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Study of the Best Orientation for Parabolic Trough Collector Works in Sebha City

Mohamed Alamen Sharif   Halima Saleh Bubisir

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Authors affiliation
Department of Engineering Renewable Energy, Faculty of Engineering, Sebha University, Sebha, Libya.
moh.sharif@sebhau.edu.ly
hlim.hasn@fenergy.sebha.edu.ly

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A B STRACT

Parabolic Trough collector assembly is made with an automatic sun-tracking system, to get the solar angle of incidence between the beam of solar radiation and the normal on the surface of the trough equal to zero. This study aims to present the best sun-tracking system for parabolic trough solar collectors operated in Sebha city. Five orientations have been selected for the Parabolic trough collector. In first orientation the axis was horizontal east-west and moving once on a single axis, in Second the axis was horizontal east-west and moving continuously on a single axis, in Third the axis was horizontal north-south moving continuously on a single axis, in Fourth the axis was north-south and parallel to the earth's axis. Fifth, the axis was north-south and moving on two axes. The results of the work serve as an information basis for future research on parabolic trough collectors that will operate in Sabha city, which showed that the First, second and Fourth orientation, was collected solar radiation values are acceptable in some applications. Although the Third (especially in summer) and Fifth orientations are collecting the largest amount of direct solar radiation, the cost these systems are very expensive.

دراسة أفضل توجيه لمجمع حوض قطع مكافئ يعمل في مدينة سبها

محمد الأمين الشريف   حليمة صالح أبوبيصير

يصنع القطع المكافئ مع نظام أوتوماتيكي لتتبع الشمس وذلك للحصول على زاوية سقوط بين الإشعاع الشمسي القادم من قرص الشمس والاشعاع العمودي على سطح المجمع يساوي الصفر. تهدف هذه الدراسة إلى تقديم أفضل نظام لتتبع الشمس لمجمعات الطاقة الشمسية ذات القطع المكافئ التي تعمل في مدينة سبها، حيث تم اختيار خمسة طرق لتوجيه مجمع القطع المكافئ. في الاتجاه الأول، كان المحور أفقيًا بين الشرق والغرب ويتحرك مرة واحدة على محور واحد، وفي الثانية كان المحور أفقيًا بين الشرق والغرب ويتحرك باستمرار على محور واحد، وفي الثالث كان المحور أفقيًا من الشمال إلى الجنوب ويتحرك باستمرار على محور واحد، في الرابع كان المحور شمال – جنوب وموازٍ لمحور الأرض. اما في الخامسة فقد كان المحور شمالاً جنوباً ويتحرك على محورين. تعتبر نتائج العمل بمثابة أساس معلوماتي للبحوث المستقبلية حول مجمعات القطع المكافئ التي ستعمل في مدينة سبها، والتي أظهرت أن الاتجاه الأول والثاني والرابع تم جمع قيم للإشعاع الشمسي مقبولة في بعض التطبيقات. على الرغم من أن الاتجاهين الثالث (خاصة في الصيف) والخامس يجمعان أكبر قدر من الإشعاع الشمسي المباشر، إلا أن تكلفة هذه الأنظمة باهظة الثمن.

INTRODUCTION:

