DOI: 10.24996/ijs.2022.63.7.17

ISSN: 0067-2904

A Performance Study of the Prototype Fixed, Open-Loop and Closed-Loop Solar Cell Tracking Systems

Baha'a A.M.Al-Hilli[1], Hussein A.Muhammed[2]

[1]*Department. Of physics, College of Education, Mustansiriyah Universit, Bagdad, Iraq*
[2]*University of Information Technology and communications, Bagdad, Iraq*

Received: 11/8/2021 Accepted: 21/11/2021 Published: 30/7/2022

Abstract:

In order to increase the amount of solar radiation reaching a solar panel, and hence increase its performance, a tracking system might be used. A prototype of an efficient and portable solar tracking system, for home applications was constructed. The Arduino Uno Microcontroller is utilized to drive the proposed tacking system. The results of area under curve show that at certain circumstances, the open-loop tracking system is more efficient as compared with fixed one, while the closed-loop tracker is slightly efficient than open-loop tracker.

Keywords: solar panel, tracking system, open loop, closed loop, fixed, AUC.

دراسة تقييم الأداء لنظام تتبع شمسي ذي الدورة المفتوحة والدورة المغلقة والثابت

بهاء عبد الرسول مجيد الحلي[1]، حسين عبد الرضا محمد[2].

[1]قسم الفيزياء، كلية التربية، الجامعةالمستنصرية، بغداد، العراق

جامعة تكنولوجيا المعلومات والأتصالات، بغداد، العراق

الخلاصة

لأجل زيادة كمية الشعاع الساقط على اللوح الشمسي، وبالتالي زيادة أداء اللوح الشمسي، يتطلب ذلك استخدام نظام تتبع شمسي. تم في هذا البحث دراسة نظام طاقة شمسية (الواح شمسية) محمولة للأستخدام المنزلي ومجهزة بمتحكم مايكروي نوع (اردوينو اونو) للسيطرة على حركة نظام التتبع. وتحت ظروف معينة تم دراسة أداء اللوح الشمسي وبينت نتائج المساحة تحت المنحني (AUC) لنظام التتبع الشمسي ذي الدورة المغلقة أكبر قليلا من المساحة تحت المنحني لنظام التتبع الشمسي ذي الدورة المفتوحة، وكلاهما اكبر بكثير من اللوح الثابت.

1. Introduction:

The sun is considered the primary renewable energy source. It is used to generate electrical power, making it a demanding matter worldwide. The output power depends on the amount of solar radiation projected and absorbed by the solar panels, which depends on the angle between the sunlight and the solar panel, i.e., the solar cell performance is high when the sunlight falls normally on the panel. Therefore, to maximize its performance, the solar panel must follow the sun position to keep a normal incidence of sunlight during the day[1].

*Email: bahahilli@uomustansiriyah.edu.iq

A solar tracker is a system on which solar panels are fitted in order to track the sun's movement across the sky, ensuring that the panels receive the maximum amount of sunshine throughout the day[2].

Sun-tracking is a practical approach in the generation of solar energy, particularly for solar panel concentration systems that may convert solar energy directly into electricity. A high level of precision in "sun-tracking systems" is necessary. The most critical aspect is its accuracy in ensuring that the solar collector can capture the maximum amount of solar energy throughout the day[3].

Solar trackers use different driving mechanisms, either the open-loop or the closed-loop control methods, to adjust the solar panel's angle. Open-loop trackers operate using the sun location in the sky during the year. The data (azimuth and elevation angle) calculation of the solar position through mathematical models [4]. Closed-loop tracker is a technology that uses the actual sun position in the sky using light sensors[5]. A microcontroller can be used, where the signal coming from the sensor is utilized to derive two servo motors to orientate the panel perpendicular to the rays of the sun, this orientation may change the efficiency of the panel[6]. Other tracking methods utilize non-moving parts, using optical methods, such as using Fresnel lens[7], reflector concentrator[8], as well as using luminescent solar concentrator[9] for concentrating solar radiation

One of the most important factors that affects the photovoltaic PV system efficiency, is the sunlight incidence angle, which depends on the generator geographic location, daytime, date and weather conditions.[10]

The ratio of the greatest generated output power to the input or incident power is solar cell efficiency[11]:

$$\eta = \left[\frac{V_{oc}\ I_{sc}\ \ FF}{A \quad G}\right] \times 100\% \tag{1}$$

Where: (A) is the panel's area and (G) is the irradiance falling on the panel's surface. The amount of energy produced by the investigated panel over a period of time is measured in units of (kW.h). The device fill factor is represented by F.F:

$$F.F. = \frac{V_m I_m}{V_{oc} I_{sc}} \tag{2}$$

The maximum power point is represented by the maximum delivered power point (Pmpp). Vm and Im is the maximum power voltage and the maximum power current, respectively, which are the voltage and current at the maximum power point. The solar cell open circuit voltage is represented by Voc which is the voltage at which no current flows through the external circuit when the solar cell terminals wire are not connected to a load. It represents the maximum output voltage that a solar cell can provide under any solar power. Short-circuit current (Isc) is the current when the electrodes of a solar cell are short-circuited, this is the current that passes via the external circuit.

