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Original Article

Improving the Efficiency of A Solar Cell As An Alternative Renewable Energy Source Using Solar Tracker System

Khairat A. Abd Elgawad[1*]; Hesham H. Gad[1]; Ahmed. A. Hegazi[2] and Helmy E. Gad[2]

[1] *Computers and control Systems Department, Faculty of Engineering, Mansoura University, El-Mansoura, Egypt.*

[2] *Mechanical Power Engineering Department, Faculty of Engineering, Mansoura University, El-Mansoura, Egypt.*

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Abstract

Solar energy is an important energy source because of its clean and renewable nature. Nowadays, since combustion products of fossil fuels pollute environment, and conventional fossil energy sources are being depleted rapidly, the need for solar energy and its efficient utilization are increasing. Photovoltaic (PV) technology has continued to develop in recent years. Tracking technology that maximizes power output of the PV panels is just one area of improvement. In the present work, a sun full tracking PV panel is developed, implemented and tested. The control circuit of the two degree of freedom tracking system is based on a 18F452 microcontroller and uses two stepper motors. The use of stepper motors enables accurate tracking of the sun. Results of experimental tests carried out in Mansoura city, Egypt showed that the power gain of the two-axis tracking PV panel over that of the fixed is equal to 53.631 %.Furthermore, the calculated power gain of the full tracking PV panel over that of the one-axis equal to 30.57%. On other hand, the calculated power gain output of the one-axis tracking system over that of the fixed mounted was 17.65%. It has been seen that full tracking system can increase energy conversion efficiency output by more than 22%.This designed system realized precise automatic full tracking of the sun and can greatly improve the utilization of solar energy when compared to the fixed mount system.

1. Introduction

One of the most important problems facing the world today is the energy problem. This problem is a result of the increase of demand on electrical energy and rise of fossil fuel prices. Another problem in the world is that global climate warming has been increased. To face these problems, alternative technologies for producing electricity have received greater attention. The most important solution was in finding other renewable energy resources (Borenstein, 2008).

Solar energy is an important energy source because of its clean and renewable nature. Nowadays, the need

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[*] *Corresponding author:*
Tel. : +20 1000641263
E-mail address: engkhadel@gmail.com

of solar energy and its efficient utilization are increasing. Photovoltaic panels convert solar energy directly into direct current for water pumping in irrigation and power generation. The amount of electrical energy obtained from the photovoltaic systems is directly proportional to the intensity of solar radiation falling on the panel surface. In order to ensure maximum power output from PV cells, the angle of incidence solar radiation needs to be constantly perpendicular to the solar panel. Tracking technology that maximizes the power output of PV panels is just one area of improvement.

The ideal tracker would allow the PV cell to accurately be directed towards the sun, compensating for both changes in the altitude angle of the sun, latitudinal offset of the sun and changes in azimuth angle. Sun-tracking systems are usually classified into two categories: passive and active trackers.

Passive trackers (Gas trackers) use a low boiling point compressed gas fluid that is driven to one side or the other. Passive trackers are mechanically operated and the absence of electrical components makes it to function properly and have less cost comparing than active trackers (Bonda, 2008).

Active trackers use motors and gear trains to direct the tracker as commanded by a controller responding to the solar direction. Active trackers are classified into microprocessor and electro-optical sensor type, PC controlled date and time based, auxiliary bifacial solar cell based and a combination of these three systems (Camacho, 2012).

Tracking systems are classified into two classes based on their motion. They are single axis and dual axis trackers (Fadil, 2013):

Single-axis trackers have a single axis of rotation but can have either a vertical or horizontal axis; only one drive mechanism is needed for daily operation. This reduces the cost and allows the use of passive tracking methods as shown in fig1.

Fig. 1. Single axis solar tracker

Dual axis systems are capable of moving in two directions, on both the horizontal and the vertical axis. Therefore, they are able to track very precisely the sun path along the period of the sun's rays from east to west, and north to south using two pivot points as shown in Fig. 2. That's why the two axis tracking systems are more efficient than the single axis, but also more expensive because they are using more electrical and mechanical parts (Paulescu, 2013). Various studies were conducted on the sun tracking systems using both analog and digital techniques based on open and closed loop control systems.

