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Truncated Compound Parabolic Concentrator without Tracker

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Abstract

Renewable energy sources, such as solar power, are becoming increasingly vital as the world tackles challenges like climate change and the urgent need to transition away from fossil fuels. Solar energy, being abundant, renewable, and clean, plays a crucial role in this transition. Conventional concentrator-based solar systems often rely on tracking mechanisms to follow the sun's movement. While effective, these tracking devices are expensive, complex, and impractical for rooftop applications. Hence, a more cost-effective and simplified solution is needed for such installations. This study evaluates the influence of Compound Parabolic Concentrators (CPCs) on the average power output of solar energy systems across varying incident angles, aiming to assess their potential to eliminate the need for traditional solar tracking systems. Using Trace Pro software, the optical performance of the CPC was simulated. The results reveal that systems equipped with CPCs consistently deliver significantly higher power output approximately two times compared to those without. Notably, CPC-enhanced systems maintain a stable and elevated power level across a broader angular range (0^0 to 124^0), effectively compensating for the absence of active solar tracking mechanisms. By leveraging the ability of CPCs to concentrate and redirect diffuse sunlight, this approach demonstrates a cost-effective and energy-efficient alternative to dynamic tracking systems. These findings underscore the practicality of CPC integration in optimizing solar energy systems for fixed installations, enhancing energy capture, and reducing operational complexities.

Keywords: compound parabolic concentrator, Solar power, Photovoltaic and thermal systems.

I. INTRODUCTION

The increasing global demand for renewable energy sources has led to significant advancements in photovoltaic (PV) technology. As the quest for efficient and sustainable energy solutions intensifies, the integration of PV systems with compound parabolic concentrators (CPCs) has garnered considerable attention [1]. CPCs, renowned for their ability to concentrate both direct and diffuse solar radiation, offer a promising method to enhance the performance of PV systems without the need for mechanical tracking. This paper explores the simulation of a PV-based CPC system, using TracePro software, to evaluate its efficacy in harnessing solar energy.

PV systems are inherently limited by their reliance on direct sunlight, which can be inconsistent due to weather conditions and geographical location. CPCs address this limitation by capturing and concentrating diffuse sunlight, thereby increasing the amount of solar radiation incident on the PV cells [2]. Unlike traditional concentrators that require precise alignment with the sun, CPCs are designed with a larger acceptance angle, allowing them to collect sunlight from a wider range of angles. This unique characteristic makes CPCs particularly suitable for stationary installations, reducing the complexity and cost associated with tracking systems [3].

The concept of using CPCs in PV applications is not new; however, the optimization and simulation of these systems continue to be an area of active research. Various studies have demonstrated the potential of CPCs to improve the efficiency of PV systems [4]. For instance, Farhan et al. (2022) evaluated the performance of a compound parabolic solar collector using different Nano fluids, highlighting the versatility and adaptability of CPC designs in different applications. Similarly, Masood et al. (2021) proposed a new approach for the design optimization and parametric analysis of symmetric CPCs, demonstrating significant improvements in energy capture and conversion [5].

The simulation study presented in this paper employs TracePro, an advanced optical simulation software, to model and analyze the performance of the PV-CPC system. TracePro's capabilities in ray tracing and photometric analysis enable a comprehensive evaluation of the CPC's optical performance, including the concentration ratio, uniformity of light distribution, and overall energy conversion efficiency [4]. By simulating various design parameters and environmental conditions, this study aims to identify the optimal configuration for maximizing the efficiency of the PV-CPC system.

One of the key advantages of using CPCs in PV systems is their ability to operate effectively without mechanical tracking. Traditional tracking systems, which move the PV panels to follow the sun, can be costly and complex to maintain [6]. In contrast, CPCs with their larger acceptance angles can collect sunlight from a wider range of directions throughout the day, making them more suitable for stationary installations. This not only simplifies the system design but also reduces the operational and maintenance costs [3].