From an astronomical point of view, the sun path tracing is constant for a specific location and date during one year period. Figure (1) shows the solar position at different hours of a day at four different weather conditions selected during a one year interval to test the systems.

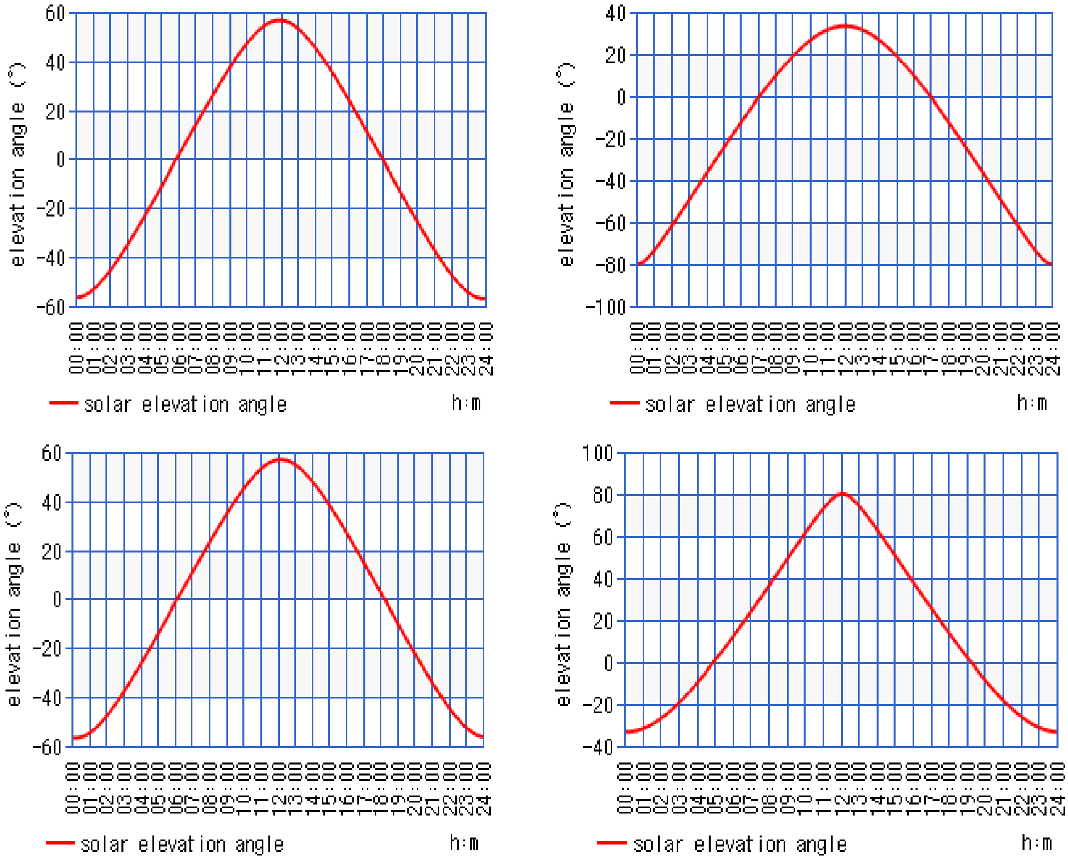

Figure 1-The ideal daily sun path of Baghdad city, chosen at (a) 23rd Sep.2018, (b) 21st Dec.2018, (c) 21st Mar.2019, and (d) 23rd Jun.2019.[12].

This work was established to develop a simple, low cost, portable and efficient open & closed-loop, dual-axes tracking system for real-time solar position measurement on an 8-bit (ATmega 382p) microcontroller along with Arduino board utilized to drive dual-axis servo-motors, and compared with a fixed panel system located at Baghdad-Iraq (22.49 ^{o}S, 41.92 ^{o}W).

2. The proposed system

The proposed system consists of solar panel, AC/DC- Inverter, microcontroller (Arduino Uno), DC servo motors and four (LDR) photosensors, which has the specifications listed in Tables 1,2, and 3.

