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Performance Analysis of 5kWpSolar Rooftop Plant using PVsyst Software

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Abstract: The present researchworkfocuses on performance of a 5kWp PV solar system, a second-generation PV technology. The Experimental PV solar system was installed at the rooftop of G.P. Convent School, located in Sankat Mochan Nagar Morar, Gwalior, M.P, India (78.21°E, 26.22°N). The research work compares the real-world performance data from 2024 with findings from the PVsyst simulation program to evaluate how closely the experimental system line up with an ideal simulated model under Madhya Pradesh climate conditions, wherethe study is conducted to evaluate the solar irradiance and compute the technical as well as economic facets of the PV solar rooftop system to supply domestic electrical energy requirements. The total yearlypower generated was6910.2kWh for experimental PV solar system and 7485kWh according to PVsyst software. The yearly global horizontal solar irradiation and diffused horizontal solar irradiation was received as 1664.6kWh/m² and 895.4kWh/m² respectively, in Gwalior, Madhya PradeshIndia. The annual average system and array losses were notes as 0.18 kWh/kWp/day for both experimental and simulated systems, therefore, additional losses were measured at 1.1kWh/kWp/day in experimental system compared to 0.84kWh/kWp/day in PVsyst model.

Keyword: PV module; PVsyst; efficiency; losses; sustainability, economic; environmental

I. INTRODUCTION

Photovoltaic (PV) solar power plants convert sunlight directly into electricity using individual cells that produce one to two watts of power. Although a single cell generates minimal energy, thousands of them grouped into panels or modules can produce substantial power. These panels come in various sizes and are widely used by commercial enterprises, residential properties, and large-scale solar farms operated by utility companies. With industrialization and growing energy demands, the shift toward sustainable development has increased interest in renewable energy. Solar energy is abundant, free, and environmentally friendly, making it a promising alternative to fossil fuels. However, widespread adoption depends on factors like efficiency, cost-effectiveness, and reliability.Renewable energy is defined as energy derived from natural processes that replenish at the same rate they are consumed. The sun's radiation, spanning from infrared to ultraviolet wavelengths, serves as the primary source of renewable energy, enabling both thermal and photovoltaic electricity generation[1]. While PV technology is relatively simple to design and install, it remains one of the more expensive renewable energy options. However, its advantages such as low maintenance and non-polluting characteristics make it an attractive choice [2]. Solar thermal systems, including water heaters, air heaters, dryers, and distillation devices, have advanced significantly in terms of efficiency and reliability, achieving 40%–60% efficiency for low- and medium-temperature applications [3]. Additionally, the cost of PV modules has dropped considerably over the past two decades, increasing their accessibility due to government incentives in many regions.

A. Types of PV system

PV systems can be broadly classified into two major types**:** grid-tied and stand-alone systems. Each type has unique characteristics, advantages, and applications.

1) Stand-Alone PV Systems

A stand-alone PV system, also known as an off-grid system, operates independently of the electrical grid. These systems rely on battery storage to provide power during periods when solar energy is unavailable, such as night time or cloudy days. Stand-alone systems are ideal for remote locations where access to the electrical grid is difficult or impossible. They are commonly used for rural electrification, water pumping, telecommunications, and emergency power supply**.**Figure 1 illustrates a typical stand-alone PV system configuration.

