# OUTDOOR ESTER TEST FACILITY FOR ADVANCED TECHNOLOGIES PV MODULES

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## ABSTRACT

In the paper the new outdoor test facility ESTER (Solar Energy TEst and Research) for PV modules of various technologies is presented. The facility has been partially funded by the Regione Lazio, Italy, in the framework of the Centre for Hybrid and Organic Solar Energy (CHOSE). This structure is intended to give support to the improvement of reliable and durable organic photovoltaic cells and modules and could offer, in the near future, quality assurance and possible calibration services for PV modules of other technologies. The facility has been designed and built in order to fulfil some of the requirements of the European standards IEC 61215, IEC 61646 and of IEC 60904-1and IEC 61829.

Characterization of the climatic conditions of the Tor Vergata site on a three years data basis is also presented, proving Tor Vergata to be a suitable site for PV monitoring and test.

## INTRODUCTION

Photovoltaic devices performances are mainly tested indoor, at Standard Test Conditions (STC). However, these conditions are not representative of the real environment in which the device will operate. Growing importance is presently devoted to PV monitoring in real environmental conditions and this is confirmed by the number of outdoor facilities operating in Europe [1, 2, 3, 4, 5, 6] and worldwide [7, 8, 9, 10] and by the number of research programmes funded for this purpose [11, 12, 13]. Moreover new emerging PV technologies such as organic photovoltaic present big concerns about durability and degradation [14] and, on the contrary, they also appear to improve their performance at certain real ambient conditions [15].

The outdoor ESTER (Solar Energy TEst and Research) facility at the University of Rome Tor Vergata, is born to give support to the development of organic photovoltaic solar cells and modules produced by the Centre for Hybrid and Organic Solar Energy (CHOSE). The facility, belonging to the Environmental Applied Physics laboratories, has been designed in order to monitor and test PV modules of various technologies for short, medium and long term periods. In the near future the facility could also provide some calibration services to meet the requirements of the European standards IEC 61215, IEC 61646 and of IEC 60904-1and IEC 61829 [16, 17, 18, 19].

## THE ESTER FACILITY

The station is located on the roof top of the Industrial Engineering building of the University of Rome Tor Vergata (41,18556° latitude North, 12,6233° longitude East) and it consists of both a meteorological station (active since 2003), that can provide 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.

Fig. 1. Overview of the ESTER outdoor station.

### The Meteorological station

The meteorological station is collecting data since July 2003. It consists of two units: a weather unit that provides temperature, pressure, wind direction and speed, rain measurements; and a solar radiation unit that can separately measure direct, diffuse, reflected and global solar radiation at ground. The latter 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 fluxes are measured by two pyranometers mounted on a dedicated plate.

Fig. 2. Sun tracker with pyrheliometer and shaded pyranometer at the solar station.

Figure 2 shows the sun tracker with the pyrheliometer and the shaded pyranometer. 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. Data collected by the station have been used to characterize the Tor Vergata site for solar radiation availability and climatic conditions.

## The PV Modules Monitoring station

The monitoring station consists of two units; a fixed stand (Stand 1, Fig. 3a) 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. Fig. 3b shows the sun tracker (Stand 2) that 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.
The PV modules are continuously monitored using an electronic unit that can keep each device at its Maximum Power Point (MPP). In this way the device is stressed as if it operates in real production conditions.

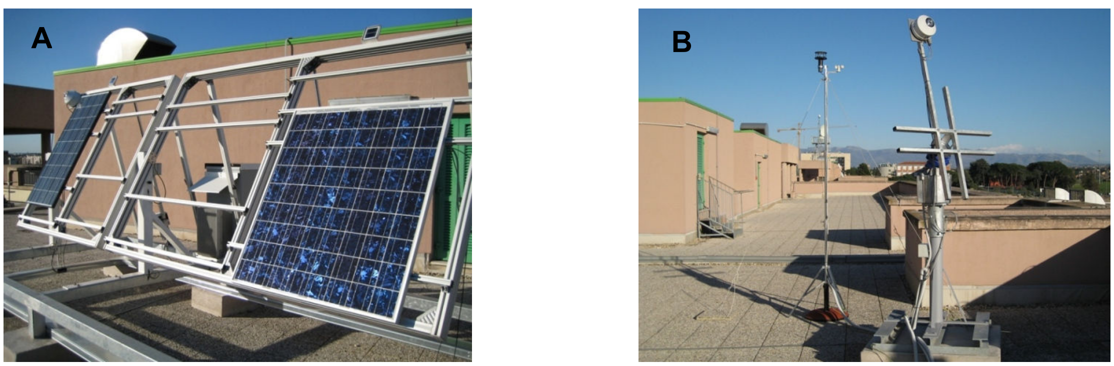


Fig. 3. a) Fixed stand mounted on the roof top of the Engineering building; two PV polycrystalline silicon modules are presently monitored; b) sun tracker for PV modules (with no modules mounted) and in-plane pyranometer.

