 4 shows the annual normalized frequency distribution of the Cloud Ratio. Lugano has experienced a high frequency of very nice and nice days (almost 60% of the total in the two first classes) compared to what observed in Rome (less than 50%). Besides, Rome exhibits a higher percentage of highly overcast days (35% against 22% in the 0.8-1 class). It can be concluded that the weather was most favourable to Lugano than Rome for the observed periods, however Rome exhibits higher energy potential at higher in plane irradiances. This is in part due to the different latitude, in part because at ESTER facility the module tilt angle was optimized each month.

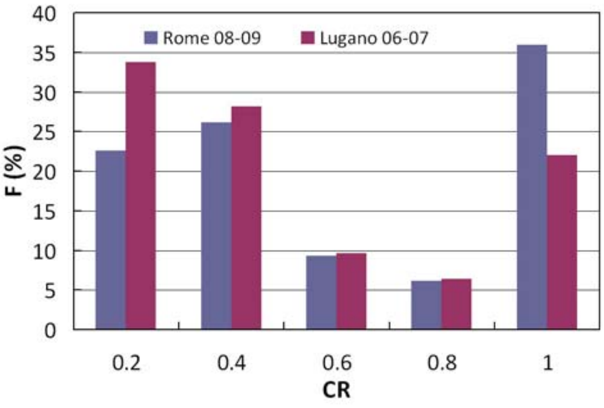

Fig. 4. Cloud ratio as observed for the two site.

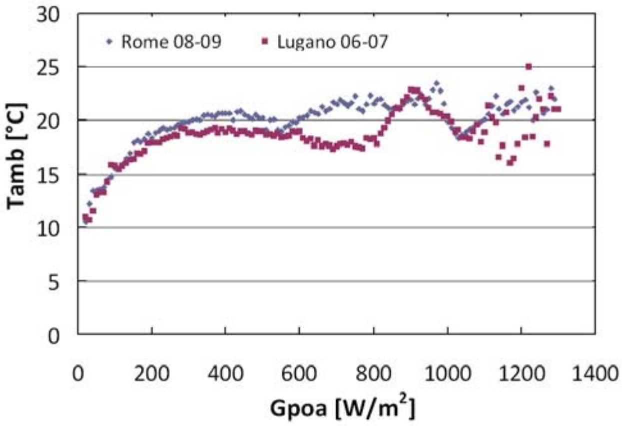

Fig. 5. Ambient temperature trends versus in plane irradiance for the two site.

Ambient temperature distributions have been evaluated in terms of irradiance. Fig. 5 shows the trends for the two locations. As expected, slightly higher temperatures have been observed in Rome.

Photovoltaic Module Performance

Module energy production has been evaluated for the two years of test at the two locations. It is well known that the module efficiency is influenced by the environmental parameters in various ways. The temperature reached by a polycrystalline module during operation influences its efficiency since higher temperatures decrease the module open circuit voltage and consequently the power produced.

Back of the module temperature (T_{bom}) has been monitored both in Rome and Lugano and the trends are showed in Fig. 6 versus the in plane irradiance.

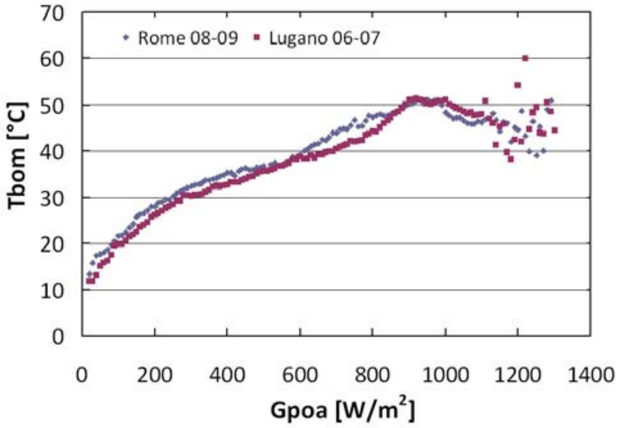

Fig. 6. Back of the module temperature versus in plane irradiance for the two site.

The module temperature is higher of about 2-4 °C, at ESTER, till approximately 900 W/m^2 following the ambient temperature trend.

The photovoltaic module performance can be studied in terms of Yield and Performance Ratio [8]. The first index is defined as:

$$Y = \frac{E}{P_n} \tag{1}$$

where E is the energy produced by the module in the time period considered and P_n represents the module nominal power evaluated at the Standard Test Conditions. The module yield is a useful index if modules of different nominal powers have to be compared.

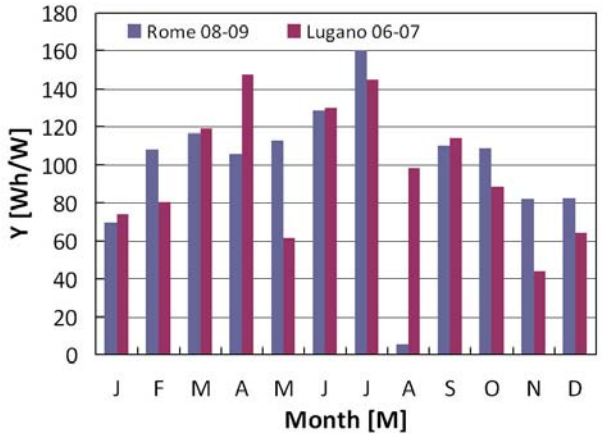

Fig. 7. Monthly Yield evaluated at ESTER and ISAAC facilities.

