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Optimization on efficiency of non-tracking non-imaging concentrator by adjusting regularly installation angle

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Introduction

The parabolic trough solar collector is one of the most mature solar thermal technologies currently available and is widely used in applications such as solar power generation, industrial process heat, and seawater desalination [1]. However, conventional PTSC typically rely on complex solar tracking systems to maintain optimal incidence angles and ensure a high solar energy efficiency [2]. Tracking systems often involve intricate designs, complicated operations, and high maintenance costs. Therefore, exploring approaches that can reduce the PTSC dependence on complex tracking systems while maintaining high solar energy utilization efficiency is a promising solution [3].

The solar incidence angle is largely determined by the installation angle of the PTSC, and a suitable installation angle can effectively enhance the optical and thermal efficiencies of the PTSC. However, current research on the optimization or regular adjustment of the installation angle remains relatively limited. This study systematically investigates dynamic installation angle adjustment strategies to explore effective alternatives to complex tracking systems.

Concentrator design

The parabolic trough concentrator primarily consists of a reflective surface, receiver, angle adjuster, and support pylons. The core optimization of the concentrator lies in the design of the angle adjuster. It enables flexible adjustment installation angle of the concentrator to accommodate variations in solar altitude, ensuring stable and efficient solar concentration. Compared to conventional tracking systems, this angle adjuster features a simpler structure, lower cost, and easier maintenance, making it especially suitable for remote areas with limited resources or unreliable power supply.