Fig. 2. Double axis tracker

Helwa (2000) compared four PV systems: fixed system facing south and tilted at 40°, vertical axis tracker, tracker with 6° tilted axis (north-south tracker) and dual-axis tracker. The comparison is based on one year measurement of solar irradiation and their power output. The comparison results have shown annual increase of collected radiation by azimuth, north-south and dual-axis trackers by 18%, 11% and 30%, respectively, over the fixed system. Abdallah (2004) designed, constructed and studied four tracking systems in Amman, Jordan: dual-axis, single axis vertical, single axis east-west and single axis north-south. The power generation by each system is greater than that of a fixed system tilted at 32° by 43.9%, 37.5%, 34.4%, and 15.7% for the dual-axis, east-west, vertical, and north-south tracking system, respectively compared to that obtained from a photovoltaic system with a fixed surface inclined at 32°.

Barsoum (2010) designed and constructed a prototype for solar tracking system with two degrees of freedom, which detects the sunlight using photocells. The control circuit for the solar tracker is based on a PIC16F84A microcontroller. This is programmed to detect the sunlight through the photocells and then actuate the motor to position the solar panel where it can receive maximum sunlight. Saravanan (2011) designed and implemented of a system with active sensors constantly monitor the sunlight and rotate the panel towards the direction where the intensity of sunlight is maximum. The control circuit does the job of fetching the input from the sensor and gives command to the motor to run in order to tackle the change in the position of the sun. The additional energy generated is around 25% to 30% with very less consumption by the system itself.

Gomez-Gil (2012) compared the energy generation of real photovoltaic systems installed in southern Spain under four different configurations. Their study concluded that the annual gain of two-axis tracking system compared to a fixed is 25.2%. Mehrtash(2012) investigated the performance of photovoltaic (PV) systems with different types of solar trackers in climate conditions prevailing in Montreal, Canada. Four PV systems were simulated; horizontally fixed, inclined fixed, azimuth tracking, and a dual-axis tracking. Annual analysis shows an increase of array irradiation of up to 16.8%, 50.1%, and 55.7% for tilted fixed, azimuth tracking, and dual-axis tracking arrays, respectively compared to the horizontal fixed array. Dual-axis tracking and azimuth tracking array have the highest efficiency among these systems. The annual efficiencies of fixed arrays are 11% and 11.7% for horizontal and tilted fixed arrays, respectively, while the azimuth and dual-axis tracking systems have the same efficiency of 12.2%.

Eke (2012) studied the performance of two double axis sun tracking photovoltaic (PV) systems at Mugla University campus. The performance is calculated that 30.79% more PV electricity is obtained in the double axis sun-tracking system when compared to the latitude tilt fixed system. Nur (2013) presented a microcontroller based energy efficient hybrid automatic solar tracking system with a view to assess the improvement in solar conversion efficiency.The two-axis solar tracking system is constructed with both hardware and software implementations. The proposed tracking system uses a new solar sensor position with an adaptive feature. A comparative analysis was performed using three systems, i.e., hybrid, dual-axis tracking, single-axis and stationary module. The results showed that the use of the dual-axis tracking system produced 18% gain of power output, compared with a single-axis tracking system. The gain of output power with the dual-axis tracking system was much higher (54%) when compared with a stationary system inclined at 23.5 ° to the horizontal.

Barin (2013) developed a system that searches for the azimuth and the tilt angle during the day time. Designed two axes tracking system which tracks the sun in both azimuth and elevation planes to the suns position using microcontroller 16F877 and align the solar panel to the point of maximum intensity. The tracker scans at an angle of 120degree east-west every day and the system is completely controlled by the microcontroller. The comparative study of the output from the fixed and tracking panel shows an efficiency of 21.7%.

