

Studies Of Energy Generation Performance Of The Spv Power Plant**U R Patel, G A Gadhiya**

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ABSTRACT

In this paper, the performance analysis of a 7.2 kWp SPV power plant installed at field of REE department, College of Agriculture Engineering and Technology, JAU, Junagadh (21.5°N, 70.1°E) is carried out and evaluated. The performance of the SPV power plant was analysed according to International Energy Agency (IEA). The plant has been in operation since September '17. The power plant is suitably monitored during 6 months *i.e.* September '17 to February '18. The final yield, reference yield and performance ratio are found to vary from 1.78 to 4.41 h/d, 2.73 to 6.27 h/d and 59 to 72 % respectively. The overall performance ratio, capacity factor and system efficiency during the experimental period was found as 68.00%, 15.69 % and 10.38 % respectively. The total energy generated during the experimental period was 4474.7 kWh. The performance of the system is compared with PV systems installed worldwide and found comparable.

1. INTRODUCTION

In India, per capita electricity consumption has been continuously increasing over the years. From 734 kWh in 2008-09, the per capita consumption has reached 1075 kWh in 2015-16, an increase of 46 % in 8 years, *i.e.* approximately 6 % every year.

Increasing demand and scarcity in conventional sources have triggered the scientist to pave way for the development of research in the field of renewable energy sources especially solar energy. India has tremendous scope of generating solar energy. The reason being the geographical location and it receives solar radiation almost throughout the year, which amounts to 3000 h of sunshine. This is equal to more than 5000 trillion kWh. Almost all parts of India receive 4-7 kWh of solar radiation per square meters.

Solar power in India is a growing industry. As of 30 April 2017, the country's solar grid had a cumulative capacity of 12.50 GW. India quadrupled its solar-generation capacity from 2,650 MW on 26 May 2014 to 12,289 MW on 31 March 2017. According to reports released by the Ministry of New and Renewable Energy (MNRE), India had added 3.010 GW in 2015-2016 and 5.525 GW in 2016-2017, the highest of any year (Pandya and Chaudhary, 2017).

Photovoltaic is the field of technology and research related to the devices which directly convert sunlight into electricity. These modules can provide you with a safe, reliable, maintenance-free and environmentally friendly source of power for a very long time. Photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity. It is anticipated that photovoltaic systems will experience an enormous increase in the decades to come. However, a successful integration of solar energy technologies into the existing energy structure depends also on a detailed knowledge of the solar resource.

Kymakis *et al.* (2009) worked on performance analysis of a grid connected photovoltaic park has a peak power of 171.36 kWp on the island of Crete. The final yield (Y_F) ranged from 1.96 to 5.07 h/d, and the performance ratio (PR) ranged from 58 to 73 %, giving an annual PR of 67.36 %.

Sharma and Chandel (2013) analysed 190 kWp solar photovoltaic power plant installed at Khatkar-Kalan, India. The final yield, reference yield and performance ratio, are found to vary from 1.45 to 2.84 kWh/kWp-day, 2.29 to 3.53 kWh/kWp-day and 55-83 % respectively. The annual average performance ratio, capacity factor and system efficiency are found to be 74 %, 9.27 % and 8.3 % respectively. The average annual measured energy yield of the plant is found to be 812.76 kWh/kWp and total estimated system losses was found as 31.7 %.

Bharathkumar and Byregowda (2014) assessed solar photovoltaic generation potential during November 2013 to May 2014 for Mandya district of Karnataka by using SCADA System. The photovoltaic power plant has a solar radiation 5.26 kWh/m²/day. The final yield (Y_F) ranged from 1.96 to 5.07 h/d and the performance ratio (PR) ranged from 58 to 73 %, giving an annual PR of 67.36 %.

The performance of 7.2 kW SPV power plant is carried out in this work with the following objectives.

- 1) To evaluate the energy generation performance of the SPV power plant according to International Energy Agency (IEA).

2. DESCRIPTION OF THE SPV POWER PLANT

The experimental SPV Power Plant structure was designed and installed earlier at the Dept. of Renewable Energy Engineering has been considered for this study. The total rating of SPV power plant was about 7.2 kW occupied over 153.88 m² area, *i.e.* 0.047 kW/m². The SPV power plant was designed in such way that shading effect on crop is minimized and land utilization is at par with conventional design of SPV Power Plant *i.e.* the amount of energy generated per unit land area remains same as that of conventional SPV power plant. The tilt angle of SPV panels is kept as an equal to latitude of the Junagadh region (*i.e.* 21.5°N) to get maximum solar radiation incident on the SPV panels.

