
Design and Implementation of a Two Axis Solar Tracking System Using PLC Techniques for Measuring Solar Radiation by an Inexpensive Method*

Hassaan Th. H. Thabet

Asst. Lect., Mosul Institute of Technology, Mosul□

Abstract

This paper presents the design and implementation of an experimental study of a two-axis (Azimuth and Altitude) automatic control solar tracking system to measure the solar radiation in an inexpensive way by a tracking solar PV panel according to the direction of the beam propagation of the solar radiation from dawn to dusk. The designed tracking system consists of four sensors (LDR) and a programmable logic controller (PLC) which controls two DC servomotors with control software designed for this purpose to move the system panel according to the information from the input sensors, keeping the panel always perpendicular to sun rays.

The designed software contains also a backup program (override part of the software) which controls the tracker in adverse weather conditions (cloudy or partly cloudy). To investigate the effect of using two-axis sun tracker system in measuring the solar radiation, an experimental study is carried out to evaluate its performance in the territory of Mosul Technical Institute.

Keywords: Programmable Logic Control (PLC), Photo Voltaic (PV) system, Solar Radiation, Two-axis Solar Tracker.

□

تصميم نظام للمتابعة الشمسية ثنائي الأحداثيات وتنفيذه

لقياس الإشعاع الشمسي

باستخدام تقنيات المتحكم المنطقي القابل للبرمجة PLC وبكلفة منخفضة

حسان ثابت حسن ثابت

مدرس مساعد، المعهد التقني، الموصل

المستخلص

تم في هذا البحث تصميم تجربة لقياس الإشعاع الشمسي بطريقة منخفضة التكاليف وتنفيذها ودراساتها، وذلك بتصميم منظومة تحكم آلية ثنائية الأحداثيات لمتابعة حركة الشمس على محورين (محور السميت و محور الارتفاع) بحيث تكون أشعة الشمس عمودية بصورة دائمية على اللوح الشمسي الكهروضوئي المستخدم في هذه التجربة من الفجر وحتى الغسق، تتكون منظومة التحكم التي تم تصميمها من أربعة أجهزة استشعار (LDR) ومتحكم منطقي قابل للبرمجة (PLC) الذي يقوم بالسيطرة على محركين من نوع (DC Servomotor) من خلال برمجية للمراقبة صممت لهذا الغرض اعتماداً على الاشارات التي يتم استلامها من أجهزة الاستشعار (المتحسسات) المذكورة أعلاه كي يبقى اللوح الكهروضوئي عمودياً دائماً على الأشعة القادمة من الشمس. تحتوي البرمجية أيضاً على برنامج اسناد يقوم بالتحكم في المنظومة في حالة الأجواء غير المشمسة (جو غائم أو غائم جزئي) كي لا تفقد المنظومة متابعتها لحركة الشمس. تم إجراء هذه التجربة لتقييم اداء منظومة التحكم لقياس الاشعاع الشمسي في المنطقة التي يقع فيها المعهد التقني في مدينة الموصل.

الكلمات المفتاحية: المتحكم المنطقي القابل للبرمجة، منظومة تحكم، الإشعاع الشمسي، نظام المتابعة الشمسية ثنائي الأحداثيات.

Introduction:

The solar tracker, a device that keeps photovoltaic (PV) or photo thermal panel in an optimum position perpendicularly to the solar radiation during daylight hours, can increase the collected energy from the sun by up to 40% [1]. Usually, the fixed PV panels cannot follow the sun movement. The single-axis tracker follows the sun's East-West movement, while the two-axis tracker follows the sun's changing altitude angle too.

Sun tracking systems have been studied with different applications to improve the efficiency of solar systems by adding the tracking equipment to these systems through various methods [2][3]. A tracking system must be able to follow the sun with a certain degree of accuracy, returns the panel to its original position at the end of the day and also tracks during cloudy periods; figure (1) shows the axes of rotation of a two-axis tracking system and its basic operation.

