

Photovoltaic Plant Efficiency Evaluation: A Proposal

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Abstract- This paper present and discuss a method that, starting from the information of a public weather station and a reference panel, gives useful information about the efficiency of a photovoltaic plant. The aim of this paper is to give a method to analyse the effects of the dust on the panel surface comparing, for a given solar radiation level, the energy production of a reference panel estimated in clean condition with the energy produced by the panel in actual condition. The novelty of the method is based on the simplification of the monitoring system devoted to the energy evaluation considering in a suitable way the information collected by public weather stations.

I. Introduction

It is well known that losses due to the dust have a significant impact in photovoltaic (PV) modules and plant efficiency [1]. In particular, dust deposition affects energy production reducing the financial incomes in a non-negligible way: in fact, the worst case related to this factor has been evaluated around 7% [2-5].

In order to evaluate energy reduction, monitoring system devoted to the energy monitoring are not really adequate: in fact they require the knowledge of environmental parameters. The installation on the plant site of an adequate monitoring system (equipped with electrical and environmental sensors) represent the optimal theoretical solution: as just shown in [6], a possible solution, in order to overcome the problem of the management of the monitoring data, could be monitor a “reference panel” using the extracted data to define the status of a more complex PV plant located in the same area. This solution is based on a statistical approach but if the measurement section devoted to the electrical signal requires only the knowledge of the electrical reference panel parameters, the knowledge of the environmental signals are strictly required. In particular, the most important information required to evaluate panel and plant performances is the solar radiation. Unfortunately, pyranometers require the definition of a suitable maintenance policy: management and related costs could be a strong drawback for an efficient and really useful use of this kind of instrument.

An alternative to the installation of a pyranometer can be also represented by the collection of the solar radiation data from a weather station near to the photovoltaic plant location. The advantage of this solution is represented by the fact that the measurement of the radiation is performed by a third part (which is responsible for the maintenance of the instrument) and it is generally a low-cost/for-free service.

In this paper, will be evaluated the status of a PV panel using the solar radiation data collected by a weather station. In section II will be analysed the drawbacks related the use of data collected by a weather station managed by a third part, in section III will be discussed the condition for the validation of the reference panel, in section IV the database built considering the data acquired by the reference panel will be discussed.

II. Data collection: some consideration

A data base coming from a public weather station has the advantages to be guaranteed in term of validation of the data and completeness for the manner in which the data are collected. It is important to highlight this solution shows few drawbacks which are mainly related to:

- the time resolution of the provided data;
- the transformation of the solar radiation from the horizontal plane to the PV panel one;
- the distance between the PV panel and the weather station.

In the following an overview about this drawbacks is summarized.

A. Effect due to the time resolution of solar radiation data

Weather stations usually collect the measured data with a relatively low time resolutions. These resolutions generally vary from tens of minutes to one hour and the stored data correspond to the mean value of the measured quantities evaluated between two consecutive time steps. It is clear that the impact of time resolution depends on the variability of the solar radiation: in fact during sunny days the irradiation of the panel varies slowly and large time steps are more tolerable with respect to the case of cloudy days, when the weather conditions present fast dynamics.

B. Effect due to the geometrical transformation of solar radiation

In general, meteorological measurement stations are installed to provide information useful in agricultural applications. For this reason the measurement of the solar radiation is performed on the horizontal plane. According to the fact that on an inclined plane its value is significantly different, an algorithm for the estimation of the radiation which hits the PV panel under test starting from the measured one has to be implemented.

A suitable procedure for this transformation has been proposed in [7] and, once the weather station has provide the collected data of direct and diffuse radiation, the amount of solar light perceived by the PV panel can be easily computed. Of course, when obstacles in the considered area hide parts of the solar trajectory, they have to be taken into account before the computation of the produced energy.

