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Performance Evaluation of Solar Photovoltaic Systems in Anand City, Gujarat, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author YV did Conceptualisation, research trials, validation, manuscript preparation. Author SA did Review of literature, manuscript editing. Author MK did Research trials, data compilation, statistical analysis, validation, manuscript preparation. Author RT did Validation, proof reading, plagiarism checking, formatting. All authors read and approved the final manuscript.

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ABSTRACT

Since, India is situated on the sunny belt in the north of equator, the scope for generating power and thermal applications using solar energy is huge. The present study was planned to evaluate the performance of rooftop photovoltaic (PV) system in Anand city of Gujarat state of India. Performance of the PV system was carried out by recording and calculating various parameters such as average yearly solar PV energy yield, performance ratio and capacity utilization factor. The average daily energy yield of solar PV system was 42 kWh. The capacity utilization factor and performance ratio of solar PV system were 15% and 88% respectively. These results can be used by project developers to select optimum size of PV system to generate specified output of solar PV system.

Keywords: Solar PV; renewable energy; photovoltaic; Gujarat.

1. INTRODUCTION

The country like India is highly dependent on energy sources from import of crude oil [1]. Energy security is therefore a serious concern for India as the country's imports exceeded 90% of total oil consumption. Any disruption in energy supplied would be harmful to the country's economic growth. BEE, [2]. Further, India is facing an acute energy scarcity which is hampering its industrial growth and economic progress. Setting up of new power plants is inevitably dependent on import of highly volatile fossil fuels. Thus, it is essential to tackle the energy crisis through judicious utilization of abundant the renewable energy resources. In the year 2020, India was the third largest primary energy (913 MTOE) and electricity (1230 TWh) consumer after China and US Enerdata, [3], BEE, [2]. As on October, 2020, many states of India were having power deficit across the country [4]. Hence, solar energy can be harnessed to tackle power deficit of the country. The Earth receives 174 petawatts (PW) of incoming solar radiation (insolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The value of the solar constant varies from day-to-day depending on the actual distance from the sun. The present accepted value of solar constant derived from space-based measurements is 1360.8 ± 0.5 W/m^2 (Tyagi, 2009; NASA, 2008). The main benefits of solar is that it can be used as heat or electricity without the release of harmful pollutants. (BEE, [2], Singh and Pal, [5], Moosavian et al., [6]. Securing sustainable and future energy supplies will be the greatest challenge faced by all societies in this century (Foster et al., 2010). Performance of solar PV system is site specific. The solar radiation collected by a surface on earth varies on seasonal (daily or monthly) basis due to the presence of clouds and the Sun position. It also varies on an hourly basis due to the east to the west relative position of the sun. To design operating systems having the highest achievable efficiency under comparable costs, the reliable database on different aspects of solar radiant energy is essential. The more precisely solar resources are identified, the better the system design gets. Further, in Indian solar market, standard ranking of solar radiation databases is not available therefore project developers adopt the solar radiation databases randomly. It was also reported that all the database either overestimate or underestimate the performance of select PV projects. Hence, it is important to know the effect of different weather parameters on the performance of the solar PV system for the selection of optimum size of PV system for the particular application. This study was conducted with the objective to analyse energy yield, performance ratio and capacity utilization factor of solar PV system.

2. METHODOLOGY

2.1 Installation of Solar PV System

A 12 kWp ballast solar PV system (Make: Topsun Energy Limited, India) was installed based on space availability on terrace of workshop building of Dairy Engineering Department of SMC College of Dairy Science in Anand city of Gujarat state located at an altitude of 45.09 meter (mean sea level) having the latitudinal and longitudinal belt of 22°32'05.1" N and 72°58'13.7" E, respectively. The coordinates were obtained from google map. The land coordinate of the site is shown in Fig 1.

Total 38 solar panels were installed at a fixed tilt angle with horizontal and facing towards true south direction instead of magnetic south direction for receiving maximum solar irradiance over the year. The drawing and layout for solar panel, orientation of all the solar panels, electrical cable connections and circuit diagram for entire solar PV system were prepared using commercial software AutoCAD mechanical (Version: 2020). A schematic drawing of grid connected Solar PV system is shown in Fig 2.

