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Performance Analysis of Solar PV System of Chitwan Medical College, Chitwan, Nepal

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Abstract
Solar PV systems, both grid-tied and off-grid, have seen widespread adoption globally, serving various purposes such as supplying excess energy to the grid or curbing electricity expenses for industrial and healthcare facilities. A 201.96 kWp solar PV plant, equipped with seven identical 25 kW inverters, was recently installed at Chitwan Medical College in Chitwan. The primary objective was a comprehensive year-long performance assessment, with a subsequent comparison of the actual results against simulations generated by the PVsyst software. Data pertaining to actual energy generation was sourced from the Wattmon Cloud Portal.The core aim of this evaluation was to calculate essential performance parameters for the existing solar installation at Chitwan Medical College. The findings revealed an impressive annual energy generation of 236.99 MWh, accompanied by a commendable performance ratio of 79.80%, highlighting the system's efficiency in converting sunlight into electricity. Additionally, the Capacity Utilization Factor (CUF) was determined to be 13.58%, indicating the consistent utilization of the plant's capacity throughout the year. Notably, the specific yield, measuring energy production per installed capacity, reached a notable 1173.24 kWh per kWp annually. The comparison between real and simulated data highlights significant discrepancies in the solar PV system's performance. These differences underscore the complexities of real-world operation, influenced by environmental factors, maintenance, and component performance. To optimize performance and bridge the gap, ongoing monitoring and maintenance practices are essential. This study emphasizes the need for a holistic approach to enhance real-world solar PV system performance.

Keywords
Photo Voltic, PV system, specific year, Performance Parameters

1. Introduction

Solar Energy, itself is comparatively new and primitively developing field. Renewable energy has been considered as high priority for fuel substitution to produce electrical energy and Solar Photo Voltaic technology is one of the best renewable energy sources. So, either the solar power has to have a provision of being connected to the national grid after production on a national scale or even household purposes, which doesn't quite look possible, or, they should have large battery banks to store the daylight energy to be used later.

Gham Power has set up a solar photovoltaic (PV) system at Nyaya Hospital in Bayalpata, Achham. This system is designed to offer backup power for various essential hospital equipment, including oxygen machines, refrigerators, laptops, routers, printers, lighting, and other machinery. [1].

The solar photovoltaic (PV) industry has historically lacked sufficient data related to rooftop load for solar installations. Also, different parameters are assumed to affect the solar PV efficiency. Some of them are solar irradiance, temperature, shading, soiling, snow and solar efficiency. Usually, the solar panel output varies according to the temperature [2]. The temperature at which solar panels operate is a significant factor affecting their electricity production. It might be a common assumption that increased sunlight and heat lead to greater electricity generation, but this is a misconception. Various types of solar panels respond in distinct ways to the surrounding temperature, yet in all instances, the efficiency of a solar panel decreases as its temperature rises.

Adoption of battery systems for bigger grid-connected PV systems is often discouraged, owing to the significant costs required and the relatively limited battery lifespan. The battery bank's job in such systems is to store DC energy, which is then transformed into AC power by an inverter. The primary goal of this thesis is to carry out a detailed performance analysis of a solar PV plant with the primary objective of identifying potential areas for improvement within the current system.

The International Electrotechnical Commission (IEC) standard 61724 [3] outlines the solar PV performance criteria related to energy generation, irradiation, and different losses within the system. These criteria serve to characterize the overall performance of a photovoltaic system. The primary parameters under consideration for this analysis include the performance ratio, final yield, reference yield, and capacity utilization factor [4].

In 2014, Shrestha and colleagues [5] carried out a techno-economic evaluation of a one MWp solar photovoltaic system located in Trishuli. As to their research, the plant can produce 1768 MWh of energy annually, with a daily yield of 4.81 kWh/kWp, a capacity utilisation factor of 20.18 percent, and a performance ratio of 77.3 percent. Over a 25-year plant life, these results produced an appealing IRR (Internal Rate of Return) of 12%.The study's conclusion emphasises Nepal's utility-scale PVGC (Photovoltaic Grid-Connected) plants' technical and financial potential. These kinds of technologies are thought to be a potential way to deal with the country's energy problems.

