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Efficiency improvements of photo-voltaic panels using a Sun-tracking system

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Abstract

This paper presents a Sun-tracking design, whereby the movement of a photo-voltaic module was controlled to follow the Sun's radiation using a programmable logic-controller (PLC) unit. All electronic circuits and the necessary software have been designed and developed to perform the technical tasks. A PLC unit was employed to control and monitor the mechanical movement of the PV module and to collect and store data related to the Sun's radiation. It is found that the daily output power of the PV was increased by more than 20% in comparison with that of a fixed module. The PV-tracking system can be employed as a stand-alone device and it could be connected to a personal computer through the RS232 serial port to monitor the whole process on a computer screen.

Keywords: Photovoltaic; Tracking system; PLC

1. Introduction

A solar collector or photo-voltaic module receives the maximum solar-radiation when the Sun's rays strike it at right angles. Tilting it from being perpendicular to the Sun will result in less solar energy collection by the collector or the module. Therefore, the optimal tilt angle for a solar energy system depends on both the site latitude and the application for which it is to be used. Many solar applications are

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mounted either on a fixed rack or on a tracking rack. Fixed collectors or modules producing heat or electricity throughout the year are usually installed and tilted at an angle equal to the latitude of the site in which the collector or module faces directly the Sun. Of course, the optimal position is suitable for the time when the Sun is at midpoint in the sky (i.e. spring and fall seasons). The energy collected by the solar system in both winter and summer is far less due to several reasons such as clouds in winter and temperature scattering in summer in addition to the Sun's changing altitude. But nevertheless in such cases, it is desirable that the average yearly collection of energy is maximized (i.e. the angle position of the collector or module is adjusted to receive maximum energy).

A Sun-tracking mechanism increases the amount of solar energy that can be received by the solar collectors or photo-voltaic modules: consequently this would result in a higher daily and annual output power harnessed. The use of a tracking system is more expensive and more complex than fixed mounts: however they can become cost-effective in may cases because they provide more power output through out the year and in many cases this increase exceeds 25% [1]. Commercially, tracking systems are available either as a single-axis or a dual-axis design. The single-axis tracker follows the Sun's apparent east-to-west movement across the sky, while the dual-axis tracker, in addition to east–west tracking, tilts the solar collector or module to follow the Sun's changing altitude angle.

To investigate the improvement in the daily output power of a photo-voltaic module, a single-axis Sun-tracking system was designed based on a programmable logic controlling unit. A suitable controlling program was also developed to accomplish the control operation with the possibility of implementing this arrangement as a data-acquisition system for solar radiation values during daytime.

2. System hardware

This consists of the following main parts.

2.1. Programmable logic controller (PLC)

A PLC type PS4-201 MM1 was purchased from Klockner Moeller. This unit is considered to be the heart of the Sun-tracker system [2]. It consists of:

- Eight digital inputs with galvanic isolation.
- Six digital transistor type outputs with galvanic isolation.
- Two analog inputs (0→10 V). These can be converted internally to digital ones by using a 10 bit analog to digital converter with a resolution of 9.7 mV.
- One analog output (0→10 V) with a resolution of 2.44 mV.
- Special connector for serial communication with the PC through the serial connection RS232.
- Special connector RS485 for the interface with an integrated control network.
- 32 kbytes dynamic memory divided into two parts. The first was used to store the operation program (control, monitor and sampling), while the second part was

