Prospects of Modern Technology in Agricultural Engineering and Management
of Environmental Problems: 651 - 662

DEVELOPING AN ELECTRONIC TRACKING SYSTEM FOR SOLAR COLLECTORS

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ABSTRACT

An increase of solar power harvesting units efficiency was obtained by using an electronic solar tracking system. The tracking system uses infra-red sensors derived by an electronic circuit to detect the solar incidence angle, which produces a controlling signal to run a dual direction DC motor. A directional solar unit is actuated by the motor throughout the daylight duration. The solar tracking system accuracy to detect solar rays inclination angle varied from 6-7°. Laboratory and field tests on photovoltaic panel showed an increase in power gain by 32.29% compared with non-tracked system.

Key words: solar energy, electronic solar tracking, photovoltaic panel.

INTRODUCTION

The world faces serious energy shortages with the ever-increasing world energy consumption from 1 to 2% a year, and increasing future requirements to 10% by year 2020 (Pimentel et-al., 1994). Domestic fossil energy supplies combustion is the major contributor to increasing pollutant concentration in the environment, which affect food production and process. In order to supply enough power for agricultural applications, large photovoltaic (PV) arrays are required. PV overall performance can be attributed to the efficiency of the cell, and the intensity of the source radiation on the cell. The materials used in the manufacture of solar cells restrict the overall performance. Instead of increasing the size of the PV arrays, it is more beneficial to increase the performance of the solar cell, it is an easier process to increase the amount of source radiation that is received at the cell by focusing the sun's incident rays onto a rigid array, or to tracking the sun's path using a dynamic tracking system, or both together.

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The aim of the study is to increase the efficiency of solar energy harvesting systems by using an efficient, low cost electronic solar tracking system. It is necessary to select the most suitable type of optical detector (sensors arrangement), building circuit for measuring and controlling solar radiation incident detection angle, using an appropriate motion source and transmission set, calculating power gain in fixed and tracked PV units, and cost analysis work. Results show increase of total harvested solar energy up to 32.29% (under the experiment conditions) and the tracking system was efficient in most environmental changes according to an infra-red detector used to detect thermal sun rays, which can perform in cloudy conditions. The use of solar tracking system recommended is for expanding the use of PV modules.

Photovoltaic cells: produce electricity when sunlight excites electrons in them. However, improvements are needed in the photovoltaic cells to make them economically competitive (Moore, 1992).

The solar constant 1367 W/m2 is the average radiation intensity over the earth atmosphere in the middle earth distance from the sun. The maximum radiation intensity is up to 1100 W/m2 on the earth surface during the sunny day. The efficiency of the best semiconductor photovoltaic solar panels ranges from 15% to 20%. It is possible to obtain 160 to 200 W per square meter area (Del Chiaro, et. al., 2004).

Elliot Larard in 1998 designed a number of dynamic sun tracking systems by use of light sensitive pyramid-shape solar cell sensors set at 45° angles. And two independent stepper motors controlling the position of PV array. The designs were plagued with problems concerning the rotation axis, variation in sensor performance with temperature, stepper motor controlling circuits and software were complicated and expensive, sensor alignment and weight problems. Hamilton in 1999, developed the Larard's tracking system (Hamilton, 1999).

Gadewadikar (2004) used a stepper motor for controlling the position of solar energy collector, and software included the positioning of collectors through stepper motor, data acquisition and processing by a microprocessor.

Three main types of sun trackers exist: passive, microprocessor and electro-optically controlled units. Passive systems track the sun without any electronic controls or motors, these are simple but can only provide moderately accurate tracking. Microprocessor controlled sun tracking units use mathematical formulae to predict the sun's location and need not sense the sunlight. This type of tracker is highly accurate but requires a very precise installation, often difficult to achieve. Electro-optical trackers give very good results during good weather conditions (Roth et al., 2005). Awady and Attar (2007) present an electronic solar tracking system. And this study aims to evaluate the design and performance of the presented solar tracking system.