Solar energy is one of the most significant forms of renewable energy for generating electricity in the commercial and residential sectors. One of the most promising technologies for producing electricity is Concentrated Solar Power (CSP), which can operate at higher temperature levels, they are usually used in temperature levels between 150–500 °C. Parabolic Trough Collector (PTC) is the most mature solar concentrating technology at this moment and is one of the most feasible solutions as it offers high temperatures, and can be used in a great range of applications for solar cooling, refrigeration, industrial heat, desalination, chemical processes and electricity production (Muzumil Anwar *et al*, 2021). Depending on the collector acceptance angle, a tracking mechanism must be dependable and able to follow the sun with a certain level of accuracy. It must also be able to perform other tasks, such as repositioning the collector at night or the end of the day and tracking through periods of intermittent cloud cover. Additionally, tracking systems are employed to safeguard collectors, they turn the collector out of focus to protect it from hazardous environmental and working conditions, such as wind gusts, overheating, and failure of the thermal fluid flow mechanism. There are many different types of tracking mechanisms, ranging from sophisticated to very basic. Mechanical and electrical-electronic systems are two broad groups into which they can be split. Electronic systems generally exhibit improved reliability and tracking accuracy. These can be further split into devices that use electronic motor control via sensors that measure the intensity of solar illumination and devices that use computer-controlled motors with feedback control from sensors detecting the solar flux on the receiver (Evangelos *et al*, 2019). Also, for example, A different message is sent to the controller to open the cover so that PTC can return and face the sun to continue the tracking of the sun when the surface of the rain sensor is dry (i.e., "no rainfall"). This is true as long as the tracking cycle for that particular day has not yet ended (Idowu David *et al*, 2020). A PTC operate on Direct Normal Irradiance (DNI), defined as the amount of received solar energy per unit area on the surface held normal to the sun's rays relative position changes every second, a solar tracking system is needed to improve its efficiency. Tracking methods are so named based on the direction of rotation of the collector's aperture plane. Figure 1 shows that the receiver, which is parallel to the tracking axis, is aligned in the east-west direction in north-south tracking, causing the collector's aperture plane to spin from north to south and vice versa. (Peter Viciana *et al*, 2017)

