Tikrit Journal of Engineering Sciences (2022) 29 (3): 43-48
DOI: http://doi.org/10.25130/tjes.29.3.5

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)

Tikrit Journal of Engineering Sciences

available online at: http://www.tj-es.com

College of Engineering

TJES Tikrit Journal of Engineering Sciences

Modeling Horizontal Single Axis Solar Tracker Upon Sun-Earth Geometric Relationships

Gzing Adil Mohammed *, **Zana Saleem Mohammed**

Oil, Gas and Energy Management, Business collage, Charmo University, Sulaymaniyah,Iraq.

Lafarge Cement Industry, Sulaymaniyah, Iraq.

Keywords:

Renewable Energy; Solar Power Generation; Solar System; Solar Tracker

A R T I C L E I N F O

Article history:

Received 02 May 2022
Accepted 20 Aug. 2022
Available online 17 Sep. 2022

Citation: Mohammed GA, Mohammed ZS. Modeling Horizontal Single Axis Solar Tracker Upon Sun-Earth Geometric Relationships. Tikrit Journal of Engineering Sciences 2022; 29(3): 43- 48. http://doi.org/10.25130/tjes.29.3.5

A B S T R A C T

Many investments and commitments have recently been set to use renewable energy source, overcome energy crisis and align with climate target. Solar power development and deployment make investment in power generation sustainability. The goal of this study is harvesting energy by rotating solar panel toward the sun direction. Astronomical formula is derivate to calculate the sun altitude and azimuth depending on given latitude, longitude coordination. The photovoltaic (PV) panels rotate horizontally and track the sun direction in 9 positions regarding to their actual time and calculated azimuth angle. Partial shaded effectiveness that produces between the adjacent panels due to PV panel's inclination is calculate accordingly. The total increment of power production from fix to tracked panel structure is 17.3% per day. The extra power generation is distributed over the period between solar noon times.

* Corresponding author: E-mail: gzing.adil@charmouniversity.org, Oil, Gas and Energy management, Business collage, Charmo University, Sulaymaniyah,Iraq.

1. INTRODUCTION

Generating electric power by using solar system get a wide demand during last period. This attention is increased obviously due to increase the cost of national grid electricity since last January 2021 in Kurdistan region. Shortage and fluctuation of national power grid affected negatively on the profitability and production sustainability for most of the industrial's plant such as iron plant, oil refinery, chemical factories, cement plants and etc. Resuming the operation for such sector need to consume five to six time of energy more than the normal operation condition. Regarding to a domestic and commercial usage of solar plant, this sector was paid attention due to seek for alternative power generation that having a better environment impact. Requesting high efficiency photovoltaic solar panels and using the Maximum Power Point Tracking (MPPT) inventor are a main concerning for all solar plants. One of the big challenges regarding this renewable solution is limited area of solar panel versus the section power demand. The area limitation obliges the investors focusing on alternative solution thus increasing the solar power generation. The mean of daily direct solar irradiance during winter session decreases dramatically into more than 50% as a compare with summer session [1], which will be worth for improve their generation volume. This study is aimed for using tilted East West sun tracker to expand the power generation band, this rotation is the most efficient among other rotation pattern for increasing radiation ratio (which is the ratio between annual solar radiation incident and tracked panel [2]. It supports to maximize the radiation ratio into about 90% and being close to radiation ration the come out from dual axis tracker. The study is trying to deploy the assigned photovoltaic panel area to install a further panel. The main goal is increasing the period for the panel direction toward the sun position in order to raising up direct irradiance ratio. In financial point of view, it is expected to decrease the overall project payback by 16-18% of the total period of investment [3]. In addition, the simplicity of structure and maintenance can be applied by suing single axes tracker [4]. This can be attracting the investor for choosing single axis instead of dual axis especially when it is considering the three elements of comparison altogether: power generation, project cost and service cost.

