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Studies on The Performance Evaluation of Agrivoltaic Insect Net House System

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ABSTRACT

Experiment on the Performance evolution of the Agrivoltaic Net Houses were conducted during December'18 to March'19 at the Experimental field of REE department, College of Agriculture Engineering and Technology, JAU, Junagadh (21.5˚N, 70.1˚E). The experimental Agrivoltaic structure having 24 solar panels each of 150 W capacity was designed and installed with total rating of SPV power plant was about 3.6 kW occupied over 76.94 m^2 area. The final yield and reference yield were found highest in February and March months respectively, whereas in December month it was found minimum among all months. The overall performance ratio during the experimental period was observed as 0.78. The capacity factor was found highest in March month whereas for December month it was found minimum among all months. The overall system efficiency during the experimental period was found as 8.49 %.

INTRODUCTION

In India, the main income in rural area is from agriculture, but only food production is not sufficient for the development of rural people. The next need after food is the energy to establish or run rural level industries, improved agriculture operations, processing of food etc. There are number of challenges in meeting the solar power capacity targets. First is the requirement of land. Solar energy installations are directly link to land and to install 1.0 MW solar PV power plant about 20,000 m^2 (about 5 acres or 2 hectare) is required.

Agriculture is field where solar power can prove to be largely inclusive. Agrivoltaic system can help irrigate farmer's fields, build cold storages in rural areas, and

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augment farmer’s incomes by feeding the surplus power generated into the grid. Harvesting solar power on farmer’s fields can thus act as harvesting another crop, and can provide a sort of insurance even when rains fail and ensures maximum utilization of land. Rural India faces sparse and sporadic supply of power even where there are grid lines. In many far North and North-East regions, the rocky and mountainous terrains pose a hurdle for laying grid and transmission lines. Solar power can help to bridge this gap in power supply and can be a game changer.

In view of the future requirement of energy and food production, Agrivoltaic system (AVS) has been proposed as a mixed system associating solar panels and crop at the same time on the same land area. The potential role of AVS has been discussed in enhancing farmer’s income and in improving livelihood.

The climate of Saurashtra region in Gujarat state is hot during the month of March, sometimes temperature touches 45 °C. Therefore, it is required to build conditions favorable for the crop, which is possible by using fan-pad and foggers system in greenhouses. Whereas operational cost of greenhouse is very high which will not affordable by most of the farmers. Protected structures with opening along the roof and/or in side walls have been effective in improving ventilation, however due to high insect and pest problems there is at most need to grow crop under protected structure. so, we have to build a structure which full fills the above problems and which is economically physible to the farmers.

REVIEW OF LITERATURE

Natsheh and Albarbar (2012) carried out the study of 28.8 kW grid-connected solar power plant located in central Manchester. The model has been implemented using the MATLAB/SIMULINK software package. It was found that the system has a good performance, since the residual difference between the model prediction and the actual power is less than 1.7 kW and degradation will be indicated when the residual difference is above 1.9 kW; due to snow cover, shading, or any other reasons that may reduce the efficiency of the PV panels.

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Sharma and Chandel (2013) carried out the analysis of 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. The total estimated system losses due to irradiance, temperature, module quality, array mismatch, ohmic wiring and inverter, are found to be 31.7%.

Bharathkumar and Byregowda (2014) assessed solar photovoltaic generation potential during November 2013 to May 2014 for Mandya district of Karnatakaby using SCADA System. The photovoltaic power plant has asolar radiation 5.26 kWh/m^2/day. The power plant was monitored for 7 Months, and the performance ratio and the various power losses (temperature, soiling, internal, network, power electronics, grid availability and interconnection) were calculated. The final yield (YF) 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%.

Shetty and Kulkarni (2014) estimated cost analysis for 500kW grid connected solar photovoltaic plant at Dharwad area in Karnataka, India. The system cost was around ▪ 6,06,00,000 at 30% subsidy and difference in bill amount annually after connection of SPV generation was found to be ▪ 75,89,307. Therefore, payback period comes out to be 8 years.

Sharma *et al.* (2016) studied economic feasibility of grid connected 40 kW SPV system based on last 14 years average value of global horizontal insolation (GHI) value. Payback period was calculated on the basis of benefits incurred by Delhi Technology University (DTU) at ▪ 8.80/unit of electricity and amount incurred by DTU for installing the SPV system. 61920 units were generated annually and the payback period comes out to be 5.08 years. As plant life is around 25 years, next 20 years energy output will be free of cost for DTU.

