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Abstract: Solar energy is gaining more grounds in the power generation industry. The effectiveness of solar tracking systems depends on the location's latitude. In addition, sky clearance has an effect on the received solar radiation. Therefore, it is important to know the effect of both factors in order to select the most appropriate system for each location. While there are many studies concentrated on either of these effects, there are no studies for their joint effect. Here, the combined effect of latitude and sky clearance on the performance of solar tracking systems is presented using data from seven locations with different latitudes and sky clearance factors. Results show that the effect of the sky clearance can overcome the effect of the latitude in terms of the effectiveness of solar tracking systems. The sky clearance factor suppresses the effect of the latitude as the sky clearance factor falls below 0.55.

Keywords: solar radiation; effect of sky clearance; effect of latitude; solar tracking

1. Introduction

Renewable sources of energy are attracting more investments around the world, and the contribution of renewable energy sources to electrical power generation is increasing and becoming more significant. In fact, it had been reported by some European countries that renewable energy sources occasionally provided 100% of electrical power demand. Solar energy is among the most promising sources of future energy sources. It is considered, after hydro and wind, as the third renewable energy source in terms of globally installed capacity. Photovoltaic (PV) cells are the most widely used solar systems for harvesting solar energy where it directly converts sunlight into electricity. In 2016, solar PV achieved maximum growth among other renewable energy sources in terms of additional power generating capacity. At that year, the annual market of solar PV increased by nearly 50% as reported by REN21 (2017).

Solar tracking systems can be classified using different methods. They can be classified into passive solar trackers or active solar trackers. Passive solar trackers do not consume electrical power. However, it lacks the precision provided by active trackers. Active solar trackers use motors and gears to track the sun position. They are more widely used and can be generally classified into single-axis trackers and dual-axis trackers. Dual-axis trackers have two degrees of freedoms in order to have the panel surface perpendicular to the direct sun ray. Single-axis tracking systems are more common due to their lower cost, higher reliability, and longer lifespan compared to dual-axis trackers. However, the dual-axis trackers offer higher output power. Another type of solar panels are the adjustable solar panels where the tilt angle can be seasonally changed several times during the year to account for the sun path variation along the north–south line.

Studies showed that solar tracking systems can increase the produced energy significantly. The percentage increase in the produced power as a result of using solar tracking systems depends on several factors such as the amount of direct sunlight in the area, cloud cover frequency, and the latitude of the site. Sungur (2007) reported a 32.5% increase in the produced energy after using a single-axis tracking system for PV panels compared to fixed-position panels. Mousazadeh et al.
(2009) and Gay, Yerkes, and Wilson (1982) showed that two axis tracking systems can produce 30–50% more power than fixed modules. Rustu and Senturk (2012) reported a 30.95% more electricity is obtained in the double-axis sun-tracking system when compared to the latitude tilt fixed PV system.

Development of new, more accurate, and more economical solar tracking systems and studying their performance have been receiving significant attention worldwide. Eke and Senturk (2012) compared the performance of double-axis tracking system with a fixed PV system experimentally. They found that the double axis sun-tracking system provided 30.79% more PV electricity compared to an optimum tilted fixed system. They reported that the difference between their simulated data and measured energy values was less than 5%. Bohrami, Okoye, and Atikol (2016) studied the effect of latitude on the performance of different solar trackers in different cities in Europe and Africa. They found that while dual trackers always provide more energy over other systems, one-axis tracking systems vary in their performance and ranking with respect to each other depending on the latitude. Dual-axis trackers gave up to 31.23% gain over the optimal fixed panel. It is worth mentioning that the Perez anisotropic model (Perez, Ineichen, Seals, Michalsky, & Stewart, 1990; Perez, Scott, & Stewart, 1986) for estimating the diffuse component of solar radiation on inclined surfaces has been used in most recent studies.

