CHAPTER 7

CONCLUSION AND SCOPE FOR FUTURE WORK

Present chapter discuss the concluding remarks on the current study and proposes future directions to expand the acceptance of solar reflection systems made from flat plate reflectors for the Indian climatic condition. These efforts aim to address energy, environmental, and social challenges in the country. Advancing research in this direction can enhance the effectiveness of solar reflection systems and contribute to sustainable solutions for India's energy and environmental needs.

7.1 Concluding remarks

According to the literature, using FPTR instead of CTR in STS reduces cost by eliminating the need for tracking. Analysing single beam performance through proposed testing methods can provide valuable insights. A generalized RTA has potential to optimize systems employed for different locations. The successful implementation of STS with FPTR, coupled with RTA holds promise for both small-scale as well as for large-scale commercial and industrial applications.

7.1.1 Experimental investigation of FPSRS

- The purpose of the experiments with FPSRS was to investigate the reflection profile and comprehend the behaviour of a single ray. The experiment involved pointing a beam of laser light towards an experimental model when analysed in a dark room at varying incidence angles. The optical performance of the FPSRS were explored through a custom method designed to track the journey of a single ray. To enhance understanding of ray behaviour, the rays were classified into six distinct cases (A to F) as shown in Table 4.2. This simplifies the experimental process and facilitates the study of individual beam behaviour.
- The experimental findings from the single-ray approach align with previous shadow experiments conducted by A. C. Andres et al. (Carrillo-Andrés et al., 2022). Validated outcomes shows that the proposed experimental procedure is simple to adopt and more reliable. The findings reveal the largest error between experimental and CAD models occurred in case D, approximately 2.1%. Furthermore, the impact of overall uncertainty is documented, with the maximum uncertainty not exceeding 5.8%.
- The thermal performance of the FPSRS is measure with evaluating value of η_{thr} for the different value of θ. This shows that when θ is in the range of 30° to 150°, the derived average value of η_{thr} is observed to 69%. The measured value of η_{thr} is 91% when θ is 90°, which

suggests that the reflector can operate at its highest efficiency level if it is fully tracked. However this improvement contributes to overall η_{thr} only by 22%. This means thermal performance of FPSRS with fixed reflectors and having azimuthal alignment will be 22% less compared to movable reflectors with azimuthal alignment or fully tracked reflectors. However, as shown by the uncertainty analysis, this loss can be compensated with increasing the surface area of the reflector. The more details can be obtained with considering the numerical investigation of the similar kind of the study. These numerical studies are crucial for gaining detailed insights into the dynamics of ray reflection and their interactions with various surfaces, which is pivotal for optimizing the design and enhancing the efficiency of solar thermal systems.

7.1.2 Numerical investigation of FPSRS and guidelines for grid refinements

- The numerical model of FPSRS provides insight information of the solar beam rays and its reflection pattern after it get reflection from reflectors with different values of Φ. A discrepancy found in the experimental data indicates that the numerical model makes it easier to understand information about neighbouring reflections from two adjacent reflectors. This model is crucial for accurately identifying intersection points and the angle formed by the reflected ray with the normal to the plane, serving as key parameters for determining subsequent intersections. Utilizing unique discretized methods, the importance of each component's participation in the system is understood, emphasizing the significance of selecting the N for the discretized approach.
- A 'general-purpose two-step guideline' for computing the value of N is proposed, which also includes changes in time- and space-dependent parameters. The first step in the proposed guidelines involves using EGR or LC techniques to identify grid areas requiring improvement. Subsequently, N is determined using R^2 or CVRMSE techniques. The study demonstrates the effectiveness of these guidelines through a case study featuring an FPSRS utilizing RTA.
- The value of N obtained by considering CM with use of SRS techniques varies from 1225 to 1681, changing due to variations in time and space variables, and it consumes a longer computation time. However in PM the grid refinement can be done with considering two steps, in step 1, EGR and LC show almost similar results for the present case study but might differ for others. In step 2, CVRMSE and R^2 yield similar N results, significantly reducing computation time compared to CM. However the final value of N obtain from the PM is 1681.
- The efficacy of this approach demonstrates a remarkable 4.3% improvement in N determination compared to CM as seen from Table 5.4. These two-step guidelines, effective

for FPSRSs, provide a systematic and scientifically grounded approach to N selection, eliminating subjectivity. Leveraging indicative techniques like LC and EGR, followed by deterministic methods like CVRMSE and R^2, streamlines grid refinement and enhances computational accuracy, significantly reducing computation time.

