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Case Study on Techno Economic Analysis of Solar Roof Top Power Plant in India

G. A. Gadhiya [a*], U. R. Patel [a] and P. M. Chauhan [a]

[a] Department of Renewable Energy Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh-362001, Gujarat, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The viability of installing a rooftop solar power plant is investigated in this research. Roof top renewable energy has recently become popular for residential buildings. In general, the electricity produced from roof-top solar panels is converted to alternating current (AC) via a power control unit and directed to the existing wire network of the houses intended primarily to serve the Electric Utilities that supply alternating current (AC). The current 1 kilowatt power plant is utilized to assess performance throughout the year. The overall cost of the solar power plant is INR 50,000 with subsidies and it generates 1403.44 kWh of electricity each year. According to government policy, Government purchase the generated solar power in residential areas costs an average of 2.5 INR/kWh, so a yearly INR 3508.60 is generated from the solar power plant if all of the electricity is directly fed into the grid, but if it is used, it will save the consumer money because 1 kWh costs an average of 8.00 rupees in India in 2023 as buyers prospective. Therefore, as the point of view of the purchaser, the buyer or owner of a solar roof top receives 11,227.50 INR every year. The solar roof top power plant has a lifespan of 25 years, hence the annual cost of the solar power plant is 2000 INR. Thus, the benefit cost ratio to the owner is 5.61 if he/she uses energy for their dwelling,

**Corresponding author: E-mail: gauravgadhiya95@gmail.com;*

and the payback period is only 4.45 years. The proposed work must be considered in terms of an overall environmentally friendly approach that will end up resulting in a new era for energy efficiency and a lower carbon footprint. It will also contribute to the expansion of renewable energy in India.

Keywords: Solar roof top; power plant; final & reference yield; efficiency.

1. INTRODUCTION

The requirement to create sufficient electricity to satisfy the globe's rising energy demand has grown more pressing over the past few decades as a consequence of variables such as growth in the population, industrialization, and altering living standards as a consequence of the growth of the economy. The entire globe now derives the majority of its power through fossil fuels, resulting in negative environmental consequences due to the production of greenhouse gases (GHG) [1,2]. As a consequence, adopting an innovative method for power generation becomes increasingly important. Considering the plentiful supply on Earth, renewable energy has been highlighted as an alternative method of energy production [3]. Solar power has enormous promise as an alternative form of electricity across the globe because it has become cost-effective, particularly in poor nations [4]. India is one of the major emerging nations, with a rapid increase in consumption of energy over the previous several decades. Considering an estimated population of over 1.5 billion, almost 43% of Indians has a connection to grid-based power, while the remaining 57% rely on non-grid supplies of energy and electricity or do not consume any electricity at all [4-6]. India plans to solve its environmental and energy concerns by promoting green energy consumption and enhanced efficiency across the country. Yet, just over 38 percent of India's existing electricity generation capacity comes from sources that are renewable (such as solar energy and wind power). Within the early 2000s, the Indian government created additional green energy laws in order to considerably expand the percentage of sources of clean energy in the nation's electricity supply via a number of measures: Electricity Act of 2003; Tariff Policies of 2006; Natural Rural Electrification Policies of 2006; Planning Commission [5].

As of today, the majority of study is being done to determine the power output from solar panels, but no work is being done to determine the economics of solar roof tops and their influence on the energy issue. As a result, the work is being done in Junagadh, Gujarat, to promote the popularity of solar roof top power plants. The study's primary purpose is to determine the techno economic viability of a solar roof to power plant.

1.1 Description of the Solar Roof Top Power Plant System

The experimental solar roof top power plant building that has been previously built and constructed at the residence has been evaluated for this investigation. The overall rating of the solar roof top power plant has been 1 kW distributed across an area of 8 m2. The solar roof top power plant has been designed to limit the amount of shade that impacts solar panels while maintaining land utilisation equivalent to the typical SPV power plant design, which means that the amount of energy generated per unit land area remains consistent. To guarantee that the solar roof top power plant panels get the bulk of the solar radiation, the tilt angle of the panels is maintained at 21.5 N, which is equivalent to the latitude of the Junagadh region.

