

## Improving Photovoltaic Panel (PV) Efficiency via Two Axis Sun Tracking System

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### ABSTRACT

In this paper two axis sun tracking method is used to absorb maximum power from the sun's rays on the solar panel via calculating the sun's altitude and azimuth angles, which describe the solar position on the Iraqi capital Baghdad for the hours 6:00, 7:00, 8:00, 9:00, 12:00, 15:00 and 17:00 per day. The angles were calculated in an average approach within one month, so certain values were determined for each month. The daily energy achieved was calculated for the solar tracking method compared with the fixed tracking method. Designed, modeled and simulated a control circuit consisting of reference position truth table, PI Controller and two servomotors that tracked the sun position to adjust the PV panel perpendicular on the rays of the sun. The results obtained by a simulation software MATLAB/Simulink.

**Keywords:** Solar Panel, Renewable Energy, PI Controller, Servomotors, MATLAB/Simulink.

### تحسين كفاءة الألواح الكهروضوئية عن طريق نظام تتبع الشمس ذو المحورين

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### الخلاصة

في هذا البحث أتمدت طريقة تتبع أشعة الشمس بمحورين وذلك لإمتصاص أقصى قدرة من الإشعاع الشمسي المسلط على اللوح الشمسي وذلك من خلال حساب زواياة الإرتفاع وزواياة الأفق التان تحددان موقع الشمس في العاصمة العراقية بغداد للساعات 6:00, 7:00, 8:00, 9:00, 12:00, 15:00 و 17:00 خلال يوم واحد. علماً أن الزوايا محسوبة بطريقة المعدل الحسابي خلال شهر كامل، أي أنه كل شهر تكون فيه زوايا محده لكل هذا الشهر. حيث تم حساب كسب الطاقة اليومية المتحقق نتيجةً لمنظومة التعقب الشمسي ومقارنته مع الطاقة الناتجة من المنظومة الأفقية الثابتة. لقد تم تصميم ونموذجة ومحاكاة دائرة السيطرة المتألفة من جدول يمثل الموقع المطلوب للوح

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الشمسي ومتحكم PI ومحركان نوع سيرفو وذلك لتعقب موقع الشمس بحيث يكون الإشعاع الشمسي عمودياً على اللوح الشمسي. جميع النتائج وجدت باستخدام برنامج ماتلاب/سيميونك.  
الكلمات الرئيسية: الألواح الشمسية، الطاقات المتجددة، متحكم PI، محركات سيرفو، ماتلاب/سيميونك.

## 1. INTRODUCTION

Due to the increasing demand for renewable energy resources because it is environmentally friendly as it reduces greenhouse gas emissions and reduces the dependence on fossil fuel energy generation and thus in the future lead to increased reliance on renewable energies at the expense of energies generated by other traditional methods.

One of the best sources of renewable energy is solar energy, especially for a country such as Iraq because it is almost continuous throughout the four seasons of the year and it is free and high quality. Also the vast land in this country, which can be grown with huge number of solar panels. The photo voltaic (PV) panels converts solar radiation into DC electrical power and the amount of this real power generated depends on the intensity of the solar radiation falling on the unit area of the PV, which changes with respect to (W.R.T) sun angles from sunrise to sunset. Therefore, the efficiency of fixed PV panels is less than tracking panels because the solar panel produces maximum output energy when the sun is vertical on it (Mishra, et al., 2017).

For this reason, this research is interested in tracking the sun to increase the efficiency of the solar panel.

In (Neville, 1978) a comparative study made between one axis tracking and fixed collectors. That showed there is around 50% declination in the maximum performance of a fixed collector. However, it is 10% for the axis-tracking panel. Although (Hartley, et al., 1999) founded the optimum tilt angle of the collectors in Valencia, Spain.

(Alata, et al., 2005) showed two axis tracking method that tracks the sun angles by using IF-THEN fuzzy control method. Whereas reference (Chin, et al., 2011) showed single axis tracker sensed by two (LDR) sensors, which positioned on the external surface of the PV panel. But (Bawa and Patil, 2013) produced sun-tracking system depend on Arduino and LDR except it presents the fuzzy logic control and maximum power point tracking (MPPT).

(Al-Najjar, 2015) showed the comparative study of using tilting tracking and fixed horizontal tracking method for 8 month in Baghdad city. The tilting angle was adjusted every day, but the azimuth angle still constant. It showed that the using of tilting method is more effective at winter with maximum energy gain at winter/February. However, the average insolation was (910) W/m<sup>2</sup> by tilting method and (713) W/m<sup>2</sup> at fixed horizontal method. In (Mishra, et al., 2017) the active tracking was presented, the tracking system was built on Arduino UNO and used of the light-dependent-resistor LDR and a stepper motor which allows accurate tracking of the sun.

All (Mishra, et al., 2017), (Bawa and Patil, 2013) and (Chin, et al., 2011) papers are active sun tracker. This type of tracking is depending on the sensors quality that are affected with heat, humidity or corrupted by any external cause (Hashim and Husien, 2016).

This paper depends on the computational method of calculating the altitude and azimuth angle of the sun position during all seasons for Baghdad city. These calculated angles will be database of the sun position that shines on Baghdad to the later researchers and this paper showed comparative results of the sun irradiances between the fixed panel and two axis-tracking panel. The two-axis tracking method is based on two servomotors with efficient and simple control circuit.

## 2. PV MODULE

To know the electronic performance of a solar cell it is important to know the PV module equivalent circuit and the output current equation where the equivalent circuit is shown in **Fig. 1**.

While Eq. (1) represents the output current equations (characteristics equations) (Bawa and Patil, 2013) , (Ozcelik, et al., 2011) , (Jackson, 2008)

$$I = I_L - I_D - I_{SH} \tag{1}$$

$$I_D = I_0 \left( \exp \left( \frac{q V_D}{n_d k T} \right) - 1 \right) \tag{2}$$

$$I_{SH} = \frac{(V + R_s I)}{R_{SH}} \tag{3}$$

As a result, the characteristics equation is as follows:

$$I = I_L - I_0 \left( \exp \left( \frac{q V_D}{n k T} \right) - 1 \right) - \frac{(V + R_s I)}{R_{SH}} \tag{4}$$

Eq. (4) produces the voltage current (V-I) curve of the PV as shown in Fig. 2.

It is clear from Eq. (4) that the PV current is mainly depend on photo current which is based on sun irradiance( $w/m^2$ ) (Jackson, 2008). For this reason, it is important to track the sun to increasing the PV efficiency.

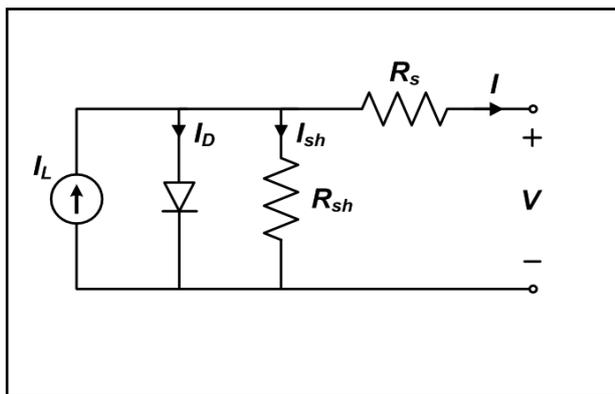


Figure 1. PV equivalent circuit.

