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Research Article

Design and Implementation of Microcontroller Based Automatic Solar Radiation Tracker

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Abstract

Solar energy is rapidly becoming an alternative means of electricity source. Fossil fuels are seriously depleting, thus the need for alternative energy source is a necessity. To make effective use of solar energy, its efficiency must be maximized. A feasible approach to maximizing the power output of solar array is by sun tracking. This paper therefore presents the design and construction of a solar tracking system that position the solar PV panel in proper orientation with the sun so as to always receive direct radiation. The prototype is designed around a programmed microcontroller which controls the system by communicating with the sensors and motor driver based on the movement of the sun. Automatic Sun Tracking System is a hybrid hardware/software prototype, which automatically provides best alignment of solar panel with the sun, to get maximum output (electricity). By doing this, the efficiency of the panel can be increased by as much as 15 – 25%.

Keywords: *Solar panel, Microcontroller, DC Servo motor, LDR sensor, Sun tracking software.*

1. Introduction

Renewable energy resources will be an increasingly important part of power generation in the new millennium. Besides assisting in the reduction of the emission of greenhouse gases, they add the much- needed flexibility to the energy resource mix by decreasing the dependence on fossil fuels. Among the renewable energy resources, solar energy is the most essential and prerequisite resource of sustainable energy because of its ubiquity, abundance, and sustainability. Regardless of the intermittency of sunlight, solar energy is widely available and completely free of cost. Recently, photovoltaic (PV) system is well recognized and widely utilized to convert the solar energy for electric power applications. It can generate direct current (DC) electricity without environmental impact and emission by way of solar radiation. The DC power is converted to AC power with an inverter, to power local loads or fed back to the utility. Being a semiconductor device, the PV systems are suitable for most operation at a lower maintenance costs.

The sun is the prime source of energy, directly or indirectly, which is also the fuel for most renewable systems. Among all renewable systems, photovoltaic system is the one which has a great chance to replace the conventional energy resources. Solar panel directly converts solar radiation into electrical energy. Solar panel is mainly made from semiconductor materials. Si used as the major component of solar panels, which is maximum 24.5% efficient. Unless high efficient solar panels are invented, the only way to enhance the performance of a solar panel is to increase the intensity of light falling on it. Solar trackers are the most appropriate and proven technology to increase the efficiency of solar panels through keeping the panels aligned with the sun's position. Solar trackers get popularized around the world in recent days to harness solar energy in most efficient way. This is far more cost effective solution than purchasing additional solar panels.

In this paper the design methodology of a microcontroller based simple and easily programmed automatic solar tracker is presented. A prototype of automatic solar tracker ensures feasibility of this design methodology.

2. The sensing and tracking system

The principle of operation of a PV cell is shown in Fig.1. The most abundant and convenient source of renewable energy is solar energy, which can be harnessed by photovoltaic cells. Photovoltaic cells are the basic of the solar system. The word photovoltaic comes from "photo" means light and "voltaic" means producing electricity. Therefore, the photovoltaic process is "producing electricity directly from sunlight". The output power of a photovoltaic cell depends on the amount of light projected on the cell. Time of the day, season, panel position and orientation are also the factors behind the output power.

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The current-voltage and power-voltage characteristics of a photovoltaic cell are shown in Fig. 2. Photovoltaic cells are the smallest part of a solar panel. Solar panel gives maximum power output at the time when sun is directly aligned with the panel.