Fig. 1. Land coordinates of solar PV site on google map

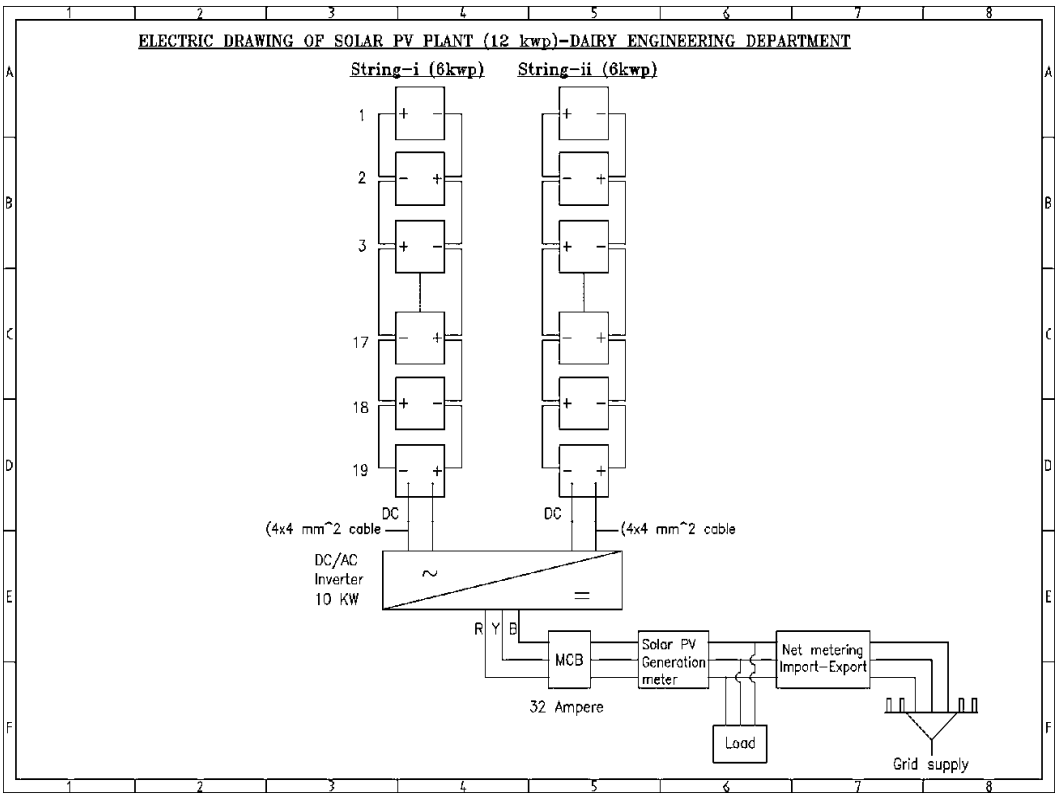

Fig. 2. Schematic drawing of grid connected solar PV system

2.2 Performance Evaluation of Solar PV

Performance evaluation of solar PV system was carried out by analysing various parameters such as energy yield in different months of the year, capacity utilization factor and performance ratio. Monthly energy yield of the system for a year was recorded from invertor screen. From the monthly data of solar PV energy yield of the system, daily energy yield in a respective month was calculated using the following formula

> Daily energy yield during the month = Actual monthly energy yield of the solar PV (kWh) / Rated output * No. of days in a respective month

Similarly, daily energy yield per year of the system was calculated by using the following formula

> Daily energy yield during the year = Annual energy yield of the solar PV (kWh) / Rated output * No.of days in a year

The capacity utilization factor is used to evaluate the capacity utilized over a year. It was calculated using the following formula.

> Capacity utilization factor (CUF) = Annual energy yield of solar PV (kWh) / 365×24×Rated output of solar PV

Performance ratio indicates the healthy operating condition of the PV system. It is calculated using the following formula.

> Performance ratio = Actual yield of PV system per annum (kWh/kWp) / Reference yield of PV system per annum (kWh/kWp)

Actual yield of PV system was recorded in kWh from invertor screen whereas reference yield of PV system in kWh was referred from technical data specified by manufacturer under ideal operating conditions (1000 W/m^2; 25°C).

3. RESULTS AND DISCUSSION

Polycrystalline rectangular solar panel with dimension of 1.950 m height and 0.99 m width was used. The panel comprised of 72 cells arranged in 6 columns and 12 rows. The effective dimensions available for electricity generation excluding the frame of the panel was 1.89 m × 0.95 m. Nineteen panels were connected in the series to form a string with an output capacity of 6 kWp. There were two such strings of identical output capacity. These two strings were connected in parallel with the grid-integrated three phase solar PV invertor (10 kW). The direct current generated from the solar PV system was converted into alternating current through the invertor. The electricity from the invertor was then supplied to grid. The solar PV system was integrated with the grid for storage of electrical energy into the grid and utilizing it as and when required throughout a day. Total 38 solar PV panels facing towards south-west direction were installed on workshop building of Dairy Engineering Department. Of the total panels, thirty panels were installed on the terrace-1 (dimensions: 15.24 m × 9.14 m) and eight panels were installed on terrace-2 (dimensions: 7.01 m × 6.40 m). So, the total space required for the installation of solar PV at dairy engineering department was 184.20 m^2. For the maximum year-round solar exposure, the ideal solar panel tilt angle equal to the latitude angle of the location was maintained. Since, the latitude of the location was 22°32'05.1" N, the tilt angle for the installation of solar panels was 23° with the horizontal surface.

