Solar Energy 155 (2017) 893–901

Contents lists available at ScienceDirect

Solar Energy

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

The influence of different irradiation databases on the assessment of the return of capital invested in residential PV systems installed in different locations of the Brazilian territory

Corrado Lacchini *, Andrigo Filippo Antoniolli, Ricardo Rüther

Universidade Federal de Santa Catarina/UFSC, Caixa Postal 476, Florianópolis SC 88040-900, Brazil

ARTICLE INFO

Article history:
Received 31 January 2017
Received in revised form 6 June 2017
Accepted 3 July 2017

Keywords:
Irradiation database
CAPEX
LCOE
Return on Investment

ABSTRACT

Rooftop residential photovoltaic (PV) generation is becoming more widespread among homeowners. A proper PV system design is crucial in order to avoid annual electricity production in excess of residential demand in countries where a net metering scheme is in place like in Brazil. It is therefore important that the information related to the average solar irradiation incident on the solar modules is accurately assessed, allowing precise estimates of photovoltaic electricity production. This work defines the criteria for the proper choice of a freely available irradiation database for the Brazilian territory and compares the results with the PVsyst-Meteonorm, a well-known modeling system. We demonstrate that, for Brazil, the Global Horizontal Irradiance (GHI) information provided by Openei-SWERA series is the best fit to different locations in the Brazilian territory, after introducing the corrections made by the horizontal to the plane-of-array transposition algorithms.

1. Introduction

Electricity represents one of the most important drivers for the development of modern societies and the uninterrupted availability of supply has become one of the most important utility services for human societies.

The challenge that planners must solve is to work with different scenarios, trying to forecast growing needs making use of the different known and available technologies for the generation of electrical energy in the quantity and time frame that will allow a smooth and growing availability of energy. Furthermore, environmental aspects are more and more driving energy markets, and renewable and cleaner energy generation technologies are becoming more widespread, with solar PV becoming the fastest-growing electricity generation technology in recent years (REN21, 2015). With the declining costs of solar PV generation, economic assessment of this renewable and benign energy generation technology points to economic competitiveness, especially when compared with residential tariffs (Colle et al., 2001; Rüther and Zilles, 2011; Mitscher and Rüther, 2012). The seasonal variations and intermittency of the solar resource availability need to be well known in order to allow for a precise forecasting of PV generation. Estimating the amount of irradiation available at any particular site is based on historical series collected for long periods (typically tens of years), which will result in fairly good approximations of what can be expected during the following years.

Assessment of the solar radiation availability is based on a number of different techniques, and the ones based on satellite data with ground base measurements validation are the most widespread and comprehensive. The enormous quantities of scientific satellites that observe the Earth with their sophisticated lenses, collect huge quantities of images of the planet's surface that, once processed, allow defining different algorithms to determine the quantity of energy that hit the surface of the globe, with sufficient accuracy.

This computation is made observing the quantity of energy reflected back toward the space as a result of different atmosphere densities, clouds, rain, pollution and particulates that act as filters to the incident light. The energy reflected is the complement to the energy absorbed by the surface of the planet, which can be calculated knowing the amount of the irradiance on the top of the atmosphere. This irradiance is calculated as 1367 W/m^2 ± 3% depending on the position of the Earth in the orbit around the Sun (Guimaraes, 2003).

Depending on the satellite observing the Earth, the images have different resolutions so that a pixel of every image may correspond to different total areas. The result of this situation is that the accuracy of the data supplied by different databases associated with different satellites is not the same; furthermore the associated

* Corresponding author.
E-mail addresses: clacchini@terra.com.br (C. Lacchini), andrigofilippo@gmail.com (A.F. Antoniolli), ricardo.ruther@ufsc.br (R. Rüther).

http://dx.doi.org/10.1016/j.solener.2017.07.004
0038-092X/

uncertainties are also related to a particular site cloud cover regime, with cloudier skies associated with higher uncertainties (Pereira et al., 2006). It is therefore necessary that the information associated with the satellites is compared and adjusted with data collected by terrestrial measuring stations spread over the territory under investigation.

This work is a follow up of our previous investigations in this area, and the continuation of a previous study (Lacchini and Rüther, 2015) which analyzed the return on investment of photovoltaic residential systems installed in four different climatic zones in Brazil. That study was based on the irradiation available in connection with the climatic series provided by the PVsyst™ modeling software updated to 2012.

More recently, many other modeling software packages and updates for the determination of the irradiation values have been made available, with some discrepancies between them. Depending on the chosen database, different PV peak power and annual electricity generation forecasts are obtained. In this context, this study aims at determining the relationship between the results obtained with the Openei-SWERA, an irradiation database selected as the best choice by the Brazilian scientific community, and the PVsyst-Meteonorm utilized by the PVsyst design software package.