Gautam*et al.* (2017) evaluated performance of 5 MWp grid connected solar PV power plant using IEC 61724.The field data such as solar irradiance, wind, ambient

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temperature, module temperature, dc and ac power output are recorded at a regular interval using SCADA software. Additionally, various losses, efficiencies and capacity utilization factor are obtained. Final yield of the plant showed a variation from 3.30 h/d to 5.05 h/d with an annual value of 3.72 h/d. Annual Performance ratio for the year 2016 is 73.02%. Plants variation in output with respect to PV-syst simulated results is compared and showed a variation in performance ratio of 6.95%.

Kazem*et al.* (2017) performed a design and techno-economic evaluation of a Grid-connected PV system in Adam city, Oman with a size of 1 MW. The numerical simulation was made using MATLAB developed code. The assessment results show that the annual yield factor of the system is 1875.1 kWh/kWp. Meanwhile, the capacity factor of the proposed system is 21.7%. The optimum array size is 250 Wp with around 4000 modules to satisfy the 1 MW with optimum inverter size is about 800 kW. The cost of energy found for the plant is around 0.2258 USD/kW h and payback period of 10 years.

MATERIALS AND METHODS

- **Details of Agrivoltaic Net House**

The experimental Agrivoltaic Net Houses occupied 3.6 kW over 76.94 m^2 area, i.e. 0.047 kW/m^2. 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. The tilt angle of SPV panels was kept as an equal to latitude of the Junagadh region to get maximum solar radiation. The details of Agrivoltaic Net House and the structure Details specified in Table 1.1.and 1.2 respectively.

Table 1.1: Specifications of Agrivoltaic Net House

Latitude	21.51 ˚N
Longitude	70.47 ˚E
Elevation (From sea level)	107 m
Type of PV Module	Poly crystalline
Capacity	3.6 kW
Capacity of Each Module	150 W
No. of solar panels	24 nos.
Inverters Capacity	4 kVA
Type of configuration	Chess Board type

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A naturally ventilated net house, 8.04 m in length, 4.10 m in breadth and having 3 m height was constructed at the department of Renewable Energy Engineering, CAET, JAU, Junagadh. As shown in Fig. 1.1 white insect net of 40 meshes (span 2.5 m) was used to make a net house by simply tie up ends with the poles of power plant. For making the doors of Agrivoltaic net house Velcro was used for reducing the cost of structure.

Total 24 numbers of panels were fixed in four rows keeping 1.36 m gap between two rows. In steel framed structure a path way of 1.36 m in the centre of the plant is provided for the easy supervision and observation on the cultivated crop under the SPV power plant. The specifications of the solar panels are in Table 1.3.

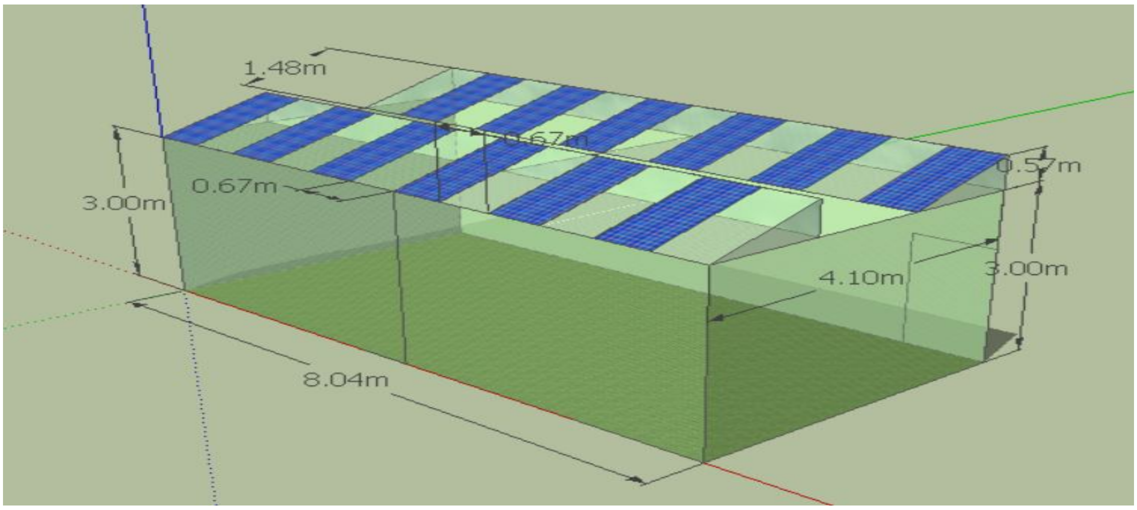

Fig. 1.1 Isometric View of Agrivoltaic Net House

Plate 1.1 Photographic View of Agrivoltaic Net House

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Table 1.2: Specifications of materials used for Agrivoltaic Net House