MATERIALS AND METHODS

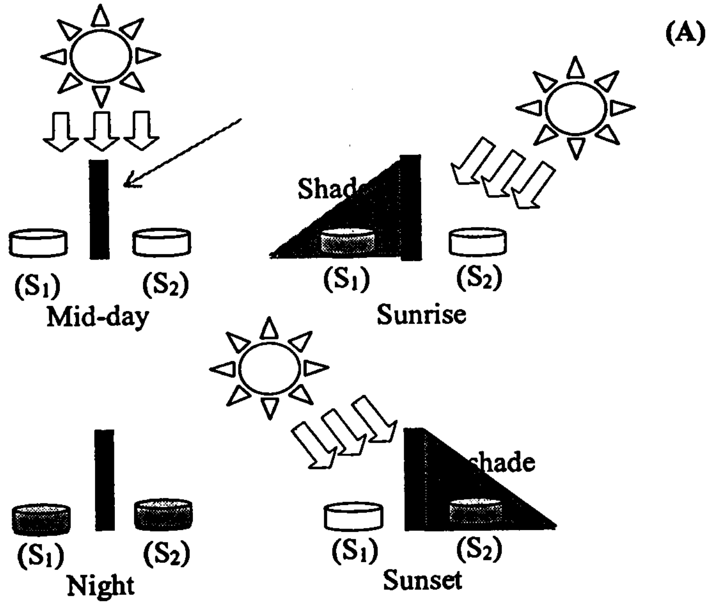
The electronic sun tracking system was tested through year 2005-2006 at the Egyptian Nuclear Power Station located at Enshas "انشاص", 30.01° latitude, and 31.14° longitude, sun declination angle of 23.177°, solar altitude 68.98°, sun rise at 05:01, and sun set at 18:56". The path of the Sun through the sky changes significantly throughout the year, so the position of the sun changes both hourly and seasonally. Maximum solar energy was obtained when the sun rays strike normally at the solar power harvesting unit. The relation of solar rays inclination angle and power gain were illustrated by equation 1.

$$I = S \cos Z, \qquad \textbf{Equation 1}$$

where I: is insolation, S:1000 W/m^2, and Z: Zenith Angle.

Solar tracker working principle

Electro-optical solar tracking system is composed of one pair of anti-parallel photo-detectors. The photo-detectors were separated by illumination baffle which are, by equal intensity of illumination of both elements when solar rays restrict their surface in right angle (fig.1).Sensor-1 (S_1), and sensor-2 (S_2), are electrically balanced so that there is either no or negligible control signal on a driving motor. By differential illumination of electro-optical sensors due to sun rays tilt angle, differential control signal occurs which is used to drive a DC motor and to drive the sensing elements attached to the collector unit in such direction where illumination of electro-optical sensors is equal and balance is restored.



(B)

Case	S_1	S_2	Action
Sun rise	OFF	ON	Turn↺
Mid-day	ON	ON	Rest
Sun set	ON	OFF	Turn↻
Dark	OFF	OFF	Rest

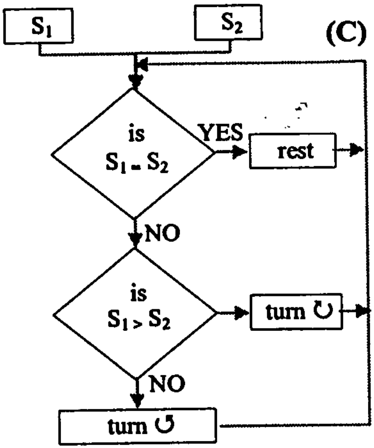


Figure 1: Solar tracker working principle: A) The four cases of sun position affecting the sensors, (B) Truth table for PV action due to sun position, (C) flow chart of tracker working principle.

The optical photoelectric sensor was chosen to meet solar tracking system characteristics to provide accurate sensing to all light intensities during the day, to use power sources normally available in the field, and to be –relatively- at low cost. Infra-red sensors (IR) and light dependent resistor (LDR) illustrated in fig.2A and fig.2B, were tested to determine their characteristics under desired system performance.