Table 1- The solar PV Panel Specification [13]

Module	*50Wp*	**Pmp(W)**	*52.0457*
Manufacturer	*FORTUNER*	**Ambient temp**	*25*
Model area(cm2)	*3589.74*	**Imp(A)**	*2.8054*
Irradiance(mW/cm2)	*100*	**Isc(A)**	*3.1054*
Vmp(V)	*18.552*	**Module eff.(%)**	*14.51*
Voc(V)	*21.8465*	**Est.shunt resistance(ohm)**	*70.6189*
F.F.	*76.72*	**Est.series resistance(ohm)**	*0.2961*

Table 2-The Arduino Uno Specifications [14]

Microcontroller	*ATmega328*
Operating Voltage	*5V*
Input Voltage (recommended)	*7-12V*
Input Voltage (limits)	*6-20V*
Digital I/O Pins	*14 (of which 6 provide PWM output)*
Analog Input Pins	*6*
DC Current per I/O Pin	*40 mA*
DC Current for 3.3V Pin	*50 mA*
Flash Memory	*32 KB of which 0.5 KB used by boot-loader*
SRAM	*2 KB*
EEPROM	*1 KB*
Clock Speed	*16 MHz*

Table 3-The AC/DC- inverter specification used in the experiment

Industrial company	**Infinity Green Power**	
Model No.	**INFINISOLAR**	*VIII 5W*
PV INPUT	**Nominal operating voltage**	*360Vdc*
	Vmax PV	*450Vdc*
	PV Input voltage range	*120-450Vdc*
	Isc PV	*27A*
	MPPT voltage range	*225-430Vdc*
AC OUTPUT	**Nominal operating voltage**	*230Vac*
	Nominal output current	*22A*
	Maximum power	*5000W*
	Power factor range	*0.9 lead-0.9 lag*

Figure (2) shows the three main parts of PV solar power components (solar panel, AC/DC inverter and Arduino-UNO microcontroller).

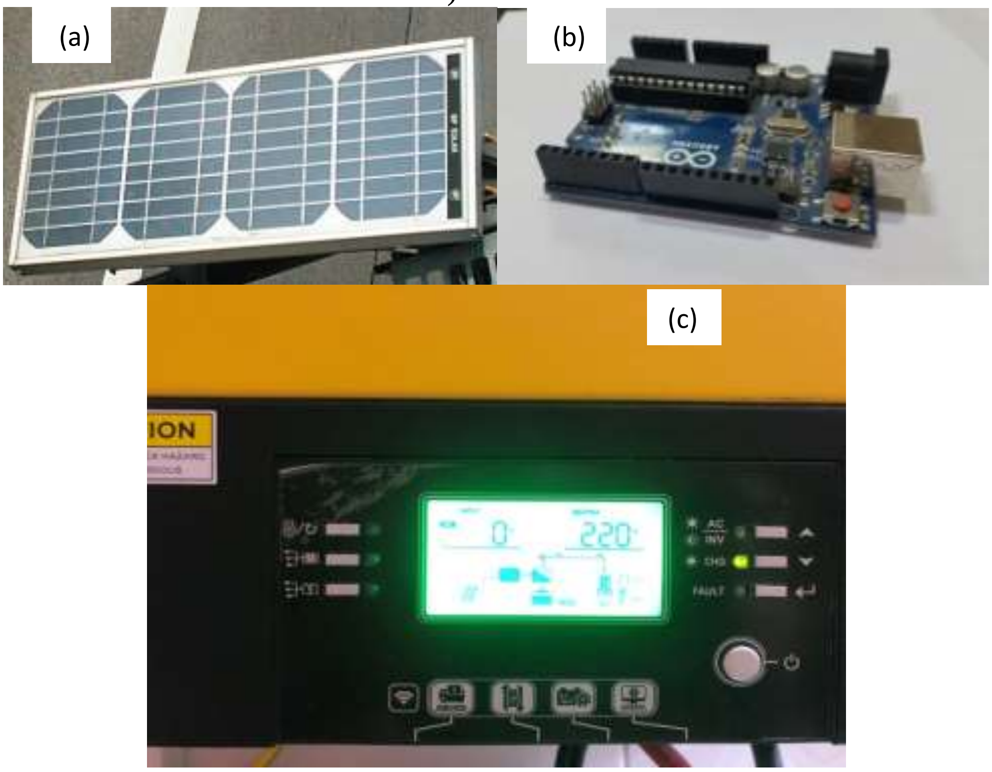

Figure 2-The solar panel from (a) Fortune(b) Arduino Uno Microcontroller) and (c) the AC/DC inverter .

In addition to the fixed solar panel, two trackers type were built and tested.

2.1 Open-loop technique[13]

In this technique, the sun location was used during the day according to Figure (1).

After loading the data into RAM, the microcontroller read the data, calculate the servo motor movement angel, position the panel, read I_{sc},V_{oc} from the inverter display and calculate the efficiency from Eqs.(1,2).