Four solar panels, each with a capacity of 250 W, have been erected facing south. Polycrystalline panels have open circuit voltage (VOC) and short circuit current (ISC) values of 37.5 V and 8.70 A, respectively. The module's efficiency is 15.4%. Its working cell temperature is 48 degrees Celsius plus 2 degrees Celsius. The bottom end of the panels has been 0.50 m above the ground, according to Fig. 1. To improve yield, panels are cleaned twice a month.

2. METHODOLOGY

2.1 Performance Analysis of the Solar Roof Top Power Plant System

The specifications of solar panels are listed in the Table 1. For the performance analysis of the solar roof top power plant, the following six metrics for performance have been taken into account as shown in Table 2. These performance indicators essentially show how well

the system performs overall in terms of energy output, solar resource utilisation, and overall system losses. Dimesion of solar module is given in Fig. 2.

- 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})
- The specifications of solar panels are listed in the Table 1.

3. RESULTS AND DISCUSSION

3.1 I-V Curve of Solar Module Under Laboratory Condition

The solar module is tested as per the international standards in laboratory condition. During the testing total 5 condition of light is applied as the 100 W/m^2, 200 W/m^2, 400 W/m^2, 700 W/m^2 and 1000 W/m^2. The standards Typical I-V curve of solar module under laboratory condition with different radiation is given in Fig. 3.

3.2 Monthly Total Energy Generated from Solar Roof Top Power Plant

The solar radiation that solar modules gather is converted into useful electricity. The energy produced overall has been stated as kWh. The computed monthly energy production for the duration of the experiment is shown in Fig. 4. The total energy produced throughout the trial time has been 1403.44 kWh.

3.3 Final yield (Y_F) and Reference Yield for Different Months of Year

The total AC energy generated by the PV system over a certain period of time (a day, a month, or a year) is divided by the rated output power of the installed PV system to get the final yield (YF). The reference yield [6] is the number of hours per day that solar radiation would need to be at reference irradiance levels in order to supply the same incident energy as has been observed. The reference yield and the final yield's estimated values are displayed as bars in Fig. 5.

Fig. 1. Photographic view of solar roof top power plant

Table 1. Specification of the solar photovoltaic module

PV module	Specifications
Type of material	Poly crystalline
Maximum power P_{max}(W)	250.00
Open circuited voltage V_{oc}(V)	37.50
Short circuited current I_{sc} (A)	8.70
Maximum power voltage V_{max} (V)	30.6
Maximum power current (I_{max}) (A)	8.18

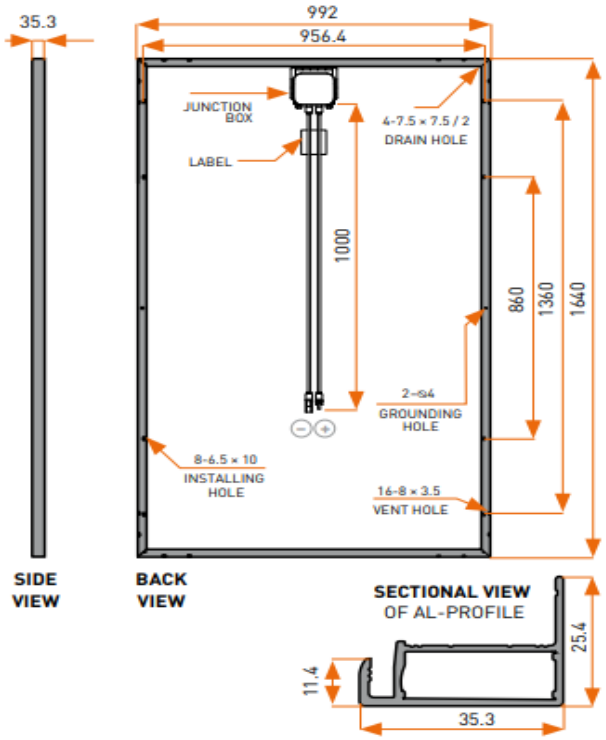

Fig. 2. Dimension of solar module (all the values in mm)