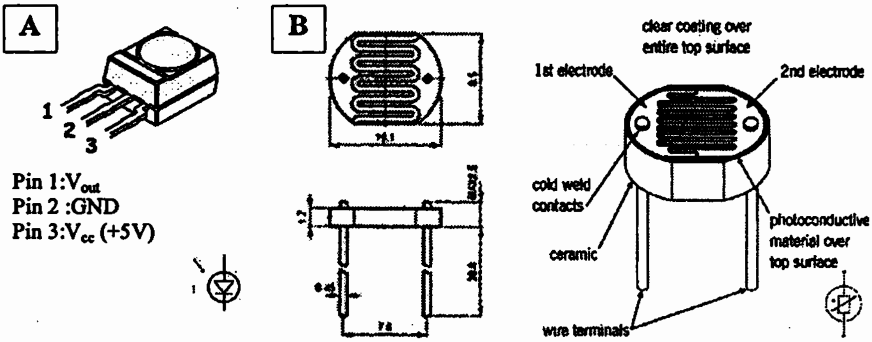


Figure 2:A) IR and B) LDR photo-electric sensors.

Sensor response to solar rays inclination angle:

A set of sensors was built to determine the accuracy for detecting solar rays inclination angle as shown in fig.3. The set was made from acrylic base with angle measurement index. A pivot sensors baffle with changeable length was set to turn right and left faces the incoming light rays. Measurements were taken to obtain optimal positioning performance by finding the proper baffle length "L", and sensor alignment (distance "D", angle°) as shown in fig.4.

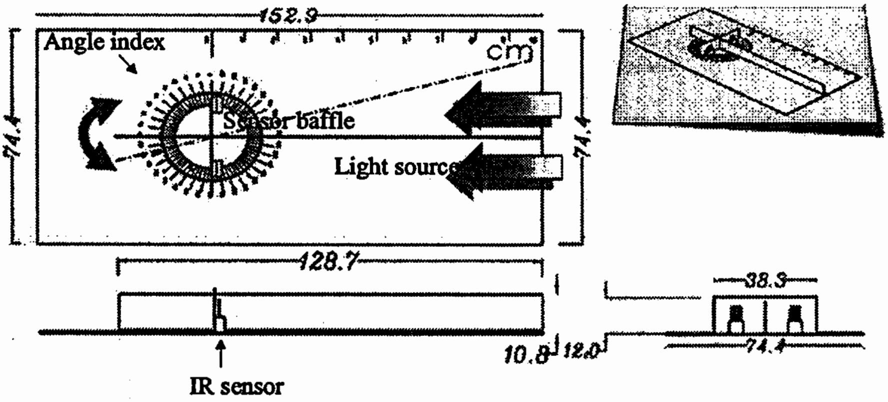


Figure 3: Measuring set for sensors response to sun rays inclination angle with sensor three inclination angles.

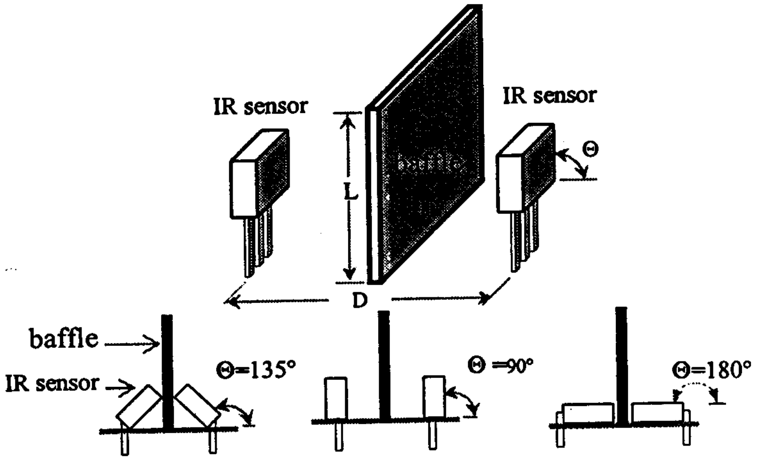


Figure 4: Sensor measuring parameters: Baffle length "L", and sensors alignment: distance "D" , Angle Θ.

