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Adaption of Collector Orientation for Parabolic Trough Plants in High Latitude Regions

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Abstract. North-South (N-S) orientation of trough collectors is a common design for parabolic trough plants, which typically provides the maximum annual production. However, such orientation is neither the only one option nor an appropriate solution, especially in high latitude like 40º or higher regions. In actual practises, significant monthly production difference is obtained using N-S orientation due to the so-called "cosine" effect. In this paper, East-West (E-W) orientation option is analysed using System Advisor Model developed by NREL. Results show that annual thermal energy incident on receiver tubes can be increased when using E-W orientation in high latitude regions. The higher the latitude, the more the energy gain. Besides, a more uniform monthly thermal energy incident on receiver tubes can be also obtained for E-W orientation, which leads to more stable monthly outputs of the plant, as well as higher utilization rate of the thermal energy storage system. Further analysis shows that row distance between collectors can be reduced at the same cost of incident solar energy losses, resulting in an appreciable savings of land, piping, insulation, HTF inventory, etc., and finally CAPEX and OPEX. Extensive study indicates collector orientation can be along arbitrary direction, and final decision shall be made considering specific site conditions and local energy needs. In conclusion, N-S orientation of collectors is not always the only option for parabolic trough plants. E-W or other orientation rather than N-S orientation shall be carefully analyzed, especially in 40º or higher latitude regions.

Keywords: Collector Orientation, High Latitude Regions, Parabolic Trough, Solar Field

1. Introduction

North-South (N-S) orientation of trough collectors is a common design orientation for parabolic trough plants, which typically provides the maximum annual production [1]. The reason for this is nearly all commercial parabolic trough plants already in operation or under construction in the world are in low- or mid-latitude regions, i.e. less than 40º latitude. However, some research has reported that an increase in annual production would be possible by rotating the collector orientation a certain degree from the N-S orientation [2]. In high latitude regions which are 40º or higher, the N-S orientation is neither the only one option nor an appropriate solution.

Urat project is a 100 MW trough plant with 10-hour storage located in Inner Mongolia of China. It is one of the projects under the framework of first batch China's CSP demonstration program. The latitude of such plant is 41.5 ºN, resulting it as the highest latitude commercial trough plant in the world nowadays. Urat project has showed pleasing performance during ramp-up period, and achieved a consecutive 11 month production of 310 GWh from February to December 2022 [3]. In April 2023, a new record of 330 GWh full-year production from April

1, 2022 to March 31, 2023 has been released [4]. However, significant difference between monthly production is also noticed, i.e. 52.3 GWh monthly production in June [5] vs. 10 GWh monthly production in January [6]. The cause of this is the so-called “cosine” effect, which is related to orientation of the collectors.

Therefore, in this paper, East-West (E-W) collector orientation is proposed. Thermal energy incident on receiver tubes after deducting all optical losses, such as optical efficiency, incident angle modifier (IAM), end loss, row shadowing loss and cosine efficiency, deploy & stow angles, etc., has been simulated and analyzed. Results were compared with the N-S orientation option.

2. Analysis Tool and Method

Simulations were carried out by System Advisor Model (SAM) software, version 2022.11.21, which is developed by National Renewable Energy Laboratory (NREL). For comparison purpose, same boundary conditions of a selected site were applied to the N-S and the E-W orientations, including:

- Weather input file.
- Solar field aperture area.
- Loop inlet/outlet HTF temperatures.
- Design turbine power.
- Design thermal energy storage (TES) hour.
- Wind stow speed.
- Receiver startup delay time and delay energy fraction.
- Collector tilt angle and stow/deploy angle.
- HTF fluid and min/max field flow rate.
- Collector type.
- Receivers.
- System availability.

Therefore, only two values were applied differently, which are collector azimuth angle (0 ° for N-S and 90 for E-W) and row spacing (17 m for N-S and 14 m for E-W, except when row distance has to be varied from 9m to 20m in order to analyze its impact on thermal energy gains).

Upon each simulation, the sum of “Receiver thermal power incident (MWt)” hour data in the “Data tables” sheet of the simulated results is taken as the final value for N-S and E-W orientations of each selected site. In this way, total amount of annual solar thermal energy incident on receiver tubes can be derived, and annual energy gained by such orientation can be easily compared between each other at the same baseline.

3. Results and Discussion

Simulation results show that a more uniform monthly distribution of thermal energy incident on receiver tubes can be obtained for E-W orientation compared to N-S orientation on Urat project site, as shown in Figure 1. This leads to more grid-friendly and stable monthly outputs of the plant along the whole year, and big difference among monthly production can be dramatically mitigated. Meanwhile, a more uniform monthly distribution also makes it easier to choose design value of the plant, especially design capacity of TES system. The red dash lines in Figure 1 represents such idea that with a same design capacity of TES, compared to N-S orientation, E-W orientation will dump less solar energy in summer, and gain more solar energy in winter. This approach will help increase equipment utilization rate of the TES system along the whole year.

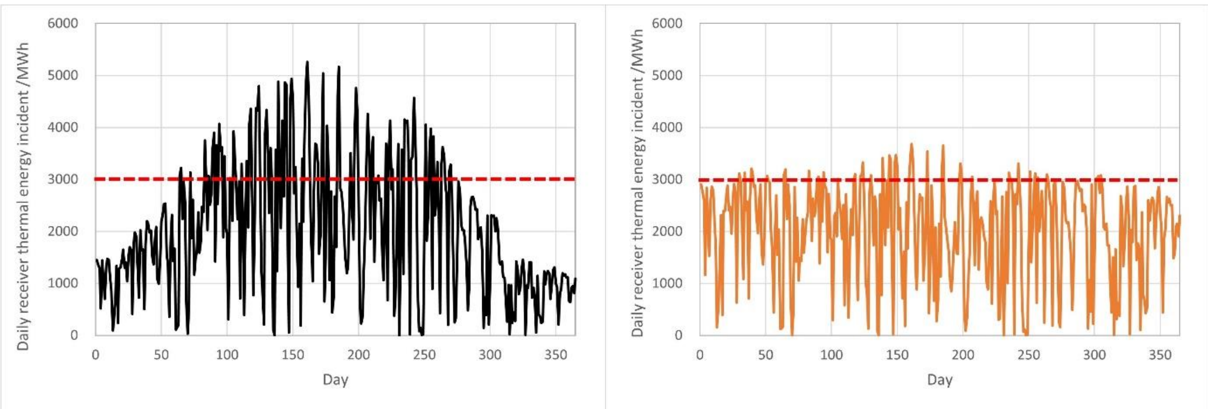

Figure 1. *Comparison of daily receiver thermal energy incident between N-S (left) and E-W (right) orientations using the same boundary conditions of Urat site. Dash lines represent design value of TES capacity selected for the plant.*

To analyze the impact of N-S and E-W orientations on different latitudes, several sites within China have been selected as illustrated in Figure 2 and the analysis results are presented in Table 1. Results indicate that higher annual thermal energy incident on receiver tubes can be achieved on high latitude sites when using E-W orientation other than N-S one, and the latitude 40º seems to be the “watershed”. The higher the latitude, the more the energy gain if deploying E-W orientation.

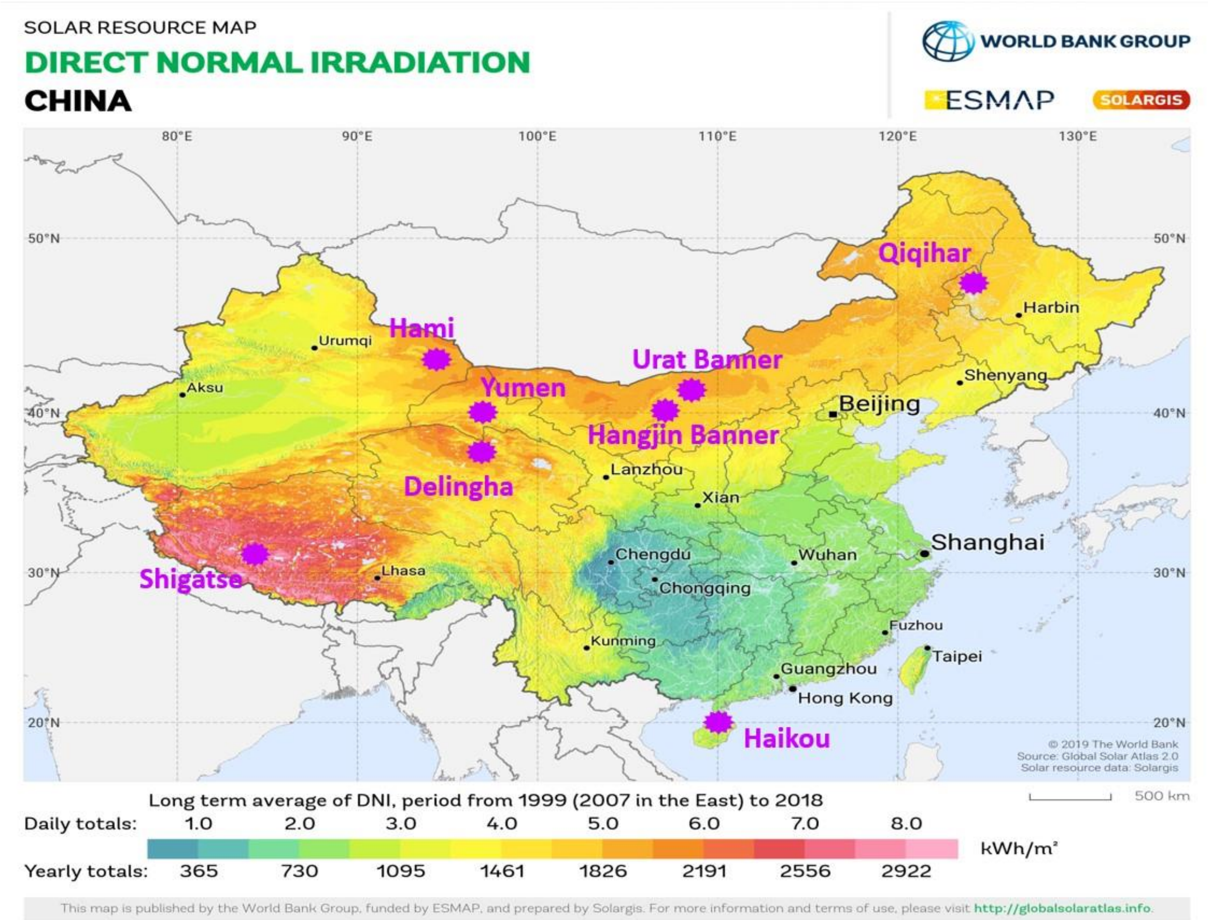

Figure 2. *Location of selected sites at different latitudes in China (Solar resource map is published by the World Bank Group, funded by ESMAP and prepared by Solargis [7]).*

***Table 1**. Comparison of annual receiver thermal energy incident between N-S and E-W orientations for selected sites located at different latitudes in China.*

Site	Latitude	Longitude	Annual thermal energy incident on receiver tubes using N-S orientation /GWh	Annual thermal energy incident on receiver tubes using E-W orientation /GWh	E-W vs. N-S difference percentage
Haikou (Hainan)	20.0 °N	110.2 °E	536	427	-20.3%
Shigatse (Tibet)	31.3 °N	84.1 °E	950	830	-12.7%
Delingha (Qinghai)	37.4 °N	97.3 °E	774	706	-8.8%
Yumen (Gansu)	39.8 °N	97.8 °E	708	660	-6.9%
Hangjin Banner (Inner Mongolia)	40.3 °N	107.0 °E	704	680	-3.3%
Urat Middle Banner (Inner Mongolia)	41.5 °N	108.6 °E	736	730	-0.8%
Hami (Xinjiang)	43.7 °N	95.0 °E	653	684	+4.8%
Qiqihar (Heilongjiang)	47.4 °N	124.1 °E	590	627	+6.3%

Other advantage has also been found in further study when using E-W orientation compared to N-S for Urat site. By varying collector row spacing distance from 9m to 20m and taking the result at 20m row distance as a 100% benchmark value, annual thermal energy percentage incident on receiver tubes for E-W and N-S orientations can be obtained, as illustrated in Figure 3. The results show that at the same cost of incident energy loss due to row shadowing, collector row distance can be reduced when using E-W orientation, e.g. at the cost of 1% incident energy loss, row distance can be reduced from 17m to 14m, which means ~20% reduction. Such row distance reduction will lead to an appreciable and immediate savings of land occupation, piping length, insulation quantity, heat transfer fluid (HTF) inventory, collector tracking angle range, etc., and at the end an appreciable and immediate savings of project CAPEX and OPEX. Such approach could make a certain meaningful contribution to the cost reduction of the whole parabolic trough plant.

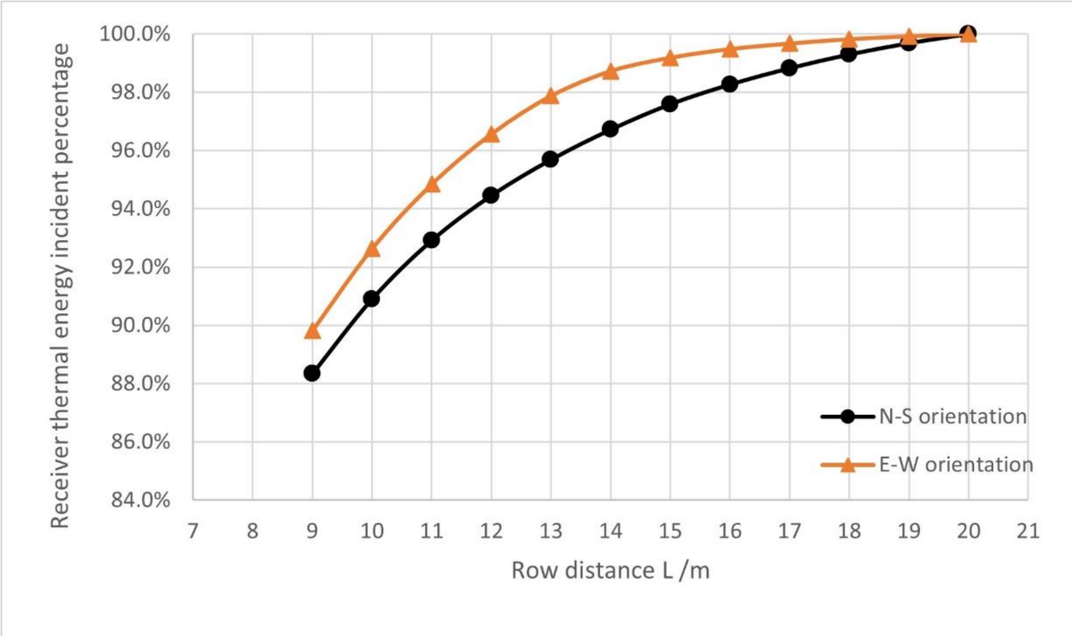

Figure 3. *Comparison of receiver thermal energy incident at different row distance between N-S and E-W orientations using the same collectors of Urat site.*

Extensive analysis also shows that N-S and E-W are not the only two options for parabolic trough collector orientations. In fact, the collectors can be oriented at arbitrary direction. Final decision of collector orientation shall be made considering specific site conditions, such as wind rose map, topography map, etc., as well as local energy needs, e.g. energy collected during the day vs. grid demand at different hours, days, months or seasons. The final purpose is to maximize project return.

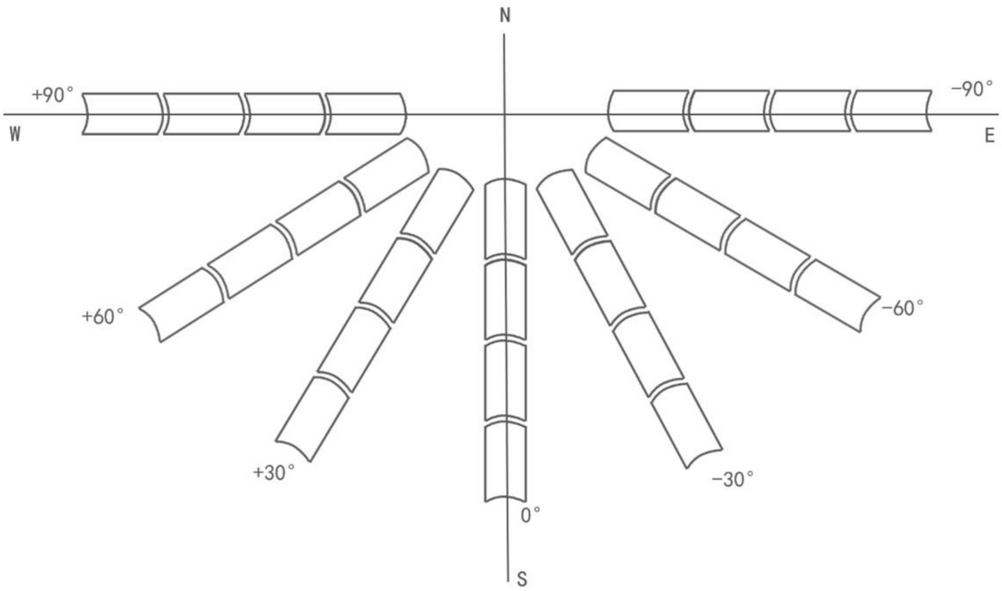

Figure 4. *Parabolic trough collectors oriented at arbitrary direction.*

4. Conclusion

In Summary, N-S orientation of collectors is not always the only option for parabolic trough plants. E-W orientation or other orientation rather than N-S orientation shall be carefully analyzed and assessed, especially in 40º or higher latitude regions. E-W orientation can generate a more uniform monthly output along the year, increase annual energy output in 40º or higher latitude regions, as well as reduce row distance to save land, piping, insulation, HTF inventory and, at the end, to save CAPEX and OPEX of the project. Therefore, decision of collector orientation shall be made considering specific site conditions and local energy needs, in order to finally maximize project return.

Data availability statement

The data that support the findings of this study are openly available on the website specifically listed in each reference.

Author contributions

The author confirms sole responsibility for the followings: conceptualization, resources, methodology, investigation, data collection, formal analysis, and manuscript preparation and review.

Competing interests

The authors declare that they have no competing interests.

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