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Design, Performance and Economic evaluation of a 4kW Grid-interactive Solar PV Rooftop in Odisha using Pvsyst

Renu Yadav[1*], Anamol Gautam[2] and Palraj Pradeepa[3]

[1]Department of Electronics and Communication Engineering, Dev Bhoomi Uttarakhand University, Dehradun, Uttarakhand, India; [2]Department of Electrical Engineering, Chandigarh Engineering College, Jhanjeri, India; [3]Department of Electrical and Electronics Engineering, Faculty of Engineering and Technology, JAIN (Deemed-to-be University), Ramanagar, Karnataka, India

E-mail/Orcid Id:

RY, ece.renu@dbuu.ac.in, https://orcid.org/0009-0002-5786-7898; *AG*, gautamanamol@gmail.com, https://orcid.org/0000-0003-0852-8371; *PP*, p.pradeepa@jainuniversity.ac.in, https://orcid.org/0000-0003-3869-1364

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Abstract: The global decline of fossil fuels has required the development of alternative energy sources to satisfy the electricity demand. This article assesses and inaugurated the viability of grid-interactive photovoltaic systems providing electricity to a residential load. Since the average solar irradiation in Odisha is 1156.39 W/m2, a 4-kW rooftop solar photovoltaic system can produce 17.8 kWh of electricity per day (5.5 sunshine hours). Carbon Dioxide (CO_2) emissions are reduced by 113 tonnes for every 4 kWp produced, which is equal to planting 181 trees. This 4kW device is analyzed with a PVsyst (V7) program for a residential load consumption of kWh/day. The device consists of 16 photovoltaic modules, each with a 320 Wp value, that are arranged in two strings of eight modules each. The efficacy of the photovoltaic arrays, surplus energy pumped into the grid, usable AC energy, efficiency ratio, and various losses occurring in the photovoltaic system are all evaluated in the simulation outcome. The paper promotes using photovoltaic systems as a cost-effective and environmentally friendly energy source.

Introduction

The conventional energy sources comprise coal, natural gas and nuclear power stations, with coal producing the most electricity (Das and Kumar, 2022; Shilpa and Sridevi, 2019). It is about 60% of the electricity in India is produced from coal, but the conversion efficiency is low and toxins are released into the atmosphere during the conversion process, endangering the environment (Koko, 2022; Yadav et al., 2023). These issues may be resolved using renewable energy sources (Lee et al., 2018). Due to its position, India has an enormous capacity for producing solar energy since it gets solar radiation practically every year in the amount of 3000 hours of sunshine or 5000 trillion kWh. According to Yadav et al. (2015), India receives average 4–7 kWh of solar radiation per square meter.

Semiconductors that use sunlight as a energy source to produce "electricity" directly are the basis of photovoltaic modules or panels (Song et al., 2018). Grid-interactive systems and SAPV systems are the two categories under which photovoltaic systems fall (Chauhan and Singh, 2022; Prajapat et al., 2021). Grid interactive systems provide electricity into the grid, and the local environment, solar array orientation, inclination, and inverter performance all impact their efficiency (Singh and Rizwan, 2022). Renewable energy is provided through grid interactive networks with minimal transmission and distribution losses (Minai et al., 2022). Unconnected to the power grid, standalone systems create energy specifically for the load (Lee and Hong, 2019). An "energy storage system" is required if the solar array is not linked to the load directly (Hong et al., 2017; Simshauser, 2022). A battery that stores extra energy

***Corresponding Author:** ece.renu@dbuu.ac.in

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generated by solar modules and may be used to provide the load in case the pv system's supply is insufficient is the energy storage system. Naturally, the separate device is utilised in homes to supply electricity (Kandasamy et al., 2013).

Various design and performance analysis techniques may be useful for discrete and grid-interactive systems (Alrawi et al., 2022; Koko, 2022). Architects, developers, and research scholars were considered while developing the Photovoltaic system simulation platform. It offers comprehensive contextual assistance, an ergonomic approach with project planning standards and a detailed explanation of the technique and templates utilized. Photovoltaic system enables you to upload personal data from 10 different sources and prediction information (Mandi, 2018; Saxena and Gidwani, 2018).

