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The effect of latitude on the performance of different solar trackers in Europe and Africa

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HIGHLIGHTS

- The effect of latitude on the performance of seven solar trackers is analyzed in Europe and Africa.
- The performance of the trackers is ranked according to the area location latitude.
- The results showed five ranking patterns.
- Based on the five patterns and the site latitude, designers can select the best available tracker.

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ABSTRACT

In this paper, the effect of latitude on the performance of different solar trackers is examined. The hourly solar radiation data of different locations around Europe and Africa measured on a horizontal surface is collected and utilized. Widely validated Perez anisotropic model is used to predict the diffuse component of the solar radiation on an inclined surface. Different solar trackers namely, Full/dual-axis, East–West (EW), North–South (NS), Inclined East–West (IEW), and Vertical-axis (V) trackers are considered in calculating the available solar potential of the locations. The performance of the solar trackers in terms of the energy gain is ranked according to the area location latitudes. The results show that the tracking performance is highly dependent on the locations, thus changes with the latitude. The percentage variation among the implemented one-axis tracking options relative to dual-axis trackers ranges from 0.42% to 23.4%. Overall, the increase in the energy gain of dual-axis trackers compared to the optimal fixed panel for the locations varies from 17.72% to 31.23%, thus emphasizes the importance of solar trackers. Finally, the study is expected to aid designers in the selection and installation of appropriate solar trackers in the regions.

1. Introduction

Ensuring global energy security will increasingly require expanding both yield and resilience of supply through source diversification. Approximately 80% of the global energy consumption are from conventional fossil fuel based resources contributing significantly to climate change [1]. Renewable energy sources of wind, solar, biomass, hydro and geothermal are currently been promoted as deployable sustainable alternatives. On the other hand, solar energy source and the allied technologies are much developed and believed to be capable of contributing significantly to the global energy generation mix in the nearest future.

For solar technologies, the amount of solar energy received is mainly affected by the installation azimuth and tilt angle. To maximize energy collected, they are usually oriented towards the equator with an optimal tilt angle from the horizon. This optimal tilt angle depends entirely on installation site latitude and other climatic variables. Comparatively, for tracking the path of the sun from sunrise to sunset, and from one season to another, a solar tracker is needed. Different types of solar trackers available are categorized into single-axis and full/dual-axis tracking. The single-axis tracking design is relatively simple due to the fact that it is pivoted to rotate about a particular axis. They are further classified according to their tracking orientations into vertical (azimuth trackers), horizontal and inclined or polar axis trackers. Conversely, the dual-axis tracking incorporates a second axis of rotation hence allow the panel to follow the path of the sun at all times. The dual-axis trackers are designed based on either serial mechanism or parallel mechanism [2–4]. A dual-axis tracking system would result in greater irradiance than a single-axis, due to its ability to minimize losses associated with cosine effect. In other words, the

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Nomenclature

β	tilt angle
ε	clearness index
F_1 & F_2	Perez brightness coefficients
$f(\theta_0)$	control function (assigned as 1 if $\cos\theta_0 \geqslant 0$ else 0)
I_β	incident global solar radiation
I_b	direct normal irradiance
$I_{b,\beta}$	beam component of solar radiation
I_d	diffuse horizontal irradiance
$I_{d,\beta}$	diffuse component of solar radiation
$I_{d,\beta,bri}$	horizontal brightening component
$I_{d,\beta,circ}$	circumsolar diffuse component
$I_{d,\beta,iso}$	isotropic diffuse component
I_e	extraterrestrial radiation
$I_{r,\beta}$	reflected component of solar radiation
I_{Gh}	global horizontal irradiance
m	air mass
n	number of day of a year counted from the first day of January
$\emptyset$	site longitude
ρ	albedo constant
θ	incident angle at any given time and location
θ_z	zenith angle
t_0	sunset time on the horizon
t_x	apparent sunset time on the south facing tilted surface
t_s	solar time in hours
τ_{day}	length of the day in hours (24 h)
ω	hour angle
ω_0	sunset hour angle on the horizon
ω_x	apparent sunset hour angle on the south-facing tilted surface
γ_s	sun azimuth angle
Z	GMT time zone
δ	declination angle
λ	location latitude
Δ	brightness