Bohrami et al. (2016) presented an economic analysis of the solar tracking systems in 21 low latitude countries. Their main study, however, was focused on nine selected locations in Nigeria and then generalized to countries with similar low latitude. They compared the feasibility of different single- and dual-axis trackers and ranked them for each of the nine locations in Nigeria. One of their findings was that as the PV installation cost increases, the dual-axis trackers become more feasible. Another example of solar tracking feasibility studies is the one done by Sharaf Eldin, Abd-Elhady, and Kandil (2016). They compared the feasibility of solar tracking systems for PV panels in hot and cold regions. They used a mathematical model for the performance of PV panels which was validated experimentally and then applied it for several cold and hot environments. Interestingly, they found that the gain in energy does not exceed 8% in case of a hot city, while it is about 39% in a cold city. This is due to the overheating of the PV panels in hot weather. They concluded that since the energy needed for running the tracking system ranges from 5% to 10% of the energy generated, then tracking systems are not feasible in hot countries. In an attempt to reduce the problem of overheating of the PV panels and increasing their efficiency in hot weather, Rahimi, Banybayat, Tagheie, and Valeh-e-Sheyda (2015) introduced a hybrid sun–wind-tracking system that employs cooling effect of wind in addition to the advantages of tracking the sun. Their system used a dual-axis sun-tracking unit. They reported that the increase in the overall daily output energy was about 49.83% compared to a fixed system, and increase of about 7.4% in the output power was achieved when the wind cooling part was added to the system.

Among the attempt to develop new tracking systems is the intelligent sun-tracking system by Tina, Arcidiacono, and Gagliano (2013). The system, which is called “SoliSector”, features nine photodiodes and advanced data analysing system. The system was outdoor tested in terms of tracking accuracy but not in terms of gain in power generation. On the other hand, Fernández-Ahumada, Casoares, Ramirez-Faz, and López-Luque (2017) provided a different approach for solar tracking where they presented equations that allow the optimization of tracking systems where diffuse and reflected irradiance are usable which can be different from the direction towards alignment with direct sunbeams. Abdollahpour, Golzarian, Rohani, and Zarchi (2018) proposed a dual-axial solar tracking system that utilizes image processing of the shadow of a bar. The system is mainly composed of a shadow casting object, a webcam, computer controls, and stepper motors. The results showed an accuracy of ±2° in following the sun and maintained the panel perpendicular to the irradiation direction. They stated that “the system works independent of its initial settings and can be used in any geographical regions”. They also noted that the system suffers from ineffectiveness in overcast weather conditions because of the pale shadow in the images. Carballo, Bonilla, Berenguel, Fernández-Reche, and García (2019) developed a low-cost
approach based on computer vision open hardware and neural network learning. They noted that the developed approach can provide crucial variables for the control of sun-tracking systems, including prediction of cloud movements, block and shadow detection, and measures of concentrated solar radiation. The system is said to be independent of solar technology, system size, location, and time. They noted, however, that the proposed method provides similar error values to the traditional method, which are within the acceptable range for most applications.

More recent and comprehensive review on advancements and challenges in solar tracking systems can be found in Nsengiyumva, Chen, Hu, and Chen (2018) and Sumathia, Jayapragasha, Bakshib, and Akellab (2017). Nsengiyumva et al. (2018) presented a review of the operational principles and features of major types of solar trackers that had been presented over the past two decades. Among their conclusions is that most of the studies have focused on the optimization of the tracking algorithms/technologies alone but paid too little attention on other important parameters affecting the efficiency. In addition, they concluded that the overall performance of closed-loop systems was found to be higher than the performance of open loop systems by about 40%. Moreover, they stated that optimizing all hardware and software parameters for energy saving must be done from the early stages of the development of the system. Sumathia et al. (2017) review targeted the review of a number of major methods adopted for solar tracking in the recent decade. They found that active solar trackers were more commonly used than passive trackers, and that dual-axis active trackers provide an increase in power collected by about 30% over fixed systems.

