Energy Conversion and Management 78 (2014) 8–13

Contents lists available at ScienceDirect

Energy Conversion and Management

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

A comparative study of three types of grid connected photovoltaic systems based on actual performance

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ARTICLE INFO

Article history:
Received 27 August 2013
Accepted 22 October 2013
Available online 16 November 2013

Keywords:
PV system
Concentrating PV system
Sun tracking PV system
Linear regression

ABSTRACT

In this study, three photovoltaic (PV) systems are evaluated based on actual performance. The energy generation of three types of PV systems namely concentrating PV system (6 units × 1 kWp), PV system with sun tracking flat (2 units × 1 kWp) and fixed flat PV system (2 units × 1 kWp) is analyzed in this research. Data analysis for ten consecutive months consisting of 12,190 samples of 15 min interval is done. The performance evaluation is done using energy yield, yield factor, capacity factor, power efficiency and PV array efficiency. Based on the experiment data, it is concluded that tracking flat PV system is the most suitable system for Malaysia in normal operation mode with average daily generation of 4.7 kW h (141 kW h as a monthly average), system efficiency of 11%, power efficiency of 85%, average daily yield factor of 2.3 kW h/kWp and capacity factor of 32%. This study also highlights the PV energy (E_{PV}) models for each PV generators with respect to the environmental factors. The advantage of employing a tracking flat system as compared to the fixed flat system is considered based on the effectiveness of the dual-axis tracking mechanism tracking the sun for maximum power output.

1. Introduction

The Government of Malaysia has approved and officially started the Fit-In-Tariff (FiT) enactment of the renewable energy law by third quarter of 2011. Solar PV received the highest FiT rate as compared to the other renewable energy resources with the rates of 0.4–0.57 USD per kW h for the duration of 21 years with 8% degradation [1]. According to this, the ministry of science, technology and innovations (MOSTI) has played an important role in funding 51 PV projects worth more than 13,000,000 USD. This policy highlights the importance of analyzing the performance of different types of PV systems in order to find out the most suitable system for Malaysia where highlights are also given to ability to mitigate CO_2 reduction [2,3].

Most research studies in the field of solar photovoltaic technology and application applies a single or multiple PV modules configured in stacks for the testing and verification. Research outcomes reflect parameters such as power, energy, system's yield factor (YF), capacity factor (CF), system efficiency, and overall performance. Fuentes et al. in [4] studied PV systems performance under natural sunlight and highlighted two issues namely data uncertainty and site-specifications when analyzing a PV system in order choose suitable PV system in the Mediterranean zone. Almonacid et al. in [5] highlighted the importance of predicting the characteristics of a PV module using artificial neural network (ANN). In [6,7], the authors provided an optimization of PV/Diesel systems and highlighted that the PV system technology is of the most suitable renewable energy technologies for Malaysia. Meanwhile, Mekhilef et al. in [8] reviewed the PV technology adaptation in Malaysia based on chronological flow and highlighted some corporate involvement such as BP Malaysia for the 8 kWp PV project in KESAS Highway and Fraunhofer ISE Germany for the prototype of solar house application in urban areas.

However, the PV manufacturing sector as well as researchers normally estimate the total energy generated from a collection of PV modules considering data incorporated with pertinent percentage energy conversion capability. It is shown that the module efficiency estimated by this method does not reflect the collective efficiency of a PV system made up of a set of single modules stacked in bundles of either parallel or series configuration. Due to factors such as cost, equipment, space and bulkiness of the system, the PV system cannot be tested in laboratories based on standard requirements at sites with different climate characteristics.