Component	Material Specification (All dimensions are in mm)	In numbers	Length (m)	Quantity (m)
Columns	Square CRC pipe 100 × 100 × 6	12	3.00	60.00
Main frame	Square CRC pipe 75 × 75 × 5	01	51.30	51.30
Beam	Square CRC pipe 75 × 75 × 5	05	8.20	41.00
Purlin	Square CRC pipe 50 × 25 × 4	64	1.48	142.08

Table 1.3: Specifications of solar panel

PV module	Specifications
Type of material	Poly crystalline
Make	Universal Solar Group
Model	UPS 150
Maximum power P_{max}(W)	150
Open circuited voltage V_{oc}(V)	22.3
Short circuited current I_{sc} (A)	8.82
Maximum power voltage V_{max} (V)	18.3
Maximum power current (I_{max}) (A)	8.2
No. of cells in a module	(4 × 9) 36 nos.
Module dimensions (mm)	1480 × 670 × 35

- **Performance Analysis of the SPV Power Plant**

The performance of the SPV power plant was analysed according to International Energy Agency (IEA). The following performance parameters were considered for the performance analysis of Agrivoltaic insect Net House. These performance parameters provide the overall system performance with respect to the energy production, solar resource, and overall effect of system losses.

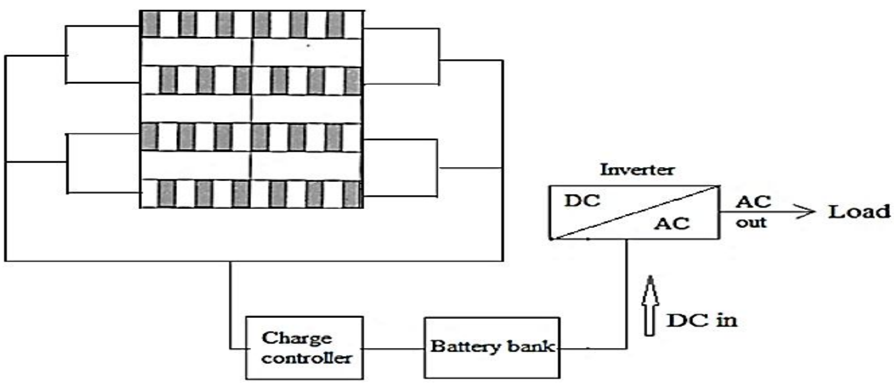

Fig. 1.2: Schematic Diagram of SPV power plant output

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- **Total energy generated by the PV system**

The total daily ($E_{AC,d}$) and monthly ($E_{AC,m}$) energy generated by the PV system is given by:

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

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).

The instantaneous energy output will be obtained by measuring the energy generated by the PV system after the DC/AC inverter on 30 min. intervals.

- **Final yield (Y_F)**

Final yield 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:

$$Y_F = \frac{E_{AC}}{P_{PV,Rated}} \tag{3.2}$$

Where,

Y_F = Final yield (kW h/kWp)

E_{AC} = AC energy output (kWh),

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

- **Reference yield (Y_R)**

Reference yield defined as the ratio of total in plane solar insolation H_t (kWh/m^2) to the reference irradiance G (1 kW/m^2). This parameter represents equal number of hours at the reference irradiance and given by:

$$Y_R = \frac{H_t(\mathrm{kWh/m^2})}{G(\mathrm{kW/m^2})} \tag{3.3}$$

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Where,

Y_R = Reference yield (kW h/kWp),

H_t= Total in-plane solar insolation (kW h/m^2),

G = Reference irradiance (kW/m^2).