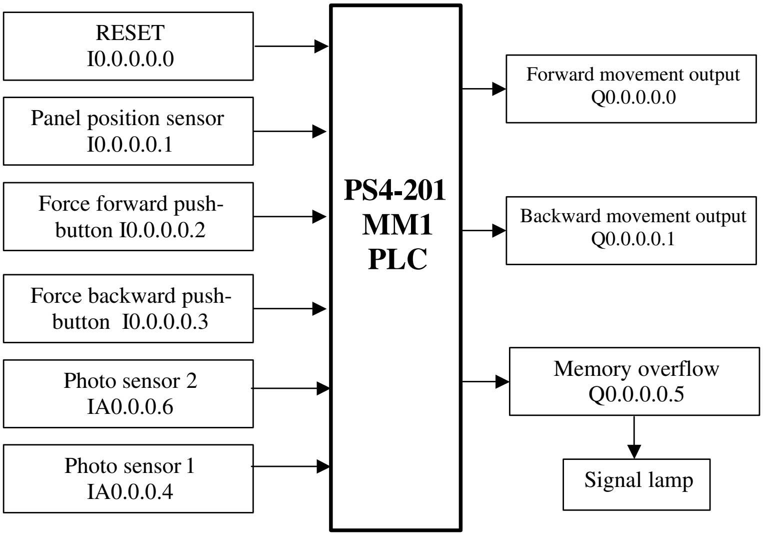


Fig. 1. PLC inputs and outputs.

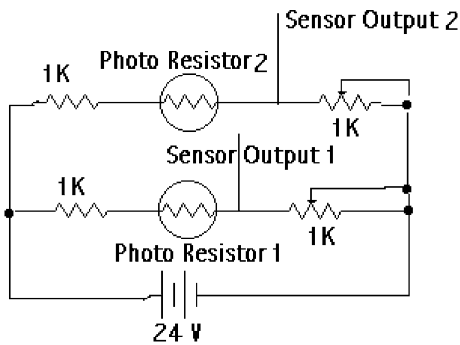


Fig. 2. Signal-processing unit.

used as storage locations for readings taken from one of the photo sensors and also for the communication commands with the personal computer.

Fig. 1 represents the input/output values applied to the various inputs of the PLC.

2.2. Sensors and signals processing unit

Two symmetric photo-resistors were used to track the Sun's position. The photo-resistors were positioned on the same holder of the PV solar module, and were separated by a solid barrier to provide shadowing for one of the resistors. The physical values of the resistors decrease when the sunlight is incident on their surfaces.

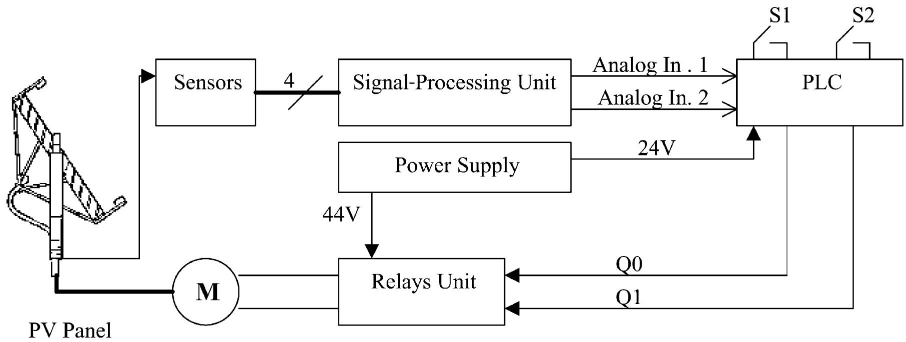


Fig. 3. The whole system block-diagram.

Fig. 2 illustrates the electronic-circuit diagram of the signals-processing unit.

When the solar-radiation intensity increases, the resistivity of the photo-resistor decreases, and consequently the voltage drop across this resistor decreases. As a result, the voltage drop across the variable resistor (1 K) increases. This will produce a direct relationship between the incident solar-radiation intensity and the corresponding voltage-drop across the resistor. The two output signals of this unit are connected directly to the analog inputs of the PLC, which in turn compares the two signals and produces a proper output signal to activate an electromechanical Sun-tracking movement.

2.3. Photo-voltaic panel and electro-mechanical movement mechanism

The photo-voltaic module used in this project was a "SM50_18A2" from SIEMENS. The module consists of 36 solar cells connected serially. The output voltage of each cell is 0.6 V: this produces an estimated output of about 17 V–50 W. This is of course under standard test conditions (STCs) of solar intensity = 1000 W/m^2, cell temperature = 25 °C and air mass = 1.5.

Fig. 3 shows the block diagram of the whole system.