In this study, a practical approach is proposed to define PV systems potential using energy generation amount for each PV system in order to evaluate the productivity of different types of PV systems in Malaysia and nearby tropical regions. To do so, a 10 kWp PV pilot plant has been installed, monitored and tested

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http://dx.doi.org/10.1016/j.enconman.2013.10.064

at Universiti Putra Malaysia, Serdang, Malaysia. This plant is consisted of a 2 kWp Fixed Flat PV system (FF), 2 kWp tracking flat PV system (TF) and 6 kWp PV system with concentrating mirrors and tracking mechanism (CPV) (see Figs. 1a–1c) with details specifications in Table 1. The fixed flat generator in Fig. 1a is slanted at 15° facing south based on the recommendation reported by [9]. In this research, performance data is analyzed for a period of ten consecutive months (September 2011 to June 2012) for the named PV systems with the aim to define energy potential from each system [10].

The study duration on PV performance is considered sufficient based on the fact that weather condition for Malaysia fluctuates all year round as described earlier and supported by some PV field studies by [11–15].

2. Field condition at the testing site

Malaysia experiences tropical weather condition almost all year round. Amin et al. [16] have conducted field test for various types of photovoltaic modules and concluded that weather condition in Malaysia is sufficient for PV application due to the availability and predictability of sunlight with the possibility of having 6 h of direct irradiation of 800 W/m^2 to 1000 W/m^2. This statement is supported by "report compared assessment of selected environmental indicators" of PV electricity in selected OECD cities where Malaysia was found among the top 5 countries in PV system production with energy generation up to 1600 kW h/KWp. Year for a rooftop integrated photovoltaic systems [17]. The solar farm approach is basically a large scale project for which to implement the proposed PV generator configuration. The system efficiency is more likely produce a much realistic figure because of the huge area usage and the exposure of the stochastic tropical environment. Specifically for this pilot project, we intend to highlight some fieldwork findings as supportive reference towards adapting tracking flat PV generators in solar-farm scale maybe in the near future. Typical example of large scale solar PV implementation and technology application in the tropics is described in [8,18,19].

In this research, it is concluded based on the data recorded at the selected site that the average daily radiation level is in the range of (253–512) W/m^2 with highest daily radiation recorded in the range of (556–1094) W/m^2. In the meanwhile, it is found that the daily maximum ambient temperature is in the range of (30.2–36.6) °C with average monthly value of 29.6 °C (see Fig. 2).

The sun hours throughout the monitoring period is calculated at 3047.5 h with 11.34 h/day of solar radiation received. The peak solar radiation level recorded is 1438 W/m^2 in 15th May 2012. Meanwhile, the minimum recorded solar radiation is found 3 W/m^2 for most of the days as early as 4.08 AM. The average solar radiation recorded for 15 min interval during generation days is 339.7 W/m^2. On the other hand, the recorded ambient temperature ranges from 22.2 °C up to 38.4 °C with an average value of 29.41 °C.

Fig. 1a. Installed fixed flat PV system.

Fig. 1b. Installed tracking flat PV system with 2-axis movement.

Fig. 1c. Installed CPV system with mirror concentrating elements.

3. Experiment description and setup

The installed PV pilot plant which covers approximately 450 squared meter of area with total generating capacity of 10 kWp. These PV systems consists of 2 × 1 kWp units of fixed flat (FF) PV system, 2 × 1 kWp units of tracking flat PV system (TF) generator and 6 × 1 kWp units of CPV System. All of the three types of the PV systems are made up of CEEG 95W Mono crystalline PV Module as described in Table 2.

The system is directly connected to UPM electrical distribution line via Feeder Pillar (FP) as shown in Fig. 3 which links to the Main Switch Board (MSB). Grid connected system ensures full capacity generation with assumption of highest generator efficiency during the operation period compared to a standalone system which has some limitations. The ten units of PV generator are connected to three units of Aurora Inverter system with the capacity of 2 × 3.6 kW and 6.0 kW for the purpose of grid-tied operation.

The difference between the systems lies in the quantity of PV modules, dual-axis tracking mechanism and mirror with twice concentration. The uniqueness of CPV generator implies the concept of V-through configuration by installing mirror reflector with certain degree of concentration to enhance the solar radiation received at the PV module surface to increase photonic effect inside the crystalline semiconductor. Recent studies done by [20–24] imply the optical efficiency of V-through technology in solar PV application which creates alternative means of reducing the overall