A lux meter (Extech instruments meter) model 407026, 3½ digit (2000 count LCD) 50000 lux, color corrected photo diode, accuracy ± 4%+2 digits was used to measure light intensity under laboratory condition with tungsten bulb light source at 434 lux.

Sensor shield

To increase the accuracy of the solar tracking system. A sensors shield was used to allow only the direct sun radiation to pass through a thin vertical entrance "1mm width" as shown in fig.5 , while blocking scattered, and diffused radiation.

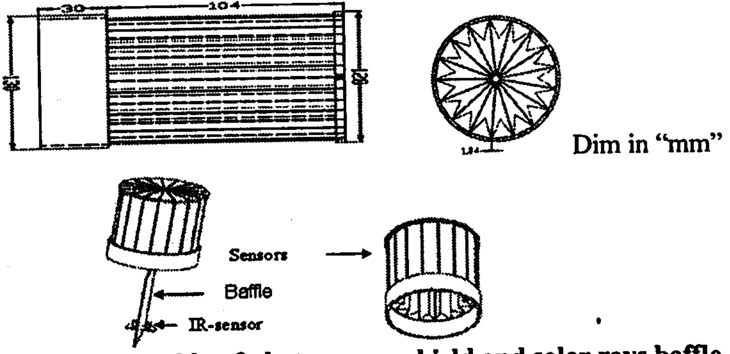


Figure 5: Schematics assembly of photo-sensor shield and solar rays baffle.

Motion direction control circuit

Circuit controls motion direction of a DC "Direct Current" motor by changing the polarity of circuit output by an electro-mechanical relays "varied according to load". Fig.6 illustrates the working principle of direction control unit in all working cases. Over-load protection was established by using a specific resistance. A resistance value was calculated according to equations 2,3.

$$R = V/I \text{ , Equation 2}$$

$$P = I^2 R \text{ , Equation 3}$$

Where, R is the resistance value "ohm", V electrical potential "Volts", and I current "amperes". Measured circuit load (resistance 36?), which worked by potential at "9V" from equation 2, I =0.25 A. So, over-load protection can be done with connecting circuit relays "14? " with resistance R_4=22? . From equation 3, R_4 rated power equals 2.25≅ 2W.

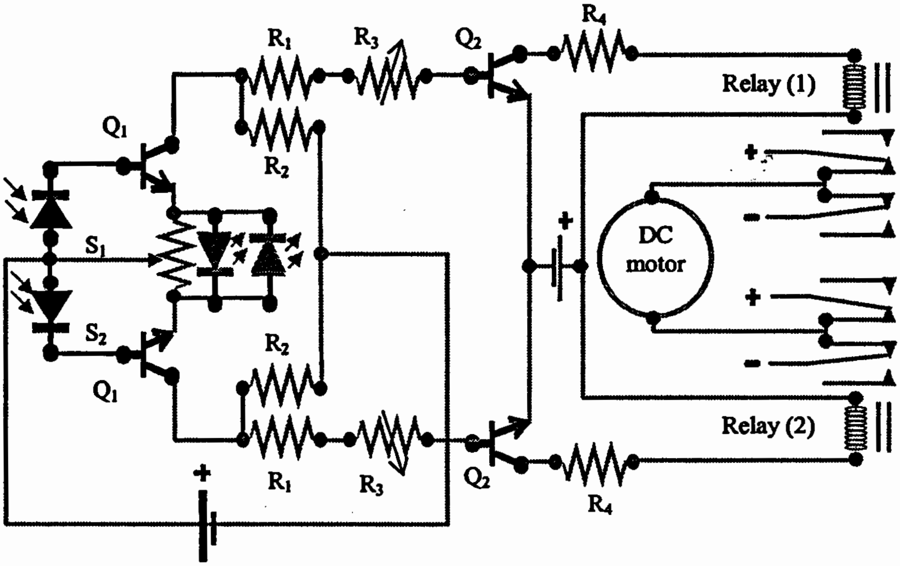


Figure 6: Schematic diagram for the electronic tracking system circuit.