Sky clearance and latitude have an important effect on the performance of solar tracking systems. Sky clearance affects the direct and the diffuse solar radiation in opposite ways. When sky clearance index decreases, the diffuse solar radiation increases, and the direct solar radiation decreases. The opposite effect results in almost constant total solar radiation on horizontal surfaces until the decrease in the index reaches a critical value. However, when calculating the received solar radiation on an inclined surface, the direct and the diffuse solar radiation are needed separately, so it is important to know each component individually. Another effect of decreasing sky clearance index is that it decreases the difference between solar radiation received by surfaces with different tilt angles. In another word, it decreases the effectiveness of solar tracking. Models predicting solar irradiance can be classified into two types: parametric or decomposition models. Parametric models use atmospheric conditions, and examples of these are ASHRAE (1999), Iqbal (1978), and Guemard (1993). Decomposition models, on the other hand, use the global radiation data to predict the direct and diffuse radiation components. Examples of these are Liu and Jordan (1962), Lam and Li (1996), and Badescu (2002). The performance of the models is affected by the location and by the clearance of the atmosphere. Klucher (1979) evaluated a number of isotropic and anisotropic models in predicting solar radiation on tilted surfaces. Isotropic models were represented by the well-known Liu–Jordan model, while the anisotropic models were represented by Temp–Coulson model (see Temp–Coulson, 1977). He found that the Liu–Jordan model predictions are good under completely cloudy weather conditions, but it underestimates the solar radiation when the sky is clear or partially cloudy. On the other hand, Temp–Coulson model provides good predictions in clear sky conditions, but overestimates solar radiation when used in cloudy days. Guemard and Ruiz-Arias (2016) compared the performance of 140 models predicting the direct normal irradiance from global horizontal irradiance. They concluded that almost all separation models suffer from lack of accuracy except in the areas where their solar radiation data are used to develop the models. They also concluded that models which use variability index, associated with sky clearance index like the Perez model, do perform generally better. Guemard (2009) studied the performance of 10 models used to predict total solar radiation on different tilt angles and on a two-axis tracking surface. He found that Perez model is one of the best models in his study specially under clear sky condition. The performance of the model was affected by cloudy weather but still performed better than most of the other models. It is clear that sky clearance is an important factor in both collecting solar radiation or predicting it.
The current work tries to study the joint effect of latitude and sky clearance on the effectiveness of solar tracking strategies. This is done by considering seven locations in Oman that vary in latitude and average sky clearance. The results are generic and can be extrapolated to other locations. Five strategies of solar tracking to minimize the angle of incidence (θ) (the angle between the beam radiation on a surface and the normal to the surface) are used in this work:

1. Rotating the flat surface about a horizontal east–west axis with continuous adjustment (HEW) (single-axis tracking).
2. Rotating the flat surface a horizontal north–south axis with continuous adjustment (HNS) (single-axis tracking).
3. Rotating the flat surface a north–south axis that is parallel to the axis of the earth with continuous adjustment (LNS) (single-axis tracking).
4. Rotating the flat surface about a vertical axis while maintaining a fixed tilting angle (V) (single-axis tracking).
5. Rotating about two axes (2A) (dual-axis tracking).

Figure 1. A flow chart diagram of the mathematical model used.
2. Mathematical modelling

The models used in estimating the various solar fluxes are the same as presented by Al-Rawahi, Zurigat, and Al-Azri (2011) and are based on models developed by (Collares-Pereira & Rabl, 1979; Duffie & Beckman, 2013; Liu & Jordan, 1962; Perez et al., 1990). Figure 1 shows a flow chart diagram of the mathematical model used. The input parameters for the model are the daily global radiation, $H$ (in kJ/m$^2$ per day) which is taken from raw station data, the latitude, the longitude, and the elevation of the weather station. Two models are used here to estimate the hourly total radiation received by an inclined surface, namely, the anisotropic model of Perez (Perez et al., 1986; Perez, Scott, & Stewart, 1986) and the isotropic model of Liu and Jordan (1962). Both models had been considered by many researchers to be among acceptable models, specially the Perez model. Liu–Jordan model is simple and assumes sky radiance to be isotropic and had been studied and used by the number of researchers. However, studies like those presented by Muneer, Fairooz, and Zhang (2003) showed that anisotropic models perform better then isotropic models.