Rout and Kulkarni (2020), proposed a PV system used to evaluate the efficiency and design of a 2kW rooftop “grid-interactive solar PV system”. The device is located in Bhubaneswar, Odisha, and is designed for usage by a domestic user load. A 2kW device is fitted when the entire load on the residence is determined. The system's economic analysis has been finished. In addition, the financial benefits during its lifespan are estimated to be Rs. 3,93,300, with just 57 tonnes of carbon dioxide emitted-equivalent to planting and raising 91 teak trees. The system's power production, failure rates, reliability, and performance ratio are determined using a PV system. More people are using solar photovoltaic devices, which provide renewable power or energy (Kappagantu et al., 2015; Rabuya et al., 2021).

Yadav et al. (2015) explained the design and evaluation of a 1 kW grid-connected solar PV rooftop using PVsyst. In Hamirpur, Himachal Pradesh, a commercial user load is intended for the machine. The statistics on global sun radiation were measured to provide more accurate findings. The total energy supplied by the apparatus and any resulting losses are calculated using PVsyst. Additionally, the efficiency ratio is predicted over a year, demonstrating the system's suitability for the location. Investing in solar PV systems is a viable strategy to address the world's growing energy needs (Lopez-Ruiz et al., 2020; Song et al., 2018).

Dey and Subudhi (2020) review the present Planning, simulating, and evaluating the economics of a 90 kW “grid interactive solar PV rooftop” were done using PVsyst. The NIT in Rourkela, Odisha, was the target market for the gadget. Using PVsyst, they chose the appropriate module settings. Additionally, it's used to monitor how much electricity the machine produces. According to the economic research, the cost savings amount to “Rs. 1,10,03,463” and the anticipated CO_2 production over 30 years is 2199.3 tonnes (Halim and Wahyuni, 2022; Sinha and Ranjan, 2021). It was shown to be a practical solution for power delivery there that would save energy bills. The photovoltaic system is capable of meeting the electrical needs of a school. 161.6 MWh of the 165.38 MWh produced annually by the 100kWp solar system are sent into the grid. The output ratio of the system is 80%, the daily useable energy is “4.42 kWh/kWp”, and the yearly losses are computed. In order to improve performance, the suggested solar system may be built utilizing a range of photovoltaic modules and implementation methodologies (Chiteka et al., 2020; Putranto et al., 2022).

Methodology

The methodology contains the “Grid-interactive Solar PV Rooftop system” design illustrated in Figure 1. The methodology also deals with the data that is inducted by the study. The methodology also deals with Geographical location, PV specifications of the System, Inclination, Positioning, Inverter and Economic Analysis of the PV grid-Interactive system.

Design

The assembly of a grid-interactive PV system is shown in Figure 1 (Rout and Kulkarni, 2020). The design consists of three parameter PV array, System, and User. The PV arrays are passed through in the form of an array from the inverter and the inverter covers the array in two parts: the P and N. The N junction arrays are used as a backup and the P junction array is used as the main supply.

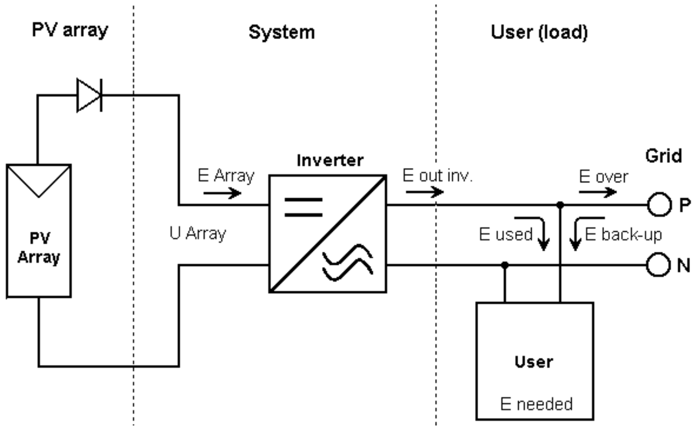

Figure 1. Solar PV grid-tied

Geographical Location of the Site

Bhubaneshwar, Odisha located at 20.296059°N and 85.824539°E. The average temperature is around 28°C. This is the ideal environment for a “solar PV system” to get the expected output (Karki et al., 2012). Figure 2 shows the geographical coordinates used in the software.