2. REVIEW OF LITERATURE

Improvement of Solar power generation has widely advanced by using various mechanisms. One the most topic related to the solar generation efficiency is tracking the sun position and increasing the direct irradiance receipt. The sun tracker categorized into two types [5]: •Single axis tracker designed to rotate the Photovoltaic (PV) panel in one direction (such as East -West, North-South, tilt vertically or rotate around itself). •Dual axis sun tracker is followed the sun through two axes [6]. Using two axis solar PV panel is increasing the energy harvesting versus using single axis PV panel configuration [7]. The cost of maintenance dual axis platform on yearly basis between (36-48 $) versus (23.6-32 $) that is belong to single axis platform. The author mentioned the to the initial installing cost as well which increase around 30 % if the design goes with dual axis platform. This study [8] made a comparison of solar generation performance for three types of tracking configuration, including fixed, one axis and dual axis platform. The ratio of the power outcome as a compare with the fixed PV panel was recorded as 32.2% 36.8 % for each of single axis and dual axis platform consequently. On the other hand, the design and assembling difficulty of dual axis platform with their periodic repairing cost recorded as a higher. Many endeavors such as [9] and [10] were used image sensor and light dependent resister (LDR) to know the sun position which can be configured with microcontroller. [11] try to prove the power consume by actuator and controller is much less than gain of energy that coming out through using single tracker under different weather condition. Another comparison made by [12] and prove the single axis tracker has the least economical saving at Mumbai, it is show that the generated energy by using single axis 27-30% more than using fixed panel. The impact of dual axis tracker has not recorded an obvious gain above single axis tracker. In this study, it is considered to adapt the PV penal structure with the optimum cost consideration and robust structure assemble with suitable regular maintenance cost. Single axis solar tracker area intends to prioritize some essential factors such as simplicity of design and cost structure. This designed of horizontal solar tracker is relying on astronomical theory to estimate the sun position and avoid using further sensors for detecting the sun position.

3. MATERIAL AND METHODS

Determining the sun position with regarding to solar plant location are the essential parameters for designing horizontal solar tracker. Accordingly, it is need to determine each of the followed parameters: local time and solar plant location (latitude and longitude coordination). The main objective for this project is calculating sun Azimuth and Altitude that help to direct solar panel to be in a perpendicular position to the sun as much as possible and increase the ration of direct sun irradiance. The steps of gathering formulas can be addressed as below points:

3.1. Find out Solar Time

3.1.1. calculation of julian day:

Number of days regarding to the year can be calculated as Eq. (1) [13]:

$$No.of\ day = integer(275 * month/9) - K * integer((month + 9)/9) + day_{of\ month} - 30 \quad \textbf{(1)}$$

3.1.2. equation of time:

It is the difference between clock time and sundial, it is needed to calculate correction of longitude as shown in below formula and presented in Fig. (1) [13]. The latitude value is substitute radian within the equation of time Eq. (2) and Eq. (3).

$$B = (No.of\ day - 1) * 360^o/365^0 \quad \textbf{(2)}$$

$$E = 229.2(0.000075 + 0.001868\cos B - 0.032077\sin B - 0.014615\cos 2B - 0.04089\sin 2B) \quad \textbf{(3)}$$

B: Longitude correction
E: equation of time

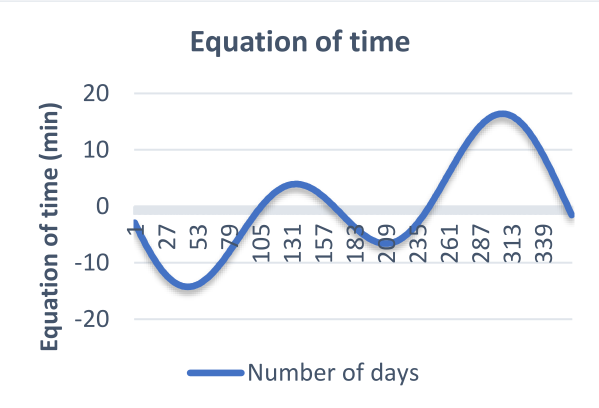

Fig. 1. Equation of time over the day of the year [14].

3.1.3. solar time

Depending of the below equation Eq. (4), it can obtain time regarding to the sun position [15]. This will be important to find leading and lagging time regarding to solar noon. The local longitude in major cities and towns in Iraq it is between ~ 400-480 east.

$$\text{Solar time} = \text{standard time} + 4(\text{longitude for the standard meridian - local longitude}) + \text{E} \quad \textbf{(4)}$$

3.2. Determining angles

Determining some astronomical angle will be the essential coefficient for building the tracking module, the below angles are used for rotating the PV panels.

3.2.1. solar altitude angle (βn)

It is the elevation of sun regarding to the earth's horizon [13]. It is show zero value at sunrise and sunset time. It can be represent in Eq. (5) and Eq. (6).

$$\beta n = Sin^{-1}(\cos(\delta)\cos(\text{local longitude})\cos(T\ \sin(\text{local longitude})\sin(\delta)) \quad \textbf{(5)}$$

$$\delta = 23.45 * \sin((360/365) * (284 + No.of\ day)) \quad \textbf{(6)}$$

δ: Declination angle
Ti: leading or lagging time from solar noon, it is getting a positive and negative sign before and after solar noon consequently.

