Evaluation of the plane of array irradiance for a photovoltaic installation equipped with flat reflectors in different geographical locations

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Introduction

The irradiance in the plane of array (GPOA) assessment is an approach requiring calculations based on several parameters and measurements and it becomes more complex when adding planar reflectors in front of the panels [1]. Several optical, geometrical and solar data must be taken into account for that purpose. On the other hand, the plane of array irradiance of a PV-Reflector system will be highly affected by the longitude, latitude and weather conditions. In this work, six different locations will be studied in this paper: Oslo, Palaiseau, Chicago, Athens, Ouarzazat and New Delhi (Table 1) over a five years period (2012-2016). The irradiance data (horizontal beam and diffuse) were taken from PVGIS (Photovoltaic Geographical Information System) dataset [2], [3].

Objectives

- Describing a plane of array irradiance (GPOA) estimation study performed for a PV system equipped with flat reflectors.
- The work presented focuses on the evaluation of GPOA for a PV-Reflector system architecture in six different geographical locations and under various weather conditions.
- Performing an architectural optimization approach by considering several geometrical variations in order to achieve the highest plane of array irradiance.

Model and Methodology

A- System's description

- BNI: The beam normal irradiance (W/m²).
- DHI: The diffuse horizontal irradiance (W/m²).
- DRSL: The direct radiation reaching the reflector to be then absorbed by the PV array (W/m²).
- DRSR: The diffuse radiation reaching the reflector to be then absorbed by the PV array (W/m²).
- Lr: The planar reflector Length (m).
- Lpv: The photovoltaic panel length (m).
- 0th: The inclination angle of the PV module to the horizontal plane (°).
- OR: The angle between reflector and the horizontal plane (°).
- GPOAref: The plane of array irradiance for a PV-Reflector installation (W/m²).

B- Analytical Model

The GPOA estimation model is given by [4]

\[ GPOA = \frac{C}{0.5 Lpv \sin (0th)} \times (\cos (A) + DHI + DRSL + BNI) + \frac{1}{2} \times \frac{1}{\cos (0th) + 1} \times \left( \frac{1}{2}\times \frac{1}{\cos (0th)} + \frac{1}{2} \right) \times \frac{BNI}{2} + \frac{1}{2} \times \frac{1}{\cos (0th)} \times \frac{BNI}{2} \]

C- Geometrical optimization process

Optimization strategy:

- Three possibilities for the reflector’s length (Lr) were considered: Lpv/2, Lpv and 2Lpv.
- Three architectural possibilities affecting 0th and OR: a fixed configuration, an optimized configuration, and a monthly adjustment.

Introduction:

- G0: Gain in GPOA added by the reflectors over the entire period (%).
- Optimum: Optimal GPOA value obtained for the architecture without mirrors.
- Optima: Optimum GPOA value obtained for the architecture with mirrors.
- ORoptimum: Optimal OR value obtained.

Table 1: Different geographical locations studied

<table>
<thead>
<tr>
<th>Country</th>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>Oslo</td>
<td>59.9</td>
<td>10.73</td>
</tr>
<tr>
<td>France</td>
<td>Palaiseau</td>
<td>48.71</td>
<td>2.24</td>
</tr>
<tr>
<td>USA</td>
<td>Chicago</td>
<td>41.87</td>
<td>-87.62</td>
</tr>
<tr>
<td>Greece</td>
<td>Athens</td>
<td>37.98</td>
<td>23.72</td>
</tr>
<tr>
<td>Morocco</td>
<td>Ouarzazat</td>
<td>30.92</td>
<td>-6.91</td>
</tr>
<tr>
<td>India</td>
<td>New Delhi</td>
<td>28.61</td>
<td>77.2</td>
</tr>
</tbody>
</table>

Table 2: Gain for the optimized architectures obtained for the entire studied period (2012-2016)

<table>
<thead>
<tr>
<th>Location</th>
<th>Reflector Length</th>
<th>Monthly Gain</th>
<th>Seasonal Gain</th>
<th>Fixed architecture Gain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oslo</td>
<td>Lpv</td>
<td>13.2</td>
<td>9.9</td>
<td>13.9</td>
</tr>
<tr>
<td>Palaiseau</td>
<td>Lpv</td>
<td>12.1</td>
<td>9.5</td>
<td>11.2</td>
</tr>
<tr>
<td>Athens</td>
<td>Lpv</td>
<td>10.7</td>
<td>8.3</td>
<td>10.2</td>
</tr>
<tr>
<td>New Delhi</td>
<td>Lpv</td>
<td>12.0</td>
<td>9.8</td>
<td>11.6</td>
</tr>
<tr>
<td>Ouarzazat</td>
<td>Lpv</td>
<td>11.8</td>
<td>9.3</td>
<td>11.2</td>
</tr>
<tr>
<td>Morocco</td>
<td>Lpv</td>
<td>13.0</td>
<td>10.8</td>
<td>13.0</td>
</tr>
<tr>
<td>India</td>
<td>Lpv</td>
<td>12.5</td>
<td>10.0</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Results

A- Geometrical optimization results for Athens case study

Fig. 5: Optimun GPOA for Athens according to the reflector’s length for monthly varied (a) seasonal varied (b) and fixed architectures (c)

B- Computing the plane of array irradiance gain

Fig. 6: Optimun OR for Athens according to the reflector’s length for monthly varied (a) seasonal varied (b) and fixed architectures (c)

Conclusion

- The optimization results showed that each region requires specific considerations.
- GPOA gain doubles or triples from Lpv/2 to Lpv in monthly and seasonal variations.
- The gain does not increase similarly going from Lpv to 2Lpv where the increasing ratio is lower (shading effect).
- Regions with close latitudes showed quite similar results in terms of geometrical optimization.
- The highest gain was achieved was 35% considering a monthly varied architecture with Lpv in Athens.
- Oslo presented the highest gains in fixed architectures because of its geographical location.
- A power production gain assessment will be conducted using a MPPT model developed in a previous work [1].

References