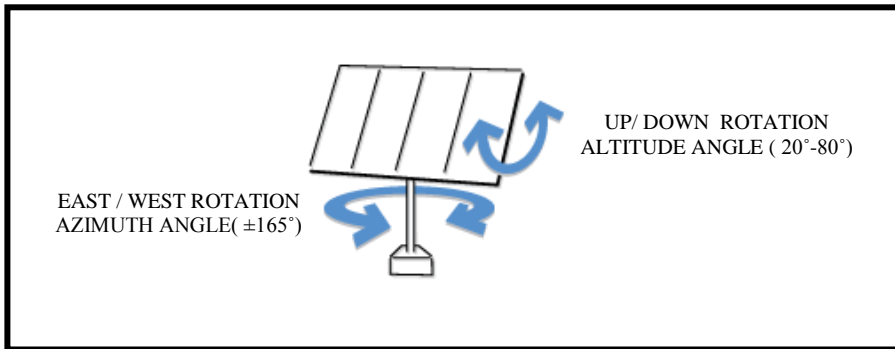


Fig. (1): Basic operation of a two-axis tracking system

Theoretical calculation of the energy in the PV panel [4][5] leads to the following equations:

$$E_{fixed} = \frac{2I\delta}{\omega} = 3.03 \times 10^7 \text{ w.s} / \text{m}^2 \text{ day} \quad (1)$$

$$E_{tracker} = I\delta_o.t = 4.75 \times 10^7 \text{ w.s} / \text{m}^2 \text{ day} \quad (2)$$

Where:

E_{fixed} : Falling energy per unit area calculated for the whole day in (watts . second) on a fixed PV panel.

$E_{tracker}$: Falling energy per unit area calculated for the whole day in (watts . second) on a tracking PV panel.

I : Maximum solar radiation (1100 watts /m²).

δ : Projection of δ_o perpendicular to radiation beams (m²)

δ_o : PV panel area (m²)

ω : The angular velocity of the sun across the sky ($7.27 \times 10^{-5} \text{ rad.s}^{-1}$)

t : daylight time (12 hours =43200 seconds)

Comparison of equation (1) and equation (2) shows that the energy surplus is 57% when it doesn't consider the atmosphere influence.

Design of a two-axis solar tracking system:

A. The electromechanical system:

The designed tracking system consists of a software based tracking method [2][5] as shown in figure (2).

The main components of the designed system are four light dependent resistors (LDR) as sun sensors, programmable logic controller (PLC) with analog inputs, two driving relay sets, two mechanical limit switches, two DC servomotors and a PV panel supporting metallic structure with mechanical gears mechanism. Table (1) lists the components of the electromechanically system and the PLC specification (technical data) used in the experiment.

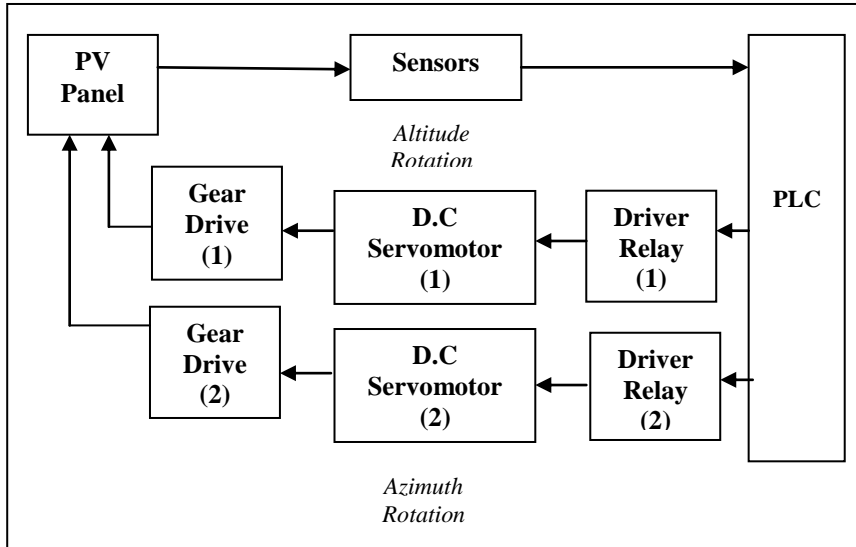


Fig. (2): Block diagram of a two-axis tracker

The electromechanical system consists of two driving relay sets, two mechanical limit switches with two DC servomotors, the first joint rotating about the vertical axis and the second for the East-West tracking as shown in figure (3).