- **Performance ratio (PR)**

Performance ratio 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:

$$PR\ (\%) = \frac{Y_F}{Y_R} \text{ x } 100 \qquad (3.4)$$

Where,

Y_F = final yield (kW h/kWp),

Y_R = Reference yield (kW h/kWp).

- **Capacity factor (CF)**

The capacity factor (CF) 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 (PV, rated) for 24 h per day for year and is given as:

$$CF = \frac{E_{AC,a}}{P_{PV,a} \times 8760} \text{x } 100 \qquad (3.5)$$

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)

- **System efficiency**

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Monthly system efficiency can be calculated by formula given below. The module size is 1480 mm × 670 mm and there are total 24 panels in agrivoltaic structure. So, A_m is taken as 23.79 m^2 for 24 panels.

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

Where,

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

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

H_t= Total in-plane solar insolation (kW h/m^2),

A_m= Total area (m^2).

Performance parameters described above were evaluated from the measured power generation data of the installed SPV power plant during the total experimental period.

- **Cost Analysis (Sahay, 2004)**
- **Assumptions:**
  - Life of the AV structure is taken as 25 years
  - Rate of interest taken as 9 % on capital investment
  - Percentage for maintenance cost is taken as 2 % for SPV power plant.
  - 30 % subsidy considered on capital investment for SPV power plant.
- **Payback period**

The payback period is the length of time from the beginning of the project until the net value of incremental production reaches the total amount of the capital investment. The payback period of the agrivoltaic net house system was calculated from ratio of total cost of structure to the profitable electricity cum crop production from it.

$$\text{Payback period (yr)} = \frac{\text{Capital Investment ( )}}{\text{Net Profit (/yr)}} \quad (3.10)$$

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RESULTS AND DISCUSSION

- **Performance Analysis of the SPV Power Plant**
- **Daily total energy generated from AV Insect Net house structure**

The total energy generated was measured in kWh. Monthly energy output calculated during the experimental period is presented in Fig.1.4

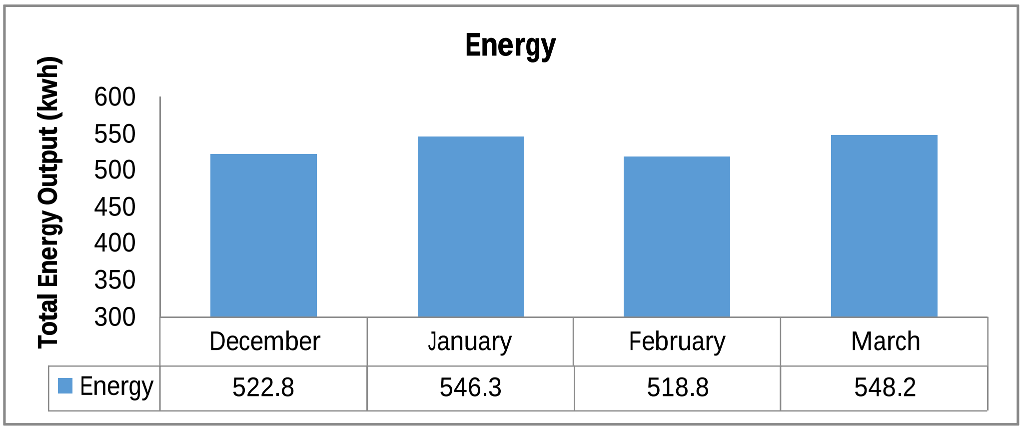

Fig. 1.4 : Monthly energy generation for different months from AV structure

The total daily ($E_{AC,d}$) and monthly ($E_{AC,m}$) energy generated by the agrivoltaic structure was calculated as per describe in methodology.It can be seen that from agrivoltaic structure capacity of 3.6 kW, the total energy output from 2ndDecember to 31stDecember which was found to be 522.8 kWh. Whereas for January, February and March (till 25th of March) month it was found as 546.3 kWh, 518.8 kWh and 548.2 kWh respectively. The total energy generated during the experimental period was 2136.1 kWh.

- **Final yield (Y_F) of AV insect net house for different months**

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. The Experimental duration was of 114 days and the agrivoltaic structure has capacity of 3.6 kW. The final yield for December month was calculated as 4.5 h/d, for the month of January, February and March month the values of final yield were 4.89 h/d, 5.14 h/d and 4.91 h/d respectively. The final yield during entire period of experiment was found as 4.86 h/d.