A techno-economic analysis was carried out by Bajra and Maharjan [6] on a 64.6 kWp grid-tied solar PV system at Nepal Telecom, Sundhara. A capacity utilisation factor of 14.09% and a performance ratio of 0.859 were found in their investigation. These results offer insightful information about the effectiveness and operation of the solar PV system at the specified location.

An off-grid rooftop solar PV system was the subject of a recent techno-economic analysis by Yemula et al. [7]. According to their analysis, the rooftop solar PV system will cost about Rs. 2.19 lakhs INR and provide a lifetime profit of approximately Rs. 3 lakhs INR over a 25-year period. It was discovered that this system had a payback period of about 10.5 years. The study's notable omission of a thorough examination of solar panel efficiency, meanwhile, suggests that this is a worthwhile area for further investigation.

According to Kazem et al. [8], power output was significantly reduced after just 35 days of dust deposition. The power generation of poly-crystalline panels decreased by 12%, whilst mono-crystalline panels showed a fall of 20%. This demonstrates the significant influence that dust deposition has on solar panel efficiency, emphasising the need for routine cleaning and maintenance to maximise their performance.

B. Shiva Kumar and K. Sudhakar [9] examined the operation of a 10 MW grid-connected solar PV system in India. The study examined the differences between the outcomes and the PVsyst simulations. The capacity utilisation factor was 17.68%, whereas the observed performance ratio was 86.12%. This study's main goal is to compute the real-world performance parameters using the International Electrotechnical Commission's (IEC) standards. Then, it compares the real values with PVsyst's simulated values. The study also attempts to offer suggestions for maximising the current PV system's ability to generate electricity.

2. Methods and Methodology

The study was carried out at Chitwan Medical College in Bharatpur, Nepal, and the following section explains the system in detail.

2.1 Description of Solar System

Chitwan Medical College is located at Bagmati Province, Bharatpur-10, Chaubiskoti, Chitwan at 27.6853°N, 83.4312°E. Nepal receiving annual average insolation of 4.9 kWh/m^2/Day. Bharatpur is a significant and growing city in Nepal, situated in the Terai Plain Area. It is located at an elevation of 196 meters above sea level (MASL). The climate in this region typically experiences extremely hot temperatures during the summer and cold, foggy conditions in the winter.

2.1.1 Block Diagram

The output from each array of solar panel is fed to a combiner box. The combiner box is a connection box, where dc output of various panels in an array is connected.

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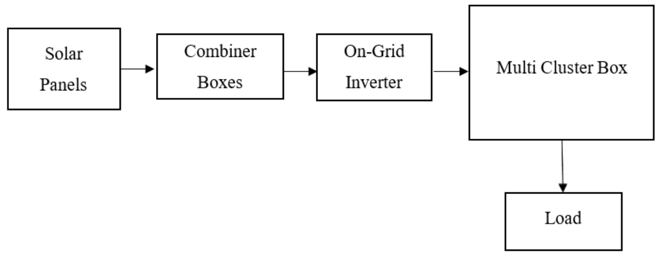

Figure 1: System block diagram existing at Chitwan Medical College

of various panels in an array is connected. The dc output form the combiner box is now fed to On-Grid inverter as shown in Figure 1. The major function of this inverter is to invert the dc signal into ac signal. Each inverter is supplied with input from combiner boxes. Thus, there are altogether Seven inverters, altogether 175 kVA capacity. The output of inverter is fed to multi cluster box, which is a common bus bar for interconnection between load and inverters.

2.1.2 System Layout

The DC output from the combiner box is then directed to the On-Grid inverter. The primary role of this inverter is to convert the DC signal into an AC signal. Each inverter receives inputs from two combiner boxes, resulting in a total of seven inverters with a combined capacity of 175 kVA. The output from these inverters is then connected to a multi-cluster box, serving as a central bus bar for interconnecting various loads and the inverters within the system.

Polycrystalline panels from Trinasolar are positioned on the rooftop of the Main Block and are also installed above the parking areas designated for two-wheelers and four-wheelers around the building perimeter.

