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Performance analysis of a grid connected photovoltaic system in northeastern Brazil

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ABSTRACT

This article presents the performance analysis of a 2.2 kW_p photovoltaic system installed at the State University of Ceará, Fortaleza, Brazil (latitude 3.40°S, longitude 38.33°W and 31 m above sea level). The system was monitored from June 2013 to May 2014. In the measured period the annual energy yield was 1685.5 kWh/kW_p. The average daily reference, array and final yields of the system were 5.6 kWh/kW_p, 4.9 kWh/kW_p and 4.6 kWh/kW_p, respectively. The annual average daily array and system losses were 1.05 kWh/kW_p and the annual average array, system and inverter efficiencies were 13.3%, 12.6% and 94.6%, respectively. The performance ratio and capacity factor were 82.9% and 19.2%, respectively. These numbers highlight the relatively good performance of PV systems installed in the northeast region of Brazil.

Introduction

Energy is one of main ingredients for the development and maintenance of a modern society with benefits of its socio-economic and technological advancements. Providing energy for homes and buildings, agriculture, transportation, services, and industries in a sustainable way and at the same time guaranteeing resources for the future generations is the ultimate challenge for the humanity. As a result of greenhouse gases emissions from fossil fuels, their decline in reserves and consequent increasing price, and potential impacts on climate change, many countries are now reexamining their national energy policies with view of shifting toward low-carbon and renewable energy sources (Adaramola, 2015; Adaramola and Vagnes, 2015). Among the various forms of renewable energies such as wind energy, bioenergy and others, photovoltaic energy occupies a prominent position due to many peculiarities.

Economic incentives, reduction in cost, and the fast technological developments allow the use of grid connected photovoltaic plants in a simple, efficient and profitable way. The photovoltaic (PV) energy assumes, therefore, an increasing role within the spectra of the energy sources, especially for its simplicity of installation and integration in building architecture (Micheli et al., 2014). Consequently the global cumulative installed capacity of PV systems increased rapidly from about 1.3 GW in 2000 to 139 GW at the end of 2013 (Adaramola, 2015).

Brazil has an excellent level of solar radiation mainly in the northeast region. In its semi-arid region there is the best insolation, with typical values of 200 to 250 W/m^2 of continuous power which is equivalent the falling solar radiation from 1752 to 2190 kWh/m^2/year (Marques et al., 2009; Braga, 2008; Ruether and Zilles, 2011). Considering the country's advantageous solar radiation conditions, grid connected photovoltaics, with an installed capacity of only 4.5 MW_p in the year 2013, is still an unrepresented energy form in Brazil (Holdermann et al., 2014). Grid connected PV experience in Brazil is still limited to a handful of small installations operating at universities, research institutes (Ruether and Zilles, 2011), some private institutions (MPX for example), few in residences and commerce, at least in its northeast region. So it is important for the country to be prepared and to accumulate experience with grid connected PV in order to be able to make the most of distributed benefits of this benign technology when it becomes more cost-effective (Jannuzzi and de Melo, 2013).

Performance assessment of PV systems is the best way to determine the potential for PV power production in an area (Adaramola and Vagnes, 2015). Usually the performance of photovoltaic modules refers to Standard Test Condition (STC) which is not always representative for the real module operation (Micheli et al., 2014). PV module technology, weather conditions (incident radiation, temperatures), inclination, inverter and control systems, sun-tracker system, and wiring are factors which influence the performance of a PV system (Díez-Mediavilla et al., 2012). There are many performance evaluation studies of PV systems installed outdoors across Europe and globally as referenced by Adaramola and Vagnes (2015), Micheli et al. (2014), Díez-Mediavilla et al. (2012), Ayompe et al. (2011), Mpholo et al. (2015), Kumar et al. (2014), Padmavathi and Daniel (2013), to name a few. However Brazil and the Latin America are poorly represented in such studies although presenting an immense potential for its utilization (Dávi et al., 2016).

As highlighted by Ayompe et al. (2011), the performance assessment of a PV system include parameters calculation such as:

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annual energy generated, reference yield, array yield, final yield, array capture losses, system losses and cell temperature losses, PV module efficiency, system efficiency, inverter efficiency, performance ratio, and capacity factor. Results obtained will provide useful information to policy makers and interested individual and organization about actual performance of grid connected PV system in a region or country (Adaramola and Vagnes, 2015).