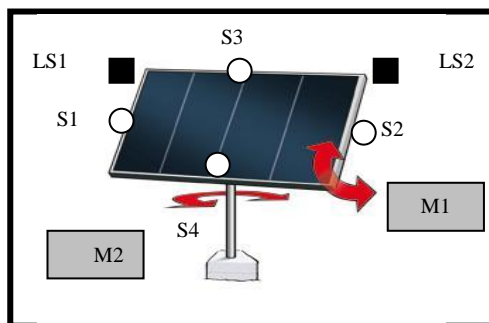


Fig. (3): Components of a Complete Solar Tracking System

Table (1)
Technical data of the electromechanical system and PLC
(hardware & software)

COMPONENT	TECHNICAL DATA	NOTES
1- Solar PV panel	Model : Reliance MT14 Is.c.: 2.586 Amps Vo.c.: 21.64 Volts Max. Power : 42.9 Watts Panel Area : 0.36 m ² Irradiance : 1100 W/m ² Max. Operating Current : 2.421 Amps Max. Operating Voltage : 17.72 Volts	one
2- D.C. Servomotors (M1, M2)	24VDC , 1.2 A	two
3- Relays	24VDC ,1.6 A , 1 NO contact	four
4- LDR sensors (S1, S2, S3, S4)	1000 Lux : 400 Ω 10 Lux : 9 K Ω Full Darkness : 1M Ω	four
5-Limit Switches (LS1, LS2)	Mechanical , Total Travel 70° Operating Torque : 0.15 N.M	two
6- LOGO! 12/24 Rc (Main Module)	Supply Voltage : 10.8 to 28.8 VDC Inputs : 8 Digital + 4 Analog (0-10 V) Outputs : 4 Relay	one
7- LOGO! Soft Comfort , Ver. 6.1 • Program Representation. • Simulation. • On Line Test.	Function Block Diagram (FBD) Ladder Diagram (LAD). Without Hardware With Connected Hardware	

The sun position sensors, (LDRs), give a voltage which is proportional linearly to the solar radiation beam position inside the sensors [6][7]. The sensors are oriented to keep the solar radiation beam normal with PV panel. Sun sensors detector determines the system misalignment (position error of the PV panel) and then sends analog signals to the controller (PLC's software). The controller (PLC's software) uses the sun sensors information as inputs to generate proper motors commands to rotate the motor at a definite angle according to the controller commands that slew the PV panel. After finding the sun, the system starts working in "CLOSED LOOP" mode.

It is rather complicated to get the transfer function of this system [2][5], but it can be derived from the block diagram of figure (4).

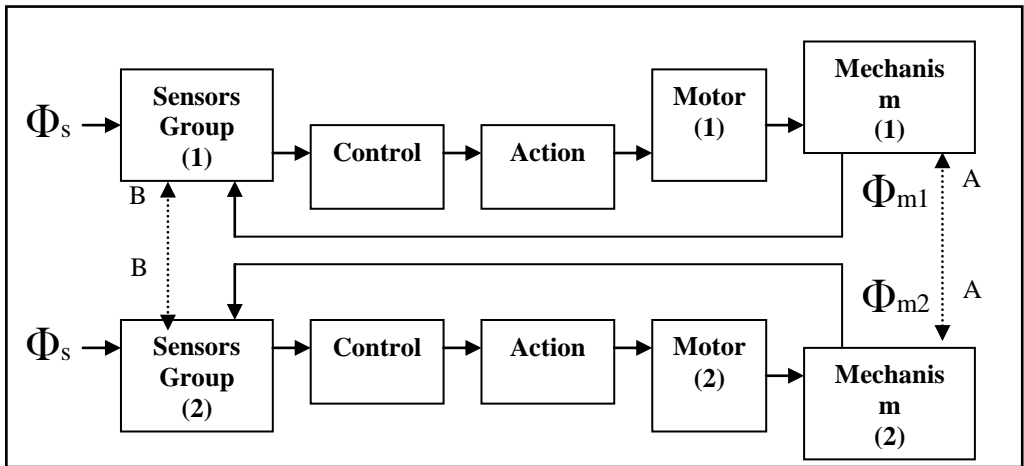


Fig. (4): Block diagram of transfer function for both axis

Where Φ_s is the angle of the sun, Φ_m is the direction to which the mechanism moves. The cross-coupling of AA and BB,

fig (4), is nearly zero because of the orthogonal disposition of the axes and the parallel mounting of the sensors [4][5].