2.1.3 Panels

The solar panels utilized in the system are Trinasolar Modules of the polycrystalline variety, with individual ratings of 330Wp. These panels have a Voltage Open Circuit (VOC) of 45.8 V, Current at Maximum Power (IMP) of 8.83 A, and Short-Circuit Current (ISC) of 9.28 A under Standard Temperature and Pressure conditions. In total, the system comprises 612 Trinasolar solar panels, resulting in a cumulative capacity of 201.96 kWp.

2.1.4 Inverter

The system incorporates SMA Sunny Tripower 25000TL inverters, which feature multiple MPPT inputs. These inverters are optimized to operate within a voltage range of 390V to 800V as part of their MPPT functionality.The seven identical On-Grid inverters are with total capacity 175 kVA. The efficiency of grid-inverter is quite high, 98.3% at full load and. The inverters run most efficiently when the PV Voltage is around 600V. The self-consumption of the inverter at night is 1 W.

2.2 Methodology

The performance of the PV system can be categorized into three distinct stages:

- Manually retrieve the system's generation data in kilowatt-hours (kWh) from the Wattmon Cloud Portal.
- Evaluate the system's performance parameters in accordance with the International Electrotechnical Commission (IEC) Standards.
- Estimate the performance parameters of the system through simulation using PVsyst.

The International Energy Agency (IEA) has established standardized parameters for evaluating the energy-related aspects of photovoltaic (PV) systems and their components. These parameters are outlined in the IEC Standard 61724. The primary performance metrics for PV systems include Specific Yield, Performance Ratio, and Capacity Utilization Factor.

For this study, the research period spans one year, commencing in May 2022 A.D. The total energy generation in kilowatt-hours (kWh) has been meticulously recorded and collected through the Wattmon Cloud Portal, providing comprehensive data for analysis.

The Reference Yield (YR) is calculated by dividing the total in-plane irradiance (H) by the PV's reference irradiance (G). This metric represents an equivalent number of hours at the reference irradiance, aiding in the assessment of the sunlight received by the PV system.

The Target Yield represents the theoretical annual energy production on the DC side of the module, focusing exclusively on the energy harnessed from incoming light and the module's nominal efficiency.

The System Yield (Yf) is determined by dividing the net energy output by the installed DC power capacity of the system. It is expressed in units of kWh per kilowatt-peak (kWp), indicating the energy generated per unit of the system's installed capacity. These standardized parameters offer a robust framework for assessing and comparing the performance of PV systems.

$$\text{Specific Yield} = \frac{\text{Actual Energy from the Plant (kWh)}}{\text{Total Plant Capacity (kWp)}}$$

The capacity utilization factor is a significant metric when evaluating the performance of a PV power plant. It serves as a critical indicator of how effectively the plant makes use of its installed capacity to generate electricity over the course of a year. This factor is derived from the comparison between the actual energy output achieved under real-world conditions and the maximum potential output that could be generated under ideal circumstances throughout the year.

Expressed as a percentage, the capacity utilization factor not only provides a measure of the plant's operational efficiency but also offers valuable insights into its ability to consistently and optimally produce electricity. This metric is particularly important for assessing the overall effectiveness and productivity of a solar PV system in real-world conditions.

$$\text{Capacity Utilization Factor} = \frac{\text{Actual Energy from the Plant (KWh)}}{\text{Plant Capacity (KWp)} \times 24 \times 360}$$

The performance ratio, often denoted as PR, is a key metric used to assess the efficiency and quality of a PV plant. It is calculated by comparing the actual energy output of the plant to the maximum energy output that could theoretically be achieved. This metric is valuable because it provides insights into the plant's performance that are independent of its location, making it a reliable measure of quality.

Expressed as a percentage, the performance ratio quantifies the relationship between the actual energy output and the theoretical maximum, highlighting how effectively the PV plant operates. This metric is often referred to as a quality factor and is an important indicator of a PV system's overall performance and efficiency.

$$PR = \frac{\text{Actual Energy from the Plant (kWh)}}{\text{Calculated, nominal plant output in kWh}}$$

3. Results and Discussion

3.1 Observed Primary Parameters

The actual field parameters were acquired with the assistance of the Wattmon Cloud Portal, which serves as a monitoring system.