The system can be controlled manually or automatically. S1 and S2 are push buttons for manual operation. In this case, the PLC releases a proper output on Q0 or Q1 which are connected to the coils of two relays in order to move the solar panel in the direction of the Sun's movement or in the reverse direction. However, in the automatic operation mode, the PLC compares the values of its two analog inputs, that come from the signals-processing unit, and then produces the correct output on Q0 or Q1.

2.4. System power supply

Fig. 4 shows a switching-mode power supply for the tracking system.

Implementation of the switching-mode technology resulted in a power-supply unit with high efficiency and low losses. The design of this unit is based solely on the L4960 switching regulator which provides a voltage output between 5.1 and 40 V

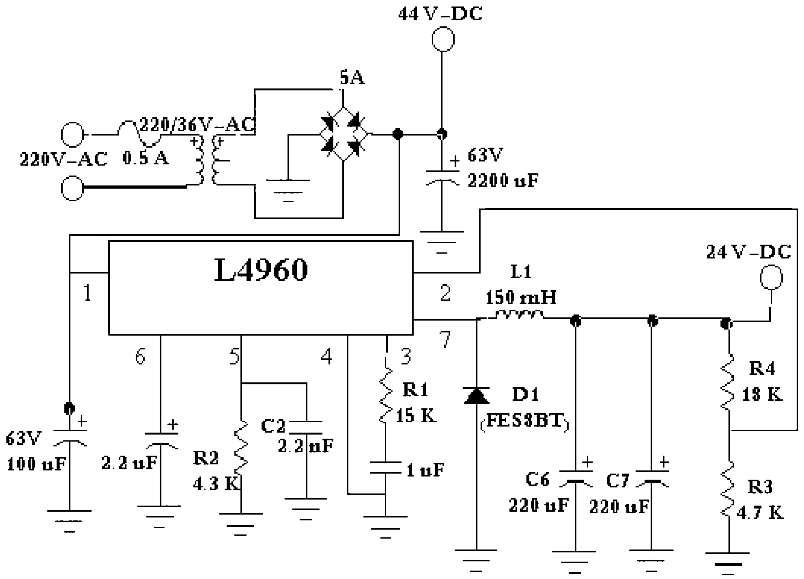


Fig. 4. Switching mode power-supply for the Sun-follower system.

Table 1

Output voltage (V)	R3	R4
12	4K7	6K2
15	4K7	9K1
18	4K7	12K
24	4K7	18K

and a driving current of 2.5 A [3]. The circuit produces a regulated DC-voltage output within the range of 12→24 V according to the values of the two resistors R3 and R4 as illustrated in Table 1.

Values of R3 and R4 were chosen to provide 24 V DC-voltage to feed the PLC. The voltage 44 V DC was derived directly from the rectifier bridge to supply the DC motor used for stimulating the mechanical movement.

3. System software

The system-control program consists of the following two main parts.

3.1. PLC control and monitoring program

A proper program to control, monitor and to collect data was developed using special software called SUCOSOFT S40 [4]. The program performs the following duties.

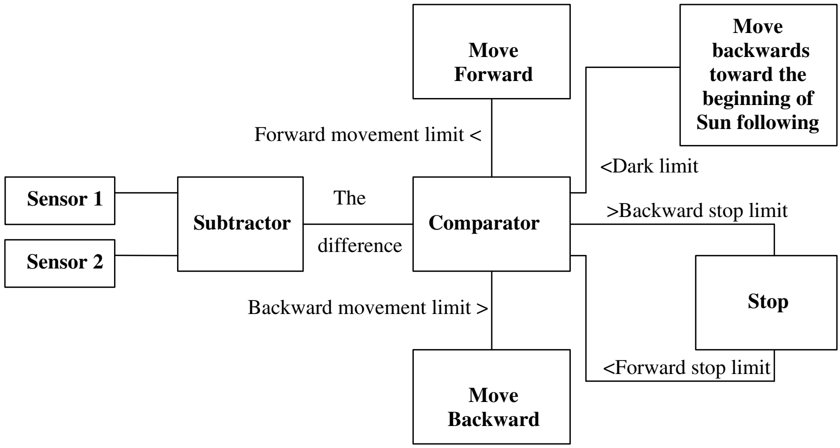


Fig. 5. The logic consequences of the controlling process.

