INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

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OPEN ACCESS

Received: 20-11-2024

Accepted: 02-12-2024

Published: 30-12-2024

Citation: Quddus AS, Usmani T, Hasan SH (2024) Analysis and Comparison of Energy Generation from a 38.4 kWp BIPV System Using PVsyst Simulation Tool. Indian Journal of Science and Technology 17(48): 5046-5054. https://doi.org/10.17485/IJST/v17i48.3772

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Analysis and Comparison of Energy Generation from a 38.4 kWp BIPV System Using PVsyst Simulation Tool

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Abstract

Objectives: Rapid growth of energy demands into all sectors like residential, industrial, and commercial sectors; PV system is the best among all alternative renewable energy systems (RES). This work provides a simulation & comparative performance analysis of a 38.4 kWp Building Integrated Photovoltaic System (BIPV). **Methods:** Using the PVsyst tool, this research focuses on energy generation and its performance ratio of 38.4 kWp rooftop PV system installed at Integral University, Lucknow (India) with the coordinates of 26.84 N and 80.94 E. BIPV system installation is dependent on geographical location and meteorological conditions like temperature window. Many system components like PV modules, inverters, cables, etc. are employed. The growth of BIPV adoption is supported by government incentives and policies, leading to its increased integration in residential, commercial, industrial, and transport sectors. **Findings:** BIPV technology is key to reducing global building energy consumption, which accounts for approximately 40% of total energy use, contributing to lower greenhouse gas emissions. 38.4 kWp rooftop PV system at Integral University in Lucknow, India, serves as a reference for BIPV system simulation, helping to validate its performance and improve system reliability. **Novelty:** To validate accuracy of BIPV system simulation, the actual data from the rooftop PV system is compared. So, the system reliability can be improved by comparing simulation results.

Keywords: Building Integrated Photovoltaic System (BIPV System); MPPT; Performance Ratio (PR); Posit Energy Generation Tool; Solar PV System

1 Introduction

BIPV is designed to combine building architectural design and solar photovoltaic technology. The fundamental of the BIPV system is to integrate this system into buildings, either residential, commercial or industrial, without impacting the aesthetics and semblance of the building. BIPV systems significantly influence urban development, mainly in modern architectural building designs where buildings are covered with glass and other advanced materials.

BIPV system provides a good look to the building and generates renewable energy locally. Unlike Building Adaptive Photovoltaic (BAPV) systems like rooftop PV systems [1,2]. The main objective of the BIPV system is to replace contemporary building materials in building constructions like roof skylights and porticos, etc. PV module generates electrical energy, converting solar energy in the form of photons from the sun and enveloping the building structure. This combination results in space efficiency for integrating PV systems and buildings [2,3]. BIPV system also provides thermal insulation and noise reduction and protects from rain & water without compromising the architecture and other look of the building [4–6].

Energy consumption for buildings has grown worldwide. The total energy consumption of buildings is estimated to be around 40% of total global energy consumption, leading to increased greenhouse gases. To reduce negative environmental impact, BIPV technology is preferred technology due to its flexible nature [7,8]. Installation is flexible in the economy's residential, commercial, industrial and transport sectors. Policies and inducements by the government, like feed-in tariffs, have increased the adoption of PV systems globally in different sectors of the economy [9]. Energy from conventional sources like coal-based grids was reduced considerably due to the use of PV systems in universities, residential buildings, shopping malls, commercial and transport sectors, etc. [10]. System efficiency and performance are reduced by the higher temperatures due to losses such as derating loss. In contrast, the efficiency and performance of the PV system are increased by the lower temperature, which provides good solar insulation. Implementing renewable energy sources like PV and wind energy systems is required to support the International Environmental Accord of Paris COP21, which aims to decarbonize the energy sectors by the year 2050 [11,12]. BIPV integration into the building plays an important role in achieving this goal. This will also help to achieve the objective of integration of PV systems in smart grid systems [13–15].