3.1.1 Monthly generation, Specific Yield, Performance Ratio and Capacity Utilization factor

The Table 1 shows the actual primary measured datas and performance parameters calculation on a monthly basis.

Table 1: Evaluated Performance Parameters

Month	Egen KWh	PR (%)	Yf kWh/kWp	CUF (%)
Jan	15,521.67	65.20	76.84	10.67
Feb	18,225.72	80.79	90.23	12.53
Mar	26,143.94	89.94	129.43	17.98
Apr	22,582.95	85.10	111.80	15.53
May	24,737.72	93.01	122.46	17.01
Jun	19,308.55	84.85	95.59	13.28
Jul	18,382.81	90.57	91.00	12.64
Aug	16,277.53	71.94	80.58	11.19
Sep	17,063.05	75.18	84.47	11.73
Oct	19,945.84	73.55	98.74	13.72
Nov	20,442.25	79.12	101.20	14.06
Dec	18,362.06	68.37	90.90	12.63
Yearly	236,994.10	79.80	1173.24	13.58

The mentioned data shows the monthly variance in the solar PV system's capacity utilisation factor, performance ratio, specific yield, and energy generation. Only 1173.24 kWh/kWp is the annual specific yield; in contrast, the performance ratio is 79.80%. The generation during January was minimum since the sunshine hour during this month is comparative less than other months. The maximum production was during March, April and May. The PR was maximum in May (93.01%) whereas least in January (65.20). The CUF is 13.58%, calculated annually. The tabular data can be represented in graphs as shown in Figure 2.

