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Effect of Seasonal Variations on 100kWp Solar PV Power Plant Installed at BVRIT

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ABSTRACT: This paper mainly focuses on the performance of modules and seasonal effect variations at filed conditions and promoting green energy technologies in the campus. Before modules are installed at site location undergo the preliminary test at standard test conditions (STC –temperature as 25℃ and irradiance 1000W/m^2, 1.5 A.M) under laboratory conditions. The performance of PV modules varies according to variation of temperature and irradiance. The study performed on a 100 kWp Solar Photovoltaic (SPV) system setup on the rooftop of Aryabatta block of B.V.Raju Institute of Technology (BVRIT), Narsapur, Medak, India in November 2013. This work focuses on the evaluation of the performance of SPV systems using the popular grading systems, namely Capacity Utilization Factor (CUF) and Performance Ratio (PR). The parameter, Module Temperature (T_{mod}) which plays a key role in the energy output of the system. The degradation rate (%/°C) is also determined to study the performance of SPV system. The actual performance ratio is observed higher in monsoon and summer because of good radiation availability comparatively post monsoon and winter.

KEYWORDS: Performance Ratio;Efficiency;Capacity Utilization Factor; Degradation Rate;Module temperature.

I. INTRODUCTION

The performance of the solar photovoltaic system is dependent upon various site specific parameters such as latitude, altitude, air pollution and seasonal parameters such as temperature and irradiance. Hence a detailed performance analysis of SPV systems will provide valuable information for the prediction of performance of such systems.

Central government policies like the Jawaharlal Nehru National Solar Mission (NSM) and the Gujarat Solar Policy have provided preferential Feed-in-Tariffs (FiT) to incentivize the installation of over 1.5 GW in the past two years. The utility electricity sector in India had an installed capacity of 305.55 GW as of 31 August 2016 [1]. The NSM alone wants to add another 3.6 GW by 2017. The Government of India has asked states to prepare action plans with year-wise targets to introduce renewable energy technologies and install solar rooftop panels so that the states complement government's works to achieve 175 GW of renewable power by 2022 [2].

The influence of tilt angle of PV panel, building azimuth and shading effects on power generation of SPV modules were considered to optimize the performance of a Building Integrated Photovoltaic (BIPV) system located in Korea. The efficiency of this BIPV system during different months were compared. According to this study, the power generation is more influenced by the above factors in summer than in winter [3].

In parallel with the above mentioned findings, there are research activities focusing on maximizing of the existing SPV modules. In 2013, an experiment demonstrating the cooling of SPV modules with temperature controlled solar collector was conducted in Turkey. This mechanism, called a PVT System, uses the heat of the SPV module to cool the PV surface by employing a heat exchanger. The efficiency of the PV modules with cooling was found to be 13%, whereas for the modules without cooling, it was 10%. The PVT system lowers the module temperature by 10–20° C, which increases the electrical output of the PV system by 5–10% [4].

A 20 kWp Solar Photovoltaic (SPV) system was set up on the library roof-top in Indian Institute of Science, Bangalore, India. This Roof-top photovoltaic (RTPV) system partly powers the Central Office of IISc. The main objective of setting up this SPV system was to study the performance of solar plants under different seasons and climatic conditions of Bangalore [5].

The SPV modules are oriented towards the south with an inclination of 17°, which is latitude of the BVRIT, Narsapur. The SPV system covers an area of 1200 sq.m. which include array to array clearance of 1.6 m. Net PV area of the SPV system is 668 sq.m. The system consists of 400 poly crystalline silicon PV modules of 250Wp each. Each module consists of 60 cells and each cell has an area of 156 sq. mm. In order to achieve optimal system voltage 20 modules are connected in series to form an array of 5kWp and four such arrays are connected in parallel to form a string of 20kWp.Total five strings are connected in parallel to get 100 kWp output. Complete SPV plant installed on the rooftop of Aryabatta block with fixed tilt as shown in Fig.1.

The SPV system is protected by a lightning arrester and isolator switches to avoid voltage surges. An array junction box is provided where the output of each array is combined and fed as the input for the power conditioning unit (PCU) which also consisting Metal Oxide Varistor (MOV) and fuse protection.