According to Figure 1, the computation of the solar radiation which hits the panel can be computed as follows:

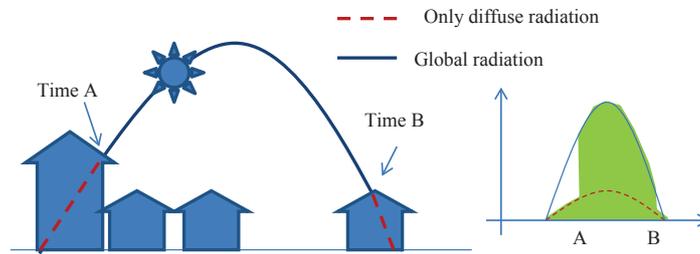


Figure 1 Shadows due to the presence of obstacles on the Sun's trajectory.

$$G_{PV} = \begin{cases} G_{bh} \max \left\{ \frac{\cos(\psi_{PV})}{\cos(\psi_0)}, 0 \right\} + G_{dh} \frac{1 + \cos(\rho_{PV})}{2} & \text{when the Sun's rays directly hit the panel} \\ G_{dh} \frac{1 + \cos(\rho_{PV})}{2} & \text{when the Sun is behind an obstacle} \end{cases}$$

Where (Figure 2):

- ψ_0 is the angle between the normal to the horizontal surface and the direction of the beam radiation (solar altitude angle);
- ψ_{PV} is the angle between the normal to the PV module surface and the direction of the beam radiation (solar altitude angle with respect to the panel surface);
- ρ_{PV} the inclination angle of the module.

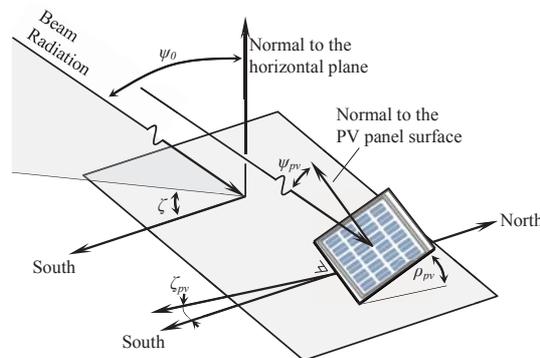


Figure 2 Coordinate system for PV panel and the Sun's position.

Both Ψ_θ and Ψ_{pv} depend on the direction of the beam radiation, so the pattern of the sun's apparent position has to be considered in order to calculate their time evolution [7].

Unfortunately some weather stations do not provide the values of all the solar radiation components but only a comprehensive value (global radiation G_h on the horizontal plane). Since the proposed transformation technique requires the knowledge of both beam and diffuse radiations, it is necessary to estimate one of them in order to use the data of these weather stations. The direct radiation values is highly dependent on weather conditions, and it is not easy to estimate (especially in not clear days). On the contrary, the diffuse component is only weakly influenced by the weather, and for soft/partly cloudy Earth's atmosphere, its trend is practically comparable with the expected one for sunny days.

In [7], a comparison between both sunny and cloudy days and clear sky model has been evaluated. Starting from this results an estimation of the diffuse component G_{dh} can be used and the beam radiation G_{bh} can be estimated as follows:

$$G_{bh} = G_h - G_{dh}$$

Moreover, since diffuse radiation is less than the direct one (in sunny and partially cloudy days), the errors in estimating it do not invalidate the proposed procedure for the evaluation of the radiation G_{PV} which hits the photovoltaic panel.

Taking into account all these aspects, the solar radiation data provided by the weather station (which is placed 2 km far from the PV panel and which acquired data with a rate of 6 samples/h) has been reported on the PV panel plane and then compared with the radiation measured locally.

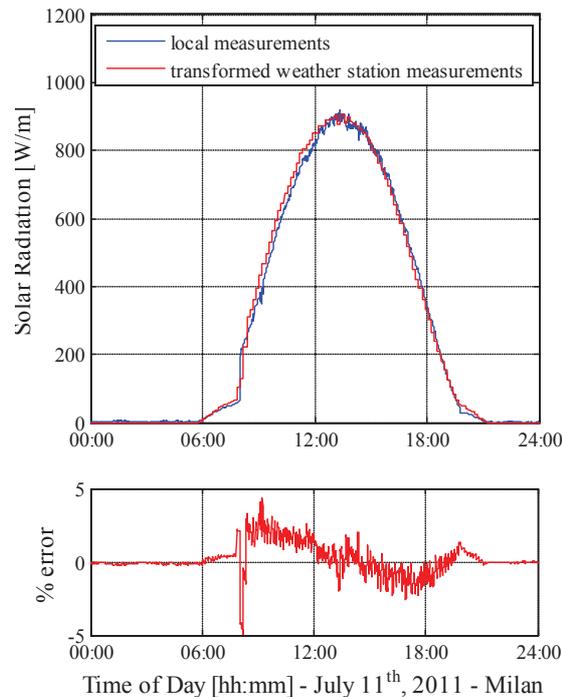


Figure 3 Comparison between the solar radiation measured on the PV panel surface and the reported one from the weather station.

