Energy Conversion and Management 128 (2016) 191–202

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Improvements in the predictions for the photovoltaic system performance of the Mediterranean regions

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ARTICLE INFO

Article history:
Received 15 July 2016
Received in revised form 22 September 2016
Accepted 23 September 2016
Available online xxxx

Keywords:
Plane of array irradiance
Meteo data
PVsyst
Module temperature
Wind speed

ABSTRACT

The performance assessment of photovoltaic (PV) systems is a complex process. Several meteorological data sources are available to evaluate the PV system generation. Different computing models can be applied to determinate the solar irradiance on the plane of the array (POA). The cooling effect of the PV module due to the wind speed should not be neglected. The present study may support several users to perform more accurate PV energy predictions, providing important suggestions to develop future PV system projects with more high reliability.

Perez and Hay-Davies models for the computing of the irradiance on tilted surfaces are combined with three meteorological datasets, characterized by different monitoring period and meteo station location, to estimate the POA irradiance, the module temperature and PV energy output for a PV system located in the Mediterranean climate area. Prediction results are performed by the PVsyst tool and compared with the actual data. Simulations are carried out taking into account the wind effects on the PV module performance.

Results demonstrate that the geographic features of the location, in which the weather station is located, have higher impact on the estimations of the PV system performance than the distance between the PV system and the meteo station. Perez and Hay-Davies models provide predictions of the PV energy and the module temperature with a difference up to 3% and 1% respectively. Yearly average wind speed in the range 2–4 m/s fosters a cooling effect up to 3% higher than one due to the wind magnitude less of 2 m/s, increasing the PV energy up to 1%.

1. Introduction

The Renewable Energy Directive (RED) 2009/28/EC establishes an increase of using renewable sources in energy consumptions [1] with a replacement of 20% traditional fossil fuels for 2020 [2].

In this context the photovoltaic solar energy is one of the most promising renewable energy and the performance evaluation of PV system plays a crucial role. An overview of existing works shows how different approaches are applied to assess the PV generation. Different mathematical models allow the computing of the solar irradiance on inclined plane, as well as several meteo datasets are available as data input for the prediction models. The paper addresses the issue, analyzing the impacts of solar radiation models and different meteo data input on the PV energy estimations.

1.1. Previous studies review

Several approaches can be applied to forecast the PV power output such as the modern methodologies of artificial intelligence [3–5], which are especially suitable under various weather conditions [6,7], but also through specific PV performance modelling tools. PVWatts [8], PVsyst [9], PV * SOL [10] and System Advisor Model (SAM) [11] are the most popular PV modelling tools, which have been amply applied to validate the performance of several PV systems [12–15].

In order to estimate the PV power generation, it is essential determinate the solar irradiance incident on the module plane and the module temperature, which mainly influence the PV system performance. Generally, starting from the global horizontal irradiance (GHI) for a given location, the plane-of-array irradiance computing models involve two steps: decomposition of GHI into direct normal irradiance (DNI) component and diffuse horizontal irradiance (DHI) component and transposition of the components to the POA irradiance [16]. In the literature several studies compare various models to compute the solar radiation incident on a tilted surface using actual data, collected in different locations [17–21].

Mathematical models for the calculation of the PV module temperature are known as thermal models [22,23], based on the thermal energy exchange of the module with the environment. Various

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http://dx.doi.org/10.1016/j.enconman.2016.09.069
0196-8904/

Nomenclature

E_{out}	PV energy output, (kW h)
H_{eff}	effective number of hours of PV generation, (h)
H_{th}	theoretical number of hours of PV generation, (h)
I_b	beam horizontal irradiance, (W/m^2)
I_d	diffuse horizontal irradiance, (W/m^2)
I_{gh}	global horizontal irradiance, (W/m^2)
I_{POA}	irradiance on plane of array, (W/m^2)
k_t	clearness index
T_{mod}	module temperature, (°C)
T_{amb}	ambient temperature, (°C)
WS	wind speed, (m/s)

Acronyms

ARPA	Regional Agency for Environmental Protection
DHI	diffuse horizontal irradiance
DNI	direct normal irradiance
GHI	global horizontal irradiance
MPP	maximum power point
MTN	Meteonorm
PD	probability distribution
PV	photovoltaic
STC	standard test condition
WMO	World Meteorological Organization

studies investigated the effects of solar irradiance, wind speed and ambient temperature on the PV module temperature [24–26]. Studies as [27–30], underlined the decrease of the PV module temperature and consequent improvements of the PV module performance due to the wind speed cooling effect.