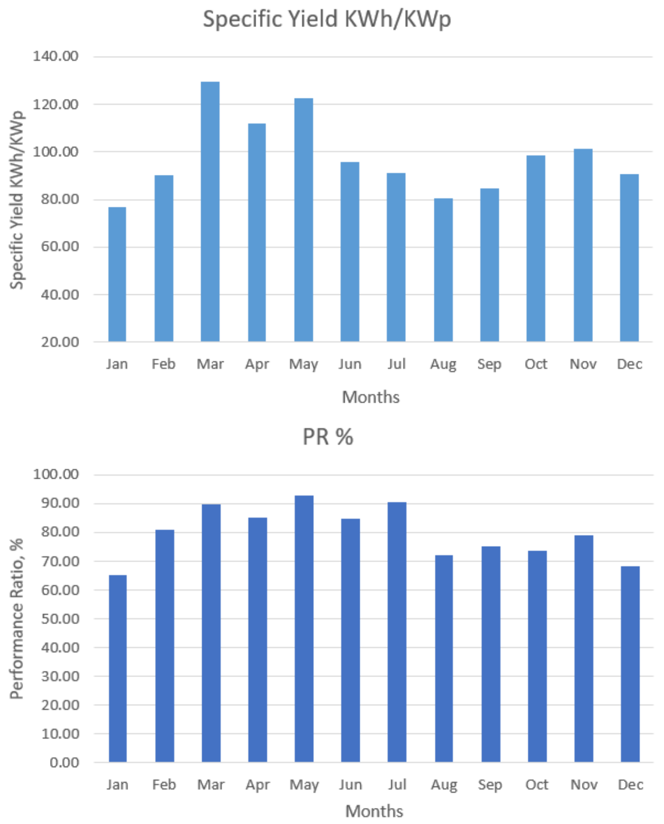

Figure 2: Specific Yield and PR Variation over the year

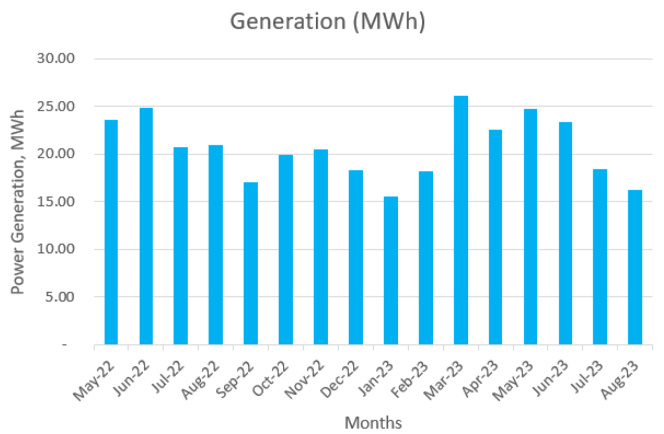

Figure 3: Monthly Energy Variation with Temperature since plant was operating

We can also observe the monthly variations in energy generation over a 16-month period since the installation. Notably, the energy generation during the last three months demonstrated a decrease when compared to the generation during the same months of the previous year, as illustrated in Figure 3.

Chitwan medical college situated alongside the East-West Highway and the maintenance of the road was ongoing so that dust was percipated in the solar panel which decreased the

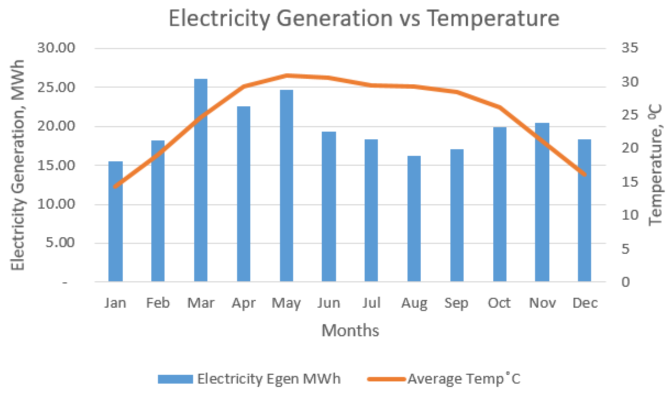

Figure 4: Monthly energy Variation with Monthly Average Temperature

energy generation. Thus, we can monitor the variation of monthly energy generation , with average monthly temperature. The generation in the march was high comparative to the other months as shown in Figure 4.

3.2 Simulated Values using PVsyst

PVsyst is a comprehensive software solution meticulously designed for the meticulous evaluation of solar PV systems. It stands out for its user-friendly interface, an extensive database, and its overall ease of operation. When you employ PVsyst to simulate a PV system, it has the capability to provide estimations regarding the amount of energy that could potentially be exported to the grid if the system were to operate in full conjunction with grid connectivity and net metering.

What further amplifies the effectiveness of PVsyst is its comprehensive database, which encompasses specific models of solar panels and inverters utilized within the existing system. These readily accessible model details can be found in Table 2. This particular feature significantly streamlines the simulation process, increasing its precision and reliability. It is particularly useful for achieving a more accurate representation of the system's performance.

Table 2: Simulation System Array

S.N	Particulars	Result	Remarks
A.	**System Summary**		
1.	No. of Solar Module Required	612	
2.	Number of String	34	
3.	Number of Module in series	18	
4.	Area Covered	1212 m^2	
5.	Number of Inverter Required	7	
6.	Pnom Total	202 kWp	
7.	P nom Ratio	1.154	
B.	Results Summary		
1.	Produced Energy	291287 kWh/year	
2.	Specific Production	1442 kWh/kWp/year	
3.	Performance Ratio	82.89%	

The tabular data can be represented in graphs as shown in Figure 5.

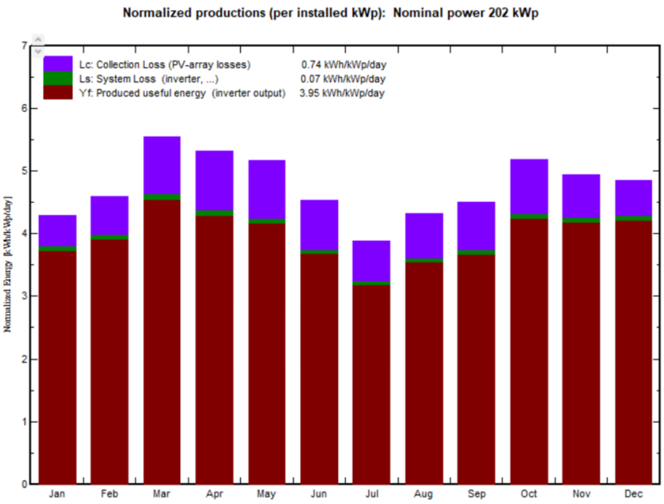

Figure 5: Specific Yield Variation over the year

The monthly specific yield is least during July and maximum during March.