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- **Reference yield (Y_R) of AV insect net house for different months**

The reference yield Y_r, can be calculated by dividing total daily in plane irradiation by the reference in plane irradiation. The total daily in plane irradiation is in units of (kWh/m^2/day) and reference irradiation is equal to 1.0 (kW/m^2). Thus the reference yield is in [kWh/ (kW-day)] units or in hours per day. This 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. Here, the whole months into consideration. For different months of the study period, monthly average in plane solar irradiation and corresponding reference yield were observed as given in Table 1.4.

Table 1.4: Final yield, Irradiation and Reference yield for different months

Months	Final Yield (h/d)	Irradiation(kW/m^2/day)	Reference Yield (h/d)
December	4.50	5.74	5.74
January	4.89	6.10	6.10
February	5.14	6.48	6.48
March	4.91	6.61	6.61
Overall	**4.86**	**6.23**	**6.23**

The reference yield for December month was computed as 5.73 h/d, whereas for the month of January, February and March month the values of reference yield were 6.10 h/d, 6.48 h/d and 6.61 h/d respectively. The reference yield of experimental duration was 6.23 h/d.The calculated values of final yield and reference yield both are presented as bar graph form in fig. 1.5.

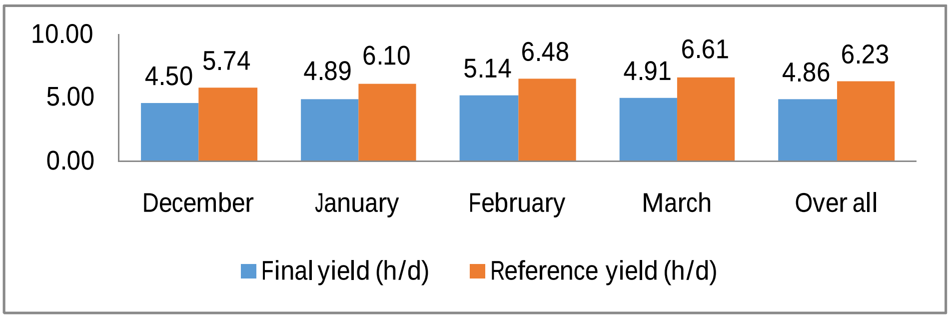

Fig. 1.5: Final yield and reference yield for different months

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- **Performance ratio (PR) of AV structure for different months**

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. 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 (December'18 to March'19) as per methodology was tabulated in table 1.5 and shown in fig. 1.6.

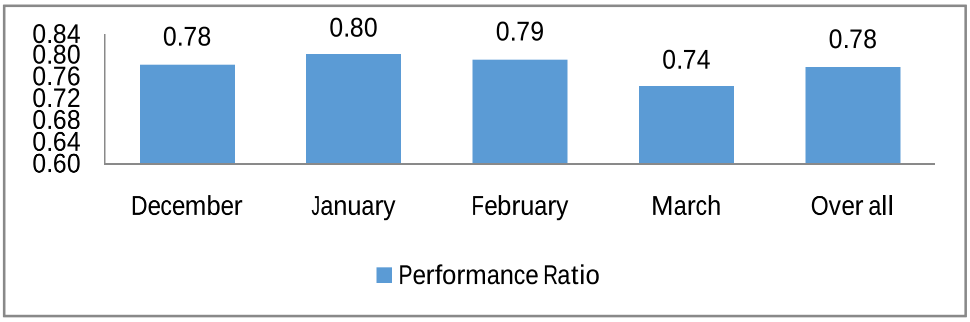

Fig. 1.6: Performance ratio for different months

The performance ratio for the month of December, 2018 was observed as 0.78whereas for the month of January, February and March it was foundas 0.80, 0.79 and 0.74 respectively. The overall performance ratio during the experimental period *i.e.*December'18 to March'19 was observed as 0.78.

- **Capacity factor (CF) of AVI Net House structure for different months**

For calculation of capacity factor (CF), we have considered only experimental duration (from December'18 to March'19). So in the formula of the capacity factor 365 is replaced with no. of days in each month. The capacity factor for the month of December was observed 19.42 % whereas for the month of January, Februaryand March it was foundas 21.08 %, 20.02 % and 21.15 % respectively. The overall capacity factorduring the experimental period *i.e.* December'18 to March'19 was observed as 20.41 %.

