Applied Energy 160 (2015) 255–265

Contents lists available at ScienceDirect

Applied Energy

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

Comparative performance investigation of mono- and poly-crystalline silicon photovoltaic modules for use in grid-connected photovoltaic systems in dry climates

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HIGHLIGHTS

- Output energy from two PV technology types (mc-Si and p-Si) are compared.
- Experimental measured data have been checked for consistency and have been validated.
- Annual average of capacity factor is found about 23.20% and 23.81% for mc-Si and p-Si, respectively.
- Effect of an increase in module temperature on output power from two PV technology types has been observed.
- Performance parameters of a grid-connected PV power plant have been experimentally studied during twelve months.

ARTICLE INFO

Article history:
Received 4 May 2015
Received in revised form 16 August 2015
Accepted 15 September 2015

Keywords:
PV power plant
Grid-connected system
Performance evaluation
Capacity factor

ABSTRACT

In this study, the design and performance of a real 11.04 kWp grid connected photovoltaic (PV) system is investigated. This plant is composed of two types of 5.52 kWp common crystalline PV technology with almost similar characteristics. The PV power plant is established in an industrial sector of Kerman, Iran which experiences the same fluctuations in solar irradiance and ambient temperature for both types of monocrystalline silicon (mc-Si) and polycrystalline silicon (p-Si) PV modules. For experimental investigation of the plant, all meteorological and performance data of PV power plant are acquired by means of dedicated systems during July 2013 to June 2014. Thus, in this pioneer study, performance evaluations of two types of crystalline PV technology are studied, and as a part of considerations in the PV power plant design, the output power from p-Si PV modules is found greater. The annual average daily final yield (Y_f), performance ratio (PR), and capacity factor (CF) for mc-Si are found to be 5.24 kW h/kWp day, 80.81%, and 23.20%, respectively. Furthermore, Y_f, PR, and CF for p-Si are estimated as 5.38 kW h/kWp day, 82.92%, and 23.81%, respectively.

1. Introduction

Nowadays, renewable energy has a controversial role in the sustainable development of countries. Moreover, a growing number of developed and developing countries have established targets for this clean kind of energy in order to reduce environmental issues of fossil energy resources such as greenhouse gas emissions, climate change, and global warming. Many sources of renewable energy such as Wind power, Hydropower, Solar energy, Biomass, Biofuels, and Geothermal energy, which come either directly or indirectly from the sun, are almost considered to be environmentally friendly.

Solar power plants are the new topic in vogue these days. There are many different types of solar power plants which can be installed. PV power plant is the most common and widespread species of solar power plants and is generally categorized into off-grid and grid-connected systems.

Solar PV power plants usually utilize different PV technologies such as mc-Si, p-Si, amorphous silicon (a-Si), and other thin film technologies like copper indium di-selenide (CIS), copper indium gallium selenide (CIGS), and cadmium telluride (CdTe). However, the majority of the installed PV power plant types around the world have crystalline silicon (c-Si) technology.

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http://dx.doi.org/10.1016/j.apenergy.2015.09.064
0306-2619/

During the last decade, grid-connected PV power plants have attracted more significant attention due to the advantage of their compatibility with the utility grid and efficient utilization in residential and industrial areas. In order to establish a grid-connected solar PV power plant or study the experimental output results of an installed one, it is necessary to consider and evaluate the performance of the most consequential factors, such as geographical location and meteorological data, PV modules and inverter characteristics, orientation and installation tilt angle, dust accumulation, humidity, and external shadings.

Over the last few years, various studies have been conducted on the performance parameters of installed PV power plants in different geographical locations, with different climatic conditions [1–15]. Performance analyses investigate the influences of PV module technologies, inverters, shading, wiring, array inclinations, tracking and fixed PV systems, type of grid connections, etc. on the overall performance of the PV power plant. The results of the performance analysis of a 1.4 kW roof top grid-connected photovoltaic power system under desertic weather conditions in Oman have been presented in the paper [16]. The performance ratio (PR) and capacity factor (CF) of the system were reported 84.6% and 21%, respectively. Pietruszko and Gradzki [17] have investigated monitoring data from a 1 kW grid-connected PV system for a period of one year in Poland. They have reported the annual energy yield was about 830 kW h and the performance ratio ranged from 60% to 80%. Milosavljević et al. [18] reviewed the state-of-the-art solar energy potential and PV power plants in Serbia as well as similar studies around the world. They also performed an analysis of a 2 kW mc-Si grid connected solar PV power plant installed on the roof of the Faculty of Sciences and Mathematics (FSM building) in Niš, Republic of Serbia. The annual mean value of the PR and CF of the PV power plant were reported 93.6% and 12.88%, respectively.

Another experimental performance study is that of Wittkopf et al. [19]. In the frame of that study, the first zero-energy office building in Singapore used the 142.5 kWp p-Si grid-connected system on the roof of the building to meet its energy target. The first performance evaluation of the building-integrated PV system over 18 months of operation showed a good overall PR of 81%. Eke and Demircan [20] performed the performance analysis of a 2.73 kWp mc-Si PV power station under Mugla climatic conditions in Turkey.

