Shadowing and blocking effect optimization for a variable geometry heliostat field

Pablo Cádiz, Miguel Frasquet, Manuel Silva, Fernando Martínez, Jose Carballo
Who are we?

**CTAER (Centro Tecnológico Avanzado de Energías Renovables)**

*Advanced Technology Centre for Renewable Energies*

- **Biomass** *(Menjibar-Jaen)*
- **Marine** *(Tarifa-Cádiz)*
- **CSP** *(Tabernas-Almería)*

**R&D**

- Area: 91 ha
- Multidisciplinary:
  - PTC
  - CRS
  - H₂ & CPV
  - L/M Temp
  - Offices/Labs

---

2nd Annual STERG Symposium  
July 2014
**Optical efficiency ($\eta_{opt}$)**

\[ \eta_{opt} = \frac{P_{REC}}{P_{av}} \]

Available power

\[ P_{av} = DNI \cdot A_{ap} \]

Power at the receiver

\[ P_{rec} \]

\[ \eta_{opt}(x, y, t) = \rho \cdot f_{\cos\theta}(x, y, t) \cdot f_{at}(x, y) \cdot f_{spill}(x, y, t) \cdot f_{sb}(x, y, t) \]
\[ \eta_{opt}(x, y, t) = \rho \cdot f_{\cos \theta}(x, y, t) \cdot f_{at}(x, y) \cdot f_{spill}(x, y, t) \cdot f_{sb}(x, y, t) \]
CASE 1 $\rightarrow f_{\cos} = 0.87$

CASE 2 $\rightarrow f_{\cos} = 0.80$
**ROTATING FIELD**

CASE 1 --> \( f_{\text{cos}} = 0.87 \)

CASE 2 --> \( f_{\text{cos}} = 0.80 \)

CASE 2a --> \( f_{\text{cos}} = 0.88 \)

**IMPROVING THE COSINE FACTOR**

21-June
TST: 12h

**SOLAR NOON**

---

21-June
TST: 17h

**SUNSET**
ROTATING FIELD

CONVENTIONAL STAGGERED FIELD

VARIABLE GEOMETRY STAGGERED FIELD

Mobile heliostats

Concentric circular rails

Centro Tecnológico Avanzado de Energías Renovables
Andalucía

2nd Annual STERG Symposium July 2014
\[ \eta_{opt}(x, y, t) = \rho \cdot f_{\cos\theta}(x, y, t) \cdot f_{at}(x, y) \cdot f_{spill}(x, y, t) \cdot f_{sb}(x, y, t) \]

**Shadowing & Blocking losses**

![Graph showing shadowing and blocking losses with TST (h) on the x-axis and S&B (%) on the y-axis.]

**Seasonal Solstices and Equinoxes:**
- **Winter solstice**
- **Equinox**
- **Summer solstice**

**Diagram illustrating solar noon and distance optimization.**

2nd Annual STERG Symposium

July 2014
\[ \eta_{opt}(x, y, t) = \rho \cdot f_{\cos\theta}(x, y, t) \cdot f_{at}(x, y) \cdot f_{spill}(x, y, t) \cdot f_{sb}(x, y, t) \]

**Shadowing & Blocking losses**

**SUNSET**

- **Winter solstice**
- **Equinox**
- **Summer solstice**
\[ \eta_{opt}(x, y, t) = \rho \cdot f_{\cos \theta}(x, y, t) \cdot f_{at}(x, y) \cdot f_{spill}(x, y, t) \cdot f_{sb}(x, y, t) \]

Shadowing & Blocking losses

ANNUAL LOSSES (1 - \(f_{sb}\))

<table>
<thead>
<tr>
<th>Field</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORTH FIELD</td>
<td>7%</td>
</tr>
<tr>
<td>ROTATING FIELD</td>
<td>8.7%</td>
</tr>
</tbody>
</table>

Winter solstice

Equinox

Summer solstice

ROVATING FIELD vs NORTH FIELD

 centroid technological advanced energies renewables andalusia

2nd Annual STERG Symposium July 2014
The staggered structure of the solar field remains static. 21 variables (radial distance, azimuthal distance, incremental spacing between rows...). The whole field rotates keeping its staggered structure. The heliostats within the field move independently. 18 variables (radial distance, azimuthal distance, incremental spacing between rows...). Field Velocity.

