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An Experimental Comparison Between Fixed and Single-Axis Tracking Photovoltaic Solar Panel Performance: Zakho City as Case Study

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ABSTRACT

The tracking system that uses for PV solar systems has a vital role to improve the energy performance of the solar panel. In the present study, the performance of both the fixed PV solar system and single – axis tracking PV solar system is investigated experimentally. The power for each PV solar panel is 150 W. The performances of the two systems are compared to display the efficient improvement of a single-axis solar tracking (SAST) system with fixed solar (FS) system under the climate conditions in the Zakho/ Kurdistan region/ Iraq. A mechanical tracking device with a controller and linear actuator was designed, and its performance was comprehensively investigated with a PV system. The findings for a sunny day due to the use of a single axis tracking system with a solar panel as compared with those of a fixed panel, that the enhancement in the overall power generation and electrical efficiency are about 28 % and 29 %, respectively.

Keywords:

Solar -tracking system, Sensors, Solar irradiance, Temperature.

1. INTRODUCTION

In recent years, the demand for renewable and sustainable energy has peaked due to the depletion of fossil fuel resources and increasing environmental problems. Various renewable sources such as wind, wave, hydrogen, and solar energy have been investigated and commercialized. The energy derived from the sun is known as solar energy. Since the solar energy is unlimited, sunlight and heat are captured using various methods such as heating, photovoltaic, thermal power, architecture, and artificial photosynthesis [1], [2]. The solar energy is entirely environmentally friendly . The solar panel collects photovoltaic cells that use the photovoltaic effect to transform the sun's energy into electricity . The performance of the PV panel reduces as its temperature rises. The solar cells are examined at 25°C; hence the solar panel's temperature should be between 15°C and 35°C when solar cells become most efficient.

On the other hand, solar panels may reach temperatures up to 65°C [3]. When the temperature of the cells changes, the power output changes, and the efficiency fluctuates due to the temperature difference [4]. The quantity of solar irradiation reaching its surface dramatically impacts the amount of power produced. As a result, a precise estimate of the quantity of solar irradiation reaching the ground is required to minimize the variance of PV energy-yield measurement, improve PV module efficiency, and anticipate output at various time scales. A solar tracker is a solar panel that automatically tracks the sun to enhance electricity efficiency [5].

The solar tracker is helpful for various applications, including solar day-lighting systems, solar cells, and thermal arrays. When the sun constantly faces the panel, it may absorb the maximum amount of solar energy since the panel performs at its most efficiently . Several known formulas are utilized to estimate the exact placement of the item on the Earth relative to the sun. For the time solar adjustment, the sun's angular location depends on longitude and local time. At noon solar time, the sun's height in the sky reaches its highest point [6]–[8].

Many researchers worked on tracking systems to enhance solar output power under different techniques and climate conditions. Rani et al. [9] established a tracking system to get maximum power throughout the day, illustrating that it is acceptable for an extensive solar system. Munanga et al. [10] created an innovative solar-tracking system; the results demonstrated a 25% improvement in efficiency. Furthermore, Kuttybay et al. [11] tested the efficiency of a single-axis tracking system with a fixed solar installation in different weather situations for one year. The results showed that the schedule-based solar- tracking system is 4.2% more efficient than LDR solar trackers. Rani et al. [8] used photovoltaic conversion panels to create a SAST device method, it was discovered that the total energy with tracking was 1742.88Wh, and the energy production without a tracking system was 829.6Wh. Motahhir et al. [12] built a simple solar tracker system in Baghdad/Iraq and compared their experiment to fixed -solar panels, revealing that solar trackers provide around 35% more electricity than fixed solar panels.

Moreover, Saymbetov et al. [13] proposed a sun- tracking technique. It was discovered that the suggested adaptive algorithm outperforms the dual-axis schedule tracker by 41%. Gabe et al. [14] presented a low-cost solar tracking system under Brazilian weather conditions. The cost of implementing a solar tracker system is roughly 25% greater than that of a fixed module system. Hidayanti et al. [15] conducted a thorough performance comparison of two types of solar systems: fixed and tracking systems. The most substantial power gain when contrasting the tracker and the static solar cell is 19.29%, while the smallest power increase is merely 8.96%. Saeedi et al. [16] simultaneously executed a sun- tracking system based on direct sunlight; it was found that the average energy of the Solar panel with a solar tracker was more than that of the fixed -solar panel.