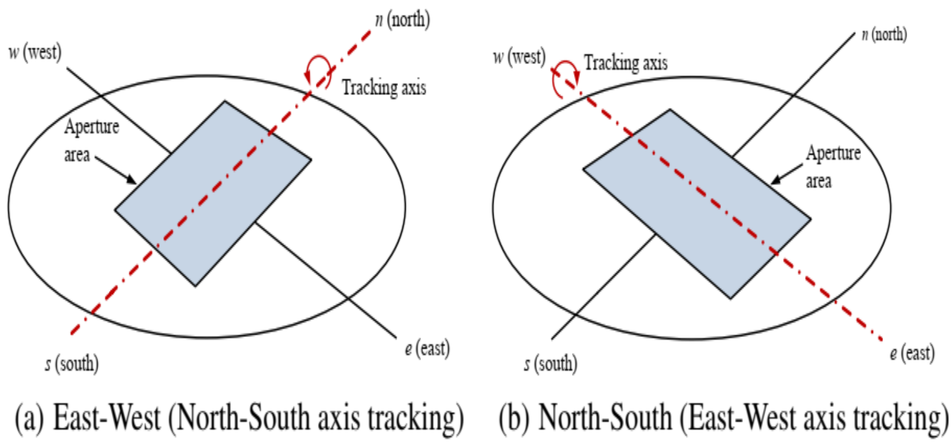

Figure 1: Tracking modes for PTC

The opposing tracking type, known as the east-west case, rotates the aperture plane from east to west while the receiver is positioned in a north-south direction. The north-south tracking approach has the benefit of using less energy for tracking, but with a higher end-effect. For east-west tracking systems, the opposite is the case (lower-end effect and higher energy consumption) (Peter Viciana *et al*, 2017; Nabeel *et al*, 2019). A study of the prospective installation of CSP plants in Libya was given by (Belgasim *et al*, 2018), and the plant Andasol-1 in Spain was a reference for comparing the performance results. The study's conclusions demonstrated that Libya is capable of doing so in an economic way, despite the proposed plant's position on the country's northern shore, where solar resources are at their lowest level compared to other places. A number of ally competitive way critical findings that could serve as a guide for solar energy projects were provided. Due to their low Levelized Cost of Energy, solar PV and PTC, for instance, are preferred candidates in the Saudi energy market. Parabolic Trough Technology was discovered in the Solar Village site to provide electricity at the lowest possible cost of 0.06 US dollars per kilowatt hour (Hafez *et al*, 2019). (Moafaq *et al*, 2019) studied the effect of the tracking axis on DNI of the collector at different times of the year and considered the north-south tracking axis of Baghdad as the best option for installing a solar collector for a longer period of the year. (Pablo *et al*, 2020) emphasized the necessity of Mirrors and thermal enhancement (with nanofluids or inserts) must receive significant research attention, and the tracking system needs to be dependable and accurate enough to track the sun, to get the best DNI. (Sharif, 2014) studied the best orientation for PTC, and has been evaluated for some locations throughout the world by adjusting the angle of incidence of the beam radiation, and was noted that the First and Second systems collected a small amount of solar radiation during the day compared to the rest of the systems, this small amount of radiation is considered to be acceptable in some studied areas (e.g., Libya). (A. Kumar *et al*, 2013) observed from the results that when the collector is continuously adjusted and rotated about a horizontal N-S axis such that the solar beam always makes the smallest angle of incidence with an aperture., also when the collector has turned about the horizontal E-W axis and adjusted continuously, are the best tracking mode for large scale power generation. (Sansoni *et al*, 2011) looked into PTC and used the findings to improve a prototype plant for residential supply that was placed in Florence, Italy. The goal was to manage the realization of mistakes and get beyond the challenges that came up when designing the solar trough plant. Imprecision in trough axis positioning is a particular topic that is tackled. (Shailesh *et al*, 2017) emphasized that the design and development of PTC and the experimental work carried out during this work led to the thermal efficiency of PTC can be increased by using an automatic solar tracking mechanism & by proper design. Keeping in view the relevant literature on tracking systems of PTC, it is identified research work has been carried out on five tracking systems, and evaluated the best solar tracking systems for PTC run in Sebha city using a variety of models. Sebha, a city in southern Libya, was chosen for examination in this study. Figure 2 shows the location of Sebha city, which is characterized by high solar radiation intensity.

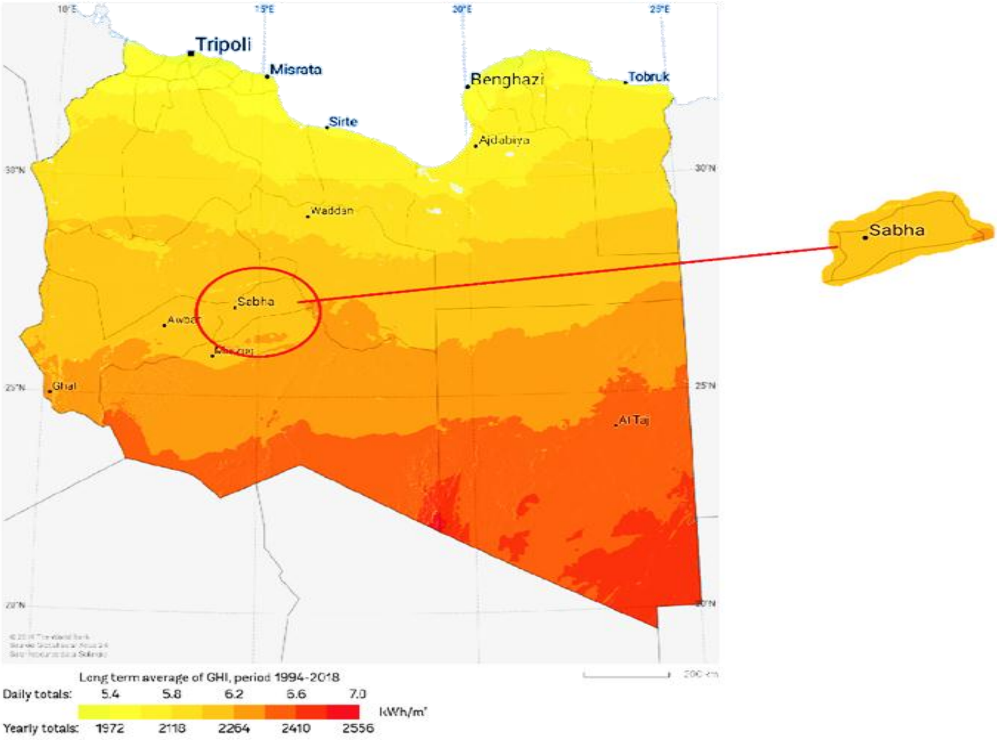

Figure 2: Solar radiation intensity of Sebha city. (Global Solar Atlas," World Bank, 2021)