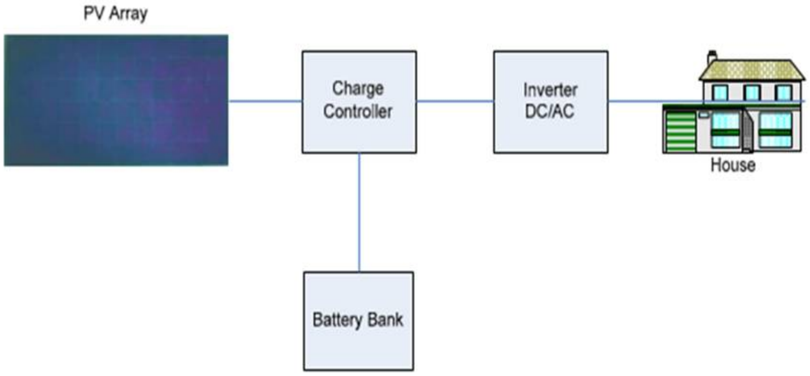


Figure 1 Stand-Alone Photovoltaic System

2) Grid-Connected PV Systems

A grid-tied PV system is directly connected to the electrical grid**.** It allows energy to be fed into the grid when solar production exceeds local demand, and electricity can be drawn from the grid when solar production is insufficient. This setup eliminates the need for battery storage, making the system more cost-effective and easier to maintain**.** One of the biggest advantages of grid-tied systems is their ability to reduce electricity costs**.**Figure 2 illustrates a typical grid connected configuration.

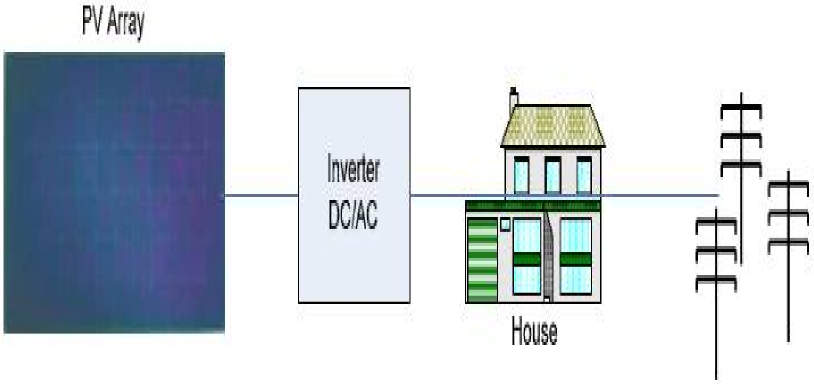


Figure 2 Grid-Tied Photovoltaic System

B. Types Of Solar Power Plants

Various types of solar power plants are designed to suit different environments and energy needs. Below are the main categories of solar power systems, along with their advantages and applications[4].

1) Rooftop Solar Plants

Rooftop solar panels are among the most common renewable energy systems. They can be seen on residential homes, businesses, and industrial buildings. These panels are mounted on either flat or angled roofs to optimize sunlight exposure while remaining unobtrusive.

2) *Ground-Mounted Solar Plants*

Not all roofs are suitable for solar panel installations, and some organizations may require more energy than rooftop panels can generate. In such cases, ground-mounted solar panels offer a practical alternative. These panels are installed directly on the ground, providing a reliable energy source for nearby homes and businesses.

3) Floating Solar Plants

Floating solar panels are designed for bodies of water, such as reservoirs, retention ponds, and lakes. These solar arrays rest on floating platforms and generate electricity while minimizing land use.

4) Concentrating Solar Power (CSP) Plants

Concentrating solar power (CSP) systems are designed to capture and focus the sun’s energy onto a specific point to generate thermal energy, which can then be stored for later use. Unlike traditional photovoltaic (PV) panels, which are flat and evenly absorb sunlight, CSP systems utilize mirrors and precise angles to direct a greater concentration of solar energy to a single location. This technology is widely used in industrial applications and large-scale power generation.