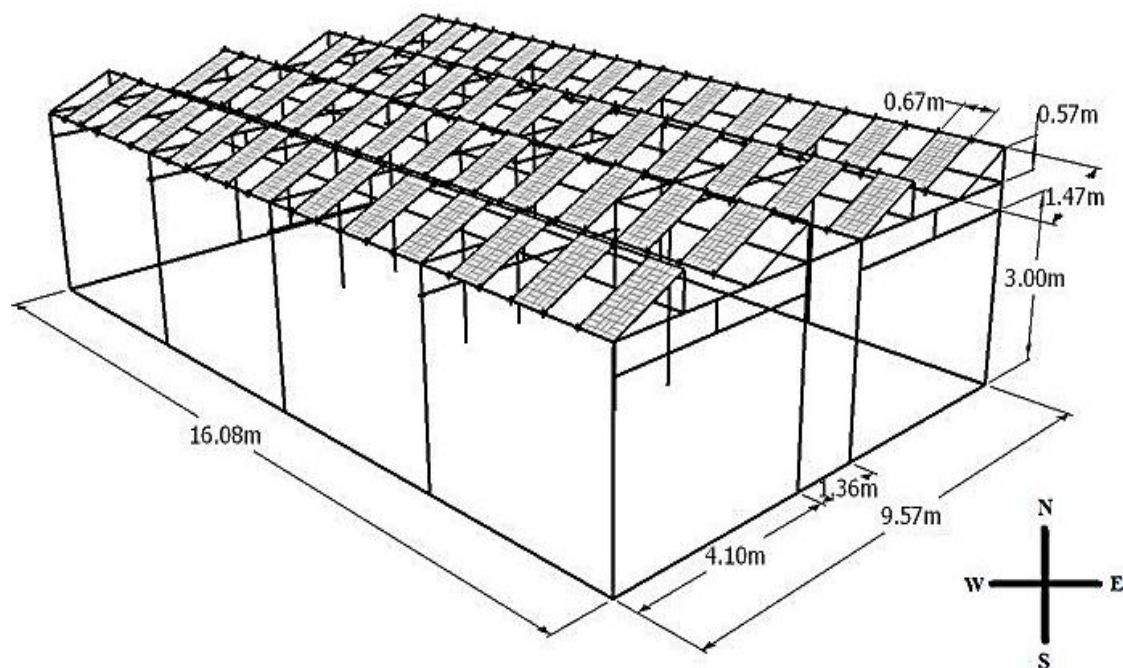


Fig.1: Isometric view of SPV Power Plant

Total 48 numbers of poly crystalline solar panels were fixed in four rows in a chess board type configuration *i.e.* 12 numbers of solar panels in each row with 150 W output

capacity of each panel were installed facing south direction. Polycrystalline panel ratings are open circuit voltage (V_{OC}) of 22.30 V and short circuit current (I_{SC}) of 8.82 A. It has a normal operating cell temperature of $48\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$. The distance between panels (panel to panel) is of 1.34 m. The lower end of panels was at 3.50 m height from the ground level as shown in Fig. 1. To have a better yield panels are cleaned twice in a month. The inverter power rating of 7.5 kVA was fixed to convert DC power into AC power. The output path of SPV power plant shown in Fig. 2.