Table 2. Performance parameter of agrivoltaic power plant

Total energy generated by the PV system (E_{AC})	$E_{(AC,d)} = \sum_{t=1}^{24} E_{(AC,t)}$, $E_{(AC,m)} = \sum_{d=1}^{n} E_{(AC,d)}$	$E_{(AC,t)}$= 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).
Final yield (Y_F)	$Y_F = \frac{E_{AC}}{P_{PV,Rated}}$	Y_F = Final yield (kW h/kWp) E_{AC} = AC energy output (kWh), $P_{PV,Rated}$= Rated output power (kWp).
Reference yield (Y_R)	$Y_R = \frac{H_t(kWh/m^2)}{G(kW/m^2)}$	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)	PR (%) $= \frac{Y_F}{Y_R} \times 100$	Y_F = final yield (kW h/kWp), Y_R = Reference yield (kW h/kWp).
Capacity factor (CF)	CF = $\frac{E_{AC,a}}{P_{PV,a} \times 8760} \times 100$	CF = Capacity factor (%) $E_{(AC,a)}$= Total annual AC energy output (kW h), $P_{PV,a}$= Total amount of energy generated (kW h)
System efficiency (η_{sys})	$\eta_{sys,m} = \frac{E_{AC,m}}{H_t \times A_m} \times 100$	$\eta_{sys,m}$= 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).

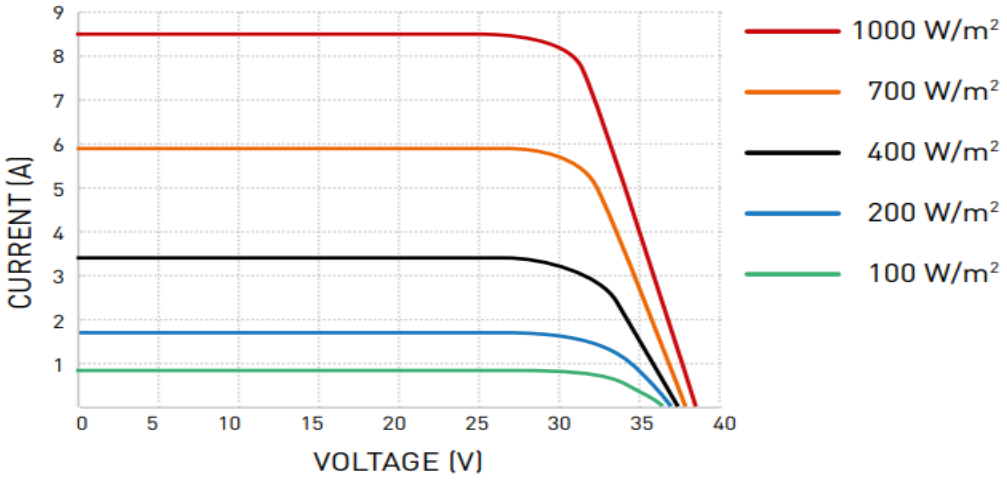

Fig. 3. Typical I-V curve of solar module under laboratory condition with different radiation

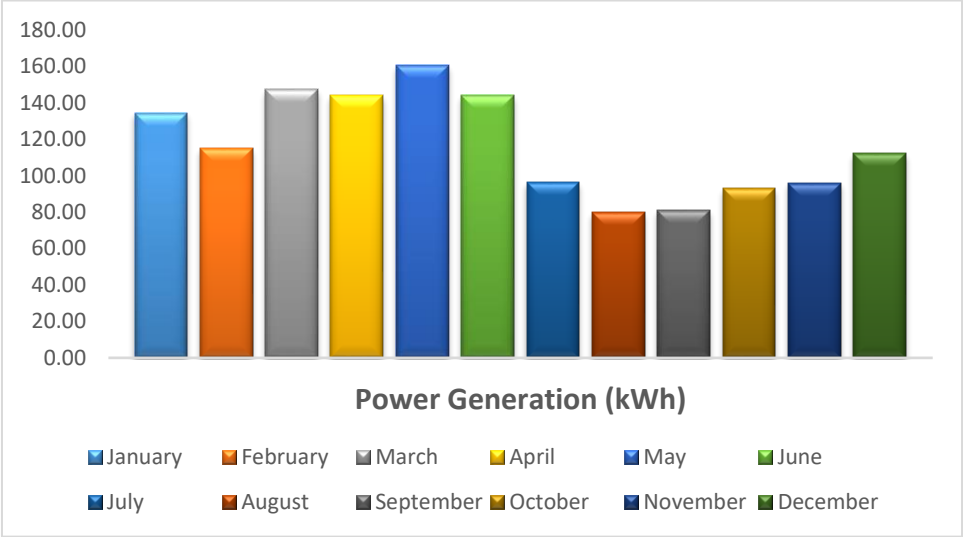

Fig. 4. Monthly energy generation for different months from solar roof top power plant

3.4 Performance Ratio (PR) of Solar Roof Top Power Plant System

It stands for all of the system losses that occurred when the AC output has been converted from the DC rating. PR usually runs from 0.6 to 0.9, depending on the location, sun irradiation, and meteorological conditions. Fig. 6 shows the experimental duration performance ratio, which has been calculated based on Table 2. The performance ratio results from [7,8] and this investigation have been quite close.