Tested photovoltaic panel specifications (PV)

Electronic solar tracking system was tested on two groups of PV (fixed and tracked of sun position) each containing six module "Shell SM55 "PowerMax®" mono-crystalline silicon solar cells". The Shell SM55 module can generate a peak power of 55W at 17.4 volt (Shell Solar manual, 2002). Fig.7, illustrates the PV panel and tracking system attached to it.

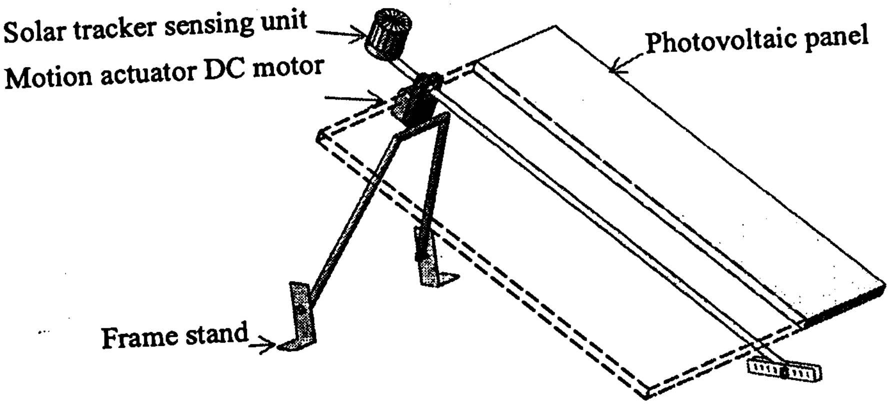


Figure 7: PV panel set with the electronic tracking system.

PV Motion actuators (the DC motor)

Modulating Spring Return Actuators by Joventa Comp. was used to drive the PV panel. The modulating actuators have the ability to change motion direction with maximum torque of 16Nm at power 5.5W, through changing DC motor electrical polarity (fig.8).

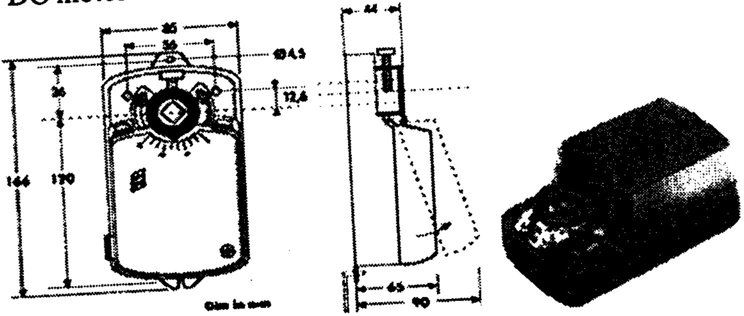


Figure 8: Illustration PV motion actuators.

Net electrical power was estimated form calculating area under curve of power-time, produced for the PV panel for both of fixed and tracked PV modules. Integration was performed on the obtained function according to equations 4,5.

$$E = \int_{\Delta t} P\,dt\,, \qquad \text{Equation 4}$$

$$Area = \int_{\Delta x} f(x)\,dx\,, \qquad \text{Equation 5}$$

Where:

E: is the energy in Watts, x: is the time "t", and f(x): the power "P".

RESULTS AND DISCUSSIONS

Results have proved that constructing the solar tracking sensor with baffle length of 4cm, and sensor spacing at 0cm in-between, with sensor tilting angle of 90° "vertical position" would give optimal response when sun rays inclined 6-7° over the sensor (fig.9).