METHODOLOGY :

Estimation of Direct Normal Irradiation

The most commonly available data where there is an albeit small survey station is the monthly average number ***n*** of hours of sunshine in a day; the monthly average value ***H*** of the daily solar radiation incident on a horizontal surface is also often provided. From these data, it is possible to estimate the direct and diffuse components of solar radiation ***H*** which is always lower than the daily extraterrestrial radiation H_o, which is why the clearness index K_T is defined as the ratio between ***H*** and H_o (Duffie *et al*. 2020; Nassar, Y., 2006).

$$K_T = H/H_o \quad (1)$$

Since the fraction of diffuse radiation increases with increasing cloud cover, a relationship was sought between the monthly average of the diffuse radiation H_d and the global radiation ***H*** with the clearness index K_T. The following relationship (Collares-Rabel) has recently proved to be of good reliability (Duffie *et al*, 2020):

$$H_d/H = \begin{cases} \mathbf{0.99} \ for\ K_T \le 0.17 \\ \left.\begin{matrix} 1.188 - 2.272K_T + 9.473{K_T}^2 \\ -21.865{K_T}^3 + 14.648{K_T}^4 \end{matrix}\right\} for 0.17 < K_T < 0.75 \\ -0.54K_T + 0.632\ for\ 0.75 < K_T < 0.80 \\ 0.2\ for\ K_T \ge 0.80 \end{cases} \quad (2$$

It has been suggested to express the global radiation H as a function of the ratio n / N (Duffie *et al*, 2020; Nassar, Y., 2006):

$$\frac{H}{H_o} = a + b\frac{n}{N} \quad (3)$$

Where: a and b are empirical constants.

It may be convenient to have analytical expressions for the intensity of the radiation per hour, given the daily value; thus, indicating with Id the diffused hourly radiation, we can write (Noushad *et al*, 2019):

$$r_d = \frac{I_d}{H_d} = \frac{\pi}{24} \frac{cos\ \omega - cos\ \omega_s}{sin\ \omega_s - \frac{\pi\omega_s}{180} cos\ \omega_s} \quad (4)$$

Where: $\boldsymbol{\omega}$ is the hour angle, and $\boldsymbol{\omega_s}$ is the sunset hour angle.

An empirical relationship is valid for the same $\boldsymbol{r_t}$ relationship (Duffie *et al*, 2020; Noushad *et al*, 2019):

$$r_t = \frac{I_G}{H_G} = (c + d\ cos\ \omega)\ r_d \quad (5)$$

Where: $\boldsymbol{I_G}$ Hourly global radiation, and the coefficients c, and d are given by (Duffie *et al*, 2020; Noushad *et al*, 2019):

$$\begin{matrix} c = 0.409 + 0.5016\ sin(\omega_s - 60) \\ d = 0.6609 - 0.4767\ sin(\omega_s - 60) \end{matrix} \quad (6)$$

Thus, Hourly beam radiation incident perpendicular to the horizontal surface can be estimated through the following equation (Duffie *et al*, 2020; Nassar, Y., 2006):

$$I_b = I_G - I_d \quad (7)$$

The radiation on a surface which is constantly normal to the sun's rays is always the maximum so to obtain it is sufficient to divide the radiation incident on a horizontal surface by the cosine of Zenith angle formed by the beam with the normal to the horizontal surface, given by (Duffie *et al*, 2020):

$$I_{bn} = I_b / cos\ \theta_z \quad (8)$$

We know that DNI depends on the angle of incidence $\boldsymbol{\theta}$, is given by (Duffie *et al*, 2020):

$$DNI = I_{bn}\ \cos\theta \quad (9)$$

Therefore, to have a good value of DNI, we try to have the minimum angle of incidence following the control systems used for PTC:

First system: PTC rotated about a horizontal east-west axis with a single daily adjustment so that the beam radiation is normal to the surface at noon each day (Kumar *et al*.2013), (Duffie *et al*, 2020):

$$\cos\theta = (\sin^2\delta \cos^2\delta \cos^2\omega) \quad (10)$$

Where: δ is Declination angle.