B. Control software :

Control software has been developed to determine the optimum position of the panel during daylight, i.e., how much deviated from maximum power point. The outputs of the two sensors in each group are determined and their differences are fed to the PLC program via its analog inputs to control the mechanism of the PV panel to the optimal position of the tracking panel during daylight hours. The program of the horizontal and vertical axes tracking system consists of two parts related to the forward and backward motions. In this paper the programming method of control works efficiently in sunny days. For all weather conditions, an override technique is used to solve the problem of bad weathers (cloudy and partly cloudy). The control software of the solar tracker is written with Soft Comfort V6.1 software (by Siemens) [8].

Figure (5) shows the complete flowchart of the control software.

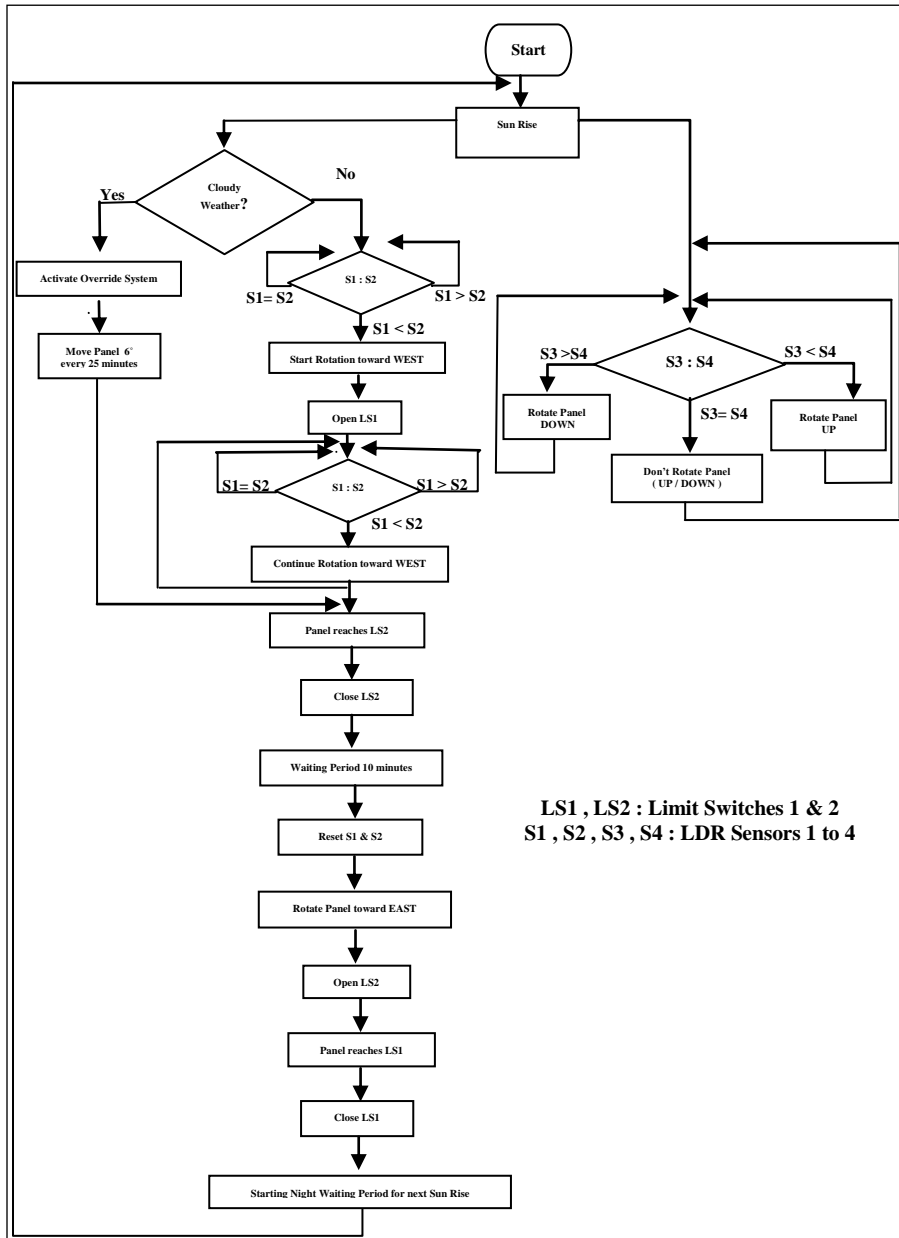


Fig. (5): Flowchart of the Control Software

Measurement of Solar Radiation:

Industrial devices for measuring solar radiation are delicate and expensive; they are called "pyranometers".