To calculate the solar radiation on a solar tracking surface, a number of angles need to be evaluated. These angles are the incidence angle ($\theta$), the surface tilt angle ($\beta$) (with respect to the horizontal plane), and the surface azimuth angle ($\gamma$). Figure 2 shows angles involved in the calculations of solar radiation. Among other angles, the following angles are used the solar tracking equations:

- Surface azimuth angle ($\gamma$), which is the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south.
- Solar azimuth angle ($\gamma_s$), which is the angular displacement from south of the projection of beam radiation on the horizontal plane.
- Zenith angle ($\theta_Z$), which is the angle between the vertical and the line to the sun, that is, the angle of incidence of beam radiation on a horizontal surface.
- Hour angle ($\omega$), which is the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15° per hour
- Declination angle ($\delta$), which is the angular position of the sun at solar noon.

Mathematical models presented by Duffie and Beckman (2013) for five solar tracking strategies are used in this work. The first solar tracking strategy is to rotate the flat surface about a horizontal east–west axis with continuous adjustment to minimize the angle of incidence (HEW),

$$\cos(\theta) = (1 - \cos^2(\delta) \sin^2(\omega))^{1/2}$$

(1)
The tilting angle of the surface can be found from
\[
\tan(\beta) = \tan(\theta_z) \cos(\gamma_s) \tag{2}
\]

The surface azimuth angle for this mode of orientation will change between 0° and 180° if the solar azimuth angle passes through ±90°. For either hemisphere,
\[
\gamma = \begin{cases} 
0^\circ & \text{if } |\gamma_s| < 90^\circ \\
180^\circ & \text{if } |\gamma_s| \geq 90^\circ
\end{cases} \tag{3}
\]

The second strategy is to rotate the flat surface about a horizontal north–south axis with continuous adjustment to minimize the angle of incidence (HNS),
\[
\cos(\theta) = (\cos^2(\theta_z) + \cos(2\delta) \sin^2(\omega))^{1/2} \tag{4}
\]

The tilting angle of the surface can be found from
\[
\tan(\beta) = \tan(\theta_z) \cos(\gamma_s) \tag{5}
\]

The surface azimuth angle will be 90° or −90° depending on the sign of the solar azimuth angle,
\[
\gamma = \begin{cases} 
90^\circ & \text{if } \gamma_s > 0^\circ \\
-90^\circ & \text{if } \gamma_s < 0^\circ
\end{cases} \tag{6}
\]

The third strategy is to rotate the flat surface about a north–south axis that is parallel to the axis of the earth with continuous adjustment to minimize the angle of incidence (LNS),
\[
\cos \theta = \cos \delta \tag{7}
\]

The tilting angle of the surface can be found from
\[
\tan(\beta) = \frac{\tan(\Phi)}{\cos(\gamma_s)} \tag{8}
\]

where \(\Phi\) is the latitude of the location. The surface azimuth angle is calculated from
\[
\gamma = \tan^{-1}\frac{\sin(\theta_z) \sin(\gamma_s)}{\cos(\theta_z) \sin(\Phi)} + 180 \frac{C_1 C_2}{1} \tag{9}
\]

where
\[
\cos(\theta_z) = \cos(\theta_z) \cos(\Phi) + \sin(\theta_z) \sin(\Phi) \cos(\gamma_s) \tag{10a}
\]

\[
C_1 = \begin{cases} 
0 & \text{if } \tan^{-1}\left(\frac{\sin(\gamma_s)}{\cos(\theta_z) \sin(\Phi)}\right) \gamma_s > 0^\circ \\
1 & \text{otherwise}
\end{cases} \tag{10b}
\]

\[
C_2 = \begin{cases} 
+1 & \text{if } \gamma_s \geq 0^\circ \\
-1 & \text{if } \gamma_s < 0^\circ
\end{cases} \tag{10c}
\]

