120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #8031

Seeking the Sun - a Student Design Competition Endeavor

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Abstract

A student team was assembled recently to participate in a Federal agency sponsored national design competition. This team named itself the Sun-Seekers. The team's objective is to design a novel photovoltaic module, which encloses groups of solar cells that can separately track the sun. This will allow the module itself to be mounted simply at a fixed tilt but still reap the substantial energy collecting benefits presently associated with active and passive solar tracking panels, while avoiding their significant additional complexity, cost and weight. The main design goal is to improve upon the amount of energy collected by a similarly-sized fixed-tilt solar panel. This paper describes the team's tasks, and then gives specific examples of the analysis and design aspects of this novel photovoltaic module that required the student team to apply what they had learnt from their completed coursework.

Introduction

A student team, which named itself the Sun-Seekers, was assembled recently by the authors to participate in a national design competition organized and sponsored by the U.S. EPA to research, develop, and design solutions to real world challenges involving the overall sustainability of human society. The P3 (People, Prosperity, and the Planet) competition highlights the use of scientific principles in carrying out innovative projects that foster progress toward sustainability by achieving the mutual goals of economic prosperity, protection of the planet, and improved quality of life for its people. The competition has five categories: energy, built environment, materials and chemicals, agriculture, and water. The contest has two phases: phase I is a competition for one-year grants of up to $15,000 to research, develop, and test, innovative scientific projects or engineering designs that will promote sustainable development. In the spring of 2013, the phase I grantees – including the Sun-Seekers team – will be presenting their projects/designs at the annual National Sustainable Design Expo in Washington, DC where they will be competing for a phase II grant award of up to $90,000 for further development and demonstration of the sustainability projects/designs created in phase I. This design competition resembles other well-known ones sponsored by professional organizations (e.g., SAE International's Baja[#]) and federal agencies (e.g., the U.S. Department of Energy's Solar Decathlon#) that are organized with the aim of challenging college students to apply what they have learnt in the classroom to the design and construction of an engineered system. As several studies[1, 2] and documented experiences[3] have shown, such competitions have several educational benefits, including providing students the opportunity to be creative[1], learn about the practical aspects of engineering[2], develop an ability to function on multidisciplinary teams[3] (an ABET engineering program accreditation criterion[4]), and compare their work to that of others from around the country (and sometimes, the rest of the world).

The Sun-Seekers are competing in the P3 competition's Energy category with a design project aimed at developing a novel photovoltaic (PV) module that encloses groups of solar cells that can track the sun's movement across the sky. This will allow the module itself to be fixed-mounted but still have the significant energy collecting benefits associated with present solar tracking systems, which however are more complex and costly, and less reliable than fixed-mounted systems. The project's main objective is to design such a module that can improve upon the amount of energy collected by a similarly-sized fixed-tilt solar panel by at least 25%. Increasing the amount of energy collected by PV panels should lead to more widespread adoption of solar energy for electric power production in this country and around the world. Consequently, less electric power produced by coal-fired and gas-fired power plants will result in less pollution from those plants, leading to healthier living conditions for all mankind.

The following section will give an overview of the new module's design requirements. These provided the motivation for the analysis and simulations that needed to be performed in order to determine the specific design of an initial prototype. A few examples of the analyses that were performed and how these called upon the prior learning of the students are then described; this section forms the main thrust of this paper. But in the interest of completeness, this section is followed by some brief remarks about the constructed initial prototype, and the testing being undertaken to compare its energy collection performance to that of a standard solar panel.

The New Module's Requirements

Solar panels that track the sun's movement across the sky can collect 29% to 40% more energy than fixed-tilt panels[5]. However, these generally require significant investments in materials and equipment (such as sensors, controllers and motors), more extensive and complex installation procedures, and additional structural requirements for the mounting surface and for the roofs (should they be mounted there). The wide range of motion also limits how close each module can be placed to other modules so as to avoid undesirable shading of the solar cells.

The Sun-Seekers project is to develop a PV module that encloses groups of solar cells that can separately track the sun. This project's tasks include the following:

- Determining the design of a passive (not motors) actuation system that would be most appropriate for rotating lightweight groups of cells in an inexpensive yet reliable and robust photovoltaic module. This will initially focus on methodologies based on the deformation of bimetallic coils.
- Researching the selection of a specific bimetallic coil to produce desired displacement and torque responses to direct solar radiation.
- Investigating approaches for rotating the cells as independently as possible from changes in ambient temperature.
- Working on the design of shadow plates or gratings, and their placement relative to the bimetallic coils, which will act to ascertain the direction of sunlight, and determine the proper amount of rotation required from those actuators.

