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Original article

Module temperature models assessment of photovoltaic seasonal energy yield

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ABSTRACT

Commercial photovoltaic systems focused on the low power sector, such as residential, commonly base their energy production estimations on simple mathematical models that use average solar irradiance values, which do not necessarily apply to the installation site. Thus, there is an overestimation/underestimation in the energy production, and the investment payback does not match to the expected one. This paper presents a module temperature models' impact assessment, which considers parameters associated with the photovoltaic-cell material, the solar irradiation site, the temperature and the wind at the installation. Four different module temperature models with different complexity degrees were used for the study case. Results of energy yield, with and without wind, are presented, and are analyzed according to the seasons of the year. The Muzathik model estimates up to 5.19%, 4.69%, and 4.8% more energy versus the Sandia, Faiman, and Skoplaki models, respectively. Up to 9.19% more available energy was observed in such circumstances where a speed difference of 8 m/s is present.

Introduction

Worldwide governments promote and incorporate Renewable Energy Sources (RES) to meet the energy demand, and to address the climate change, derived from the excess burning of hydrocarbons for many years. It is estimated that 19.1% of globally final consumption will be provided by RES, where hydropower, wind, and solar energy are used to produce electricity in large scale power stations, and a further percentage growth is foreseen [1]. For example, in Mexico, the use of renewable energy is increased exponentially since the publication in 2008 of the Law for the Use of Renewable Energy and the Financing of Energy Transition. In addition, since 2012 the Secretary of Energy, SENER, has designed mechanisms that encourage policies, programs, actions and projects related to clean technologies.

Different types of renewable energy is available, in which photovoltaic (PV) systems are being promoted as a sensible alternative to distributed electric energy production, and many low-power users have successfully adopted such technologies. However, other users are still reluctant to install PV systems due to the high initial investment required and the high degree of uncertainty in the assessment of its profitability. Profitability depends on many factors, some of them related to the performance of different elements, such as the photovoltaic cell technology [2,3], the power converters [4–6], the control systems [7–9], the site of installation [10,11], and the maintenance [12,13], where each of them play an important role in the overall performance.

Other factors related to environmental parameters, such as solar irradiance and temperature, are also responsible for significantly reducing the conversion efficiency. Recently, several studies have been conducted to assess their impact in the total energy yield [14–19]. It is a well-known fact that cell temperature increases as the solar irradiance gets higher, and few studies have determined that temperature can degrade the conversion efficiency, up to 12% [20–24].

In order to improve energy conversion, several methods have been proposed by reducing the cell temperature. The most common methods are the fluid flowing techniques, where cold water flows are applied [25–27]. One of the main disadvantages of this method is the high cost that increases even more when a heat exchanger is used. In addition, accelerated corrosion and mineral deposition on surfaces occurs due to the direct flow of water. Other methods are the forced air systems [28–31], which in many cases can use natural air currents [32]. Since air cooling can be taken advantage of in areas that have high speed winds, and a natural cooling effect can be achieved without resorting to forced air systems, various models that consider wind speed have been proposed and validated [33–35]. However, only few studies take wind speed into account [36–38]. Further, the majority of these studies have been performed in optimal conditions, without significant disturbances

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Nomenclature

E_{PV}	the total DC energy available (W/t)
$\mathbf{E_{PV}}$	the total DC energy available vector (W/t)
G	the irradiance (W/m^2)
$\mathbf{G}$	the irradiance vector (W/m^2)
G_{STC}	the irradiance at STC (W/m^2)
P_{STC}	the installed power rating (W)
$\mathbf{T}$	the cell temperature vector (°C)
T_{air}	the air temperature (°C)
T_{amb}	the ambient temperature (°C)
T_{cell}	the cell temperature (°C)
T_{STC}	the cell temperature at STC (°C)
U_0	the constant heat transfer component (W/m^2 K)
U_1	the convective transfer component (W/m^3 s K)
V_{wind}	the wind speed (m/s)
$\mathbf{W}$	the wind speed vector (m/s)
δ	the temperature coefficient (−%/°C)
η_{PV}	the module electric efficiency
η_{ref}	the cell efficiency

Abbreviations

NOCT	Nominal Operating Cell Temperature
PV	Photovoltaic
RES	Renewable Energy Sources
STC	Standard Test Conditions

in irradiance, temperature or wind speed.

