Performance Analysis of Grid-Connected Photovoltaic Systems in Western India: A Case Study

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Abstract—This paper reports the performance 250kW photovoltaic pilot plant for 340 days of 2012, which is in central of Gujarat, Western India. The development of large scale applications of photovoltaics demonstrates that the technology has spread from demonstration stages to large-scale deployment. The performance parameters and their performance evaluation are demonstrated for a variety of technologies established at this geographic location. The system consist of photovoltaic arrays containing modules of polycrystalline, Amorphous thin film and power conditioning units. During the year 2012, this systems operation, the PV system generated about 408500 kWh. The average of generating electricity production per day was 1116 kWh. It varied between 240 to 1515 kWh. The maximum solar irradiance, ambient temperature and Photovoltaic module (PV) was 1040 W/m², 42oC and 74 oC respectively. The efficiency of the PV array system varied between 12 to 14 %. The efficiency of the power conditioning units (PCU) is in the range from 96 to 99% with power factor close to unity. The average capacity utilization factor (CUF) of the plant is 18.28% and the average performance ratio (PR) was ranged between 77.20 to 84.04.

Index Terms—Capacity utilization factor, Performance ratio, Grid connected system, power conditioning units, final yield.

I. INTRODUCTION

THE large scale application of photovoltaics large-scale deployment is an emerging, challenging and innovative market that is currently being created at a rapid pace. Several countries have started to exploit this huge potential as part of their future energy supply. Parameters describing energy quantities for the PV system and its components have been established by the International Energy Agency (IEA) Photovoltaic Power Systems Program and are described in the IEC standard 61724 [1]. IEA task members have used these performance parameters to develop a database of operational and reliability performance [2]. The performance parameter facilitates the comparison of grid-connected photovoltaic (PV) systems that may differ with respect to design, technology or geographic location. The performance parameters that define the overall system performance with respect to the energy production, solar resource, and overall effect of system losses are as followed: final PV system yield, capacity utilization factor and performance ratio. Currently 44% of the 200 million Indian households do not have access to electricity and 75 million rural households still use kerosene and woods for lighting which implies a supplementary requisite of energy via grid interactive and decentralized sources. So the grid connected and the off grid PV system will play a vital role for the countrys energy need fulfillment. Many researchers calculated the performance of PV systems at different sites around the globe. Kymakis et.al conducted the performance analysis of a grid connected photovoltaics park of C.Rokas SA in Sitia, Island of crete. The photovoltaics parks has a peak power of 171.36 kWp. The park is suitably monitored for 1 year. The results showed that the average annual PV park energy output in 2007 is 1336.4kWh/kWp, the average annual performance ratio of the is 67.36%, and the average annual capacity factor is 15.26% [3]. Cucumo et.al conducted the performance analysis of a photovoltaic plant built near the Building energy research laboratory at university of Calabria, Italy.

The PV plant is subdivided into 3 strings of 10 modules. The plant has a peak power of 2.7kW and 9.1 kWh mean daily electric energy [4]. Ayompe et.al presented the measured performance of 1.72kW rooftop PV system in Dublin, Ireland. The claimed results showed that the annual total energy generated is 885.1kWh/kWp and the PV systems annual average daily yield is 2.4kWh/kWp/day [5]. Gong and Kulkarni [6] presented the design optimization of large scale rooftop PV system and it is installed on the rooftop of a Federal Office Building in Carbondale, IL, USA. The system performance is simulated with a through economic analysis and it is has been found that the annual output is 59,622 kWh and the simple payback time is 12.6 years. Al-Badi et.al [7] studied the energy production of PV power plant in 25 locations in Oman.

The study utilizes average daily global solar radiation and sunshine duration data of 25 locations in Oman to study the energy production of PV power plant of 5 MW. The results showed that the annual energy output of PV power plant varies between 9000 MWh at Marmul and 6200 MWh at Sur, while the mean value is 7700 MWh for all the 25 locations. India is located in the equatorial sun belt of the
earth, thereby receiving abundant radiant energy from the sun. The India Meteorological Department (IMD) maintains a nationwide network of radiation stations which measure solar radiation and also the daily duration of sunshine. In most parts of India, clear sunny weather is experienced from 250 to 330 days a year.

The annual global radiation varies from 1600 to 2200 kWh/sq.m. The equivalent energy potential is about 6,000 million GWh of energy per year [8]. While India receives solar radiation of 5 to 7 kWh/m2 for 300 to 330 days in a 2 year, power generation potential using solar PV technology is estimated to be around 20MW/sq.km and with that Gujarat state has a very good solar power potential which receives 5.5 to 6 kWh/sq.m/day with 330 sunny days/year as shown in fig 1. The highest annual global radiation is received in Rajasthan and northern Gujarat. In Rajasthan, large areas are sterile and sparsely populated, making these areas suitable location for large central power stations based on solar energy.

The site is central of Gujarat state located in the western part of the India. This solar plant spread over an area of five acre and has a very high sunshine throughout the year and a high ambient temperature with dry dusty wind during most of the period of the year [9]. The plant capacity size is 250kW, which consists of 62.5 kW of amorphous thin film and 188kW of polycrystalline modules of three different manufacturers make each of 62.5 kW capacity. From Delsolar there is two 62.5kW module connected to two ABB inverter. In this paper, the annual power generation with respect to solar insolation, performance ratio of the plant, capacity utilization factor of each PV module technology is evaluated and result obtained from it for duration of one year (2012) is presented. The output power of the plant is fed into local substation via 11kV.