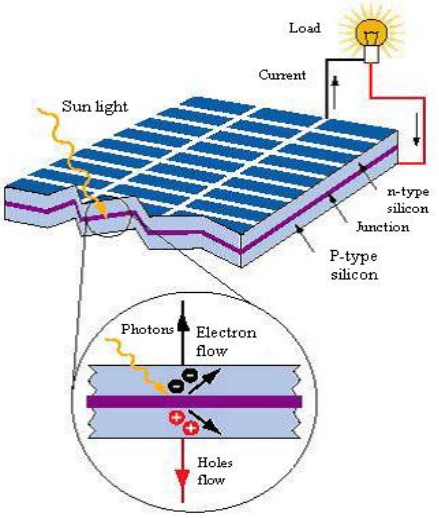

Fig.1 Principle of photovoltaic cell

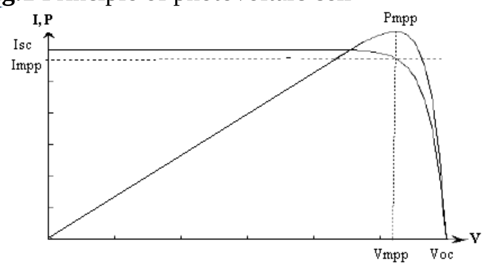

Fig.2 I-V and P-V characteristics of PV cell

Various methods have been implemented and used to track the position of the sun. The simplest of all uses an LDR – a Light Dependent Resistor to detect light intensity changes on the surface of the resistor. Other methods, such as that published by Jeff Damm in “Home Power” [03], use two phototransistors covered with a small plate to act as a shield to sunlight, as shown in Fig. 3.

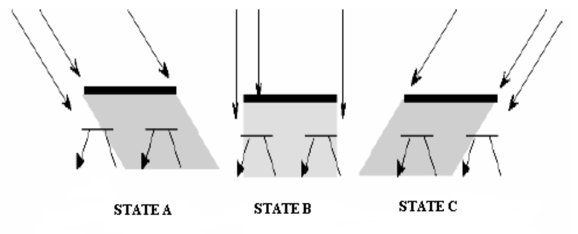

Fig.3 Operation of LDR

When morning arrives, the tracker is in state A from the previous day. The left phototransistor is turned on, causing a signal to turn the motor continuously until the shadow from the plate returns the tracker to state B. As the day slowly progresses, state C is reached shortly, turning on the right phototransistor. The motor turns until state B is reached again, and the cycle continues until the end of the day or until the minimum detectable light level is reached.

The problem with a design like this is that phototransistors have a narrow range of sensitivity, once they have been set up in a circuit under set bias conditions.

It was because of this fact that solar cells themselves were chosen to be the sensing devices. They provide an excellent mechanism in light intensity detection – because they are sensitive to varying light and provide a near-linear voltage range that can be used to an advantage in determining the present declination or angle to the sun. As a result, a simple RTC based control system is proposed, with the natural positioning of the sun with respect to time has been implemented as an algorithm to control the solar PV by controlling the DC servo motor.

3. Solar tracker system description

3.1 Mechanical system

After the solar panels and other components were selected, the overall structural design of the solar tracker as seen in Fig.4 was fabricated.

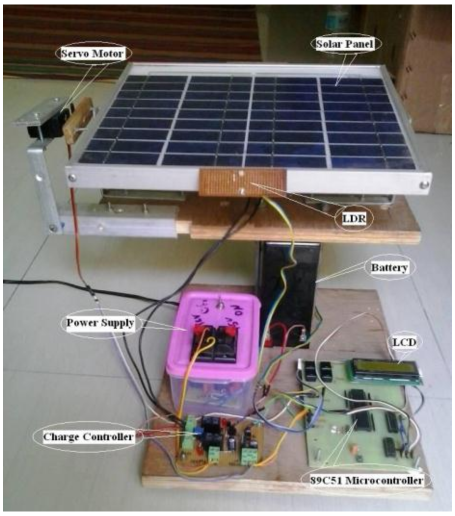

Fig.4 Actual solar tracker design

The entire structure was fabricated using the aluminum rods and plates. The pillar holding panel is aligned to the centre of the panel for better flexibility during the panel rotation. The tracker is designed to have a single-axis rotation (East to West), and the motor is mounted in such a way that the tracker systems have only a single-axis freedom of rotation. The fixture to hold the sensors are then assembled and aligned at both ends of the PV panel to sense the sun irradiance. The two mechanical stoppers at each ends were incorporated to limit the rotation of the panel.

