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A Programmable Logic Controller to Control Two Axis Sun Tracking System

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Abstract: This study describes a system that uses the Programmable Logic Controller (PLC) to control the motion of a two-axis sun-tracking surfaces. The present study was conducted to monitor the performance of system and measure long-term values of global solar radiation on moving surfaces in Amman, Jordan. Results are compared with those on a fixed surface tilted at 32° towards south. Preliminary measurements indicated that the use of two-axis tracking would increase daily energy collection by more than 40%. The designed system operated smoothly with precise positioning even in adverse weather conditions.

Key words: Programmable logic controller, open loop control, two-axis tracking, electromechanical system, solar radiation measurements

INTRODUCTION

Jordan imports most of its energy demands in the form of crude oil and petroleum products. In the year 2005, the cost of consumed energy reached 40% of total export earnings (Ministry of Energy and Mineral Resources, Energy, 2005).

This caused a big burden on the national economy. The problem is expected to get worse since energy demand is growing at a rate of 5.2% per year. One of the solutions to this problem is to utilize Jordan's renewable energy resources like solar energy. Currently, its share in total energy consumption is only 2%. It is expected that with increasing scientific and technological capacities in the field of renewable energy in Jordan, this share will rise up to 15% in the year 2010 (Agend 21, Preliminary Report prepared by Several Organizations, 2006).

Jordan is blessed with excellent solar energy resources. In the desert region, which covers more than 80% of the country, the average global solar radiation on horizontal surfaces is 5.5 KW m^2 d^{-1} and the annual sunshine duration is 3000 h (Mamlook *et al.*, 2001). Hence, solar energy has a great potential in Jordan. A very promising application is its use for space heating and cooling (Nijmeh and Baker, 2000). Another vital application is solar water desalination. This contributes partly in solving Jordan's severe shortage of fresh water resources. Some of the new methods being studied are the photovoltaic (PV) Reverse Osmosis (RO) desalination. Mohsem and Jaber (2001) investigated its utilization in Jordan. Their work shows that most sites studied have a favorable application towards PV-powered RO desalination. Other applications being considered include solar water pumping (Hammad *et al.*, 2000a) and solar electric power generation for remote Badia regions (Hammad *et al.*, 2000b)

Sun tracking could be applied in most types of high temperature thermal and electric solar systems to increase their efficiency. For example, photovoltaic panels could be oriented in varying degrees to track the sun to increase their power output by more than 20% (Barakat *et al.*, 2001). Khalifa and Al-Mutwali (1998) performed an experimental study to investigate the effect of using a two-axis sun-tracking system on the thermal performance of compound parabolic concentrators. The tracking concentrators showed a better performance with an increase in the collected energy of up to 75% compared with an identical fixed collector. Poulek and Libra (2000) presented a new polar axis tracking soft concentrator which could double solar energy gain of PV panels in comparison with fixed ones. Early results show that on a clear day in Prague, an energy surplus of 107% was observed.

An accurate long-term knowledge of the available solar radiation is essential for the design and development of tracking and fixed solar systems. Such knowledge was not addressed in Jordan. Only few places posses measured data of hourly global solar radiation on horizontal surfaces. Data on moving and fixed tilted surfaces are non-existent. This had directed us to conduct the present study that involves in the first stage:

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- Design and construction of a two-axis sun-tracking PLC system.
- Measurement and comparison of long-term values of hourly and daily global solar radiation on tracking and fixed surfaces in Amman (latitude: 32 N; longitude: 36 E; altitude: 980 m).

CONTROL METHOD

Various methods are used for the control of solar tracking systems, most of which are complex and costly. The classical method depends on the existence of photo-sensors. They discriminate the position of the sun and send signals to the controller to actuate the motor to track the sun. This closed loop method of control was used by the majority of researchers, for example in works (Khalifa and Al-Mutwali, 1998; Poulek and Libra, 2000; Hession and Bonwick, 1984; Shinni and Rumala, 1986).

In this study, we presented an alternative method based on the PLC system. It is an open control method. The PLC has a programmable memory in which instructions are stored to implement various functions used to control the actuation of processes. A designed program is included in the PLC system to determine the positions of the tracking surfaces which are functions of time. The program leads the actuator, which in turn moves the tracking surface into the required positions.

Mathematically, the surface position is defined by two angles β and γ. Where β is the slope of the surface and γ is the surface azimuth angle. For two-axis tracking, the required surface positions are determined as follows (Duffie and Beckman, 1991):

$$\beta = \theta_z \quad (1)$$

and

$$\gamma = \gamma_s \quad (2)$$

where:

θ_z is the zenith angle of the sun.

and:

γ_s is the sun-azimuth angle.