3.2.2. solar azimuth angle (ϕs)

It is angle on the horizon plane between the lines on due south and projection sun ray on the horizon plane. The formula is as below Eq. (7) and Eq. (8) [16]:

$$\sin(\phi_s) = \cos(\delta)\sin(h)/\cos(\beta n) \quad \textbf{(7)}$$

$$h = 15^o * T_i \quad \textbf{(8)}$$

h: solar hour angle.

3.3. Usage material

3.3.1. actuator

The actuator is a device with shaft moved linearly by rotating a stepper motor [17]. Generally, it is moved 4-6 mm/sec. and trigger by pulsed DC voltage. The domestic type withstands dynamic load between (300-1200 lbs.), this load is suitable for rotating five panels.

3.3.2. controller and real-time clock (RTC)

Arduino Uno is the most widely microcontroller board for such experiment due to the simplicity of programming, availability and configurable with many other solutions [18]. RTC is design to keep the current clock time [19], this will be important to state the calendar date and time within relevant formula. Thus, both solar altitude and azimuth angle can be determined.

4.EXPERIMENTAL, RESULT AND DISCUSSION

Domestic solar plant is installed in Kirkuk city/Iraq with invertor capacity 3 kW, hybrid module. 10 PV panel has been used with power capacity (330 w for each solar panel). The solar panels are set into to two parallel groups (5 PV panel to each side) as it is shown in Fig. (2, 3) for different times. The group of panels are rotated as the same time by satellite dish actuator with 18" stroke length. Due to area limitation for PV panel place the distance between each row of the panels was around 65 Cm. This distance has limit solar power generation during early morning or close to sunset [20]. This constrain is coming out from partial shade of adjacent PV panel during the rotation and low altitude angle. A heuristic method is applied to find optimum altitude angle for lunching the panel's rotation. (180-230) altitude angle was a starting and ending point for servo motor to operate over this interval. Otherwise, the panels are direct to solar noon position.

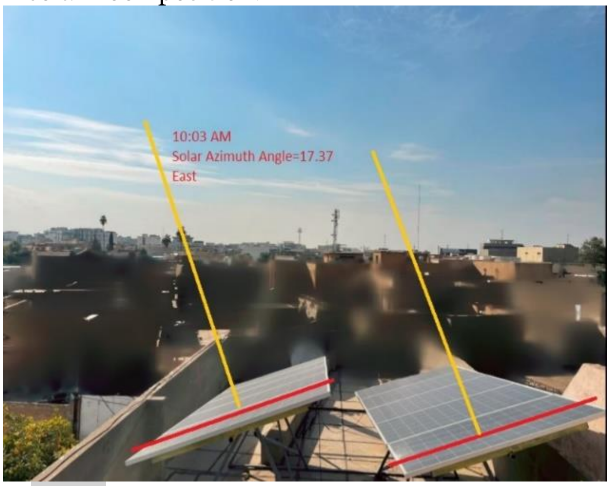

Fig. 2. Pv panels set in two rows and track the sun position before noon time.

Fig. 3. Pv panels set in two rows and track the sun position at noon time.

The servo motor stroke has been adjusted regarding to the azimuth angle. Nine panel positions have been selected with regard of solar position. The relation between the length of motor stroke and azimuth angle is shown as in Table 1. Running the servomotor and assigning the starting and ending point is operate according to two factors: shading angle and seasonality.

Table 1 Set of Azimuth angle vs stroke length

Direction	Azimuth angle	Stroke length Cm
	75 °	0
	60 °	4.5
East	45 °	9
	30 °	13.5
	15 °	18
Solar Noon	0 °	22.5
	-15 °	27
	-30 °	31.5
West	-45 °	36
	-60 °	40.5
	-75 °	45

In order to avoid partial shade for the back-row PV panel as shown in Fig. 4, the altitude angle is determined between 18°-23° for sunrise and sunset sides. Accordingly, it is selected as a starting and ending point for the tracker. The sun ray angle is changed over the four seasons, the longest and influences period can be occurred in winter season. One of the solutions was decided to delay the motor during morning and evening time. Fig. 5. present the azimuth angle regarding to time that calculated on December. For example, the azimuth angle reaches to around 23 ° at 8:30 Am. Utilization period for using this tracker was around (7.5 Hours).