II. PERFORMANCE OF 1MW SOLAR PV POWER PLANT

The installed PV modules are tilted at 22 degree, with 24 dc array junction box and a 24- dc disconnect switches connected to the three central Inverter make (ABB PVS) and one from XANTARANX, which converts the dc power generated by the modules to the ac power which is boosted up by transformers and connected to 11kV grid network available at the site. The PV module details are given in the table below. The layout of this solar Photovoltaic plant is shown in fig 3

Among the three PV module manufacturer make (62.5kW each) connected to four inverter (each 62.5kW) of equal capacity. Modules from Delsolar is performing little higher than REC and Nexpower as shown in fig 2. The peak solar power production during the July, August and September is not available due to technical fault in the monitoring system.

The monthly total power generation for the year 2012 was 408500 kWh and is shown in fig 4. From fig 5, it is observed that during first quarter of the year the difference between average module and ambient temperature remained almost
negligible and average irradiance was also high. During month of May, even though difference

![Fig. 3. Layout of 250kW PV power plant](image)

Fig. 3. Layout of 250kW PV power plant

in average ambient and PV module is high due to which there is variation in voltage of the modules but the high average irradiance manages to generate power equivalent to months of first quarter of the year. As the voltage increases or decreases from the max power point, the power from the array decreases as compared to the maximum power output possible.

![Fig. 4. Monthly power generation of 250kW solar plant](image)

Fig. 4. Monthly power generation of 250kW solar plant

![Fig. 5. Monthly average ambient and PV module temperature](image)

Fig. 5. Monthly average ambient and PV module temperature

The art of the state inverter deployed in the system and it senses when the maximum power conditioned output of the inverter is about to be exceed, and instructions are sent to the maximum power point tracker to decrease the amount of power produced. These inverters use the grid to synchronize their AC output power and to set the AC output voltage. Inverters are constructed so that if the AC voltage sensed by the inverter from the grid gets outside a specified range, the inverter will shut down immediately. These inverter shuts down for about 5 minutes if it senses the grid going down or DC power at its input is below the minimum requirement. The performance of the plant was monitored in terms of CUF and PR. In the following section these parameters are discussed in details.

Capacity Utilization Factor (CUF) is considered to be most appropriate parameter to evaluate the performance of solar power plants and it is defined as the ratio of the actual electricity output from the plant, to the maximum possible output during the year. It is very useful in comparing different technologies and is particularly important to an investor who would like to know which technology offers the maximum value [10]. It indicates on how well a solar PV plant is utilized. The solar power plant is wisely planned and implemented with art of the day technologies. The PV panels, power inverters, transformers and cables selected are of very high quality and long durability. But since there are several variables like atmospheric factors such as non uniform irradiation, high module and ambient temperature, prolonged cloud cover during monsoon and mist are the major hindrance in not contributing to the optimal final output from a plant, and these results in variation of CUF over a wide range. The CUF calculated

![Fig. 6. Capacity utilization factor of solar plant](image)

Fig. 6. Capacity utilization factor of solar plant

for modules make by different manufacturer is calculated and plotted graph is shown in fig 6.

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CUF = \frac{\text{Energy measured (KWh)}}{\text{Installed Capacity (KW) × 8760 (hr)}}
\]  

(1)

The average CUF of the plant is 18.28% which implies that the investment is being usefully utilized for 18.28% of the maximum possible limit which comparatively better than other solar plants installed in other parts of India. The
spikes of Nexpower amorphous thin film are due to the malfunction of the inverter of 62.5kW thin film arrays, which often went to sleep mode. In months of March and April which received optimum temperature and irradiance recorded the highest power production of the year as shown in figure 6. Because of losses due to PV module temperature, PR values are greater in the winter than in the summer and normally lies within the range of 0.6 to 0.8. If PV module soiling is seasonal, it may also impact differences in PR from summer to winter. Decreasing yearly values may indicate a permanent loss in performance [11]. Fig 7 shows variation of monthly average daily performance ratio and the PV systems capacity factor over the monitored period. The performance ratio varied between 77.20% and 84.04% and the annual average performance ratio was 80.71%. The monthly average daily capacity factor varied between 12.25% to 20.87% with an annual average of 18.43%.

III. CONCLUSION

250kWp grid connected PV system installed in central Gujarat, India. It was monitored whole of year 2012 and its performance parameters were evaluated on monthly. Site data during the monitored period showed that the maximum solar irradiance, ambient temperature and Photovoltaic module (PV) was 1067 W/m², 45°C and 70°C respectively.

The performance ratio varied between 80.52% in January and 77.44% in December and the annual average performance ratio was 80.71%. The monthly average daily capacity factor varied between 19.01% in January and 18.34% in December with an annual average of 18.43%. The performance data from such photovoltaic power plants provide us an opportunity to evaluate the potential for solar energy to provide the future energy needs of Gujarat and rest of India. The role of dust in power loss is negligible because modules are cleaned twice in fifteen days interval in rotation and it is one of the factor for improved capacity utilization factor and performance ratio.

REFERENCES