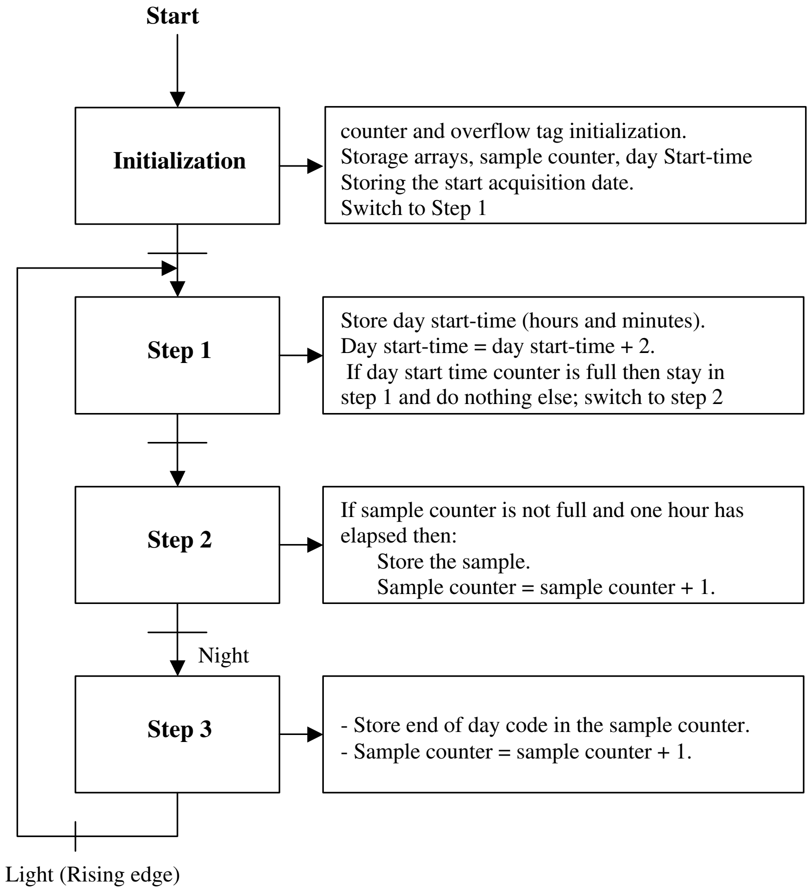
- Controls the tracking system movement: the logic consequences for the controlling process are illustrated in Fig. 5.
- Monitors the PLC inputs and outputs: the main duty of this subroutine is to copy the status of the PLC inputs and outputs to specific positions within the memory called the Markers Range so that the PC monitoring program can directly read the input/output status from this memory range at any time.
- Samples storage: an on-line sample storage process, for reading of the photo sensors, is carried out every hour via a special array inside the data-storage RAM. This process is executed only during the daytime and stops at night until the sunrise of the next day. At the beginning of each day, the starting time (hours and minutes) is stored in a separate array to be displayed later on the PC's screen. When the memory RAM is full, the storage function is stopped until a reset process is carried out to clear the stored data.

This part of the program was written using a sequential functioning chart (SFC) programming. The algorithm of this process is illustrated in Flowchart 1.

3.2. PC monitoring and data-handling program

A special computer program was developed using an object-oriented programming language (VISUAL BASIC 5). This program handles the following:

- Automatic detection of the RS232 PC port (com1, 2, 3 or 4) with which the PLC is connected.
- System monitoring: determines the actual position and the direction of movement of the photo-voltaic module and displays the two photo-sensors' readings and the memory overflow tag.
- Compulsory forward-and-backward movements of the module in the case of any unexpected situation.
- Displays the Sun's tracking settings that are stored inside the PLC memory (i.e. forward- and backward-movement limits, dark limit, forward-and-backward stop



Flowchart 1. Sequential functioning chart for storage process.

limits) with the possibility of modulating these settings without the need to access the software of the PLC.

- Displays the values of the photo-sensor readings that are stored in the PLC's RAM during the operation cycle of the PLC and also stores these values in a special file. In addition, printing and plotting the stored values on daily bases are other tasks for this program to perform.