Lucknow in Uttar Pradesh, India, provides a good opportunity for BIPV systems due to its growing modern infrastructure. It lies in the country's Northern region; it has good solar irradiance. The rooftop PV system installed in NLT-A Block of Integral University with a capacity of 38.4kWp will be used as a reference to the proposed BIPV system. To validate the accuracy of the BIPV system simulation, the actual data from the rooftop PV system is compared. Also, simulation using PVsyst can be performed for any location across the globe by providing inputs to the software, and it can be analyzed by comparing to the installed system. So, the system's reliability can be improved. The limitation of using posit in the given location is that every of these standard parameters cannot be considered for evaluation, so taking this as an important point, all parameters are assumed to be equivalent to region-specific or ideal. This paper is organized into 1. Introduction 2. Methodology 3. Results and discussion are concluded in section 4.

2 Methodology

2.1 BIPV System Description

The study of the 38.4 kWp BIPV system simulation for the geographical location of Lucknow city has been performed, having coordinates 26'84" N, 80'94" E with time zone +5:30 UTC. System simulation and climate data are based on Metronome 8.2 from 2001 to 2020. For BIPV system simulation, the time resolution or time step is to be 1 minute for the entire year to include all seasonal variations [16,17]. For more precise simulation results, the time step is to be taken 1 minute. The grid parameters are 415 Volts, 50 Hz and Power Factor 0.9, respectively, as the BIPV system is grid-connected [18,19].

2.1.1 PV Module

The PV modules Flextron F15F-245B1 series manufactured by BIPVCo. are used in the system installation with 156 in nos. of BIPV modules, each rated 245 Wp, and other technical details as shown in Table 1.

Table 1. Technical parameters of bipv modules simulation parameter

Electrical Performance at STC	Values	Unit
Nominal Power	**245**	Watt
Max Power Voltage (Vmpp)	**93.83**	Volt
Max Power Current (Impp)	**3.84**	Amp
Open Circuit Voltage (Voc)	**115.95**	Volt
Short Circuit Current (Isc)	**4.41**	Amp
Max Series Fuse Rating	**10**	Amp
Max System Voltage	**1000**	Volt
Cell Efficiency	**15.5**	%

Continued on next page

Table 1 continued

Temperature Coefficient of Pmpp	**-0.268**	[% /^{o} C]
Temperature Coefficient of Voc	**-0.209**	[%/^{o}C]
Temperature Coefficient of Isc	**-0.0007**	[%/^{o}C]

2.1.2 PV Inverter

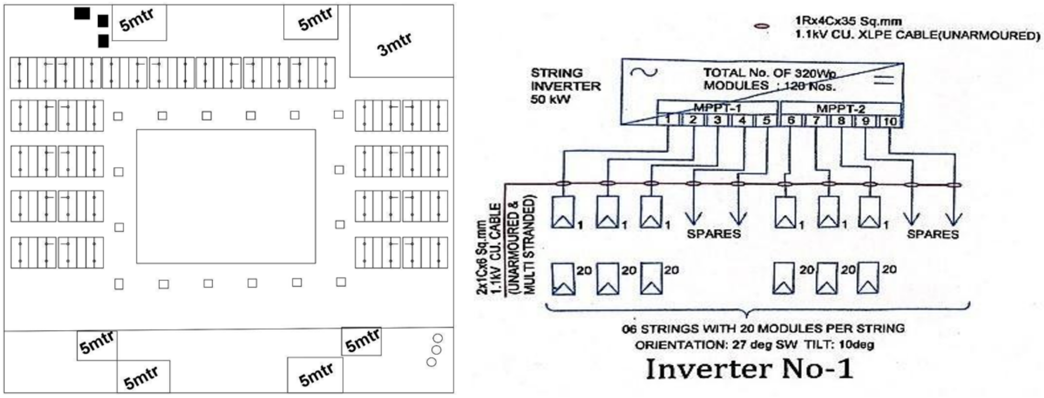
Dual The PV inverter used in the BIPV system is **SUN2000-6KTL** manufactured by Huawei Technologies having operating voltage 90-560V.