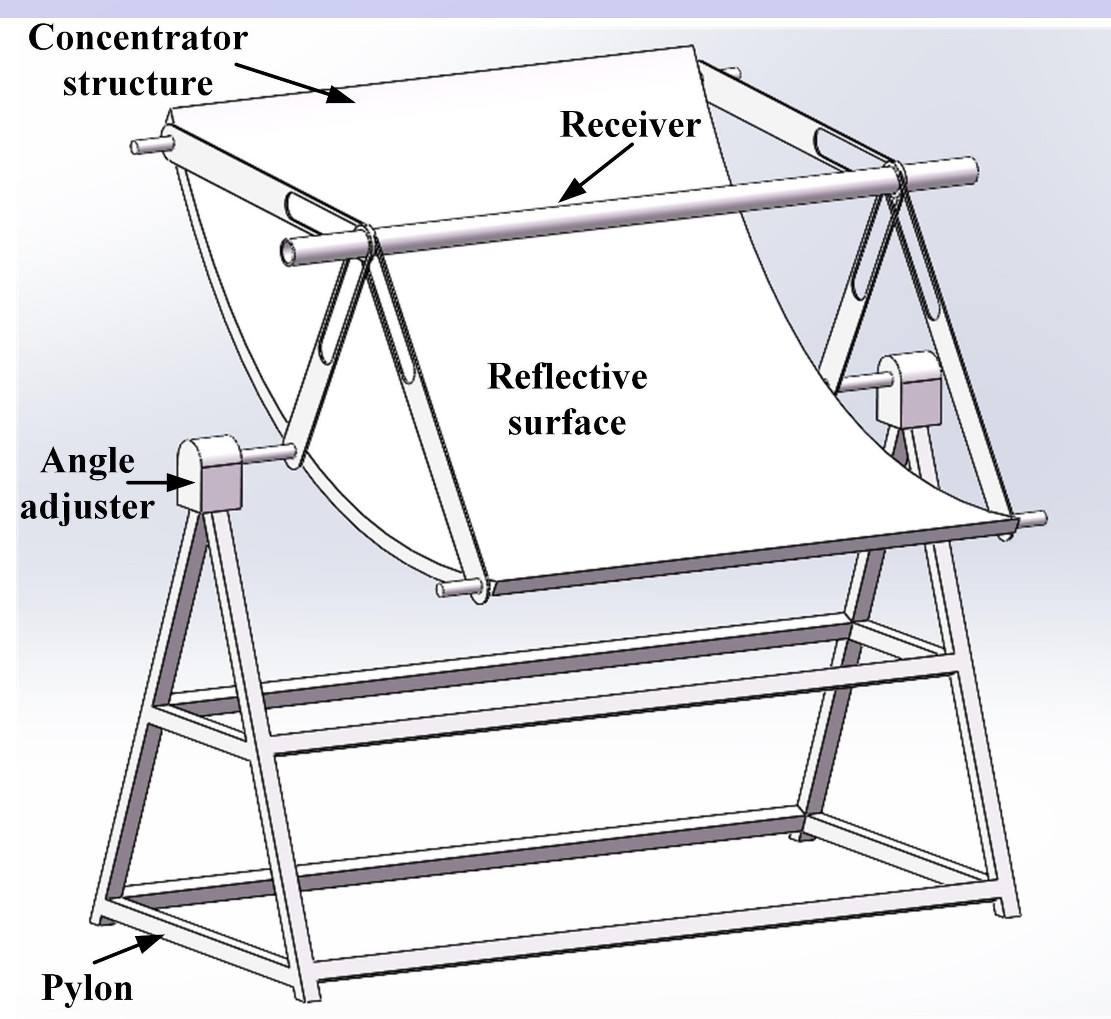

Fig. 1. Parabolic trough concentrator

Installation angle adjustment

In Fig. 2, the incident angle (θ_{in}) changes with the variation of the PTSC installation angle (θ_a). This indicates that the incident angle (θ_{in}) of the PTSC largely depends on the installation angle of the concentrator.

The regular adjustment strategies for the installation angle discussed in this study include semi-annual, seasonal, monthly, and daily adjustment. Among them, the semi-annual adjustment strategy consists of two schemes: the conventional calendar-based division (Jan-Jun; Jul-Dec) and the seasonal-based division (Feb-Jul; autumn-winter). These different adjustment strategies are compared and analyzed to confirm the most strategy for practical applications. Fig.3 shows the calculational process and thought of optimal installation angle required for adjusting regularly. During the calculation process: First, according to geographic location and time parameters, the solar declination angle, hour angle, solar altitude angle, solar azimuth angle, and incident angle are calculated. Then, the optical efficiency for each installation angle is computed. Next, the optimal installation angle is found by traversing the range of installation angles. Finally, the impact of different adjustment schemes on the optical efficiency of the PTSC is analyzed and the optimal adjustment scheme is identified.