Fig. 1. 100kWp grid connected solar photovoltaic plant installed at BVRIT.

A 20kWp wall mounted PCU of REFUsol (IP65 rated) is connected to each string. This PCU is installed near to each string to avoid DC wiring losses. This PCU is transformer less (TL) inverter, which uses computerized multistep process and electronic components to convert DC to high frequency AC, Back to DC , and ultimately to standard frequency AC with an efficiency of 98.2%.

A remote monitoring system called Refu-Log has been installed in laboratory of the SPV plant which records the real-time data and maintains the database of the previous data. The Plane of Array (POA), module temperature and power output data are being collected at an interval of 10 min.

II. PERFORMANCE ANALYSIS OF SPV SYSTEM

The performance analysis of an SPV system involves evaluation of various instantaneous parameters that are recorded by the data acquisition system incorporated in the SPV system. The parameters considered in this study are yield, incident solar radiation (Plane of Array - POA), module temperature and ambient temperature during Jan 2014 to Dec 2015.

The monthly yield, $Y_{net\ (m)}$ of the SPV system during the study period considered is shown Fig. 2. The highest $Y_{net\ (m)}$ of the study period was in April 2015 with 14219 kWh and least was in July 2014 with 9469 kWh, corresponding to summer and monsoon months. The highest and lowest daily yields of the SPV system in the period observed was 591kWh and 108 kWh, respectively, with corresponding specific yields, Sday of 5.91 kWh/kWp and 1.08 kWh/kWp, respectively. The net annual yield, $Y_{net\ (annual)}$ during this period was 152.85 MWh with an annual average daily specific yield, $S_{day\ (avg)}$ 4.19 of kWh/kWp. The total yield of the system up to 31st march, 2016 is 372.528 MWh and the annual average daily yield over the study period is 419 kWh.

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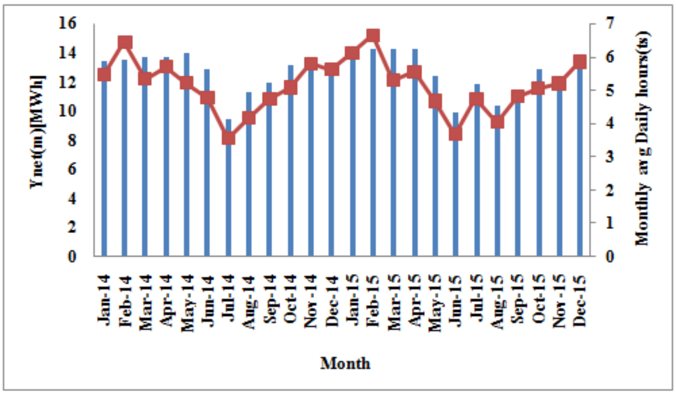

Fig. 2. Variation of monthly yield, $Y_{net\,(m)}$ corresponding to average daily sunshine period, t_s. The bars denote monthly yield and circles denote monthly average daily sunshine period.

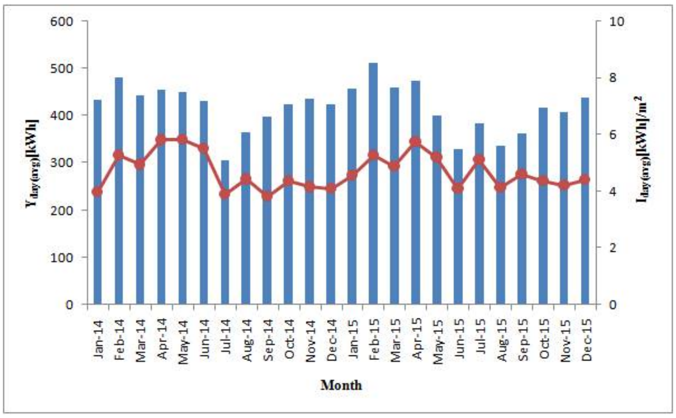

Fig. 3. Variation of monthly average daily yield, $Y_{day\,(avg)}$ corresponding to monthly average daily POA, $I_{day\,(avg)}$. The bars denote monthly average daily yield and circles denote monthly average daily POA.