Second system: PTC rotated about a horizontal east-west axis with continuous adjustment to minimize the angle of incidence (Kumar *et al*, 2013; Duffie *et al*, 2020):

$$\cos = (1 - \cos^2\delta \sin^2\omega)^{0.5} \quad (11)$$

Third system: PTC rotated about a horizontal north-south axis with continuous adjustment to minimize the angle of incidence (Kumar *et al*, 2013; Duffie *et al*, 2020):

$$\cos\theta = (\cos^2\theta \cos^2\delta \sin^2\omega)^{0.5} \quad (12)$$

Fourth system: PTC rotated about a north-south axis parallel to the earth's axis with continuous adjustment to minimize the angle of incidence (Kumar *et al*, 2013; Duffie *et al*, 2020): $\beta = \varphi$

$$\cos\theta = \cos\delta \quad (13)$$

Where: β is the tilt angle, and φ is the latitude angle.

Fifth system: PTC that is continuously tracking about two axes to minimize the angle of incidence (Kumar *et al*.2013; Duffie *et al*, 2020):

$$\cos\theta = 1 \quad (14)$$

RESULTS AND DISCUSSION :

In this study, MATLAB program was used to estimate the average DNI for each month, during the day, where the data of the monthly average daily hours of bright sunshine in Sebha city were entered for the program, shown in Figure 3 (weather-and-climate, 2022). Also, Latitude angle was entered for Sebha city (27.0377), and the value of empirical constants ***a****=0.3*, and ***b****=0.43* for Desert or arid climate, the solar constant=1367W/m^2 (Duffie *et al*, 2020).

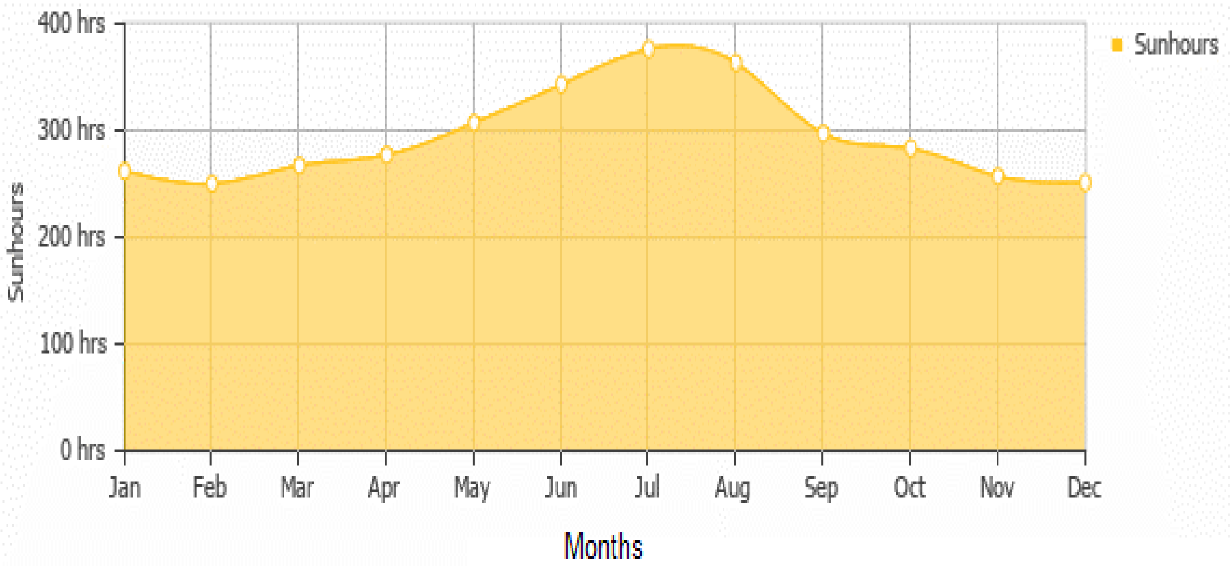

Figure 3: The monthly total of sun hours over the year in Sebha, Libya (weather-and-climate, 2022).