Examples of Analysis and Design of Module Components

The first design aspect addressed was the PV cell arrangement/configuration. It was quickly decided that the cells should be grouped into columns affixed to rotatable rods (think shish-kebab) that will be oriented in a North-South direction when the new module is installed. Then a key technical issue presents itself when these cells are turned towards the early-morning sun or the late-afternoon sun, and cast a shadow on the cells behind them. Clearly bypass diodes will be needed, but we also asked the question - is there a cell arrangement that would produce less shading. Coming up with the arrangement shown in Fig. 1a, which can be referred to as an interleaved ‘diamondback’ cell arrangement, the student team calculated the shading percentage it produces in comparison to the (conventional) arrangement shown in Fig. 1b for various angles of the sun, and various angles of the assumed square PV cells (see Fig. 2a), allowing for some sun-tracking imprecision. This was a straightforward yet good exercise on the subject of *Trigonometry* for them, and the percentage differences between the shaded areas per cell are displayed in Fig. 2b.

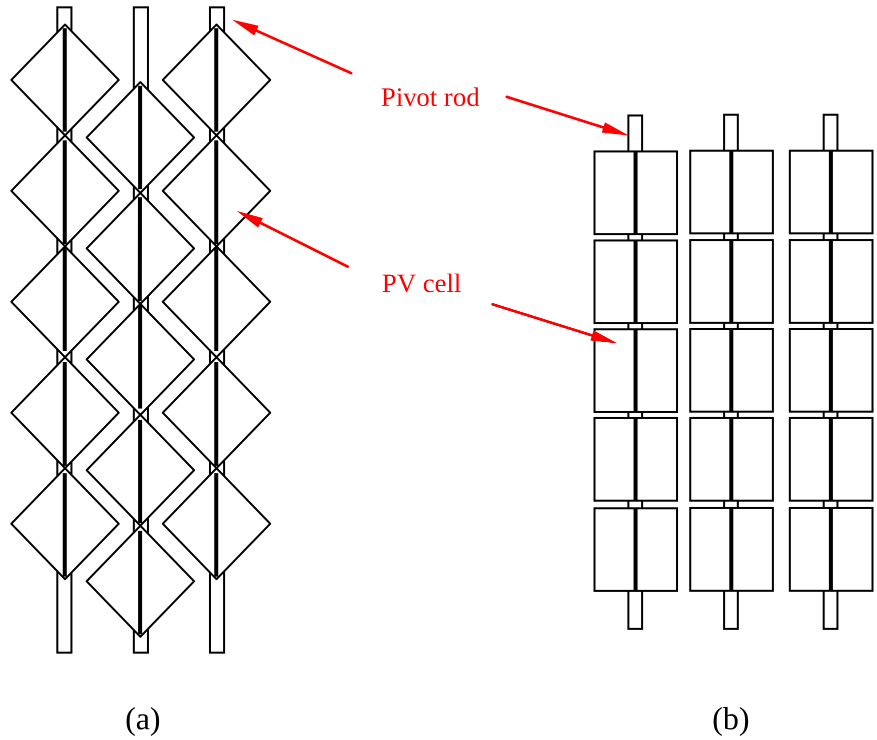

Fig. 1. Five-cell by three-column illustration of the (a) ‘diamondback’ cell arrangement, and (b) ‘squared’ cell arrangement.