The fourth strategy is to rotate the flat plate about a vertical axis (V). The flat plate has a fixed tilt angle. The angle of incidence is given by
\[
\cos(\theta) = \cos(\theta_z) \cos(\beta) + \sin(\theta_z) \sin(\beta) \tag{11}
\]

The tilting angle of the surface is fixed to a constant value \(\delta\). The surface azimuth angle is
\[
\gamma = \gamma_s \tag{12}
\]

The fifth strategy is dual axes solar tracking in which the flat plate is being rotated about two axes to maintain zero incidence angle (2A). The three angles are given by
\[ \cos(\theta) = 1 \]  
\[ \beta = \theta z \]  
\[ \gamma = \gamma_s \] 

3. Results and discussion

The mathematical formulation used in this work had been validated in Al-Rawahi, Zurigat, and Al-Azri (2011). Typical meteorological year (TMY) for each location had been used to get daily average solar radiation fluxes, which are needed as an input to the simulating code. Generally, Perez model gives a higher estimation for the solar radiation on tilted surfaces than the Liu and Jordan model. However, the two models provide similar trends. When a close comparison was carried out between the two models, it was noted that there is a strong relation between the sky clearance factor and the difference between the results of the two models. This is shown in Figure 3. The figure shows that as the sky clearance factor decreases, the difference between the two models increases. This can be explained through looking at the models and observing that the Liu–Jordan model is an isotropic model and uses fixed daily sky clearance index. On the other hand, the Perez model is an anisotropic model and uses variability factor in the sky clearance index which intends to make it more sensitive to sky conditions. According to some of the studies presented in the introduction, like Klucher (1979), the Liu–Jordan model was found to underestimate solar radiation in clear or partially cloudy sky, while Perez model was found to perform well especially in clear sky condition. In light of this comparison, the tables presented in this article results from both models are provided; however, to make trends more visible, the figures display only results using the Perez model. Perez model might overestimate solar radiation but presented earlier studies suggest that it performs better.
| Location | Latitude, degree | Average annual sky clearance | Annual solar radiation on fixed horizontal surface kW.h/m² | Percentage increase in annual solar radiation compared to solar radiation on a fixed horizontal surface. The upper value is found using Perez model while the lower value is found using Liu and Jordan model(%) |
|----------|------------------|-----------------------------|---------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| Majis    | 24.47            | 0.65                        | 2,061                                                   | Fixed, $\theta = \text{latitude}$ | HEW | HNS | LNS | V | 2A |
|          |                  |                             |                                                        | 8.88 | 18.34 | 43.03 | 49.54 | 34.00 | 55.07 |
|          |                  |                             |                                                        | 4.99 | 12.60 | 32.34 | 36.62 | 25.53 | 41.10 |
| Seeb     | 23.58            | 0.60                        | 1,830                                                   | 8.51 | 17.65 | 41.72 | 47.86 | 32.06 | 53.19 |
|          |                  |                             |                                                        | 4.50 | 11.58 | 30.20 | 34.01 | 23.19 | 38.17 |
| Sur      | 22.54            | 0.44                        | 1,189                                                   | 6.09 | 12.71 | 30.08 | 34.55 | 23.48 | 38.73 |
|          |                  |                             |                                                        | 2.49 | 6.72  | 18.65 | 20.84 | 14.94 | 23.67 |
| Fahud    | 22.35            | 0.61                        | 1,850                                                   | 8.12 | 17.55 | 41.12 | 46.89 | 30.49 | 52.47 |
|          |                  |                             |                                                        | 4.38 | 11.54 | 29.54 | 33.20 | 22.03 | 37.50 |
| Masira   | 20.67            | 0.51                        | 1,454                                                   | 7.04 | 15.22 | 35.86 | 40.77 | 25.46 | 45.75 |
|          |                  |                             |                                                        | 3.36 | 8.81  | 23.64 | 26.42 | 17.03 | 29.83 |
| Marmul   | 18.14            | 0.64                        | 2,055                                                   | 6.80 | 16.90 | 41.32 | 45.90 | 25.57 | 51.38 |
|          |                  |                             |                                                        | 4.00 | 10.70 | 30.35 | 33.50 | 18.96 | 37.56 |
| Salalah  | 17.03            | 0.49                        | 1,397                                                   | 6.00 | 14.10 | 33.02 | 36.99 | 20.59 | 42.12 |
|          |                  |                             |                                                        | 3.03 | 7.96  | 21.31 | 23.67 | 13.69 | 26.92 |
| Correlation with latitude |                  |                             |                                                        | 0.745 | 0.502 | 0.357 | 0.448 | 0.808 | 0.417 |
| Correlation with average annual sky clearance factor |                  |                             |                                                        | 0.770 | 0.907 | 0.981 | 0.964 | 0.761 | 0.968 |
Figure 4 and Table 1 show the effect of average annual sky clearance factor and latitude on the performance of different solar tracking strategies in seven locations in Oman. The results show a trend of decreasing the effect of tracking systems as we go closer to the equator (decreasing the latitude). However, the average annual sky clearance plays a role in disturbing the latitude effect. In fact, using the correlation function to define the strength of relation between the different variables, it is noticed from Table 1 that the correlations between sky clearance and effectiveness of solar tracking systems are higher than the correlations of the latitude. In addition, comparing Figure 4(a and b), it is noticed that the relation between effectiveness of solar tracking and sky clearance is stronger than the relation between the effectiveness of solar tracking and latitude. The effect of sky clearance overcomes the effect of the latitude when the sky clearance factor is less than 0.55. This is clearly seen with the decrease in the effectiveness of solar tracking systems in Sur where the minimum gain for most of the systems as a result of having the minimum average annual sky clearance is recorded. For the single-axis systems, LNS tracking systems show
Table 2. Effect of implementing different solar tracking strategies compared to fixed horizontal surface in Majis