C. Effect due to the distance between the PV panel and the weather station

Another factor which could impact significantly the estimation of the production is represented by the distance between the weather station and the PV panel under test. Assuming that the weather station is close to the tested panel (on the order of few kilometres) the apparent position of the Sun with respect these two points can be reasonably considered the same. The only phenomenon which can introduce a relevant error is represented by the assumption that the solar radiation measured on the weather station is the same of the place where the PV panel is installed. In fact this statement is not verified for each weather condition, since for non-uniform cloud coverage of the sky the irradiation of the ground can vary significantly in the range of few hundreds of meters.

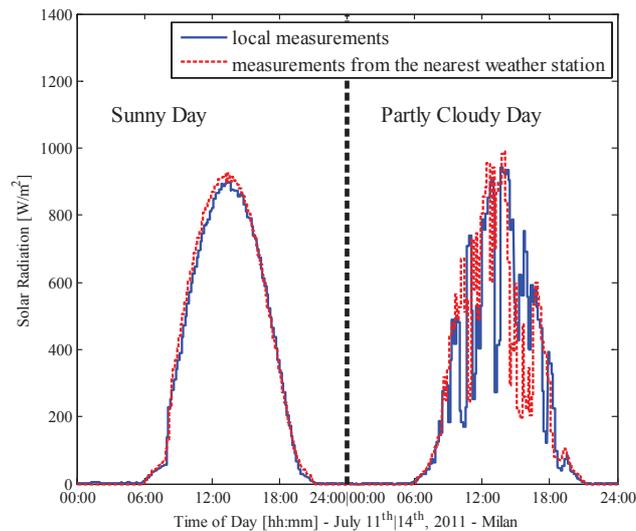


Figure 4 Solar radiation measured in two different locations (distance of 2 km) and different weather conditions.

In Figure 4 the solar radiation measured in two different locations are compared. It can be seen that, despite the distance is only 2 km, in partly cloudy days the solar light of the measurement points are pretty different. Otherwise, the measurement performed during clear days result very similar.

III. Data base definition

In order to use the information acquired by a weather station for maintenance policy, it is important to know the functioning information of the panel plant. This information can be extracted by means of suitable models [7], [8] or acquired and mapped during the actual working conditions; the second approach requires to develop a database where radiation and panel temperature are strictly required. As just shown in [1], when the PV panel is affected by a failure mode that reduces his power production capability, the Maximum Power Point (MPP is the point of maximum on the Voltage-Power, V - P , curve) value assumes a value lower than the expected one for the assigned values of radiation and temperature. The failure mode effect can be evaluated in term of a reduction of the MPP.

Starting from this assumption, a comparison between the data collected in the data base and the actual one allows to evaluate the status of the degradation of the panel itself and the time evolution of the aging of the panels.

It is important to highlight that the comparison of data cannot be easily performed, for example, for all the panel of a large plant. In this situation a more suitable approach could be based on the analysis of the data acquired monitoring a reference panel.

This kind of monitoring activity doesn't require the support of an expensive complex monitoring system but starts from the assumption that the behaviour of the reference PV module could represent, with a given confidence level, the behaviour of the PV plant in different condition of dust deposition and aging.

In order to perform this comparison, we have to assure that the PV panel belongs to an homogeneous production lot. In this way, the MP value, for given environmental condition, can be analysed from a statistical point of view. In other words, MP values can be considered as measurement of a character on individual samples from a large population: these can be used as starting point for inferences about numerical characteristics of the population from which the sample was extracted [9].

In order to verify this assumption, we have evaluated a sample of ten homogenous panels whose characteristics are reported in table I (in the sample polycrystalline PV panels with dimensions 24.5×23.2 cm and active area of 21×18.5 cm² have been considered) [6].

P_{max}	5 W
V_{pm}	17.5 V
I_{pm}	0.285 A
V_{oc}	21.3 V
I_{sc}	0.31 A

Table I: PV panel characteristics

This sample has been exposed to different actual environmental conditions (this conditions have been assigned in

a random way). In order to avoid the effect of different ageing factor due to the different expositions, the MPP evaluations in clean condition have been performed after the dirty one. The clean and dirty condition have been verified, using a sun simulator realized by the authors; this simulator guarantees the repeatability of the measurement process and at the MPP the relative standard deviation is 0.13% [1].

