Int. J. of Thermal & Environmental Engineering
Volume 2, No. 2 (2011) 103-106

Grid-Tied Solar Panel and Controller for Small Residential Applications

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Abstract

This paper presents a small photovoltaic system model to supply electricity to residential applications and reduce the electricity bill by reducing the dependence on the power utility company. The presented model includes a PV Silicon solar cells system with sun tracking capability, battery storage, a DC to AC inverter and a microcontroller. The system determines whether a certain residential load would be powered by the PV panel or the utility company. The PV system provides electrical energy to the residential load as the primary source of electricity. If the load demand exceeds the energy available by the photovoltaic system, the controller would switch on the utility power line to supply the load with the additional electricity required. If the load electricity demand dropped back below the energy available by the photovoltaic system, the controller would switch off the utility power line. The battery pack is used to store the excessive electrical energy for later use.

Keywords: *PV Systems, Grid-Tied PV Systems, Solar Energy, Rooftop PV Systems, Residential PV Systems.*

1. Introduction

Of the many available renewable energy resources nowadays, solar energy remains to be the most promising and encouraging. It is free from mechanical losses, produces no noise, and requires less maintenance than other renewable energy resources. However, with all the focus among researchers around the world on photovoltaic systems, solar energy remains mostly wasted and not sufficiently or efficiently used. Solar energy systems can be truly considered a universal power source, because almost everyone has access to the sun [1]. For many years, solar energy has been used for direct heating in residential applications, such as water heaters and solar cooking. PV systems have also been used to generate electricity for remote locations, where the grid power is not available. After that, PV systems were installed on rooftops of buildings, and were connected to the grid to reduce the dependence on utility companies [2-4]. It seemed feasible to do so with large buildings; however, in recent years, PV systems have been widely used across the globe for residential homes, where the output power is little, but large enough to reduce the electric bill [5, 6]. Other solar systems used for residential applications include hybrid systems, such as combined heat and power systems [7] and wind-PV residential systems [8]. Most of these systems are directly connected to the grid, and see the entire home as one bulk load.

This paper presents a small photovoltaic system model, which supplies electricity to residential applications to reduce the dependence on the power utility company and reduce the electric bill. This is achieved by designing and building an active PV system to provide electric power to small loads that would simulate real household applications. The power delivered to the loads is controlled by a microcontroller, which determines whether a certain load would be powered by the PV system or the utility company. The microcontroller would measure the available amount of power generated by the photovoltaic system, and based on that, it would determine how many loads could be powered by the system. To maximize the power output of the PV system, a sun follower system is designed and built for the PV cells to allow them to capture more perpendicular sunrays. Figure 1 shows the block diagram of the presented residential PV system.

2. Residential PV System Model

As a first stage in this work, and to better examine the proposed system before building a complete rooftop PV system on a home, a small model was used to replicate the real system. A single PV array of four solar cell panels was built and implemented to provide electric power to five small loads that would simulate real household applications, as shown in Figure 2. The rated DC power provided by the PV array is 36W and the loads used were three 5W lamps, a 40W lamp, and a 15W fan. Figure 2(a) shows a diagram of the complete system model; and Figure 2(b) shows a photograph of the complete system.

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DOI: 10.5383/ijtee.02.02.007

All five loads were AC loads, thus the PV array is followed by a DC/AC inverter. A DC battery pack is also used for excessive energy storage. The output of the battery pack is also connected to the DC/AC inverter, which is followed by the control circuit. The control circuit has a voltage regulator, switches, and a programmable microcontroller, which was programmed and implemented to determine when a specific load would be powered by the photovoltaic system or by the utility company. The microcontroller is powered separately through dry cell batteries.