The city location where the solar panel is positioned is assigned to forecast the corresponding sun path of that location, after that, the sun path data of the specific location will be fed and stored in the SD-ROM, to be acquired and processed in the microcontroller to drive two servo-motors and keep the panel at normal position with the sun.

Figure (3) shows a block diagram of the open-loop system connection, which includes ATmega microcontroller chip, ADC and SD-ROM embedded on an arduino – Uno board. The ADC converts the analog data into digital signal and then sends it to the microcontroller.

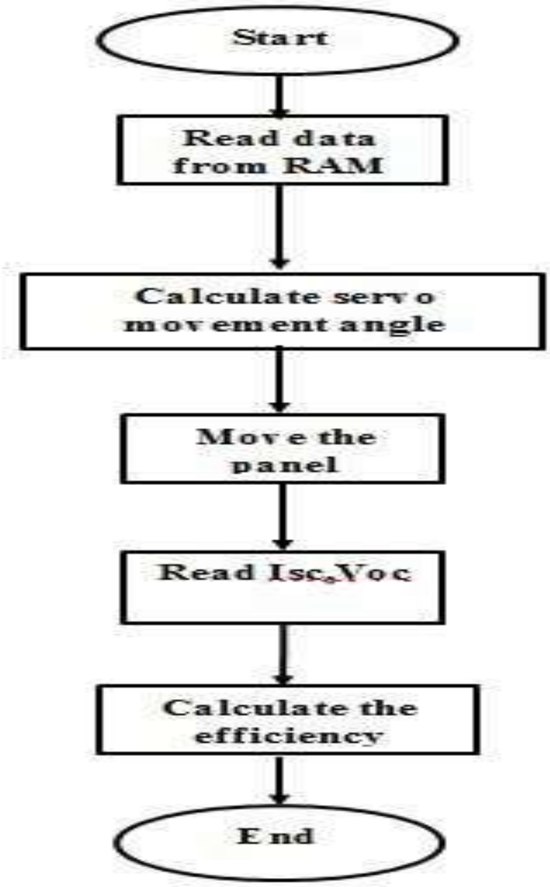

Figure 3-open-loop flow chart

The software code operation is compiled in the microcontroller in order to control the hardware components operation. The software operation is prepared to assign the initial position before starting up the tracking system, in order to reset the panel manually to a zero point. When the panel is set to its primary position, it will be ready to align and track the sun path precisely. Figure 4 shows a block diagram of the open-loop tracking items and their connection.

This technique has a benefit; that it can track the sun independently, it can be used in cloudy days, and/or when the sun light intensity is reduced due to fogs, smokes… etc. The solar panel position calculation can be measured according to the geographical location data of the city at which the panel is located, the daily sun path data for one a year period will be fed to the Arduino UNO microcontroller, subsequently; it will guide the dual-axis motors of the solar panels.