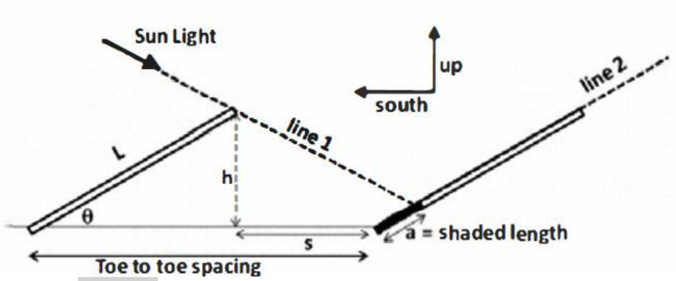

Fig. 1. partial shaded effectiveness on the lower part of back line PV panels.

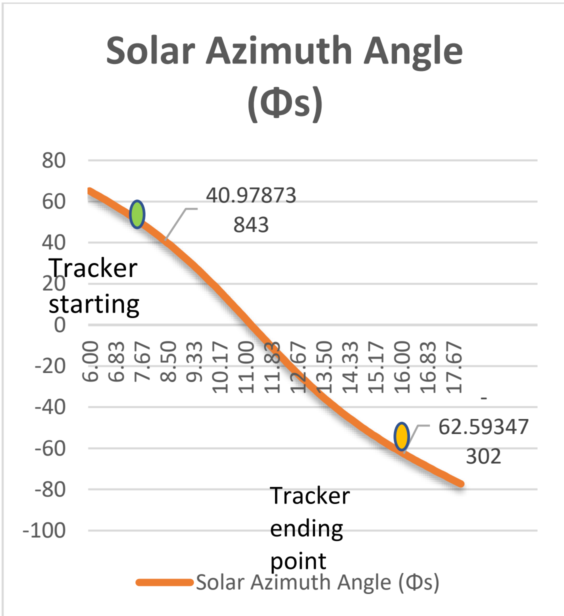

Fig. 2. Calculated azimuth angle regarding to time for December 2021.

Fig. 6 is the comparison of generated power between fixed and turned PV panel. The used invertor has Maximum power point tracker that able to maximize the energy and increasing the profitability. Nevertheless, it is obvious that power harvesting is enhance furthermore and it is deeply influenced by directing the PV panel. A positive power offset is appeared over two main periods especially between the solar noon times. The impact can have around 350 watt of power harvesting for the mentioned plant capacity.

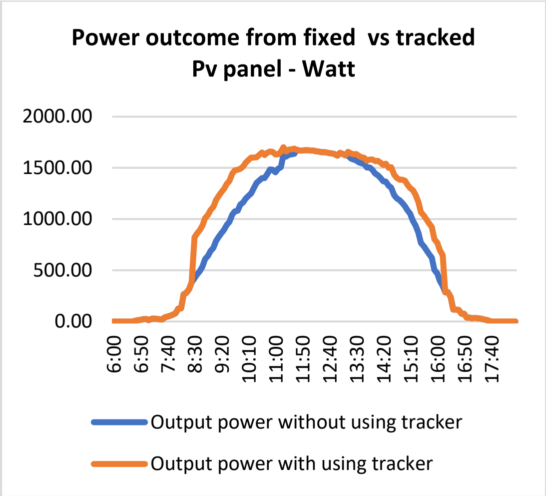

Fig. 3. Generated power outcome for fixed and turned PV panel, Blue line represent power generate from fixed panel, red line present enlarging of energy by using the tracker.

5. CONCLUSION

Synthesis formula of astronomical sun position is used and applied in this study. The application approved practically with rotating 10 panels that distributed in two rows. Power generation for total one day is measured to figure out their efficacy. Fix and rotate PV panel structures produce 9.9 kWh/day and 11.61 kWh/day respectively. The total power gain was 17.3 % by using horizontal solar tracker. Front line panels shade the lower part of back line panel at sunrise and sunset, the shade area is considered as an energy loss for period between 2-3.5 hours on daily basis that change up on seasonality and sun ray inclination. Delaying the starting point of tracker movement at morning and evening is one of the empirical and fast solution to avoid annually losing 2-4.5% of power through shading. Tracker operation is deactivated during occurring partial sun irradiance shading on the back-line panels. 23o and 153o were the altitude angle that selected to be starting and ending point of tracker operation respectively.

REFERENCES

[1] Mohammed ZS, Mohammed GA. **Prediction of solar direct irradiance in Iraq by using artificial neural network**. *Zanco Journal of Pure and Applied Sciences*, 2021;**33**(4):43-50.

