Analyzing the Outdoor Performance of Different Types of PV Module Technologies

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Abstract. The purpose of the extension project is to find out the practical applicability and performance of various solar module innovations in real outdoor conditions. By systematically measuring voltage and monitoring electricity production, the research aims to produce valuable research data that can inform and guide local and global stakeholders in the optimization and implementation of various solar energy innovations. The research focuses on the comparative analysis of three visible PV module types - monocrystalline, polycrystalline and amorphous silicon. The study focuses on collecting daily routine performance parameters of these modules to provide meaningful and actionable information. The project recognizes the importance of evaluating solar panel technologies in real outdoor environments, as performance in controlled laboratory environments may not accurately reflect real-world conditions. Therefore, the research uses a comprehensive methodology that combines rigorous data collection techniques with advanced monitoring systems. To ensure the reliability and validity of the findings, a large experimental setup will be established in an outdoor environment that promotes the collection of solar energy. Each type of PV module is strategically placed to receive optimal sunlight throughout the day, minimizing potential shading and obstructions. An advanced data acquisition system continuously measures and records the voltage readings of the modules. In addition, the system closely monitors power generation to capture performance fluctuations over time.

1 Introduction

The growing global demand for sustainable energy solutions has brought solar energy to the forefront of renewable energy sources. Central to solar technology, photovoltaic panels play a key role in converting sunlight into electricity. However, the performance and behavior of monocrystalline, polycrystalline, and amorphous solar panels can experience significant differences when exposed to real-world conditions [1]. Focusing on the practical operation of these panels, this study integrates voltage and current sensors to collect comprehensive data. Delving into nuanced operational aspects, the goal is to provide key insights for renewable energy decision makers. The goal is to facilitate the demanding choice of the most suitable solar panel technology, adapting the choices to project-specific requirements and environmental complexity. With the global desire for sustainable energy, solar energy has risen to the forefront among viable options.

Photovoltaic panels, the cornerstone of photovoltaic innovation, play a key role in harnessing sunlight to generate electricity. However, the efficiency and effectiveness of monocrystalline, polycrystalline, and amorphous solar panels can vary significantly under real-world outdoor conditions. Based on a thorough review of their specific performance, this study uses voltage and current sensors to accurately collect operational data. By providing nuanced perspectives to renewable energy decision makers, the study aims to improve the identification of optimal solar panel technology [2]. This requires careful consideration of project-specific needs and environmental complexities to ensure a tailored approach to implementing sustainable energy. The multifaceted nature of solar technology requires a comprehensive understanding of how it actually works [3]. Monocrystalline, polycrystalline, and amorphous solar panels represent different approaches to harnessing solar energy, each with their own unique advantages and limitations. However, their performance in real-world conditions can differ significantly from laboratory-based simulations.

This study addresses this gap by applying voltage and current sensors to gather detailed information about the actual performance of these panels. By examining performance indicators such as voltage productivity and energy production, the study aims to provide decision makers with practical insights into the practical performance of various solar panel technologies [4]. As the global community increasingly embraces sustainable energy solutions, the importance of accurate

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performance assessment becomes paramount. Renewable energy decision makers are tasked with navigating complex technology options, each with specific nuances and trade-offs [5]. This study aims to empower these decision makers by providing empirical evidence on the performance of monocrystalline, polycrystalline and amorphous solar panels under real outdoor conditions. Using voltage and current sensors to collect real-time data, the study aims to bridge the gap between theoretical expectations and practical results. Ultimately, the goal is to facilitate informed decision-making and promote widespread adoption of efficient and reliable solar technologies [6].

2 Materials and strategies

2.1 Outdoor measurement

The research evaluation will be conducted in a college yard in Hyderabad, an area known for its dry climate and intermittent rainfall, especially in September. The solar radiation in the area varies and the peak levels of the modules are 300-600 W/m2. Temperature fluctuations vary between 16 °C and 48 °C, reflecting the different environmental conditions characteristic of the region. The test platform contains three types of photovoltaic modules using different technologies: monocrystalline silicon, polycrystalline and amorphous. These modules will be installed and evaluated on an experimental photovoltaic platform. The support structures are fixed and oriented south at an angle that optimizes exposure to sunlight for maximum energy production [7], [8].

Table 1 provides an overview of the essential electrical characteristics provided by the manufacturer for each module type.

Table 1. Solar panel characteristics.