The instrument is a Maximum Power Point Tracker (MPPT) developed and provided by ISAAC-SUPSI of Lugano. 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. All the ESTER facilities are connected to the web and data are downloaded every 30 minutes in a database of a dedicated server. The architecture of the data acquisition system for Stand 1 and meteorological station is showed in Fig. 4. Stand 2 (sun tracker) acquisition system resembles that of Stand 1.
As far as the Authors know, only few outdoor test facilities like the ones in Lugano [2] and Ispra [6], in South Africa [9] and at MUERI in Australia [10] produce continuously measured energy output of individual modules. ESTER facility has also the capability of continuously producing I-V curves for each module under test.

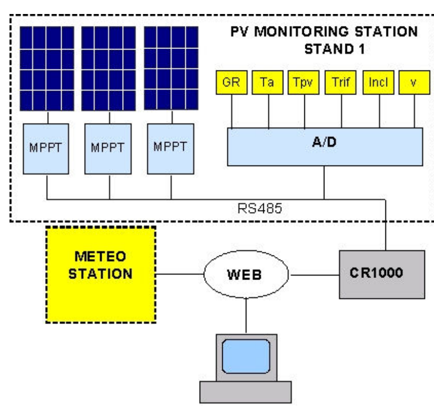


Fig. 4. Sketch of the data acquisition system for Stand 1 of ESTER facility.

## The Noria data management software

To extract data from the ESTER database a management software called Noria has been expressly conceived. The software is highly flexible and for each configuration of stand 1 and 2, it allows to visualize arrangements of PV modules. On the basis of the configurations under test, the database can be queried by a syntactic query builder and logical composer in order to extract I-V curves, PV module maximum current and voltage and temperature with respect to date and time, radiation intensity and environmental parameters.

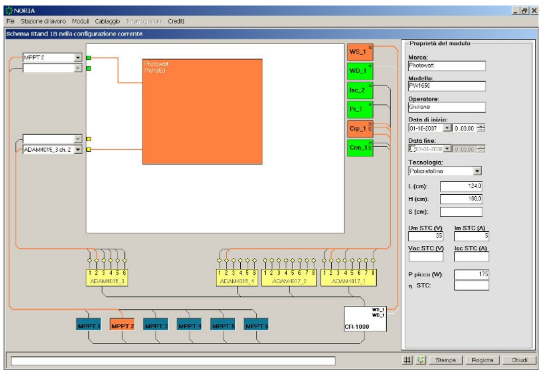

Fig. 5. Visualization of Stand 1 with a Photowatt PV module mounted.

The software consists of a “hardware repository” where all the instruments, converters and sensors of the monitoring station are listed. The configuration section allows to assign the environmental sensors to the specified channel of the data acquisition system and after the stands are properly configured they can be visualized as shown in Fig. 5. On the virtual stand is then possible to add the PV modules currently under test and to connect them with the corresponding MPPT (Fig. 5).

PV modules information as well as stands configurations are stored in the database and used to extract environmental and modules parameters from the ESTER database.

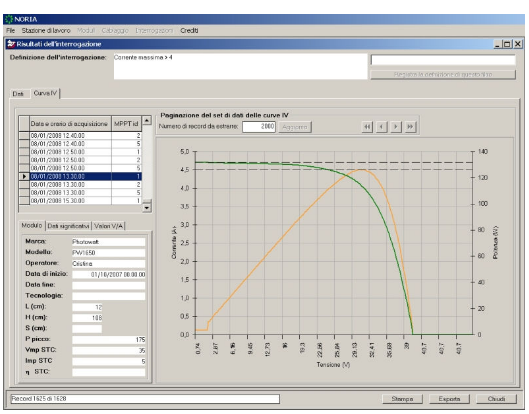

Fig. 6. Noria presentation of I-V curves.

Data extracted with respect to the specified criteria are presented in terms of PV modules tested and are located in two folders, one that lists all data referred to 1 minute acquisition rate, and the other with the I-V curve collected every 10 minutes.