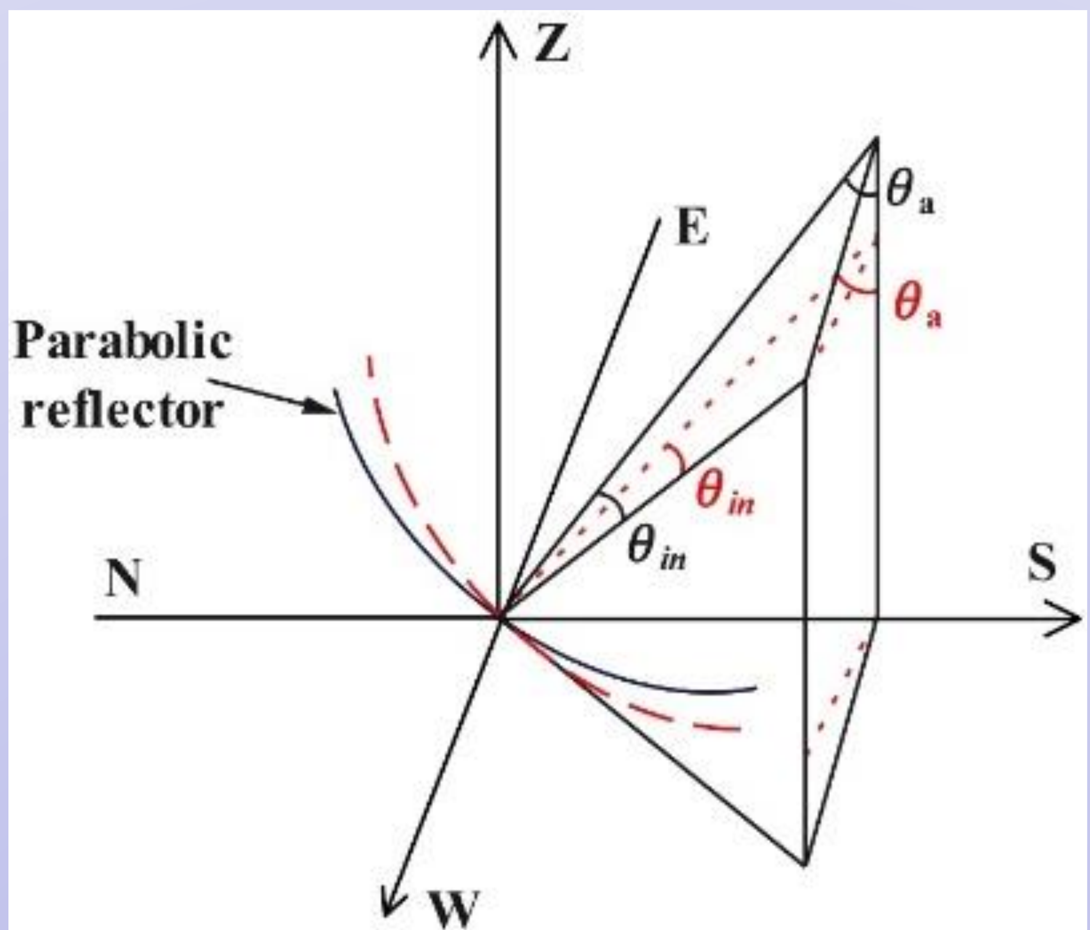

Fig. 2. Schematic of installation angle adjustment

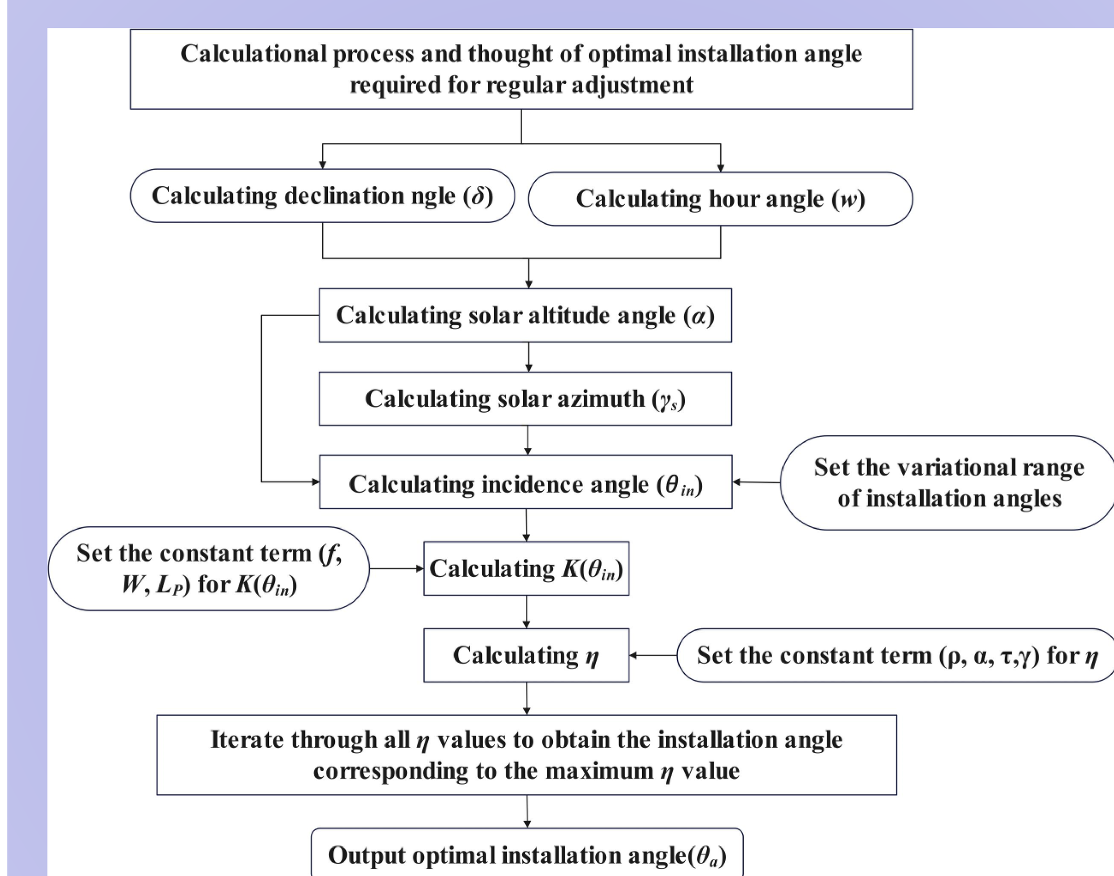

Fig. 3. Calculational process of installation angle.