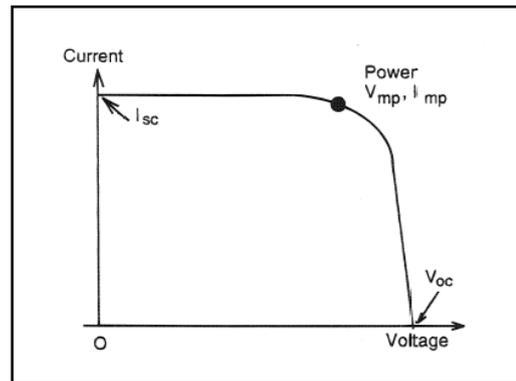


Figure 2. V-I curve of PV.

### 3. TYPES OF SUN TRACKERS

#### 3.1 Active Trackers

This type of trackers are made by using microcontroller which receives the signal from sensing element that monitors the sun’s location during the day like LDR then drive the motor to adjust the PV panel position. (Mishra, et al., 2017), (Bawa and Patil, 2013), (Chin, et al., 2011), (Otieno, 2015).

#### 3.2 Sun Trackers Based on Solar Geometry

These trackers depend on the fact that the earth rotation about itself and around the sun is constant, hence the sun angles can easy calculated. Therefore, by knowing these angles, the sun can be tracked from specific location regardless the presence of sun rays. Therefore, this type of tracking is simple and accurate (Ozcelik, et al., 2011), (Alata, et al., 2005), (Otieno, 2015), (Maleki, et al., 2017).

### 4. SOLAR ANGLES

The position of the sun differs at all the time depend on the earth rotation around itself and around the sun. To understanding and calculating these angles there are some important identifies as follows:

**4.1 Solar Time:** it is the time of the real position of the sun. This means it differs between a few kilometers east or west while the clock time (local standard time) is the same (Alata, et al., 2005), (Duffie and Beckman, 1980). The difference between these two times is known as the equation of time (E) (Ozcelik, et, al., 2011), (Alata, et al., 2005), (Maleki, et al., 2017).

$$E = 229.2(0.000075 + 0.001868\cos B - 0.032077\sin B - 0.014615\cos 2B - 0.04089\sin 2B) \tag{5}$$

Where:

$$B = (n - 1) \frac{360}{365} \quad \text{for} \quad (1 \leq n \leq 365) \tag{6}$$

To get the solar time from the local standard time, the following equations is used.

$$t_s - t_1 = 4(L_{st} - L_{10c}) + E \tag{7}$$

**4.2 Hour Angle (w):** it is angle represents a time in terms of degrees instead of minutes where one degree for four minutes. This means fifteen degrees for one hour and it is positive after solar noon and negative before it as shown in Fig. 3. It expresses as follows.

$$w = 15(t_s - 12) \tag{8}$$

**4.3 Declination Angle (δ):** is the angular location of the sun south or north of the equatorial plane as shown in Fig. 4 and states as follows.

$$\delta = 23.5 \sin \left( 360 \frac{284+n}{365} \right) \tag{9}$$

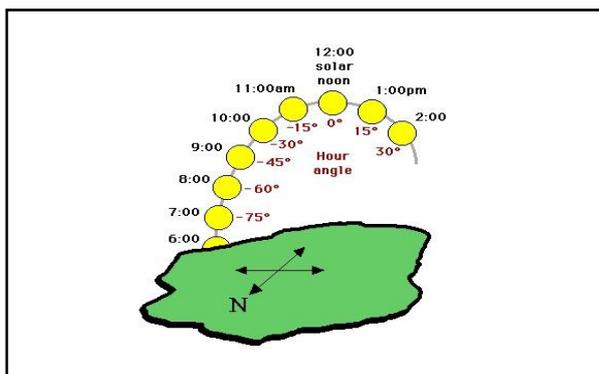


Figure 3. Hour angle.

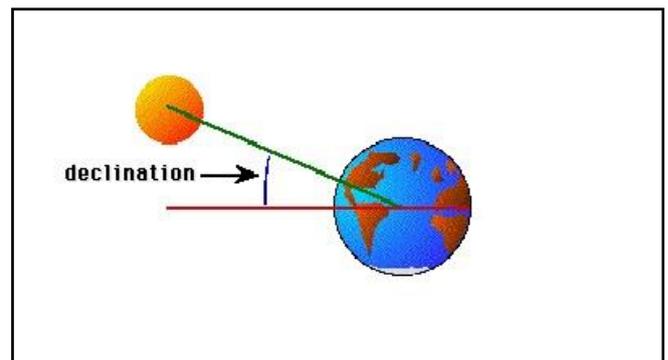


Figure 4. Declination angle.

**4.4 Altitude Angle (α):** it is the angle between the horizontal plane and the direct rays of the sun as shown in Fig. 5.

**4.5 Zenith Angle (Θ<sub>z</sub>):** is (90°-α) in other wards the angle between the vertical line and the direct rays of the sun.

$$\alpha = \sin^{-1}(\sin\delta \sin\phi + \cos\delta \cos\phi \cos\omega) \tag{10}$$

$$\theta_z = 90 - \alpha \tag{11}$$

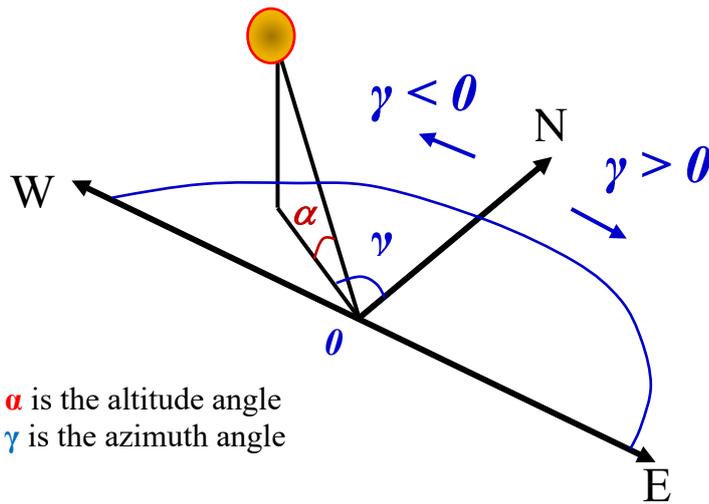
**4.6 Azimuth Angle ( $\gamma$ ):** it is the angle that calculated clockwise from the north coordinate axis to the sun central rays as shown in **Fig. 5 (Otieno,2015), (Ozcelik, et, al., 2011), (Alata, et al., 2005), (Chin, et al., 2011)**.

$$\gamma' = \sin^{-1}\left(\frac{-\cos\delta \sin\omega}{\cos\alpha}\right) \tag{12}$$

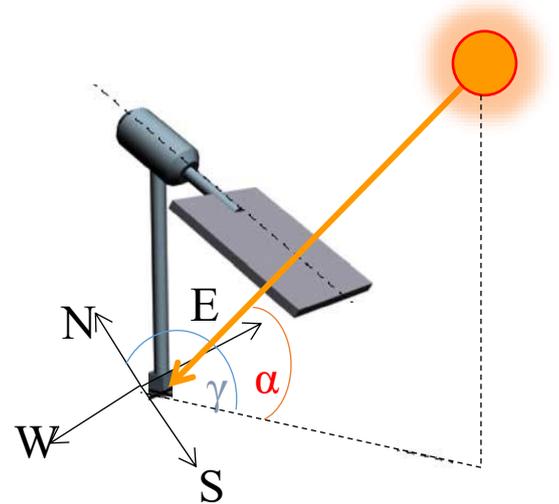
If:

$$\cos\omega \geq \frac{\tan\delta}{\tan\phi}; \text{ then } \gamma = 180 - \gamma' \tag{13}$$

$$\text{Else } \gamma = 360 + \gamma' \tag{14}$$



**Figure 5.** Altitude and azimuth angle w.r.t. horizontal plane



**Figure 6.** Sun tracking by PV panel

Therefore, the sun-tracking can achieved by considering the altitude and azimuth angles as a references position of the two servomotors, which adjust the PV panel position perpendicular to the sun rays at all time as shown in **Fig.6**.