| Month | Average monthly Sky clearance | Solar radiation on fixed horizontal surface kW.h/m² | Percentage increase in solar radiation compared to solar radiation on a fixed horizontal surface with different strategies. The upper value is found using Perez model while the lower value is found using Liu and Jordan model(%) |
|-------|-----------------------------|---------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|       | Fixed, $\theta = 24.47^\circ$ | HEW | HNS | LNS | V | 2A |
| 2     | 0.59                         | 118 | 24.68 | 31.81 | 44.76 | 62.15 | 41.65 | 66.75 |
|       |                              | 17.30 | 20.85 | 33.26 | 46.32 | 31.29 | 48.58 |
| 4     | 0.68                         | 206 | 1.28 | 4.68 | 43.18 | 44.41 | 28.81 | 45.80 |
|       |                              | -1.36 | 2.86 | 33.50 | 33.28 | 21.77 | 35.19 |
| 6     | 0.67                         | 218 | -10.94 | 5.53 | 36.76 | 29.70 | 23.72 | 38.53 |
|       |                              | -10.76 | 3.70 | 26.05 | 19.15 | 16.72 | 27.48 |
| 8     | 0.64                         | 195 | -2.25 | 3.89 | 40.99 | 39.86 | 26.68 | 42.63 |
|       |                              | -4.24 | 2.35 | 29.80 | 27.56 | 18.98 | 30.82 |
| 10    | 0.70                         | 170 | 22.42 | 27.97 | 53.07 | 68.45 | 43.66 | 71.61 |
|       |                              | 16.08 | 19.30 | 42.44 | 54.20 | 34.37 | 55.82 |
| 12    | 0.67                         | 122 | 41.30 | 62.62 | 50.43 | 79.58 | 56.01 | 95.02 |
|       |                              | 31.81 | 46.10 | 39.52 | 63.14 | 44.46 | 73.44 |
**Table 3. Effect of implementing different solar tracking strategies compared to fixed horizontal surface in Sur**