Mahdi Hossain Nabil et al. (2024) studied the implementation of a 15 MW on-grid solar PV system in Bakalia Char, Chittagong, Bangladesh, with the objective of assessing its performance and economic viability. Furthermore, the findings of this study aim to contribute valuable insights for the Bangladesh Power Development Board (BPDB) in advancing clean energy initiatives across the country. The results reveal that the system operates with a remarkable performance ratio of 84.03%, generating approximately 21,510.186 MWh of electricity annually. Economically, the system proves to be highly viable, offering a short payback period of 4.5 years, a competitive electricity cost of 0.024 USD/kWh, and an impressive return on investment (ROI) of 389%.Moreover, the system offers significant environmental advantages, with an estimated reduction of approximately 252,168.5 tons of CO2 emissions over its operational lifespan. This project serves as a benchmark for future solar energy developments in regions facing similar energy challenges, highlighting the potential of renewable energy in fostering economic and environmental sustainability [5].Wang et al. (2024) focused on the development of a 50 MW photovoltaic (PV) + energy storage power generation system, designed and optimized using PVsyst software. A comprehensive system architecture and energy storage capacity plan have been proposed to enhance the efficiency and performance of electrochemical energy storage systems within photovoltaic power stations. By utilizing PVsyst simulation tests, the study evaluates the operational effectiveness of the integrated system under varying conditions.Notably, the majority of incident solar radiation falls within the 380–900 W/m² range, with an energy density distribution of 25–60 kWh/m² per bin [6].Baqir M et al. (2022) presented a detailed simulation and performance evaluation of the **700 kWp solar power plant in Daykundi province** using **PVsyst software**. The findings emphasize the growing potential of **solar energy technology** as a viable and sustainable solution for Afghanistan’s energy needs, offering a path toward greater **energy independence** and rural electrification. Afghanistan is currently facing a severe energy crisis, relying heavily on electricity imports from neighbouring countries such as Iran, Uzbekistan, Tajikistan, and Turkmenistan. Each year, the country spends approximately **$280 million** to import **670 MW** of electricity, yet many rural areas still suffer from energy shortages. To address this challenge, the Afghan government has set an ambitious goal of generating **5,000 MW** of renewable energy by **2032**, with **1,500 MW** specifically allocated for solar power projects. According to the **Afghanistan Renewable Energy Union (AREU)**, solar energy is expected to account for **30%** of the nation's electricity demand by that time. Among Afghanistan’s provinces, **Daykundi**stands out for its **abundant sunlight**, making it a promising location for solar energy generation. A **700 kWp grid-connected solar power system**has been designed and tested using **PVsyst software**, demonstrating an **annual energy production of 1,266 MWh**and a **performance ratio of 0.797**. Since an optimal **power factor typically ranges between 0.7 and 0.9**, these results confirm that the system operates efficiently under real-world conditions [7].

Kumar R et al. (2022)focused on the case study on assessing the **energy load requirements** of the **Mechanical Engineering Department office** at an engineering college in **Bikaner** and subsequently designing and installing a **standalone solar PV system**. The system's performance and efficiency were analysed using **PVsyst simulation software**, with a particular focus on **performance ratio (PR) and system losses**.The findings indicate that the department's **average annual energy demand**is **1,086.24 kWh**, while the solar PV system generates **1,143.6 kWh**annually. However, the**actual energy supplied to the users**amounts to**1,068.12 kWh**, slightly below the required load due to various **system losses**. The **performance ratio analysis** reveals seasonal variations, with the highest PR recorded in **December at 86%**, while the lowest PR was observed in **April at 64%**, leading to an **annual average PR of 72.8%**. The study highlights the impact of **system losses** on power output, emphasizing the need for **efficient solar PV system design and optimization** to maximize performance. These findings contribute valuable insights into the feasibility and challenges of implementing **standalone solar PV solutions** for institutional energy needs [8]. Mohammad Parhamfar, and Alireza Zabihi (2025) examined the design and implementation of a 100-kW rooftop solar power plant in Arak, Iran, highlighting key challenges and best practices for optimizing bifacial PV systems. One of the most complex aspects of bifacial panel deployment is the accurate assessment of rear-side radiation, which directly impacts energy generation. Proper row spacing and shading prevention strategies are essential to enhance efficiency. Additionally, determining the ideal installation angle and panel height above the ground is critical for maximizing energy capture [9].

This research aims to conduct an experimental performance evaluation of a 5 kWp solar rooftop plant and validate the results using PVsyst software. The specific objectives of this study include:

a) To analyse the actual energy generation and performance of a 5 kWp rooftop solar plant under real environmental conditions, including variations in solar radiation, temperature, and system losses.
b) To validate PVsyst simulation results with experimental data by comparing predicted and actual performance metrics such as energy yield, efficiency, and capacity utilization factor (CUF).
c) To evaluate the financial and economic viability of a 5 kWp solar rooftop plant by analysing cost-benefit aspects, payback period, and return on investment under real-world conditions.

