AC 2007-1213: A MICROCONTROLLER-BASED SOLAR PANEL TRACKING SYSTEM

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A Microcontroller-Based Solar Panel Tracking System

Abstract

Renewable energy is rapidly gaining importance as an energy resource as fossil fuel prices fluctuate. At the educational level, it is therefore critical for engineering and technology students to have an understanding and appreciation of the technologies associated with renewable energy. One of the most popular renewable energy sources is solar energy. This paper describes a capstone design project where a student in Electrical Engineering Technology designed and built a microcontroller-based solar panel tracking system. Solar tracking enables more energy to be generated because the solar panel is able to maintain a perpendicular profile to the sun's rays. This system builds upon a prior senior design project where students built a solar-powered battery charger, thus making this system ideally self-contained. The student was able to demonstrate a working system, thus validating the design. Potential improvements to the system are presented.

Introduction

There are three ways to increase the efficiency of a photovoltaic (PV) system[1]. The first is to increase the efficiency of the solar cell. The second is to maximize the energy conversion from the solar panel. To better explain this, please refer to Figure 1. A solar panel under an open circuit is able to supply a maximum voltage with no current, while under a short circuit is able to supply a maximum current with no voltage. In either case, the amount of power supplied by the solar panel is zero. The key is to develop a method whereby maximum power can be obtained from the voltage and current multiplied together. This "maximum power point" is illustrated by looking at a voltage-current (VI) curve in Figure 1, and finding the "knee" of the curve. A number of maximum power point tracking (MPPT) algorithms have been developed and employed.[2]

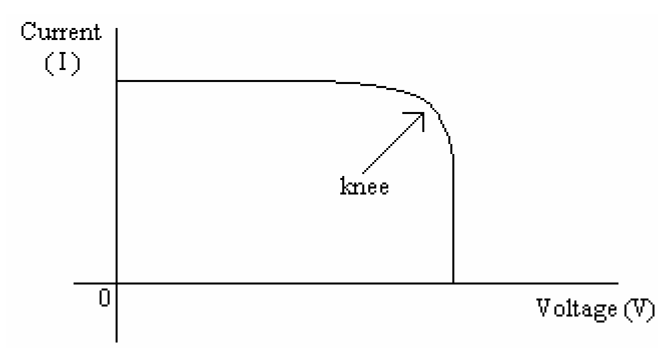

Figure 1. Illustration of a V-I Curve for a Solar Panel

The third method to increase the efficiency of a PV system is to employ a solar panel tracking system. Development of solar panel tracking systems has been ongoing for several years now. As the sun moves across the sky during the day, it is advantageous to have the solar panels track the location of the sun, such that the panels are always perpendicular to the solar energy radiated by the sun. This will tend to maximize the amount of power radiated by the sun. It has been estimated that the use of a tracking system, over a fixed system, can increase the power output by 30% - 60%[3].

When tracking the sun, it is noted that the direction of the sun, as seen by the solar panel, will vary in two directions. The azimuth angle is the horizontal direction from the observer to the sun[4]. There is also an altitude angle, representing the vertical direction from the observer to the sun. More effective solar panel trackers are two-axis in nature[5,6,7] and have been demonstrated, for example, in the use of a solar oven concentrator[8].

The purpose of this paper is to present the results of a project whereby an Electrical Engineering Technology student developed a one-axis (azimuth) solar panel tracking system to satisfy the requirements for his capstone senior project. The capstone design project covers two semesters. In the first (fall) semester, requirements for the project are identified and long lead materials are ordered. A schedule (Gantt chart) is developed by the student to ensure that steady progress occurs. During the second (spring) semester, the project is designed, built and tested to ensure specification compliance. At the end of the second semester, each project is presented to the faculty, other students, and to the community at large as part of a senior design day

System Design

At the beginning of the project, the student and faculty advisor agreed to the following design requirements:

- Must track the sun during daylight hours
  - During the time that the sun is up, the system must follow the sun's position in the sky.
  - This must be done with an active control, timed movements are wasteful.
- Self powered, must be fully autonomous
  - The system must operate on, and charge its own battery supply
- Semi-permanent installation on the flat roof of a building
  - A base must be designed to allow installation without fasteners onto a flat section of roof
- Weather resistant
  - This system will be designed to be fully functional outdoors and resist any wind and weather complications.
- Remote instrumentation to monitor status
  - A method will be implemented to allow the system to be monitored remotely.