Table 2. Parameters of the pv inverter

Output Parameters		
Grid Connection	**3**	Phase
Rated Output Power	**6,000**	Watt
Max Apparent Power	**6,000**	VA
Rated Output Voltage	**220/380,230/400**	3W N+PE
Rated AC Grid Frequency	**50/60**	Hz
Max Output Current	**10.1**	Amp
Technical Specification	**Value**	Unit
Input Parameters		
Max Efficiency	**98.6**	%
Max PV Power	**9,000**	Watt
Max Input Voltage	**1,100**	Volt
Start Up Voltage	**200**	Volt
Rated Input Voltage	**600**	Volt
Max. input current per MPPT	**11**	Amp
Max. short-circuit current	**15**	Amp
Number of MPP trackers	**2**	Numbers

2.1.3 Rooftop PV System description installed at Integral University, Lucknow

The rooftop PV system is installed at NLT BLOCK A building of Integral University. It has total of 120 PV modules each rated at 320 Wp of the brand Vikram Solar. The total number of strings is 6 and the maximum number of modules in series per string is 20. Inverter used in the system is 50 kW of brand Delta. Tilt angle of the module is 10 degrees and azimuth angle or orientation is 27 degrees South West. The grid parameters to which the inverter is connected are 415 V, 3 phase, 50 Hz. Installed BIPV system at Integral University. It has 156 BIPV modules connected to inverter. The output from BIPV modules is fed to injection point[20,21]. Circuit breakers are recommended on either side of the inverter for safety reasons as well as ease of maintenance. The output of the inverter is being fed to a grid operating at 415 V, 50 Hz. PV string layout of rooftop PV system Inverter 1 (50 kW) has 6 strings with 20 PV modules connected in series per string. Total number of modules is 120 (320 Wp each). And the output of the inverter is being fed to grid via AC Distribution Box. The grid parameters are 415 V, 50 Hz, 3 phase. Technical parameters are given as (a) Input parameters are; max efficiency of 98.6%, max power PV of 5800 Watts, max. voltage input of 1000V, startup voltage 250V, MPP voltage range of 520-800V, max. current MPPT input 50Amp, trackers and max. nos. input is 2 (b) Output Parameters are; grid connection is 3 phase, rated output power & max. output power is 5.5kW, rated output voltage and ac grid frequency is 220/380, 230/440 & 50/60 Hz respectively. Parameter for Electrical Performance at STC is given as nominal power is 320Watt, max power voltage (Vmpp) is 37.7V, max power current (Impp) is 8.5A, open circuit voltage (Voc) is 46V, short circuit current (Isc) is 9.03A, max series fuse rating is 15A, max system voltage is 15A, cell efficiency is 16.49%, temperature coefficient of Pmpp is -0.38%/^{o}C, temperature coefficient of Voc is -0.29%/^{o}C and temperature coefficient of Isc is 0.057%/^{o}C.



(a) Layout of 38.4 kWp rooftop PV system (b) String connection layout of rooftop PV system

Fig 1. Layout & string connection of rooftop PV system

3 Results & Discussion

3.1 BIPV System Simulation

BIPV system's output energy performance is directly proportional to the climatic conditions of the geographical location where the system is installed [22,23]. Solar insolation affects current generation in BIPV module, whereas ambient temperature has impact on the output voltage of BIPV modules. Figure 2 shows direct and diffuse solar irradiance at 25 degrees from horizontal and ambient temperature for Lucknow city for a complete year [24,25].