This paper presents a module temperature models impact assessment focused on the energy yield of a photovoltaic system. The assessment considers parameters associated with the installation site such as solar irradiance, temperature and wind speed, along with the photovoltaic-cell material. A PV electric efficiency comparison between four different models, with and without wind effects, is performed. A seasonal estimation is assessed for nine sites selected in the Yucatan Peninsula tip, an area surrounded by the Gulf of Mexico and the Caribbean Sea. The ultimate goal of the analysis is to determine by which percent energy production can be underestimated when the wind effect is neglected. This, in turn, will help potential DC microgrid users take a better-informed decision about the profitability of PV systems.

Meteorological profiles

The sites considered are labeled from A to I, and its geographical coordinates are shown in Fig. 1. A 1 year range of simultaneous and ungapped meteorological data is available for test purposes. Data for each site is grouped into three vectors containing ten-minutes averages of solar irradiance, ambient temperature, and wind speed, measured by automated weather stations located in the facilities belonging to the national utility company. The wind speed was measured at the standard meteorological height of 10 m.

The meteorological data of each site consist of 52,560 measurements points. Based on a diurnal profile the relationship between wind, ambient temperature, and solar irradiance for each site can be seen in Fig. 2.

Table 1 shows the annual means of the different meteorological data. It can be noted that the wind speed exceeds 5 m/s in all locations, which is denned high enough to observe the positive effect of the wind cooling effect. The highest speed was reported at site F, which is located at the Caribbean Sea. The average solar irradiation was around 400 W/m^2, which is a common value in coastal regions with cloudy weather conditions.

The data was organized by seasons: autumn, winter, spring, and summer, and the wind speed variation between seasons at each site are shown in Fig. 3. The highest peak values were presented in the spring, where it reached values up to 17 m/s as at site B. In the summer the wind speed was reduced with respect to the spring, and a reduction of wind between 1.5 m/s and 5.7 m/s was perceived, that values correspond to the minimum and the maximum change observed in site E and H.

The spring diurnal profile of each site is shown in Fig. 4. Site E (Celestun) and site C (Oxkutcab) had the largest and the smallest curve area of wind speed throughout the day, respectively.

DC energy yield

The increment of cell/module temperature had a negative effect on the PV electric efficiency η_{PV}, which was defined as the effectiveness of solar energy conversion to DC energy, and can be defined by [39]:

$$\eta_{PV} = \eta_{ref}\left(1 - \frac{\delta}{100}(T_{STC} - T_{cell})\right) \tag{1}$$

where η_{ref} is the cell efficiency, T_{STC} is the temperature at standard test conditions (T_{STC} = 25 °C), and δ is the PV temperature coefficient in %/°C.

The total DC energy available at the photovoltaic module E_{PV} can be obtained by:

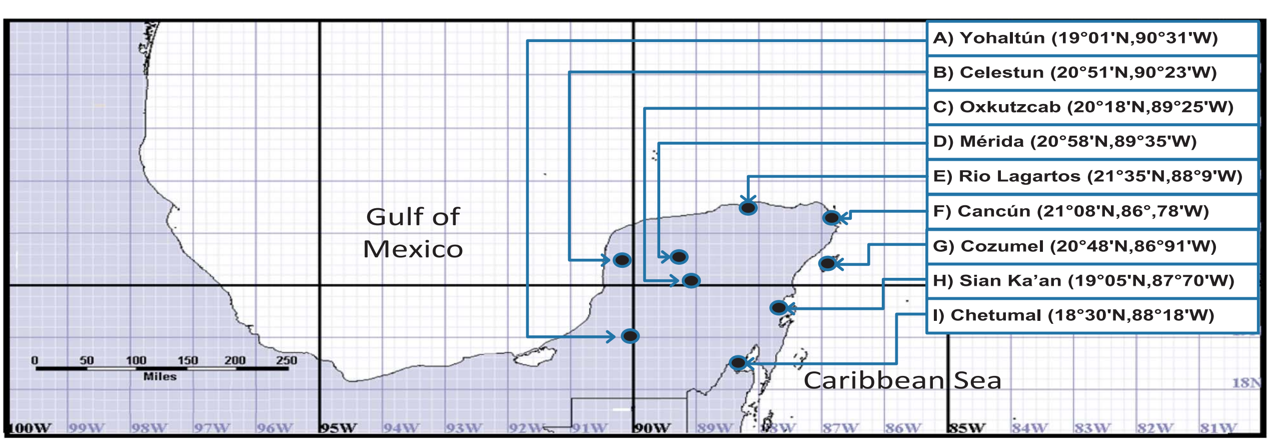

Fig. 1. Geographical coordinates of the sites considered for this study.