It can be seen that all the above systems are either complicated, expensive or contain many components. Therefore, this work was to develop and implement a cheaper solution design of a solar tracking system with both degrees of freedom in real time. The control circuit for the solar tracker was based on a PIC18f452A microcontroller, This PIC was programmed to solve solar radiation equations and then actuate the stepper motors to the right azimuth and altitude angles. Therefore, this system depends on the real time, not on illumination.

2. Experimental Setup and Procedure

The schematic circuit was designed using Lab-center proteus 8.1 professional software. The components were picked from the library and connected appropriately as represented in Fig.3 (Hesham 2009). A voltage supply of 12V is applied to the circuit which is then passed through a 5V voltage regulator. The PIC18f452A will be combined with voltage regulator circuit and crystal circuit. The crystal will set the frequency of the PIC microcontroller, 4MHz crystal is connected to PIN14 and PIN13. If not, The PIC microcontroller will be useless. The LCD will be used to show the angle of the solar panel, current time of the solar panel. The circuit of LCD is taken from datasheet. The LCD need to be constructing carefully because if the input voltage is below than 5 volt, the LCD will not operate. The potentiometer connected to LCD VEE pin will be used to adjust the brightness of the LCD. The stepper motor will rotate the solar panel to the right direction based on the data that send by PIC microcontroller. Each stepper motor will use transistor bridge bipolar circuit to drive a current to stepper motor. A high current is needed to drive the stepper motor. The outputs which drive the two motors is obtained from two PWM pins RC1 and RC2 for motor 1 and RC6, RC5 for motor 2, and direction controlling from RC0, RC3 for motor1 and RC4, RC7 for motor 2.

The PIC microcontroller can be reset if the error occurred by reset button circuit. MCLR reset input port is also connected to 5V supply via 10kΩ resistor. In order to supply power to the PIN11, PIN 32 is set to positive 5V and the PIN12, PIN 31 is set to ground, and control circuit block diagram is shown in Fig.4.

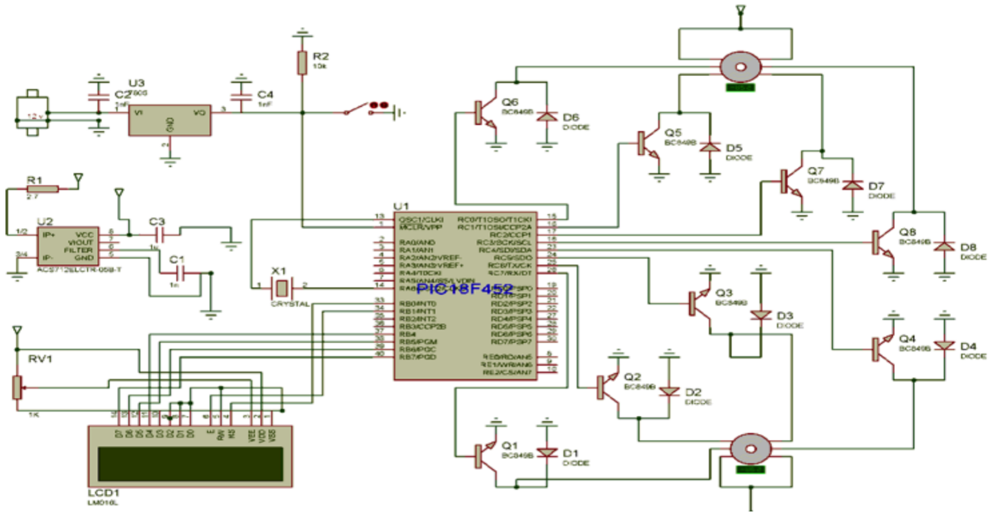

Fig. 3. Solar tracker schematic circuit.