| Month | Average monthly sky clearance | Solar radiation on fixed horizontal surface kW.h/m² | Percentage increase in solar radiation compared to solar radiation on a fixed horizontal surface with different strategies. | Fixed, $\beta = 22.54^\circ$ | HEW | HNS | LNS | V | 2A |
|-------|-------------------------------|--------------------------------------------------|-------------------------------------------------------------------------------------------------|---------------------------------|-----|-----|-----|-----|-----|
| 2     | 0.42                          | 74                                               |                                                                                                 | 16.62                          | 21.08 | 30.83 | 28.41 | 45.99 | 43.00 |
|       |                               |                                                  |                                                                                                 | 9.86                           | 10.69 | 19.50 | 18.64 | 27.97 | 27.45 |
| 4     | 0.43                          | 107                                              |                                                                                                 | 0.36                           | 2.86  | 28.93 | 19.07 | 30.66 | 29.37 |
|       |                               |                                                  |                                                                                                 | -1.84                          | 1.14  | 18.10 | 11.72 | 18.82 | 17.11 |
| 6     | 0.43                          | 118                                              |                                                                                                 | -8.53                          | 3.69  | 24.26 | 15.68 | 25.65 | 18.32 |
|       |                               |                                                  |                                                                                                 | -7.49                          | 1.74  | 12.98 | 8.73  | 13.89 | 7.51  |
| 8     | 0.41                          | 107                                              |                                                                                                 | -2.28                          | 2.15  | 25.81 | 16.71 | 26.79 | 24.38 |
|       |                               |                                                  |                                                                                                 | -3.43                          | 0.90  | 15.00 | 9.78  | 15.44 | 12.72 |
| 10    | 0.50                          | 107                                              |                                                                                                 | 16.60                          | 20.63 | 38.39 | 31.68 | 52.55 | 50.06 |
|       |                               |                                                  |                                                                                                 | 9.53                           | 10.57 | 25.00 | 20.87 | 32.99 | 32.45 |
| 12    | 0.44                          | 67                                               |                                                                                                 | 26.03                          | 38.65 | 35.34 | 36.65 | 64.02 | 53.95 |
|       |                               |                                                  |                                                                                                 | 17.14                          | 22.45 | 23.37 | 25.25 | 41.20 | 36.52 |
| Month | Average monthly sky clearance | Solar radiation on fixed horizontal surface kW.h/m² | Percentage increase in solar radiation compared to solar radiation on a fixed horizontal surface with different strategies. |
|-------|------------------------------|-------------------------------------------------|--------------------------------------------------------------------------------------------------|
|       |                              | Fixed, $\beta = 17.03^\circ$ | HEW | HNS | LNS | V | 2A |
| 2     | 0.54 | 111 | 13.89 | 20.57 | 37.47 | 47.00 | 25.05 | 51.15 |
|       |      |     | 8.33  | 10.66 | 23.74 | 30.20 | 16.63 | 31.74 |
| 4     | 0.54 | 146 | -0.51 | 1.85  | 33.77 | 33.20 | 17.40 | 34.55 |
|       |      |     | -2.08 | 0.66  | 20.88 | 19.58 | 10.93 | 21.26 |
| 6     | 0.50 | 135 | -7.56 | 6.54  | 29.86 | 24.26 | 16.06 | 31.24 |
|       |      |     | -6.58 | 3.66  | 18.20 | 13.37 | 10.01 | 19.87 |
| 8     | 0.28 | 72  | -2.86 | 0.78  | 12.20 | 10.07 | 7.45  | 12.58 |
|       |      |     | -2.51 | 0.28  | 5.13  | 3.04  | 4.01  | 5.32  |
| 10    | 0.54 | 128 | 11.83 | 16.56 | 40.66 | 48.60 | 24.65 | 51.24 |
|       |      |     | 6.95  | 8.79  | 28.06 | 33.29 | 16.93 | 34.18 |
| 12    | 0.55 | 108 | 22.06 | 40.45 | 41.52 | 56.75 | 31.71 | 69.27 |
|       |      |     | 15.07 | 25.22 | 29.08 | 40.35 | 22.72 | 47.19 |
gains of about 5% less than the 2A systems in all locations, while the HNS systems show average gains of 5% less than LNS systems with gains varying from 6.5% in the farthest northern location to about 4% in the furthest southern location.

