DATA VALIDATION AND UNCERTAINTY EVALUATION OF THE ESTER OUTDOOR FACILITY FOR TESTING OF PHOTOVOLTAIC MODULES

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ABSTRACT: In the paper the uncertainty analysis of the FTA Lab ESTER facility instrumentation is presented together with the procedure used to validate data outputs through measurements on a reference polycrystalline module provided by ISAAC-SUPSI. The reference module has been tested for several months and a procedure has been identified to sort the IV curves for translation at STC conditions. Blaesser method has been implemented and comparison between STC data from indoor measurements by ISAAC and translated outdoor curves produced quite satisfactory results.

Keywords: PV module, monitoring, uncertainty.

1 INTRODUCTION

Outdoor monitoring of PV modules is recently having a great interest for the photovoltaic community because it can provide precious information on the real performances of solar energy conversion devices in various climates and in various local environmental conditions. Therefore, it is important that outdoor laboratories could provide reliable and high quality measurements in order to facilitate and encourage comparison of results obtained at different locations.

ESTER facility of the FTA Laboratories at the University of Rome Tor Vergata has been built with the aim of testing and comparing performances of PV modules of various technologies, focusing on new emerging materials like Dye Sensitized Solar Cells (DSC) as compared with the standard silicon devices. A great effort has been done during the laboratory design stage in order to get the largest and most accurate amount of information from the monitoring procedure and a fruitful collaboration with the photovoltaic section of the ISAAC-SUPSI in Lugano has permitted to validate the system.

In the paper, the uncertainty analysis on the measurements provided at the facility is presented and a brief summary of the uncertainty analysis procedure is done. A reference polycrystalline module provided by ISAAC-SUPSI has been exposed to the environment for several months and a comparison between electrical characteristics of the module at STC provided by ISAAC and outdoor measurements at ESTER has been made through IV curve translation at STC using the Blaesser method [1]. A fast filtering procedure for the large amount of data collected by the system has been identified in order to get the most suitable curves for the translation.

2 UNCERTAINTY ANALYSIS

2.1 Types of uncertainty

Several works in the literature show the procedure to evaluate uncertainty in the measurements of solar conversion devices [2, 3, 4, 5], and they are mainly based on the ISO guide for the expression of uncertainty in measurements [6]. Measurement uncertainties can be broadly classified in two categories: Type A, which are calculated from statistical methods or historical data on identical measurements; and Type B, which are derived from non-statistical methods, such as single-reading and propagation of uncertainties through related parameters or components. Since outdoor monitoring mainly consists on non repeatable measurements, due to the time and weather dependence of the measured variables, only type B uncertainty can be applied.

2.2 Procedure for uncertainty calculation

Type B evaluation can be stated as an estimation of the uncertainty of a variable that has not been obtained from repeated observations. The estimated uncertainty is, therefore, evaluated using all relevant information on the variability of the data (the manufacturer's specifications, prior observational experiences, and calibration experience). The procedure for the determination of uncertainty related to the measured variables consists of few steps. First of all it is necessary to collect information on all components of uncertainty, u_x, of variable x, then an uncertainty component probability distribution is assumed, based on all available information on the component. This could come from a manufacturer's specifications, instrument calibration history or other information. Once all the uncertainty components for the variable are collected, the combined standard uncertainty, u_c, is calculated by combining the component uncertainties using the law of propagation of uncertainty (this procedure is often referred to as the root-sum-of-squares).

2.3 Measurements uncertainty at FTA Lab ESTER

The outdoor facility consists of a fixed stand with variable tilt angle that can host up to 6-8 PV modules of medium size and of a sun tracker where two medium size modules can be positioned. Each module is taken at the point of maximum power by a dedicated MPPT3000. The device collects Imax and Vmax. Back of the module temperature is measured by PT100 temperature sensors. Solar irradiance is measured on the plane of the modules by secondary standard pyranometers provided by EKO and reference cells of various materials (mono crystalline silicon, poly crystalline silicon, amorphous silicon) provided by IKS and calibrated by ISET. Air temperature and wind speed and direction near the stand are also constantly monitored. Each environmental sensor is connected to a A/D converter and the output signals are stored by a Campbell Scientific CR1000 data logger into a dedicated database. An overview of the station is showed in figure 1.

Figure 1: Overview of the stands at FTA Lab ESTER facility.

For each of the measured variables mentioned the uncertainty calculation procedure previously explained has been applied and combined uncertainty has been calculated. Table 1 summarizes the results obtained.

Table 1: Summary for uncertainties.