PV Technology	Mono Crystalline	Poly Crystalline	Amorphous
Maximum Power	250-400 W	200-350 W	100-250 W
Efficiency	15 %	13%	8%
Voltage	24V	24V	24V

In the test phase, the modules are exposed for a month under reliable on-site conditions, which provides a longer period for in-depth observation and data collection. At the same time, a data logger is used to monitor the power output of each solar module. This comprehensive monitoring ensures that all relevant module performance data is accurately collected. The experiment uses a voltage sensor, a current sensor and a data acquisition device with the technical characteristics shown in Table 2, and it facilitates the collection of solar current and voltage measurement data [9], [10]. These sensors and data acquisition equipment were carefully selected to ensure the accuracy and reliability of data collection, allowing researchers to reliably interact with the modules on site for a month during a detailed testing phase, allowing a longer period for in-depth study. observation and data collection.

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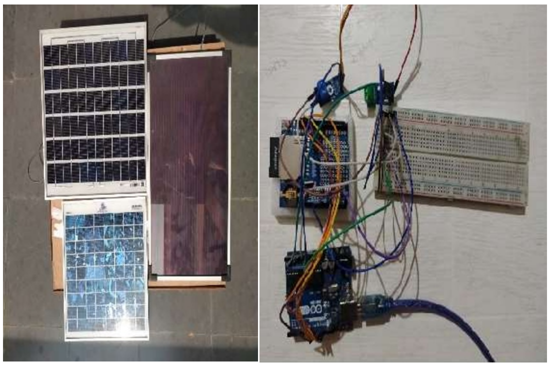

(a) (b)

Fig. 1. (a) Platform containing PV modules, Voltage and Current Sensors. (b) Data acquisition device.

Table 2. Technical characteristics of the data acquisition system.

Parameters	Voltage Range	Current Range
Voltage	0-25V	--
Current	--	0-10A

The operating mechanism of this data logger is based on the use of Data Logger software, which facilitates the configuration of channels, measurement areas and data collection sampling intervals [11], [12]. In practice, the device is connected to a computer where the Data Logger software is installed, enabling real-time measurement processes and continuous recording of collected data. Through a software interface, researchers can flexibly change various parameters such as channel settings and sampling rates, ensuring accurate data collection tailored to the specific requirements of the experiment. This integrated approach streamlines the data collection process, allowing seamless monitoring of the electrical characteristics of PV modules over long periods of time. In addition, the real-time measurement capabilities provided by the Data Logger software allow researchers to quickly identify variations or anomalies in module performance, facilitating timely adjustments or interventions when necessary. In general, the use of Data Logger software improves the efficiency and accuracy of data collection, which contributes to the reliability and robustness of test results.

3 Outcomes and discussions

This paper provides a comprehensive overview of the performance of three different photovoltaic technologies - monocrystalline, polycrystalline and amorphous - by analyzing data collected on site during a specific monitoring period. This study focuses on specific metrics such as daily average solar radiation, productivity, voltage and current, which provide valuable information about the performance of each PV technology under real-world conditions. Figure 2 visually illustrates the dynamic daily variation of solar radiation levels at the module level in September 2023, showing a wide range of intensities from 3 kW/m2 to 90 kW/m2. Such variability highlights the critical importance of considering environmental factors when evaluating PV module performance. The focus of this study is a careful analysis of field data to determine the performance characteristics of each solar technology. By evaluating the daily average solar radiation, the research aims to quantify the amount of sunlight received by photovoltaic modules, which provides important information about their energy absorption capacity. In addition, evaluating the daily average efficiency provides valuable information about the efficiency of each solar technology in converting solar energy into electricity. This analysis is completed by an overview of the daily average voltage and current, which provides an overview of the electricity production and overall performance of the PV modules under different environmental conditions. Together with the analysis of the daily average solar radiation, the temperature fluctuations observed during the observation period are studied. In addition to solar radiation data, a noteworthy description of temperature fluctuations, where the highest and lowest daily average temperatures of certain days are measured. This highlights the important influence of environmental factors, especially temperature, on the performance of PV modules.

Understanding the complex interaction between solar radiation, temperature and electrical parameters is critical to optimizing the design and operation of solar energy systems and maximizing energy production. The purpose of this research is to help better understand the working dynamics of different solar technologies through accurate analysis of data collected on site. By providing valuable insights into their performance under real conditions, the study aims to enable renewable energy stakeholders to make informed decisions in the selection, design and implementation of solar energy systems. Ultimately, the goal is to promote the adoption of sustainable energy solutions and advance the global transition to a more sustainable future. This article provides a comprehensive overview of the performance characteristics of three different photovoltaic technologies (monocrystalline, polycrystalline and amorphous). — analysis of on-site data collected during a specific monitoring period. This study focuses on specific metrics such as daily average solar radiation, productivity, voltage and current, which provide valuable information about the performance of each PV technology under real-world conditions. Figure 2 visually illustrates the dynamic daily variation of solar radiation levels at the module level in September 2023, showing a wide range of intensities from 3 kW/m2 to 90 kW/m2. Such variability highlights the critical importance of considering environmental factors when evaluating PV module performance.