The state of Ceará located in the northeast cost of Brazil, in the semi-arid region, has a land extension of about 149,000 km^2 which correspond to 1.74% of the Brazil's territory and population of about 8.5 million inhabitants. Ceará has a considerable potential for renewable energies under the forms of solar, wind and biomass. The wind energy potential of Ceará is estimated in 35 GW and at the end of the present year it is expected to reach 1.8 GW of installed wind farms in operation. The average daily solar radiation in one square meter in Ceará reaching about 5.5 kWh is one of the highest in Brazilian territory. At the year 2011 the state launched a 1 MW private and commercial photovoltaic power plant in the city of Tauá, 350 km far from its capital, Fortaleza (Esteves et al., 2015). At the present time, the government of such state is improving regulatory framework in order to promote the increase in the insertion of photovoltaic systems in the domestic market. In the near future it is expected to reach 270 MW of installed photovoltaic systems (Jornal diário do nordeste, 2016).

The main objective of this article is to show the one year performance of a grid connected 2.2 kW_p photovoltaic system installed at the State University of Ceará in the city of Fortaleza – Brazil.

The grid connected PV system

The grid connected PV system used in the present study is installed in the dependence of the Master Program on Applied Physics of the State University of Ceará, as shown in the Fig. 1. The system started operation on November, 2012. The University is located on the latitude 3.40°S and longitude 38.33°W, and about 31 m above sea level. The PV system consists of 18 modules covering a total area of 29 m^2 with an installed capacity of 4.4 kW_p. For the present study only 9 modules were used because of limitation on the number of available inverters. By this way the used system consists of 9 modules covering an area of 14.5 m^2 with an installed capacity of 2.2 kW_p. The Canadian Solar CS6P-245P of 245 W_p modules were used. The modules were tilted at a fixed angle of 13° and oriented northward at an azimuth angle of 12°.

The SMA Sunny Boy SB 2500-HF-30 inverter was used for transforming the voltage from DC to AC and connected to the utility grid. The inverter had a rated maximum efficiency of 96.3% and maximum AC power of 2500 W. The sizing ratio which represents the ratio between the PV array installed capacity and the inverter capacity, in the present case, it was 0.9. The inverter was connected to the Sunny WebBox via a serial RS485 link. Data recorded on 5 min intervals in the WebBox was extracted via an SD card and read directly into a computer. Solar radiation, wind speed and ambient temperature were provided by an automatic Meteorological Station (50 m close to the PV system) of the FUNCEME – Ceará State Foundation for Meteorology and Water Resources.

Fig. 1. Picture of the PV array used.

Performance parameters

The performance of a grid connected PV system usually is evaluated taking as reference the IEC 61724 Standard. Evaluated parameters are: energy output, yields (reference yield, array yield and final yield), array and system energy losses, system efficiencies (array efficiency, system efficiency and inverter efficiency), performance ratio and capacity factor (Adaramola and Vagnes, 2015; Díez-Mediavilla et al., 2012; Ayompe et al., 2011; IEC, 1998; Ozden et al., 2017; Dobaria et al., 2016; Elhadj Sidi et al., 2016; Mpholo et al., 2015; Sundaram and Babu, 2015; Kumar et al., 2014; Sharma and Chandel, 2013; Padmavathi and Daniel, 2013; Wittkopf et al., 2012). Energy quantities are evaluated normalized to rated array power and referred to as yields which indicate the actual array operation relative to its rated capacity. System efficiencies are normalized to array area (Padmavathi and Daniel, 2013). These normalized performance parameters are relevant since they provide a basis under which grid tied PV systems can be compared under various operating conditions (Adaramola and Vagnes, 2015).

Energy output

The total energy is defined as the amount of alternating current (AC) power generated by the system over a given period of time. The total hourly, daily and monthly energy produced can be determined respectively as:

$$E_{AC,h} = \sum_{t=1}^{60} E_{AC,\ t} \tag{1}$$

$$E_{AC,d} = \sum_{h=1}^{24} E_{AC,\ h} \tag{2}$$

$$E_{AC,m} = \sum_{d=1}^{N} E_{AC,\ d} \tag{3}$$

where $E_{AC,t}$ is AC energy output at time t (in min); $E_{AC,h}$ is AC energy output at hour h; $E_{AC,d}$ is the daily AC energy output; $E_{AC,m}$ is the monthly AC energy output and N is the number of days in a month.

System yields

The system yields can be classified into three types which are array, final and reference yields. The yields indicate the actual array operation relative to its rated capacity. The array yield Y_A is defined as the direct current (DC) energy output from the PV array over a given period of time normalized by the PV rated power (Adaramola and Vagnes, 2015). It represents the time, measured in kWh/kW_p, that the PV array must be operating with its nominal power to generate the energy produced (Elhadj Sidi et al., 2016). It is given as:

$$Y_A = \frac{E_{DC}}{P_{PV,rated}} \quad (kWh/kW_p) \tag{4}$$

where E_{DC} is the DC energy output (kWh) from the PV array.

The final yield Y_F is defined as the total AC energy generated by the PV system for a defined period of time divided by the rated output