**5. CALCULATING CLEAR SKY INSOLATION**

The direct insolation (H) applied on a two axis tracking PV panel with known latitude, altitude over the sea level and the time can be calculated by the following the equation (**Ozcelik, et, al., 2011), (Hu and White, 2009)**.

$$H = K \times 0.7^{M^{0.678}} \tag{15}$$

Where K and M are:

$$K = 1373(1 + 0.0033\cos(\frac{2\pi(n+10)}{365.25})) \tag{16}$$

$$M = (\frac{1}{\cos\theta_z} + 0.15(3.885 + \theta_z)^{-1.253})\exp(-0.0001184 \times \text{Altitude}) \tag{17}$$

While the insolation with respect to horizontal plate (Mohamed, et al., 2017) is given by:

$$H = 1360 \times 0.7(\frac{1}{\sin\alpha}) \times \sin\alpha \tag{18}$$

### 6. POSITION CONTROL CIRCUIT

The general block diagram of the position control circuit is shown in Fig. 7 which compares the  $\alpha, \gamma$  reference position with the current position then the error signal enters PI controller to adjust the location of the PV panel via DC servomotors.

The proposed system tracks the sun position at 6, 7, 8, 9, 12, 15 and 17 time o'clock. This means long period of time between the previous and the next position, where one hour is the minimum period. Therefore, the PI controller is more suitable choice than PID controller when the speed of the system isn't an issue (Rao, 2013).

The speed of the motors are proportional to error signal. Consequently, when the motor is near enough the wanted position, it move slowly. Else, it turns fast where this is a proportional control.

The advantages of using servomotors among others type of motors are its holding torque, has 90% of the rated torque at high speeds, quiet, no vibrations, their high efficiencies and it supplies about double their rated torque for short time (Otieno, 2015), (Luque and Andreev, 2007).

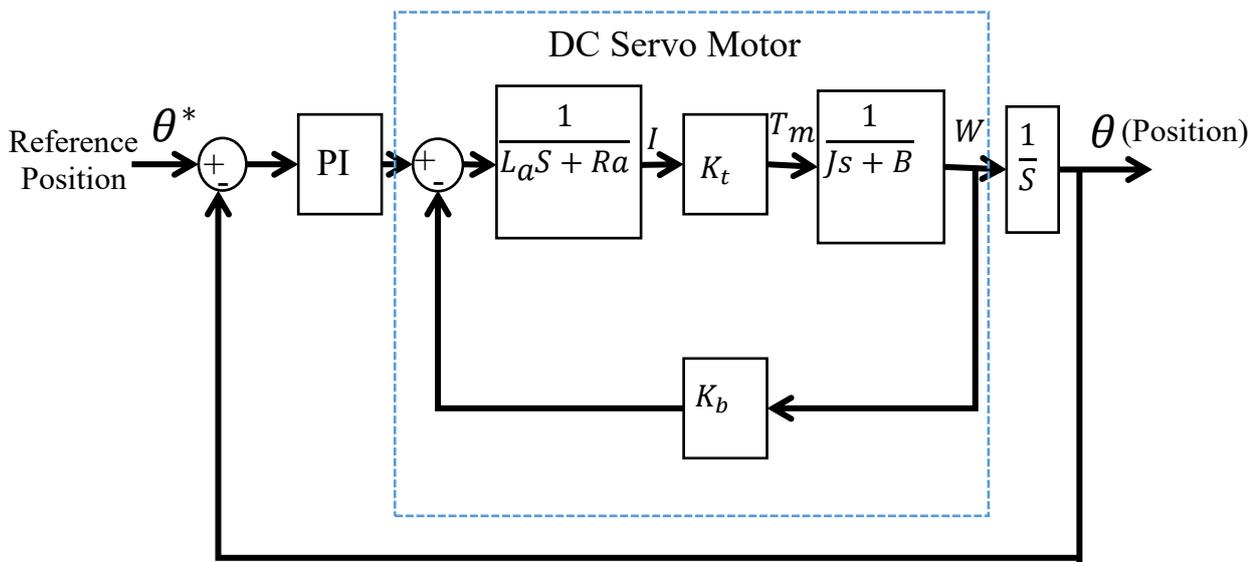


Figure 7. Position control block diagram of DC servo motor



### 7. SIMULATION AND RESULTS

The location of Baghdad capital of Iraq was studied, where the altitude over the sea level is (34) meters, latitude is (33.312805) and longitude is (44.361488) for 6:00, 7:00, 8:00, 9:00, 12:00, 15:00, 17:00 time o'clock in all the four seasons. So as to find the insolation on two axis tracking PV panel and fixed PV panel in addition to the angles  $\alpha$ ,  $\gamma$ ,  $\Theta_z$ . A program is written using MATLAB/Simulink software (appendix A&B).

**Fig. 8** and **Fig.9** show the variation of the altitude angles along the year for example at 12:00 o'clock in winter/December it reaches its minimum value  $33^\circ$  then increases slightly until arrives to spring/March  $53^\circ$  next continues directly increasing to reaches its maximum rate at summer/June  $80^\circ$  lastly decreasing to  $37^\circ$  at autumn/November. These measurements explained intensively in **Table 1**.

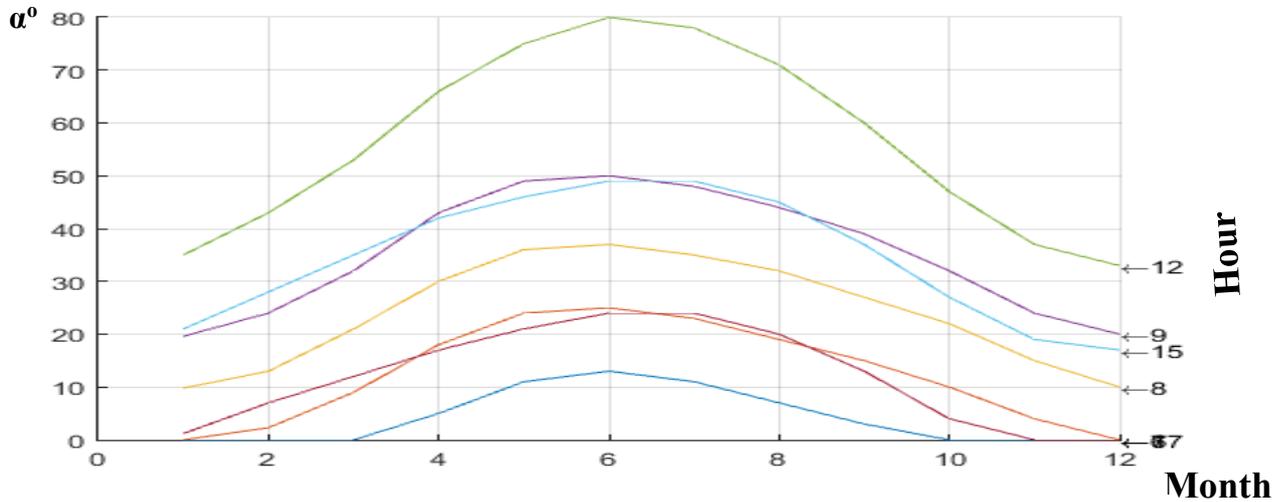


Figure 8. 2D Variation of altitude angle w.r.t. the month and hour.

