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 planar 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.

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.


2.1. 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 α1 from collector plane and on the bottom side inclined at α2 from collector plane as illustrated in Fig. 1), which have the same dimensions as the solar collector, for constructing a V-Trough concentrator.

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

\[
I_{\text{tot, col}} = I_{\text{net, col}} + I_{\text{refl,1}} + I_{\text{refl,2}},
\]

\[
I_{\text{net, col}} = I_{\text{dir, col}} + I_{\text{sky, col}} + I_{\text{gr, col}},
\]

\[
I_{\text{dir, col}} = I_{\text{dir, h}} \cos(\theta),
\]

where \( I_{\text{dir, h}} \) is the direct solar irradiation on a horizontal plane and \( \theta \) is the angle of incidence of the beam irradiation.

The \( \alpha_s \) and \( \delta_s \) are the sun’s altitude and declination angles, which can be calculated using the expressions [16]:

\[
\alpha_s = \arcsin[\cos(\delta_s) \cos(\omega_s) \cos(\phi) + \sin(\delta_s) \sin(\phi)],
\]

\[
\delta_s = 23.45 \sin[(360(N_f - 121))/365],
\]

where \( \omega_s \) is the hour angle of the sun; \( \phi \) is the longitude of the localization; \( N_f \) is day of the year.

The sun’s azimuth angle \( \gamma_a \) can be found using [16]:

\[
\gamma_a = \arcsin[(\cos(\delta_s) \cos(\omega_s))/\cos(\alpha_s)],
\]

where \( I_{\text{refl,1}} \) is the sum of the reflected solar irradiation from 2 reflectors and given by:

\[
I_{\text{refl,1}} = I_{\text{refl,1}} + I_{\text{refl,2}},
\]

\[
I_{\text{refl,1}} = \rho \cdot I_{\text{dir, h}} \cdot \sin(2(\alpha_1 + \alpha_2 - 180^\circ) - \sin(180^\circ) - (\alpha_1 + \alpha_2 + \beta)),
\]

\[
I_{\text{refl,2}} = \rho \cdot I_{\text{dir, h}} \cdot \sin(2(\alpha_2 - \alpha_1 - \beta)) \sin(\alpha_1 - \alpha_2 + \beta),
\]

where \( \rho \) is the reflector’s reflectance.

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

\[
I_{\text{sky, col}} = I_{\text{dir, h}}(1 + \cos(\beta))/2,
\]

\[
I_{\text{gr, col}} = \rho_g \cdot I_{\text{dir, h}}(1 - \cos(\beta))/2,
\]

where \( I_{\text{dir, h}} \) is the diffuse solar irradiation on a horizontal plane; \( I_{\text{gr, col}} \) is the global solar irradiation on a horizontal plane; \( \rho_g \) is the reflectance of the ground.

2.3. Simulation procedure. The previous equations have been implemented in a MATLAB program. \( I_{\text{refl,1}} (i = 1 \text{ and } 2) \) have been measured for different values of \( \alpha_s (i = 1 \text{ and } 2) \) varied from 0° to 90° in each perfect day of the month (Table 1). The optimal tilt angles of reflectors \( \alpha_{opt,1} (i = 1 \text{ and } 2) \), corresponds to the optimum of \( I_{\text{refl,1}} (i = 1 \text{ and } 2) \) 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 \( \alpha_{opt,1} (i = 1 \text{ and } 2) \) are achieved by searching the maximum of the reflected solar irradiation from each booster alone \( I_{\text{refl,1}} (i = 1 \text{ and } 2) \) described in (8) and (9), for the average day of each month (Table 1).

<table>
<thead>
<tr>
<th>Date</th>
<th>Perfect Day Number</th>
</tr>
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<tbody>
<tr>
<td>17 January</td>
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<tr>
<td>16 February</td>
<td>47</td>
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<tr>
<td>16 March</td>
<td>75</td>
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<td>15 April</td>
<td>105</td>
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<td>15 May</td>
<td>135</td>
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<tr>
<td>11 June</td>
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<td>16 July</td>
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<td>318</td>
</tr>
<tr>
<td>10 December</td>
<td>344</td>
</tr>
</tbody>
</table>

Table 1

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 \( \alpha_s (i = 1 \text{ and } 2) \).
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.

Figure 3 shows the annual variation of optimal tilt angles of reflectors, as a function of the day number of the year. \( \alpha_{\text{opt},1} \) achieved a maximum in June (83°) and a minimum in December (51°). Furthermore, \( \alpha_{\text{opt},2} \) 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. \( I_{\text{refl},1} \) take a minimum in the summer period and a maximum in spring and autumn. On the other hand, \( I_{\text{refl},2} \) 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.


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


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