A pyranometer is basically a flat plate, covered with a transparent dome, which is coated with an extremely absorptive surface. As the sun strikes it, the surface gets hot. The temperature of the surface is measured with a thermopile, giving an output voltage related to the amount of solar radiation striking the surface [9].

In this paper, an inexpensive device for measuring the solar radiation is built using the PV panel that works pretty well out of inexpensive and readily available components. Although it will not be of laboratory quality, it will suffice for comparative measurements and educational purposes.

PV panels act like a current source over a part of their operating region, they act like a voltage source over the other part of their region. Figure (6) shows what is known as a (V-I) characteristics curve of a PV panel, it shows how current and voltage related to each other in a typical PV panel [9][10].

Note that when voltage is very low, the PV panel acts like a current source. That is, it delivers a rather constant current, independent of the voltage. The point at which the V-I curve intersects the vertical axis is called short circuit current (I_{sc}). I_{sc} is directly proportional to the solar radiation striking the PV panel [9][10].

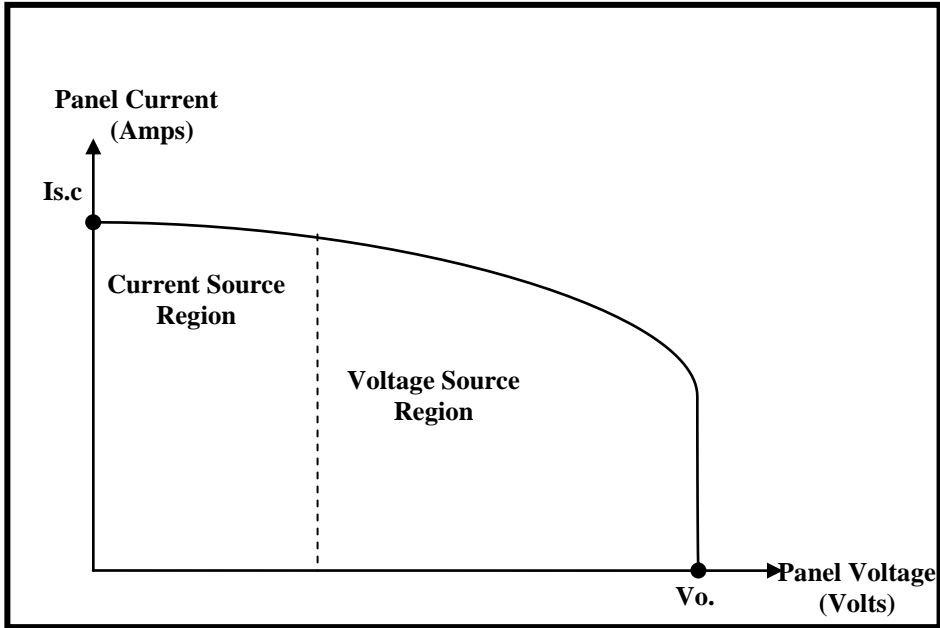


Fig. (6): V-I characteristics of a typical PV panel

Experimental Procedure:

A software-based online tracking method has been used in this designed tracking system to obtain the PV panel performance of the tracking module where firstly the system was kept in fixed mode and secondly it was kept in tracking mode. The simplest method to obtain a V-I characteristics is to load the PV panel with a variable resistor and measure the voltage and the current through digital meters as shown in figure (7).

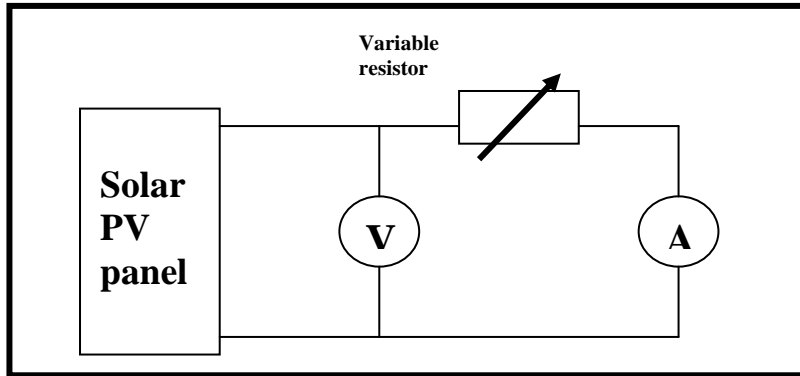


Fig.(7): Connection diagram for determination of V-I of a PV panel

In fixed mode, the panel was kept tilted at an angle of 45° . where as in tracking mode; the tracking panel tracks the sun through changing the Azimuth and Altitude positions so that it is always remained perpendicular to the solar radiation. The measured values of voltage and current were the open circuit voltage and short circuit current of the PV panel. To use a PV panel in measuring solar radiation, its output current must be calculated as shown in figure (8).