3.5 Capacity Factor (CF) of Solar Roof Top Power Plant for Different Months

The capacity factor (CF) calculation only considered the duration of the experiment. As a result, the capacity factor 365 in the calculation is replaced with the total number of days in each month. The calculated capacity factor values for each month are listed in Table 3.

3.6 System Efficiency During Experimental Duration

The monthly system efficiency for the study period is computed and presented in Fig. 6 in line with Table 2. The system efficiency values obtained from this investigation nearly matched those from a different study [9,10].

3.7 Economic Analysis of Solar Roof Top Power Plant

The economic analysis of solar roof top power plant is given in Table 4. Total cost of power

plant is 50,000 INR. The total revenue collected from solar power plant is 11227.50 INR. The benefit cost ratio of the system is 5.61 and system's payback period is 4.45.

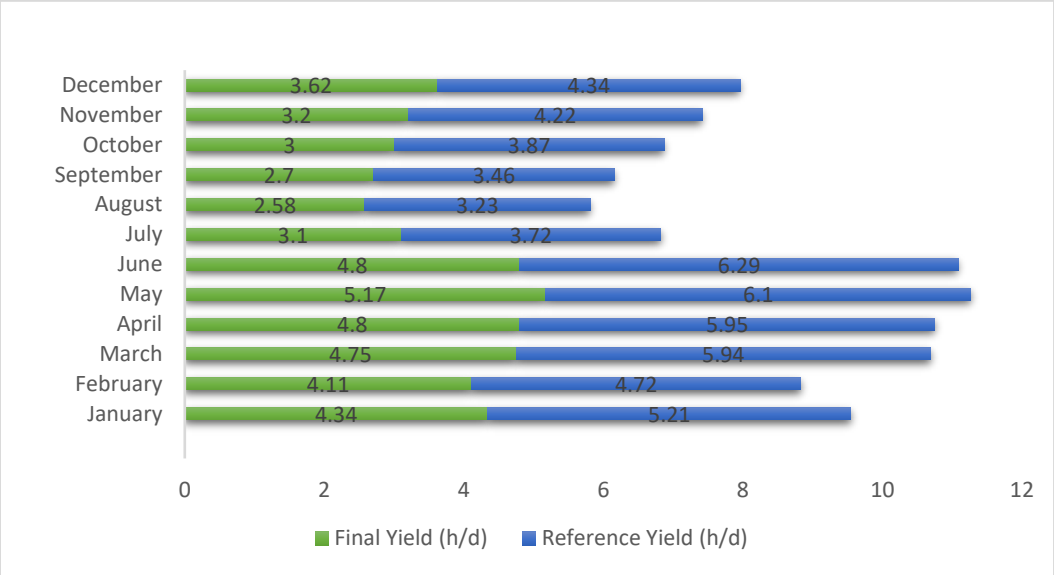

Fig. 5. Final yield and reference yield for different months

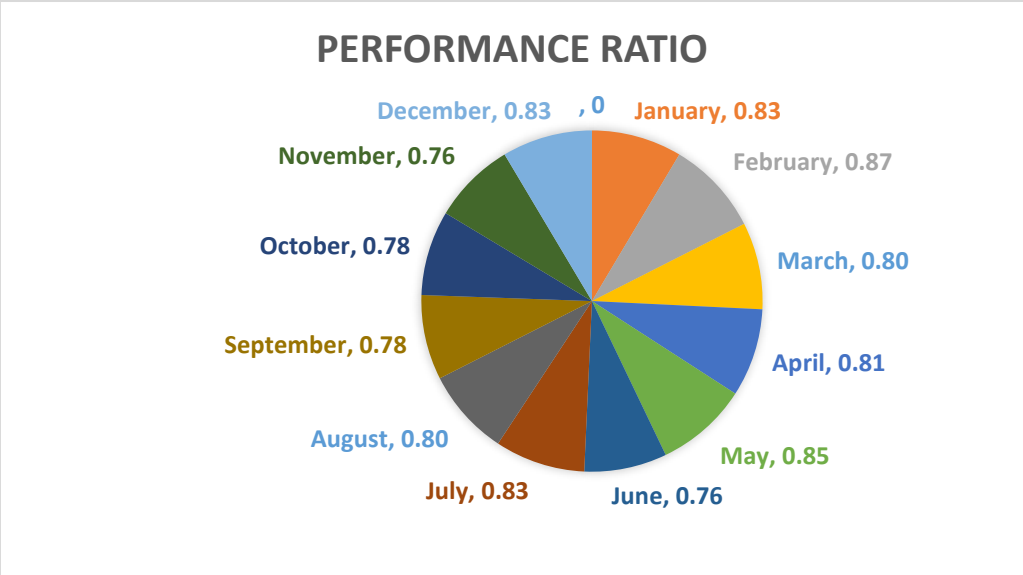

Fig. 6. Performance ratio for different months

Table 3. Capacity factor for different months of study period

Months	Capacity Factor (%)
January	18.08
February	17.11
March	19.81
April	20
May	21.53
June	20
July	12.92

Months	Capacity Factor (%)
August	10.76