Furthermore, under the weather circumstances of Rayong province, Thailand, Jamroen et al. [17] tested an autonomous solar -tracking system, and the energy efficiency of the PV system was raised by 44.89% compared to the fixed system. Motahhir et al. [18] and Hammoumi et al. [19] demonstrated the design and installation of a simple low active solar -track system. It is a possible idea for a sizable solar tracker to work with the suggested test bench. The suggested innovative tracking system provides 36.26% higher energy than a fixed panel [19]. Fadhil et al. [20] offered a recent prototype and effective solar photovoltaic tracker in Baghdad/Iraq that collected 26.83% more power than the static module. Morón et al. [21] created a modern prototype of a solar photovoltaic tracker.

The contrast of the created prototype with a static panel revealed an 18% energy improvement over five months. Chowdhury et al. [22] used a low-cost, high-precision sun-tracking system which improved performance over the fixed system by 13.9%.

The increasing demand for electricity in the Kurdistan region, the rising population from fossil fuels, and rapid technological advances are the main reasons for seeking new ways in solar energy to enhance necessary electrical energy. The output energy from fixed PV solar system is low compared with those of tracking- solar systems. There are some studies displayed in the literature survey including the improvement of the PV solar systems using different cooling systems to decrease the cell temperature. The enhancement due to this improvement is low. The experimental studies which deal with the PV solar panel using a tracking system are rare in the Kurdistan region. Furthermore, few applications of modern automated controls have been implemented to enhance solar energy systems and reduce human effort. Therefore, the solar tracker system's construction is designed to handle the solar panels efficiently and rotate them towards the sunlight direction. The main target of this work is to make a detailed comparison between single-axis solar -tracking systems and fixed solar systems using similar photovoltaic solar panels characteristics under the same climate conditions to measure the effect of tracking systems on their output power improvement.

2. THE PROPOSED METHODOLOGY

2.1 This Design method

This experimental study includes designing and implementing a fixed, single-axis solar -tracking system equipped with a photovoltaic panel. It explains the procedure used to carry out the research objective. As illustrated in Fig. *1* as a flowchart, this work illustrates that designing a suitable mechanism for the SAST system based on a solar -tracking system and programming and indicating an automated control system using an Arduino program to control and measure sensor data and collect them, analyzing and performing the output data to indicate the results. The developed tracking systems and fixed -angle photovoltaics will be compared regarding their efficiency output.

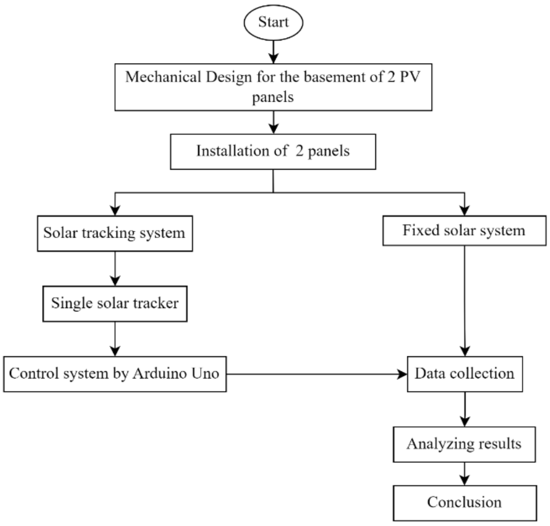

Fig. 1 Implementation of the comparison solar system, including data collection and analyses.

2.2 Experiment set-up and procedure

Two identical PV systems were placed on two different mechanical systems. One was a single-axis sun -tracking system, and the other was a fixed-tilted PV system, as illustrated in Fig. 2. The PV systems were installed on the rooftop of the college of engineering building of Zakho University, Zakho, Kurdistan Region/Iraq (37.1136° N, 42.6735° E).