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Figure 3 shows the average productivity data for each PV technology over the entire test period. The calculated average efficiency of monocrystalline, polycrystalline and c-Si Amorphous modules are 15.12%, 12.65% and 8.12%, respectively. These results show a direct relationship between modular technology and its performance parameter. However, a comparison of the calculated average efficiencies with the standard nominal efficiencies provided by the manufacturers, as shown in Figure 3, shows a significant difference. The test results show a decrease in efficiency compared to the Standard Test Conditions (STC) values specified by the manufacturers.

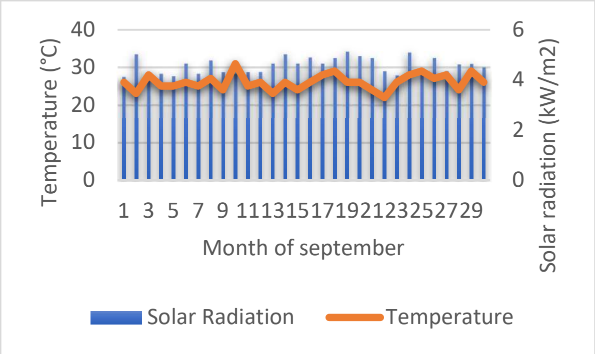

Fig. 2. Daily averages of solar radiation.

This decrease is mainly due to the increase in the temperature of the PV modules, which increases the energy losses. This difference highlights the importance of considering real conditions and temperature variations when evaluating the actual performance of PV modules, which deviate from the ideal conditions assumed by standard test protocols. The observed difference between calculated and nominal efficiency highlights the need for a better understanding of PV module efficiency under real operating conditions. Although manufacturers typically provide performance ratings based on standardized testing protocols, real-world factors such as temperature fluctuations can significantly affect performance.

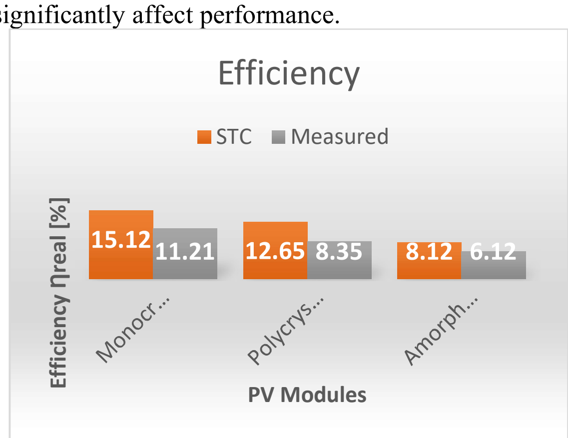

Fig. 3. Efficiency of PV modules.

The experimental results presented in Figure 3 illuminate the practical implications of these differences and provide valuable information for stakeholders in the renewable energy sector. By quantifying the deviation from calculated and nominal efficiency, the study emphasizes the importance of considering environmental variables in the design and operation of a solar energy system. In addition, the findings highlight the importance of robust data collection and analysis methods to accurately assess PV module performance. Using data collected on site over a long monitoring period, the study provides a comprehensive assessment of the effectiveness of various solar technologies. This approach allows a more realistic assessment of performance, taking into account factors such as temperature fluctuations and environmental conditions. The results presented in Figure 3 are a critical benchmark for evaluating the effectiveness of PV module technologies in real-world applications and provide valuable guidance for decision-making in the renewable energy sector. The research will continue to emphasize the need to continue research and innovation to meet the challenges arising from real working conditions. By improving test protocols and developing advanced modeling techniques, researchers can improve the accuracy of efficiency predictions and optimize a PV system. Ultimately, the goal is to promote the adoption of sustainable energy solutions by providing stakeholders with reliable information and knowledge about decision-making processes. By working with universities, industry and policy makers, the renewable energy sector can overcome existing barriers and accelerate the transition to a more sustainable energy future.