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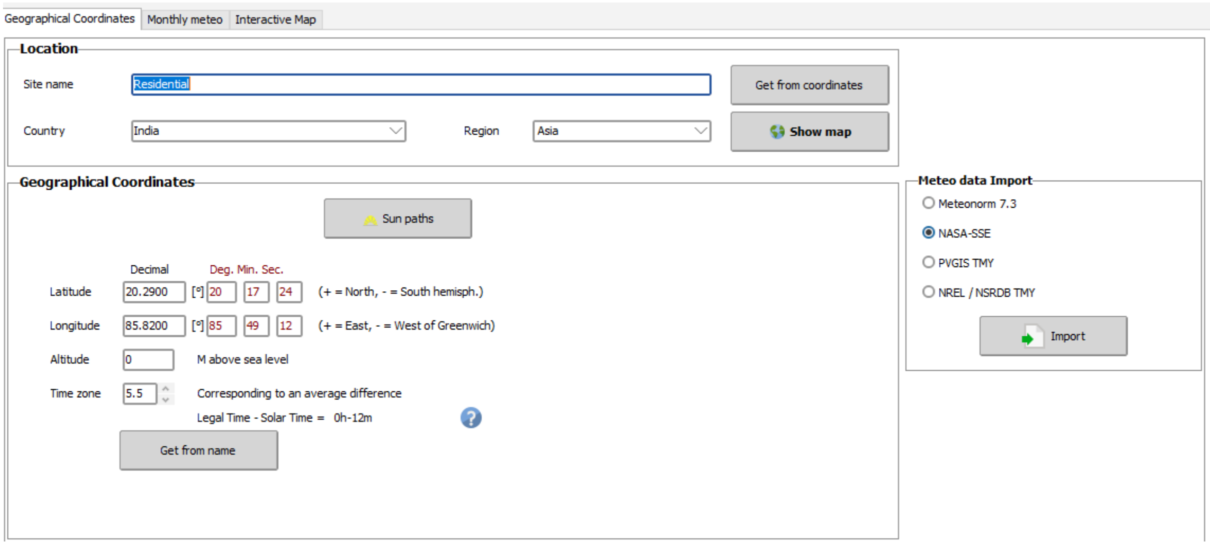

Figure 2. Geographical coordinates of the site

Specification of PV module used in the system

Considering a 4 kW system at Odisha, we have selected Tata Power Solar 320Wp, 32V. The total number of modules used is 16. The specification of PV modules used is in Figure 3.

The calculation and standard values from the MNRE website are shown in Table 2.

Result and Discussion

PVsyst software produced a descriptive report with numerous graphs and charts, which are represented and depicted below. The calculated data mounted, obtained and collected from pyranometers in Bhubaneswar were used as input for the global horizontal radiation data. The global incident radiation rises to 1883 kWh/m^2 due to the photovoltaic modules' seasonal maximum tilt. Wiring loss, light-induced degradation, and mismatch losses all account for 1.33 percent, 2% and 2.1 percent of the total losses in a photovoltaic device, respectively. The energy received from the device for load is 7.356 MWh, with inverter losses of 2.83 percent. The performance parameters of the 4 kW PV system and the loss occurring in the system are illustrated in Table 3 (Belmahdi and Bouardi, 2020). Figure 7 shows the loss diagram of the SPV system.