2.2.1 Solar Photovoltaic Panels and Control Systems

This study has two identical systems, each including a 150 W PV solar module (1.48 × 0.67 m^2) polycrystalline silicon photovoltaic cell in serial connection and two light-dependent resistance LDR. The PV modules' characteristics are presented in Table 1.

Table 1: PV electrical characteristics

Properties	Value
Peak maximum power Pmp (Wp)	150
Open-circuit voltage Voc(V)	21.6
Short-circuit current Isc (A)	9.16
Peak maximum voltage Vmp (V)	18
Peak maximum current Imp (A)	8.33

The sun -tracking system consists of a mechanical frame, a linear actuator, an electronic control system, and azimuth positioning sensors. Each azimuth positioning sensor consists of two LDRs, which were used to test the eastern and western lights on the plane of the solar module. The controller includes an Arduino microcontroller that compares the signal from the light sensors to the linear actuator. Design of Mechanical Parameters

For the fixed and single-axis PV system, the solar cell was tilted at 37.1◦N toward a North-South orientation. The annual optimum tilt angle for the fixed system was approximately equal to the location's latitude [23], [24]. The sun-tracking PV system was designed with the East-West rotation orientation. Fig. 3 illustrates the mechanical structure of the proposed single-axis sun tracker, with the weight of the solar modules being m = 10.4 kg. A rectangular frame of panel carrier with the same panel dimension and height of h=0.15m was designed, and a basement of dimension 1.6× 0.7 m2 and h= 0.8 m was chosen for the solar modules. Autodesk Inventor software [28] was used to create the 3D design of the solar tracker sketching tool. This software, compatible with different graphic design forms, allows the user to illustrate the prototype's features and envision the outcome before manufacture.

According to the mechanical design, the weight and the dimensions of the panel linear actuator was chosen for tracking the panel because its strength, elongation and contraction which it become suitable for large size panel. Fig. 3 depicts the solar tracker's design.

(a) (b)

Fig. 2 a) Sun tracking and b) fixed-tilted PV systems.

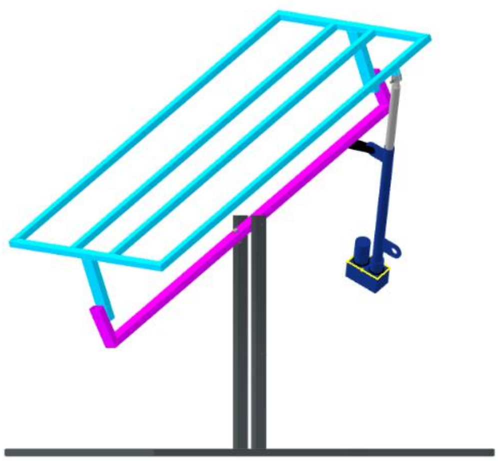

Fig. 3 The photovoltaic single solar tracker prototype in 3D orientation.

A model was developed before the prototype's construction to validate the equipment's performance concerning the light intensity variations on the LDRs (East = LDR1, West = LDR2). Both LDR1 and LRD2 are made of a photoresistor, a semiconductor, when the photoresistor absorbs the light of the right wavelength and the energy in the radiation is high enough, electrons are excited from the atom. The more radiation of the photoresistor absorbs, the more accessible electrons in the material.

Validating the proposed scheme and the response of the sensors block towards the variations of LDRs value in azimuthal movements (checking the response of LDRs) model was implemented through the programming of the tracker at a functional level with the help of a serial monitor in Arduino UNO software. The block diagram of the single-tracking system is presented in fig. 5.

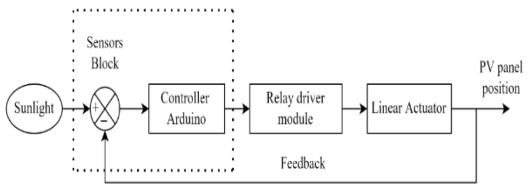

Fig. 5 Closed-loop blocks diagram of the tracking system.