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Table 1.5 Performance ratio and Capacity factor for different months

Months	Performance ratio	Capacity Factor (%)
December	0.78	19.42
January	0.80	21.08
February	0.79	20.02
March	0.74	21.15
Overall	0.78	20.41

- **System efficiency during experimental duration**

Monthly system efficiency during study period was calculated as per methodology and shown in fig 1.7.

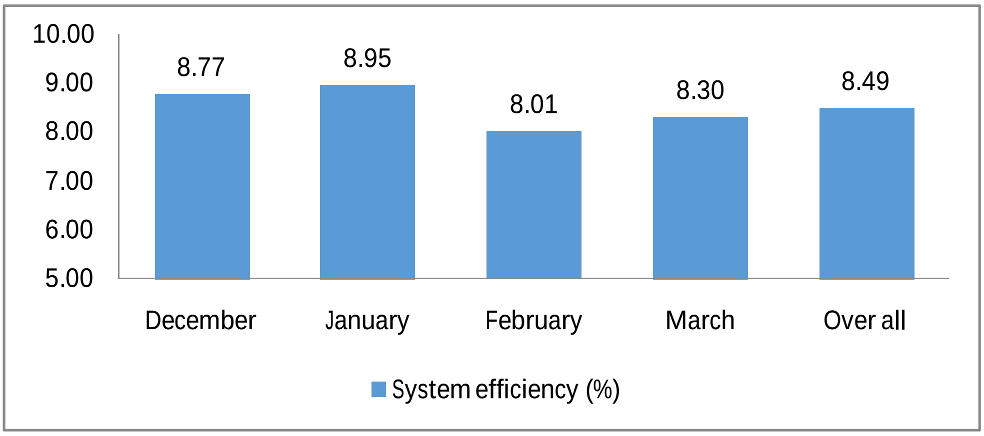

Fig. 1.7: System efficiency for different months

The system efficiency for the month of December was found 8.77 % whereas for the month of January, February and March it was foundas8.95 %, 8.01 % and 8.30 % respectively. The system efficiency duringthe experimental period *i.e.* December'18 to March'19 was found as 8.49 %.

- **Cost Analysis**
- **Capital investment made by farmer without and with subsidy:**

The fixed cost of the AV structureand insect net house was calculated as per Methodology. The details of capital investment for chess board type AV structure without and with subsidy of 76.94 m^2 area is presented in Table 1.6. Accordingly various costs without subsidy *i.e.*structure components,solar panels, installation and inverter of 4 kVA

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with wiring was considered as ▪ 75,000, ▪ 1,23,360, ▪ 25,000 and ▪ 18,000 respectively. Whereas it was ▪ 52,500, ▪ 86,352, ▪ 25,000 and ▪ 12,600 respectivelywith subsidy.

Table 1.6 Cost of Different materials used in Agrivoltaic Insect Net House

Sr. No.	Components of SPV	Without subsidy	With 30% subsidy
(1)	**Structure components**	▪ 75,000	▪ 52,500
(2)	**Solar panels**	▪ 1,23,360	▪ 86,352
(3)	**Installation**	▪ 25,000	▪ 25,000
(4)	**Inverter of 4kVA with wiring**	▪ 18,000	▪ 12,600
(5)	**Insect Net**	▪ 2880	▪ 2016
(6)	**Total cost**	**▪ 2,42,240**	**▪ 1,78,468**

- **Payback period**

Total energy generation is 6836.45 KWh/yr(Considering Rs 5 /KWh for own use) generate an income of ▪ 34,182.25/yr.so the payback period of the Agrivoltaic Insect Net House is 7.08 yr without consideration of subsidy and 5.22 yr with considerartion of subsidy.

CONCLUSIONS

1. Total energy output during the experimental period was obtained as 2136.1 kWh and daily energy output was observed higher in March month. The final yield and reference yield were found highest in February and March months respectively, whereas in December month it was found minimum among all months.
2. The overall performance ratio during the experimental period was observed as 0.78.The capacity factor was found highest in March month whereas for December month it was found minimum among all months. The overall system efficiency during the experimental periodwas found as 8.49 %.
3. Total energy generation is 6836.45 KWh/yr (Considering Rs 5 /KWh for own use) generate an income of ▪ 34,182.25/yr.so the payback period of the Agrivoltaic Insect Net House is 7.08 yr without consideration of subsidy and 5.22 yr with considerartion of subsidy.

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