The performance analysis of a fully monitored 171.36 kWp p-Si grid connected PV park in Greece has been conducted for the year 2007 on hourly, daily, and monthly bases. The authors [21] reported that the PV park supplied 229 MW h to the grid ranging from 335.48 to 869.68 kW h during 2007. PR varied from 58% to 73%, giving an annual PR of 67.36%. The final yield (Y_f) ranged from 1.96 to 5.07 h d^{-1}, and the average annual CF was 15.26%. Sharma and Chandel [22] explored the performance characteristics of a 190 kWp p-Si PV power plant in India and found that the maximum energy generated from the PV power plant is during March, September, and October and the minimum in January.

In the literature, there are also some studies which compare and investigate the performance of two PV power plants, simultaneously. A recent study is that of Congedo et al. [23], which focuses on the influence of climatic characteristics on a 960 kWp mc-Si PV power plant, divided in two subfields with different tilt angles and different nominal powers (606.6 kWp and 353.3 kWp) in south-eastern Italy. The results revealed that the performance ratio varies between 79% and 86.5% for the period of March to October 2012. Another relevant investigation is that of Al-Otaibi et al. [24]. They analyzed a twelve-month-long performance of the 80.05 kWp and 21.6 kWp CIGS grid-connected PV systems in Kuwait; the findings indicated that the performance ratio was maintained between 74% and 85% while the annual average daily final yield of the PV systems was 4.5 kW h/kWp day. On the other hand, Micheli et al. [25] evaluated the performance of two grid-connected PV systems (17.94 kWp and 15.9 kWp) with different PV technology, rated power, and efficiency in northern Italy. The yearlong calculated performance ratio was 89.1% for the first PV system, which was equipped with mc-Si wafer surrounded by ultra-thin amorphous silicon layer (hetero-junction with intrinsic thin layer) and 82.7% for the second PV system, which was equipped with different kind of mc-Si PV modules. Further, in the paper [26] Tripathi et al. conducted a performance investigation for solar PV systems from mc-Si and a-Si grid-connected PV technologies in two 500 kWp solar PV power plants located at the same place in Gujarat, Western India. Performance analysis was done over an entire year; the PR of mc-Si ranged from 57.1% to 93.14%, and for a-Si it ranged from 53.72% to 87.64%. The final yield of mc-Si power plant ranged from a lower value of 2.79 h d^{-1} to a maximum value of 5.14 h d^{-1}, and for a-Si power plant, it ranged from a lower value of 2.62 h d^{-1} to a maximum value of 4.84 h d^{-1}.

At the present time, grid-connected PV power plants studies are interesting and informative, but based on the recent experimental studies, which are available in the literature [27–29] and to the authors' knowledge, there is still a lack of detailed performance analysis about mc-Si and p-Si PV module with almost similar electrical and mechanical characteristics. This paper aims to fill this gap by comparing the experimental behavior of these two common PV module technologies (mc-Si and p-Si) with exactly the same efficiency and maximum power at standard test conditions, the same mechanical properties, and almost similar in other electrical properties which experience the same fluctuations of solar irradiance and weather conditions. A series of field performances of these two PV module technologies in a grid-connected PV power plant in Kerman, Iran were consequently measured during twelve months to identify the more appropriate one.

2. PV-power plant description

The PV power plant is located at a latitude of 30°12′N, longitude of 56°52′E, and with an altitude of 1772 m above sea level in Khazra industrial park in Kerman, Iran with the monthly average daily values of solar radiation range from 3.86 to 8.28 kW h m^{-2}. An overall view of the power plant is given in Fig. 1.

The plant is installed on a gradual drop of a stony hill in two stairs. The top row is designed by mc-Si PV modules and the lower row is designed by p-Si PV modules. It is important to note that the results concerning the PV plant only are reported in this paper.

As can be seen in Fig. 1, two rows of PV arrays are installed on two stairs with a 3 m gap in such a manner that they do not cast a shade over each other. Seeing that the hill, on which the PV arrays are mounted, is high enough so that no shade is produced by surrounding buildings and trees. Fig. 2 indicates that the site layout is far away from any obstacles capable of shading over the arrays.

The PV power station is almost in the middle of the industrial park, and the surrounding regions have a semi-moderate and dry climate among semi-arid steppe lands (Fig. 2). Mani and Pillai [30] have suggested general recommendations to mitigate the impact of dust accumulation on PV performance according to climatic characteristics and conditions influencing PV performance. As they proposed weekly cleaning for PV modules in the steppe climate, there is a timetable for cleaning the power station modules by the use of weekly water jets. Using the excellent guidance of Mani and Pillai will prevent and mitigate the effect of soiling on the PV modules [9,31].

3. Design and selection consideration of PV power plant

In grid-connected PV power plants, the system is usually composed of the three main following components: