UDC 621.3.013 https://doi.org/10.20998/2074-272X.2022.5.11

M.Y. Rachedi, D. Bechki, Y. Marif, H. Bouguetaia

Solar flat plate collector enhanced by two reflectors: optimum tilts of reflectors

Introduction. *In some solar concentrating system applications, in which the incoming sunlight is augmented by using commercial flat plate reflectors placed on different sides of the planar collector, it is very important to choose the optimum tilts of boosters (attached edge-to-edge on the top and bottom sides of the solar collector) for each month, to enhance their received solar irradiation over the year in the southern Algeria. The* ***novelty*** *of the proposed work consists of the development of a novel mathematical model in which the reference of the reflector's tilt angles is the collector plane, and optimal tilts are optimized on the average day of each month.* ***Purpose.*** *This paper proposes a novel analytical model of two identical planer reflectors, placed on the top and bottom of a latitude tilted flat plate solar collector, for optimizing their optimal inclination angles during the daytime throughout the year in Ouargla city, southeast of Algeria.* ***Methods.*** *Optimal tilt angles of reflectors were obtained by searching for the optimum captured solar irradiation on the collector's surface from each reflector in the representative day of each month of the year. After that, the obtained tilts were used for calculating incoming solar irradiation on the received area and comparing them to the solar collector without reflectors.* ***Results.*** *The findings of this paper showed that the reflector's inclination angles were variable from one month to another in which the upper reflector's tilts reached its maximum in June and minimum in December, contrarily for the lower reflector. Again, an increase of 28.05 % in the daily received solar irradiation on the collector surface with reflectors compared to the conventional one.* References 17, table 1, figures 4.
Key words: **booster reflectors, flat plate collector, optimum tilts, solar irradiation.**

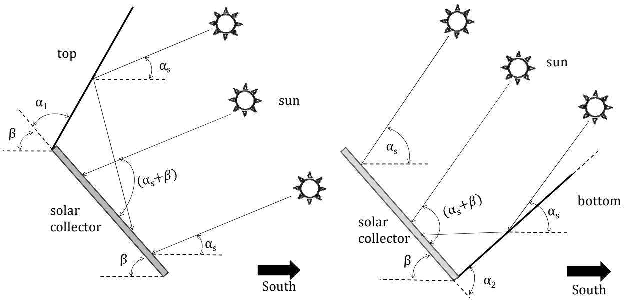
Вступ*. У деяких сонячних концентруючих системах, в яких сонячне світло, що падає, посилюється за рахунок використання комерційних плоских відбивачів, розміщених по різні сторони плоского колектора, дуже важливо вибрати оптимальні нахили підсилювачів (прикріплених кромкою до кромки зверху). і нижні сторони сонячного колектора для кожного місяця, щоб збільшити одержуване ними сонячне випромінювання протягом року в південному Алжирі.* ***Новизна*** *запропонованої роботи полягає у розробці нової математичної моделі, в якій еталоном кутів нахилу рефлектора є площина колектора, а оптимальні нахили оптимізуються у середній день кожного місяця.* ***Мета****. У цій статті пропонується нова аналітична модель двох ідентичних плоских відбивачів, розміщених зверху та знизу плоского сонячного колектора з нахилом по широті, для оптимізації їх оптимальних кутів нахилу вдень протягом року у місті Уаргла, на південний схід від Алжиру.* ***Методи****. Оптимальні кути нахилу рефлекторів були отримані шляхом пошуку оптимального сонячного випромінювання на поверхню колектора від кожного рефлектора в репрезентативні дні кожного місяця року. Після цього отримані нахили використовувалися для розрахунку сонячної радіації на отриману площу і порівняння їх з сонячним колектором без відбивачів.* ***Результати*** *цієї статті показали, що кути нахилу рефлектора змінювалися від місяця до місяця, коли нахил верхнього рефлектора досягав максимуму в червні і мінімуму в грудні, на відміну від нижнього рефлектора. Знову ж таки, збільшення на 28,05 % щоденно одержуваного сонячного випромінювання на поверхню колектора з відбивачами порівняно зі звичайним.* Бібл. 17, табл. 1, рис. 4.
Ключові слова: **підсилювачі відбивачі, плоский колектор, оптимальні нахили, сонячне випромінювання.**

Introduction. In recent years, the use of solar energy has become persistent all over the world, which has attached significant efforts. So, for the no-tracking flat plate solar collector, augmenting solar-gain using booster reflectors is a key area of interest in the context of reducing the cost factor of the system. Moreover, it is an economical solution for enhancing the output of solar collectors, which is strongly influenced by the amount of received solar irradiation [1-4]. For that, many reports about the effect of adding multi-reflectors on different sides of a flat plate solar collector on the received solar irradiation have been presented. Garg et al. [5] studied the maximization of the solar energy received by the collector attached to two mirrors at their top and bottom sides. Bhowmik et al. [6] examined two mirrors on the right and left sides of the solar collector and their effects on the power output of the whole system. They obtained that the average energy yield was about 10-19.84 % in the summer period and 10-13.23 % in the winter. Huang et al. [7] experimented with the effect of top-bottom side mirrors on photovoltaic panel power output. They found that the PV power generation was increased by about 23 % compared to the panel without mirrors. Bahaidarah et al. [8] investigated the performance of the V-trough PV system. They obtained that the power output was enhanced by 34.6 % on March 13th and by 37 % on September 16th. Baig et al. [9] analyzed and experimented with the seasonally tracked V-Trough PV/T system in India. They observed an average augmentation of 35 % in the electrical power output from the V-Trough PV/T system as compared to the conventional one. Kostić et al. [10] examined the influence of the position of reflectors made of aluminum sheet on the thermal efficiency of a solar thermal collector. They have found that the reflectors made of aluminum sheet have a positive effect on the thermal efficiency of the PV/T system. An energy gain of about 35-44 % has been attained in this study [10]. Rahman et al. [11] examined the performance enhancement of a PV solar system by mirror reflection. They achieved an average increase of around 25 % in short-circuit current, as high as the sun tracking, can be obtained. Bione et al. [12] compared the performance of PV water pumping systems driven by fixed, tracking, and V-Trough generators. They realized a cost reduction of 19 % for the tracking system and a reduction of 48 % for the concentrating system compared to the static configuration. Tabet et al. [13] optimized tilts of reflectors placed in left-right sides of PV/T collector. They obtained an increase of about 23 % in received solar irradiation on the collector's surface by using reflectors compared to the conventional one.

Those boosters must be tilted at their optimal inclination angle to capture more incoming sunlight during the whole year, which is the **aim of this paper**, where an optimization tilt of two flat plate reflectors, placed on the top-bottom sides of a fixed solar collector in the southeast of Algeria [14], will be exposed.

2. Method.

2.1. Description of the system. In order to enhance incoming sunlight, the south-oriented solar collector with a tilt angle equal to the latitude of the Ouargla region (β = 31° 57' N fixed over the year) in the southeast of Algeria , is attached to two identical reflectors (on the top side tilted at α_1 from collector plane and on the bottom side inclined at α_2 from collector plane as illustrated in Fig. 1), which have the same dimensions as the solar collector, for constructing a V-Trough concentrator.



a *b*

Fig. 1. Schematic diagram of the solar collector with: (*a*) top and (*b*) bottom reflectors

2.2. Mathematical model. The total received solar irradiation by the collector surface $I_{tot,col}$ is estimated using Capderou's model [15], and is equal to the sum of solar irradiation on its surface without reflectors $I_{net,col}$ ($I_{net,col}$ is equal to the sum of the direct solar irradiation $I_{dir,col}$, solar irradiation diffused from the sky $I_{sky,col}$, and the reflected solar irradiation from the ground $I_{gr,col}$) and the sum of the reflected solar irradiation from the top reflector $I_{refl,1}$ and the bottom one $I_{refl,2}$, which are calculated by using the following expressions:

$$I_{tot,col} = I_{net,col} + I_{refls,col}, \quad (1)$$

$$I_{net,col} = I_{dir,col} + I_{sky,col} + I_{gr,col}, \quad (2)$$

$$I_{dir,col} = I_{dir,h}\cdot\cos(\theta), \quad (3)$$

where $I_{dir,h}$ is the direct solar irradiation on a horizontal plane and θ is the angle of incidence of the beam irradiation.

The α_s and δ_s are the sun's altitude and declination angles, which can be calculated using the expressions [16]:

$$\alpha_s = \arcsin[\cos(\delta_s)\cdot\cos(\omega_s)\cdot\cos(\phi) + \sin(\delta_s)\cdot\sin(\phi)], \quad (4)$$

$$\delta_s = 23.45\cdot\sin[(360\cdot(N_j - 121))/365], \quad (5)$$

where ω_s is the hour angle of the sun; ϕ is the longitude of the localization; N_j is day of the year.

The sun's azimuth angle γ_s can be found using [16]:

$$\gamma_s = \arcsin[(\cos(\delta_s)\cdot\cos(\omega_s))/\cos(\alpha_s)], \quad (6)$$

where $I_{refls,col}$ is the sum of the reflected solar irradiation from 2 reflectors and given by:

$$I_{refls,col} = I_{refl,1} + I_{refl,2}, \quad (7)$$

$$I_{refl,1} = \rho\cdot I_{dir,h}\cdot\sin(2\cdot\alpha_1+\alpha_s+\beta-180°)\cdot\sin(180°-(\alpha_s+\alpha_1+\beta)), \quad (8)$$

$$I_{refl,2} = \rho\cdot I_{dir,h}\cdot\sin(2\cdot\alpha_2-\alpha_s-\beta)\cdot\sin(\alpha_s-\alpha_2+\beta), \quad (9)$$

where ρ is the reflector's reflectance.

The solar irradiation diffused from the sky $I_{sky,col}$ and the reflected solar irradiation from the ground $I_{gr,col}$ are given by:

$$I_{sky,col} = I_{dir,h}\cdot(1 + \cos(\beta))/2, \quad (10)$$

$$I_{gr,col} = \rho_{gr}\cdot I_{dir,h}\cdot(1 - \cos(\beta))/2, \quad (11)$$

where $I_{dir,h}$ is the diffuse solar irradiation on a horizontal plane; $I_{tot,h}$ is the global solar irradiation on a horizontal plane; ρ_{gr} is the reflectance of the ground.

2.3. Simulation procedure. The previous equations have been implemented in a MATLAB program. $I_{refl,i}$ (i = 1 and 2) have been measured for different values of α_i (i = 1 and 2) varied from 0° to 90° in each perfect day of the month (Table 1). The optimal tilt angles of reflectors $\alpha_{opt,i}$ (i = 1 and 2), corresponds to the optimum of $I_{refl,i}$ (i = 1 and 2) over the perfect day of each month. This procedure has been repeated for all average days of months [17].

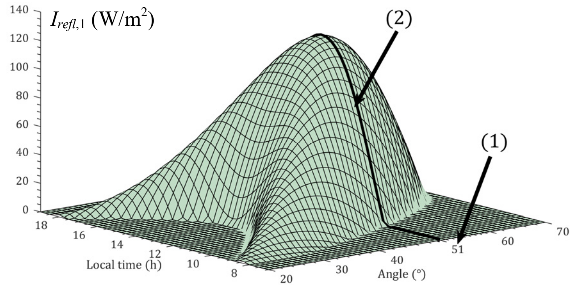
3. Results and discussion. The optimal inclination angles of reflectors $\alpha_{opt,i}$ (i = 1 and 2) are achieved by searching the maximum of the reflected solar irradiation from each booster alone $I_{refl,i}$ (i = 1 and 2) described in (8) and (9), for the average day of each month (Table 1).

Table 1

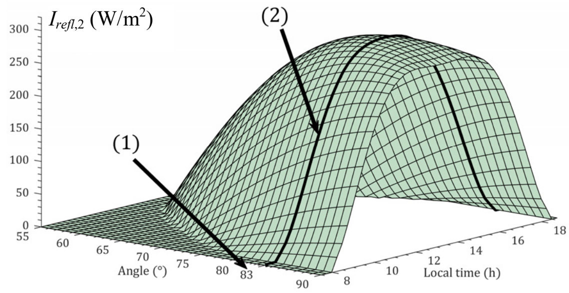
Average days of months [17]

Date	Perfect Day Number
17 January	17
16 February	47
16 March	75
15 April	105
15 May	135
11 June	162
16 July	198
16 August	228
15 September	258
15 October	288
14 November	318
10 December	344

Figure 2 shows the variation of the reflected solar irradiation from each reflector on the solar collector surface in the average day of December (December 10th), as a function of local time and angles α_i (i = 1 and 2).



a



b

Fig. 2. Variation of reflected solar irradiation from (*a*) top and (*b*) bottom reflectors on December 10th. 1 – optimal tilts; 2 – optimal reflected solar irradiation

For the top side reflector (Fig. 2,*a*), to obtain the maximum reflected solar irradiation from this booster in December, it must be tilted at 51° from the collector plan, which is the optimum tilt of the top reflector in this month.

Similarly, for the bottom reflector (Fig. 2,*b*), the optimal inclination angle in December for this reflector is 83° calculated from the receiver plan.

Doing the same steps for the other months, the obtained results are presented in Fig. 3.