3.2 Electrical system

The overall mechanical and electrical subsystems were integrated into the solar tracker system as shown in Fig. 5. The detailed design of the circuitry could be found. The block diagram of the solar tracker system consists of mostly electrical components. The solar tracker consists of the PV cells, the charge controller and the lead-acid battery. Other subsystems such as the LDR sensors, the voltage regulator, and the microcontroller target board were also used. The LDR sensors sense the sunlight intensity and send the signal to the microcontroller to rotate the PV panel via the servo motor. The electrical energy is then stored in the lead-acid battery that is later used to power the respective components

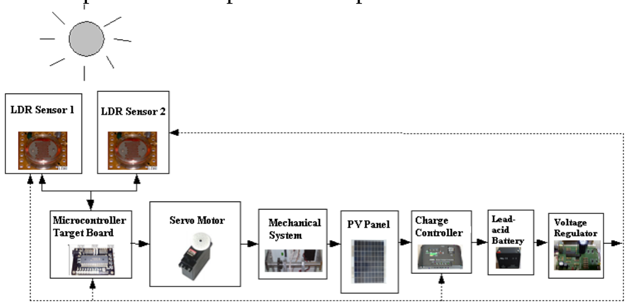

Fig.5 Actual solar tracker design

4. Functionality and mechanism of the system

To understand the principle of operation of solar tracking system, we present in this part a description of the diagram of figure 5.

4.1 Light dependent resistor (LDR)

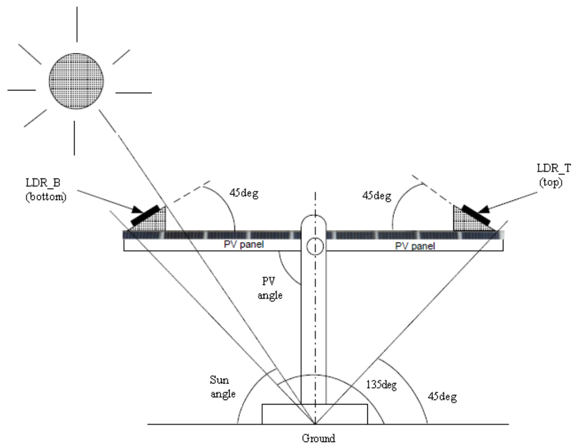

Fig.6 PV panel and LDR sensor angle position

The LDR sensor is a variable resistor that changes the resistance according to the intensity of incident ray illuminated onto it. As the intensity of sunlight changes, the resistance and the voltage of LDR sensors change. The output voltage across the resistor is converted into digital signal at the input of the microcontroller. Based on the TTL input, the DC servo motor rotates clockwise (CW) or counterclockwise (CCW).

The smart tracker panel was installed with two LDR sensors. Assuming both sensors are placed in parallel with the PV panel, the effective irradiance is similar. As the results, the smart tracker is unable to perform the proposed sun tracking algorithm. To circumvent this, the top and bottom sensors were positioned at 45° and 135° respectively as seen in Fig. 6. When the sunlight falls onto the PV panel, the LDR sensors generate different voltages to move the PV panel.

4.2 Control unit

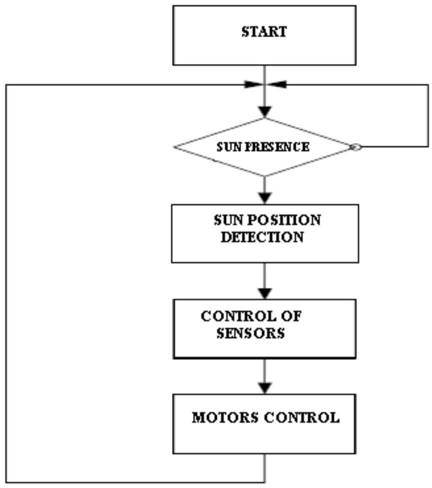

Fig.7 Cycle of Control

The control unit is the intelligent part of the system. It consists of a 89C51 microcontroller programmed out of C language. The system can communicate with the computer through the serial standard RS232. Fig. 7 describes in short the cycle of the system control.