2.2.2 Measurement and Control Systems

The metrological data were measured, and the solar radiation intensity was measured using a pyranometer which was connected to a specific control system consisting of an Arduino microcontroller, DS1302RTC, and micro-SD card modules to display the readings at the specified time. Thermocouples are used to measure the cell and ambient temperature values which are measured using Arduino software with specific programming to calculate and display seven temperatures (three thermocouples for each panel) and ambient temperature throughout the day. The wind speed was measured using a digital anemometer. The alternating current and voltage for PV panels for fixed and solar- tracking system panels are measured using a control system which is performed to store the specific data at the exact time every 10 minutes. The calibration using the thermocouples and thermometer is performed within a temperature range between 32 – 40°C shown in fig. 4. The difference between the thermocouple and thermometer readings is very low.

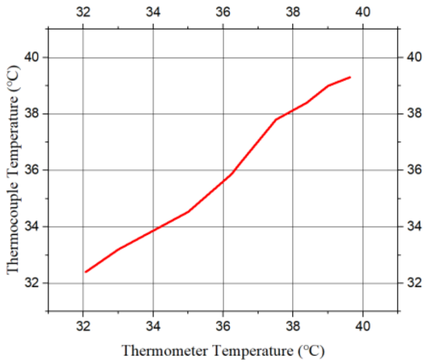

Fig. 4 Calibration of Thermocouples

2.2.3 Uncertainty analysis

The accuracy of the experimental results depended on the precision of the measuring instruments. However, an error percentage should be calculated in the results. In the present work, the solar panel power and its electrical efficiency uncertainties are calculated. The calculation of the power depended on the variables I_{mpp} and V_{mpp}. The uncertainty for the output power is obtained using the following equation [24]:

$$\frac{w_p}{P} = [\left(\frac{w_v}{V}\right)^2 + (\frac{w_I}{I})^2]^{1/2} \quad (1)$$

where $a_v = a_I = 1$, w_v, w_I , and w_p are uncertainty coefficients for V_{mpp} and uncertainty in I_{mpp}, respectively. The maximum uncertainty values for voltage and current are 0.078 % and 0.16 %, respectively. The uncertainty for output power is obtained as 0.2 %. The electrical efficiency is achieved using the independent variables I_{mpp}, V_{mpp} and G. therefore, the electrical efficiency uncertainty is the flowing equation [24]:

$$\frac{w_\eta}{\eta} = [\left(\frac{a_v w_v}{V}\right)^2 + \left(\frac{a_I w_I}{I}\right)^2 + \left(\frac{a_G w_G}{G}\right)^2]^{1/2} \quad (2)$$

Where $a_G = -1$ and w_G represents the uncertainty in solar irradiance which equals 0.1%. The calculated uncertainty of the electrical efficiency is 0.245%.

1.2.4 Data Reduction

To compare the efficiency of the two systems as the aim of this work related to power and several meteorological parameters, the measurement of day power generated P_m The system with the sun- tracking was required, and the power generated by the system without sun-tracking was by using the following equation [25]:

$$P_m = V_{oc} * I_{sc} * FF = V_m * I_m \quad (3)$$

Where are open circuit voltage and current, the FF fill factor is the ratio of maximum attainable power to the product of V_{oc} (open-circuit voltage) and I_{sc} (short-circuit current), as shown in equation 2 [25]:

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}} \quad (4)$$

The system efficiencies could be estimated by using this equation [25]:

$$\eta_{el} = \frac{P_m}{G\, A_{PV}} \quad (5)$$

Where, G is the solar irradiance intensity (W/m2), and A_{PV} . It is the area of the panel section that explains the proposed research, including research design, research procedure (such as systems, algorithms, pseudocode, or others), test mechanism, and data acquisition [1] - [3] .

3. RESULTS AND DISCUSSIONS

After collecting the data for a sunny day in August, the data are analyzed, and the average results are selected. The experimental tests were carried out from 7 am to 5 pm. The ambient temperature starts increasing gradually from 7:00 am until reached 47℃ as the highest temperature then decreases until 43℃ at 5:00 pm, as shown in fig. 6. In addition, the solar irradiance that was measured by using the pyranometer shows that increased from the sunrise and reach its highest level at 12:30 pm, then decreased during sunset.