The results illustrated the effect of the tracking axis on the DNI of the PTC at a different time during one year. Figure 4, (from a to c) shows the amount of DNI for the different systems. It was noted that the collected values from clock10 to 14, have the highest amount of DNI and are almost similar, except for the third system, which collects the least amount of DNI during the day because the solar incidence angle is larger in winter, which leads to cosine loss. However, it is comparatively small in Summer. Since it is relatively small in Summer, we notice that the third system approaches the rest of the systems during the middle of the day, as shown in Figure 4 (from d to f). Also, Figure 5 (g, h). First and Second systems collect the least amount of DNI at the beginning and end of the day, compared to other systems.

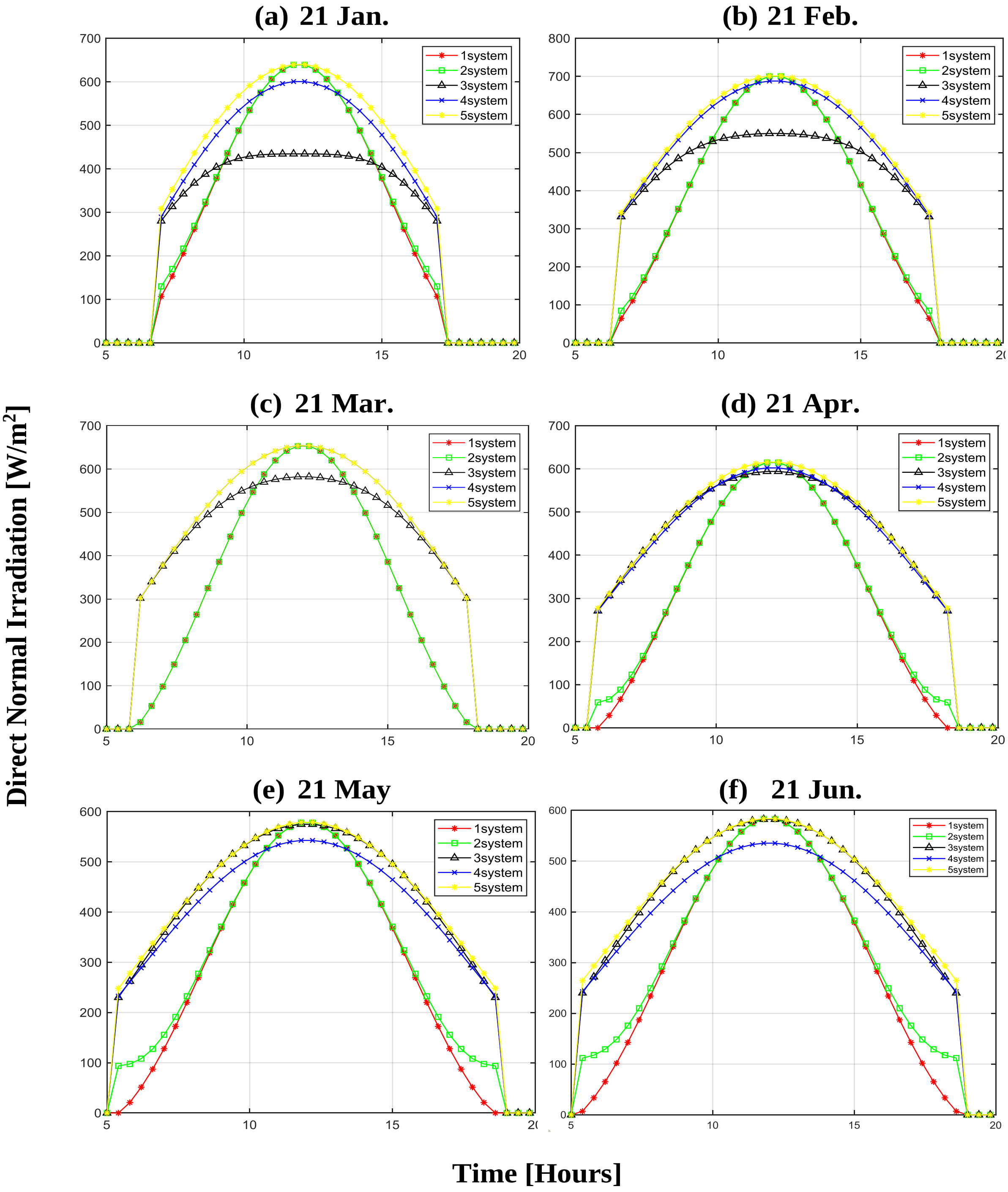

Figure 4: The daily pattern of DNI for (21Jan., 21Feb., 21Mar., 21Apr., 21May., 21Jun.)