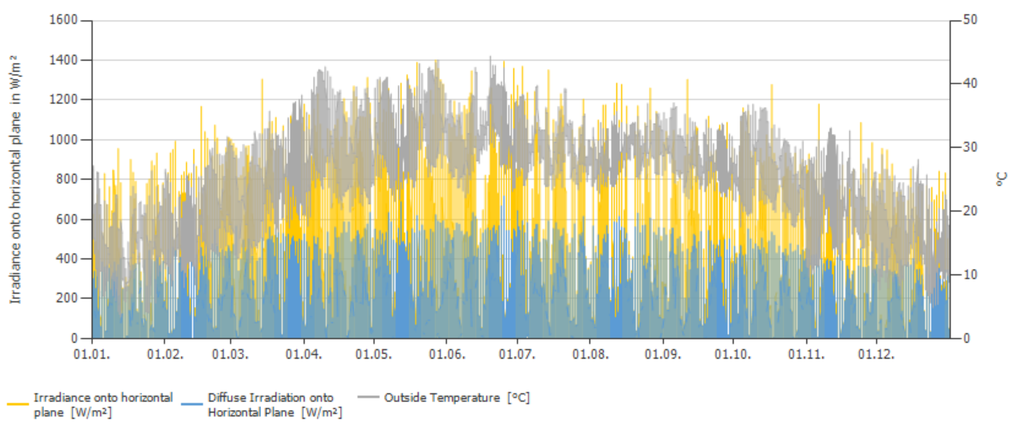
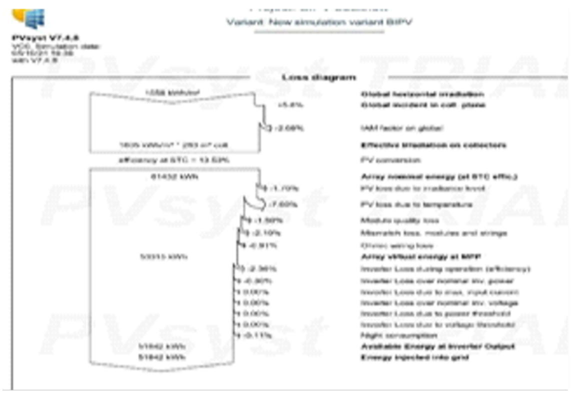


Fig 2. Irradiance & Ambient Temperature Graph

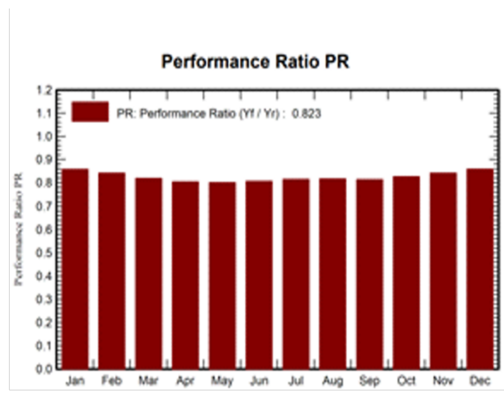
Lucknow city is in subtropical climate with medium to high temperatures during all seasons of year and considerable rainfall during monsoon. Figure 2 shows irradiance and ambient temperature levels includes all metrological parameters for electricity generation using photovoltaic system [25]. The average annual direct irradiance at one minute resolution is 249.53 w/m^2, diffused irradiance is 88.22 w/m^2 and average ambient temperature of 28.71°C [26]. Minimum direct irradiance observed is 154.39 w/m^2 on 17 Dec 9:11 AM, diffused irradiance at 11 Feb 9:23 AM, value is 13.68 w/m^2 and maximum direct irradiance is observed on 6th August 2024 at 12:29 PM, the value was 1,408.32 w/m^2 and diffuse irradiance having value of 458.85 W/m^2 [27,28]. Energy generation of a inverter output of inverter for a year has been forecasted into which minimum energy generated during month of January having value 3,636 kWh/month and maximum generated during month of March having value 5,852 kWh/month whereas annual average monthly energy generated is 4,429.66 kWh [29,30].