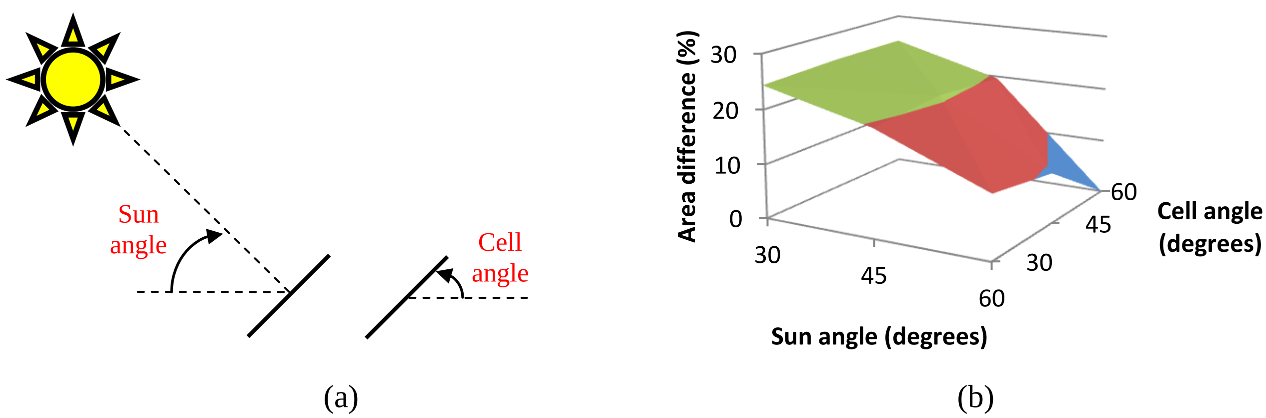

Fig. 2. (a) Shading due to cell adjacency, and (b) difference in cell shading percentage between the ‘diamondback’ arrangement and the ‘squared’ arrangement.

Next, although the previous results indicated that the ‘diamondback’ cell arrangement of Fig. 1a produces less shading than the ‘squared’ cell arrangement of Fig. 1b, the difference in moment of inertia between these two arrangements needed to be analyzed, since this would impact the actuator design. This was a straightforward yet good exercise of their knowledge of *Statics* for the students, and for the ‘diamondback’ cell arrangement shown in Fig. 3a, its moments of inertia was found to be $d^4/48$, given that the square PV cell with diagonal d is a uniform thin plate. Thus it was determined that there’s *no* difference in the two cell arrangements’ moments of inertia, since it is well-known[6] that the moment of inertia of a square uniformly thin plate of side l with axis of rotation along its middle is equal to $l^4/12$, and we have d = ‾ l.

(a) (b)

Fig. 3. Cell orientations for the calculation of moment of inertia: (a) ‘diamondback’ arrangement and (b) ‘squared’ arrangement.

As a final example of the engineering analysis performed by this student team, we describe the testing and analysis of the torque capability of a bimetallic coil actuator (Fig. 4), which was determined by conceptual design as the best choice for rotating the PV cell columns in this novel module. Note that torque is produced at the inner tab of a bimetallic coil (see Fig. 4a), with its outer tab fixed in position, when the coil is heated or cooled, resulting in the inner tab rotating one way or the other way; this can be used, for example, in rotating the pointer of an outdoor dial thermometer. Absent the availability of a torque sensor/transducer, the following test and analysis procedure was followed, which exercised the students’ knowledge of *Dynamics*:

- The bimetallic coil was placed away from any heat source, so it attained its room-temperature shape.
- A 1” x 6” thin aluminum strip was attached to the inner end tab of the coil, and the outer tabbed end of the coil was clamped into a fixed position on a piece of cardboard (see Fig. 4b).
- The initial orientation of the aluminum strip was noted, and also the coil temperature as measured by a cooking thermometer with its point in contact with the coil.
- A lamp with a 20W halogen bulb was positioned so the bulb was 4” above the coil.
- At 30 second intervals after switching on the lamp, the orientation of the inner end tab of the coil (and the attached aluminum strip) was marked as the coil slowly expanded, thus rotating the inner end tab.
- After the coil’s inner end tab reached its steady-state position, the lamp was switched off.
- The angular displacements were determined from the markings; then the angular velocities, and angular accelerations were calculated.
- The coil’s produced torque over time was calculated using the value of the aluminum strip’s inertia.

The above test and analysis determined that the coil produced a maximum torque of about 2 nN·m, and also confirmed that it has an activity of about 2° of displacement per °F of temperature change, as labeled. This information was a useful guide for estimating the maximum number of PV cells each column could have. Additional testing also allowed us to explore reducing the required number of coils by 50%, by linking two parallel rods together near their end-points. Hence the rotation of a ‘powered’ rod can be transferred to rotate the second ‘unpowered’ rod.

As a summary, Table 1 shows those courses in the engineering curriculum at Southern Polytechnic State University (SPSU) that the students had completed and from which they acquired knowledge that was applied to this project in the form of the above-mentioned analyses.

Table1 – Engineering courses relied on students for this design project.

Course number	Description	Level
ENGR 2214	Statics	Sophomore
ENGR 3122	Dynamics	Sophomore

(a) (b)

Fig. 4. (a) Bimetallic coil, and (b) Coil torque determination test setup.