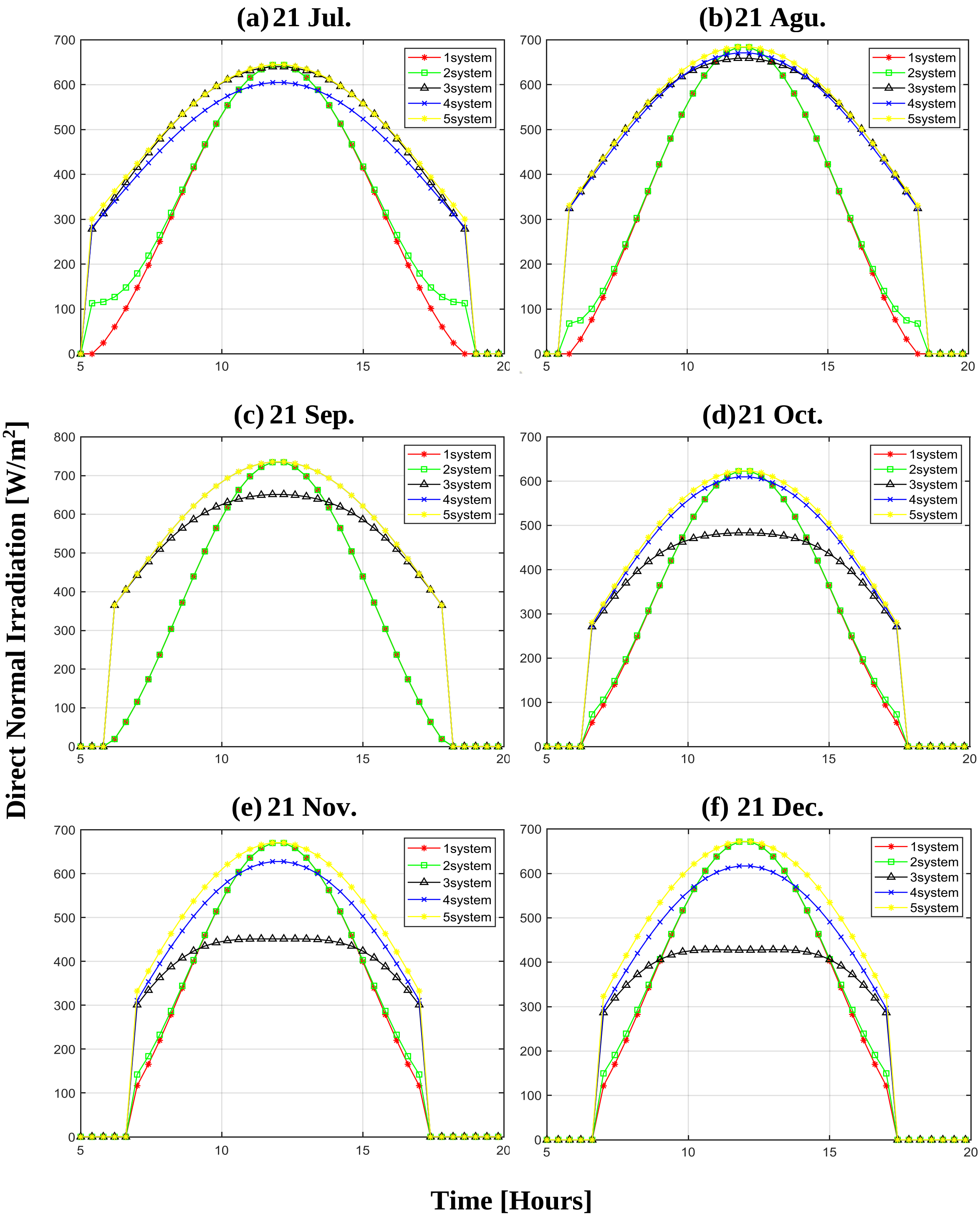

Figure 5: The daily pattern of DNI for (21Jul., 21Agu., 21Sep., 21Oct., 21Nov., 21Dec.)

In order to clarify the results in another way, the average DNI was compared for the five systems, as shown in the following Figure 6.

From Figure 6, it is clear that Third, Fourth and Fifth systems collect the largest amount of DNI during the year, while the First and Second systems have a small amount of radiation relative to the previous systems.

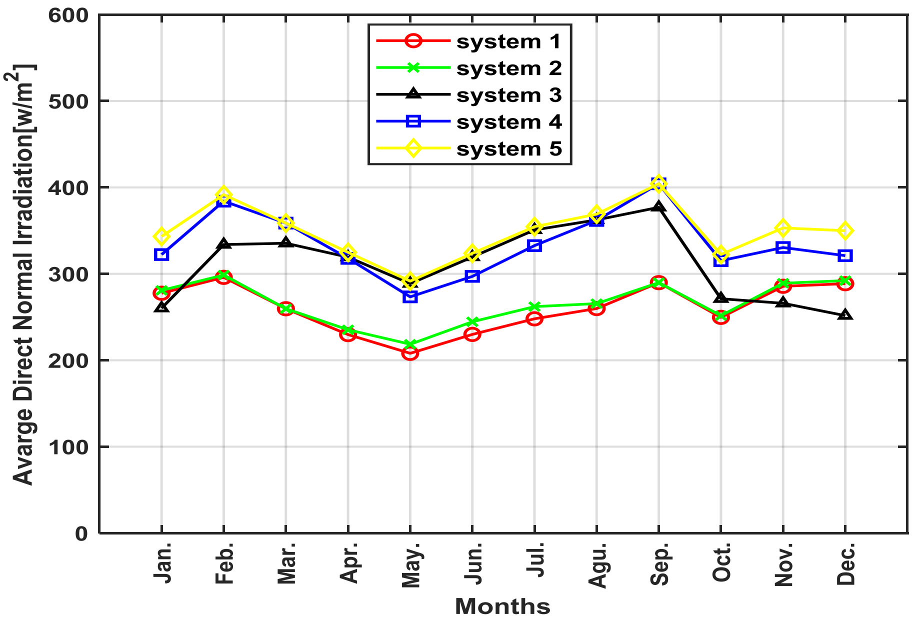

Figure 6: Comparison of the monthly average **DNI** for the five tracking systems.

CONCLUSION:

In the design and economic analysis of CSP, specific information on the direction that PTC should be used in for a certain installation site is crucial.

PTC can maintain its orientation toward the sun and hence capture the most DNI during the day and increase the effectiveness and power output of PTC, thanks to the tracking mechanism.

This study's main goal is to use several models to investigate the best solar tracking systems for PTC operated in Sebha city. The majority of conclusions state:

1. The optimal DNI for PTC over a longer period of the year is shown by the North-South tracking axis.
2. Although the fifth system has the maximum efficiency, it is expensive, and hard to operate; yet, it can be utilized for small-scale power generation. Two-axis tracking for PTC was also tested at the beginning of the technology, but it did not achieve acceptance.
3. The optimum tracking mode for massive power generation is the third system.
4. Due to its lower efficiency when compared to the third system, the fourth system is not economically viable for power generation.
5. Since the First and Second systems have the lowest efficiencies, they should only be used for cooling and water heating, not for producing electricity

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