In this study, two tracking motors were used. One for the joint rotated around the horizontal axis to control β and the other for the joint rotated around the vertical axis to control γ.

THE SYSTEM (ELECTROMECHANICAL)

The electromechanical system consists of two drivers to achieve two-axis tracking. The system for vertical rotation control is shown in Fig. 1. This system has two bridge rectifiers. The first one, PS1, converts the 220 V AC of supply network into 24 V DC to power the PLC1 system. The second rectifier, PS2, converts 220 V AC into 24 V AC to supply the electrical motor M1.

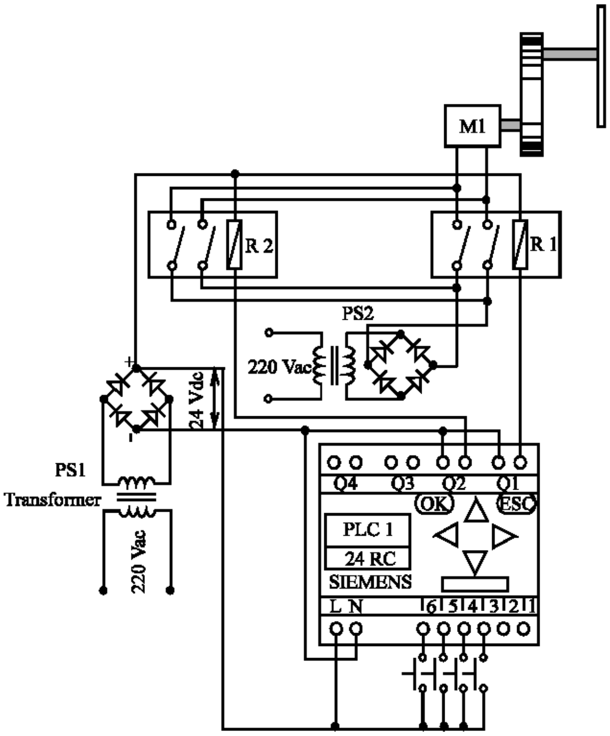


Fig. 1: Electromechanical system circuit for vertical rotation control

The PLC system was chosen of the LOGO 24 RC type because it is well suited for this application. In addition, it is fairly simple and inexpensive. LOGO 24 RC has six inputs of which only four were actually used. These are as follows:

I_1 - Push button to start automatic mode of tracking.
I_2 - Push button to stop tracking.
I_3 - Switch for manual operation of tracking in the forward direction. It is used to adjust the system.
I_4 - Switch for manual operation of tracking in backward direction.

In addition, LOGO 24 RC has four outputs of which only two were used. These are as follows:

Q_1 - It represents the forward direction of motion through the relay R1.
Q_2 - It represents the backward direction of motion through the relay R2.

The system for the horizontal rotation is similar to that shown in Fig. 1, except that it is designed to drive the tracking system, by means of a 36 V DC motor M2 and a worm gear (Fig. 2). The system for the vertical rotation used 24 V AC motor and a spur gear.

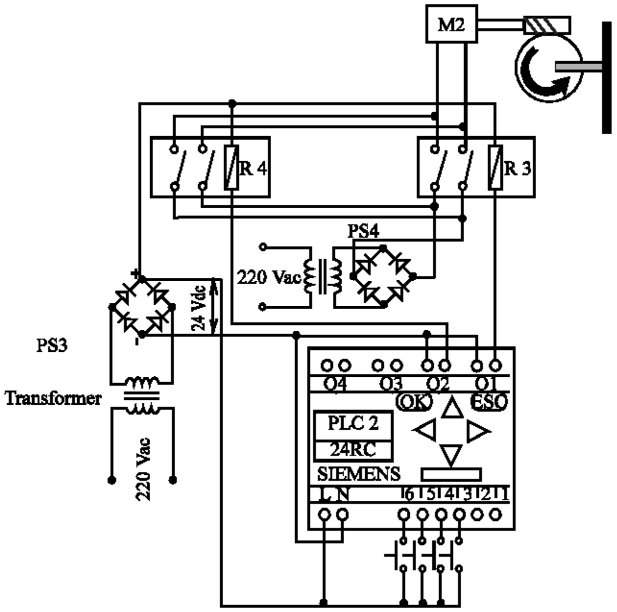


Fig. 2: Electromechanical system circuit for horizontal rotation control

Our electromechanical sun-tracker is characterized by uncomplicated electromechanical programmable logic control system. This reduces cost, maintenance and possibility of failures. In addition, it could be easily installed and operated.