The parameters obtained from PVsyst simulation are shown in Figure 6.

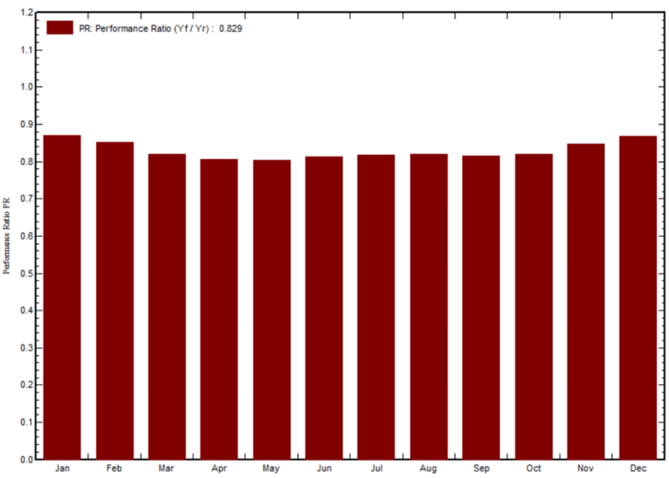

Figure 6: PR Variation over the year

The monthly Performance Ratio (PR) exhibits its lowest value in May (80.50%) and its highest in January (86.9%). The average PR across the months stands at 82.9

Furthermore, the mean values for global horizontal irradiation and global diffuse irradiation are recorded as 1594.7 kWh/m^2 and 860.2 kWh/m^2, respectively. The annual mean temperature is reported at 25.01 °C , and the total annual energy generation amounts to 291,287 kWh, as detailed in Table 3.

The energy loss diagram show that total 344,351 kWh energy generated but only 291,287 kWh injected to the grid with 53,064 kWh losses as shown in Figure 7. The losses are due to irradiance losses, cable losses, inverter losses, etc.

Table 3: Balance and Main Results

New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	98.1	43.7	14.31	133.1	131.3	23807	23372	0.869
February	105.9	56.9	19.10	128.8	126.5	22558	22150	0.852
March	153.9	76.9	24.74	172.1	168.9	29067	28516	0.821
April	160.4	90.7	29.36	159.9	156.3	26536	26040	0.807
May	172.8	100.6	31.01	160.5	156.7	26597	26094	0.805
June	151.7	93.7	30.66	136.0	132.3	22757	22335	0.813
July	133.8	82.1	29.50	120.5	117.0	20297	19926	0.819
August	139.9	87.2	29.36	134.2	130.7	22628	22221	0.820
September	128.9	69.0	28.39	135.4	132.1	22696	22269	0.815
October	135.2	64.9	26.22	160.6	158.1	27118	26599	0.820
November	110.0	50.9	21.01	148.2	146.0	25838	25380	0.848
December	104.0	43.7	16.15	150.7	148.5	26855	26386	0.867
Year	1594.7	860.2	25.01	1740.0	1704.5	296752	291287	0.829