Fig. 4.

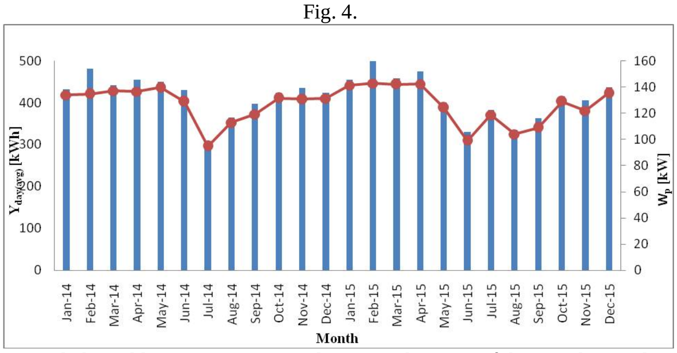

Fig. 5. Variation of monthly average daily yield, $Y_{day\,(avg)}$ corresponding to peak power of the month, W_p, during the period 2014–15. The bars represent monthly average daily generation and circles represent peak power of the month

The monthly average daily sunshine period (t_s), is also represented in Fig. 2. During the months July and August, the sunshine period was lower due to southwest monsoon over Indian subcontinent, which reflected on the Y_{day} of the PV system. Fig. 3 represents the variation in the monthly average Y_{day} corresponding to monthly average I_{day} during the period Jan 2014 to Dec 2015.

Fig. 4 represents the variation of Y_{day} with peak power, W_p. It is clear from Fig. 4 that the daily POA, I(day) was high during the summer months – February, March and April. The highest peak power of the study period attained was on February, 2015, rising up to 142.78 kW. The average peak power of this month was 416.89 kW. However, the instantaneous peak power rising up to 99% of installed capacity cannot be taken into account while judging the performance of the SPV system and hence could be misleading.

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A. CAPACITY UTILISATION FACTOR

The Capacity Utilization Factor (CUF) of the SPV system is the ratio of actual energy generated by the SPV system to the equivalent energy output from a similar system that works 24 hours a day [6]. CUF of the SPV system is calculated as shown below

$$CUF=\frac{\text{Annual yield}}{100kW\times 24h\times 365days}\times 100 \quad (1)$$

$$=\frac{153064}{100kW\times 24h\times 365days}\times 100 = 17.47\%$$

CUF of the SPV system is 16.5% and is well within the Range of average CUF of all the rooftop SPV system in India, which is 16–17% [7]. CUF is Dependent on the location. For example, the average CUF of SPV system located in Arizona, USA is 19% where as in Massachusetts, USA, it is 13–15% [8]. The CUF of the system depends on the irradiance on panel at the location of the SPV system and the cell efficiency of the SPV module.

B. PERFORMANCE RATIO

The performance ratio is one of the most important variables for evaluating the efficiency of a PV plant. Specifically, the performance ratio is the ratio of the actual and theoretically possible energy outputs. It is largely independent of the orientation of a PV plant and the incident solar irradiation on the PV plant. For this reason, the performance ratio can be used to compare PV plants supplying the grid at different locations all over the world.

However, 100% PR cannot be achieved in ideal case as unavoidable losses always arise with the operation of the PV system. High performance PV systems can however reach a performance ratio of up to 80% [9]. PR can be calculated using the following equation

$$PR=\frac{\text{Annual yield(in kWh)}}{\text{Calculated nominal energy yeild}} \quad (2)$$

Where

$$\text{Calculated nominal energy yeild} = \text{GHI (in kWh/m}^2) \times \text{Rated module efficiency} \times \text{Total PV area (in m}^2)$$

The ratio of the output power to the input power is defined as module efficiency, η and is given by,

$$\text{Efficiency}(\eta) = \frac{\text{Power output}}{\text{Power input}}\times 100 \quad (3)$$

$$= \frac{94920}{1.67\times 400\times 1022.512}\times 100$$

$$= 13.8\%$$

Where,

Power input = area of module × no. of modules × incident solar radiation

Power output = $V_{oc}\times I_{sc}\times FF$

V_{oc} = Open circuit voltage

I_{sc} = Short circuit current

FF = Fill Factor

For better understanding , the study period is divided into four seasons, namely December – February (winter), March – May (Summer), June – August (Monsoon), September – November (Post Monsoon).

