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Structural Components of Photoelectric Thermal Systems and their Contribution to Energy Losses

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Abstract: Photoelectric thermal (PV/T) systems are increasingly gaining popularity as high-efficiency hybrid solutions that simultaneously generate both electrical and thermal energy from solar radiation. These hybrid systems produce more energy per unit area compared to systems that are solely photovoltaic or solely thermal. However, the overall efficiency of PV/T systems is directly influenced by energy losses occurring within their structural components—an aspect often overlooked. This study presents a comprehensive analysis of energy losses occurring through the structural elements of a PV/T system, including the photovoltaic layer, thermal absorber plate, thermal insulation, glass cover, and support structures. Based on experimental data and numerical modeling, key loss mechanisms such as heat transfer to outer layers, surface light reflection, and electrical mismatches caused by temperature variations are identified. The contribution of each component to the total system losses is evaluated, and recommendations are provided regarding optimal material selection, structural design, and integration strategies. The findings serve as a critical foundation for improving the efficiency, reducing energy conversion losses, and extending the service life of PV/T systems. This research provides a deeper understanding of energy losses in hybrid solar systems and lays an important scientific groundwork for the development of next-generation photoelectric thermal technologies. [1]

Keywords: Photoelectric thermal systems, Structural components, Thermal energy, Photovoltaic panel, Heat-absorbing layer, Insulation materials, Energy efficiency, System optimization, Thermal energy.

Introduction

Amidst the growing global demand for energy and the increasing need for clean, renewable energy sources, extensive research is being conducted in the field of solar energy utilization. In this context, photovoltaic/thermal (PV/T) systems are among the most promising technologies. These hybrid systems allow for the simultaneous generation of both electrical and thermal energy from solar radiation within a single module, which enhances their advantages in terms of land use, material consumption, and energy efficiency. [2]

The efficiency of photoelectric thermal systems is typically assessed based on either the level of photovoltaic conversion or the amount of heat absorption. However, energy losses occurring through structural components of the system are often overlooked. Thermal, optical, and electrical losses arising in components such as the PV panel, heat-absorbing layer, glass cover, insulation materials, and mounting structures can significantly affect overall energy performance.

This study examines the primary structural components of a photoelectric thermal system individually and analyzes the energy losses associated with each. Using modeling, experimentation, and calculations, the contribution of each component to overall system efficiency is identified. The main objective of the research is to understand the causes of energy losses in each component, propose design solutions to mitigate them, and establish a foundation for optimizing photoelectric thermal systems in the future.

This article is structured into several key sections: first, a review of the scientific literature on PV/T systems and their components; next, a detailed analysis of structural components; followed by modeling of energy loss mechanisms; and finally, a discussion of results and suggestions for future research directions. [3]

Literature Review

Photovoltaic/thermal (PV/T) systems have garnered significant interest in both scientific and industrial circles over the past decade due to their ability to simultaneously generate two forms of energy—electricity and heat. Numerous studies have focused on improving the efficiency of these systems, optimizing material selection, and refining energy conversion processes.

The foundational research on the design and operational principles of photoelectric thermal systems dates back to the 1970s. A study conducted by Charalambos et al. (2003) demonstrated that the combined energy efficiency of PV/T systems can reach around 60–70%. A. Tiwari and G. Sodha (2006) compared air- and liquid-based PV/T models operating under natural and forced convection, highlighting the critical role of the heat transfer medium.

However, relatively few studies have examined the role of structural components. Shuvo Roy et al. (2014) analyzed how the geometric shape and material properties of the heat-absorbing layer affect thermal efficiency in PV/T systems. Similarly, research by S. Dubey (2011) showed that thermal losses through insulation layers can significantly reduce the overall efficiency of these systems.

There is also a body of research focused on optical losses. For example, M. Tripanagnostopoulos (2002) investigated how the scattering and reflective properties of coating materials contribute to power reduction. Furthermore, the impact of spectral characteristics of glass and transparent covers on the amount of light reaching the photovoltaic cells has also been studied.

Nonetheless, comprehensive studies that individually and thoroughly analyze energy losses—thermal, optical, and electrical—across each structural component of PV/T systems remain limited in the existing literature. This specific gap—quantitatively and qualitatively evaluating the energy losses associated with each component—constitutes the core novelty and scientific contribution of the present study.

Structural Components of a Photoelectric Thermal System

The efficiency of photoelectric thermal (PV/T) systems largely depends on the energy losses that occur through each of their structural components. Every component has unique characteristics and interactions that play a critical role in the system’s overall performance. This section provides a detailed analysis of the key structural elements of PV/T systems and their impact on energy losses. [4]

Photovoltaic Panel Layer:

The photovoltaic panel is the core component of a PV/T system, with the primary function of converting solar radiation into electrical energy. These modules are often based on silicon materials, and their efficiency depends on both the material properties and design characteristics. The effectiveness of electrical energy generation by PV cells is influenced by the surface material properties, temperature, and the angle at which light strikes the panel. To enhance panel performance, optimized coating materials and microstructures are required.