Parameter	Uncertainty
Irradiance (pyranometer)	+/- 8% at 100 Wm^{-2} +/- 3% at 1000 Wm^{-2}
Irradiance (ref. cells)	+/- 4%
Temperature (ref. cells)	+/- 0.12°C at 25°C +/- 0.15°C at 50°C
Temperature (back of modules)	+/- 0.16°C
Temperature (air)	+/-0.17 K
Wind speed	+/- 0.022 at 1 m/s +/- 0.1 at 5 m/s
Wind direction	+/- 2 °
Current and Voltage (MPPT)	+/- 0.2%
Pm (MPPT)	+/- 0.5%

2.4 A systematic error correction

In order to verify the consistency of irradiation data on the plane of the modules, correlations between broad band pyranometer measurements and reference cells measurements have been made. Comparison among data have been performed since October 2007, when the station has been put in operation. Reference cells are spectral selective devices and for this reason they should exhibit a lower irradiance level with respect to the broad band pyranometer [7]. Correlation between pyranometer and reference cells data has evidenced a systematic overestimate of solar irradiance for the mono-Si and poly-Si reference cells as shown in figure 2, for the poly-Si cell.

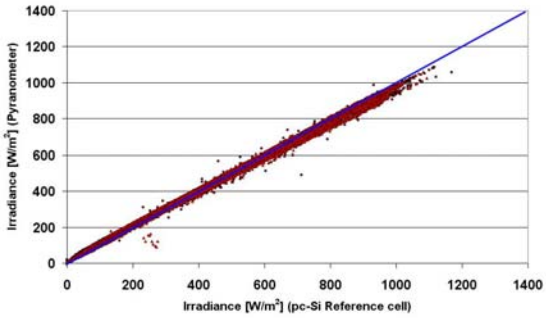

Figure 2: Correlation between irradiance measured by the pyranometer and the poly-Si reference cell (till February 08).

In order to find the reason for this trend an accurate check of the sensor positioning has been performed and a slight misalignment of the two reference cells with respect to the plane of the south oriented stand (figure 1) has been found. After the sensors re-alignment a new correlation check has been performed as shown in figure 3. Data correlation now confirms the standard behaviour of the two instruments.

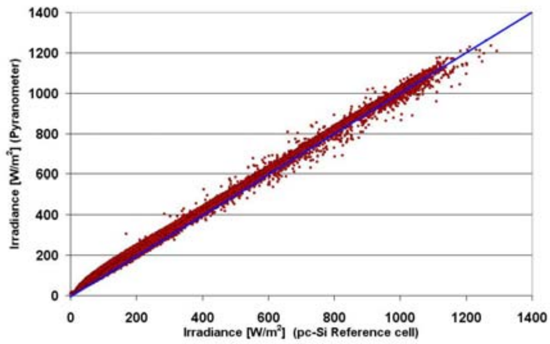

Figure 3: Correlation between irradiance measured by the pyranometer and the poly-Si reference cell after re-alignment.

3 MEASUREMENTS VALIDATION PROCEDURE

A reference polycrystalline module from Kyocera (KC125–GHT), extensively tested at the ISAAC SUPSI, has been used to validate the outdoor measurements. The module has been exposed to the environment since January 2008 but only data from March have been taken into account due to the abovementioned misalignment of the radiation instruments.

The validation procedure consisted of three steps:

1) Identification of the right criteria for the automatic sorting of a suitable outdoor IV curves data set.
2) Translation of the set to STC with a suitable translation algorithm.
3) Calculation of the main parameters of the translated curve averaging the parameters calculated for each IV curve of the data set and comparison with the ISAAC-SUPSI indoor measurements.

The facility data acquisition system collects environmental data as well module electrical properties at point of maximum power, with a time rate of 1 minute, while every 10 minutes a complete IV curve for each module under test is traced. Large amount of data are then continuously stored in a dedicated database. A custom made data management software [8], has been built to sort the data using logical query that can be applied to the various measured variables.

Table 2: Conditions applied for the IV curve sorting

Parameter	Condition
G (W/m^2)	1000 ± 100
Tm (°C)	25 ± 5
tilt angle	⊥

Table 2 summarizes the filtering criteria applied to the data set for the IV curve sorting. Irradiance greater than 800 W/m^2 as well solar radiation at normal incidence are prescribed by IEC 60904-1 [9]. Irradiance (G) range and also module temperature (Tm) range have been restricted to maximize translation accuracy. For a suitable curve to be traced, solar radiation stability plays a very important role. For this reason a check algorithm has been implemented in order to identify the curves which correspond to irradiance stable within 1% in the 2 minutes before and after the IV acquisition.