[2] Zhu Y, Liu J, Yang X. **Design and performance analysis of a solar tracking system with a novel single-axis tracking structure to maximize energy collection**. *Applied Energy*, 2020;**264**:114647.

[3] Munanga P, Chinguwa S, Nyemba WR, Mbohwa C. **Design for manufacture and assembly of an intelligent single axis solar tracking system.** *Procedia CIRP*, 2020;**91**:571-576.

[4] Martín-Martínez S, Cañas-Carretón M, Honrubia-Escribano A, Gómez-Lázaro E. **Performance evaluation of large solar photovoltaic power plants in Spain**. *Energy conversion and management,* 2019;**183**:515-528.

[5] Du X, Li Y, Wang P, Ma Z, Li D, Wu C. **Design and optimization of solar tracker with U-PRU-PUS parallel mechanism**. *Mechanism and Machine Theory,* 2021;**155**:104107.

[6] Prinsloo G, Dobson R. **Combined solar heat and power with microgrid storage and layered smartgrid control toward supplying off-grid rural villages.**, 2015;**3**:135-144.

[7] Saputra ID, Sajayasa IM, Suryawan IK, Sugirianta I, Purbhawa IM, Putra IME. **A New Approach in Controlling A Single Axis Solar Tracker Based on Photovoltaic Output.** 7th International Conference on Electrical, Electronics and Information Engineering (ICEEIE). Malang, Indonesia. : IEEE; 2021. p. 49-53.

[8] Fahad HM, Islam A, Islam M, Hasan MF, Brishty WF, Rahman MM. **Comparative analysis of dual and single axis solar tracking system considering cloud cover.** International Conference on Energy and Power Engineering (ICEPE). Dhaka, Bangladesh.: IEEE; 2019. p. 1-5.

[9] Wei C-C, Song Y-C, Chang C-C, Lin C-B. **Design of a solar tracking system using the brightest region in the sky image sensor.** *Sensors*, 2016;**16**(12):1995.

[10] Sharma P, Malhotra N. **Solar tracking system using microcontroller.** 2014 1st International Conference on Non-Conventional Energy (ICONCE 2014). Kalyani, India: IEEE; 2014. p. 77-79.

[11] Ngo XC, Nguyen TH, Do NY, Nguyen DM, Vo D-VN, Lam SS, Heo D, Shokouhimehr M, Nguyen V-H, Varma RS. **Grid-connected photovoltaic systems with single-axis sun tracker: case study for Central Vietnam**. *Energies* 2020;**13**(6):1457.

[12] Fuke P, Yadav AK, Anil I. **Analysis of Fixed, Single and Dual-Axis Tracking Solar PV System**. 9th Power India International Conference PIICON: IEEE 2020. p. 1-6.

[13] Meeus J. **Astronomical Algorithms 2nd ed.** Richmond, Va: Willmann-Bell; 1998.

[14] Kher V, Sharma S, Santhosh H, Manoj N, Yogesh O, Bhinge NA. **Scheduled single axis solar tracker system for improvisation of energy efficiency**. 2022 4th International Conference on Smart Systems and Inventive Technology (ICSSIT). Tirunelveli, India IEEE; 2022. p. 787-791.

[15] Ahmed R, Oh SJ, Mehmood MU, Kim Y, Jeon G, Han HJ, Lim SH. **Computer vision and photosensor based hybrid**

control strategy for a two-axis solar tracker-Daylighting application. *Solar Energy*, 2021;**224**:175-183.

[16] Goswami DY. **Principles of solar engineering**. 3rd ed. Hoboken: CRC Press; 2015.

[17] Ayamolowo OJ, Manditereza P, Kusakana K. **Investigating the potential of solar trackers in renewable energy integration to grid**. Journal of Physics: Conference Series. South Africa: IOP Publishing; 2021. p. 012031.

[18] Alijanov DD, Topvoldiyev N. **Solar tracker system using arduino**. *Theoretical & Applied Science,* 2021;**101**:249-253.

[19] Wu C-H, Wang H-C, Chang H-Y. **Dual-axis solar tracker with satellite compass and inclinometer for automatic positioning and tracking**. *Energy for Sustainable Development*, 2022;**66**:308-318.

[20] Thakkar N, Cormode D, Lonij VP, Pulver S, Cronin AD. **A simple non-linear model for the effect of partial shade on PV systems.** 35th IEEE Photovoltaic Specialists Conference. 2010, Jun; Honolulu, HI, USA: IEEE; p. 002321-002326.