Figure 4 presents a comprehensive analysis of the deviation of the upgrade qualification rate for each PV module, showing the calculated values of 24.6%, 25.83% and 33.99% for amorphous, monocrystalline and polycrystalline modules, respectively. In particular, Polycrystalline technology has the highest deviation, which is in stark contrast to amorphous modules, which show the lowest deviation of 24.6%. This striking contrast highlights the robust performance of Amorphous technology, especially in adapting to the complex temperature conditions that modules experience in real outdoor environments. This difference in deviations reveals important insights into the dynamic performance of each technology under different environmental factors. The observed significant deviation in the polycrystalline efficiency indicates an increased sensitivity to the conditions prevailing during the monitoring period. In contrast, the relatively smaller deviation of the amorphous efficiency emphasizes its flexibility and adaptability to different temperature scenarios. Understanding these efficiency variations is critical to optimizing PV technology selection based on real-world conditions.

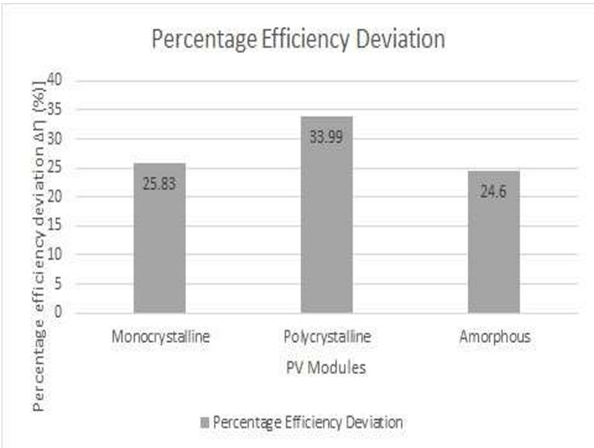

Fig. 4. Percentage deviation efficiency of PV modules.

The data not only illuminates the different performance of amorphous, monocrystalline and polycrystalline modules, but also provides practical insights for decision makers seeking to improve the efficiency and reliability of solar energy systems. In addition, deviations in the qualification rate provide valuable information about the adaptability and stability of each PV module technology under different environmental conditions. By quantifying the extent of deviation from expected levels of efficiency, the study provides a nuanced understanding of how different technologies perform. This information can inform strategic decisions about the deployment and optimization of solar energy systems, ultimately driving the adoption of renewable energy. Through continuous research and improvement in solar technology, stakeholders can use this knowledge to develop more sustainable and efficient solar energy solutions that meet the requirements of real-world applications. The findings in Figure 4 underline the importance of considering environmental factors and technology-specific characteristics in the design and implementation of solar electric systems, which ultimately promotes development towards a more sustainable energy future.

Figure 5 presents a detailed overview of the voltage profiles of different PV module technologies, showcasing average calculated values of 17.5V, 16.25V, and 13.56V for Monocrystalline, Polycrystalline, and Amorphous modules, respectively. Notably, the Monocrystalline module achieves the highest voltage at 17.5V, while the Amorphous module records the lowest value at 13.56V. This distinction underscores the remarkable voltage performance of Monocrystalline technology, particularly notable in confronting the harsh temperature conditions experienced by the modules in real outdoor environments.

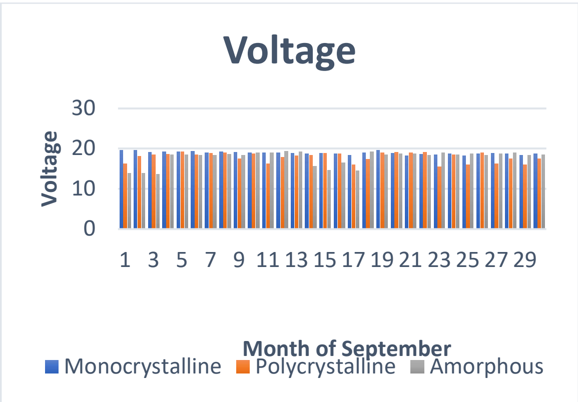

Fig. 5. Voltages of PV modules.

The significant variation in voltage values highlights the substantial impact of technology on the electrical characteristics of PV modules. Monocrystalline modules, renowned for their efficiency, not only exhibit favorable voltage properties but also demonstrate robust performance under the challenging conditions of the monitoring location. This performance disparity becomes particularly evident when comparing Monocrystalline with the other two modules, Polycrystalline and Amorphous, providing further insights into the unique characteristics of each technology in practical outdoor scenarios.Analyzing these voltage variations is critical for optimizing PV system designs, ensuring efficient energy conversion, and strengthening overall reliability under diverse environmental conditions. It also informs decision-making processes for stakeholders seeking to implement efficient and sustainable solar energy solutions tailored to specific settings and performance requirements. By understanding the voltage profiles of different PV module technologies, stakeholders can make informed choices about technology selection and system configuration, ultimately improving the efficiency and effectiveness of solar energy utilization. The observed voltage profiles provide valuable information about the performance characteristics and limitations of each solar cell. technology in real conditions. By quantifying the voltage output of monocrystalline, polycrystalline and amorphous modules, the study provides a comprehensive overview of their electrical behavior and performance. This knowledge is an important resource for scientists, engineers and policy makers working to advance the deployment and integration of solar energy into conventional energy systems, contributing to the global transition to a more sustainable energy future. Through continuous research and innovation, stakeholders can harness the potential of solar energy to solve pressing energy challenges and mitigate the effects of climate change.