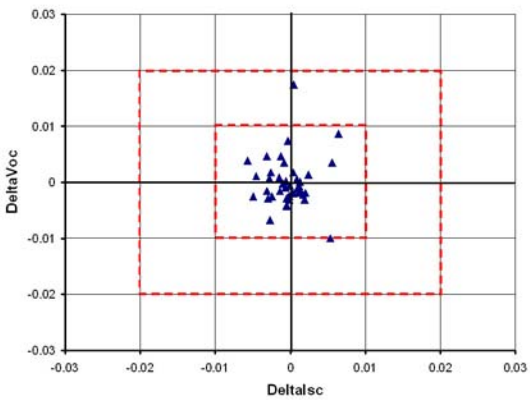

Figure 4: Deviation of the single Isc e Voc data with respect to the average value calculated over the 44 curves.

The Blaesser method [1] has been chosen for the curve translation at STC. This method, in fact, can be simply implemented without additional information on the properties of the PV module. The algorithm has been implemented in a Matlab program that automatically translates the suitable curves and provides the characteristics of the averaged translated curve. Considering data collected from March 2008 to July 2009, 44 suitable IV curves have been extracted and translated at STC. Figures 4 and 5 show the deviation of Isc, Voc and Im, Vm, obtained by the translation of each curve, with respect to the corresponding average values.

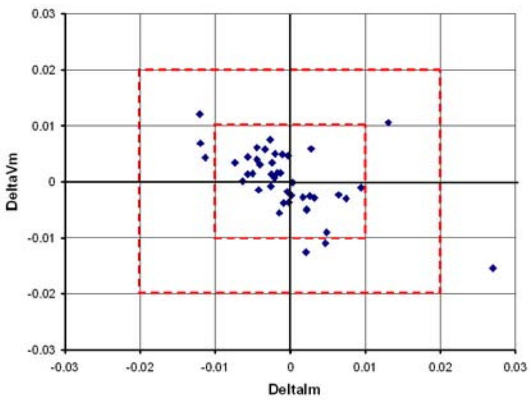

Figure 5: Deviation of the single curve Im e Vm data with respect to the average value calculated over the 44 curves.

It can be observed that the deviation is mainly contained in the 1% range for Isc and Voc while for Im and Vm a 2% deviation can be considered. These deviations can be assumed as the uncertainty in the translation process. The results show a good precision in the translation procedure as well as a good filtering of the suitable curves.

Translated outdoor IV curve parameters have been compared to values provided by indoor measurements at ISAAC-SUPSI. Results are summarized in figure 6.

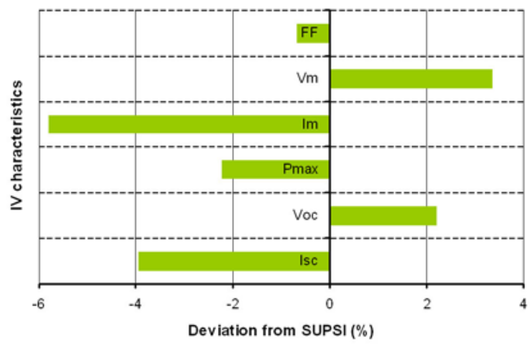

Figure 6: Deviation of IV characteristics at STC between ESTER and SUPSI laboratories.

The x axis indicates the percentage deviation on the parameters between the two laboratories. Deviation of -2.2% is observed for Pmax, a good result considering that the comparison is made between indoor and outdoor measurements. A quite high deviation is instead observed on the Im parameter and in general on the current measurements that results higher than the SUPSI values.

Translation procedure on the current is simply a scaling procedure so that translation itself could not be responsible for this results. The uncertainty on PV module current measurement given in table 1 is the one of the instrument itself (MPPT) and it does not take into account for the error deriving from the reference cell irradiance as specified in [5]. If this term is taken into account a combined uncertainty of 4.5% as to be considered for current measurements. This uncertainty can, in part, justify the large deviation from indoor SUPSI measurements. However further investigations are required to understand the possible underestimation of the reference cell irradiance.

4 CONCLUSIONS

After a preliminary check and correction of misalignment of the irradiation measurements, composition of error uncertainties has been evaluated for every measured parameter at the facility.

A sorting procedure of IV curves suitable for translation at STC has been identified and implemented. The procedure allows to make IV curve translation with an accuracy of 2% maximum.

The comparison with the indoor data shows a good agreement for Pmax (2.2%) while a greater deviation has been observed for photovoltaic current measurements. This can be only partially justified by a combined uncertainty in the photovoltaic current of 4.5%, essentially provided by the reference cell irradiance measurements. Further investigations are consequently needed.

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