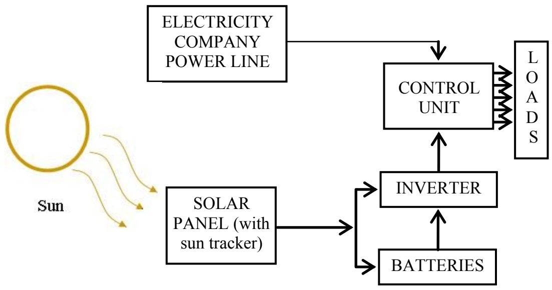
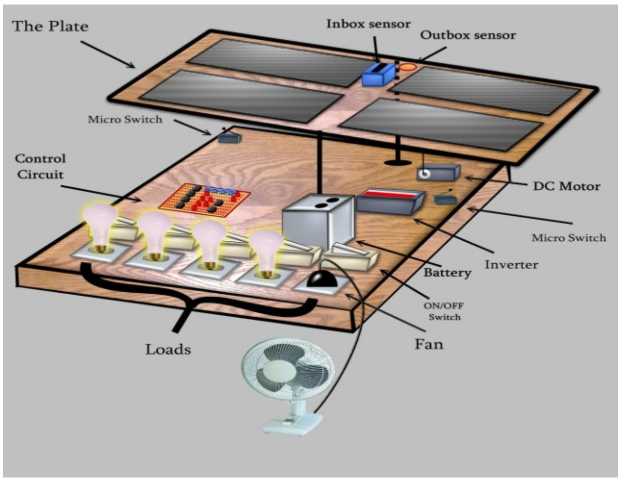
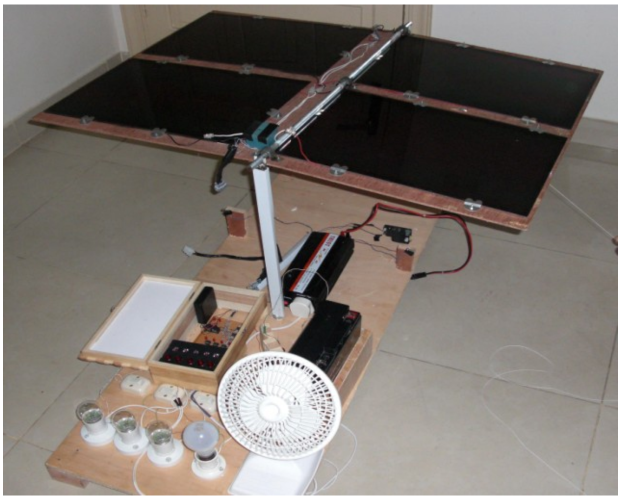


Fig. 1. Block diagram of the presented residential PV system



(a)



(b)

Fig. 2. (a) Diagram of the complete PV system and its loads
(b) Photograph of the complete PV system and its loads

In addition, the control circuit has load monitoring panel, which consists of two sets of five LED lamps each, connected in parallel with the loads. The first set indicates when the loads are turned on or off, and the second set indicates when the loads are supplied from the utility power line.

2.1. Sun-Tracker Design

To maximize the electricity output of the photovoltaic system, a motorized, automatic sun-tracker is used on the PV array to guarantee that the sunrays are perpendicular to the solar cells panels at all times. The array would follow the sun from east to west and maximizes the collected sunrays. The sun tracker system consists of two wooden plates: a base plate and moving plate, two support steal rods, two light sensors, and a motor with gear box. The steal rods hold the moving plate and form the center for rotation. One of the light sensors is used to determine if it is day or night. The other light sensor detects when the sunrays are perpendicular to the moving plate and the motor moves the plate accordingly to track the sun. The tracking system has its own power through separate batteries. The way the sun tracker operates is as follows. First, the default position for the array is facing east. When the day/night light sensor indicates it is night time, the PV array is rotated to be in its default position. As the day starts and the sun rises higher, the motor slowly rotates the array towards the west until the second light sensor indicates that the sunrays are perpendicular to the solar panels again. The motor then stops until the sun rises higher again and the process repeats. At the end of the day after sunset, the PV array is set back to its default position waiting for the new day's sun to rise.

2.2. Microcontroller Circuit Design

The microcontroller IC used was the PIC 16f84. Figure 3 depicts the block diagram for the microcontroller circuit. The Inbox sensor is basically a light depending resistance (LDR), and is used to monitor the sunrays. The LDR is kept in a dark box with a small hole on top, allowing sunrays to fall on the LDR only when they are perpendicular to the moving plate.