Table 3 provides a brief summary of the test results, including efficiency, performance index and voltage for each PV module technology. A notable observation from the data is that during September, monocrystalline technology outperforms the other two module innovations, showing the highest efficiency. This demanding pattern highlights the remarkable efficiency and voltage characteristics of monocrystalline modules under real outdoor conditions during the monitoring period. The inclusion of performance ratio deviations adds depth to the analysis, illuminates the dynamic performance of each technology, and reinforces the specific strengths of monocrystalline technology in this environment. The consistent superiority of monocrystalline technology in efficiency and voltage underlines its efficiency and voltage. suitable for demanding outdoor environments. These modules show strong performance and stability, making them a compelling choice for applications where reliability and efficiency are paramount. On the other hand, although polycrystalline and amorphous modules also show respectable performance, their efficiency and voltage characteristics are slightly lower than monocrystalline modules. This nuanced understanding of each technology and performance characteristics is critical to making informed decisions when designing and implementing solar energy systems.

Adding values for the deviation of the productivity ratio provides valuable information about the dynamic performance of each technology. While monocrystalline modules consistently have the lowest deviation, indicating stable performance, polycrystalline and amorphous modules show slightly larger deviations, indicating some sensitivity to environmental factors. This understanding enables stakeholders to anticipate and mitigate potential performance fluctuations, improving the reliability and efficiency of PV systems in real-world applications. The comprehensive analysis presented in Table 3 helps to understand the comparative performance of different PV module technologies under real outdoor conditions. . By determining the deviation of efficiency, voltage and productivity ratio, the study provides valuable information about the strengths and limitations of each technology and enables stakeholders to make informed decisions about technology selection and system optimization. Finally, this knowledge enables the development of more efficient, reliable and sustainable solar energy solutions adapted to specific environmental conditions and performance requirements, contributing to the global transition to a sustainable energy future.

Table 3. Result comparison of various PV modules.

PV Module	Efficiency	Percentage Efficiency Deviation	Voltage
MonoCrystallie	11.21	25.83	17.5
PolyCrystalline	8.35	33.99	16.25
Amorphous	6.12	24.6	13.56

4 Conclusion

In summary, this comprehensive study carefully examined the performance of three different photovoltaic technologies - monocrystalline, polycrystalline and amorphous - under real outdoor conditions during September. Analysis based on precise measurements such as daily average solar radiation, efficiency, voltage and current provides a nuanced understanding of their practical behavior. Monocrystalline technology is constantly becoming a pioneer, showing excellent efficiency and voltage characteristics. The average efficiency of the monocrystalline modules is 11.21%, the smallest efficiency deviation is 25.83%, and the largest voltage value is 17.5 V. The monocrystalline modules show strong performance in various environmental conditions. efficiency deviation of 33.99%, average voltage of 16.25 V. In contrast, Amorphous technology with an efficiency of 6.12% shows considerable flexibility, with a lower efficiency deviation of 24.6% and a voltage value of 13.56 V. Advanced measurement tools such as voltage and current sensors and a reliable data acquisition system ensure comprehensive data collection and real-time monitoring. These findings not only bring valuable information to the renewable energy sector, but also provide decision makers with nuanced information to select the most appropriate solar panel technology based on project-specific requirements and environmental nuances. As the global demand for sustainable energy solutions increases, such research plays a key role in guiding the renewable energy landscape towards optimal and informed decision-making.

The practical implications extend beyond the laboratory and guide stakeholders in optimizing solar energy systems to improve efficiency and reliability in a variety of real-world scenarios. The insights gleaned from this research have implications for the broader energy transition to sustainability. By highlighting the performance differences and strengths of different solar technologies, stakeholders can better align their investments and strategies with long-term sustainability goals. In addition, the emphasis on real conditions emphasizes the importance of holistic approaches to renewable energy research and implementation, considering factors such as climate change and geographical differences. Fundamentally, this study highlights the importance of empirical research in shaping the future of renewable energy. . By providing practical knowledge and tools for informed decision-making, such research paves the way for widespread adoption of solar energy as a clean and sustainable energy source. As the world continues to move towards a low-carbon future, research like this will continue to be key to driving innovation and progress in renewable energy.

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