II. MATERIAL AND METHODS

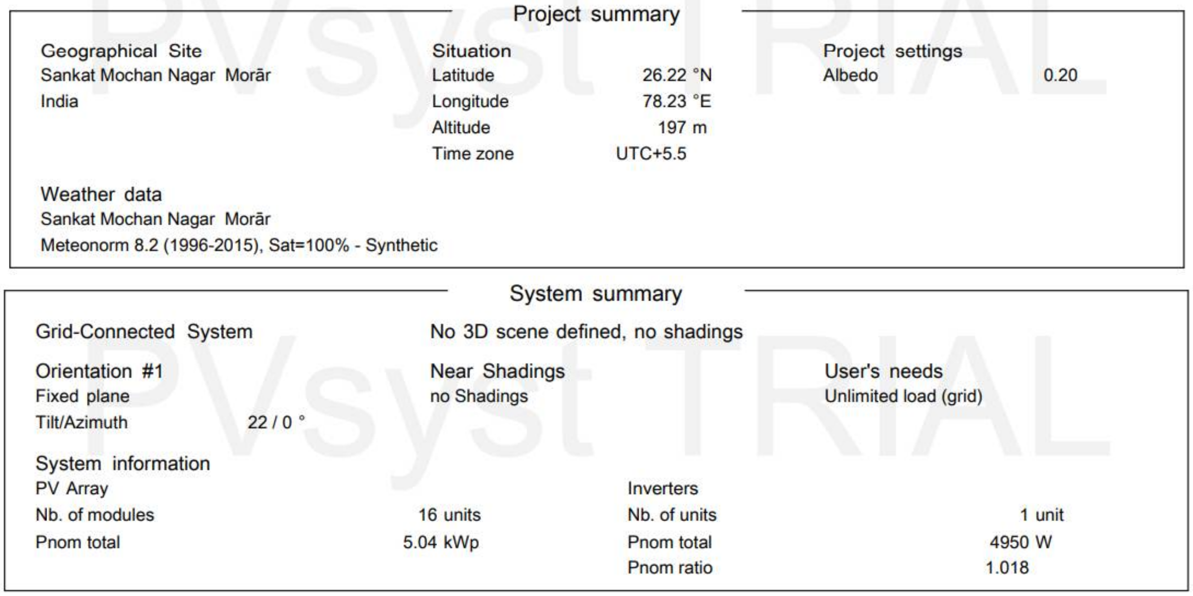
This section deals with the location 0f site and specification of installed PV solar system.

A. Simulation Modeling of a PV Solar System

PVsyst 8.0.6 is an advanced software tool designed for the simulation and modeling of PV solar systems. It offers a comprehensive solution for designing grid-connected, pumping, standalone, and DC grid PV systems. The software is user-friendly, requiring only a few known variables, and provides detailed insights into the sizing of systems, no. of inverters, number of PV arrays, and the overall system performance analysis [10]. For this simulation, G.P. Convent School, located in Sankat Mochan Nagar Morar, Gwalior, M.P, India (78.21°E, 26.22°N), was selected as the site for analysis (Figure.3).

Figure:3 Location of Site

The following project summary and system summarywere considered for the simulation and modeling of the solar photovoltaic system. The PV array characteristic is demonstrated in Figure 4.



Project summary

Geographical Site
Sankat Mochan Nagar Morār
India

Situation
Latitude 26.22 °N
Longitude 78.23 °E
Altitude 197 m
Time zone UTC+5.5

Project settings
Albedo 0.20

Weather data
Sankat Mochan Nagar Morār
Meteonorm 8.2 (1996-2015), Sat=100% - Synthetic

System summary

Grid-Connected System
No 3D scene defined, no shadings

Orientation #1
Fixed plane
Tilt/Azimuth 22 / 0 °

Near Shadings
no Shadings

User's needs
Unlimited load (grid)