September	11.25
October	12.49
November	13.33
December	15.07

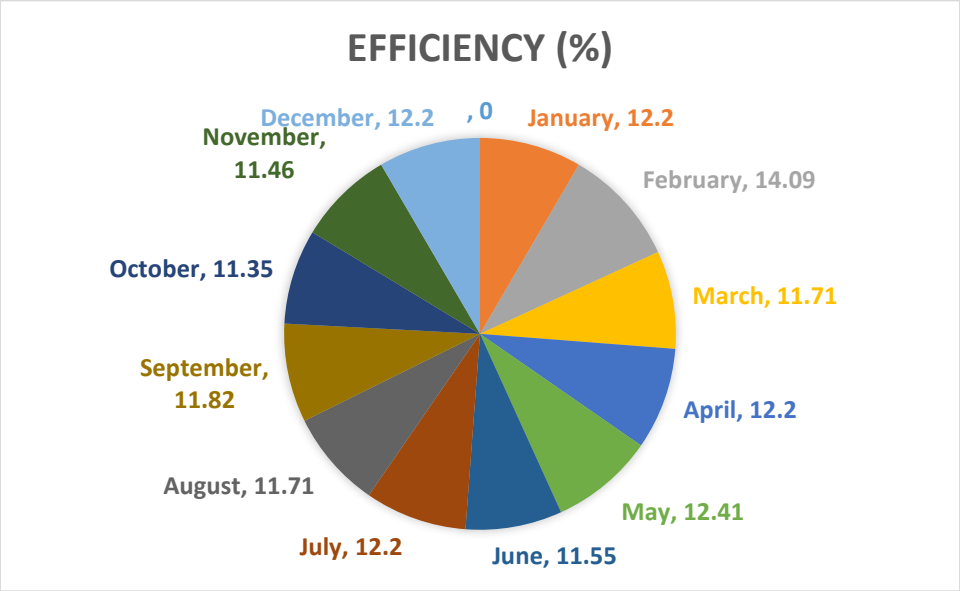

Fig. 7. System efficiency for different months

Table 4. Economic analysis of solar roof top power plant

System cost (INR)			Revenue generated		Benefit cost ratio	Payback period
Cost of solar panel	Wiring and other grid inverter cost	Total	Energy generation	Revenue generated		
30000.00	20000.00	50,000.00	1403.44	11227.50	5.61	4.45

4. CONCLUSION

The established solar roof-top power plant has been constructed and constructed in Junagadh, covering an area of 8 m^2 and having a 1 kW capacity.1403.44 kWh of energy has been generated overall over the trial period, with May showing a greater daily energy output. Energy generation has been found to be lower during the monsoon season, which is July, August, September, and October, than it is during other months. During the trial period, an overall performance ratio of 80.83 has been noted. The overall system efficiency during the experimental period has been found as 12.07 %. The benefit cost ratio of the system is 5.61 and system's payback period is 4.45. Considering year-round access to solar energy, this solar roof top technology is making a big difference for India's future energy demands.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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