As expected, all the panels present a reduction of the generated power. In table II the computed MP values generated by the PV modules in dirty condition and after cleaning are reported.

It can be observed that the power variations, in any conditions of expositions, are bigger than the measurement system resolution. The power variation can be evaluated by means of the MP decrease value reported in Table II according to the formula:

$$MP_{Decrease} \% = \frac{MP_{clean} - MP_{dirty}}{MP_{clean}} \cdot 100$$

# Panel	Time of exposure [DAYS]	Conditions of exposition		Clean [W]	Dirty [W]	MP Decrease %
		Inclination	Rain exposition			
1	34	Horizontal	No	0.4744	0.4573	3.6
2	34	Horizontal	No	0.4713	0.4427	6.1
3	34	Horizontal	No	0.4484	0.4181	6.8
4	24	30°	Yes	0.5062	0.4887	3.5
5	24	30°	Yes	0.4700	0.4541	3.4
6	34	horizontal	Yes	0.4699	0.4545	3.3
7	34	horizontal	Yes	0.4680	0.4375	6.5
8	21	horizontal	No	0.4738	0.4562	3.7
9	21	horizontal	No	0.4781	0.4663	2.5
10	21	horizontal	No	0.5052	0.4937	2.3

Table II MP values for used panels

IV. Data base discussion

In order to build a data base, one of the ten panels has been installed on the roof of the laboratory of DEIB Department at Politecnico di Milano. The measurement database has to include a set of measured Voltage-current ($V-I$) characteristic curves, temperature and solar radiation which cover most of the possible working condition of the photovoltaic panel. For this reason a measurement campaign has been performed and starting from the $V-I$ curves the MPP values have been extracted (a plot of MPP value vs. temperature and solar radiation is reported in Fig. 5).

In order to have an adequate set of MPP value, the $V-I$ curves have been collected from July to October 2012 (the data base provide 3150 different values).

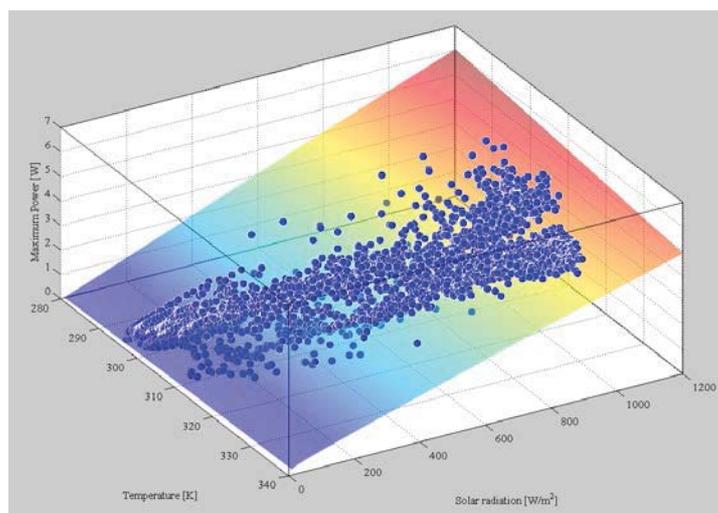


Figure 5: MPP vs. Temperature [K] and solar radiation[W/m²]

As just shown in Figure 3, when the sky can be considered in clear condition, the maximum error in the evaluation of the solar radiation using data acquired by a weather station placed 2 km far from the PV panel is in the range $\pm 5\%$.

In this way, if we imagine to use the information reported by the data base using the data acquired by a for-free

service weather station, we have to consider that the estimation of the MPP could be affected by an error. In order to do an estimation of this error, we have considered the data collected by the data base itself, evaluating, for a measured variation of $\pm 5\%$ in the solar radiation the measured MPP variation (considering a negligible temperature variation). In this condition, we have noticed a variation in the MPP value of about $\pm 4,3\%$: this value can be considered as the error that we have when we estimate MPP using data acquired by a weather station far from the plant.

When the absolute value of the difference between the actual MPP value and the ones collected in the data base (in the same condition of temperature and solar radiation) is greater than 4% , MPP data can be evaluated to define adequate maintenance policy.

V. Conclusions

In this paper the authors have evaluate the opportunity of using environmental data acquired by means of public weather station located in the same climatic area of the PV panel but far from it. Starting from this results the authors will exploit the opportunity to enrich the data base using interpolated data in order to use the proposed method for maintenance policy.

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