This research is anchored in the broader context of renewable energy innovation and sustainability. The findings from this simulation study contribute to the ongoing efforts to develop high-efficiency solar energy systems that are both economically viable and environmentally friendly [2]. The use of CPCs in PV applications not only enhances energy output but also extends the operational lifespan of PV modules by reducing thermal stress and degradation.

In summary, this paper provides a detailed simulation analysis of a PV-based CPC system without tracking, highlighting Compound Parabolic Concentrators (CPCs) offer a passive solution, concentrating sunlight over a wide range of angles to enhance power output without requiring active tracking. This study examines the performance of CPC-equipped systems compared to non-CPC systems, showing that CPCs significantly improve power output, particularly at smaller incidence angles, while maintaining higher efficiency as angles increase. The results highlight CPCs as a cost-effective, low-maintenance alternative for optimizing solar energy systems, reducing complexity, and improving sustainability.

II. CPC DESIGN

Flow Chart for CPC design without tracker is depicted in Figure 1: To check the performance of the said concentrator, optical simulator based on ray tracing software Trace Pro is used. The simulation setting and the window panel of the said software is depicted in Figure 2. The concentrator is designed with a length of 14 cm and a focal length of 6 cm. After completing the design, an optical simulation was conducted. Figure 3 illustrates the simulation results of the designed CPC with the absorber.

To increase the intensity of radiation on the absorber two extra plane reflectors of dimensions 14cm, 8cm and 0.1cm are also added with concentrator.

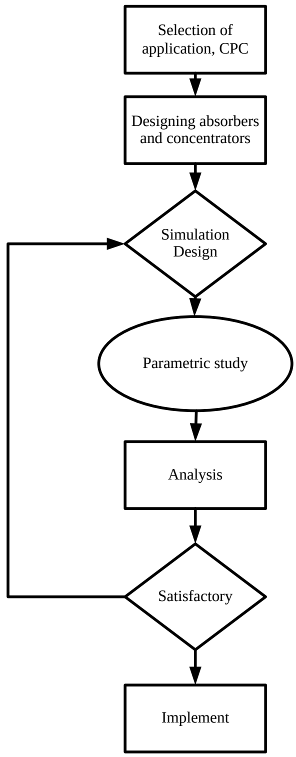


Figure 1: *Flow Chart for CPC design without tracker*

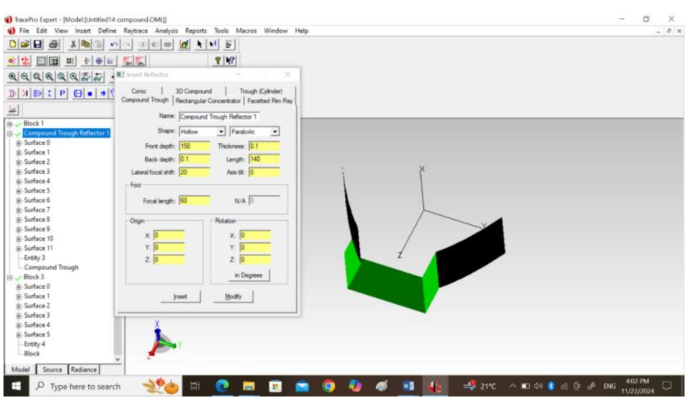


Figure 2: *CPC Implemented in TracePro*

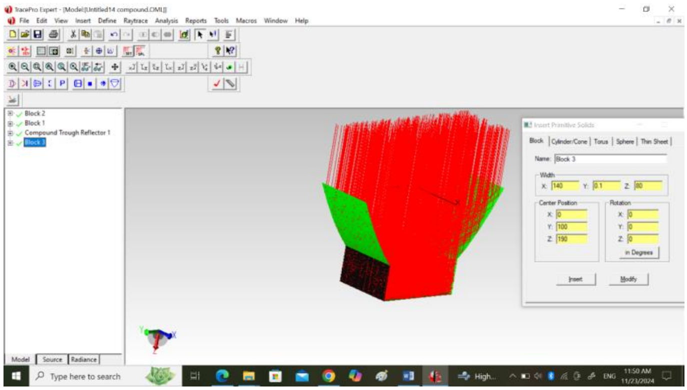


Figure 3: Optical simulation of the implemented CPC design

III RESULTS

This section presents the results of the optical simulation with and without the CPC. Figure 4 illustrates the optical power incident on and absorbed by the absorber without the CPC. The average power incident on the absorber is 17,737 W/m².