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III. RESULTS AND DISCUSSION

The variation in the performance of the solar PV plant is discussed by considering the plane of irradiance at site, temperature of module which gives the performance ratio of the plant. The variation of performance ratio according to the monthly average daily yield is represented in fig 5. The corresponding change in performance ratio with temperature is shown in fig 6. The seasons considered here are summer (March-May), monsoon (June-August), post monsoon (September-November) and winter (December, January and February).

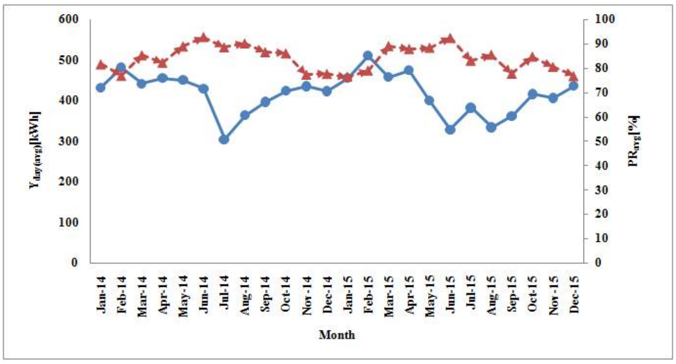

Fig. 6. Variation in monthly average daily performance ratio, PR_{avg} corresponding to monthly average daily yield, $Y_{day\ (avg)}$.

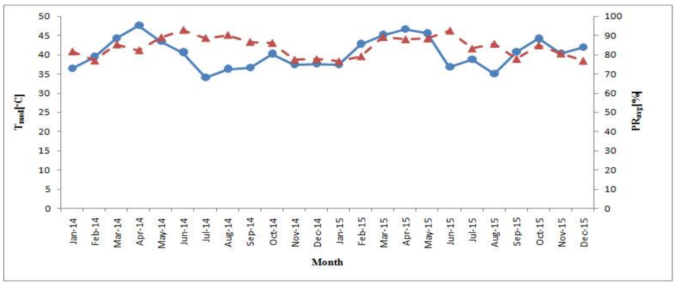

Fig. 7. Variation in monthly average daily performance ratio, PR_{avg} corresponding to monthly average module temperature, T_{mod}.

A. SUMMER

It is seen that the highest module efficiency,η_{max} during summer is 13.06% at T_{mod} of 60˚C, which is 90% of η_{rated}. For $T_{mod} > T_{mod\ (M)}$ (T_{mod} at η_{max}), η_i reduced by 0.0349% per degree rise in T_{mod}. In peak summer months, T_{mod} and T_{amb} are quite high, thus leading to low PR values. PR_{avg} value during summer months is 87.01%, which is significantly lower compared to monsoon.

B. MONSOON

T_{mod} during the monsoon period are in the range of 31℃ to 56℃, with η_{max} of 13.30% at Tmod (M) of 39℃, which is 91.73% of η_{rated}.

C. POST MONSOON

At Tmod(M) of 47˚C, η_{max} which is 13.90%, which is 95.84% of η_{rated}. The rate of rise in T_{mod} during this period is PR_{avg} value of this period is 82.21% which is lesser than monsoon and summer but greater than winter. In this season, random variation in PR_{day} is observed due to erratic variation in T_{amb} and T_{mod}.

D. Winter

The performance of the system is observed low during winter season. η_{max} during this period is 12.17% at $T_{mod\ (M)}$ of 38.27˚C, which is 83.96% of η_{rated}. PR_{avg} value during this period is 78.1% which is lower than monsoon, post-monsoon and summer.