The major components of this system are as follows. Each component required the student to make decisions that would ultimately affect the final design, based on both technical as well as financial constraints.

- The solar panel that will convert the radiation of the sun into electricity
  - The solar panel in direct sunlight is capable of sourcing 23V under open circuit conditions, and approximately 0.75A under short circuit conditions. The solar panel used in this project was already available and therefore did not cost any money towards the project.
- A base to support the solar panel

    - The base must be able to mount with no fasteners on a flat roof. It must also be large enough and heavy enough to provide a solid mounting point that will prevent the system from being damaged by strong winds.
- A weather-resistant housing to protect the electronics
    - The final control box had two parts (bottom and top). The interface between the two included a gasketed design for water-resistance.
- A motor to move the solar panel as the sun traverses through the sky
    - The intent of the project was to automatically rotate the solar panel to orient the panel perpendicular to the sun's rays.
    - An antenna rotor was chosen because of its inherent robustness.
    - The antenna rotor requires 30Vac to operate. An inverter (12Vdc – 120Vac) and a transformer were employed to convert the dc from the batteries/solar panel to a 30 volt modified sine wave ac power source.
- Electronics to sense the sun's position, and determine whether the solar panel needs to move
    - The approach employed to orient the panel with the sun was to find the point that maximized the amount of power being converted by the panel. Current was measured through a fixed resistance to determine the power consumed.
    - An 8051 microcontroller would be the brains of the operation, sensing which position of the panel yielded maximum power, and sending signals to the antenna motor to move the solar panel accordingly.
- A set of two 6V lead-acid batteries, connected in series, that will be charged up during the day by the solar panel
    - The lead-acid batteries were already available and therefore did not cost any money towards the project.

The basic operation of the system is as follows:

- The solar cell operates as a current source with current being proportional to light intensity.
- Current measurement is performed at 3 different points of rotation, and the system repositions to the position which provides the greatest power.
- The Earth rotates 5 degrees per 20 minutes.
- The control software includes a 15 minute delay between measurement routines.
    - The increment of movement is chosen as 5 degrees.
- A low light level sensor disables the movement controls; this prevents battery rundown while looking for the sun in low light conditions.
    - This will also provide a night-time idle state.
- After sundown the panel will be facing west. To facilitate a system reset to face east, a 24 hour timer is incorporated that will drive the panel to the east every morning at dawn.
    - To allow the system's 24hour timer to work properly, the system must be initialized at dawn.
- The rotor's base must be initially positioned with the back of the rotor facing north. The system will not operate correctly otherwise.

Results

The completed solar panel tracking system (sans base) is shown in Figure 2:

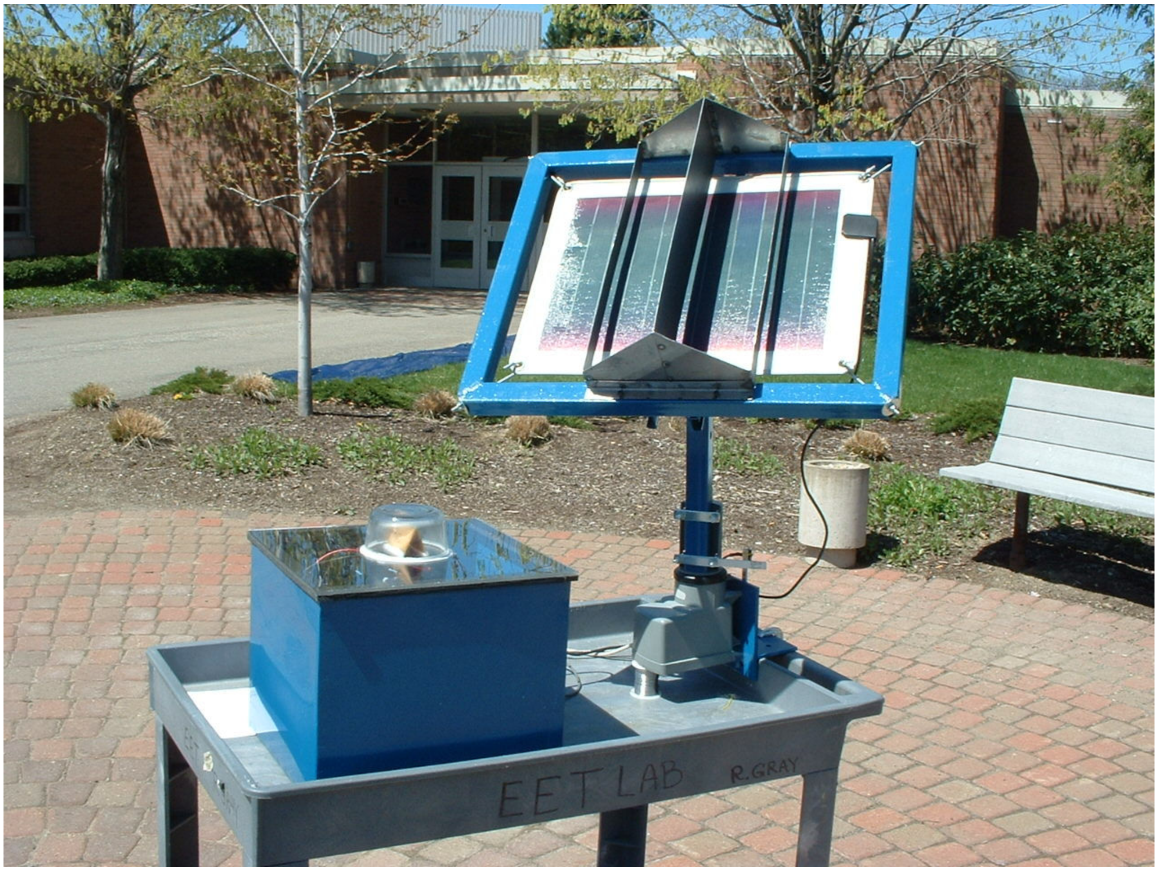

Figure 2. The Completed Solar Panel Tracking System (Without the Base)

Design modifications and improvements were incorporated as necessary. As an example, a blinder system was developed and employed to allow for accurate focusing of the solar panel. The blinder system resulted in little power change with respect to the observed azimuth angle. Without the blinder the panel needed at least 40 degrees to facilitate a significant drop in measured power. With the blinder the panel required less than 10 degrees to achieve a measurable drop.

The output power measurements for varying degrees of orientation to the sun are displayed below in Table 1. Without the blinder the power differences would be miniscule and excess power would be wasted during unnecessary moves.

Table 1. Measurement of Power With and Without the Blinder

Power Measurements	Load of 30 ohms			
With Out Blinder				
Degrees from sun	V Output (V)	I Output (A)	P output (W)	% Change
0	16.8	0.565	9.49	0.0%
10	16.7	0.563	9.40	0.9%
20	16.65	0.561	9.34	1.6%

30	16.56	0.561	9.29	2.1%
40	**15.9**	**0.54**	**8.59**	**9.5%**

With Blinder

Degrees from sun	V Output (V)	I Output (A)	P output (W)	% Change
0	16.5	0.56	9.24	2.7%
10	**15.9**	**0.55**	**8.75**	**7.9%**
20	14.5	0.5	7.25	23.6%
30	13.4	0.48	6.43	32.2%
40	13.2	0.45	5.94	37.4%

As indicated above, an 8051 microcontroller was employed to control the movements of the solar panel. This microcontroller was chosen because of the student's familiarity with this family of microcontroller. A flowchart of the system operation was developed, and is provided in Figure 3 below. The subroutine for moving the solar panel and taking measurements is provided in Figure 4. As seen in Figure 4, three power measurements are made at and around the last azimuth angle of the solar panel. The location of the largest power measurement becomes the new azimuth angle of the solar panel.