Results

Fig.4 compares the monthly average optical efficiency under seasonal and monthly adjustment strategies. Significant improvements are observed in February, April, May, June, August, and October, with increases of 3.61%, 3.74%, 5.01%, 1.55%, 3.53%, and 3.97%, respectively. However, the improvements only are 0−0.10% in winter (Nov, Dec, and Jan). Therefore, winter can use the fixed angle of 48.5 °(determined from the seasonal adjustment scheme) to maintain high optical efficiency while reducing adjustment frequency.

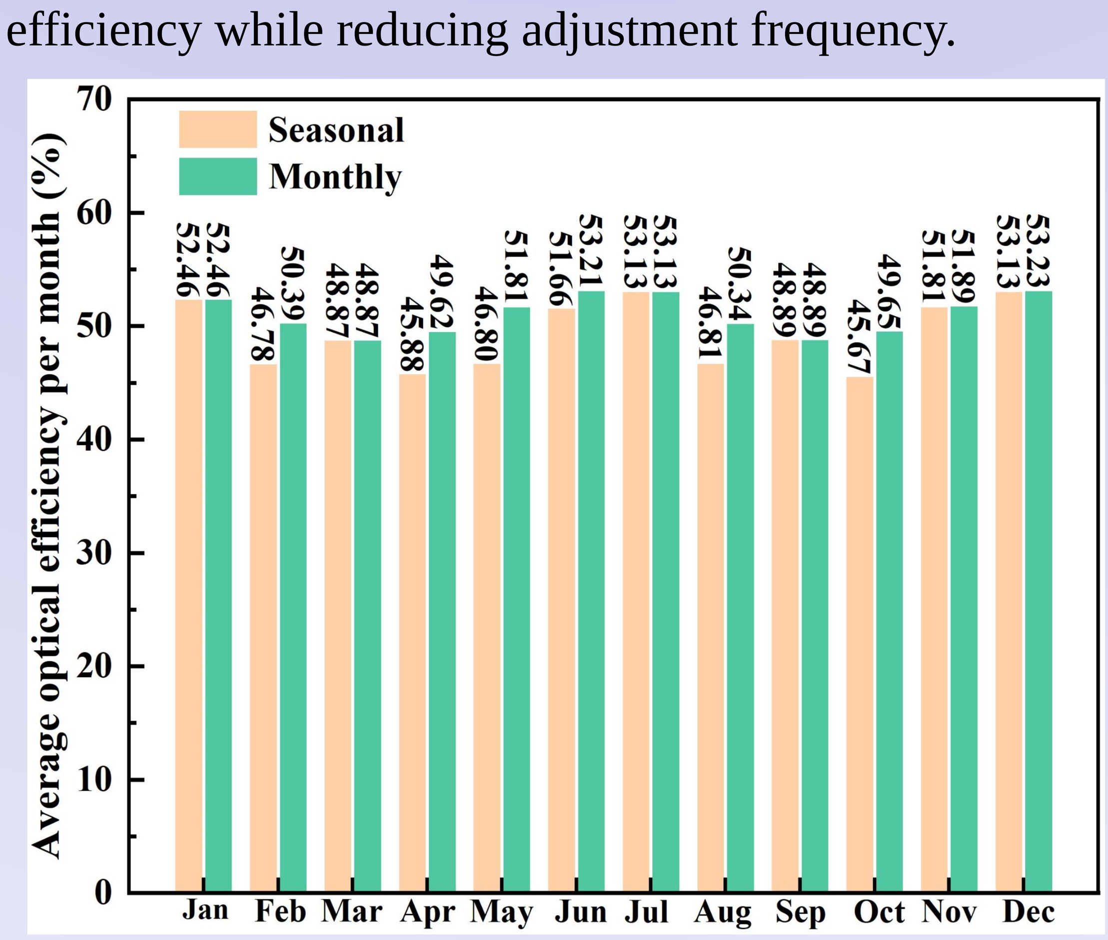

Fig. 4. Optical efficiency under seasonal and monthly adjustment strategies.