System information
PV Array
Nb. of modules 16 units
Pnom total 5.04 kWp

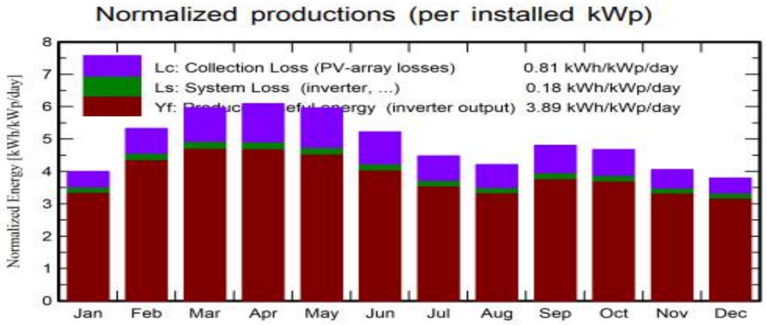
Inverters
Nb. of units 1 unit
Pnom total 4950 W
Pnom ratio 1.018

Figure 4 Demonstrated the PV array characteristic

III. RESULT AND DISCUSSION

A. Calculation Of Electrical Energy Generation

Figure.5 represents the monthly generation of electrical power as well as solar irradiance in the collimated plane. Lower value of generated electrical power was noted as 588kWh, due to low solar insolation, clouds, and rain in December. Therefore, the higher value of electrical power generation (885kWh) was achieved in month of June due to higher solar intensity, clear sky, as well as long day. The solar irradiances fluctuate from 4590.2kWh to 7612kWh in Dec and Jun, due to rainy as well as partially cloudy day and arid summer day, respectively. In twelve months, the generation of electrical power was 6910.20kWh, therefore a monthly average of 575.5kWh. It was noted that the electrical energy produced during the 12 months over nominal power of photovoltaic solar system was 1795.5kWh/kWp. The temperature was also fluctuated in the range of 17.2 to 45.2°C in the months of Jan and July respectively, therefore the annual average of the highest temperature was noted as 31°C. It was observed that, despite the high temperatures in June, which reduced the efficiency of the photovoltaic solar system, the maximum electrical energy production was still noted this month. This is mainly because June has the longest daylight hours (15 hrs) and the highest solar irradiance intensity. In another aspect, December sees lower energy production because of its shorter daylight hours (9 hrs) and lower solar radiation intensity.Table 1 indicate the of balance sheet of PVsyst results.



Figures 5 shows the trends of normalized energy generation,

B. Determination Performance Ratio

Figures 6 indicates monthly average performance ratio (PR) of actual system and PVsyst software respectively. The annually average PR for experiment system was 81.01%, with maximumvalues recorded in Jan and Dec (84.1%) and the minimum in July (77%). PR serves as an indicator of how closely the experimental system operates to its theoretical maximum performance.PR of the system tends to drop in May, June, July, and Aug, mainly because of high temperatures throughout these months. When comparing annually average PR of the experimental system (81.01%) at an annual average temperature of 31°C with the PVsyst simulation result (79.7%) at 25.5°C, the difference is small. This suggests that the experimental system performs very well despite the higher atmospheric temperature, indicating that it is not significantly affected by extreme heat.