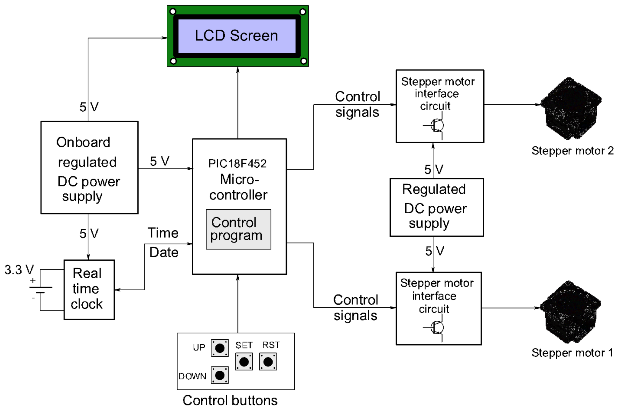

Fig. 4. Control circuit block diagram.

3. Experimental Installation

In order to validate the proposed modeling, it was necessary to compare the experiment results for the fixed panel with the smart solar tracker system. To obtain this data, simple experiments were performed. A photograph of the experimental setup for fixed panel is shown in Fig. 5 and tracker system in Fig. 6.

The setup were installed on the roof of the Thermal engineering laboratory, Mechanical power department, Faculty of Engineering, Mansoura University, Egypt latitude 31.04083° N and longitude 31.4861° E. The open-circuit voltage and the current readings were recorded using a millimeter connected to the solar cells. The climatic condition considered for experiments was sunny during the entire test period. The average temperature recorded was around 30 ˚C and the local wind speed was broadcasted to be around 5.5m/s during the tests.

Fig. 5. Photo of Experimental setup for fixed panel

Fig. 6. Photo of Experimental Setup for smart tracker

4. Results and Discussion

The current and voltage measurements for the photo-voltaic module, using a fixed load, were conducted in clear and sunny days of the summer season in year 2014. Readings were collected from 7:00 AM to 19:30 PM in 30 minutes interval time from 1/6/2014 for all modes of operation (fixed and tracking). In the fixed position mode, the module was fixed at a tilt angle of 31° facing the south which is the optimal inclination in Mansoura city, Egypt at all over the year.

4.1. Solar Radiation for Fixed and Tracking Systems

Figure 7 shows the total solar radiation for a clear day as measured by a solar power meter TES-1333 fixed on the surface of the panel. As it can be seen from the graph, the dual axis tracker receives more radiation than fixed.

Approaching reading in the afternoon where the sun is almost perpendicular to the solar cell in the two cases, then start reading in decline for both cases when entering the time of sunset The solar radiation after the noon hours during the experiment was decreased due to the appearance of clouds in late afternoon hours. It can be seen that after the decrease of solar radiation intensity, the developed controlling circuit is helping the photovoltaic to follow the sun up to the end of the day.

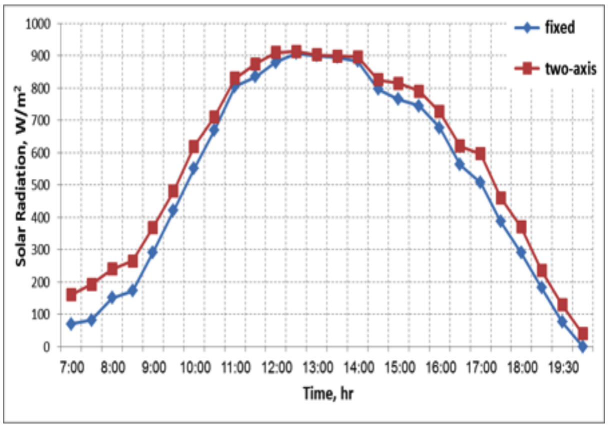

Fig. 7. Variation of solar radiation with time for fixed and two-axis.

4.2. Short circuit current for Fixed and Tracking Systems

Figure 8 shows the values of short circuit current data recorded from 1/6/2014.As observed from the plots, the current generated increased markedly in the period between 9 AM in the morning until 2 PM, as noted a marked change in the current intensity between the three cases in the morning period. The smart solar tracker produces a higher current output as compared to the static PV panel.