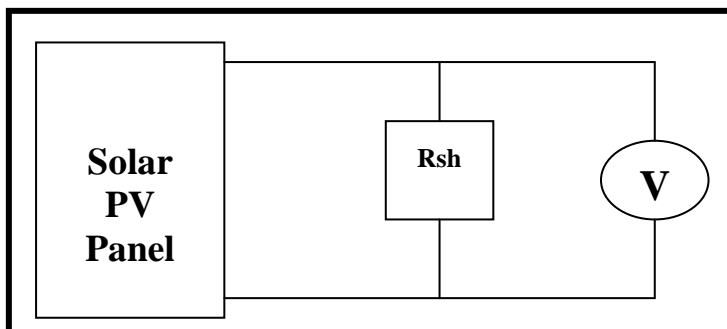


Fig.(8): Measuring solar radiation by calculating I_{sc} of the PV panel

A very low resistance was chosen (approximately 0.0768Ω) to be connected across the output of the PV panel used in the experiment in order to make the output voltage very low, so the panel will act as a current source as shown in figure (9).

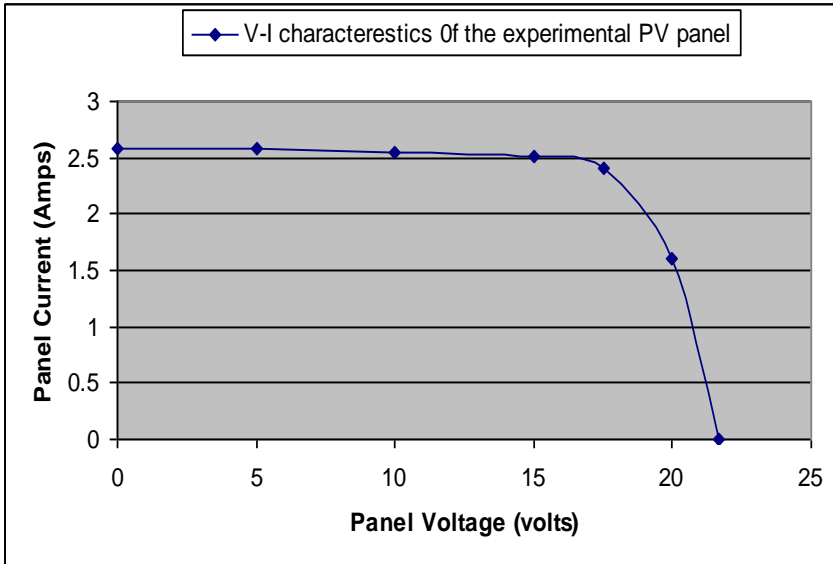


Fig (9): V-I characteristics of the PV panel used in the experimental work

It can be noted from fig(9), that the current of the PV panel is calculated by measuring the voltage across a very small resistor (R_{sh}), so for smaller resistors, the operating points will fall along the constant current portion of the PV panel characteristic, so the current through the resistor is proportional to the falling solar radiation [9][10].

Results and Discussion:

Three tests were carried out in May 2012 at the football field (Latitude 36.381136° N, Longitude 43.149686° E, 247 m above sea level) of the Technical Institute of Mosul, Mosul, Iraq

[11]. In these tests the PV panel was used as a pyranometer. Measurements of the PV panel which are proportional to the solar radiation in (watt/m^2) were recorded every hour and stored (the measurements were in volts then by calculating the I_{sc} in Amps). The collected data were processed using excel Microsoft. The data presented in this paper were conducted for the period 10, 11, 12 May 2012 and they were averaged and then plotted as shown in figure (10), it can be seen from this figure that the pattern of hourly variations is typical of a cloudless day.