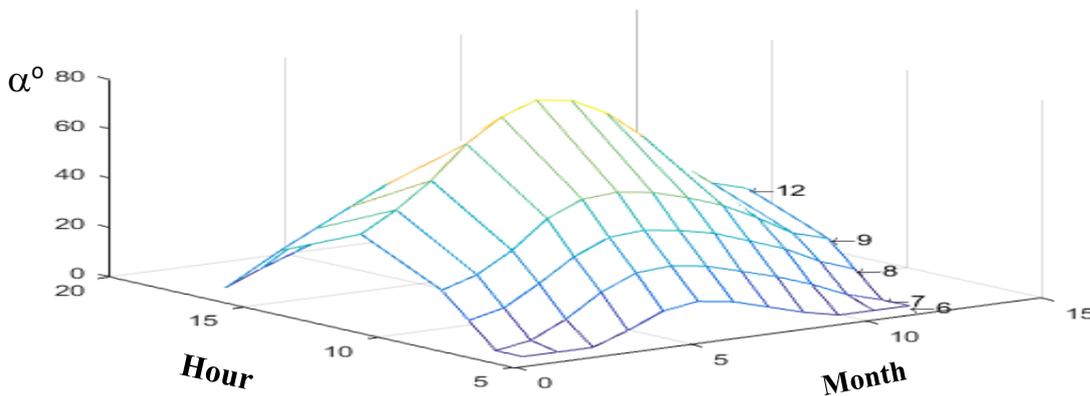


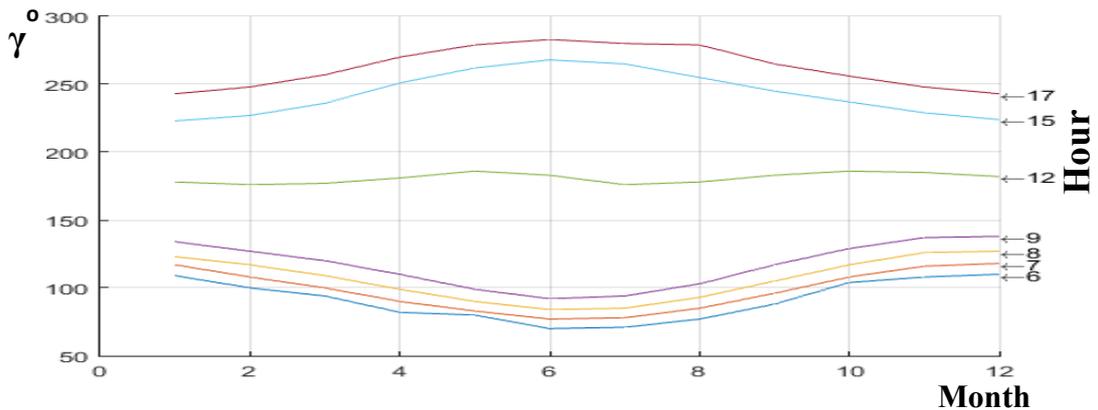
Figure 9. 3D variation of altitude angle w.r.t. the month and hour.



**Table 1.** Lookup Table of altitude angle  $\alpha$  at Baghdad.

Season	Hour \ Month	6	7	8	9	12	15	17
	Winter	12	0	0	10	20	33	17
1		0	0	9.8	19	35	21	1.2
2		0	2.3	13	24	43	28	7
Spring	3	0	9	21	32	53	35	12
	4	5	18	30	43	66	42	17
	5	11	24	36	49	75	46	21
Summer	6	13	25	37	50	80	49	24
	7	11	23	35	48	78	49	24
	8	7	19	32	44	71	45	20
Autumn	9	3	15	27	39	60	37	13
	10	0	10	22	32	47	27	4
	11	0	4	15	24	37	19	0

While the **Table 2.** show the range of variation of azimuth angle at deferent seasons from the east to the west and its draw w.r.t. month and hour is shown in **Fig. 10** and **Fig. 11**. The smallest range in winter about  $133^\circ$  whereas increases at spring to  $181^\circ$  then becomes maximum at summer  $213^\circ$  and again decreases to  $177^\circ$  at autumn.



**Figure 10.** 2D variation of azimuth angle w.r.t. the month and hour.

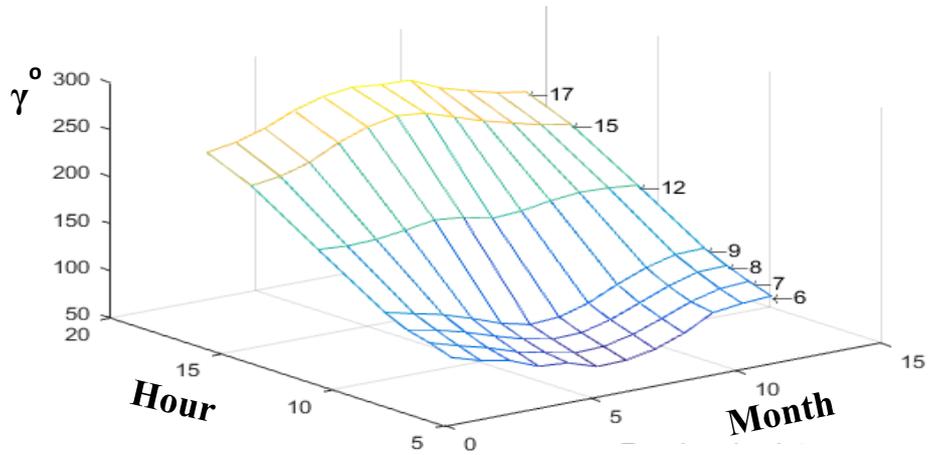


Figure 11. 3D variation of azimuth angle w.r.t. the month and hour.

Table 2. Lookup Table of azimuth angle  $\gamma$  at Baghdad.

Season	Hour \ Month	6	7	8	9	12	15	17
	Winter	12	110	118	127	138	182	224
1		109	117	123	134	178	223	243
2		100	108	117	127	176	227	248
Spring	3	94	100	109	120	177	236	257
	4	82	90	99	110	181	251	270
	5	80	83	90	99	186	262	279
Summer	6	70	77	84	92	183	268	283
	7	71	78	85	94	176	265	280
	8	77	85	93	103	178	255	279
Autumn	9	88	96	105	117	183	245	265
	10	104	108	117	129	186	237	256
	11	108	116	126	137	185	229	248



Fig.'s 12, 13, 14 and 15 show the sun irradiances (w.r.t.) time during the day uses a fixed tracking at winter, spring, summer and autumn seasons respectively. These calculations was done w.r.t. horizontal plane according to Eq. (18). Where it shows that, the sun irradiances increases at the beginning of sun rise even arrives its maximum point at 12:00pm o'clock for each season. Then reduced to zero at sunset because the altitude angle increases during the beginning of the period of sunrise even 12:00pm o'clock, but decreases during the 12:00pm o'clock to the sunset. However, it has the best value at summer/June 12:00pm o'clock, which is the value equal to 950  $w/m^2$  because the altitude angle is high and the worst value at 12:00pm o'clock in winter, which is equal to 420  $w/m^2$ , because the altitude angle is low.