Figure 6 shows an example of I-V curve presentation after the query. In this case maximum current higher than 4A is the search criterion: Noria lists all I-V curves corresponding to the query; when a particular curve is selected, its trend is shown in a graph; the PV module characteristics, the environmental data corresponding to the curve acquisition time and the single data of the curve are also shown in the folders at the left of the graph. These information can be exported in ASCII and/or Excel format files and also printed in a report.

## TOR VERGATA SOLAR RESOURCE

A complete evaluation of the effective availability of solar radiation and of climatic conditions at ESTER site have been performed processing data collected by the meteorological station since 2003 [20]. Maximum, minimum and average ambient temperature together with humidity, rain rate, wind speed and direction have been evaluated for the average year. Table 1 summarizes the climatic and sky conditions at Tor Vergata site.

Table 1. Weather and solar conditions at Tor Vergata site.

| | | Gen | Feb | Mar | Apr | Mag | Giu | Lug | Ago | Set | Ott | Nov | Dic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T (°C) | max | 13.8 | 15.2 | 21.8 | 23.7 | 29.3 | 37.2 | 35.9 | 34.6 | 33.8 | 25.3 | 22.7 | 18.3 |
| | min | -0.8 | 1.1 | -0.1 | 5.8 | 11.0 | 13.6 | 17.9 | 16.4 | 13.3 | 12.9 | 4.8 | 2.5 |
| | **Avg.** | **7** | **8.4** | **10.9** | **14.7** | **19.2** | **23.4** | **26.6** | **24.9** | **21.9** | **18.2** | **12.7** | **9.8** |
| UR (%) | max | 94.8 | 95.1 | 96.2 | 93.1 | 93.0 | 87.7 | 87.5 | 90.3 | 95.7 | 96.3 | 96.3 | 93.9 |
| | min | 33.9 | 35. 3 | 19.6 | 21 | 25.2 | 22.8 | 20.4 | 26.1 | 31.58 | 43.92 | 40.3 | 41.4 |
| | **Avg.** | **73.3** | **70** | **69.7** | **67.6** | **62.6** | **56** | **52.5** | **61.7** | **68.7** | **76.8** | **76.4** | **76.5** |
| **mm of rain** | | 48. 3 | 79.4 | 65.1 | 84.1 | 42.1 | 15.1 | 10.1 | 16.3 | 90.5 | 76.8 | 117.3 | 130 |
| **Days of rain** | | 11 | 11 | 14 | 12 | 7 | 4 | 3 | 5 | 10 | 11 | 12 | 14 |
| Wind speed (m/s) | max | 11.5 | 14.9 | 16.2 | 16.2 | 13.6 | 12.2 | 11.4 | 13.9 | 11.1 | 11.1 | 10.2 | 11.8 |
| | **Avg.** | **2.1** | **2.5** | **2.6** | **2.4** | **2.5** | **2.47** | **2.6** | **2.5** | **1.7** | **1.7** | **1.9** | **2.1** |
| Sky cond. (%) | **CS** | **35** | **25** | **34** | **24** | **41** | **60** | **60** | **46** | **41** | **41** | **30** | **24** |
| | OS | 26 | 31 | 19 | 27 | 4 | 2 | 2 | 6 | 21 | 21 | 29 | 37 |
| | PS | 39 | 43 | 47 | 49 | 55 | 39 | 39 | 48 | 38 | 38 | 40 | 40 |

Figure 7 shows the prevailing wind directions for the average year. Tor Vergata experiences a prevailing South, South-East wind direction in Summer and Spring while a North, North-West most frequent direction during Winter and Autumn.

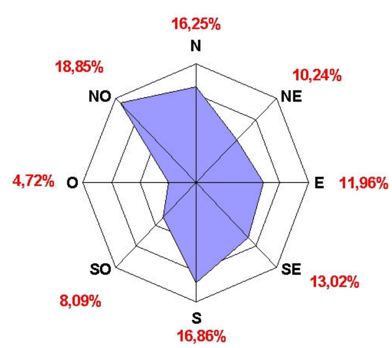


Fig. 7. Frequency distribution of annual wind direction.

Solar radiation data have been used to characterize sky conditions. Cloud ratio daily trend has been identified for three sky conditions: clear sky, intermediate sky and overcast sky [21]. All days of the years have been grouped with respect to the three sky conditions and in Fig. 8 the percentage of the occurrence of the three conditions for every month is shown.