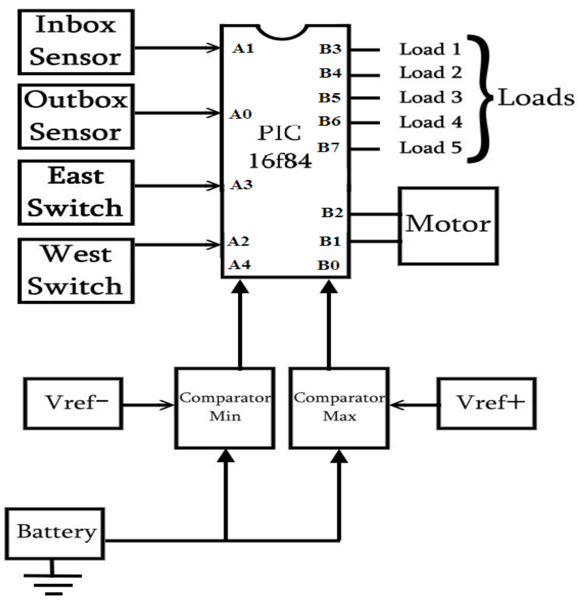


Fig. 3. Block diagram of the microcontroller circuit

The outbox sensor is another LDR. It determines if it is day or night. The motor is responsible for moving the plate, which holds the PV array to track the sun. It is controlled by the east and west switches. The east switch is responsible for tracking the sun, and controls the movement of the plate from east to west. It is activated when the outbox sensor indicates it is daytime and the inbox sensor indicates the sunrays are not perpendicular to the moving plate. The west switch is responsible for stopping the motor. It is activated to stop the motor when the sunrays are perpendicular to the moving plate, indicating maximum absorption of sunlight. As the sun moves towards the west, the sunrays will stop falling on the inbox switch, which will indicate that the PV array is off-track. The east switch will be activated again to move the plate until the sunrays are perpendicular to it again, where the west switch will be activated to stop the motor. The west switch also stops the motor when the moving plate reaches its end point of rotation. When the sun sets, the day/night time sensor will indicate it is night time, and the motor will rotate the moving plate back from west to east until it reaches its start point again. The cycle repeats when the sun rises the next day. The loads control part of the circuit switches loads between the PV system and the power utility line, and determines which load is connected to each source. Finally, two comparators are used to determine whether the voltage of the battery is above the maximum level, below the minimum level, or between them.

3. System Operation and Findings

Adding the sun tracker has improved the panels' power output by about 20%.
The microcontroller was programmed to make sure the photovoltaic system would provide electricity to the loads as the primary source of electrical energy. If the load's demand exceeds the energy available by the photovoltaic system, the controller would switch on the utility power line to supply only the load requiring more electricity. If the electricity demand dropped back below the energy available by the photovoltaic system, the controller would switch off the utility power line. To illustrate how the system works, the loads were added to the system one after the other and the source of electricity was monitored. When each of the three 5W lamps was switched on, the power to all three came only from the solar panels. Figure 4 shows a photograph of the three 5W lamps turned on and the monitoring LEDs corresponding to them indicate the power source is the solar panels. When the 40W lamp was turned on, the controller switched to the utility power line to power the 40W lamp only, while the three 5W lamps were still powered by the solar panels. Figure 5 shows a photograph of the three 5W and 40W lamps turned on and the monitoring LED corresponding to the 40W lamp indicates that its power source is the utility line, while the LEDs corresponding to the three 5W lamps indicate their power source is the solar panels. When the 15W fan was turned on, it was powered by the solar panels only, while the 40W lamp was still being powered by the utility line, and the three 5W lamps were still being powered by the solar panels.

Fig. 4. The three 5W light bulbs powered by the PV system.

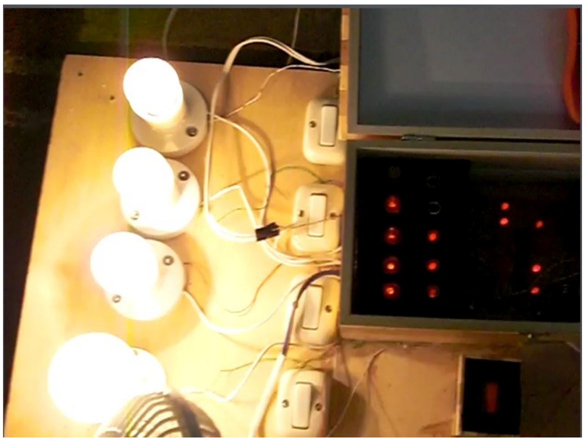


Fig. 5. The three 5W light bulbs powered by the PV system and the 40W light bulb powered by the utility.

4. Conclusion

This paper presented a photovoltaic system to produce electricity to residential applications to reduce the dependence on the power utility company, which would reduce the electric bill. The presented model included a PV Silicon solar cells system with sun tracking capability, battery storage, a DC to AC inverter and a microcontroller, which determines whether a certain residential load would be powered by the PV system or the utility company. The designed system may be implemented in real residential applications; however, both the solar panels and microcontroller have to be adapted and modified to fit the desired applications' power demand.

Acknowledgments

Many thanks and appreciation is due to Engineers Abdullah Saad AlAmri, Nawaf Salem AlJehani, and Rayan Mohamed Hawsawi for their hard work and participation in building and implementing the system.

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