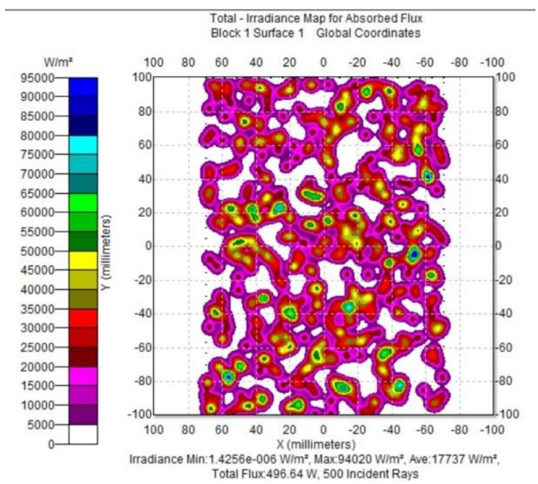


Figure 4: Irradiance distribution without CPC

For the system with CPC the irradiance distribution is depicted in Figure 5. From Figure 5, the average power incident on absorber is 35461 W/m2. On comparing the result with Figure 4 it is evident that power in CPC based system is almost twice the power as that of system without CPC.

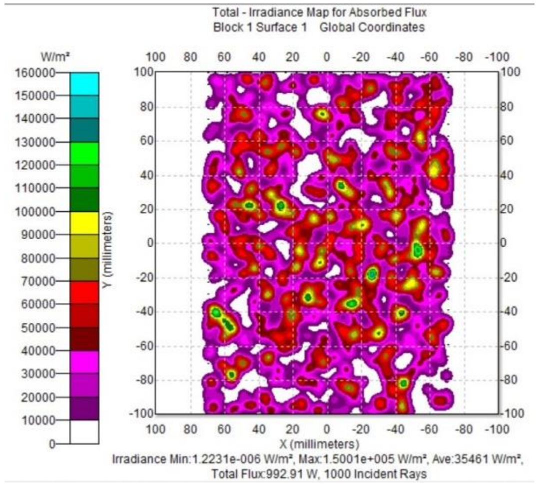
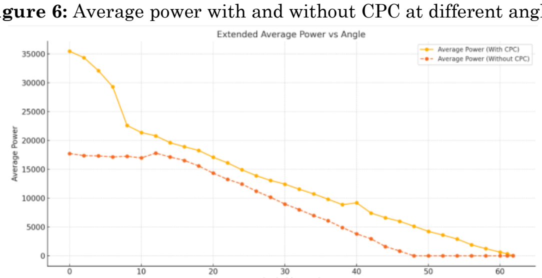


Figure 5: Irradiance Distribution with CPC

On rotating the source of rays it is found that the average power with CPC is greater than that without CPC. The graph showing average power with and without CPC at different angle is depicted in Figure 6.

Figure 6: Average power with and without CPC at different angles



IV CONCLUSION

The CPC significantly boosts the average power collected on the absorber compared to a setup without it, showing its effectiveness in improving energy capture. As the angle increases, the average power decreases for both cases. However, the CPC slows this decline, maintaining higher efficiency across a wider range of angles. Without the CPC, power drops quickly after 20° and reaches nearly zero beyond 48°. The CPC retains power even at larger angles, with measurable output up to 60.8°, proving its ability to redirect light efficiently The CPC's performance advantage becomes more noticeable beyond 20°, where the difference in power between the two setups increases significantly.The CPC ensures better energy collection across all angles, especially in challenging conditions with off-axis light, making it ideal for solar energy and optical applications. In summary, the CPC greatly improves power collection and efficiency, particularly at wider angles, making it a valuable tool for systems needing consistent performance.

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