Figure 5 shows the monthly percentage gain of the solar tracking systems for the seven locations considered in this work. Detailed data for the locations of Majis, Sur, and Salalah are presented in Tables 2–4, respectively. The decrease in the percentage gains as we go from North to South is noticed. In addition, the strong effect of low sky clearance factor is clear. For example, when the sky clearance factor in Salalah reduces to 0.28 in August, the percentage gain of 2A tracking system is only about 12% compared to 51% in February. It should be noted that Salalah is annually affected by cool, cloudy, and foggy weather from July to September. Another behaviour that is noted from the figure is the seasonal change in the relative effectiveness of solar tracking systems. For example, the HNS system performs similar to the 2A system from April to September which covers the summer hot months in Oman. This is important since electrical energy consumption increases considerably during this period due to the increased use of air conditioning devices. The increase as reported by the Authority for Electricity Regulation (AER) in Oman reaches 30% of the annual average peak load and more than double the peak loads from December to February. Therefore, since the summer period is the most important period to produce energy that can support the electricity grid, single-axis systems looks to be more attractive.

4. Conclusion
The effect of both sky clearance factor and the latitude on five solar tracking strategies has been presented in this article using data of seven locations in Oman. When the effect of sky clearance is not strong, two-axis tracking systems become more effective as the latitude increases. However, the results show that the dependence on sky clearance is stronger than the latitude. In other words, the effect of sky low clearance factor can overcome the effect of lower latitude regarding the effectiveness of solar tracking systems. This is clear when the sky clearance factor falls below 0.55.

The joint effect of the sky clearance and latitude is observed through the general behaviour of solar trackers. Two-axis tracking systems showed better performance with lowest percentage gain of 12% in Salalah (which has the minimum latitude among the selected sites), during August (when the average monthly sky clearance factor is 0.28). The maximum gain was 95% in Majis (which has the maximum latitude among the selected sites), during December (when the average monthly sky clearance factor is 0.67). The gain from single-axis systems depends on the strategy used, where the best one-axis solar tracking strategy is shown to be the system that rotates the surface about a tilted north–south axis, with tilting angle equal to the latitude of the location. This system provides percentage gain ranging from 10% in Salalah in August to 80% in Majis in December. It is noticed also that although Sur is located in the North region with latitude of 22.54°, it has the minimum annual gain. This shows that the effect of low sky clearance factor overcomes the effect of the latitude in this location. Among the seven sites in this study, Sur has the minimum average annual sky clearance of 0.44.

It is clear that the selection of solar tracking systems depends also on the seasonal requirements of the electricity grid. In many countries, the electricity load increases significantly during the summer due to the increased demand in cooling and air conditioning systems while the decrease in the demand in the winter allows power stations to shut down some of its units. This can shift the decision-makers into the selection of the relatively cheaper and less complicated one-axis tracking system that will give similar performance to the two-axis tracking systems in the summer and reasonable performance in the winter.

It should be noted, however, that the solar radiation received in these systems will be different in reality due to many factors such as different sky clearance and dust on the
surface of the panel. In addition, the effect of overheating the solar panel due to solar heat that will increase certainly with solar tracking is something to be considered as shown by Sharaf Eldin et al. (2016). Cooling the solar panel using wind, for example, like the one tested by Rahimi et al. (2015), can reduce the overheating effect. Furthermore, feasibility of any of the above systems will depend also on their initial, installation, and maintenance cost.

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Author details
N. Z. Al-Rawahi
E-mail: alrawahi@squ.edu.om
N. Z. Al-Azri
E-mail: nalazi@squ.edu.om
1 Department of Mechanical and Industrial Engineering, Sultan Qaboos University, AlKhoud, P.Code: 123, Sultanate of Oman.

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