- Stationary Field
  - Common Operation strategy
  - 21 variables
    - (radial distance, azimuthal distance, incremental spacing between rows...)
  - Commercial codes

- Variable Geometry Field
  - Individual Operation strategy
  - 18 variables
    - (radial distance, azimuthal distance, incremental spacing between rows...)
    - Field Velocity
  - Modification over existing codes

- Variable Geometry Field
  - 624 variables
    - (Heliostat position)
    - Field Velocity
  - NEW CODE
**CODE STRUCTURE**

New code developed in MatLab (Energy simulation)

- **Optimization problem**
  - Heliostat position with field symmetry
  - \( \text{Int} \left( \frac{n}{2} \right) \)
  - Field Velocity

- **Optimization algorithm**
  - Genetic algorithm
  - Modified deterministic hill-climbing

- **NSPOC**
  - (Hourly Energy simulations)

- **Validation**
  - On field real validation
  - Ray-tracing
    - Commercial codes

- **Validation**
  - Re-design Shadow & Blocking calculation engine
  - Commercial codes

---

**Centro Tecnológico Avanzado de Energías Renovables**

2nd Annual STERG Symposium

July 2014
RESULTS (4pm – 113 hel)

<table>
<thead>
<tr>
<th>FIELD</th>
<th>Cosine effect efficiency (CE)</th>
<th>Shadowing effect efficiency (SE)</th>
<th>Combined effect (CE*SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATIONARY STAGGERED</td>
<td>54.2%</td>
<td>76.2%</td>
<td>41.3%</td>
</tr>
<tr>
<td>Annual</td>
<td>81.1%</td>
<td>93.6%</td>
<td>75.9%</td>
</tr>
<tr>
<td>ROTATING STAGGERED COMMON</td>
<td>95.6%</td>
<td>62.3%</td>
<td>59.5%</td>
</tr>
<tr>
<td>Annual</td>
<td>93.7%</td>
<td>85.5%</td>
<td>80.1%</td>
</tr>
<tr>
<td>ROTATING INDIVIDUAL</td>
<td>90.6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPERATION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual</td>
<td>91.1%</td>
<td>96.4%</td>
<td>87.8%</td>
</tr>
</tbody>
</table>

SIMULATION TIME

8.3 min

2 weeks
CONCLUSIONS

- Although rotating fields show significant benefits in terms of optical efficiency, rotating the whole field keeping the staggered structure decreases the Shadowing & Blocking performance.

- It is necessary to use an individual operation strategy instead of a common strategy.

- To calculate the heliostat position in each moment is necessary to solve an optimization problem of a significant number of variables.

- The code developed by CTAER reduces the time spent in S&B calculations and uses new optimization algorithms.

- Using an individual control strategy the combined effect of the cosine factor and S&B can be improved more than 10% with respect to a north stationary field.
Thanks for your attention!

For further information please contact:

- Miguel Frasquet Herraiz  
  miguel.frasquet@ctaer.com
- Sol Luca de Tena  
  sol.lucadetena@ctaer.com
APPENDIX
\[ \eta_{opt}(x, y, t) = \rho \cdot f_{\cos\theta}(x, y, t) \cdot f_{at}(x, y) \cdot f_{spill}(x, y, t) \cdot f_{sb}(x, y, t) \]
\[ \eta_{opt}(x, y, t) = \rho \cdot f_{\cos\theta}(x, y, t) \cdot f_{at}(x, y) \cdot f_{spill}(x, y, t) \cdot f_{sb}(x, y, t) \]

**Rotating Field vs North Field**

- **Spillage**
  - Size of the receiver
  - Slant range
  - Incidence angle on the receiver
  - Optic aberration (Astigmatism)

**Case 1 = Case 2**

Same Incidence angle on the receiver in both cases
\[ \eta_{opt}(x, y, t) = \rho \cdot f_{\cos \theta}(x, y, t) \cdot f_{at}(x, y) \cdot f_{spill}(x, y, t) \cdot f_{sb}(x, y, t) \]

**Spillage**

- **Size of the receiver**
- **Slant range**
- **Incidence angle on the receiver**
- **Optic aberration (Astigmatism)**

**Depends on the incidence angle on the heliostat**

**CASE 1 ≠ CASE 2**
\[ \eta_{opt}(x, y, t) = \rho \cdot f_{\cos\theta}(x, y, t) \cdot f_{at}(x, y) \cdot f_{spill}(x, y, t) \cdot f_{sb}(x, y, t) \]

Spillage

Reflected image | Incidence angle | Area
--- | --- | ---
**Ideal** | = 0 | Area 1

\[
\left( \frac{h_s}{\beta_s \cdot d} \right) = \frac{\text{Area 2}}{\text{Area 1}}
\]

Dimensionless size

Represents the increase of the reflected image with respect to the ideal one (incident angle equal to zero)