Subscripts

0	fixed panel
1	one axis tracker
2	dual-axis tracker

panels are always normal to the sun's beam radiation, thus maximizing the amount of energy intercepted by the surface. Different numbers of tracking strategies have been identified and implemented in the literature for several locations as highlighted in Sections 1.1–1.4.

1.1. One tracking strategy

Many authors have only used a single tracking strategy such as dual-axis, EW, NS, vertical-axis and inclined EW trackers [5–22]. They demonstrated that tracking would significantly increase the annual energy productivity relative to systems in a fixed position.

- Dual-axis tracking was studied by Abdallah and Nijmeh [5] in Jordan, Baltas et al. [6] and Lave and Kleissl [7] in USA, Senpinar and Cebeci [8], Kacira et al. [9], and Sungur [10] in Turkey, Quesada et al. [11] in Canada, Cruz-Peragon et al. [12] in Spain, and Yao et al. [13] in China.
- EW tracking was investigated by Al-Mohamad [14] in Syria.
- NS tracking has been examined by Chang [15] in Taiwan.
- Vertical-axis tracking was studied by Eldin et al. [16] in Germany and Egypt, and Abdallah and Badran [17] in Jordan.
- IEW tracking was applied by Chang [18,19] and Huang and Sun [20] in Taiwan, Bione et al. [21] in Brazil, and Lazaroiu et al. in Italy [22].

1.2. Two tracking strategies

In an attempt to find which tracking strategy performed better relative to the others, several authors applied only two tracking strategies [23–30]. They evaluated and compared the energy productivity for the two tracking strategies.

- Dual-axis and IEW trackers have been studied by Maatallah et al. [23] in Tunisia, Ghosh et al. [24] in Bangladesh, Zhong et al. [25] and Li et al. [26] in China, and Nann [27] in USA and India.
- Dual-axis and Vertical axis trackers were investigated by Li et al. [28] and Ma et al. [29] in China, Lubitz [30] in USA, and Nann [27] in Canada, Germany, Italy, and France.
- Dual-axis and EW trackers were examined by Nann [27] in Kenya, Singapore and Guinea-Bissau.

1.3. Three tracking strategies

In an effort to have several alternatives to choose from, several studies applied only three tracking strategies [31–35]. The energy productivity has been evaluated and compared for the three tracking strategies.

- Dual-axis, IEW and EW trackers were studied by Neville in USA [31].
- Dual-axis, EW and NS trackers have been investigated by Okoye et al. in Nigeria [32].
- Dual-axis, IEW and vertical-axis trackers were examined by Koussa et al. [33] in Algeria, Ai et al. [34] in China, and Helwa et al. [35] in Egypt.

1.4. Four tracking strategies

A few authors applied only four tracking strategies out of five possible tracking strategies [36–39]. They evaluated and compared the energy gain for the four tracking strategies.

- Dual-axis, IEW, EW and NS trackers were considered by Dickinson [36] in USA, and Kalogirou [37] in Cyprus.
- Dual-axis, vertical-axis, EW and NS trackers have been studied by Abdallah [38] in Jordan.
- Vertical-axis, IEW, EW and NS trackers were investigated by Abu-Khader et al. [39] in Jordan.

In summary, literature review reveals the following; the use of solar trackers are imperative to enhance the energy gain of an installed systems, existence of different solar trackers grouped according to their tracking method and orientations, energetic performance of these trackers changes from one location to another, and comparison of four different solar trackers has been carried out in the best case for some limited locations [36–39]. According to the present literature review and to the best of the authors' knowledge, there is no study that has been dedicated solely to