3.1 Performance Evaluation of Solar PV System

The specifications of the solar panel, grid connected solar invertor and grid connected solar PV system is shown in Tables 1, 2 and 3 respectively.

The performance of solar PV was affected by time of the day, month and season of the year. Variation in monthly PV energy yield of 12 kWp throughout the year is shown in Fig 3. The highest and the lowest monthlysolar PV energy yield of 12 kWp solar PV system recorded was 1780.22 kWh and 998.7 kWh in May-2021 and August-2020 respectively. The highest monthly solar PV energy yield in May-2021 was due to higher average monthly solar irradiance and the longest day length whereas the lowest monthly solar PV energy yield in August-2021 was due to monsoon season. Similar trend was reported by Harinarayana and Kashyap [7]. They observed that the monthly energy generation begins to increase in September with the highest energy generation period between March to May. Most parts of the India receive a daily solar irradiance of 4–7 kWh per square metre per day

(kWh/m2/day) and sunshine of about 6–8 h a day, averaging to about 2300 to 3200 h per year (Sharma et al., [8], Raghavan et al., [9]. The highest and the lowest solar PV energy yield per kWp of solar PV system obtained was 4.96 kWh and 2.69 kWh respectively. The actual average daily solar PV energy yield per kWp solar PV system for the year 2020-2021 was 3.5 kWh as against 4.0 kWh per day per kWp of solar PV system mentioned by manufacturer. The lower yield was due to real site conditions deviating from the standard test conditions (1000 W/m^2, 25°C and 1.5 Air mass). As per the manufacturer's specifications, the performance was expected to degrade to the tune of 0.7 to 1.0% per annum with the age of the plant. Since, the performance of the solar PV system was evaluated at the fourth year of the installation, the performance of the solar PV system was expected to decline compared to first year of installation.

Table 1. Specifications of solar panel

Make	**Topsun Energy Ltd.**
Model No.	TEL24P315
Year of Manufacturing	2017
Dimensions (mm) (L x W)	1950 × 990
Electrical Ratings	Nominal ratings at STC (1000 W/m^2 spectrum AM 1.5G at 25^{0}C). All values are nominal unless designed as tested
Power rating (P_{mpp})	315 W_p
Voltage at Max Power (V_{max})	36.0 V
Current at Max Power (I_{max})	8.75 A
By-pass Diode Rating	20 A
System Voltage	1000 VDC
Application Class	A
Open Circuit Voltage (V_{oc})	44.0 V
Short Circuit Current (I_{sc})	9.4 A
Series Fuse Rating	15 A

Table 2. Specifications of grid-connected solar inverter

Make	**Schenzhen INVT Electric Co., Ltd.**
Type	Three phase grid-tied
Model No.	iMars BG12KTR
Rated Power	10 kW
Grid Monitor	3N~400V/50 Hz
DC Input	
V_{max}. PV	1000 V
MPPT Range	280-800 V
Max. current	25A x 2
AC Output	
Max. continuous current	32 A
Max. continuous Power	10 kW
Nominal Frequency	50 Hz
Nominal Voltage	3N–400 V
Temperature	-25 to 60°C
Protection class	II (DC)
Over voltage Category	I
IP level	IP65
Grid Monitoring	VD0126 AS4777 CQC G38/G59 C10/11 TF 2 1 PEA

Table 3. Specification of grid connected solar PV system

Capacity	12 kWp
Make	Topson Energy Ltd.
Structure for installation of solar panel	Ballast-rooftop with fixed tilt
No. of modules	38
Year of installation	2017
The power rating of solar panel	315 Wp
No. of string invertor	1
No. of string	2
No. of panels per string	19
Connection between string	Parallel
Connection between panels	Series
Tilt angle with horizontal surface	23^{o}
Facing towards	True south
Magnetic declination from south	12^{o}
Rating of Invertor	10 kW