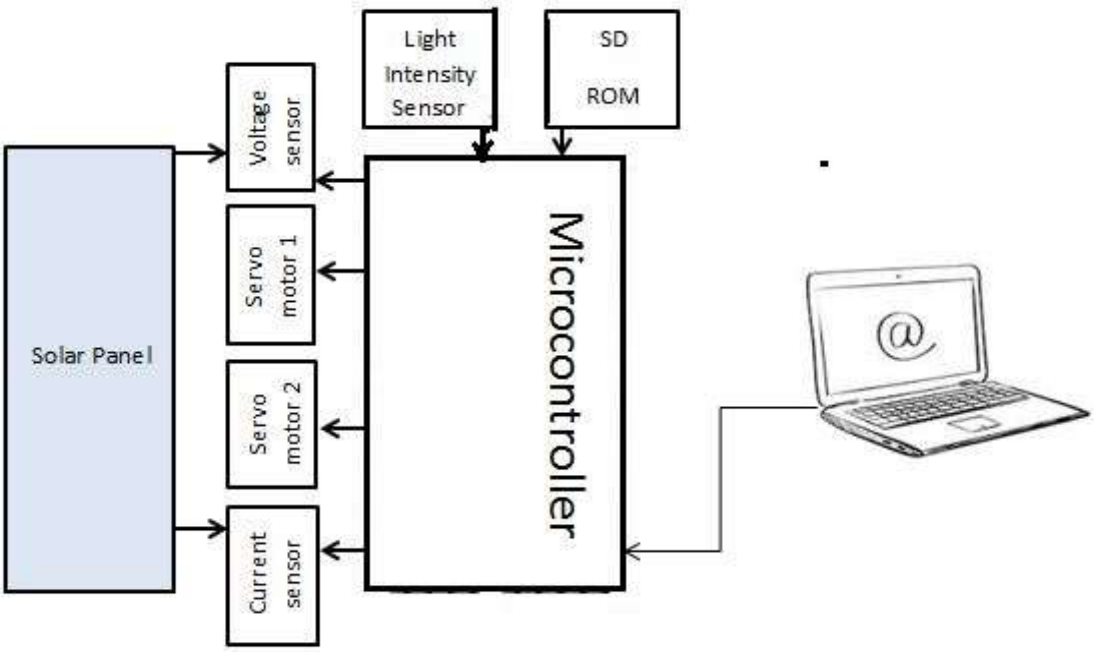

Figure 4-the schematic block diagram of the open-loop system

2.2 Closed loop technique

In this technique, the light dependence resistors (LDR)(type PGM5506) were used to sense the sun light (direct beam radiation) and locate the best solar panel direction. The microcontroller read the voltage of each LDR sensor, and energize the servo motors until the voltage reading is equal to one. Figure 5 shows the flow chart of the procedure sequence of this method.

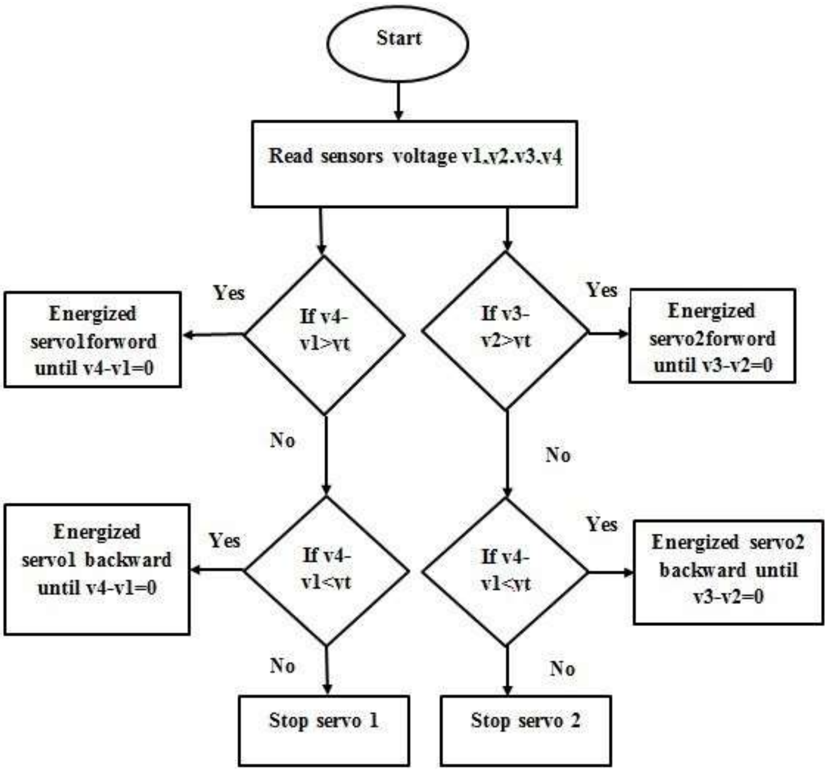

Figure 5-The closed-loop flowchart

This technique is used in sunny days, four light dependence resistor LDR are used type PGM5506 to sense the sun light (direct beam radiation) and locate the best solar cell direction. By current is driven to two servo motors and Arduino Uno microcontroller. Figure (6) shows a block diagram which describes this technique. It consists of four LDR each one represents the sun direction in azimuth and elevator angle. The sun light is focused on the 4 LDRs using a lens. When the sun changes its position in the sky, four different voltages are produced across the (LDRs) when the solar panel is not perpendicular to the sun. This difference in the voltages is calculated and compared in the microcontroller to energize the servo motors (SM1) or (SM2) that represent azimuth and elevation error angles.