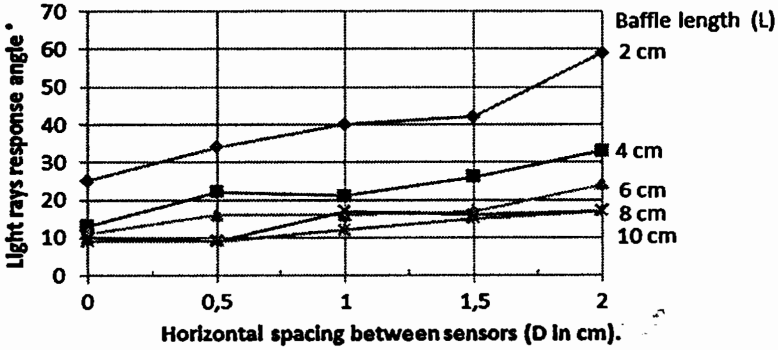


Figure 9: Relation of IR sensor response to sensor position at varied baffle length.

Sensor shielded was found to play an important rule in preventing sensor from being saturated due to scattered light form the surroundings. Another roule for using sensor shield is to protect the sensor form environmental contaminants such as rains and dust (fig.10).

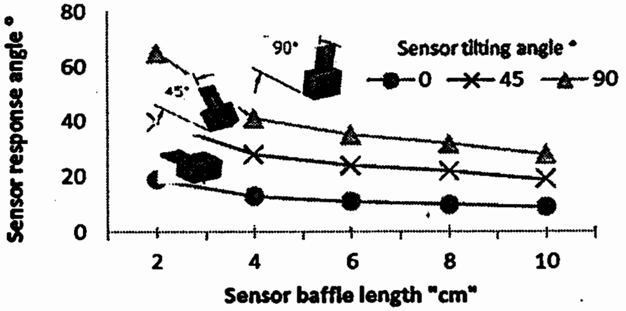


Figure 10: IR sensor respons at different tilting angles (0°, 45°, and 90°).

IR sensor, according to the results and visual inspection was the most approparte choice compared with other sensor "LDR sensor" for fast response to the fluctuated environmental conditions, and for the higher resistance change due to detected solar radiation, compared with LDR sensor (fig.11). IR sensors produce the optimal electrical potential for driving the circuit at 0.6V. The IR sensor which has the ability to detect IR lights in the range of thermal rigone will be a good choice for eleminating the effect of clouds and dust which prevents the other waveform from reaching the sensor, and benefit in orientation the system toward the important portion of solar rays falling in the thermal region.

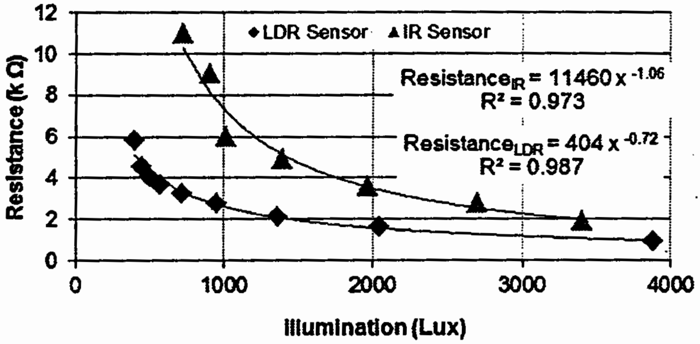


Figure 11: Comparasone between LDR and IR sensor resistance response to different illumination levels.

The net gain of electrical power form fixed, and tracked PV panel was obtained (fig.12). The fixed PV panel produced a varied electrical power in relation to light intenstiy fluctuating during the day, compared to fixed PV panel.

A solar tracked PV panel performs better in increasing the total harvested electrical power by 32.29%, by keeping the panel facing the sun all the time.