Fig. 6 shows the control and monitoring screen of the overall operation of the tracking system.

4. Experimental results and discussion

The performance of the designed Sun's tracking-system has been tested and was found to operate well. The movement of the PV module following the Sun's incident

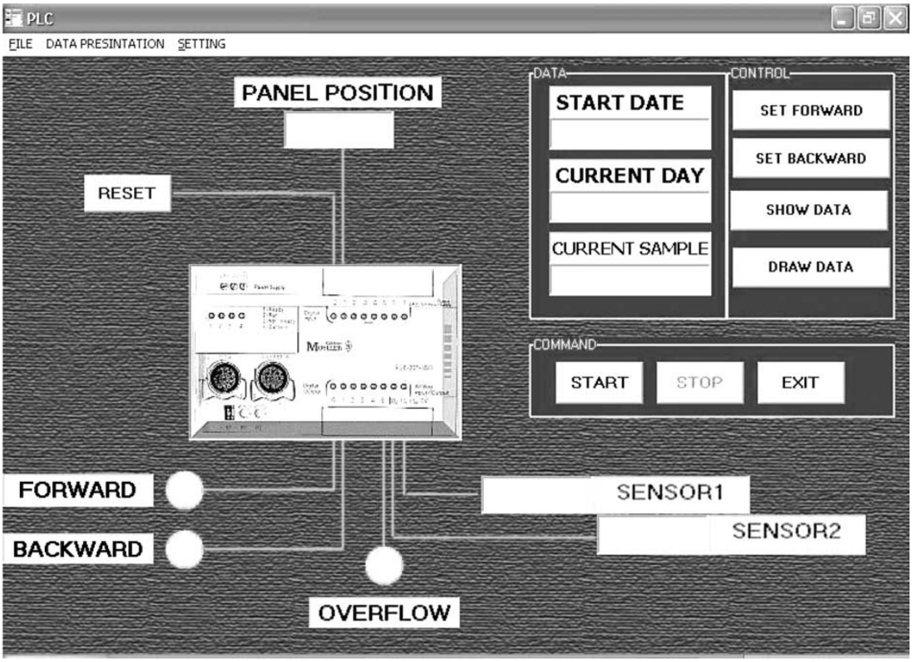


Fig. 6. Control and monitoring screen.

radiation was smooth and without any time-lag. The process starts when a shadow is developed on one of the two resistors causing a resistivity difference. This difference is converted to a voltage applied directly to the analog inputs of the PLC. The tracker scans an angle of about 120° east–west every day, and it stops tracking and returns to its starting point automatically at the time when the value of the incident solar-radiation decreases to a very small value at sunset.

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 2000. The starting day was considered to be the first day of each month for this period. Readings were collected from 5:00 o'clock in the morning until 19:30 every day for both modes of operation (i.e. fixed and tracking). In the fixed position mode, the module was fixed at each time of measurement facing the south position with an altitude angle of 33° which is the optimal inclination in Damascus at this time of the year.

Fig. 7 shows an example of the module output's power gain as a function of time in both cases for the 14th of August 2000. As can be seen, the output power shows a considerable increase during the early and late hours of the day. In fact the overall improvement, in the case of the tracking mode, exceeded 40% for the period from 6:00 to 10:00 a.m. and for the period from 15:00 to 17:00 p.m. However, the improvement was about 2–4% during mid-day. This is attributed mainly to a decrease in the open-circuit voltage of the module caused by the temperature increase at this time of the day.