In Fig. 5, the optimal installation angles from January to December are 48 °, 40.5 °, 28 °, 14 °, 4 °, 0 °, 1.5 °, 10 °, 22.5 °, 36 °, 47 °, and 50 °, respectively.

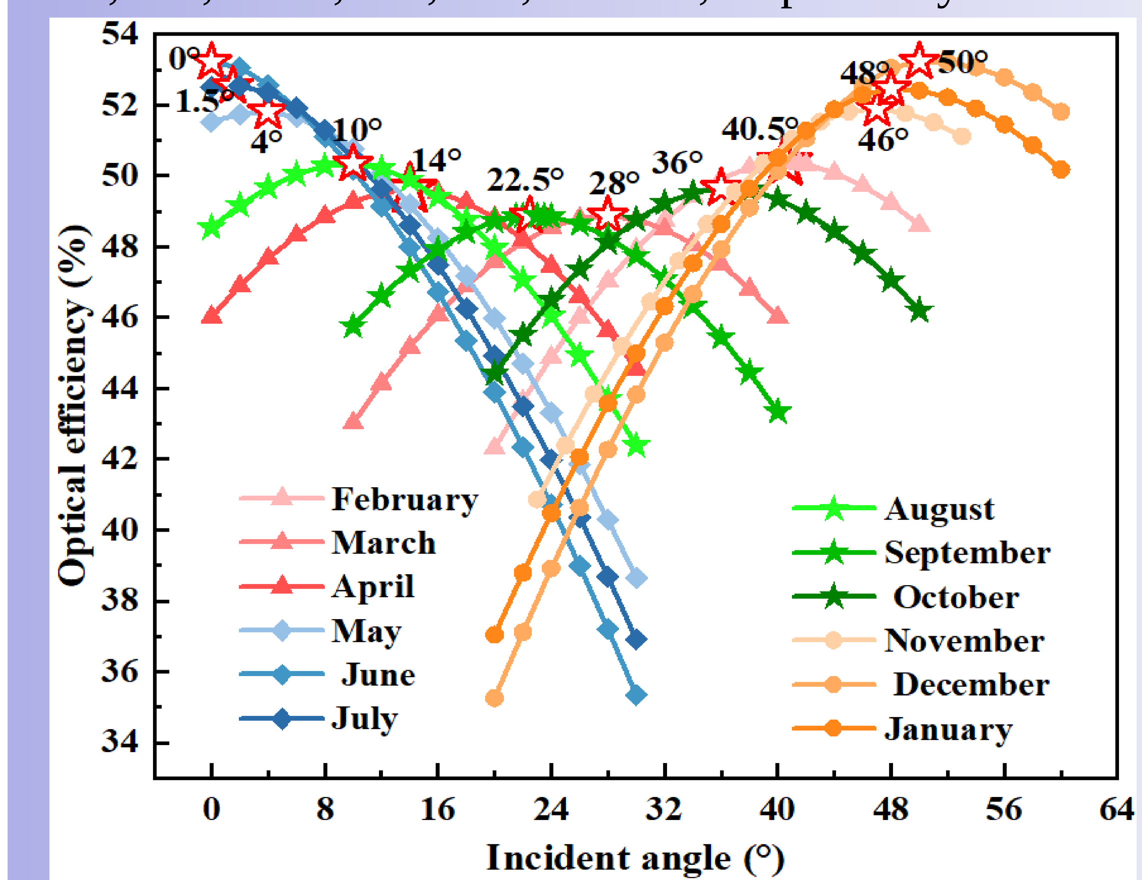

Fig. 5. The best installation angle of the month

Fig.6 shows the thermal efficiency under different adjustment schemes. Compared to the fixed-angle strategy using local latitude, semi-annual, and seasonal adjustments, the combined monthly-seasonal scheme enhances the thermal efficiency by 2.34%, 5.46%, and 1.71%, respectively. In contrast, daily adjustment offers only a marginal 0.15% improvement over the monthly-seasonal strategy.