One of the key elements of the design is for the system to be autonomous. An energy balance calculation was performed to determine if the overall energy consumption (to drive the motor, etc.) would be less than the amount of energy generated by the solar panel. Note that the system needed to be designed to operate effectively over a 72 hour period (with 10 hours of available sunlight) to account for the possibility of three successive cloudy/overcast days. The results of this analysis are as follows:

Table 2. Power Consumption Required to Operate the Autonomous System

Power Consumption

Load Element	Current (A)	Duration (s)	Duration (Hours)	Energy (Ah)
System @ idle	0.059	259200	72	4.248
Movement routine	4	750	0.208	0.833
Reset movement	4	120	0.033	0.133
Battery charging	-0.49	36000	10	-4.9
		Total per period		**0.314**

Based on Table 2, the energy consumed during the 72 hour period may exceed the energy available to charge the battery. In fact, although the system was able to operate in front of an audience during the senior design day, the system eventually drained the batteries during subsequent testing during the summer. This may have been due to the energy balance, a software glitch in the microcontroller, or a combination of the two. Clearly, the major energy drain over a long period of time is due to the system at idle. Minimization of this steady drain of the batteries would enable the solar panel tracker to become useful in applications such as remote lighting or water pumping.

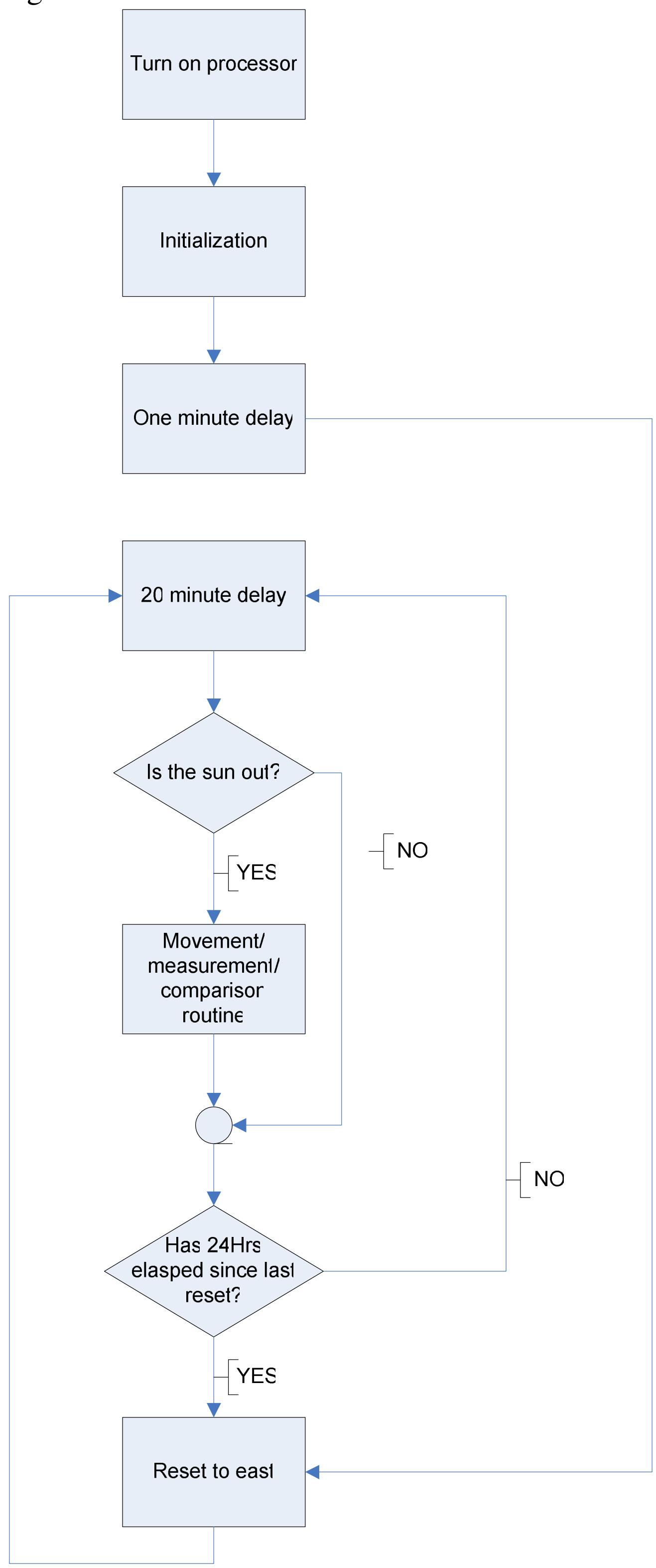

Figure 3. High Level Flowchart of System Operation

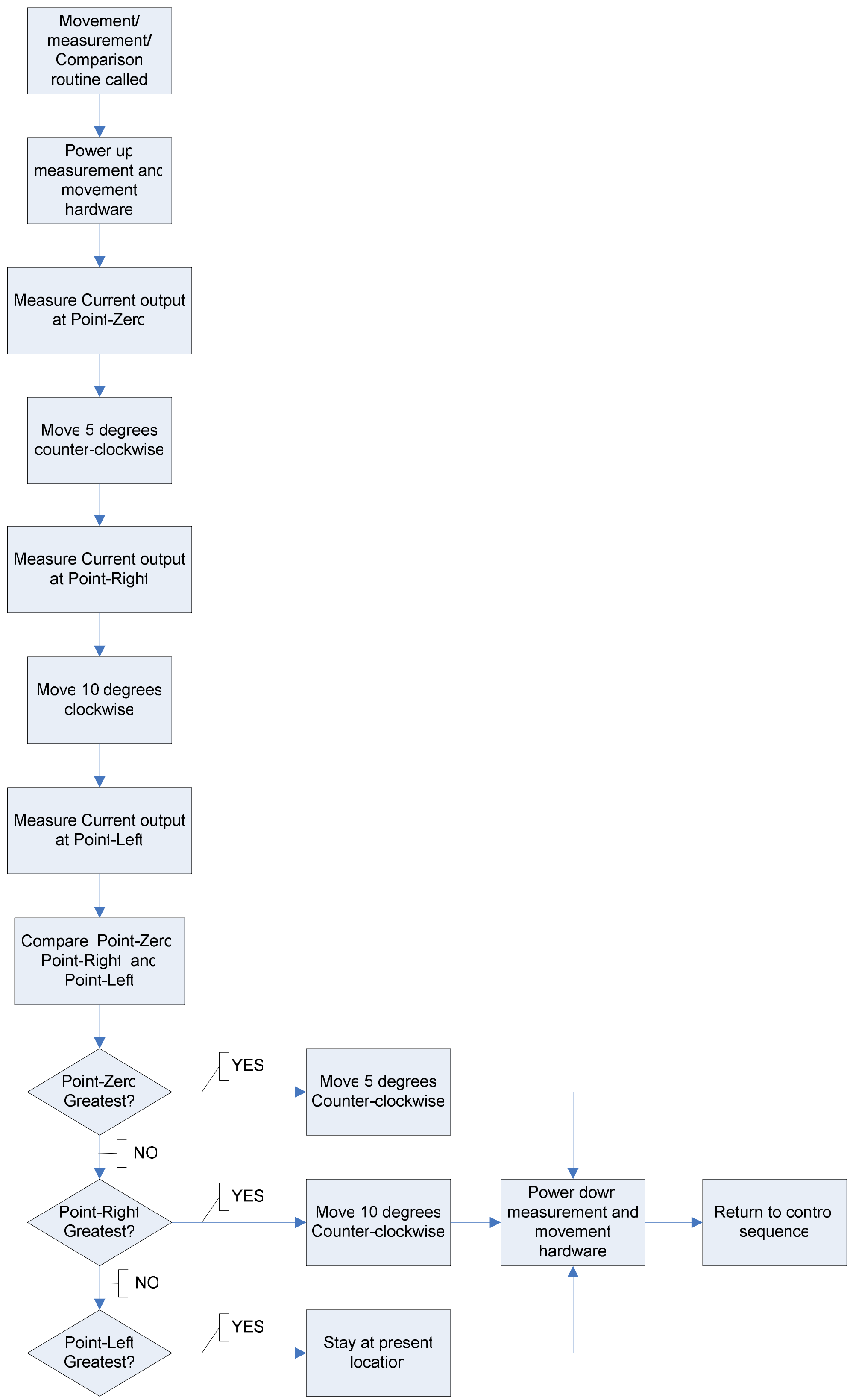

Figure 4. Flowchart of Solar Panel Movement and Comparison

Student Reactions and Potential Improvements