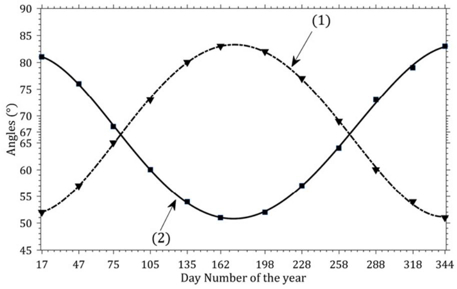
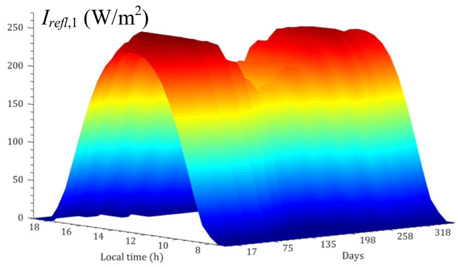


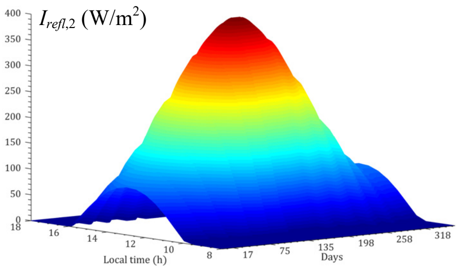
Fig. 3. Annual variation of optimal tilts of: (1) top and (2) bottom reflectors

Figure 3 shows the annual variation of optimal tilt angles of reflectors, as a function of the day number of the year. $\alpha_{opt,1}$ achieved a maximum in June (83°) and a minimum in December (51°). Furthermore, $\alpha_{opt,2}$ touched its uppermost in December (83°) and lowermost in June (51°).

Figure 4 illustrates the annual variation of the reflected solar irradiation from the top and bottom reflectors as a function of local time and days number of the year. $I_{refl,1}$ take a minimum in the summer period and a maximum in spring and autumn. On the other hand, $I_{refl,2}$ extended their superior in the summer months when the sun will be at its highest, and inferior in winter when it will be at its lowest.



a



b

Fig. 4. Annual variation of the reflected solar irradiation from the (*a*) top and (*b*) bottom reflectors

4. Conclusions.

In this paper, optimal tilt angles of two flat plate reflectors, attached edge to edge on the top and bottom sides of a solar collector, are optimized. The impact of adding reflectors on the amount of incoming solar irradiation is examined. The principal results obtained in this paper are:

- the quantity of solar irradiation reflected from the top side reflector can be increased by tilting this booster forward during the summer and backward during the winter, in contrast to the bottom reflectors.
- Due to the difference in the sun's altitude angle, the optimal tilts of the top and bottom reflectors were observed to fluctuate significantly from month to month.
- The model described in this work can be utilized anywhere for all solar applications with the exception of photovoltaic applications that do not require cooling, particularly during the hot months of April to August in hot climates.

Conflict of interest. The authors declare that they have no conflicts of interest.

REFERENCES

1. Saeed H., Mehmood T., Khan F.A., Shah M.S., Ullah M.F., Ali H. An improved search ability of particle swarm optimization algorithm for tracking maximum power point under shading conditions. *Electrical Engineering & Electromechanics*, 2022, no. 2, pp. 23-28. doi: https://doi.org/10.20998/2074-272X.2022.2.04.

2. Praveen Kumar T., Ganapathy S., Manikandan M. Improvement of voltage stability for grid connected solar photovoltaic systems using static synchronous compensator with recurrent neural network. *Electrical Engineering & Electromechanics*, 2022, no. 2, pp. 69-77. doi: https://doi.org/10.20998/2074-272X.2022.2.10.

3. Akbar F., Mehmood T., Sadiq K., Ullah M.F. Optimization of accurate estimation of single diode solar photovoltaic parameters and extraction of maximum power point under different conditions. *Electrical Engineering & Electromechanics*, 2021, no. 6, pp. 46-53. doi: https://doi.org/10.20998/2074-272X.2021.6.07.

4. Sahraoui H., Mellah H., Drid S., Chrifi-Alaoui L. Adaptive maximum power point tracking using neural networks for a photovoltaic systems according grid. *Electrical Engineering & Electromechanics*, 2021, no. 5, pp. 57-66. doi: https://doi.org/10.20998/2074-272X.2021.5.08.

5. Garg H.P., Hrishikesan D.S. Enhancement of solar energy on flat-plate collector by plane booster mirrors. *Solar Energy*, 1988, vol. 40, no. 4, pp. 295-307. doi: https://doi.org/10.1016/0038-092X(88)90002-3.