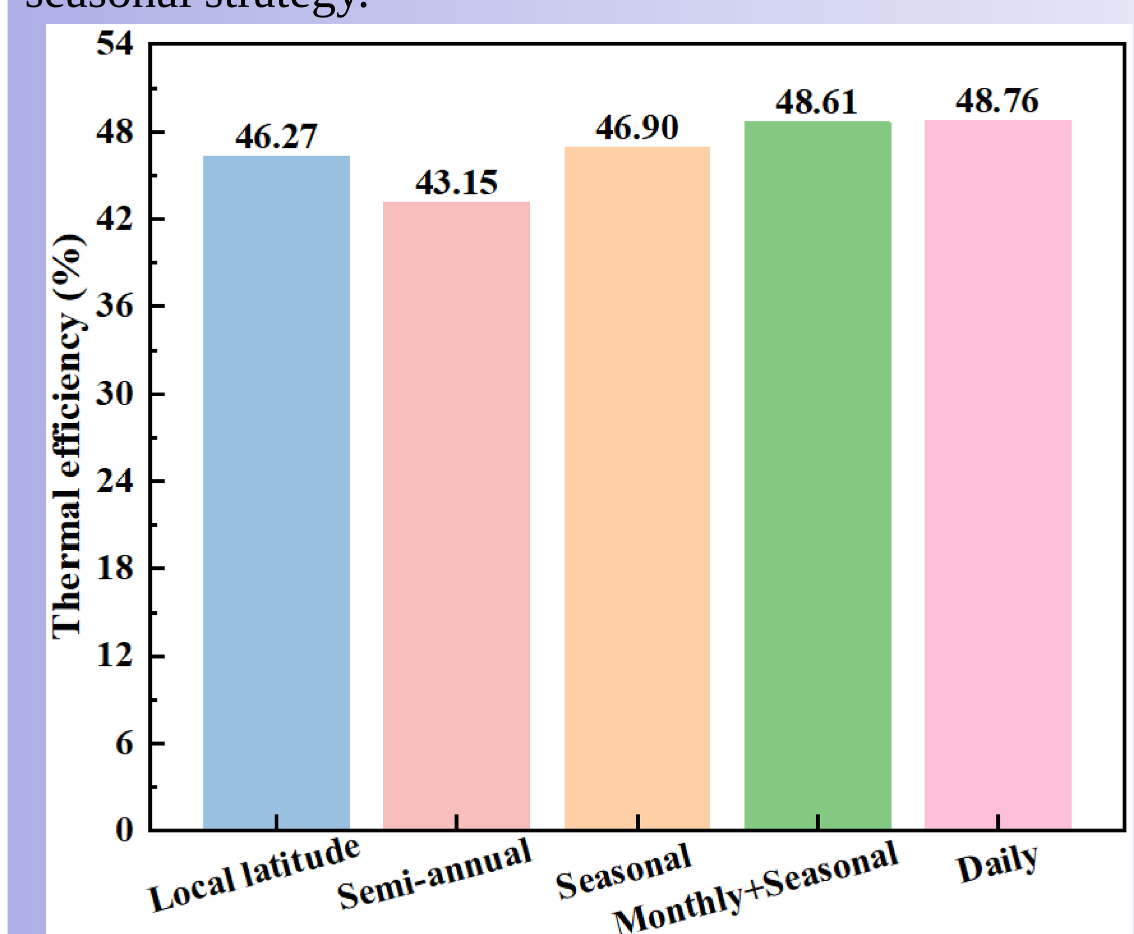

Fig. 6. Thermal efficiency under adjustment strategies

Conclusions

Although daily adjustment allows the PTSC to respond precisely to changes in the solar altitude angle, it offers only limited efficiency improvement compared to monthly adjustment. Considering efficiency, operational cost, and system complexity, the combined monthly-seasonal adjustment strategy offers a more practical solution for PTSC. Under the combined monthly-seasonal adjustment strategy, the installation angles are adjusted monthly during spring, summer, and autumn (Feb-Oct) and seasonally during winter (Nov-DEC-Jan). The corresponding optimal installation angle ranges are 0−40.5 ° and 0−48.5 °. With this strategy, the annual average optical and thermal efficiencies reach 51.12% and 48.61%, respectively. Compared with the semi-annual and seasonal adjustment strategies, the optical efficiencies are improved by 5.85% and 1.80%, and the thermal efficiencies are improved by 5.46% and 1.71%, respectively.

References

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