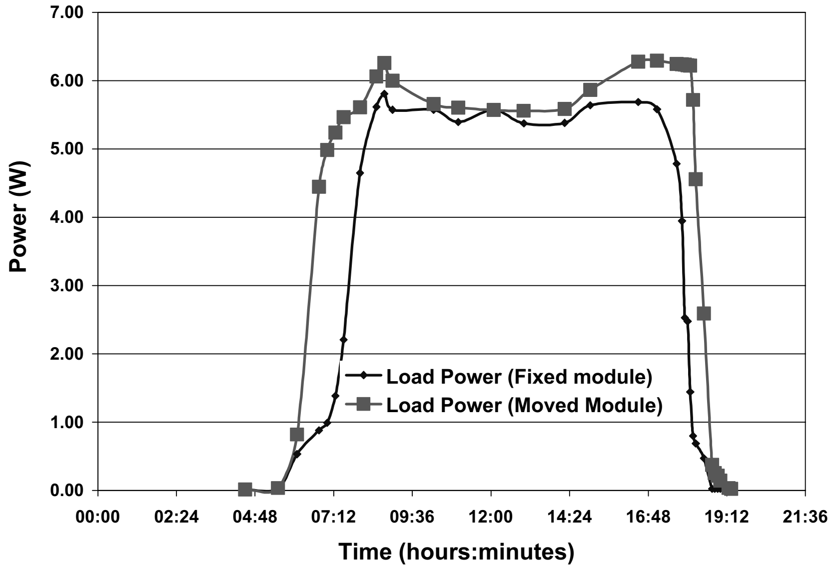


Fig. 7. Load power-curves (for fixed and movable modules).

Fig. 8 shows the output-power improvement of the module (i.e. the difference between the load power curve for both tracking and fixed mounts). To determine the exact value of the power gain for the system, the ratio of the areas under the two curves, shown in Fig. 7 (i.e. the area of the tracked module over the area of the fixed module) was calculated using a numerical integration. The gain in the photo-voltaic

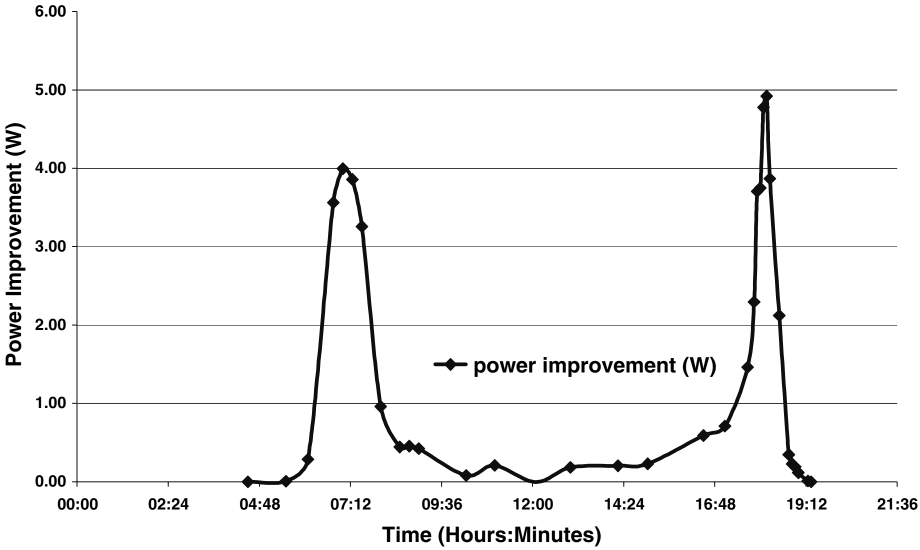


Fig. 8. Power improvement during various periods of the day.

collector output power was found to be better than 66% from 6:00 a.m. until 8:45 a.m., 3% from 8:45 a.m. until 4:30 p.m., and better than 45% from 4:30 p.m. until 6:30 p.m. The average overall improvement during the whole day was better than 20%. The previous measurements represent an ideal case for most of the summer-season days. The deviation in these measurements was less than $\pm 2\%$.

Although, the implementation of PLC technologies for controlling tracking systems and monitoring PV solar panels is more expensive and more complex than for fixed ones, it becomes cost-effective when used for controlling applications having a large number of modules at the same time, since more power can be provided throughout the year.

5. Conclusion

The first advantage of using the designed Sun-tracker system was the substantial improvement in the output power from the PV module. The overall daily output-power gain was increased by more than 20% compared to that for a fixed mounted system and it exceeded it by at least 40% for the period spanning morning and evening hours. Secondly, using the PLC unit as a controller allows the connection of many PV-modules in series or parallel connection. This technique reduces the costs of tracking systems and makes it a cost-effective technology.

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