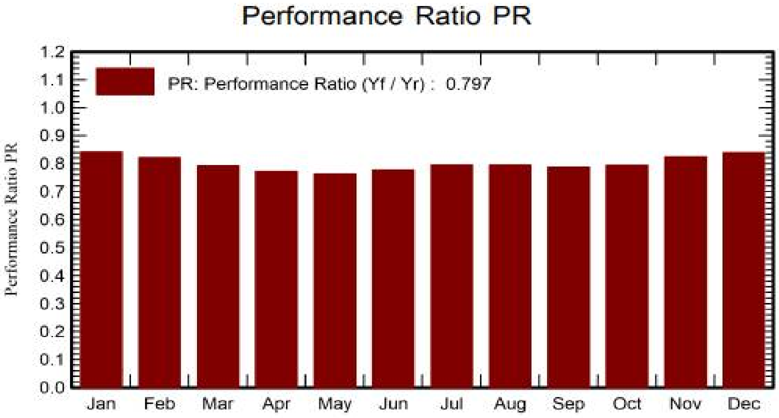
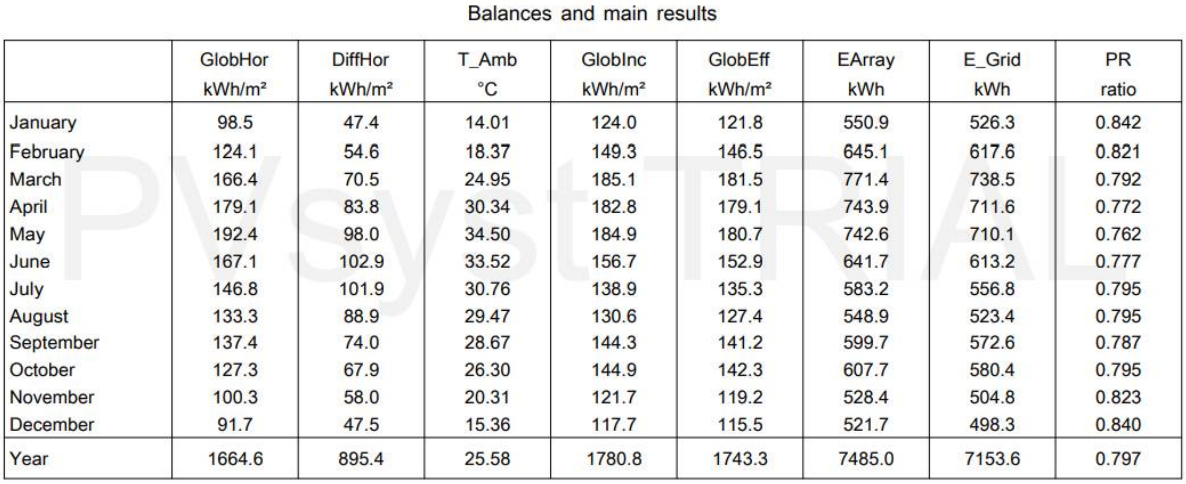


Figure 6Representation of performance ratio of PVsyst software

Table: 5.1 indicate the of balance sheet of PVsyst results.



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	98.5	47.4	14.01	124.0	121.8	550.9	526.3	0.842
February	124.1	54.6	18.37	149.3	146.5	645.1	617.6	0.821
March	166.4	70.5	24.95	185.1	181.5	771.4	738.5	0.792
April	179.1	83.8	30.34	182.8	179.1	743.9	711.6	0.772
May	192.4	98.0	34.50	184.9	180.7	742.6	710.1	0.762
June	167.1	102.9	33.52	156.7	152.9	641.7	613.2	0.777
July	146.8	101.9	30.76	138.9	135.3	583.2	556.8	0.795
August	133.3	88.9	29.47	130.6	127.4	548.9	523.4	0.795
September	137.4	74.0	28.67	144.3	141.2	599.7	572.6	0.787
October	127.3	67.9	26.30	144.9	142.3	607.7	580.4	0.795
November	100.3	58.0	20.31	121.7	119.2	528.4	504.8	0.823
December	91.7	47.5	15.36	117.7	115.5	521.7	498.3	0.840
Year	1664.6	895.4	25.58	1780.8	1743.3	7485.0	7153.6	0.797

C. Calculation of Losses

PV modules and arrays experience various kinds of losses, including wiring losses (1.5%), module quality losses (2.5%), and module mismatch losses (2%). These all losses primarily result from temperature variations, module inconsistencies, as well as wiring inefficiencies.After accounting for inverter losses, the total amount of energy delivered to grid is computed. The final energy output from the PV system for load/grid is evaluated to be 7153.6 kWh. This value is attained after applying multiple loss corrections within PVsyst software, as presented in Figure.7.