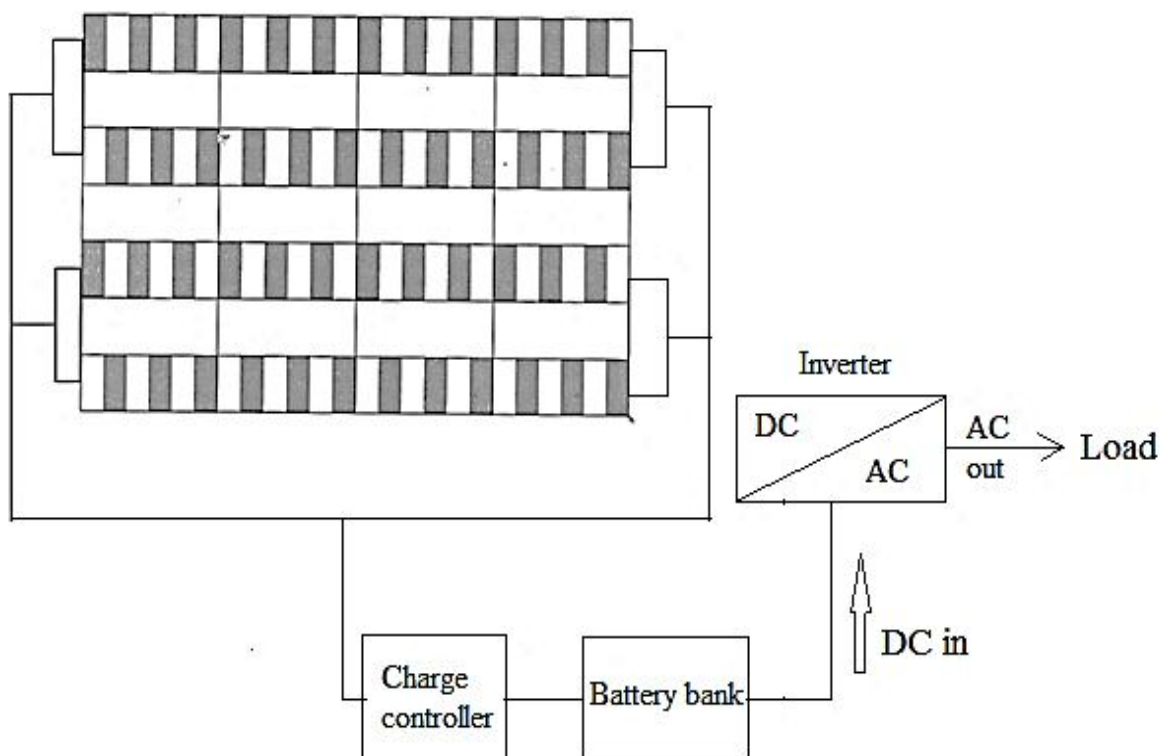


Fig. 2: Schematic diagram of SPV power plant output

3. METHODOLOGY FOR PERFORMANCE ANALYSIS OF THE PV SYSTEM

3.1 Performance Analysis of the SPV Power Plant

The following six performance parameters were considered for the performance analysis of SPV power plant. These performance parameters basically provide the overall system performance with respect to the energy production, solar resource, and overall effect of system losses.

- Total energy generated by the PV system (E_{AC})

- Final yield (Y_F)
- Reference yield (Y_R)
- Performance ratio (PR)
- Capacity factor (CF)
- System efficiency (η_{sys})

3.1.1 Total energy generated by the PV system

The daily energy output was obtained by measuring the energy generated by the PV system after the DC/AC inverter on every day. The total daily ($E_{AC,d}$) and monthly ($E_{AC,m}$) energy generated by the PV system is given as:

$$E_{(AC,d)} = \sum_{t=1}^{24} E_{(AC,t)}, \quad E_{(AC,m)} = \sum_{d=1}^n E_{(AC,d)} \dots (3.1)$$

Where, n = Number of days in the month,

$E_{(AC,t)}$ = Total hourly AC energy output (kW h),

$E_{(AC,d)}$ = Total daily AC energy output (kW h),

$E_{(AC,m)}$ = Total monthly AC energy output (kW h).

3.1.2 Final yield (Y_F)

Final yield (Y_F) is defined as the total AC energy generated by the PV system for a defined period (day, month or year) divided by the rated output power of the installed PV system and is given by:

$$Y_F = \frac{E_{AC}}{P_{PV,Rated}} \dots (3.2)$$

Where, Y_F = Final yield (kW h/kWp)

E_{AC} = AC energy output (kW h),

$P_{PV,Rated}$ = Rated output power (kWp).

3.1.3 Reference yield (Y_R)

Reference yield is defined as the ratio of total in plane solar insolation H_t (kWh/m²) to the reference irradiance G (1 kW/m²). This parameter represents equal number of hours at the reference irradiance and is given by:

$$Y_R = \frac{H_t}{G} \quad \dots (3.3)$$

Where, Y_R = Reference yield(kW h/kWp),

H_t = Total in-plane solar insolation (kW h/m²),

G = Reference irradiance (kW/m²).