The control unit receives data sent by the sensors in the form of a binary word coded on 10 bits. This binary word describes the sun presence sensors status, sun position sensors' and butted of race end status. The treatment of the data by the control unit lets the later send the suitable control signals towards the operative part.

4.3 Driving mechanism

The driving mechanism includes the servo motor and the pulley system. The servo motor was controlled using the microcontroller. The controller uses the PWM (Pulse Width Modulation) signal to drive the servo motor at a controlled speed correspond to a maximum voltage of 6V. The PWM wave is a continuous square wave signal that changes between 0V and 6V. The duration or width of the pulse determines the angle of the shaft's rotation. A voltage regulator circuit was used to bring the supply voltage down to a level suitable for use in the microcontroller, the charge controller and the LDR sensors. The microcontroller target board in the system was used to control the servo motor. It receives the signals from the LDR sensors. The analogue voltage is converted into digital signal (logic 1 or 0) for processing.

5. Operation of the solar tracker

There are three modes of operation in the solar tracker. They are namely: automatic, preset and manual mode. In the automatic mode, the microcontroller rotates the PV panel to balance the light intensity at both LDR sensors. In the case when both sensors receive a low voltage due to cloudy conditions, the PV panel is programmed to wait for 15 minutes and automatically switched to preset mode. In this mode, the PV panel is programmed to rotate 10° towards west in every 1 hour. If the extreme position towards the west is sensed (at sunset), the night return algorithm repositioned the panel to its initial home position facing the East (at sunrise). In the manual mode, it allows the panel to rotate to the desired angle by manually increasing or decreasing the angle via the input to the microcontroller. Once the PV panel is positioned to the desired angle, it switches back to the automatic mode.

In summary, the operation modes for the control of solar tracker and the features in these user options are given below.

5.1 Selection of mode

When the RST switch is pressed, the solar tracker will reset and waits for the user to select the manual mode (SW1), the automatic mode (SW2) or preset mode (SW3).

5.2 Manual mode

When the SW1 switch is pressed; the panel is allowed to rotate manually to a desired position. Once it is positioned, it switches back to the automatic mode.

5.3 Automatic mode

When the SW2 switch is pressed, it starts the tracking in "automatic mode". In this mode, the rotation of the PV panel depends on the LDR sensors.

5.4 Preset mode

When the SW3 switch is pressed, it starts the tracking in "preset mode". In this case, it rotates the panel in a pre-determined angle till the sunset.

5. Experimental results

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.

Table 1 Solar output of PV panel in fixed mode

Time of the day	Voltage (V)	Current (A)	Power (W)
9 am	13.47	0.44	5.93
10 am	15.25	0.45	6.86
11 am	15.45	0.46	7.11
12 pm	16.11	0.51	8.22
1 pm	18.11	0.57	10.32
2 pm	16.23	0.53	8.60
3 pm	15.78	0.49	7.73
4 pm	13.32	0.43	5.73
5 pm	12.04	0.33	3.97

To obtain this data, simple experiments were performed. The setups were installed on building roof top. The open-circuit voltage and the current readings were recorded using a multi-meter connected to the solar cells. The readings are as shown in Table 1 and Table 2

The value from PV panel in fixed mode and in tracking mode were measured and obtained at different hours of the day. This experiment was carried out on 20th and 21st October, 2013 between 9am and 5pm at 1 hour intervals. The readings are as shown below.