Table 3. Overview of BIPV System Parameters

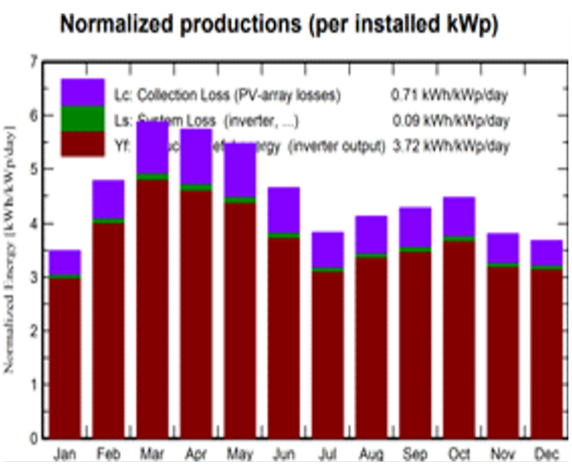
System Information – PV Array		
No. of Modules	156	Units
Pnom Total	38.2	kWp
Performance Ratio (PR)	82.25	%
Produced Energy	51842	kWh/Year
Specific Production	1356	kW h/k Wp/Year
No. of Inverter	5	Units
Pnom Total	30.0	kWac
Pnom Ratio	1.274	



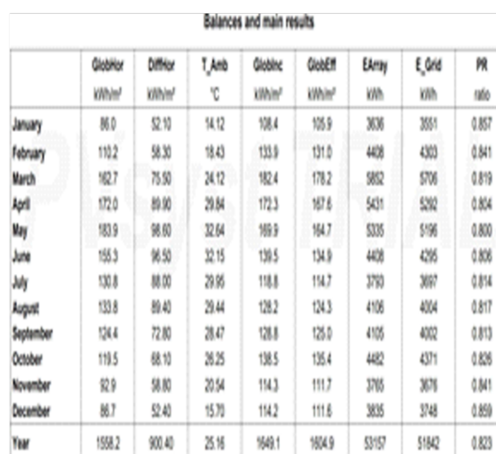
(a) Loss Diagram



(b) Performance ratio (PR)



(c) Normalized Production



Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	ratio
January	86.0	52.10	14.12	108.4	105.9	3636	3551	0.857
February	110.2	58.30	18.43	133.9	131.0	4408	4303	0.841
March	162.7	75.50	24.12	182.4	178.2	5852	5706	0.819
April	172.0	89.90	29.84	172.3	167.6	5431	5292	0.804
May	183.9	98.60	32.64	169.9	164.7	5335	5196	0.800
June	155.3	96.50	32.15	139.5	134.9	4408	4295	0.806
July	130.8	88.00	29.96	118.8	114.7	3790	3697	0.814
August	133.8	89.40	29.44	128.2	124.3	4106	4004	0.817
September	124.4	72.80	28.47	128.8	125.0	4105	4002	0.813
October	119.5	68.10	26.25	138.5	135.4	4482	4371	0.826
November	92.9	58.80	20.54	114.3	111.7	3765	3676	0.841
December	86.7	52.40	15.70	114.2	111.6	3835	3748	0.859
Year	1558.2	900.40	25.16	1649.1	1604.9	53157	51842	0.823

(d) Balances and main results

Fig 3. BIPV Results

3.2 Rooftop PV system

Capacity of rooftop PV system at Integral university is 38.4 kWp. PV modules are installed at a tilt of 10 degrees facing south-west. The monthly production data of the PV system for three consecutive years (2021, 2022 & 2023) & simulated values for BIPV system is collected & presented in Table 4. These data is collected from online dashboard of rooftop PV system developed by QOS Energy's Quantum Data Acquisition Module.

Table 4. Three-Year Energy Production Data

(a) Three Year Energy Production Data

Three-Year Energy Production Data- 38.4kWp PV system-Integral University					
2021		2022		2023	
Month	Production (kWh)	Month	Production (kWh)	Month	Production (kWh)
Jan	2762	Jan	2653	Jan	2681
Feb	3858	Feb	3999	Feb	3918
Mar	5242	Mar	5280	Mar	4715
Apr	5589	Apr	5247	Apr	5106
May	4487	May	4992	May	5339
Jun	3435	Jun	4542	Jun	4867
Jul	3994	Jul	4542	Jul	4281
Aug	3592	Aug	4525	Aug	3777
Sep	3869	Sep	3788	Sep	3750
Oct	4330	Oct	3012	Oct	4194
Nov	3321	Nov	3462	Nov	2979
Dec	2990	Dec	3321	Dec	2930
Average	**3956**	**Average**	**4114**	**Average**	**4045**

