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Impact of Temperature on Solar Panel Efficiency

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ABSTRACT

Photovoltaic (PV) systems are widely used for renewable electricity generation; however, their efficiency is significantly affected by operating temperature. As temperature increases, the electrical performance of solar cells decreases due to reduced band-gap energy, increased internal resistance, and voltage losses. This paper presents a thermal regulation approach using copper tubes attached to the rear surface of the solar panel combined with fluid circulation to extract excess heat. The proposed system reduces panel temperature while simultaneously recovering waste heat for secondary applications such as water heating or powering a Stirling engine. The study includes system design, theoretical modeling, prototype development, and performance analysis. Results indicate that effective thermal management can significantly improve photovoltaic efficiency and extend panel lifespan. The proposed system provides a cost-effective and scalable solution suitable for high-temperature regions.

Index Terms— Photovoltaic systems, solar energy, temperature effects, thermal management, renewable energy, energy efficiency.

INTRODUCTION

The Solar energy has become one of the most promising renewable energy sources for addressing global energy demands and environmental concerns. Photovoltaic (PV) technology directly converts solar radiation into electrical energy without producing greenhouse gas emissions. Due to decreasing installation costs and increasing energy demands, solar PV systems are being widely deployed in residential, commercial, and industrial applications.

Despite these advantages, photovoltaic systems face several operational challenges, one of the most significant being the effect of temperature on system efficiency. During operation, solar panels absorb sunlight, but only a portion of this energy is converted into electricity. The remaining energy is converted into heat, which increases the temperature of the solar cells. Elevated temperatures negatively affect electrical performance, reducing voltage output and overall system efficiency.

In hot climates, this issue becomes more severe because panels operate at temperatures significantly higher than ambient conditions. This results in considerable energy losses and reduced system reliability. Consequently, effective thermal management strategies are required to maintain panel efficiency and improve overall system performance.

Several cooling techniques have been proposed in the literature, including water spraying, air cooling, heat sinks, and phase-change materials. However, many of these methods involve high installation costs, complex maintenance, or additional energy consumption.

This paper proposes a practical and cost-effective cooling mechanism using copper tubes and circulating fluid. The system removes excess heat from the photovoltaic panel and reuses it for secondary applications, thereby improving both electrical efficiency and overall energy utilization.

LITERATURE SURVEY

The performance of photovoltaic (PV) systems is strongly influenced by environmental conditions, particularly temperature. Researchers across the world have studied the thermal behavior of solar panels and proposed various techniques to reduce temperature-related efficiency losses. This section reviews important studies related to photovoltaic temperature modeling, cooling techniques, and performance optimization.

Hybrid Modeling for Photovoltaic Module Temperature Estimation

Santos et al. (2024) presented a hybrid modeling approach for estimating the operating temperature of photovoltaic modules using environmental inputs such as solar irradiance, ambient temperature, and wind speed. The model combines both physical laws and data-driven techniques to provide accurate predictions of module temperature.

The study demonstrates that accurate temperature estimation is crucial for predicting photovoltaic performance and energy output. By integrating environmental data into the model, the authors were able to convert ambient conditions into realistic module temperature values and estimate expected power losses.

One of the major advantages of this approach is its improved accuracy compared to simple empirical models. However, the complexity of hybrid models requires large datasets and computational resources, which can make implementation difficult for small-scale systems.

Cooling of Photovoltaic Panels Using Calcium Chloride

Asri et al. (2024) investigated a cooling technique that uses Calcium Chloride ($CaCl_2$) placed beneath photovoltaic panels. The study aimed to reduce the operating temperature of solar panels and improve efficiency.

Experimental results showed that the presence of Calcium Chloride effectively reduced panel temperature and increased power output. The researchers also used Artificial Neural Network (ANN) modeling to predict the performance of the photovoltaic system, which provided more accurate results than traditional regression techniques.

The proposed method offers several advantages, including low cost, ease of application, and improved efficiency. However, Calcium Chloride is highly hygroscopic, meaning it absorbs moisture from the environment. This can cause maintenance issues and may affect long-term system performance.

Temperature Measurement Under High Irradiance Conditions

Geisz et al. (2023) conducted a detailed study on temperature measurement in photovoltaic devices operating under continuous high-intensity illumination. The researchers used fast open-circuit voltage (VOC) measurements to determine the junction temperature of solar cells.

Their work highlights how thermal design affects photovoltaic performance and identifies key loss mechanisms caused by temperature rise. The study demonstrates that accurate measurement of junction temperature is essential for understanding efficiency degradation in solar devices.

Although the method provides precise measurements, the research focuses mainly on photovoltaic laser power converter devices rather than standard solar panels. Therefore, its direct application to conventional photovoltaic systems is limited.

Influence of Temperature Coefficients on PV System Performance

Mussard et al. (2023) analyzed how temperature coefficients influence the performance evaluation of photovoltaic systems. The study compares manufacturer-provided temperature coefficients with experimentally derived coefficients obtained through field testing.

The results showed that experimentally derived temperature coefficients provide more accurate performance ratio calculations. The study also emphasized that the method used to estimate solar irradiance significantly affects the temperature coefficient values.

While this research provides valuable insights into photovoltaic performance analysis, the experiments were conducted at a single test site over a limited time period. Therefore, the findings may not fully represent different environmental conditions.

Impact of Hydrogen Configuration on Temperature-Induced Degradation

Hammann et al. (2023) investigated the impact of hydrogen configurations on Light- and Elevated-Temperature-Induced Degradation (LeTID) in photovoltaic cells. LeTID is a phenomenon that occurs in silicon solar cells when they are exposed to light and elevated temperatures for long periods.