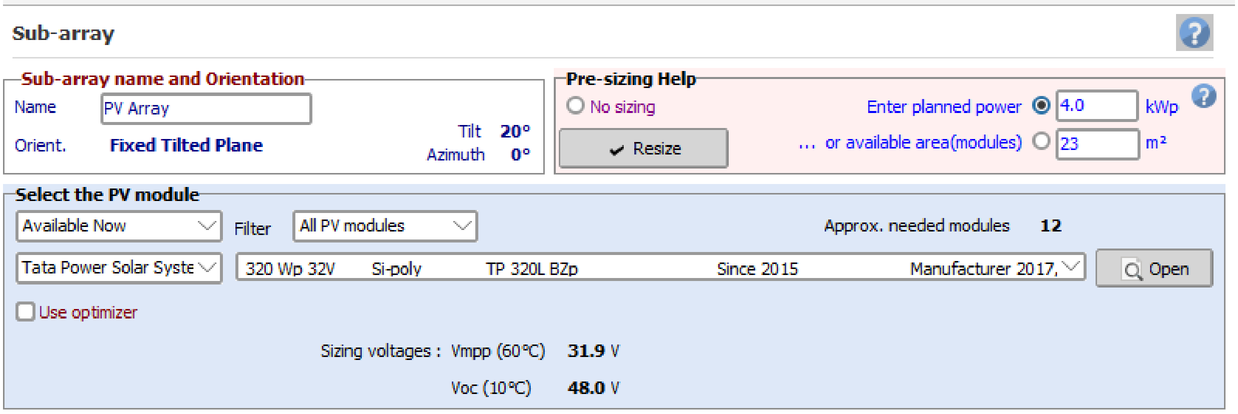

Figure 3. Specification of PV module used

Inclination and Positioning

The solar path is illustrated in Figure 4, and the PV panels are best positioned accordingly. The tilt angle of the panels is 15°, azimuth angle is 0° and the optimization of the PV panel is yearly irradiation yield (Shiva Kumar and Sudhakar, 2015). Figure 4 shows the sun path of the given location and Figure 5 shows the module's tilt angle and azimuth angle.

Inverter

We select a Delta Energy Inverter of 4 kW for a four-kilowatt system for the site. The specifications of the inverter used are shown in Figure 6.

The appliances used in a residence are considered and details related to the appliances are shown in Table 1.

Economic analysis

Total photovoltaic (PV) plant capacity = 4 kW

Area required = 420 sq. ft.

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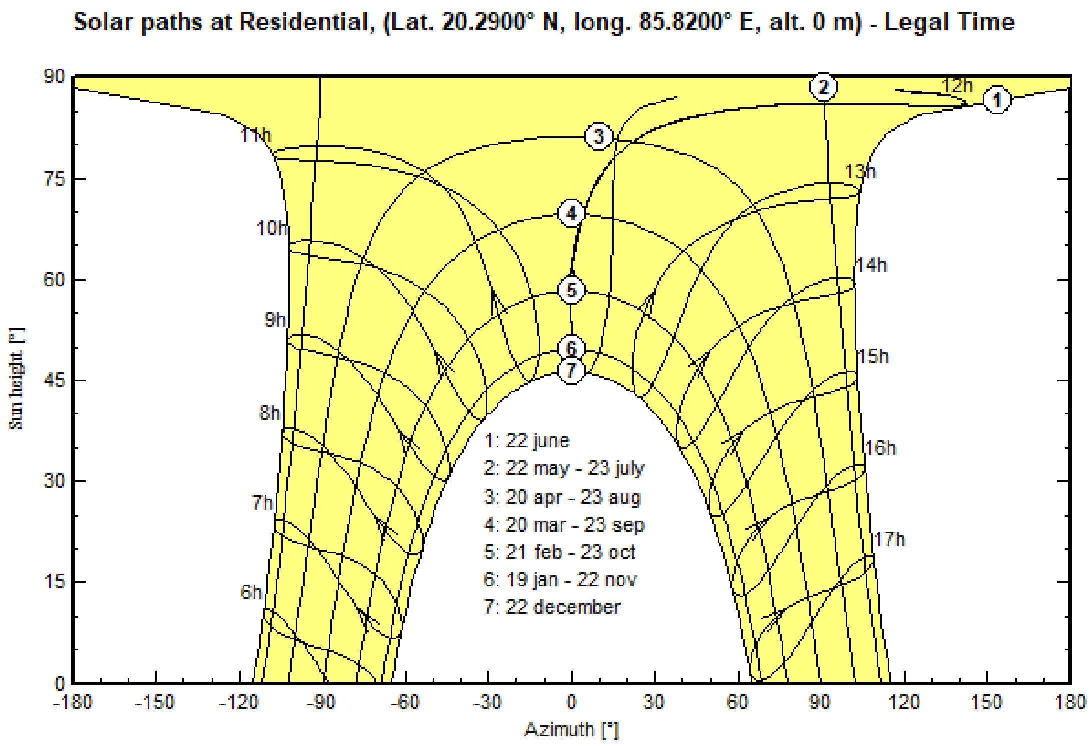