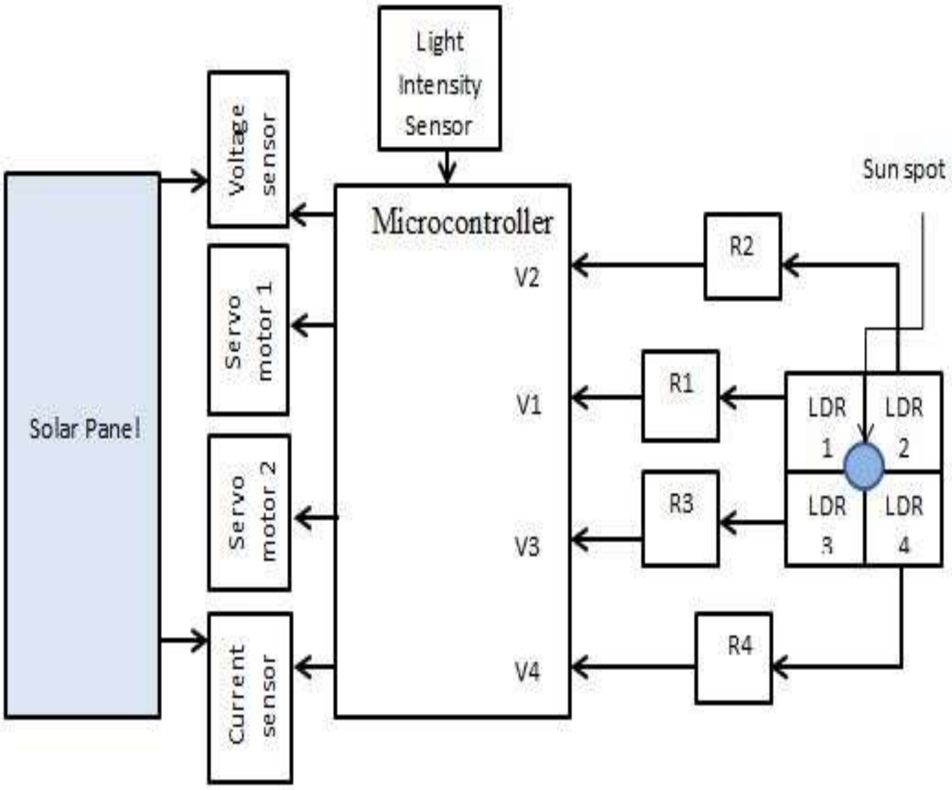

Figure 6-The schematic block diagram of the closed-Loop tracking system

3. Results and Discussion:

The daily solar irradiance in Baghdad city was acquired and registered from the website[14] at a selected days of the year (21^{st} Mar, 23^{rd} jun, 23^{rd} Sep, and 21^{st} Dec.) for different sensor angles of inclination (horizontal, vertical, and 50^{o} tilted to the south).

