Astronomic Sun Tracker
Performance and Solar
Energy Collection Comparison
for Different Italian Sites

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Introduction

Context: Engineering applied to energy production

Case study: Astronomic vs. Feedback double axis sun trackers

Target: Performance analysis of a particular astronomic sun tracker and solar energy collection comparison for different Italian sites.
Solar Energy Growth in Italy

Italian PV market 2006-2011

PV installed (MW)  Cumulative installations (MW)
Ground-level Radiation

- Beam:
  - from sun disk

- Diffuse and Reflected:
  - circumsolar
  - isotropic from sky dome
  - horizon brightening
  - ground reflected

- Global:
  - Beam + Diffuse + Reflected
Ground-level Radiation

- Meteorological databases
  - Hourly global insolation on horizontal surface

- Direct/diffuse separation models
  - Hourly direct/diffuse insolation on horizontal surface

- Models for sky radiance
  - Hourly diffuse insolation on tilted surface

Perez et al.

\[ H_{d,t} = H_{d,h}(1 - F_1) F_d + H_{d,h} \frac{a}{b} + H_{d,h} F_2 \sin(\beta) \]

HDKR

\[ H_{d,t} = H_{d,h} [ (1 - A_t) \cdot F_d \left[ 1 + f \left( \sin \left( \frac{\beta}{2} \right) \right) \right] + A_t \cdot R_b ] \]
Feedback Dual Axis Sun Trackers

- Tracking the sun can result in energy gains up to 30%

- In feedback trackers, light intensity sensors detect the brightest point of the sky: usually this point is the sun disk.

- The control system points hence the sun accordingly.

- In case of overcast sky, the feedback tracker can choose to orient the solar panel horizontally, in order to collect the maximum diffuse radiation from the sky dome.
Present Astronomic Sun Tracker

- The primary (vertical) shaft (1) is powered by a single motor (2)
- A connecting rod (3) is connected to the motion cam (4)
- The second horizontal shaft (5) is not driven by any motor
- No feedback control on sun real position
Proposed tracker: laws of motion

- \( \sin' \alpha_{\text{sur}} = \cos \omega \sin \varepsilon \) (daily)
- \( \sin \gamma_{\text{sur}} = \left( \frac{\sin \omega}{\sqrt{1 - (\cos \omega)^2 (\sin \varepsilon)^2}} \right) \)
Proposed tracker: laws of motion (II)

- Law of motion 1: \( \sin \alpha_{\text{sur}} = \sin \alpha_{\text{sur}} + \Delta \)
- Law of motion 2: \( \sin \alpha_{\text{sur}} = \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos \omega \)
Proposed tracker vs reference one

The reference solar tracker is a perfect system able to collect 100% of the available solar energy either by perfectly point the sun disk or by adjusting its position for best diffuse radiation collection.

The astronomical tracker is affected by pointing errors, due to:

- law of azimuthal motion does not change every day of the year (maximum error on azimuthal angle: 19°),
- law of daily tilt motion does not change every day of the year (maximum error on tilt angle: 5°),
- simplified law of seasonal tilt motion (maximum error on tilt angle: 3°),
- effects of the equation of time and other minor variables neglected (maximum error on azimuthal and tilt angles: 5°),
- inability to orient the solar panel horizontally in cloudy days (variable penalization according to different sky conditions)
Procedure for tracker performance evaluation

- TMY data generation (hourly direct and diffuse radiation + sun position)
  - 3 Italian cities: Genova, Roma, Siracusa
- Calculations:
  - Azimuthal and tilt angles of the solar panel surface, incidence angle (as a function of the sun tracker kinematics)
  - Diffuse radiation calculation according to L&J, Perez, HDKR models
- Results:
  - Insolation values $H_b,t$, $H_d,t$, $H_r,t$, $H_g,t$ (as a function of the sky radiance models)
Results (aiming accuracy)

Astronomic tracker hourly incidence angle at Equinox and Solstices

The cam has been designed with reference to the celestial equator.

At solstices the pointing error is maximum, but the effect on energy collection is reduced due to the good aiming accuracy at noon.

At sunrise and sunset the accuracy is mainly affected by the simplified azimuthal law of motion.
Results (insolation)

TMY data for two typical days (mostly sunny and mostly cloudy)

In case of overcast sky the reference tracker orients itself horizontally while the astronomic system goes on pointing the sun expected position.
Sky radiance models comparison: HDKR underestimates with respect to the Perez model the diffuse insolation on a tilted surface. Both these anisotropic models are still much more accurate than the Liu and Jordan isotropic sky radiance model.
Results (astronomic vs reference, Diffuse)

Diffuse insolation collection during the year according to Perez and HDKR sky models. Astronomic tracker is here compared to a perfect feedback tracker.
Results (astronomic vs reference, Global)

Global insolation collection during the year according to different sky models. Astronomic tracker compared to reference tracker.
Results (astronomic vs reference, Different Sites)

Global insolation collection during the year according to HDKR sky model and for different Italian sites. Astronomic vs Reference.
## Results (astronomic vs reference, Global)

Global insolation collection at different sites in Italy. Astronomic vs reference vs fixed collector

<table>
<thead>
<tr>
<th>Selected Site</th>
<th>Annual Global Insolation (HDKR)</th>
<th>Difference Between Tracking Systems [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Tracking [kWh/m²]</td>
<td>Astronomic Tracker [kWh/m²]</td>
</tr>
<tr>
<td>Genova</td>
<td>1376</td>
<td>1805</td>
</tr>
<tr>
<td>Roma</td>
<td>1721</td>
<td>2288</td>
</tr>
<tr>
<td>Siracusa</td>
<td>1907</td>
<td>2534</td>
</tr>
</tbody>
</table>
Conclusions

- In this paper a comparison in terms of collectable solar energy has been made with reference to two tracking strategies, astronomic vs feedback control.

- To this aim a proper model has been developed in order to take into account the hourly variation of available solar energy and the kinematics of the trackers.

- Two sky models for diffuse radiation has been considered.

- Calculations revealed that, with respect to different Italian sites an astronomic tracker like the one here presented is able to collect 97-98% of the global solar energy with respect to a perfect tracking system.

- The energy gain of the astronomic tracker with respect to fixed collectors resulted to be in the 30-33% range.

- This study confirms that for non concentrating solar systems, simple single axis tracking devices can be successully employed to maximize the solar yield.
End of presentation

thank you for your attention