The Prototype Module

Based on the team’s various analyses, including the above examples, it was decided that a prototype module consisting of six cell strings (an even number being needed to implement the concept of dual-rod actuation) of six 52mm x 52mm cells each would be constructed (see Fig. 5). Furthermore, to ensure a valid comparison of energy collection performance, a standard panel was also built (see Fig. 6) with several panel parameters kept the same including the following:

- 36 cells of the same material (16% efficient multi-crystalline Silicon solar cells) and dimensions (52mm x 52mm) connected in series, so the total cell area and the panel voltage are practically identical;
- both had their cells wired together using the same type of tabbing wire;
- both include the same type, number and connection of diodes (bypass and blocking).

The team first characterized the standard panel, although under non-ideal conditions due to various constraints. The obtained *i*-*v* characteristic indicates in particular that the open-circuit voltage is about 18V, and the maximum power point occurs at 16.5V and 0.4A, yielding 6.6W; sufficient for the charging of 12V batteries. This provided guidance in setting the load values (each an adjustable power resistor set to 41 Ω) for the subsequent energy collection tests. Limited test data available at the time of completing this paper indicate that the new prototype does collect more energy than the standard panel. More complete test results will be presented at the National Sustainable Design Expo held on April 18 and 19, 2013, and we plan to present and/or publish a detailed technical paper about this PV module at a Solar Energy conference or in a Solar Energy journal.

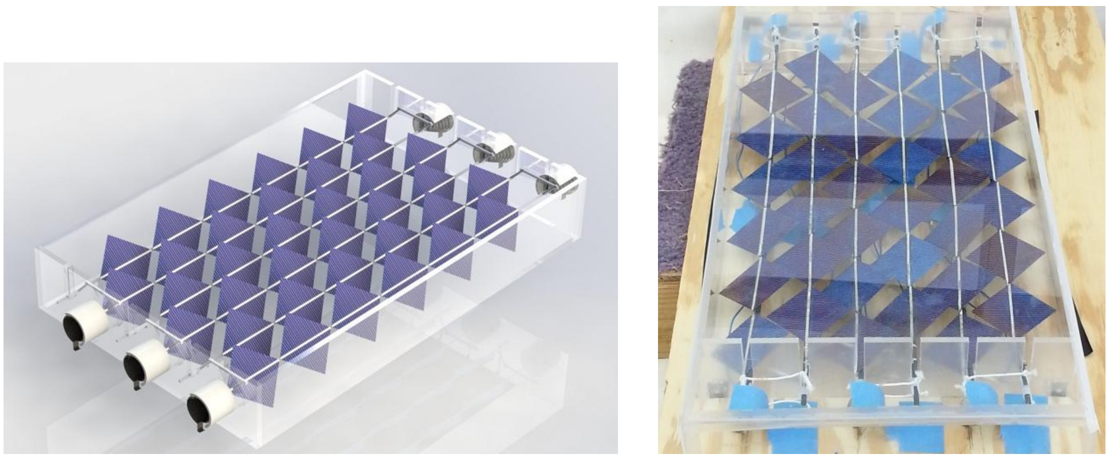

Fig. 5. The prototype module: (a) SolidWorks® model, and (b) actual device.

Fig. 6. The standard panel being used as the baseline for energy collection comparison.

Conclusions

A student team was assembled recently to participate in the EPA-sponsored P3 national design competition. The team's objective is to design a fixed-tilt PV module, enclosing individual columns of solar cells that can separately track the sun. A preliminary design has been completed, and the team is performing tests to quantify the improvement upon the amount of energy collected by a similarly-sized fixed-tilt solar panel.

This paper has presented a few examples of the analysis and design aspects of this novel PV module that required the student team to apply what they had learnt from their completed coursework. The opportunity for these eight students to apply their education to a real-world challenge was welcomed by all of them, as evidenced by their voluntary contribution of uncompensated time and effort to this project. Their continued work on this project provided positive feedback of how much it meant to them. We (the team's faculty advisors) conclude from this experience that national design competitions provide several excellent benefits, including opportunities for engineering students to apply what they have learnt in the classroom, obtain practical extra-curricular experience, develop useful teamwork skills, and compare their work to that of others from around the country. Therefore, we heartily recommend that other engineering faculty encourage their students to participate in a national student design competition, with them serving as the team's advisor.

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