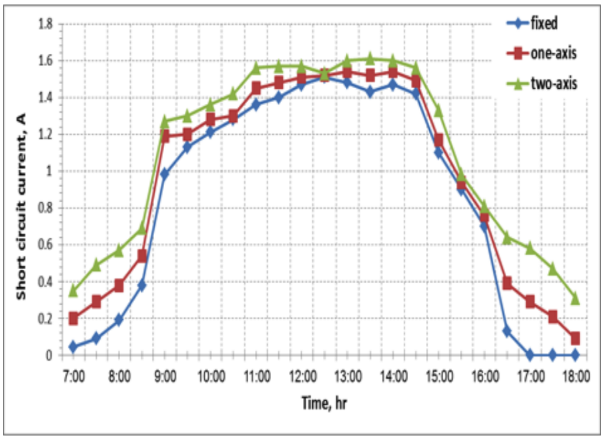

Fig. 8. Variation of Short circuit current with time for fixed and tracking systems.

4.3. Open circuit voltage for Fixed and Tracking Systems

Figure 9 represents the values of open circuit voltage data for 1/6/2014, it was observed with the emergence of the first light and sunrise that read voltage given high reading and getting quickly to be given semi-consistent results. It is the same case at sunset. Read the voltage remains high until it begins the process of sunset.

4.4. Maximum Power for Fixed and Tracking Systems

It is clear from Fig. 10, the effect of using tracking system on power output, shows that the difference in the early hours of the day and the period approaching the sunset, Curve up to a maximum value at 13:00 pm.

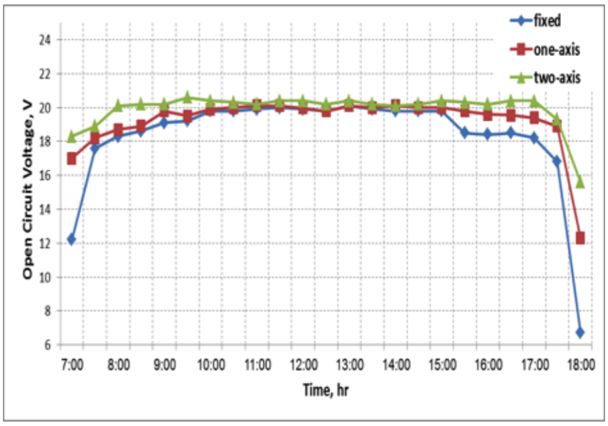

Fig. 9. Variation of Open circuit voltage with time for fixed and tracking systems.

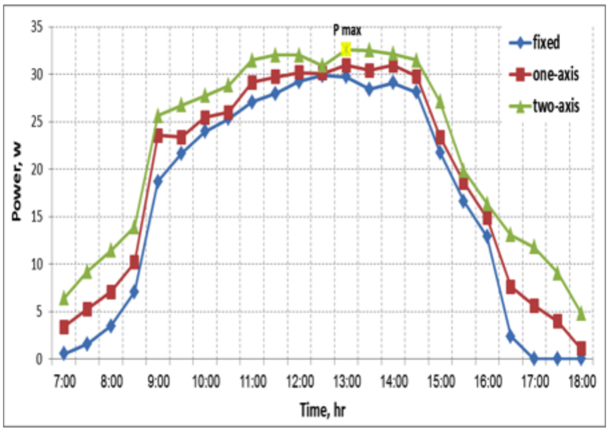

Fig. 10. Variation of Maximum power with time for fixed and tracking systems.

4.5. Energy conversion efficiency of the Tracker System

From the previous Figure 10 is determined the highest value for power at time 13:00 PM of which define the maximum Short circuit current, I max = 1.6 A and maximum Open circuit voltage, V max = 20.4 v to calculate the maximum power output Pmax.