The study demonstrates that hydrogen distribution within the solar cell significantly affects the rate and extent of degradation. Understanding these mechanisms is important for improving the long-term reliability of photovoltaic modules.

However, the study focuses specifically on hydrogen interactions within the material structure and does not directly address practical cooling techniques for reducing operating temperature.

Summary of Literature
From the reviewed studies, it is clear that temperature plays a critical role in determining photovoltaic performance. Most research focuses on temperature modeling, degradation mechanisms, or advanced cooling technologies. While these approaches provide valuable insights, many of them involve complex systems, expensive materials, or high maintenance requirements.

Therefore, there is a need for a simpler and more cost-effective solution that can be implemented easily in real-world solar installations. The proposed system in this project addresses this gap by introducing a copper-tube-based cooling mechanism combined with fluid circulation to reduce solar panel temperature and improve efficiency.

COMPARITIVE ANALYSIS OF LITERATURE SURVEY

Various research studies have been conducted to understand the impact of temperature on photovoltaic (PV) systems and to develop techniques that improve solar panel efficiency. Each approach offers specific advantages while also presenting certain limitations. A comparative analysis of these studies helps identify the research gap and highlights the need for an improved solution.

A. Hybrid Modeling for PV Temperature Estimation

Santos et al. proposed a hybrid modeling technique that estimates photovoltaic module temperature using environmental parameters such as solar radiation, wind speed, and ambient temperature. This approach improves prediction accuracy and helps in understanding how temperature affects power output.

The major advantage of this method is its ability to combine physical models with data-driven approaches, which improves reliability. However, the model requires extensive datasets and computational resources, making it difficult to implement in simple photovoltaic installations.

B. Chemical Cooling Using Calcium Chloride

Asri et al. introduced a cooling method that uses Calcium Chloride ($CaCl_2$) to reduce the temperature of photovoltaic panels. Their experiments showed that this method effectively lowers the panel temperature and improves electrical efficiency.
Although the system is relatively low-cost and easy to apply, Calcium Chloride is highly sensitive to moisture. This property can cause handling difficulties and may require frequent maintenance, which limits its practicality for long-term outdoor installations.

C. Temperature Measurement Under High Irradiance

Geisz et al. focused on measuring the junction temperature of photovoltaic devices under high-intensity illumination conditions. Their approach uses open-circuit voltage measurements to determine temperature variations and analyze performance degradation.

The study provides a clear understanding of thermal losses in photovoltaic systems. However, the research is primarily focused on specialized photovoltaic devices rather than conventional solar panels used in power generation.

D. Temperature Coefficient Analysis of PV Systems

Mussard et al. investigated how temperature coefficients affect the performance evaluation of photovoltaic systems. Their study compared manufacturer-provided temperature coefficients with experimentally measured values and found that experimental values give more accurate results. While this research improves performance estimation methods, it does not provide a practical solution to reduce temperature or improve thermal management in photovoltaic panels.

E. Temperature-Induced Degradation in Solar Cells

Hammann et al. studied the effects of hydrogen configuration on Light- and Elevated-Temperature-Induced Degradation (LeTID) in photovoltaic cells. Their research highlights how high temperature accelerates degradation processes within solar cells.

Although this work contributes to understanding long-term reliability issues, it mainly focuses on material-level analysis rather than proposing practical cooling systems.

Comparative Summary
From the analysis of existing literature, it is evident that most research focuses on either temperature prediction, material degradation, or advanced cooling technologies. While these studies provide valuable insights into photovoltaic behavior, many of the proposed methods are complex, expensive, or difficult to implement in real-world applications. There remains a need for a simple, efficient, and cost-effective thermal management solution that can be easily integrated with existing solar panel systems.

The proposed system in this project addresses this gap by introducing a copper-tube-based cooling mechanism with fluid circulation. This approach reduces panel temperature, improves efficiency, and allows reuse of extracted heat for additional applications.

CONCLUSION

This study examined the impact of temperature on the performance of photovoltaic (PV) panels and highlighted the importance of effective thermal management in solar energy systems. It is evident that a significant portion of solar radiation absorbed by PV panels is converted into heat, which increases the operating temperature of the cells and reduces their efficiency. Higher temperatures lead to voltage losses, increased electrical resistance, and long-term degradation of solar panel components.

Based on the analysis of existing literature, many previously proposed solutions focus on temperature prediction models, chemical cooling techniques, and advanced measurement methods. Although these approaches contribute valuable insights, many of them are either complex, expensive, or difficult to implement in practical installations.

To address these limitations, this work proposes a cooling-based thermal management system using copper tubes and circulating fluid attached to the rear side of the photovoltaic panel. The system effectively extracts excess heat from the panel, thereby reducing its operating temperature and improving electrical performance. Additionally, the recovered heat can be reused for secondary applications such as water heating or operating a Stirling engine, which enhances overall energy utilization.

The proposed system offers several advantages, including improved efficiency, reduced thermal degradation, low implementation cost, and ease of installation. Due to its simple design and scalability, the system has strong potential for real-world deployment, particularly in regions with high solar radiation and elevated ambient temperatures.

In conclusion, effective temperature regulation plays a crucial role in optimizing photovoltaic performance. The proposed cooling mechanism provides a practical and sustainable solution for improving solar panel efficiency while contributing to better utilization of renewable energy resources.

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