(b) Simulated values for BIPV system

BIPV Simulation	
Month	**Performance Ratio (PR)**
Jan	85.7
Feb	84.1
Mar	81.9
Apr	80.4
May	80
Jun	80.6
Jul	81.4
Aug	81.7
Sep	81.3
Oct	82.6
Nov	84.1
Dec	85.9
Average	**82.48**

This monthly generation data of actual rooftop PV system will be compared with simulated generation data for BIPV system in order to assess its validity and hence technical feasibility. From the Table 4, it can be observed that average annual production in kWh is 4,430, while the 3-year annual production average from an actual rooftop PV system is 4,038. The percentage difference between both values is less than 10% (actual is 9.2%). Thus, simulated data is accurate as expected and validated against actual production data. The PR is lower than expected due to various environmental factors such as soiling losses, temperature derating, maintenance & downtime, etc. The highest PR was observed for the month of Apr 2021 – 78.38 % & lowest PR was observed for the month of Jun 2021 – 62.79%. Overall, a difference of 17.32% is observed between simulated & actual values. Table 5 below shows performance ratio data of rooftop PV for three years (2021, 2022 & 2023). The table below shows simulated values for BIPV system. Minimum value for PR is observed for May – 80.00%, while maximum is observed for Dec – 85.90% annual average value is 82.48%. This system can be employed for the colleges, hospitals and similar organisations with larger rooftop areas.

Table 5. Performance ratio data of rooftop PV for three years (2021, 2022 & 2023)

2021		2022		2023	
Month	**Performance Ratio (PR)**	**Month**	**Performance Ratio (PR)**	**Month**	**Performance Ratio (PR)**
Jan	69.7	Jan	69	Jan	67.69
Feb	74.1	Feb	70.2	Feb	68.94
Mar	77.66	Mar	70.21	Mar	73.68
Apr	78.38	Apr	70.8	Apr	68.37
May	63.5	May	70.3	May	69.87
Jun	62.79	Jun	63.56	Jun	63.22
Jul	70.24	Jul	70.89	Jul	70.25
Aug	72.93	Aug	68.1	Aug	71.67
Sep	67.27	Sep	68.92	Sep	70.12
Oct	69.47	Oct	67.36	Oct	71.28
Nov	69.61	Nov	66.19	Nov	69.93
Dec	68.89	Dec	64.58	Dec	66.57
Average	**70.36**	**Average**	**68.34**	**Average**	**69.3**

4 Conclusion

As per the simulation results of the 38.4 kWp BIPV system for Lucknow city, it can be concluded that the system is technically feasible, having an annual average PR of 82.48, and the actual rooftop PV system average PR is 69.33%. As usual, the actual system has around 70% PR value. Minimum energy generation is observed for the month of January, value is 3,636 kWh in PVSyst simulation, actual rooftop system is 2,623 kWh year 2022. Maximum energy generation is observed for the month of March value is 5,852 kWh for PVSyst simulation and for actual rooftop PV system it is month of April 2021, value is 5,589 kWh. Annual average monthly energy generation is observed at 4,430 kWh in PVSyst simulation while actual rooftop PV system is 4,038 kWh. Specific Annual yield of BIPV system is 1,356 kWh/kWp/year. In terms of greenhouse gas equivalencies calculator as provided by US Environmental Protection Agency, annual energy generated through BIPV system resulted in avoiding 3.1 metric tons of CO_2. Also, when results are compared with the simulated results efficiency is found to be impressive. To improve the performance ratio (PR) which is closer to the simulated value of 82.48%, consider regular cleaning of the panels, optimizing tilt angles, and addressing shading issues. Regular maintenance can reduce losses and improve efficiency.

Acknowledgements

The authors of this article are thankful to Integral University, Lucknow, for providing support and communication reference no. (MCN): IU/R&D/2024-MCN0003275. The opinions expressed here are solely the authors' responsibility.

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