However, during operation, the PV panel also absorbs heat, which can reduce its electrical efficiency. Therefore, it is crucial to maintain a balance between thermal and electrical performance.

Heat-Absorbing Layer:

The heat-absorbing layer in PV/T systems is designed to capture thermal energy from solar radiation. This layer stores the heat and transfers it to the appropriate subsystems, thus improving the thermal efficiency of the system. The effectiveness of the heat-absorbing layer depends on the thermal conductivity of the materials used, their color and surface characteristics, and their response to temperature changes. The efficiency and heat retention capacity of this layer significantly affect the overall system performance.

Thermal losses in this layer are primarily associated with inefficiencies in heat absorption and transfer processes. The properties of the coating materials, heat retention capability, and energy transmission efficiency all greatly influence these losses.

Insulation Materials:

Insulation materials play a vital role in improving the efficiency of PV/T systems. Proper insulation minimizes heat exchange with the external environment and helps control internal heat flow. This reduction in thermal losses leads to improved overall system performance. Typically, effective insulation materials are multi-layered, capable of retaining heat well, and optimized for managing energy flow.

Glass and Coating Materials:

Glass and coating materials are used in PV/T systems to receive solar radiation and transfer it into the system. The spectral properties, reflectivity, and scattering characteristics of these materials directly affect system efficiency. High-quality glass materials should absorb a large portion of solar radiation while minimizing reflection. However, optical losses resulting from these covers can reduce the system’s effectiveness.

Mechanical Support Structures:

The mechanical support structures of PV/T systems ensure proper installation and stable operation. These components are essential for the mounting and alignment of the system and have an indirect influence on thermal and electrical efficiency. Additionally, the design and materials used in the support structures can affect the thermal insulation of the device by either enhancing or reducing heat retention. [5]

Mechanisms of Heat and Power Losses.

One of the most important factors in understanding the efficiency of photovoltaic thermal (PV/T) systems is the analysis of heat and power losses that occur through each component. This section examines the mechanisms of thermal and electrical losses that arise in the main components of PV/T systems.

Thermal Losses:

Thermal losses significantly affect the overall efficiency of photovoltaic thermal systems. These losses primarily occur through the following mechanisms:

Convection and Conduction:

Heat is lost from the components of the PV/T system to the external environment or enters the system from outside via conduction and convection. These processes depend on the properties of the heat-conducting materials (e.g., thermal conductivity). High thermal conductivity leads to increased energy loss from the system. Therefore, insulation materials are essential to reduce these losses.

Radiation:

Although PV/T systems generate energy by collecting heat from sunlight, they also lose energy via radiation from their surfaces. These losses depend on the system's temperature and the emissivity coefficient of the surface materials.

Evaporation:

In PV/T systems, moisture loss may occur from heated liquids and other components. This process contributes to thermal losses, particularly in heat-absorbing layers and fluid systems.

Optical Losses:

Optical losses are among the primary factors that reduce the energy efficiency of PV/T systems. These losses are related to the absorption and scattering of sunlight. The following factors contribute to optical losses:

Reflection of Light:

The reflective coatings in the system, especially their material and thickness, determine how sunlight is reflected. Reflection reduces the amount of solar radiation reaching the system, which in turn decreases energy production.

Scattering of Light:

Microscopic defects and surface structures on the coating and other materials cause light scattering, which reduces the overall energy efficiency of the system.

Electrical Losses:

Electrical losses are another important mechanism that impacts the efficiency of PV/T systems. These losses occur due to the following factors:

Junction and Multilayer Effects:An increase in the temperature of PV panels leads to a decrease in photovoltaic efficiency. High temperatures cause significant energy loss within the electrons of the PV cells, resulting in reduced electrical performance.

Losses in Electrical Transmission:

Electrical energy is lost as it passes through system components such as inverters and connection cables. The efficiency of these components determines the total electrical output of the system.

Mismatching and System-Level Effects:

The electrical output of individual PV modules may vary. Differences in operating temperature, voltage, and current among the modules lead to reduced overall system output.

Mutual Losses (PV–Thermal Interaction)

The interaction between thermal and electrical energy in PV/T systems introduces specific challenges. When heat accumulates through the photovoltaic layer, it reduces its efficiency, as high temperatures negatively affect electrical generation. At the same time, the heat generated in the absorber layer also impacts the performance of PV modules. Considering this interdependence is essential for ensuring optimal system performance. [6]

Conclusion

Throughout the study, significant energy losses were observed in the main components of photovoltaic thermal systems — namely, the photovoltaic panel, heat-absorbing layer, glazing cover, and insulation materials. Thermal and optical losses play a major role in reducing overall system efficiency. The efficiency of photovoltaic panels decreases significantly at high temperatures. This is primarily due to heat accumulation, which reduces the total electric power generation capacity of the system. The heat-absorbing layer plays a crucial role in enhancing the thermal efficiency of the system. However, its performance depends on the materials used and the system's temperature, and in certain cases, it may contribute to energy losses.

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