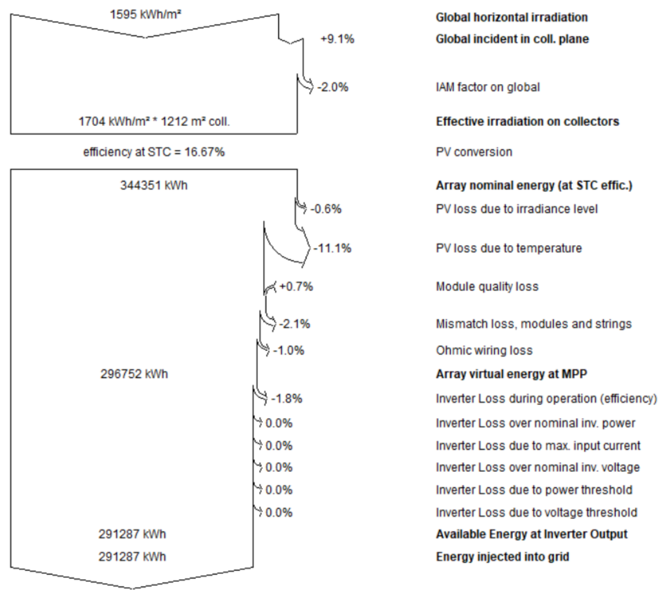

Figure 7: Energy Loss Diagrams

3.3 Comparison between Actual and simulated parameters

The real energy generation and various performance parameters appear to be lower when compared to the simulated values obtained through PVsyst. The yearly analysis is summarized in Table 4.

Energy generation, a fundamental parameter, shows a substantial difference. The actual energy generation, totaling 236.99 MWh, falls notably short of the simulated projection of 291.29 MWh. This gap emphasis the necessity of considering a wide array of real-world variables that can affect energy production, such as environmental conditions, seasonal variations, and component degradation.

The system's energy output per unit of capacity, measured by Specific Yield, varies significantly. The simulated estimate of 1496.08 kWh/kWp is significantly higher than the actual Specific Yield of 1173.24 kWh/kWp. This variation could be

Table 4: Actual and Simulated Parameters Comparison

Annual Data	Actual	Pvsyst	Differences	Units
EGEN	236.99	291.29	54.30	MWh
YF	1173.24	1496.08	322.84	kWh/kWp
CUF	13.58	17.01	3.43	%
PR	79.8	82.9	3.1	%

explained by practical factors that affect the system's overall performance, such as temperature changes, accumulation of dust, and shading.

The Capacity Utilization Factor, a metric that measures how well the system utilizes its installed capacity, is found to be lower in the real-world scenario (13.58%) compared to the simulated outcome (17.01%). This suggests that the system may not be operating at its full potential under actual operating conditions, indicating opportunities for enhancing capacity utilization.

While the Performance Ratio values are close, there is still a small difference between actual (79.8%) and simulated (82.9%) performance. This discrepancy could be attributed to minor differences in component performance, measurement accuracy, or even localized weather fluctuations.

These findings highlight the importance of a thorough understanding of solar PV system performance. While simulations such as PVsyst can be useful throughout the planning and design phases, they may not adequately depict the variety and complexity of reality. Environmental conditions, maintenance methods, and system aging can all influence system performance.

Continuous monitoring, regular maintenance, and optimization tactics are crucial for closing this performance gap. Scheduled inspections, cleaning regimens, and future component upgrades can help real-world performance match simulated expectations more closely. This knowledge is useful not only to system owners and operators, but also to researchers and engineers who want to improve the accuracy of future performance projections in the field of solar PV.

4. Conclusion

The actual data indicates that the annual energy generation was 236,994.10 kWh, with a Performance Ratio of 79.80%, a Capacity Utilization Factor of 13.58%, and a Specific Yield of 1173.24 kWh per kWp per year. In contrast, the PVsyst simulations suggest a higher estimated annual generation at 291,287 kWh, a greater Specific Yield of 1496.08 kWh/kWp per year, a Performance Ratio of 82.9%, and a Capacity Utilization Factor of 17.01%. This clearly illustrates the disparities between the real-world performance and the projected results from PVsyst, indicating areas where the actual system could potentially be enhanced.

5. Recommendations

The solar system at Chitwan Medical College now covers around one-third of the hospital's energy requirement during daylight hours, and a significant section of the solar panels is regularly obscured by dust. Further research can be conducted to determine the precise energy generation losses sustained by the solar plant as a result of dust deposition on the solar panels. This investigation could provide useful insights into the influence of dust deposition and viable strategies to prevent these losses, thereby optimizing the system's performance.

Acknowledgments

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