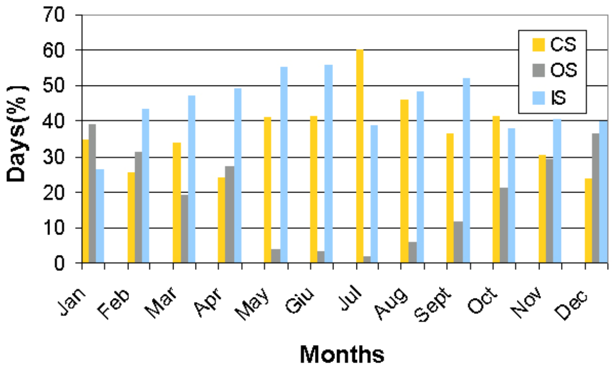


Fig. 8. Percentage of Clear Sky (CS), Overcast Sky (OS) and Intermediate Sky (IS) for the standard year at the Tor Vergata site.

It can be noted the prevailing occurrence of clear days for July while in June, due to high variability of the weather for this area there is a strong impact of intermediate sky days. For the average year Tor Vergata exhibits 37% of clear days and only 19% of overcast days proving to be a well-suited site for PV modules applications.

The occurrence of high values of Direct Normal Irradiance (DNI) has also been determined to evaluate the possibility of tracing I-V curves fulfilling the requirements of IEC 60904-1 [16] and 61215 [17] all year long. The cited norms prescribe to measure PV module parameters at normal incidence and with radiation intensity higher than 800 W/m$^2$.

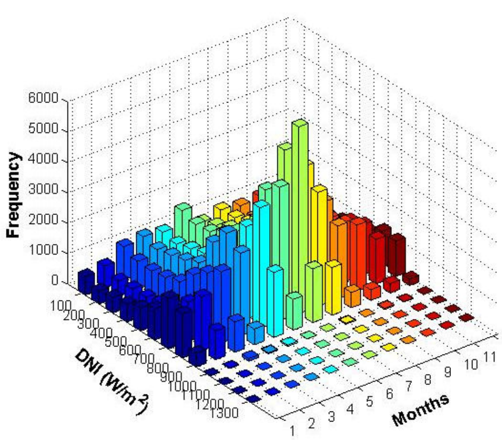


Fig. 9. Frequency distribution of DNI values for the months of the year at the Tor Vergata site.

Figure 9 shows the frequency distribution of DNI values for the months of the year. As expected, the higher frequency of high irradiance values is concentrated in the summer months where the probability of having irradiation in the range 650-850 W/m$^2$ is approximately 40%; however even during mid seasons and winter there is a good probability (approximately 30%) of reaching the same DNI values.

Solar energy availability has also been evaluated on a horizontal plane for the Tor Vergata site. Fig. 10 shows the average daily solar energy (SE) on a horizontal plane for each month of the average year (yellow bar), compared with SE prescribed for Rome area by the UNI10349 [22] norm which is used for PV systems design (orange bar). A small difference (approximately 4% on the annual value) is visible for the two data set. The annual solar energy for Tor Vergata has been estimated to be 1.54 MWh/m$^2$, fully lined up with the availability for Central Italy. Blue line in the graph shows the monthly average ambient temperature in Tor Vergata.

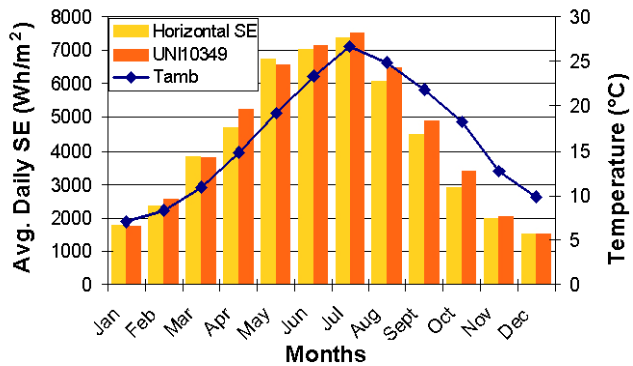


Fig. 10. Daily solar energy availability on a horizontal plane for each month of the year. The blue line shows the average ambient temperature trend for Tor Vergata site.

## CONCLUSIONS

A new outdoor facility for testing PV modules of various technologies at the University of Rome Tor Vergata has been presented together with an evaluation of climatic conditions and solar resource of the site. Both the facility and the site show high potential for research and qualification tests on PV modules. The outdoor facility ESTER can provide reliable and accurate tests on PV modules of different technologies and in the near future it will be able to characterize and compare outdoor performance of the new DSC modules built by CHOSE laboratories. Moreover the structure will provide test services for PV modules to designers and manufacturers.

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