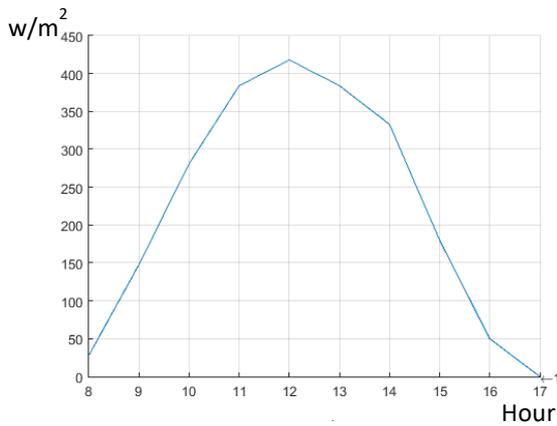


Figure 12. Sun irradiances variation during one day in winter w.r.t. horizontal plane

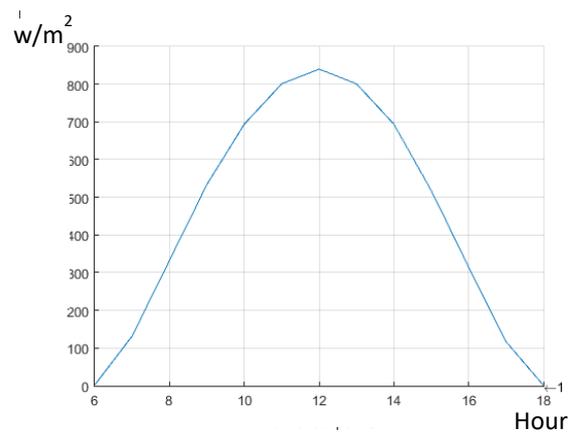


Figure 13. Sun irradiances variation during one day in spring w.r.t. horizontal plane

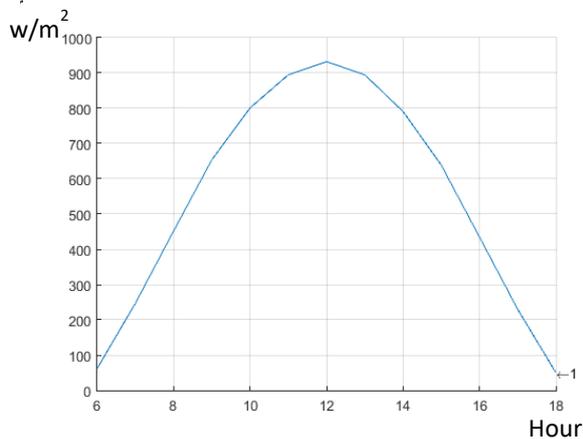


Figure 14. Sun irradiances variation during one day in summer W.R.T horizontal plane

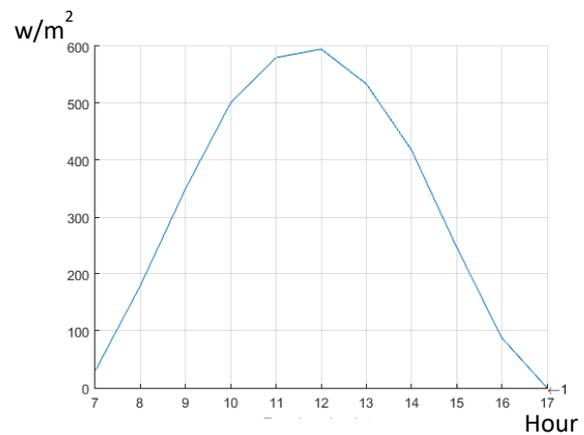


Figure 15. Sun irradiances variation during one day in autumn W.R.T horizontal plane

Fig.'s 16, 17, 18 and 19 show the improvement of sun irradiance at PV panel uses two-axis tracking. Which ensure that the position of the PV is perpendicular to the sunrays during the day and the altitude angle is  $90^\circ$  for most of the day. The results are obtained by MATLAB code explained in appendix (B), which based on Eq. (15)

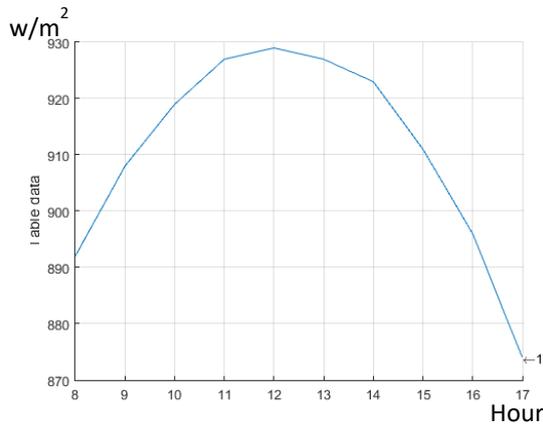


Figure 16. Sun irradiances variation during one day of winter incident on tracking PV panel

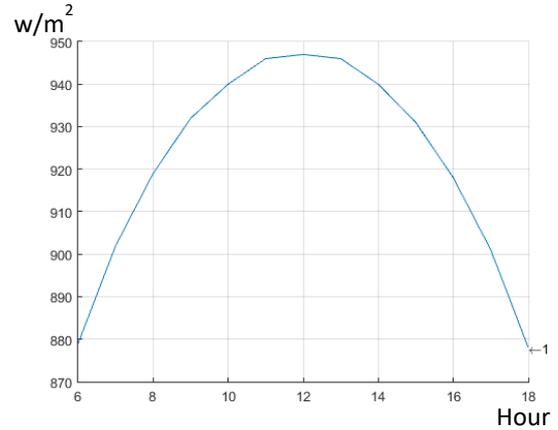


Figure 17. Sun irradiances variation during one day of spring incident on tracking PV panel

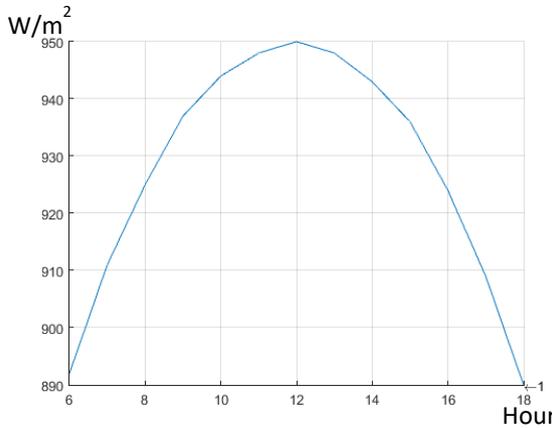


Figure 18. Sun irradiances variation during one day of summer incident on tracking PV panel