$P_{max} = V_{max} \text{ x } I_{max}$

$P_{max} = 20.4 \text{ V x } 1.6 \text{ A} = 32.64 \text{ W}$

Where solar radiation = 913 W/m^2

and Solar cell area, A = 0.16 m^2

(width x 32 cm- height = 50 cm)

Energy conversion efficiency, η: This is defined as the ratio of the maximum power output to the power input to the cell:

$$\eta\ \% = \frac{P_{max}}{P_{in}} * 100 = \frac{P_{max}}{E\ A} * 100$$

$$\eta\ \% = \frac{32.64}{913 * 0.16} * 100\ = 22.34\ \%$$

4.6. Energy output Gain of two-axis tracking system over fixed mount

There is a difference between the energy gain of the tracking system two-axis and fixed system. The difference is biggest from 7.00 am in the morning to 17.00 pm in the afternoon when the sun is high enough above the horizon at the same time oriented away from south, as shown in fig.11.

The calculated energy of two-axis over fixed mounted can calculated as:

$$Power\ Gain\ \% = \frac{Power_{two\ axis} - Power_{fixed\ mode}}{Power_{fixed\ mode}} * 100$$

$$Power\ Gain\ \% = \frac{8.8997 - 5.7929}{5.7929} * 100 = 53.63\%$$

It has been shown that the sun tracking systems can collect about 53.631 % more energy than what a without controllers and thus high efficiency is achieved through two trackers.

4.7. Energy output of Two-axis tracking system over one-axis tracking system

$$Power\ Gain\ \% = \frac{Power_{two\ axis} - Power_{one\ axis}}{Power_{one\ axis}} * 100$$

$$Power\ Gain\ \% = \frac{8.8997 - 6.8160}{6.8160} * 100 = 30.57\%$$

The calculated energy output of the two- axis tracking system over that of the one-axis equal to 30.57 %.

4.8. Energy output gain of one-axis tracking system over fixed mount

The percentage increase in solar power output gained is computed as:

$$PowerGain\ \% = \frac{Power_{one\ axis} - Power_{fixed\ mode}}{Power_{fixed\ mode}} * 100$$

$$PowerGain\ \% = \frac{6.816 - 5.7929}{5.7929} * 100 = 17.71\%$$

The calculated energy output of the one axis tracking system over that of the fixed mounted was 17.71 %.

4.9. Comparison between two-axis, one axis and fixed

In Figure 11 the line represents the solar tracker (two-axis)is favorable, because it does not specify an angle, works easily and free movement. It achieved the average value of the output power 8.8997 W, in 1-6-2014.The line represents the solar tracker (one-axis) is proven at the angle of an annual work 31o. This type of tracker works in daily movement from east to west. The system is less efficient in cloudy and dusty days. The recorded reading of this system which is done was 6.8160W.

The latter system fixed was less important than the other types because it is of fixed angle and proven throughout the year at 31o. The average value obtained was 5.7929 W, which is less than the previous tracking systems.

It is clearly seen that both one and two axis tracking systems, produce higher amount of energy when compared with the fixed systems, this Gains arebetween17.71% to 53.63 %. It is also observed that two axis sun tracking systems produce much more energy than one- axis systems as expected equal to 30.57 %.

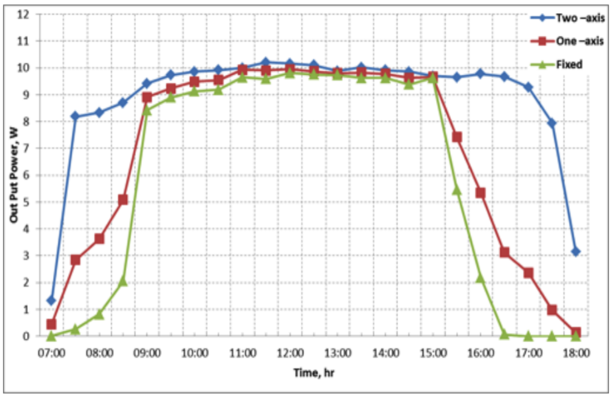

Fig. 11. Variation of Output power with time for fixed and tracking systems.

5. Conclusion

In the present study, a smart two axes sun tracking system is designed with both degree of freedom and which detected the sunlight based on pic microcontroller. The control circuit for the solar tracker was based on a 18F452 microcontroller to keep the PV panel pointing toward the sun by using a stepper motor. The use of stepper motor enables accurate tracking of the sun.