Figure 4. Sun path of the location

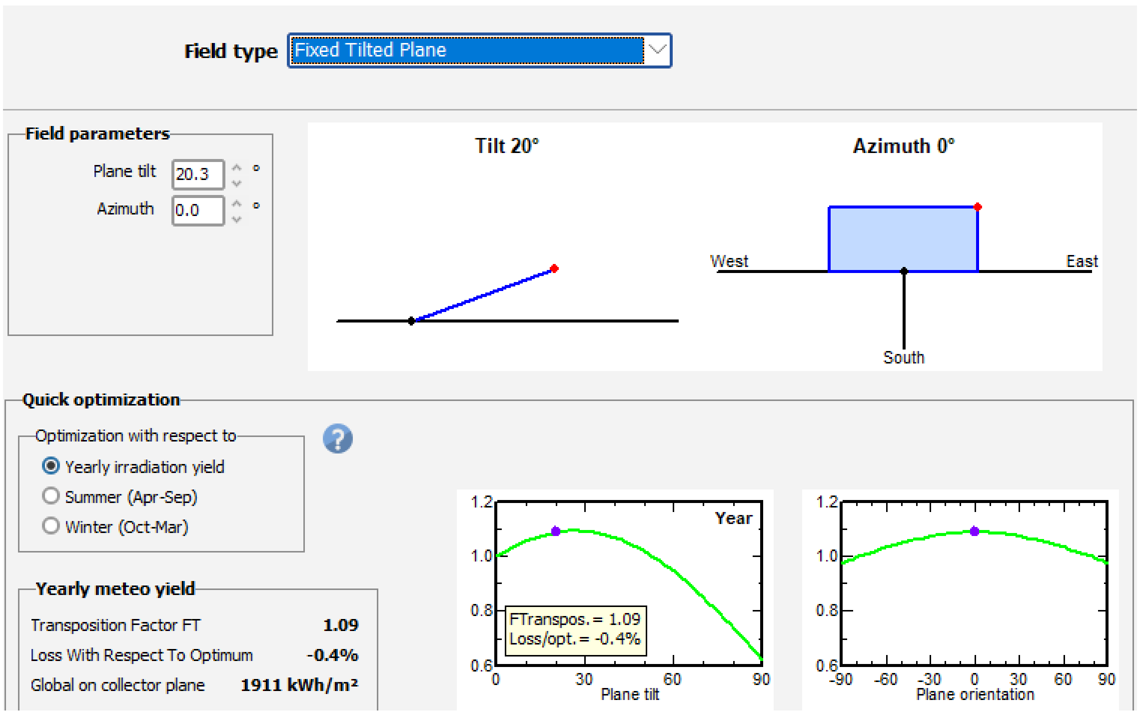

Figure 5. Tilt and azimuth of PV modules

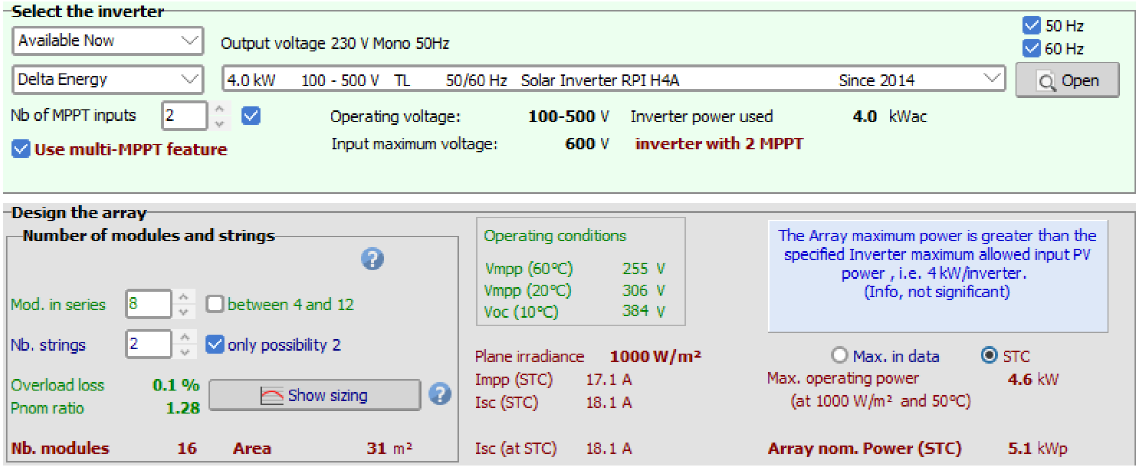

Figure 6. Specification of the Inverter used

Table 1. Resident Load usage

Sl. No	Name of appliances	Power	No. of appliances	Total watts	No. of hours	Energy (Wh)
1	LED	10	10	100	6	600
2	Fan	150	4	600	6	3600
3	TV	100	1	100	2	200
4	Fridge	150	1	150	24	3600
5	Washing Machine	1500	1	1500	2	3000
6	Laptop	50	1	50	2	100
7	Air Conditioner	1500	1	1500	6	9000
Total Hourly Load (Wattage)=3460 W/h						
Total energy for daily load = 20100 Wh/day						