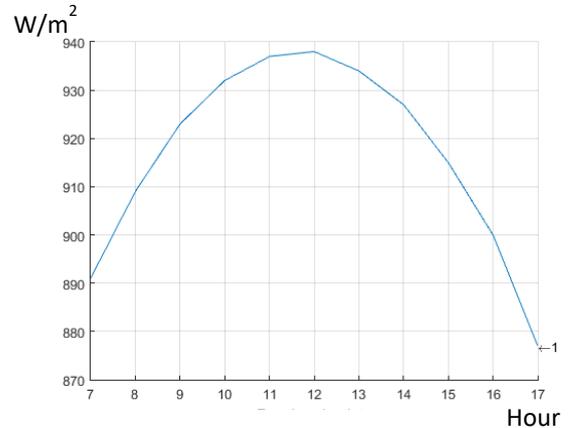


Figure 19. Sun irradiances variation during one day of autumn incident on tracking PV panel

Consequently, the energy gain at different season via two axes tracking system can be calculated according to Eq. (19). It expresses as below:

$$\text{Saving daily energy} = (\text{the daily energy of the two axes tracking system}) - (\text{the daily energy of a fixed tracking system w.r.t. horizontal plane}) \quad (19)$$

In general, the daily energy was found in a linear approximation method as expression below:

$$\text{Daily energy} = \{(\text{irradiance at 5 o'clock (W/m}^2) \times 1 \text{ hour}) + (\text{irradiance at 6 o'clock (W/m}^2) \times 1 \text{ hour}) + \dots + (\text{irradiance at 17 o'clock (W/m}^2) \times 1 \text{ hour})\} \quad (20)$$



**At Summer:**

The data of sun irradiance for the two axis tracking system and a fixed tracking system at summer was taken from **Fig.14** and **Fig. 18** respectively. As illustrated in **Table. 3**.

**Table. 3** Sun’s irradiance applied on the two axis tracking system and a fixed tracking system at summer season.

Hour	6	7	8	9	10	11	12	13	14	15	16	17
Irradiance (KW/m <sup>2</sup> ) of tracking system	892	911	925	937	944	948	950	948	943	936	924	909
Irradiance (KW/m <sup>2</sup> ) of a fixed system	62	247	452	654	801	895	932	895	791	639	435	230

$$\text{Saving daily energy} = \{ (892 \times 1 + 911 \times 1 + 925 \times 1 + 937 \times 1 + 944 \times 1 + 948 \times 1 + 950 \times 1 + 948 \times 1 + 943 \times 1 + 936 \times 1 + 924 \times 1 + 909 \times 1) - (62 \times 1 + 247 \times 1 + 452 \times 1 + 654 \times 1 + 801 \times 1 + 895 \times 1 + 932 \times 1 + 895 \times 1 + 791 \times 1 + 639 \times 1 + 435 \times 1 + 230 \times 1) \}$$

$$\text{Saving daily energy} = \{ (11167) - (7033) \} = 4134 \text{ (Wday/m}^2\text{)} = 4.134 \text{ (KWday/m}^2\text{)}.$$

**At Winter:**

The data of sun irradiance for the two axis tracking system and a fixed tracking system at winter was taken from **Fig.12** and **Fig. 16** respectively. As illustrated in **Table. 4**.

**Table. 4** Sun’s irradiance applied on the two axis tracking system and a fixed tracking system at winter season.

Hour	6	7	8	9	10	11	12	13	14	15	16	17
Irradiance (KW/m <sup>2</sup> ) of tracking system	0	0	892	908	919	927	929	927	923	911	896	874
Irradiance (KW/m <sup>2</sup> ) of a fixed system	0	0	28	148	281	384	418	384	333	180	50	0



Saving daily energy =  $\{(8232) - (2206)\} = 6026 \text{ (Wday/m}^2\text{)} = (6.026 \text{ KWday/m}^2\text{)}$ .

**At Spring:**

The data of sun irradiance for the two axis tracking system and a fixed tracking system at spring was taken from **Fig.13** and **Fig. 17** respectively. As illustrated in **Table. 5**.

**Table. 5** Sun’s irradiance applied on the two axis tracking system and a fixed tracking system at spring season.

Hour	6	7	8	9	10	11	12	13	14	15	16	17
Irradiance (KW/m <sup>2</sup> ) of tracking system	876	902	919	932	940	946	947	946	940	931	918	901
Irradiance (KW/m <sup>2</sup> ) of a fixed system	2	132	333	534	694	801	840	801	694	518	315	117

Saving daily energy =  $\{(11098)-(5781)\} = 5317 \text{ (Wday/m}^2\text{)} = 5.317 \text{ (KWday/m}^2\text{)}$ .

**At Autumn:**

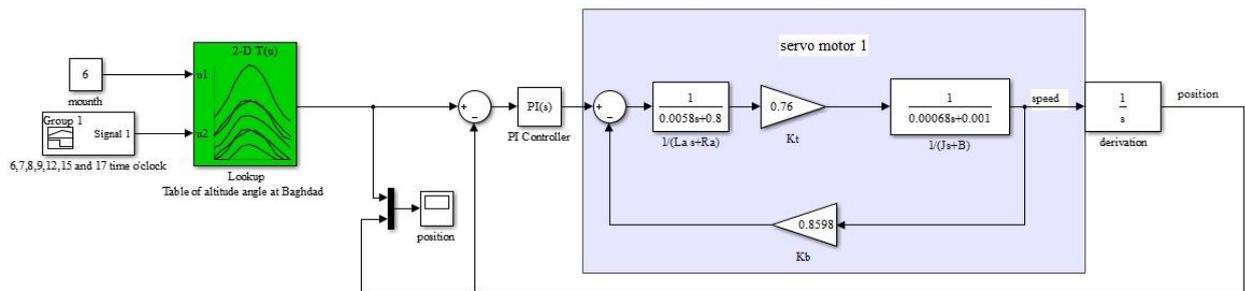
The data of sun irradiance for the two axis tracking system and a fixed tracking system at autumn was taken from **Fig.15** and **Fig. 19** respectively. As illustrated in **Table. 6**.