In this case it essentially compares the energy production at the two sites. The index has been calculated on a monthly basis and the results are showed in Fig. 7. Since the yield is dependent on the incoming irradiation which is higher in Rome than Lugano, a higher yield is observed in Rome. The exception of August is due, as already mentioned, to the lack of data at ESTER. The higher yield observed in Lugano, in April, is mainly due to the most favourable weather experienced at that site with respect to Rome (that has been verified through the CR distribution for the month). As already pointed out, 16 days are missing for the ISAAC dataset in May and this explain the consistent low yield. Winter months look more favourable to Rome, as expected.

The Performance Ratio is defined as:

$$PR=\frac{Y}{Y_r} \qquad \text{with: } Y_r=\frac{I}{G_{STC}} \tag{2}$$

I is the incoming energy calculated over the time period of interest and $G_{STC} = 1000$ W/m^2. PR is almost independent on irradiance so that it is more appropriate for the inter-comparison of monitoring data with system failures or other types of data holes. The remaining differences are so mainly influenced by temperature effects or degradation and in a second order by spectral and angle of incidence effects.

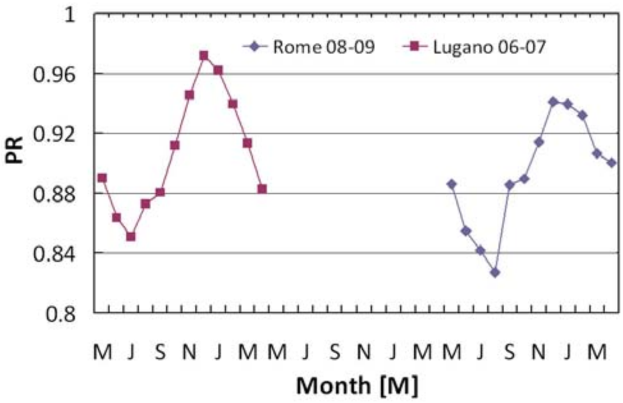

Fig. 8. PR versus the months of the year at the two sites.

Table 1. Ambient temperature variation and PR deviation for each month of the year.

Month	DeltaTamb (°C)	PR deviation (%)
Jan	0.8	2.3
Feb	0.8	0.7
Mar	1.7	0.6
Apr	-1.0	-1.8
May	2.9	0.4
June	3.0	0.9
July	1.6	0.9
Aug	10.3	4.5
Sept	2.7	-0.5
Oct	4.8	2.2
Nov	3.6	3.1
Dec	3.2	3.1

The PR uncertainty for ESTER and ISAAC data is in the order of ±5%. For the purpose of this study an uncertainty of ±3% can be assumed due to the inter-comparison of the same module. The measurement uncertainty of the STC power has not to be considered here. Moreover no significant degradation of the power over time could be observed. The main contribution to overall uncertainty is coming from the pyranometer irradiance measurements and in a smaller amount from the current and voltage measurements.

Fig. 8 shows the trend of the monthly PR calculated for Rome and Lugano for the years of test. The typical seasonal effect induced by the temperature variation can be observed. The polycrystalline module, as expected, shows a lower PR during summer months due to the negative effect of the increasing temperatures. Moreover slightly higher PR can be observed for Lugano. Table 1 visualize better the difference between the two sites. The PR deviations for each months are listed, together with the difference of the average ambient temperature. Ambient temperature has been averaged over the period of observation. Positive PR deviation means higher PR for Lugano. The maximum PR deviation of 4.5% is observed in August. However this cannot be considered a significant value due to the lack of data for that period at the ESTER facility. The lowest ambient temperature experienced in Lugano during the winter months is responsible for the better behaviour of the module at that site. The correlation between ambient temperature and PR is also confirmed by the April case for which a lower average ambient temperature in Rome produced the only negative PR deviation. However it can be noted that most of the calculated percentage deviations fall into the limit of the measurement uncertainty.

The KC125 GHT-2 module produced 148.69 kWh in the 2008-09 year in Rome and 145.80 kWh in the 2006-07 year in Lugano. Considering the incoming energy at the two sites, the module has experienced an annual efficiency of 12.00% in Rome and 12.05% in Lugano.

CONCLUSIONS

The same polycrystalline photovoltaic module KC125 GHT-2 has been tested for one year at two different locations: Lugano, CH and Rome, IT. The test has been carried out to investigate the influence of the climatic conditions on the module performances and to compare the test configuration of the two outdoor facilities, ESTER in Rome and ISAAC in

Lugano. The two datasets have been filtered using the same procedure and a deep climatic characterization allowed to explain most of the module behaviour.

The climatic conditions at the two sites for the years of interest appeared quite similar with a slight higher average ambient temperature in Rome and more favourable weather in Lugano for some months.

It can be concluded that the different test configuration at the two sites do not significantly influence the module performance. The monthly PR presents a typical temperature dependence with lower values at higher temperature. The PR percentage difference between the two sites reached a maximum of 4.5% for the month of August but this is not very significant due to a large amount of data missed at the ESTER facility. However a 3% deviation observed for the cold months and favourable to Lugano can be ascribed to the lower temperatures measured at that site and to a higher number of very clear sky days. The annual behaviour of the module is the same at the two sites with an efficiency of 12%.

ACKNOWLEDGMENT

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NOMENCLATURE

Symbol	Quantity	SI Unit
CR	Cloud Ratio	dimensionless
E	Energy of the module	Wh
F	Frequency distribution	dimensionless
G	Irradiance	W/m^2
I	Irradiation	Wh/m^2
P	Power	W
PR	Performance Ratio	dimensionless
T	Temperature	°C
Y	Yield	Wh/W

Subscript

amb	ambient
bom	back of the module
n	nominal
poa	plane of array (module)
r	reference
STC	Standard Test Conditions

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