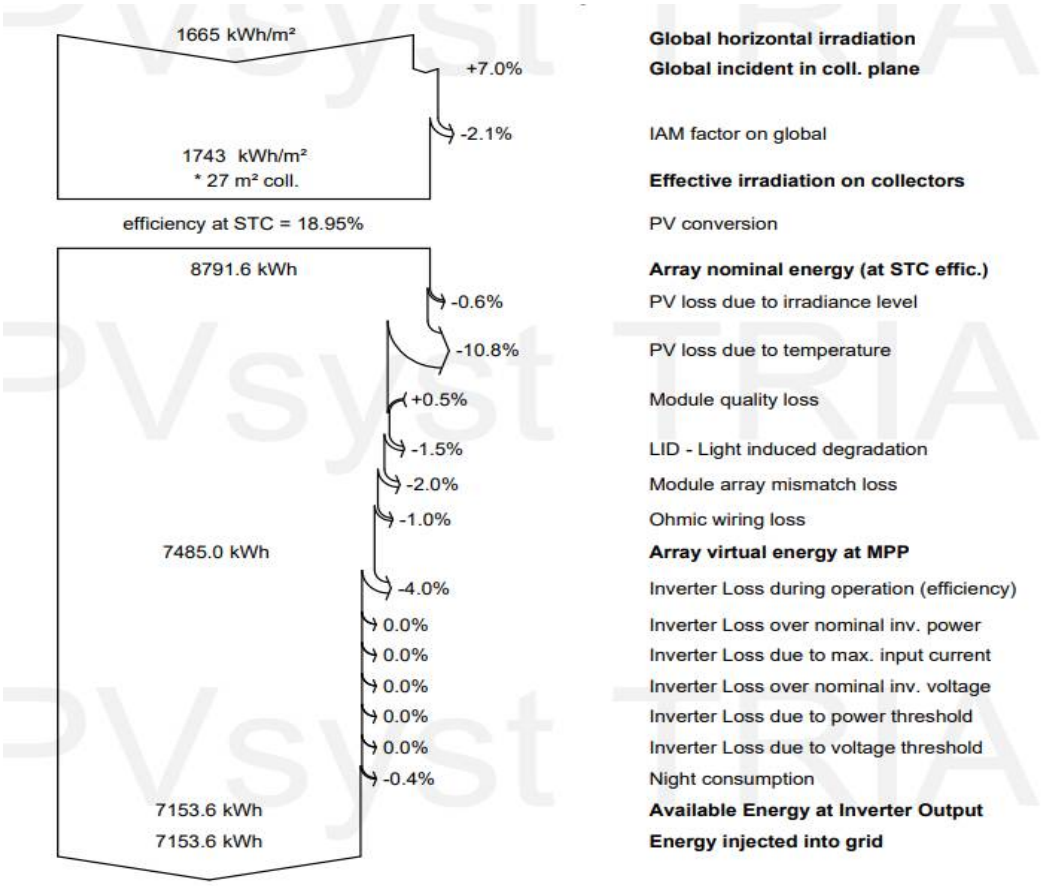


Figure 7Demonstration of losses

IV. CONCLUSION

A Photovoltaic solarsystem was designed using PVsyst software to assess the energy requirements for aninstitutional building's total load of 5.00kWp. The PVsyst simulation provided valuable insights into the performance of the PV modules. The results indicated that as load demand decreases, the performance ratio increases, and power generation remains proportional to load. Further analysis confirmed that the system performs well and is capable of reliably supporting a load of approximately 5.00kWp.

1) The variance between the PVsyst simulation results and the actual performance of the experimental system was minimal, despite the PVsyst model assuming an annual average temperature of 25.5°C, while the experimental system operated at 31°C.
2) In terms of efficiency, the experimental system closely matched the performance of PVsyst simulation, with comparable energy losses between the two.
3) The outcomes highlight that PV solar system technology performs remarkably well under real-world conditions, even though the PVsyst model signifies an ideal scenario unaffected by clouds, rain, as well as dust. The experimental PV solar system, operating under a higher average temperature of 31°C, demonstrated resilience against Gwalior, Madhya Pradesh India.

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