**Table. 6** Sun’s irradiance applied on the two axis tracking system and a fixed tracking system at autumn season.

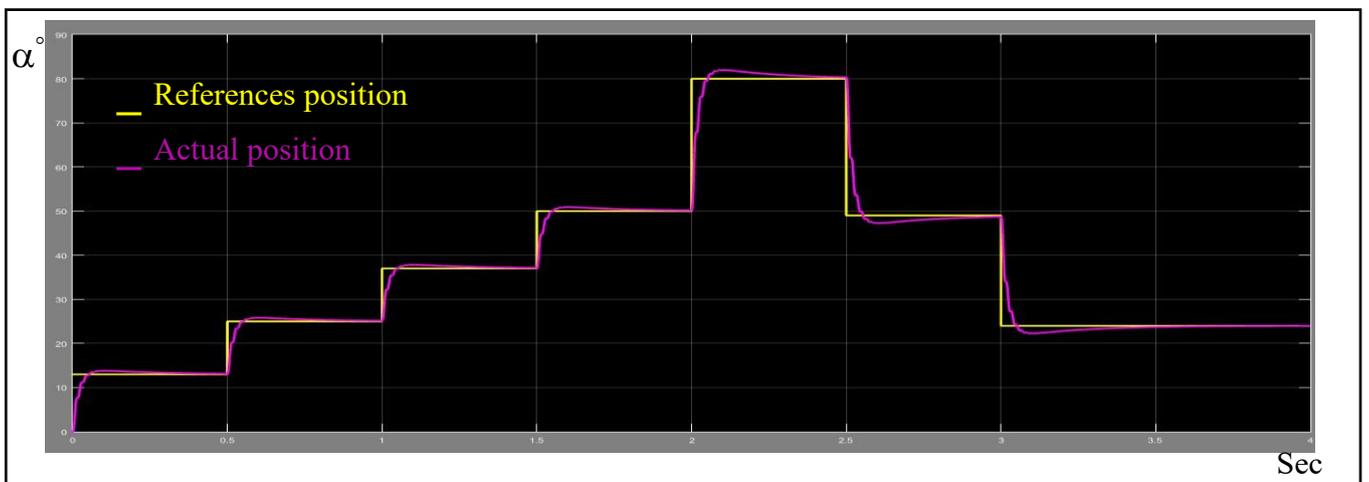
Hour	6	7	8	9	10	11	12	13	14	15	16	17
Irradiance (KW/m <sup>2</sup> ) of tracking system	0	891	909	923	932	937	938	934	927	915	900	877
Irradiance (KW/m <sup>2</sup> ) of a fixed system	0	30	180	350	501	580	595	534	418	247	88	0

Saving daily energy =  $\{(9206) - (3523)\} = 5683 \text{ (Wday /m}^2\text{)} = 5.683 \text{ (KWday/m}^2\text{)}$ .

Finally, **Fig. 20** shows the simulation module of the vertical position control using DC servo motor1, which tracks the altitude angle of the sun while the **Fig. 21** shows the reference position and the actual position of the PV panel that tracks the sun's altitude angle in summer/June. However, the **Fig. 22** shows the simulation module of the horizontal position control using DC servo motor 2 which tracks the azimuth angle of the sun in in summer/June too, while their results shown in **Fig. 23**. The proportional-integral (PI) controller was tuned by trial and error, where the proportional constant ( $k_p$ ) was equal to 45, while the integration constant ( $k_i$ ) equal to 200. The specifications of servomotors is shown in appendix (C).



**Figure 20.** Position control module of the sun's altitude angle at Baghdad.



**Figure 21.** Reference position and the actual position of the PV panel that tracks the sun's altitude angle in summer/June.

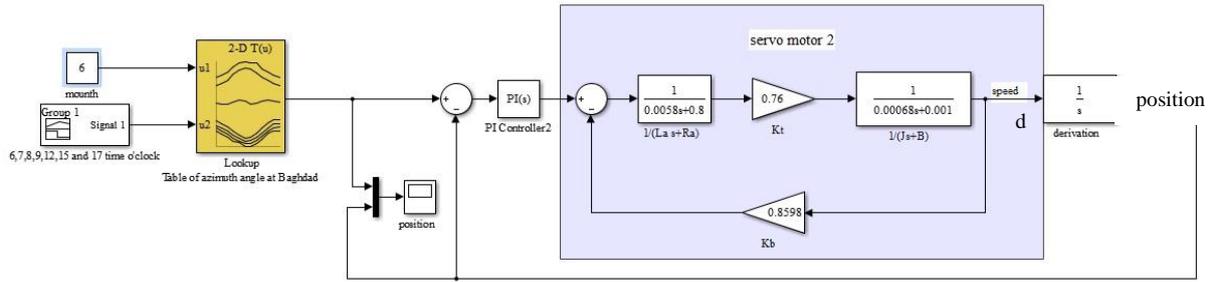


Figure 22. Position control module of the sun’s azimuth angle at Baghdad.

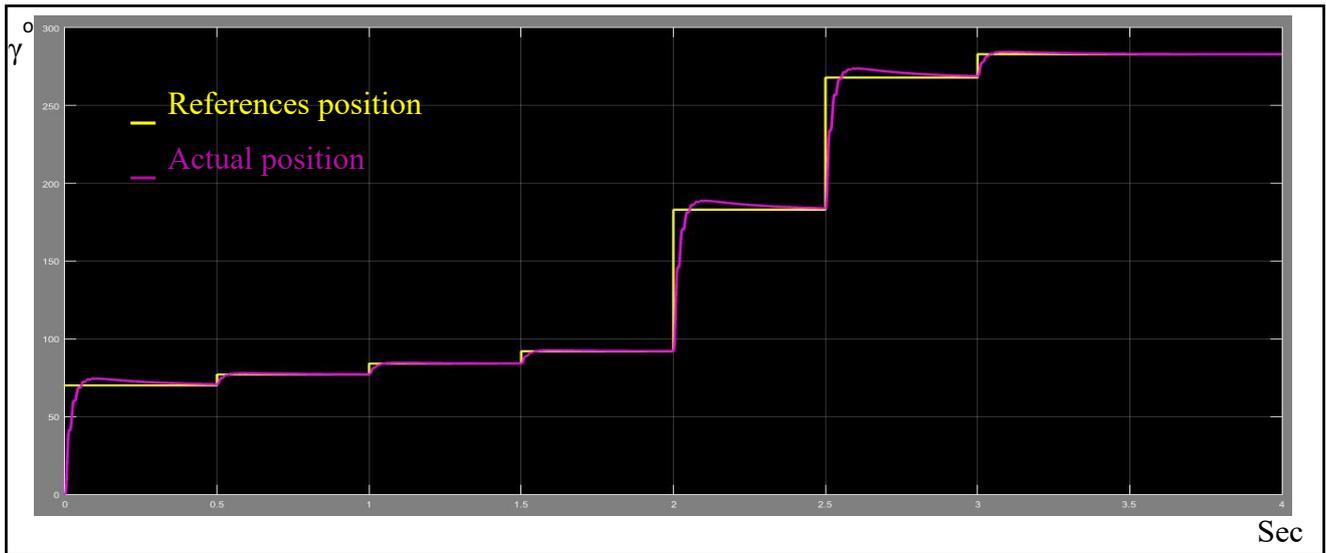


Figure 23. Reference position and the actual position of the PV panel that tracks the sun’s azimuth angle in summer/June.

**9. CONCLUSION**

The sun angles of the sun were calculated at Baghdad was varied in wide range through the year. Therefore, at fixed panel position more losses will be in active power. These positions tracked by two servomotors of the PV panel, which improved the efficiency of the PV and energy is saved during all the season, but it was bigger at winter because the altitude angle at winter had much enhancement. Where it was before tracking low around 33° at 12:00 o’clock of December, but after tracking became 90°. Therefore, it is improved than the summer. Finally, it can be concluded that large energy losses will be at the fixed PV panel position, which saved via PV panel tracking system. The position control was simple and efficient using servomotor that offers high torque at low speed controlled by PI controller that is simple and easy implemented. In addition, the sun angles that calculated in this paper could be database for other researches about sun tracker in location of Baghdad.