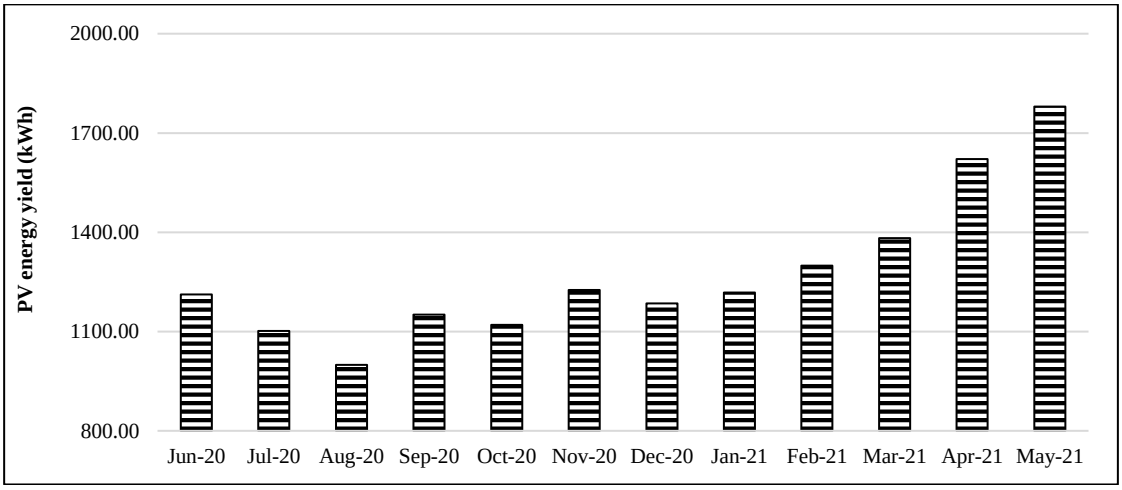

Fig. 3. Variation in monthly PV energy yield of 12 kWp throughout the year

3.2 Capacity Utilization Factor

The capacity utilization factor indicates the actual electricity output from the solar PV system over the maximum possible output during the year if the plant was operated for 24 h a day over a year. Therefore, it is an indicative of productive capacity utilization for electricity generation from the plant. The total solar PV energy yield was calculated by adding monthly energy yield of 12 KWp solar PV system over a year 2020-2021. The capacity of the plant as indicated by manufacturer's specification was 12 kWp with 38 solar panels of 315 W output capacity each. However, when output capacity of individual panel is multiplied with the numbers of panel, it comes out to be 11.97 kWp. The reference yield of the PV system was referred from the solar PV specifications provided by manufacturer [10].

$$\text{Capacity utilization factor (CUF)} = \frac{\text{Actual yield of PV system per annum (kWh)}}{365 \times 24 \times \text{Installed capacity of plant (kW)}}$$

$$= \frac{15297}{365 \times 24 \times 11.97}$$

$$= 0.15$$

So, the effective utilization of solar PV system was 15%.

3.3 Performance Ratio

Performance ratio (PR) is the ratio of the energy effectively produced with respect to energy which would be produced if the system was continuously working at its nominal standard test conditions efficiency. PR ranges between 0.80 to 1.0. Higher PR indicates the efficient working of solar PV system and therefore it is an indicative of maintenance requirement of the system if it is less than the normal range. PR below 0.7

indicates faulty operation of the system. Actual yield of solar PV was recorded from invertor screen whereas as reference yield was referred from the solar PV specifications provided by manufacturer [11,12].

$$\text{Performance ratio} = \frac{\text{Actual yield of PV system per annum (kWh/kWp)}}{\text{Reference yield of PV system per annum (kWh/kWp)}}$$

$$= 15297/17382$$

$$= 0.88$$

4. CONCLUSION

Grid-connected, ballast roof top solar PV system (12 kWp) was used to analyze the electrical energy generated depending on site specific weather parameters. Installation space required per kWp plant was 15.36 m^2. Polycrystalline solar panel with 72 solar cells at an output of 315 Wp under ideal conditions (1000 W/m^2, 25°C) was used in solar PV system. Total 38 solar panels were installed in south west direction with inclination angle of 12° from south and tilt angle of 23° to receive maximum solar energy throughout the year. The average daily energy yield of solar PV system was 42 kWh. The capacity utilization factor and performance ratio of solar PV system were 15% and 88% respectively. It is evident from the study that the energy yield of PV system is dependent on solar radiation. Further, the latest developments in bi -facial solar PV system can be evaluated in local weather conditions to help project developers to select proper size of solar PV system.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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