2. Methods

The uncertainties associated with the irradiation data, used to assess PV system performance, affects directly the financial results; it is therefore of utmost importance to select the best available irradiation database to work with. As a result of the choice, the system's power may be influenced as well as the amount of the energy generated by PV systems and the return on the investment over the lifetime. To assess and quantify the influence of the radiation database, two of such databases are utilized in equal conditions and the results are compared. The methods explain how the databases are selected, how case studies are defined and modeled, and which financial indicators are utilized to compare the economic results, from the point of view of the residential investor, per each one of five selected locations.

2.1. Criteria for selecting a reference irradiation database

Almost all databases supply values of GHI (Global Horizontal Irradiation) obtained from data collection satellites, orbiting in cycles of several days, covering a great portion of the globe's surface, utilizing optical equipment with different accuracy and sensitivity. The brightness of every pixel is the record of the solar energy reflected by the surface, filtered by clouds, aerosols and turbidity of the atmosphere. The value of GHI is used to determine the amount of energy hitting the tilted surface of solar modules, utilizing appropriate transposition algorithms that have been the object of several previous studies to account for deviations of azimuth and tilt (BIrd and Riordan, 1985; Perez et al., 1987, 1990; Colle and Pereira, 1998; Pereira et al., 2006; Martins et al., 2007; Gueymard, 2008; Krenzinger and Bugs, 2010; Krenzinger, 2012; Notton et al., 2012). Furthermore, data from satellites must be validated with corresponding data obtained by terrestrial measuring stations spread over a given territory, working with precise calibrated instruments.

Based on the extensive participation of the Brazilian scientific community contributing to validate the data collected with the satellites selected by NREL (National Renewable Energy Laboratory) under the SWERA project, the Openei-SWERA (SWERA-Opencarto, 2016) database is the natural selection choice for the Brazilian territory. Given the continental extension of Brazil, the turbidity of the atmosphere and the climatic phenomena vary with the different locations (Martins et al., 2007), therefore a transposition model BRASIL-SR has been created and utilized by INPE (Brazilian National Institute for Space Research), under the SWERA project, to validate the satellite data (Colle and Pereira, 1998; Martins et al., 2007).

The Openei-SWERA database (SWERA-Opencarto, 2016) utilizes a tool supplied by NREL that allows selecting directly on world maps the location of interest. For the Brazilian territory it is possible to choose irradiation maps with high or moderate resolution. The high resolution maps provide pixels corresponding to 10 km, whereas the moderate resolution inform values for 40 km resolution pixels (SWERA-Opencarto, 2016). An updated and upgraded version of the Brazilian Solar Atlas is in preparation, and resolution will be improved to better than 4 km.

2.2. Alternative database

A well known, globally used alternative for the irradiation information is the software package PVsyst™ that provides databases for the entire world. Aiming at the European users as well as USA and Canada, it provides for the rest of the world irradiation time series that are either synthetic, like the Meteonorm 7.1, which is embedded from version 6 of PVsyst onwards, or generated with satellite images that are only available to paying users. The Meteonorm monthly irradiance data are available for 1200 stations in the main European countries. Data for any of the other sites have to be obtained by interpolation, although only monthly series may be averaged, thanks to the seasonal distribution that is very similar from one year to the other (PVsyst, 2012, 2016). Anyway not all the Brazilian cities are covered by the Meteonorm 7.1 dataset.

The PVsyst™ database has its own transposition model, which is designed for the territories that represent its most important markets. When utilized for different geographical locations, some inherent error due to local climatic conditions is likely to occur. With this in mind, a closed attention must be paid to the system's composition that will affect directly the capital expenditure and consequently the LCOE and Return on Investment – ROI.

2.3. Evaluation of the different results

The comparison of the modeled results using the two alternative databases is evaluated in three steps: in the first step a single-family residential building is modeled by defining the internal loads for electricity appliances, lights and air conditioning; these loads are affected by the location of the residence and the environmental conditions, resulting in the monthly energy demand. The modeling software used in this step is the EnergyPlus, version 8.4 (DoE, 2014).

In the second step the PV technology is selected, represented in this study by the more traditional crystalline silicon (c-Si) PV technology, considering its extensive market share worldwide. By using a feature of the PVsyst Software (PVsyst, 2012), the losses of the entire PV system are then calculated over one year, allowing to estimate the performance ratio of each location and system. Performance Ratio (PR), also named Quality Factor, is the ratio between the actual yield (annual AC production of energy) and the target DC yield. It takes in account all energy losses between the PV modules and the grid. As a reference value, the Performance Ratio for a PV system could range between 75% and 85%.

In the third step, the power of the PV systems and all the financial indicators are determined, using two different approaches:

(1) By utilizing the Openei-SWERA daily average monthly data irradiation for each location, the energy demand of each residence is modeled and, as a consequence, the dc power requirements of all electrical systems, the capital expenditure, the LCOE and the ROI are calculated.