THE CONTROL SYSTEM

Computer software was developed to determine the different solar angles and the optimal positions of the tracking surfaces during daylight hours. Daylight hours were divided into four time intervals as shown in Fig. 3, during which the required motors speeds (deg $\sec^{-1}$) were determined. Next, the PLC programming was performed based on solar angles and motor speed calculations.

This controls the intermittent position adjustments made by the motors. The two motors will be idle for 5 to 10 min and work only for few seconds. This stepwise tracking simplifies the work of the electromechanical system without great loss in power. The motors will work only for few minutes during the whole day. The estimated consumed power by the electric motor and control system is less than 2% of the collected energy.

The LOGO 24 RC PLC system uses the functional diagram language of programming described in (Mandado *et al*., 1996; Seimens Company Catalogue of LOGO PLC 24 RC, 2006). The program of the horizontal axis tracking system is represented in Fig 4. It consists of two parts related to the forward and backward motions of

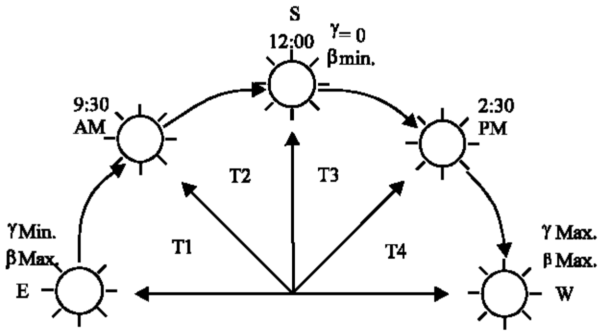
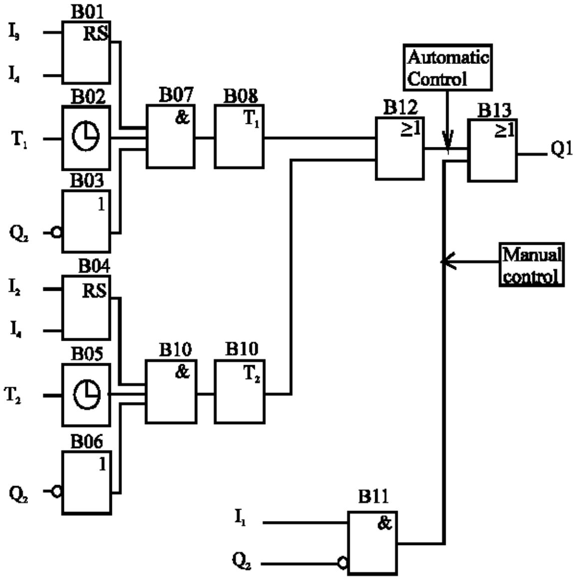