Table 2 Solar output of PV panel in tracking mode

Time of the day	Voltage (V)	Current (A)	Power (W)
9 am	16.07	0.47	7.55
10 am	16.42	0.51	8.37
11 am	16.41	0.51	8.37
12 pm	16.68	0.55	9.17
1 pm	18.06	0.57	10.29
2 pm	17.55	0.56	9.83
3 pm	16.87	0.55	9.28
4 pm	14.95	0.50	7.48
5 pm	14.19	0.37	5.25

The graphical representation of current and power output of both the fixed PV panel and the tracking PV panel against day time is shown in fig. 8 and fig. 9. It illustrates improvement in efficiency gained with using solar tracking system

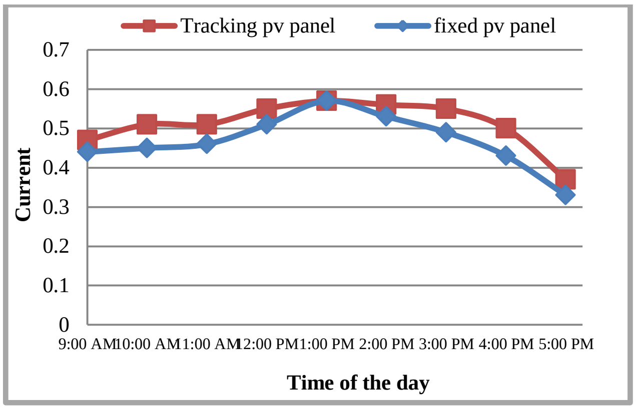

Fig.8 Output current of fixed and tracking PV panel

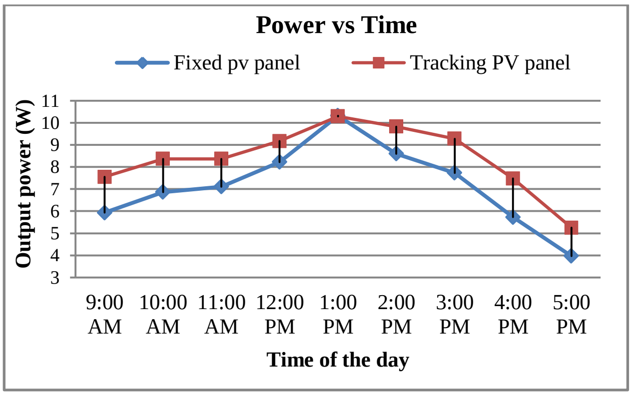

Fig.9 Output power of fixed and tracking PV panel

From the graph, it can be seen that solar intensity increases with day time to maximum at 1pm and then starts decreasing. Some fluctuations notable in the graph were as a result of some cloudy sky and abnormal atmospheric condition. The percentage increase in solar power output gained is tabulated below.

Table 3 Solar output of PV panel in fixed mode

Power obtained by tracking mode	Power obtained by fixed mode	Percentage gain
7.55	5.93	27.32%
8.37	6.86	22.01%
8.37	7.11	17.72%
9.17	8.22	11.56%
10.29	10.32	0%
9.83	8.60	14.30%
9.28	7.73	20.05%
7.48	5.73	30.54%
5.25	3.97	32.24%

The table 5.3 shows the percentage power increase that is obtained from tracking the sun with respect to that obtained without tracking. It is seen that at a point the power output of both the solar panel with and without tracking are the same. This is as a result of both panels facing the sun at the same time.

Conclusion

In this project, the sun tracking system is developed based on microcontroller. The microcontroller based circuit is used in this system with a minimum number of components and the use of DC servo motors enables accurate tracking of the sun. After examining the information obtained in the data table section and in plotted graph, It has been shown that the sun tracking systems can collect maximum energy than a fixed panel system and high efficiency is achieved through this tracker, it can be said that the proposed sun tracking system is a feasible method of maximizing the light energy received from sun. This is an efficient tracking system for solar energy collection. The method implemented in this project is simple, easy to maintain and requires no technical attention for its operation. The software developed for this work can be used outside the mechanical part, thus it is flexible for future modification. The solar module with tracking system as demonstrated in the analysis achieves about 21% efficiency improvement over the static solar module. Hence implementation of this technique in building solar systems will greatly improve utility satisfaction.

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