Table 2. Economic analysis of the proposed system

Size of Power Plant:	
Feasible Plant Size as per capacity	4kW
Cost of the Plant:	
MNRE current benchmark cost	Rs. 41000/kW
Without subsidy	Rs. 164000
With subsidy (40% upto 3kW and 20% above the 3kW upto the 10kW)	Rs. 106600
Total Electricity Generation from Solar Plant:	
Annual	5520kWh
Life-Time (25 years)	138000kWh
Financial Savings:	
Tariff @ Rs. 5.5/kWh	
Monthly	Rs. 2530
Annually	Rs. 30360
Life Time (25 years)	Rs. 759000
CO_2 emission	113 tons
This installation is equivalent to the planting of 181 teak tree over the life time.	
EMI for Loan amount of Rs. 98400 for loan period of 10 years @8.45% is Rs.1217/month	

Table 3. Performance parameters of 4 kW PV system

	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_Grid MWh	PR ratio
January	140.4	42.36	20.33	175.9	166.2	0.723	0.720	0.719
February	147.3	47.45	22.33	178.0	165.3	0.733	0.509	0.345
March	180.4	77.34	25.11	178.3	176.3	0.333	0.305	0.445
April	190.2	42.33	25.33	167.2	172.3	0.433	0.556	0.556
May	191.6	57.00	23.11	178.2	177.1	0.345	0.667	0.356
June	191.6	24.33	20.22	177.2	175.2	0.432	0.449	0.776
July	135.0	77.34	29.33	174.3	190.2	0.442	0.993	0.843
August	120.3	75.33	28.33	173.2	180.3	0.472	0.440	0.765
September	124.5	55.44	27.43	170.3	170.3	0.320	0.339	0.678
October	141.7	66.33	24.55	171.9	186.2	0.459	0.456	0.734
November	132.6	80.33	23.55	172.3	190.3	0.432	0.567	0.566
December	135.4	81.33	22.33	174.3	187.2	0.332	0.451	0.881
Year	1831	726.91	291.95	2091.1	2136.9	5.456	6.452	0.7664