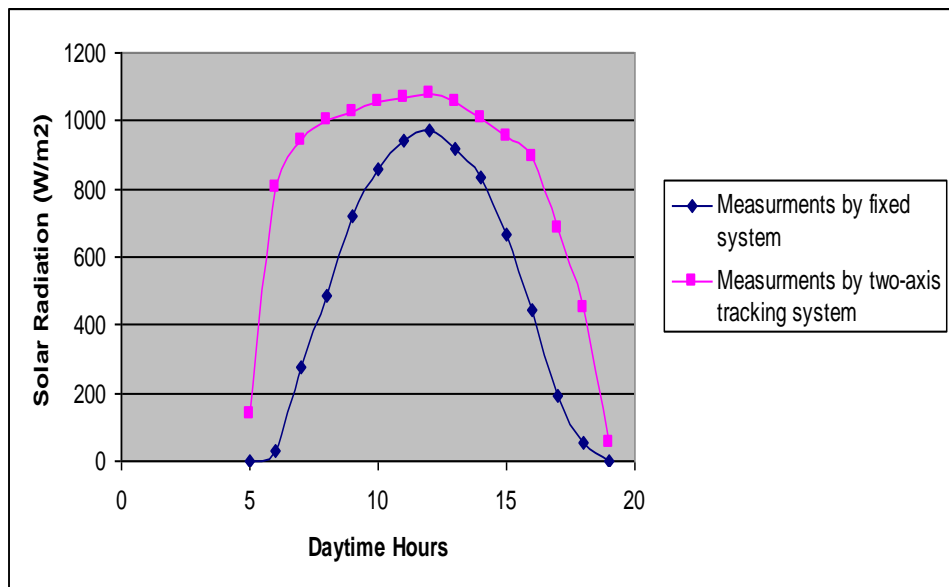


Fig (10): Solar radiation Measurements

Surplus energy at tracking system with respect to a fixed system of PV panel was obtained by the following formula [5]:

$$\text{Energy gain (\%)} = \{(\text{P}_{\text{tracking}} - \text{P}_{\text{fixed}}) / \text{P}_{\text{fixed}}\} * 100\% \quad (3)$$

Where:

P_{tracking} : power obtained by tracking system.

P_{fixed} : power obtained by fixed system.

The results shown in figure (11) indicate that there is an overall increase of output power about 30 – 40% for the two axis sun tracking system compared to the PV fixed system. High energy gains are found at the beginning and at the end of the day compared to the fixed system, figure (12). The energy gains found at the midday period are very low as shown in figure (12) because the sun ray will be perpendicular on the PV panels of the two systems.

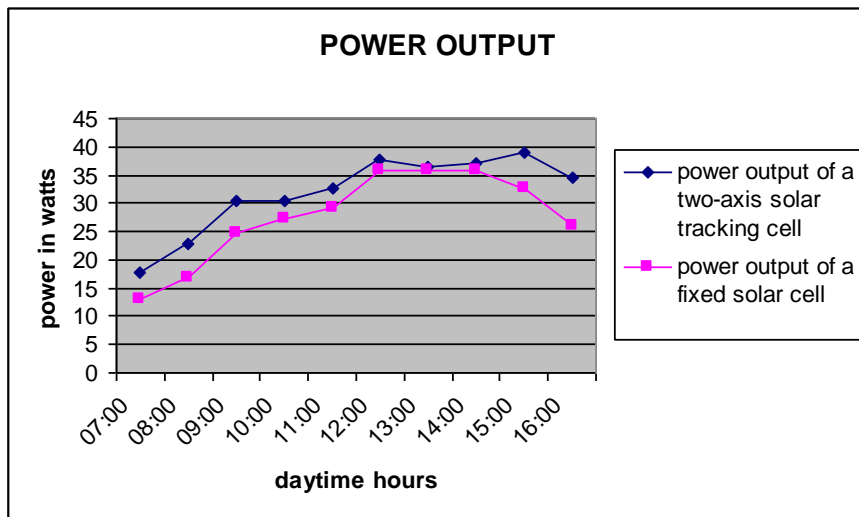


Fig.(11): Power Output of the experimental solar PV panel in both fixed and tracking modes.