Fig. 3: Division of daylight hours into four time intervals

a) Forward program



b) Backward program

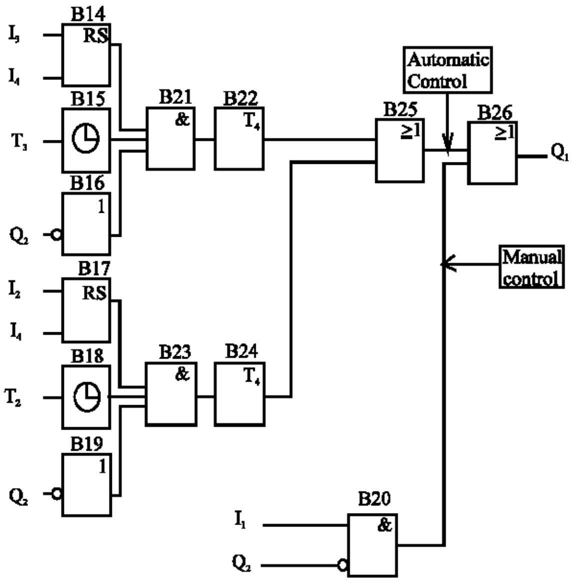


Fig. 4: Functional program of horizontal axis tracking system

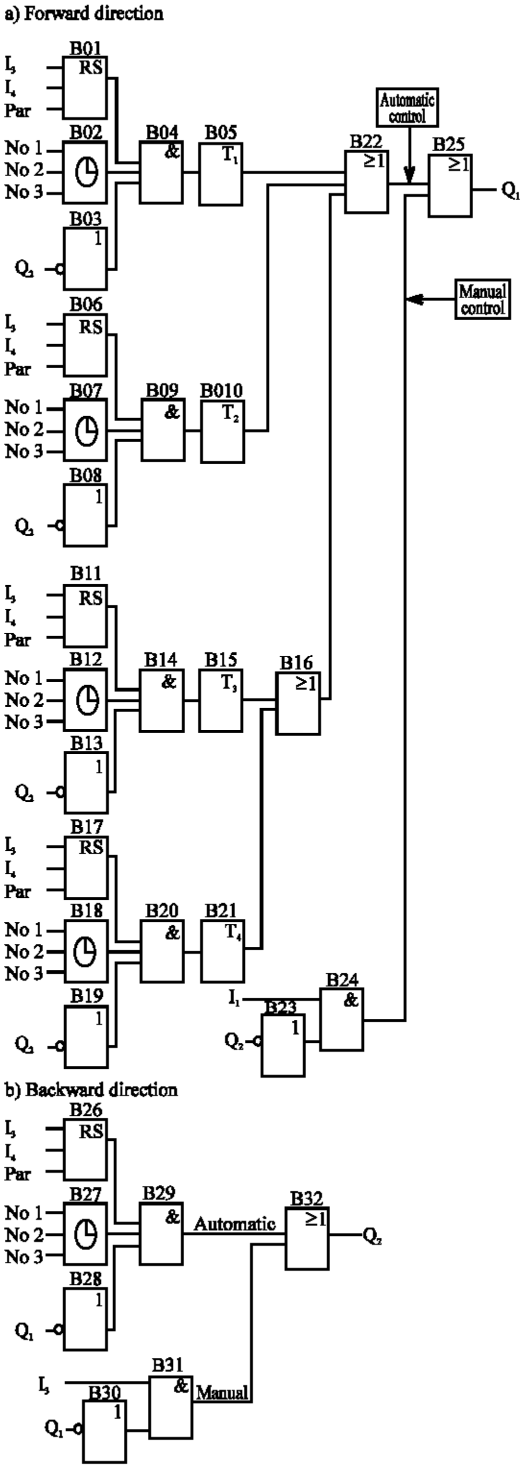


Fig. 5: Functional program of vertical axis tracking system

the tracking surface. The forward motion spans the intervals of time T_1 and T_2, during which β decreases from maximum until it reaches minimum at noon. Then, β will increase until maximum value is attained at sunset. The backward motion will cover the remaining time intervals, T_3 and T_4. The blocks B02, B05, B15 and B18 are clocks that cover the four times intervals mentioned above. The clocks actuate recyclers B08, B10, B22 and B24, respectively, which represent on-off timers. The clocks must be adjusted to the calculated positions function of time. For example, the clock B02 is set to be active in T_1, which in turn will activate recycler B08 during this interval of time. The recycler will operate the motor for 2 sec and turn it off for 7 min.

The PLC two-part program of the vertical tracking sub-system is shown in Fig. 5. In this case, the forward motion covers all intervals of time T_1, T_2, T_3 and T_4. This can be easily deduced from calculations of γ. The clock B27 will operate the vertical tracking motor in the backward direction after sunset, so that the surface is in the optimal position at the next sunrise.

RESULTS

Tests were carried out in May 2006 at the Renewable Energy Laboratory of the Applied Science University-Amman, Jordan. In this study, two pyranometers (Kipp and Zonen) are mounted on the two-axis tracking and fixed surfaces. The pyranometers are connected to data logger which in turn connected to a computer. Radiation measurements are recorded every 5 min and stored. Collected data is processed using Microsoft Excel. The data presented in this paper was conducted for the period 9, 12-14 May 2006. The measured solar radiation values in W m^{-2} are averaged and multiplied by 3600 to obtain the total hourly solar radiation which is MJ m^{-2} as shown in

Table 1: Measured daily total solar radiation in MJ m^{-2}

Date	2-axis tracking	Fixed at the rate of 32 latitude	Gain (%)
09/05/2006	40	27	48
12/05/2006	28	21	33
13/05/2006	35	24	46
14/05/2006	36	26	38
Average	35	25	41

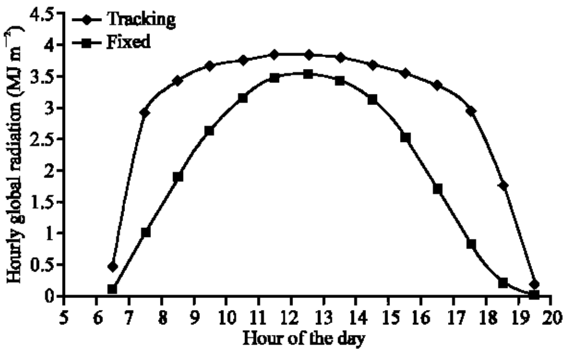


Fig. 6: Comparison of hourly global solar radiation

Fig. 6 for the 9 of May 2006. It can be seen from Fig. 6, that the pattern of hourly variations is typical of a cloudless day and that largest gains occur early and lately in the day.