Another issue not less important regards the availability of the meteorological database. The PV power prediction method needs the historical weather data as input [31,32]. Nowadays, numerous meteo data sources are available for the user, which may be included in PV modelling tools or available on the web. Most of meteorological databases are derived from ground measurements or satellite data, with different time and spatial resolutions and refer to different time periods. Consequently, for the same site it is possible to have more of one meteorological database obtained from different data sources [33].

1.2. Present work contribution

The literature review shows the existence of several mathematical models useful to know the solar irradiance on inclined plane, but how these computing models impact on the predictions of the module temperature and PV energy output has not been evaluated. In addition, it is noted that the wind should not be neglected in PV performance assessment, but previous studies do not quantify the benefits of the cooling effect in term of the PV energy. Furthermore, comparison studies of the PV system performance when different meteo datasets are used as input for the prediction model have not been carried out.

The aim of the present work is to analyze the impact on the PV energy estimations when different transposition models are implemented to determinate the POA irradiance and how such models influence the module temperature predictions performed by thermal models, with and without considering the wind effect. We quantify the cooling effects and estimate the resulting increase of the PV energy. Finally, we analyze how different meteorological datasets, used as input in the PV performance assessment, influence the predictions of module temperature and PV energy. Some indicators as the monitoring period, the geographic area of the meteo station location and the distance from the meteo station to the PV system are introduced to identify the main characteristics that need to be taken into account for an appropriate choice of the meteo dataset.

In order to address the main matters of the present research, the module temperature and the PV energy estimations have been performed through PVsyst tool vers. 6.3.9 that allows to choose between two transposition models: Hay-Davies [34] and Perez [35] and to implement different meteorological databases. The PVsyst simulation results were compared with the actual data of the PV system located in Lecce in the southern Italy. For three different meteorological databases, the POA irradiance was computed through the transposition models provided from PVsyst. For each case the module temperature and the PV energy output were estimated with and without the wind speed contribution. Adequate statistical metrics were adopted to carry out a comparative analysis between the simulation results and measured parameters on the site, in terms of POA irradiance, module temperature and PV energy output, underlining how different meteo sets affect on the results. Finally, an analysis was carried out to investigate the effects of sunny or cloudy sky on the PV performance assessment.

This study supports several users operating in the solar field to improve the accuracy of the PV performance predictions for the new PV systems planning.

The paper is organized as follows. After the introduction, Section 2 describes the PV system under investigation and meteo datasets applied to the PVsyst simulations. The methodology for different impacts assessment is presented in Section 3. Results and discussion are provided in Section 4, followed by conclusions in Section 5.

2. Simulation input data

2.1. PV system description

A grid connected PV system of 960 kW$_P$ supplies power to the facilities of the campus of the University of Salento sited in Monteroni of Lecce, Southern Italy (40°19′32″16 N, 18°5′52″44E). The PV plant covers an area aimed to parking lots. The 3000 monocrystalline silicon PV modules, each of 320 W$_P$, are installed on a metallic structure as the roof of the car parking. The plant presents two different array configurations. A subfield of nominal power of 606.7 kWp is 10° southeast oriented and 15° tilt angle. The second one of 353.3 kWp has the same azimuth and an inclination of 3°. Three inverters provide to convert the direct current output of the PV field into alternating current. Further details of the technical features of the PV modules and inverter are given in [36].

The PV solar parking is equipped with web-connected monitoring system. A Siemens Supervisory Control And Data Acquisition (SCADA) system with sensors to measure solar irradiance on the plane of the array, module temperature and ambient temperature, provides the data by protocols Modbus. The monitored parameters are available on the ESAPRO private web site [37] starting from the year 2012.

In the present study the solar irradiance on the plane of module with tilt 3° (W/m^2), the irradiance on the plane of array tilted 15° (W/m^2), the module temperature (°C) and the PV energy output (kW h), measured during the year 2013, were considered. It should be noted that the investigated PV system is characterized