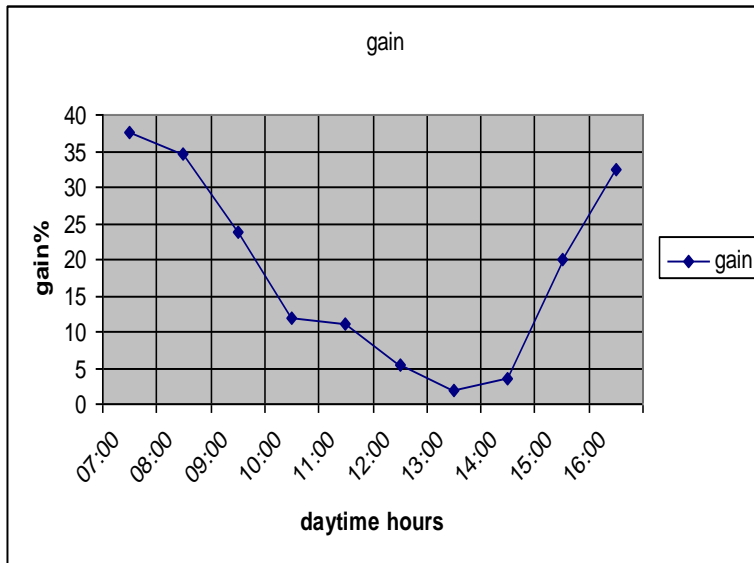


Fig.(12): Energy Gain in percentage of the module in tracking mode compared to fixed mode.

Conclusion:

The solar tracker has been designed to increase the efficiency of the solar panel through tracking the sun. An experimental study has been performed to measure the solar radiation using the PV panel. The tracking mechanism is capable of tracking the sun automatically so the direction of beam propagation of solar radiation is always perpendicular to the PV panel.

From the results of the performance test of the designed system, the following conclusions can be drawn:

- During the operation of the system at the testing period, it proved to be fairly precise and reliable, but it wasn't tested in adverse weather conditions (cloudy and partly cloudy conditions). The override part of the designed system will solve this problem as shown in fig. (5).

- V-I characteristics were tested for PV panel outputs , which approximately meet with ideal characteristics curve, and show good results for measuring of solar radiation which lead to a new and inexpensive method of measuring this important variable.
- Design simplicity, low cost, material availability, low maintenance requirements, ease of installation and operation will make this PLC-based tracking system more effective and competitive to other tracking systems.
- The results obtained have good agreements with that found in the results of Rustom, Nijmeh and Abdallah (2006), and with some of the results found in Sarker, Pervez and Beg (2010).

Acknowledgment:

The author gratefully acknowledges the financial support of the Mosul Institute of Technology for the building of the experimental system and the laboratory tests and measurements

References:

- 1) Francisco D. , Pedro D.G. and Luis C.G. , “ Two axis solar tracker based on solar maps , controlled by a low-power microcontroller ” *proceeding of the international conference on renewable energies and power quality .Granda (spain) ,23rd to 25th March , 2010*
- 2) Chia-Yen L., Po-Cheng C, Che-Ming C. and Chiu-Feng L., “ Sun tracking systems :A Review” ,*sensors* ,Vol .9 , pp. 3875 – 3890 ,2009.
- 3) Rustom M., Nijmeh S. and Abdallah S., “A Programmable Logic Controller to control Two Axis Sun Tracking system”, *Information Technology Journal*, Vol. 5, pp. 1083 – 1087, 2006.
- 4) Hossein M., Ali reza K.,Arzhang J., Hossein M., Karen A. and Ahmad S. , “A review of principle and sun-tracking

- methods for maximizing solar systems output ” *Elsevier*, Vol.13, pp.1800 – 1818, 2009.
- 5) M. R. I. Sarker, Md. Riaz Pervez and R.A. Beg, “Design, Fabrication and Experimental Study of a Novel Two-Axis Sun Tracker ” *IJMME-IJENS*, Vol.10, No.01, 2010.
 - 6) Romy K., *PIC Based Automatic Solar Radiation Tracker*, MSc.College of engineering, University of Thapar, Patila (Punjab), 2008.
 - 7) Jack H., Automating manufacturing systems with PLCs, *Published by The Free Software Foundation*, USA, 2nd Ed, 2005
 - 8) 0BA6, Simatic LOGO! Manual, Siemens, 2009.
 - 9) [Http: // Chuck-Wright .com /projects / PV- measures .html](http://Chuck-Wright.com/projects/PV-measures.html)
 - 10) Solar Cells, Panasonic Technical Handbook, 98/99.
 - 11) [Http: // earth.google.com / download-earth .html](http://earth.google.com/download-earth.html).