3.1.4 Performance ratio (PR)

Performance ratio is defined as the ratio of the final yield (Y_F) to the reference yield (Y_R). It represents the total losses in the system when converting DC rating to AC output. Therefore, the PR can be expressed as:

$$PR (\%) = \frac{Y_F}{Y_R} \times 100 \quad \dots (3.4)$$

3.1.5 Capacity factor (CF)

The capacity factor (CF) is defined as the ratio of the actual annual energy output ($E_{AC,a}$) of the PV system to the amount of energy the PV system would generate, if it operates at full rated power ($P_{PV, rated}$) for 24 h per day for year and is given as:

$$CF = \frac{E_{AC,a}}{P_{PV,a} \times 8760} \times 100 \quad \dots (3.5)$$

Where, CF = Capacity factor (%)

$E_{(AC,a)}$ = Total annual AC energy output (kW h),

$P_{PV,a}$ = Total amount of energy generated at full rated power (kW h)

3.1.6 System efficiency

Monthly system efficiency can be calculated by formula given below. The module size is 1480 mm × 670 mm and there are total 48 panels in agrivoltaic structure. So, A_m is taken as 47.60 m² for 48 panels.

$$\eta_{sys,m} = \frac{E_{AC,m}}{H_t \times A_m} \times 100 \quad \dots (3.6)$$

Where, $\eta_{sys,m}$ = Monthly system efficiency (%),

A_m = Total module area (m²).

4. RESULTS AND DISCUSSION**4.1 Monthly total energy generated from SPV power plant**

Solar irradiance absorbed by solar modules is converted touseful power. The total energy generated was measured in kWh. monthly energy output calculated during the

experimental period is shown in Fig 3. The total energy generated during the experimental period was 4474.7 kWh.

4.2 Final yield (Y_F) of SPV power plant for different months

The final yield of experimental duration was calculated as per section 3.1.2. The maximum final yield was found as 4.41 h/d during February month and during entire period of experiment the final yield was found as 3.71h/d. The findings obtained for final yield were in close agreement with those of Kymakiset *al.* (2009), Bharathkumar and Byregowda (2014) and Gautamet *al.* (2017).

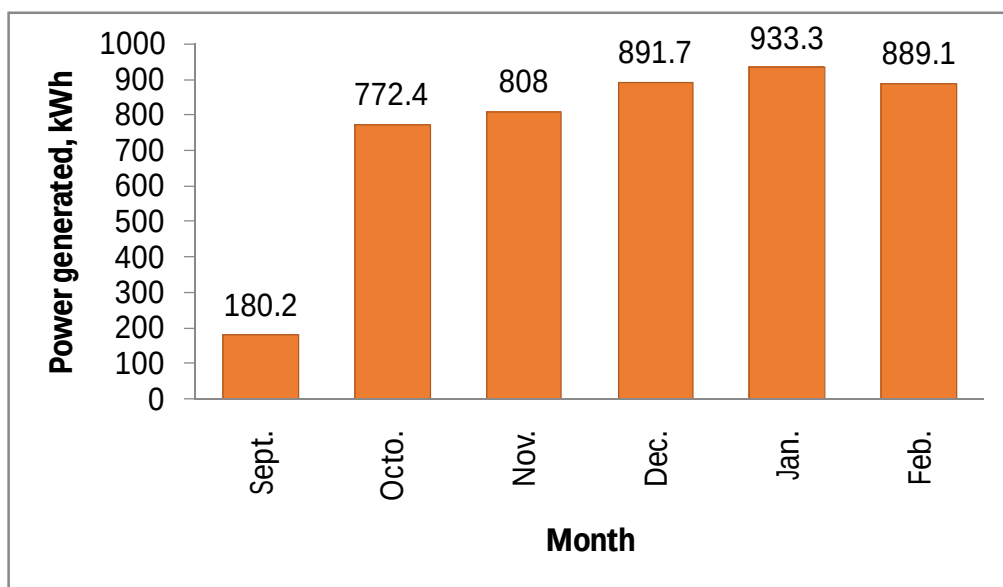


Fig. 3: Monthly energy generation for different months from SPV power plant

4.3 Reference yield (Y_R) of SPV power plant for different months

The reference yield represents the number of hours per day during which the solar radiation would need to be at reference irradiance levels in order to contribute the same incident energy as was monitored. The reference yield of experimental duration was calculated as per section 3.1.3. The maximum reference yield was found as 6.27 h/d during February month and during entire period of experiment the reference yield was found as 5.49h/d.