The hourly values are added to obtain the total daily solar radiation as shown in Table 1. Comparison is made between tracking and fixed surfaces based on percentage gain in daily energy collection. It is noted that the smallest gain (33%) is on 12 of May due to partly cloudy weather conditions and the average percentage gain for the period considered is 41%.

CONCLUSIONS

A detailed description of an electromechanical sun-tracker PLC system has been presented. The system used the PLC method of control to achieve two-axis tracking. The tracker was characterized by a mechanical set-up and PLC system. During its relatively short time of operation, it proved to be fairly precise and reliable, even in adverse weather conditions. Preliminary results indicated that the use of two-axis tracking will increase total daily energy collection by as much as 41% comparing with 32° tilted fixed surface. This gain is very significant as predicted. Also a work has been done that includes measurement and comparison of power output of PV panels mounted on tracking and fixed surfaces using fuzzy logic (Mamlook *et al*., 2005). Early results showed similar gains in output (Mamlook *et al*., 2003).

REFERENCES

Agend 21, Preliminary Report Prepared by Several Organizations, 2006. Amman, Jordan.

Barakat., B., H. Rahab, B. Mohammed and N. Naiit, 2001. Design of a tracking system to be used with photovoltaic panels (Arabic). Proceedings of the 4th Jordanian International Mechanical Engineering Conference JIMEC, Amman, pp: 471-488.

Duffie, J. and W. Beckman, 1991. Solar Engineering of Thermal Processes, 2nd Edn., J. Willy and Sons.

Hammad, M., Y. Etaibi and M. Altaani, 2000a. Characteristics of solar water pumping in Jordan. Proceedings of the International Conference of Energy Systems, Amman, pp: 4-19.

Hammad, M., S. Habali and M. Altaani, 2000b. Design, construction and operation of a multi-purpose solar electricity power supply. Proceedings of the International Conference of Energy Systems, Amman, pp: 1-3.

Hession, P. and W. Bonwick, 1984. Experience with a sun tracker system. Solar Energy, 32: 3-11.

Khalifa, A. and S. Al-Mutwali, 1998. Effect of two-axis sun tracking on the performance of compound parabolic concentrators. Energy Conver Manage., 39: 1073-1079.

Mamlook, R., B. Akash and S. Nijmeh, 2001. Fuzzy sets programming to perform evaluation of solar systems in Jordan. Energy Conver. Manage., 42: 1717-1726.

Mamlook, R., S. Nijmeh and S.M. Abdallah, 2003. Sun tracking programmable logic control system. ACIT'2003 The International Arab Conference on Information Technology, Arab Academy for Science and Technology and Maritime Transport, Egypt, December 20th-23rd.

Mamlook, R., S. Nijmeh and S.M. Abdallah, 2005. Photovoltaic sun tracking programmable fuzzy logic control system. SCSC: Summer Computer Simulation Conference, Philadelphia, USA, July 24-28.

Mandado, E., J. Marcos and S. Perez, 1996. Programmable Logic Devices and Logic Controllers, 1st Edn., Prentice-Hall.

Ministry of Energy and Mineral Resources, Energy 2005-Facts and Figures, 2006. Amman, Jordan.

Mohsem, M. and J. Jaber, 2001. A photovoltaic-powered system in water desalination. Desalination, 138: 129-136.

Nijmeh, S. and N. Baker, 2000. Bioclimatic design strategies for buildings in Amman, Jordan. Proceedings of World Renewable Energy Congress VI (WREC2000), Brighton, pp: 524-529.

Poulek, V. and M. Libra, 2000. A new low-cost tracking ridge concentrator. Solar Ener. Mat. Solar Cells, 61: 199-202.

Seimens Company Catalogue of LOGO PLC 24 RC, 2006.

Shinni, S. and N. Rumala, 1986. A shadow method for automatic tracking. Solar Energy, 37: 245-247.