**NOMENCLATURE**

- b = diode ideality factor
- H = direct beam insolation (W/m<sup>2</sup>)
- I = output current of PV equivalent circuit (A)



$I_D$  = diode current  
 $I_L$  = photocurrent, A.  
 $I_0$  = reverse saturation current, A.  
 $I_{SH}$  = shunt resistive current, A.  
 $K$  = solar constant,  $W/m^2$ .  
 $k$  = Boltzmann's constant ( $1.3806503 \times 10^{-23} J/k$ )  
 $L_{loc}$  = local meridian of location, Minutes.  
 $L_{st}$  = standard meridian for local time zone, Minutes.  
 $M$  = air mass, Kg.  
 $n$  = day of the year, number.  
 $n_d$  = diode ideality factor, constant.  
 $q$  = elementary charge ( $1.60217646 \times 10^{-19} C$ )  
 $R_s$  = series resistor, ohm.  
 $R_{sh}$  = shunt resistor, ohm.  
 $T$  = absolute temperature, C.  
 $t_l$  = standard time, Minutes.  
 $t_s$  = solar time, Minutes.  
 $V_D$  = diode voltage, V.  
 $V$  = terminal voltage, V.  
 $w$  = hour angle, °.  
 $\delta$  = declination angle, °.  
 $\phi$  = latitude angle, °.  
 $L$  = longitude angle, °.  
 $\alpha$  = altitude angle, °.  
 $\Theta_z$  = zenith angle, °.  
 $\gamma$  = solar azimuth angle, °.

## REFERENCES

- Alata M., Al-Nimr M.A. and Qaroush Y., 2005. Developing a multipurpose sun tracking system using fuzzy control, *Energy Conversion and Management*, 46, pp., 1229–1245.
- Al-Najjar H.M.T, 2015. Study of Energy Gains by Orientation of Solar Collectors in Baghdad City. *Journal of Engineering*, Vol. 21, No. 10, pp. 17-35.
- Bawa D. and Patil C.Y., 2013. Fuzzy Control based Solar Tracker using Arduino Uno. *International Journal of Engineering and Innovative Technology (IJEIT)*, Vol. 2, No 12, pp. 179-186.
- Chin C.S., Babu A. and McBride W., 2011. Design, Modeling and Testing of a Standalone Single Axis Active Solar Tracker using MATLAB/Simulink. *Renewal Energy*, Vol. 36, pp. 3075-3090.
- Duffie J.A. and Beckman W.A., 1980. *Solar Engineering of Thermal Processes*. New York: John Wiley and Sons
- Hartley L., Martinez-Lorenzo J., Utrillas M., Tena F. and Pedros R., 1999. The Optimization of The Angle of Inclination of A Solar Collector to Maximize The Incident Solar Radiation. *Renew Energy*, Vol. 17, No. 3, pp. 291-309.
- Hashim E.T. and Husien T.A., 2016. Dust Effect on the Efficiency of Silicon Mono Crystalline Solar Modules at Different Tilt Angles at Al-Jadryia Climate Conditions. *Journal of Engineering*, Vol. 22, No. 2, pp. 56-73.



- Hu C., White R.M., 1983. *Solar Cell: From Basics to Advanced Systems*. New York: McGraw-Hill.
- Jackson F., 2008. *Planning and Installing Photovoltaic Systems*, A guide for installers, Berlin: The German Energy Society (Deutsche Gesellschaft für Sonnenenergie (DGS LV Berlin BRB)).
- Li H. and Zhang Y., 2010. Seven-Bar Mechanical Press with Hybrid-Driven Mechanism for Deep Drawing; Part 2: Dynamic Modeling and Simulation. *Journal of Mechanical Science and Technology*, Vol. 24, No. 11, pp. 2161-2167.
- Luque L. and Andreev V., 2007. *Concentrator Photovoltaics*, Berlin: Springer Series in Optical Sciences.
- Maleki S.A.M., Hizam H. and Gomes C., 2017. Estimation of Hourly, Daily and Monthly Global Solar Radiation on Inclined Surfaces: Models Re-Visited. *MDPI*.
- Mishra, J., Thakur, R. and Deep, A., 2017. Arduino based Dual Axis Smart Solar Tracker. *International Journal of Advanced Engineering, Management and Science IJAEMS*, Vol. 3, No.5, pp. 532-335.
- Mohamed N.A., Abdel Karim I.H. and Jassim F.H., 2017. Analysis of Monthly Rates of Direct Solar Radiation over Iraq for the Period 1900-2009. *Journal of the University of Babylon*, Vol. 25, No. 4, pp. 1352-1359. (it was written in Arabic language).
- Neville R., 1978. Solar Energy Collector Orientation and Tracking Mode. *Solar Energy*, Vol. 20, No. 1, pp. 7-11.
- Otieno O.R., 2015. *Solar Tracker for Solar Panel*, Project report, University of Nairobi.
- Ozcelik S., Prakash H. and Chaloo R., 2011. Two-Axis Solar Tracker Analysis and Control for Maximum Power Generation. *Procedia Computer Science*, Vol. 6, pp., 457-462.
- Rao V.M., 2013. Performance Analysis Of Speed Control Of Dc Motor Using P, PI, PD And PID Controllers. *International Journal of Engineering Research & Technology (IJERT)*, Vol. 2, No. 5, pp. 60-66.

## Appendices

### Appendix (A) Altitude and Azimuth Estimation Code by MATLAB/Simulink Software Program

```
function [Beta,PH] = fcn(n,h)//this code represent simulated
block in MATLAB/Simulink with two inputs n=day and h=hour and
two outputs Beta = altitude angle and PH = azimuth angle.
de=pi/180;
B=de*360*(n-1)/365;
ET=229.2*(0.000075+0.001868*cos(B)-0.032077*sin(B)-
0.014615*cos(2*B)-0.04089*sin(2*B));// equation of time
d=de*23.5*sin(de*0.9863*(284+n));
L=33.312805*de;// latitude of Baghdad
LO=44.361488;// longitude of Baghdad
LZ=3*15;
Lcorrect=4*(LZ-LO);
TLT=h+Lcorrect/60+(ET/60);
ha=de*(TLT-12)*15;
Ba=asin(sin(d)*sin(L)+cos(d)*cos(L)*cos(ha));
```



```

Beta=180*Ba/pi;
if cos(ha)>=(tan(d)/tan(L))
    PH=180-180*asin((-cos(d)*sin(ha))/(cos(Ba)))/pi;
else
    PH=360+180*asin((-cos(d)*sin(ha))/(cos(Ba)))/pi;
end

```

**Appendix (B) Sun’s Irradiances Estimation Code of Two Axes Tracking System By Matlab/Simulink Software Program**

```

function H = fcn(B,d)// this code represents simulated block in
MATLAB/Simulink to calculate the irradiances of two axis
tracking panel with two input d =day and B = altitude angle and
one output H= insolation w/m2.
K=1373*(1+0.0033*cos(2*pi*(d+10)/365.25));
rad=pi/360;
Z=90-B;// zenith angle.
M=(1/cos(Z*rad)+0.15*(3.885+Z*rad)^-1.253)*exp(0.0001184*34);
H=K*0.7^(M^0.678);

```

**Appendix (C) The Specification of DC Servo Motor (Li and Zhang, 2010)**

Rated power	3 KW
Maximum operating speed	3000 r/min
Rotor moment of inertia	$6.8 \times 10^{-4}$ kg.m <sup>2</sup>
Winding resistance	0.8 ohm
Winding inductance	5.8 mH
Motor voltage constant	0.8598 V/rad/sec
Motor torque constant	0.67 Nm/A
Continuous stall torque	10.2 Nm
Peak torque	19.7 Nm