6. Bhowmik H., Amin R. Efficiency improvement of flat plate solar collector using reflector. *Energy Reports*, 2017, vol. 3, pp. 119-123. doi: https://doi.org/10.1016/j.egyr.2017.08.002.

7. Huang B.J., Sun F.S. Feasibility study of one axis three positions tracking solar PV with low concentration ratio reflector. *Energy Conversion and Management*, 2007, vol. 48, no. 4, pp. 1273-1280. doi: https://doi.org/10.1016/j.enconman.2006.09.020.

8. Bahaidarah H., Tanweer B., Gandhidasan P., Rehman S. A Combined Optical, Thermal and Electrical Performance Study of a V-Trough PV System – Experimental and Analytical Investigations. *Energies*, 2015, vol. 8, no. 4, pp. 2803-2827. doi: https://doi.org/10.3390/en8042803.

9. Baig H., Jani R., Markam B.K., Maiti S., Mallick T.K. Modelling and experimental analysis of a seasonally tracked V-trough PV/T system in India. *Solar Energy*, 2018, vol. 170, pp. 618-632. doi: https://doi.org/10.1016/j.solener.2018.06.018.

10. Kostić L.T., Pavlović Z.T. Optimal position of flat plate reflectors of solar thermal collector. *Energy and Buildings*, 2012, vol. 45, pp. 161-168. doi: https://doi.org/10.1016/j.enbuild.2011.10.059.

11. Rahman R., Khan M.F. Performance enhancement of PV Solar System by mirror reflection. *International Conference on Electrical & Computer Engineering (ICECE 2010)*, 2010, pp. 163-166. doi: https://doi.org/10.1109/ICELCE.2010.5700652.

12. Bione J., Vilela O.C., Fraidenraich N. Comparison of the performance of PV water pumping systems driven by fixed,

tracking and V-trough generators. *Solar Energy*, 2004, vol. 76, no. 6, pp. 703-711. doi: https://doi.org/10.1016/j.solener.2004.01.003.
13. Tabet I., Touafek K., Khelifa A., Baissi M.T., Bellel N. Optimization tilts angle of flat plate reflectors placed in left-right side of Hybrid Photovoltaic thermal collector. *2016 International Renewable and Sustainable Energy Conference (IRSEC)*, 2016, pp. 343-347. doi: https://doi.org/10.1109/IRSEC.2016.7983946.
14. Rachedi M.Y., Bechki D., Marif Y., Bouguettaia H. Solar Flat Plate Collector Enhanced by Two Reflectors: Optimum Tilts of Reflectors. *2022 1st International Conference on Modern Electrical Engineering and Technology (CIETM)*, 2022.
15. Capderou M. *Atlas Solaire de l'Algérie* [Solar Atlas of Algeria], Tome 1, vols. 1 and 2, Algeria, University Publication Office, 1987. 399 p. (Fra).
16. Duffie J.A., Beckman W.A., Blair N. *Solar Engineering of Thermal Processes, Photovoltaics and Wind*. 5th ed., New York, Willey Publ., 2020. 906 p.
17. Klein S.A. Calculation of monthly average insolation on tilted surfaces. *Solar Energy*, 1977, vol. 19, no. 4, pp. 325-329. doi: https://doi.org/10.1016/0038-092X(77)90001-9.

Received 08.04.2022
Accepted 13.06.2022
Published 07.09.2022

Mohamed Yacine Rachedi[1,3], *PhD, Assistant Professor,*
Djamel Bechki[2,3], *Doctor of Physics, Professor,*
Yacine Marif[2,3], *Doctor of Physics, HDR, MCA,*
Hamza Bouguettaia[2,3], *Doctor of Physics, Professor,*
[1] Department of Electrical Engineering,
Faculty of Applied Sciences,
University of Ouargla, Algeria.
[2] Department of Physics,
Faculty of Mathematics & Matter Sciences,
University of Ouargla, Algeria.
[3] LENREZA Laboratory,
University of Ouargla, Algeria.
e-mail: rachedi.yacine@univ-ouargla.dz (Corresponding Author),
d_bechki@yahoo.fr, yacine.marif@yahoo.fr;
h_bouguettaia@yahoo.co.uk

How to cite this article:
Rachedi M.Y., Bechki D., Marif Y., Bouguetaia H. Solar flat plate collector enhanced by two reflectors: optimum tilts of reflectors. *Electrical Engineering & Electromechanics*, 2022, no. 5, pp. 67-70. doi: https://doi.org/10.20998/2074-272X.2022.5.11