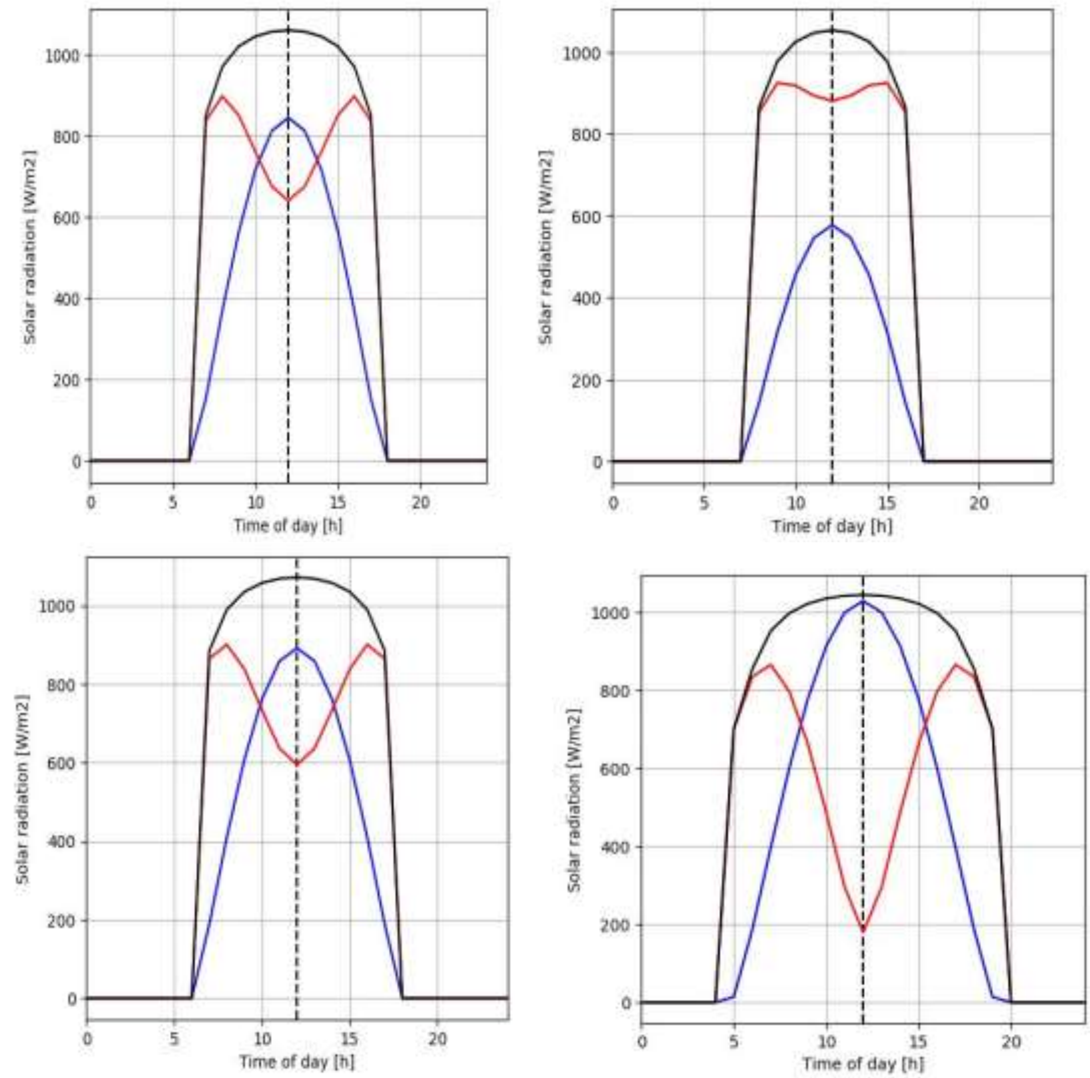

Figure 7-The solar irradiance of Baghdad city chosen at: (a) 23rd Sep.2018, (b) 21st Dec.2018, (c) 21st Mar.2019, and (d) 23rd Jun.2019, horizontal (blue), vertical (red), 50o inclination (black)[11]

Multiplying the solar irradiance value by the wattage of the PV panel gives the amount of energy generated by the PV-system in (Watt.hour). The outperformance energy of the proposed open-loop tracking system as well as fixed panel are plotted as a function of the same days as shown in Figure (7).

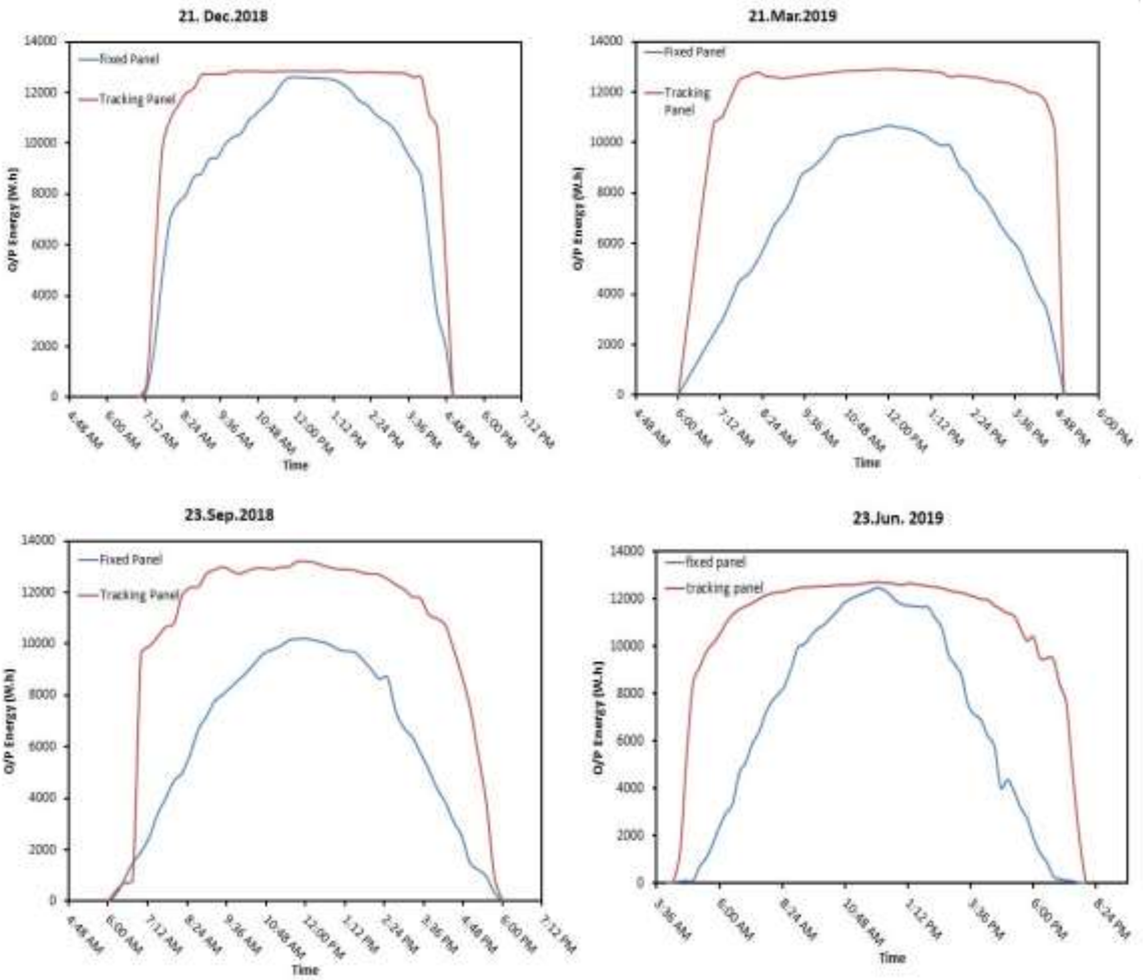

Figure 8-The output Energy of the fixed (blue) and Tracking panel (red) at: (a) 21st Dec.2018, (b) 21st Mar.2019, (c) 23rd Sep.2018 and (d) 23rd Jun.2019.