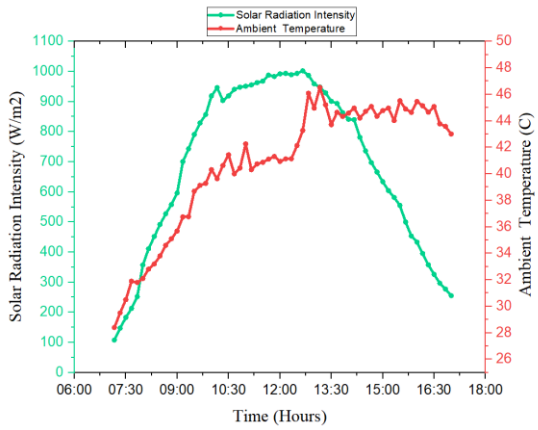

Fig. 6 Solar radiation and Ambient temperature Vs Time

Fig. 7 shows that the wind speed variation related to time at the same time; it does not significantly impact the PV panel's power because of less wind speed.

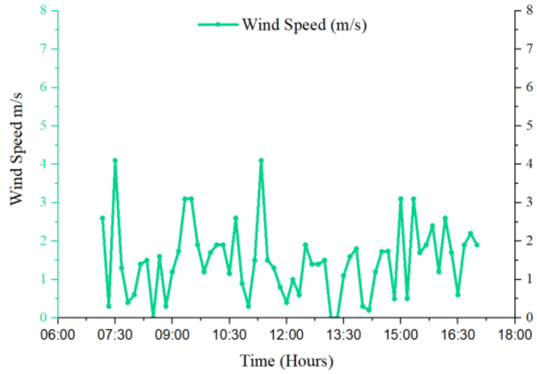

Fig. 7 Wind speed Vs. time

Error! Reference source not found.illustrates the power results of a comparison between fixed panel FS and SAST systems and their power difference.

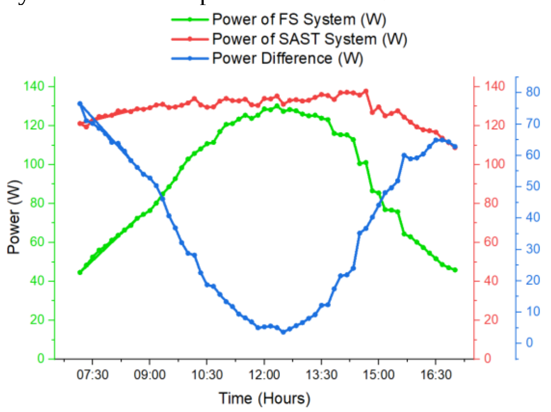

Fig. 8 Differences in power generated by the two systems under the same conditions.

Both systems used identical solar panels. The power generated by the two systems was measured simultaneously under the same conditions.

It is noticed that the generated power using a fixed PV panel is low during the morning and before sunset hours. The SAST increases the power during these hours. The average difference in the power generation between the two systems was approximately 36.4 W and the maximum enhancement in the power generation reached about 80 W after sunshine (7 – 11 am) and before sunset hours (2 – 5 pm). It is evident that on a sunny day, the tracking system worked efficiently and thus produce more power as shown in fig. 8.

On this sunny day, as shown in Fig. 9, when gathering the experiment data, the ambient temperature ranged between 27 – 30℃ until 8 am. Then the temperature rose to 47 ◦C around 1 pm as a peak ambient temperature, then remained nearly stable at 44◦C until 5 pm. The average cell temperature was measured for the two systems. Fig. 9 displayed that the cell temperatures have considerably higher temperature values than ambient temperature, affecting the efficiency of the two solar panels. The average cell temperature of the SAST system is higher than the FS system because the single-axis is automatically oriented to the sunlight.