At the conclusion of the project, the student was asked to provide feedback on the project. The following were questions and responses from the student (in italics):

"What did you find most interesting about your senior design project?"
I found it interesting how easy and efficient it is to make an active solar power system use less energy than it consumes and that this efficiency is compounded by the active sun tracking feature.

"What were the most interesting things you learned?"
System integration and certain facets of A to D to A feedback control.

"What recommendations would you make for improving on the project in future years?"
My recommendation would be: the addition of an accurate position (rotational) feedback, and the refinement of the control software (using the same hardware). I would also push very hard to have the charger system made more robust and reliable.

"Rate the amount of learning in your senior design experience on a scale of 1-5 (1 implies didn't learn anything, 5 implies learned a great deal)"
3. My learning was limited by choice. I purposefully kept my project goals within the realm of what I believed was attainable. I did this because of my "team of one" situation. I believe that this decision was crucial to producing a functional prototype on time.

"Rate your enjoyment for working on your senior design experience on a scale of 1-5 (1 implies didn't enjoy at all, 5 implies enjoyed a great deal)"
5. I enjoyed the challenge a great deal.

One of the biggest hurdles for this student was due to teaming issues that arose during the course of the senior design project. Originally, there were two students on the team. Eventually, due to issues regarding the second student on the team, the other student was dropped from the team. The remaining student then had to work on tasks that had been assigned to both team members. This most likely impacted the amount of progress that could have been achieved on the project. As indicated above, the student was forced to focus on providing a system that would be functional within the given time constraints.

In addition to the recommendations provided by the student above, other potential improvements to the project would be:

- to implement a two-axis controller (both azimuth and altitude control),
- to implement a remote monitoring system (included in the original design requirements but not incorporated due to time constraints),
- to perform a more detailed energy balance over a longer period of time to gauge the ability of the system to be truly autonomous, and
- to identify potential systems (such as the solar oven concentrator) that may be employed using this system

Conclusion

In this paper a solar panel tracker has been developed to increase the amount of power generated by the solar panel as the sun traverses across the sky. An 8051 microcontroller was used to control the movement of the solar panel. The system was designed to be autonomous, such that energy generated by the solar panel would be used to charge two lead acid batteries. The system was successfully demonstrated during a senior design day presentation, although later subsequent testing yielded system design and/or implementation flaws. Overall, the system was a positive learning experience for the student, and allowed him to both maximize his creative potential as well as utilize many different technologies in the Electrical Engineering Technology discipline.

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