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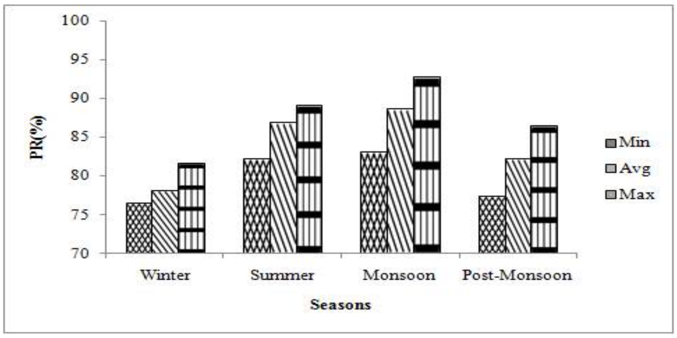

Fig. 8. Variation in seasonal average daily PR (PR_{avg}), seasonal maximum PR (PR_{max}) and seasonal minimum PR (PR_{min}) in different seasons. Diamonds box represent PR_{min}, diagonal lines represent PR_{avg} and vertical lines represent PR_{max}.

The variation of module efficiency and the plane of array irradiance in different seasons as a function of module temperature are shown in fig 8. During monsoon season highest efficiency and lowest degradation are recorded and at winter least efficiency with high degradation are observed.

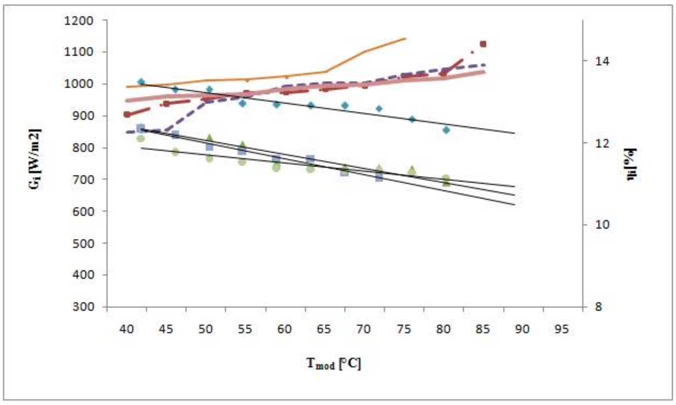

Fig. 9. Variation of module efficiency, ηi and POA, G_i (irradiance) in different seasons as a function of module temperature, T_{mod}. Triangles, rhombuses, squares and circles represent ηi during summer, monsoon, post-monsoon and winter, respectively. Bold lines denote Gi and normal lines denote trend line for ηi. Red lines, blue lines, orange lines and pink lines represent summer, monsoon, post-monsoon and winter, respectively.

IV. CONCLUSION

The performance of the 100 kWp SPV is studied and the variation of the daily and monthly yields during the study period is analysed. Performance evaluation of the SPV system is carried out using the popular grading systems - CUF and PR. The calculated CUF of the system is 17.47%, which lies within the range of CUF of well – performing solar plants located in INDIA. Average Performance Ratio (PR) of the system is 84.03%, which indicates that the performance of the SPV system is satisfactory. PR of the SPV system is correlated with the behavior of SPV modules in different seasons, with module temperature (T_{mod}) as the key factor of comparison.

The annual average $T_{mod\ (M)}$ is calculated as 40°C. The efficiency (η_i) is attained at different T_{mod} for the four seasons considered. It is observed that η in summer is comparatively low than monsoon and post monsoon. In summer, $T_{mod\ (M)}$ at 60°C, η_i is decreased by 0.060% per degree rise in T_{mod}. In monsoon $T_{mod\ (M)}$ at 39°C, η_i is decreased by 0.065% per degree rise in T_{mod}. In post- monsoon period, $T_{mod\ (M)}$ at 47°C, η_i is decreased by 0.091% per degree rise in T_{mod}. In winter $T_{mod\ (M)}$ at 38°C, η_i is decreased by 0.097% per degree rise in T_{mod}.

The PR average in monsoon and summer are higher than post monsoon and winter at installation location, because of good radiation availability comparatively post monsoon and winter. From this analysis it is concluded that the site-specific parameters influencing the performance ratio and module efficiency of SPV systems. Hence to get maximum benefit from roof-top grid-connected PV installations, it is essential to maintain the surface of the modules clean and low temperatures, especially during summers and similar weather conditions. Both temperature and irradiance shows a great impact on seasonal performance of solar PV system.

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