7.1.3 Topology optimization of FPSRS

- The topology optimisation of the FPSRS has been done with numerically analysis with considering the effect of different configurations. Initially, methods for obtaining the most suitable H/B ratio are discussed, with a numerically analysed case study of STC-based FPSRS. Subsequently, the three chosen configurations named STC, HTC, and OTC are evaluated for SS and WS solar radiation conditions, and the best configuration is selected for further study. The best selected OTC is analysed across different cities in India to understand its dynamic performance and improve the optical performance of the system under varying geometric conditions. Based on the results obtained, conclusions are drawn and discussed in the following,
- The findings suggest that the average RDP is at its best in SS solar radiation condition when H/B is 2, but the RDP is at its best in WS solar radiation condition when H/B is 1.52. Moreover, the value of Φ for the SS and WS solar radiation condition is 53° and 58°, respectively.
- The maximum attainable η_{opt} of the HTC was found to be 15% higher than that of the STC. This substantial difference underscores the geometrical advantages of the HTC. The higher value of η_{opt} is found in the case of HTC due to a greater participation of case of C and D types of rays compared to STC. The involvement values are 8% and 13% higher in the case of HTC. On the other hand, the STC showed increased engagement of case of E and F type of rays in the morning and evening hours. These elements together resulted in a lower overall RDP value for the STC than the HTC. It is clear from the overall findings that HTC outperforms STC in terms of performance.
- The numerical analysis of the OTC-based FPSRS suggests that it outperforms the STC system in terms of RDP for the different values of θ. A comparative study between HTC and OTC reveals that OTC achieves a higher value of η_{opt} than HTC under both SS and WS solar radiation conditions. Furthermore, despite its complex geometry, OTC demonstrates superior performance and effectively offsets its manufacturing costs. The numerical results from different cities for the OTC-based system indicate that the maximum value of η_{opt} is 93% for Bengaluru, while the minimum value is 87% for Gandhinagar. However, overall, the OTC system performs better and exhibits superior optical performance across all cities.

- Finally it is concluded that with utilizing OTC-based FPSRS proves beneficial in diverse scenarios, including extreme solar radiation conditions like SS and WS. However, increasing reflector numbers or transitioning to other configurations escalates costs without substantial optical performance gains. Optimizing system design and reflector placement is crucial for efficiency.

7.2 Key contribution of the present work

The key contribution of the present study is presented as follows,

- The experimental investigation conducted on FPSRS, utilizing a unique laser technique, is regarded as the very useful method for testing any solar reflecting system with limited resources. These experiments aid in comprehensively understanding the reflection properties and behaviour of individual rays. Through categorizing rays into distinct cases (refer to Table 4.2) and employing a custom tracking method, the study streamlines the experimental process and enables focused analysis.
- The results obtained of RDP for the STC based FPSRS underscore the importance of understanding the impact of θ on the RDP within FPSRS and it also offering insights into optimizing the design and orientation of the reflector system for enhanced performance across a range of solar conditions. The CAD model offers a detailed virtual representation of the system, allowing for precise analysis and visualization of ray paths.
- The numerical model of FPSRS helps in gaining insight into the behaviour of solar beam rays after reflection from reflectors with varying values of Φ. It also facilitates understanding of information regarding neighbouring reflections from two adjacent reflectors. This model is crucial for accurately identifying intersection points and the angle formed by the reflected ray with the normal to the plane, serving as key parameters for determining subsequent intersections.
- The utilization of unique discretized methods enables a comprehensive understanding of the significance of each component's contribution to the FPSRS. The proposed RTA based on the discretized approach opens up opportunities for solving complex numerical problems involving solar reflective systems. It is also easily understandable as it utilizes derived solar radiation and three-dimensional geometric equations in its development.
- The proposed general-purpose two-step guideline expands the scope of finding N for any computational problem, considering time- and space-dependent parameters in the analysis. Employing EGR or LC techniques to identify grid areas requiring improvement, followed by the use of R^2 or CVRMSE techniques, provides precise information about N for the selected computational problem.

- The topology optimization study provides insights into various configurations and potential operational conditions of the FPSRS under different scenarios in India. Additionally, critical observations offer in-depth information regarding the significance of conducting topology optimization and the benefits derived from thermal and optical analyses of the system.

7.3 Scope of the future work

The present study focuses on developing testing methodologies for solar reflecting systems utilizing flat plate reflectors. The RTA is employed to investigate various configurations for different geographical locations and solar radiation conditions, aiming to find optimal solutions. Future research could involve more precise experimental methods and instruments to test in depth thermal performance, including curved and flat plate reflectors in a single setup. Additionally, exploring numerical studies with machine learning and advanced algorithms can enhance understanding of dynamic ray behaviour in larger systems. The possible future research scope is discussed below.

- The present study focuses on experiments conducted on square-type configurations of FPSRS. However, further experimental study could involve increasing the number of reflectors to study more complex configurations. Considering the reflectivity and materials used for reflection could provide qualitative insights. Advanced laser lighting and improved experimental setups could offer better understanding of system functionality. Additionally, studying changes in reflectivity and materials could enhance comprehension of ray behaviour under experimental modifications.
- The RTA can be further enhanced through the integration of machine learning and artificial techniques. By leveraging optimized configurations tailored to various geometric and solar radiation conditions, there is potential to achieve maximum optical and thermal performance.
- Similarly, the proposed grid refinement method is currently limited to square-shaped discretized zones. A study on the impact of utilizing different shapes for the discretized zones on the computational system's performance could be conducted. Additionally, advancements can be made by incorporating statistical methods to minimize numerical errors through optimal grid refinement processes.
- The topology optimization study offers insights into different configurations and potential operational conditions of the FPSRS under various scenarios in India. While it could be modified to incorporate a single-side baffle-type reflector arrangement to allow for the entry of a greater number of rays into the system, thereby increasing incoming solar radiation and enhancing output efficiency.