The calculated values of final yield and reference yield both are presented as bar graph form in Fig. 4.

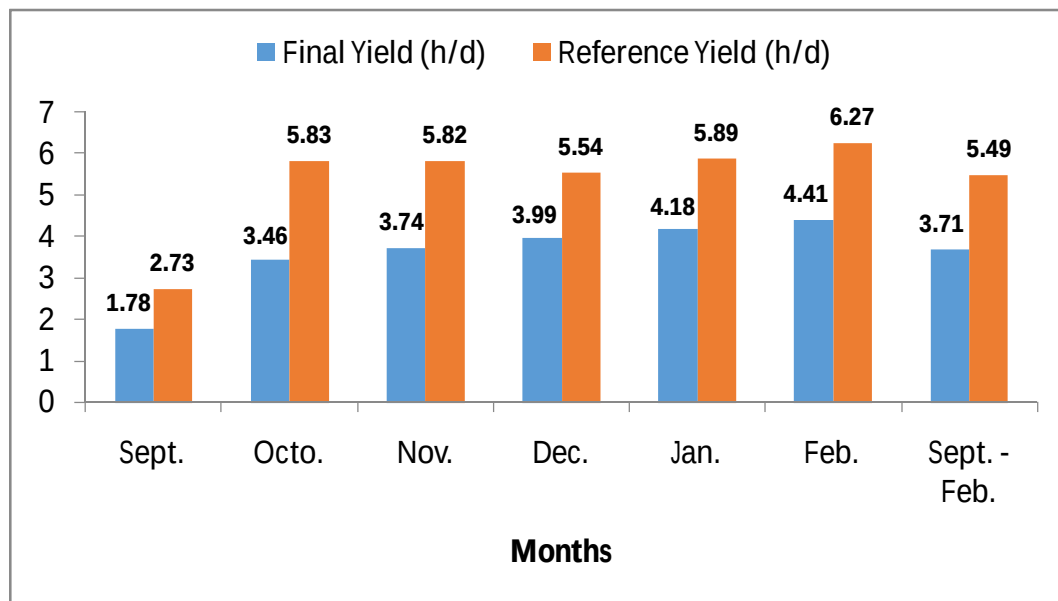


Fig. 4: Final yield and reference yield for different months

4.4 Performance ratio (PR) of SPV power plant for different months

It represents the total losses in the system when converting DC rating to AC output. Normally PR varies from 0.6 to 0.8 depending on the location, solar irradiance and climatic conditions. The calculated Performance ratio for experimental duration) as per section 3.1.4 and shown in Fig. 5. The overall performance ratio during the experimental period was obtained as 0.68. The values of performance ratio obtained in this study were in close agreement with those of Kymakiset *al.* (2009), Sharma and Chandel (2013) and Bharathkumar and Byregowda (2014).