Using MS-Excel, the area under the curve, AUC values, of the system is calculated as shown in Table (4).

Table 4-The calculated (AUC) of the fixed and tracking systems

(AUC) (a.u.) / Day	Fixed at 50° inclination system	Open-loop tracking system	Closed-loop tracking system
21st March	*76525.75*	*124385.3*	*124389.78*
23rd June	*106028.4*	*172109.8*	*172256.42*
23rd September	*74720.5*	*125905.5*	*126003.1*
21st December	*92973.25*	*115094.8*	*115170.5*

The results revealed that the proposed tracking system has the highest average AUC values. It exceeds the values of the projected power from a fixed panel. As a result, the system with the best orientation toward the sun produced higher average (AUC) values.

4. Conclusions:

PV solar systems can create more electric energy if a tracking system is used. The AUC results indicated that the performance of the open-loop and the closed-loop tracking system is equivalent. Using these two tracking systems gave the highest AUC values, making them better than the fixed panels.

Closed-loop tracking is more expensive than open-loop tracking since it is more accurate, but open-loop tracking systems are more appealing due to its own features, such as efficiency, simplicity, low cost, reliability, and independence from ambient weather conditions.

5. Acknowledgment:

The authors would like to thank Mustansiriyah University (www.uomustansiriyah.edu.iq) Baghdad – Iraq for adopting the present work, as well as University of Information and communications for supporting this work.

6. References:

[1] Y. Chu and P. Meisen, “Review and comparison of different solar energy technologies,” *Glob. Energy Netw. Inst. (GENI), San Diego, CA*, 2011.

[2] S. Ray and A. K. Tripathi, “Design and development of tilted single axis and azimuth-altitude dual axis solar tracking systems,” in *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, 2016, pp. 1–6.

[3] G. K. Singh, “Solar power generation by PV (photovoltaic) technology: A review,” *Energy*, vol. 53, pp. 1–13, 2013.

[4] M. H. M. Sidek, N. Azis, W. Z. W. Hasan, M. Z. A. Ab Kadir, S. Shafie, and M. A. M. Radzi, “Automated positioning dual-axis solar tracking system with precision elevation and azimuth angle control,” *Energy*, vol. 124, pp. 160–170, 2017.

[5] C.-Y. Lee, P.-C. Chou, C.-M. Chiang, and C.-F. Lin, “Sun tracking systems: a review,” *Sensors*, vol. 9, no. 5, pp. 3875–3890, 2009.

[6] H. Mousazadeh, A. Keyhani, A. Javadi, H. Mobli, K. Abrinia, and A. Sharifi, “A review of principle and sun-tracking methods for maximizing solar systems output,” *Renew. Sustain. energy Rev.*, vol. 13, no. 8, pp. 1800–1818, 2009.

[7] A. H. Obaid, E. J. Mahdi, A. H. Muslem, A. N. Jafer, S. S. Abed, and T. Y. Khuder, “Evaluation of the Performance of Silicon Solar Cell with Fresnel Lens as Photovoltaic Solar Concentrator,” *Iraqi J. Sci.*, pp. 3400–3406, 2021.

[8] Y. H. Mahmood and R. Y. J. Al-Salih, “Experimental study of two different types of solar dish characteristics and its efficiency based on Tikrit, Iraq weather conditions,” in *Journal of Physics: Conference Series*, 2018, vol. 1032, no. 1, p. 12006.

[9] E. Abd alkareem Fadhil and M. M. Abdullah, “CdSe/ZnS Core/Shell for Luminescent Solar Concentrator,” *Iraqi J. Sci.*, pp. 1645–1649, 2020.

[10] W. D. Lubitz, “Effect of manual tilt adjustments on incident irradiance on fixed and tracking solar panels,” *Appl. Energy*, vol. 88, no. 5, pp. 1710–1719, 2011.

[11] A. R. Jha, *Solar cell technology and applications*. CRC press, 2009.

[12] “https://www.meteoexploration.com/en/,” *Thin Solid Films*, 2019. .

[13] A. G. Melo, D. Oliveira Filho, M. M. O. Junior, S. Zolnier, and A. Ribeiro, “< b> Development of a closed and open loop solar tracker technology,” *Acta Sci. Technol.*, vol. 39, no. 2, pp. 177–183, 2017.