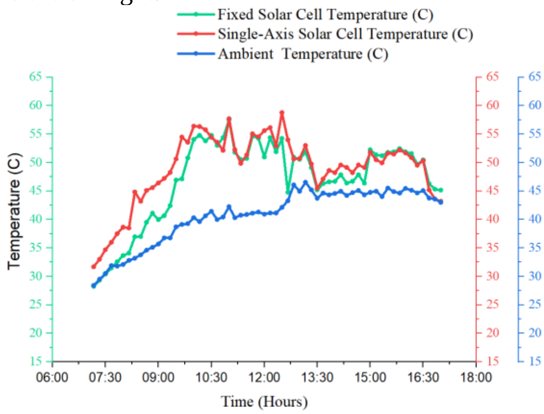

Fig. 9 The ambient temperature and the cell temperature for fixed and tracking solar panels

Fig. 10 displayed the significant difference in efficiencies between the systems noticed from sunrise until 10:30 am and from 02:00 pm until sunset. During the noon period, from 10:30 am to 02:00 pm, both systems possessed the same azimuth and angle to the sun; therefore, the power generated by the two systems was quite similar. The average difference efficiencies between the PV systems with and without sun tracking was 9.75%. Fig. shows the enhancement of the efficiencies of both panels, from sunrise to 9:00 am and from 2:00 pm to sunset. The maximum enhancement is due to the tracking systems, because the PV solar system tracks the sun throughout all time. Therefore, the power increases while the solar irradiance decreases during the sunrise and sunset. This result verifies the critical role of sun trackers in PV systems in Zakho city.

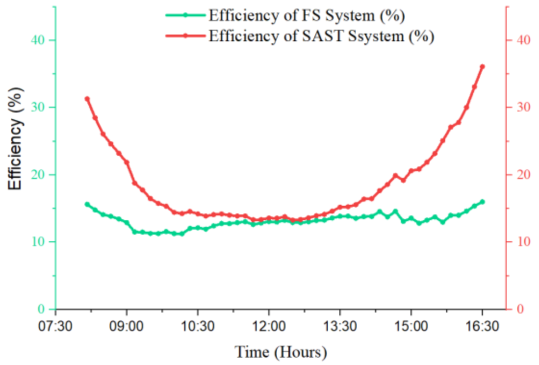

Fig. 10 The efficiency comparison between the two systems

4. CONCLUSION

This study analyzes the comparison in the performance of photovoltaic systems using fixed and single-axis sun trackers in Zakho city/Iraq. Two 150 Wp PV systems for fixed and single-axis sun-tracking were designed and installed; further, their performances were investigated. The results demonstrated a significant difference in power generation between the two systems, especially during early mornings and late afternoons. At noon, the power generated by both systems was almost identical.

On a sunny day, the maximum power generated by the PV with the sun tracker was 137.8 W. The overall efficiency of the PV system was improved by up to 29.3%; this was achieved by using a single-axis sun tracker. The cell temperature increases with the employment of the SAST as compared with a fixed PV panel. This work indicates that a simple hand-made sun - tracking system could effectively improve solar plants' performance.

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مقارنة عملية للأداء بين لوحين شمسيين كهربائيين أحدهما ثابت والآخر بنظام تتابعى بمحور منفرد: مدينة زاخو كدراسة حال

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الملخص

نظام التتبع المستخدم للمنظومة الكهروضوئية الشمسية له اهمية كبيرة لتحسين اداء الطاقة للوحة الشمسية. في العمل الحالي، تم فحص الاداء لكل من المنظومة الشمسية الكهروضوئية الثابتة والمستخدمة لنظام التتابع الاحادي الاتجاه. القدرة لكل لوحة شمسية مساوي لـ150 واط. تم مقارنة الاداء للمنظومتين لاظهار تأثير نظام التتابع الشمسي الاحادي الاتجاه على المنظومة الثابتة خلال الظروف الجوية لمدينة زاخو في كردستان العراق. تم تصميم جهاز التتابع الميكانيكي مع متحكم و محث خطي لفحص الاداء بشكل متكامل. نتائج البحث في يوم مشمس بوجود نظام التتابع الشمسي مقارنة باللوح الشمسي الثابت، ان التحسين في قدرة اللوحة والكفاءة الكهربائية يبلغ تقريبا 28% و 29% بشكل متعاقب.

الكلمات الداله :

نظام تتابع شمسي، المتحسسات، الطاقة الشمسية الساقطة، درجة الحرارة.