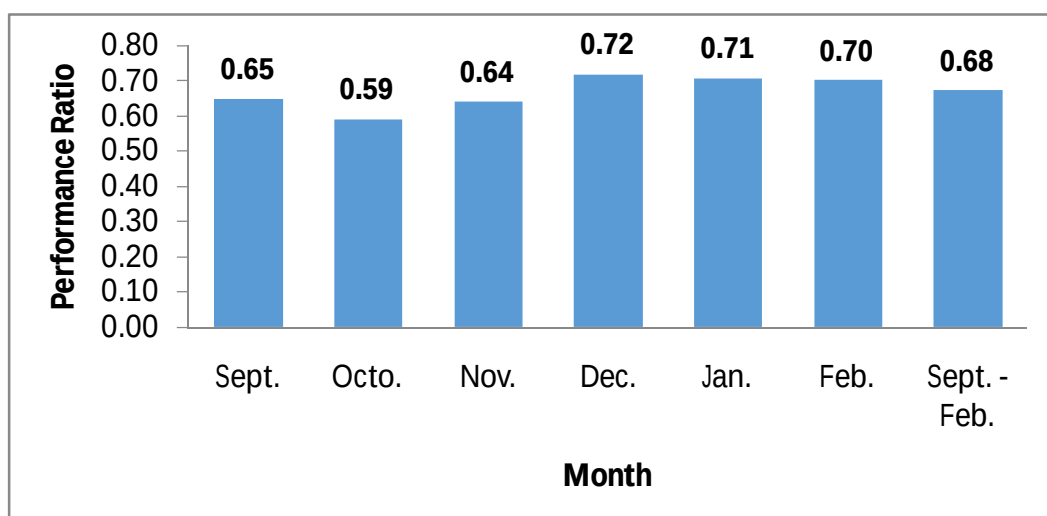


Fig. 5: Performance ratio for different months**4.5 Capacity factor (CF) of SPV power plant for different months**

For calculation of capacity factor (CF), we have considered only experimental duration. So in the formula of the capacity factor 365 is replaced with no. of days in each month. The calculated values of capacity factor as per section 3.1.5 for each month are tabulated in Table 1. The highest capacity factor was found as 18.38 % during February month and overall capacity factor during the experimental period was observed as 15.69 %.

Table 1: Capacity factor for different months of study period

Months	Capacity Factor (%)
September	7.44
October	14.41
November	15.58
December	16.65
January	17.42
February	18.38
Overall	15.69

4.6 System efficiency during experimental duration

Monthly system efficiency during study period was calculated as per section 3.1.6 and shown in Fig.6. The system efficiency during the experimental period was found as 10.38 %. The obtained values of system efficiency in this study were in close agreement with those of Sharma and Chandel (2013).

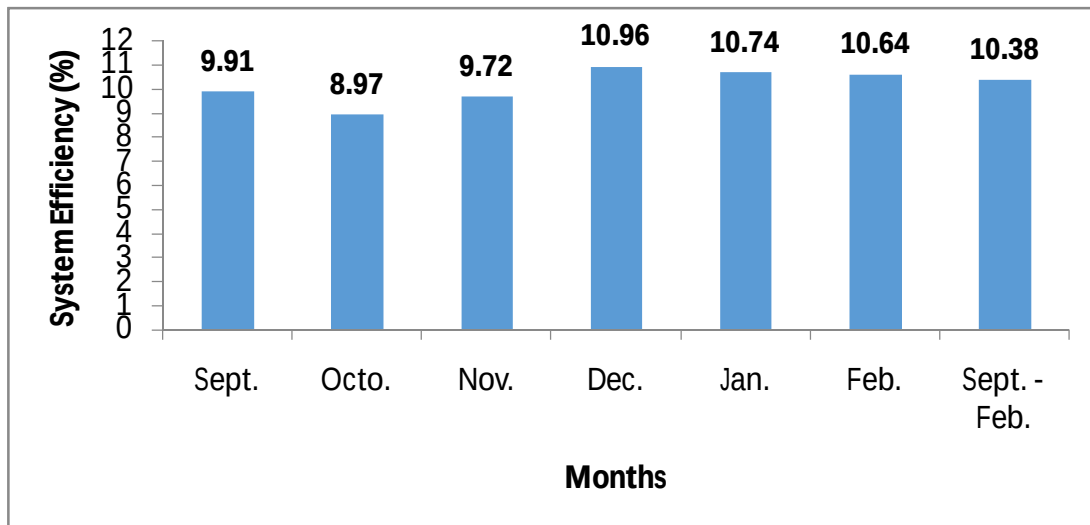


Fig. 6: System efficiency for different months

5. CONCLUSION

The experimental SPV Power Plant structure of 7.2 kW occupied over 153.88 m² area was designed and installed earlier at the Dept. of Renewable Energy Engineering, JAU, Junagadh was evaluated during the 11th September '17 to 28th February'18. The following conclusions are drawn from the study.

- 1) Total energy output during the experimental period was obtained as 4474.7 kWh and daily energy output was observed higher in February month. The final yield and reference yield were found highest in February month whereas in September month it was found minimum among all months.
- 2) During winter months *i.e.* December, January and February performance ratio was found higher than previous three months. The overall performance ratio during the experimental period was observed as 0.68. The capacity factor was found highest in February month whereas for September month it was found minimum among all months.
- 3) During winter months *i.e.* December, January and February system efficiency was found higher than previous three months. The system efficiency during the experimental period *i.e.* September '17 to February '18 was found as 10.38 %.

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