Results of experimental tests carried out in Mansoura city, Egypt showed that the power gain of the two-axis tracking PV panel over that of the fixed is equal to 53.631 %.Both the solar panels mounted on the tracker and the fixed amount system is identical 20W panels. Furthermore, the calculated power gain output of the two- axis tracking system over that of the one-axis equal to 30.57%. On other hand, the calculated power gain output of the one-axis tracking system over that of the fixed mounted was 17.65%. It can be concluded that both single-axis and dual-axis are highly affected on the electrical energy output when compared to the fixed mount system. It has been seen that full tracking system can increase energy conversion efficiency output by more than 22%.

After examining the solar system, it can be said that the proposed sun tracking solar system is a feasible methods of maximizing the energy received from solar cells. It can be built for a very low cost and most importantly; this system would be within the financial reach of many developing country communities. It can greatly improve the utilization of solar energy when compared to other tracking systems.

NOMENCLATURE

I max	maximum Short circuit current,
V max	maximum Open circuit voltage,
P max	maximum power output,

GREEK SYMBOLS

η	Energy conversion efficiency,

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الملخص العربى

تحسين كفاءة خلية شمسية كمصدر بديل للطاقة المتجددة باستخدام نظام تتبع شمسى

خيرت عادل عبد الجواد[1] **هشام حلمى جاد[1]**
أحمد عبد السلام حجازى[2] **حلمى السيد جاد[2]**

[1]قسم هندسة الحاسبات ونظم التحكم ، كلية الهندسة ، جامعة المنصورة

[2]قسم هندسة القوى الميكانيكية ، كلية الهندسة ، جامعة المنصورة

الطاقة الشمسية هي مصدر مهم للطاقة بسبب طبيعتها النظيفه والمتجدده. حالياً، نواتج إحتراق الوقود الحفرى تسبب تلوث البيئة، ويتم استنزاف مصادر الطاقة التقليدية بسرعة، وأصبحت الحاجة ملحة إلى الطاقة الشمسية واستخدامها بكفاءة. إن تكنولوجيا الخلايا الضوئية (PV) أصبحت فى تطوير سريع فى السنوات الأخيرة. التتبع الشمسى أحد التكنولوجيات التى تزيد كفاءة الطاقة المنتجة من الألواح الكهروضوئية. لذلك كان الهدف من هذا البحث هو تصميم واختبار نظام تتبع كامل للشمس للوح PV قائم على متحكم رقمى PIC 18F452 باستخدام محركين خطويين. حيث أن استخدام محرك الخطوة يُمكن من تتبع دقيق للشمس. وأظهرت التجارب التى أجريت فى مدينة المنصورة، مصر أن الطاقة المكتسبة من خلال تتبع الشمس بدقة أكثر بكثير من الطاقة التي اكتسبتها نظامثابت. حيث تبلغ كمية الطاقة المكتسبة من نظام تتبع محورين اكثر من الالواح الثابتة بما يعادل 53.631? وأيضا، كمية الطاقة المكتسبة من نظام تتبع محورين اكثر من محور واحد بما يعادل 30.57% من ناحية أخرى كمية الطاقة المكتسبة من نظام تتبع محور واحد مقارنة بالثابتة تقدر ب 17.65% وقد ثبت من خلال البحث أن نظام التتبع الشمسي لمحورين يمكن أن تزيد من كفاءة تحويل الطاقة بأكثر من 22% بعد دراسة هذا النظام الشمسى، يحقق النظام المصمم تتبعا دقيقا لمسار حركة الشمس و تحسين الاستفادة من الطاقة الشمسية بالمقارنة بالانظمة الثابتة.

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Khairat A. Abd Elgawad[1*]; Hesham H. Gad[1]; Ahmed. A. Hegazi[2] and Helmy E. Gad[2]

[1]Computers and control Systems Department, Faculty of Engineering,
Mansoura University, El-Mansoura, Egypt.
[2]Mechanical Power Engineering Department, Faculty of Engineering,
Mansoura University, El-Mansoura, Egypt.

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