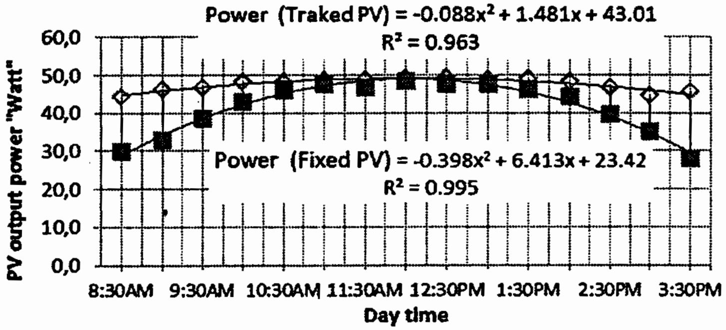


Figure 12: Net electrical power output for fixed and tracked PV module.

CONCLUSIONS AND RECOMMENDATIONS

The energy from the sun can serve many purposes; one of them is to generate electricity through PV panel. PV can meet electricity demand at remote areas where there is no connection to the electricity grid, households, powering water pumps, refrigerators, and for power generators. Using electronic tracking system increases the efficiency of water solar collector, solar dryers of agricultural materials, maturing compost, shading animal buildings, and control the environment of the green houses.

Using solar tracking system can improve the total efficiency of the PV panels, which ranges between 15 to 20 %. With no sophisticated or new arrangement to develop the current working units.

For optimum performance of harvesting solar power, the tracking sensing element must be aligned to each other, and with the solar rays baffle between them with 4 cm length, each facing the opposite side in a vertical orientation to achieve tracking accuracy of 6-7° of detecting solar rays.

For peak performance, a solar module should face the brightest part of the sky. Tracking system may be utilized to improve system performance (by up to 32.29%).

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الملخص العربى

تطوير نظام تتبع إلكترونى للمجمعات الشمسية

العطار م.ز.*

تتزايد كمية الطاقة المولدة بواسطة المجمعات الشمسية عند تعامد أشعة الشمس الساقطة وسطوح الامتصاص للمجمعات الشمسية. تم تطوير نظام إلكترونى يهدف إلى رفع كفاءة وحدات تجميع الطاقة الشمسية باستخدام نظام توجيه إلكترونى، مزودة بمستشعرات كهروضوئية ووحدة توجيه آلية تعمل بمحرك كهربى.

تعمل المستشعرات الكهروضوئية على تحديد زاوية السقوط للأشعة الشمسية، وإصدار أشاره تحكم لوحدة التوجيه فى حالة عدم تعامد الأشعة الشمسية وسطح المجمع الشمسى. والتى توجه سطح المجمع الشمسى ليتخذ وضعا عموديا والأشعة الشمسية الساقطة عليه. تم مقارنة عدد من أنواع المستشعرات الكهروضوئية (مقاومة كهروضوئية LDR، ومستشعرات الأشعة تحت الحمراء IR) ، وعدد من التجهيزات المختلفة لتقصى أفضلها فى التعرف على زاوية سقوط الأشعة الشمسية. دلت النتائج على مقدرة نظام التوجيه على استشعار الأشعة الشمسية الساقطة بدقة توجيه تقع فى حدود ٦-٧° عند استخدام المستشعرات الكهروضوئية التى تعمل بالأشعة تحت الحمراء. وعدم تفضيل استخدام مستشعرات المقاومة الضوئية لبطء استجابتها الزمنية، وعدم مواءمتها للتغيرات فى كثافة الطاقة الضوئية أثناء ساعات العمل. كما دلت النتائج التى أجريت على وحدة توليد الطاقة الكهربية من الخلايا الكهروضوئية بالمزرعة التجريبية لهيئة الطاقة الذرية بأنشاص على زيادة الطاقة الكهربية المنتجة بنسبة ٣٢،٢٩٪ تحت ظروف التجربة.

الكلمات المفتاحية: الطاقات المتجددة - الطاقة الشمسية – الخلايا الكهروضوئية - متتبعات شمسية- تحكم الكترونى.

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