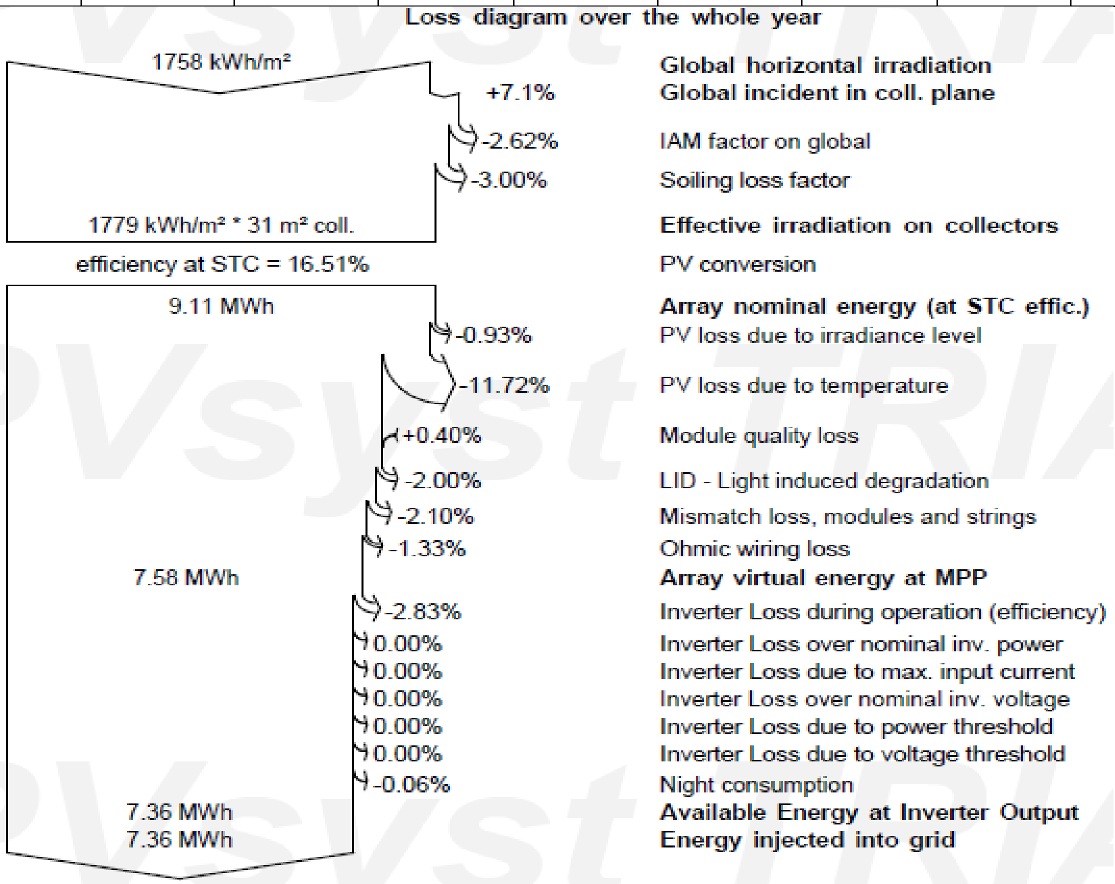

Figure 7. Loss diagram of the SPV system

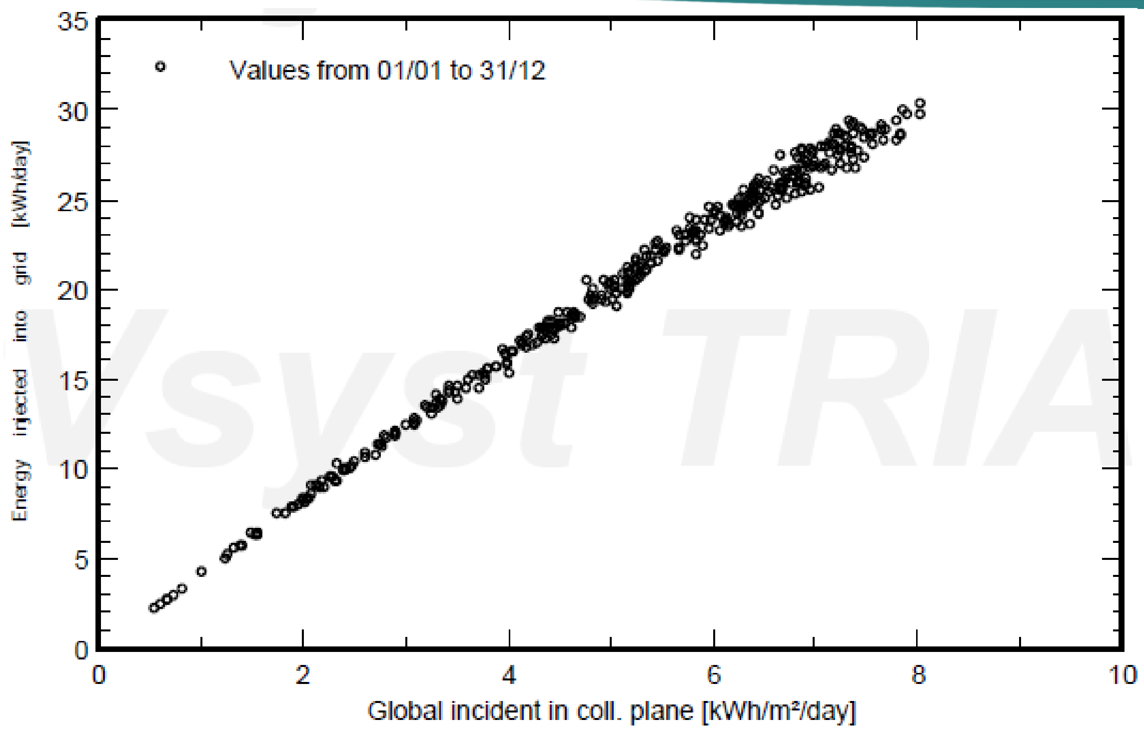

Figure 8. Output energy of the proposed system

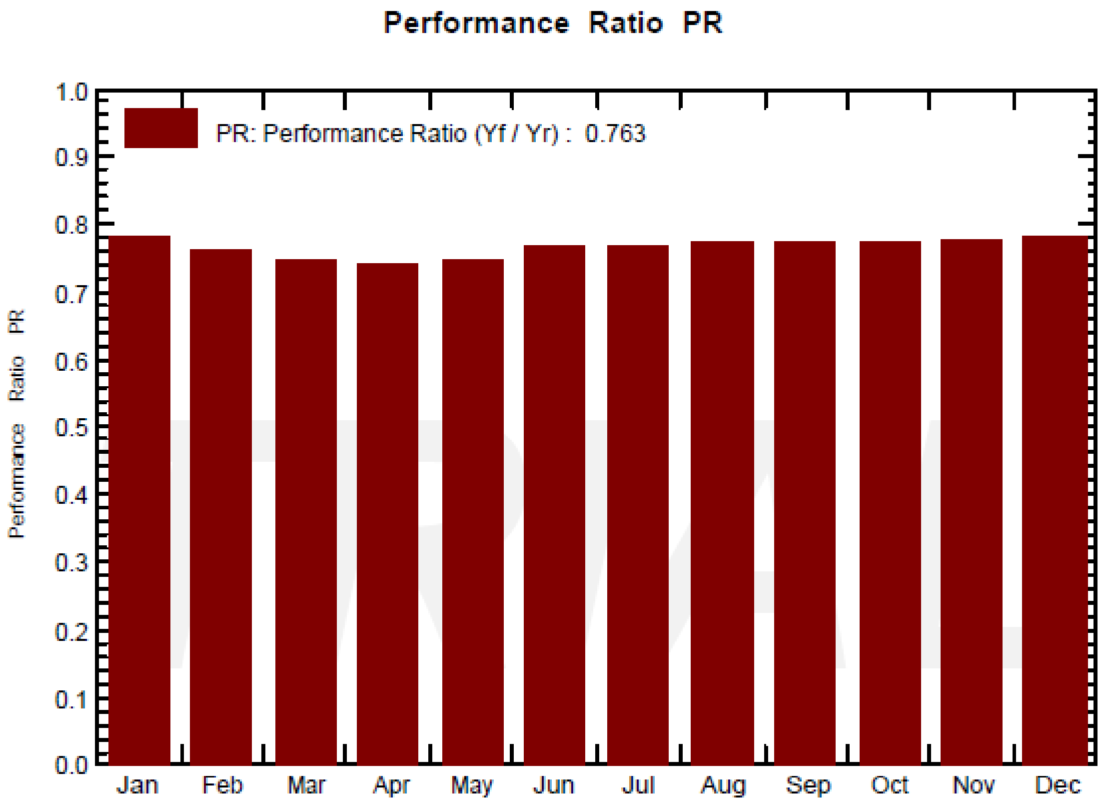

Figure 9. Monthly variation of PR

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Legends: GlobHor: Global horizontal irradiation
GlobEff: Effective Global, Corr. For IAM and shading
DiffHor: Horizontal diffuse irradiation
EArray: Effective energy at the output of the array T_Amb: T amb.
E_Grid: Energy injected into the grid
GlobInc: Global incident in coll. Plane
PR: Performance Ratio

Figure 8 depicts the system's daily production capacity, including variations in the system's normal output energy caused by different parameters. The output ratio (PR) depicts the system's efficiency. It is the system's energy output proportion to the radiation incident on the module region. Figure 9 depicts the system's output ratio for each month, with an average of 0.763, which is adequate for a system (Kumar et al., 2017).

Conclusion

The PVsyst software provides a complete methodology for developing and simulating a 4kW grid-interactive solar system (Dey and Subudhi, 2020). According to the simulation, the mean solar irradiation obtained at a tilt angle of 20° is 1757.9 kW which is related according to the data. In addition, the photovoltaic system includes sixteen 320Wp solar panels and a 4kW inverter. The following is a summary of the findings:

i. According to the MNRE solar rooftop calculator, a cost savings of Rs.759000 over 25 years is a significant financial saving.
ii. The total CO_2 emissions are 113 tonnes, which is the same as planting 181 teak trees for a 25-year cycle.
iii. The total amount of energy generated each year is 7.36MWh.
iv. The system's performance ratio is 0.7631.

After reviewing its overall efficiency, the mounted grid interactive solar photovoltaic system is a viable solution for power supply in Odisha. The appliance provides all of the household's energy needs throughout the year while also creating extra power that the user may utilize afterward. The development of PV systems indicates that the systems' capital costs will drop and their efficiencies will rise. "photovoltaic energy" systems also generate cleaner energy than traditional energy systems.

Conflict of interest

None

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