AC 2007-455: A STUDENT-CENTERED SOLAR PHOTOVOLTAIC INSTALLATION PROJECT

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In his fifty years at the University Arthur C. Haman has progressed through the academic ranks to his current position of Professor of Mechanical Engineering and Associate Dean for Operations. His industrial experience was acquired as a Structures and Armaments engineer at Northrup Aviation and as an engineer in the Scientific Laboratory of the Ford Motor Company. He has also held visiting professorships at what was Carnegie Institute of Technology and Dartmouth College. His current interests are in thermodynamics and internal combustion engines.

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Robert Ross is an Associate Professor of physics at the University of Detroit Mercy, where he teaches general and modern physics courses. His research interests include physics education and photovoltaic energy conversion. He has fourteen years of industrial experience where his research and publications in the field of amorphous silicon photovoltaic cells helped lead to the development of more efficient solar panels. Ross earned his B.S. and Ph.D. degrees in physics from Wayne State University.

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Mark Schumack is Professor of Mechanical Engineering at the University of Detroit Mercy, where he teaches courses in heat transfer, thermodynamics, fluid mechanics, and energy systems. His ongoing pedagogical interests include developing ways to teach energy conservation and sustainability principles. He has held several leadership positions in the Energy Conversion and Conservation Division of ASEE. His research interests include thermal/fluid modeling using computational techniques, with applications in the automotive, manufacturing, and energy fields. Dr. Schumack earned his B.S., M.S., and Ph.D. degrees in Mechanical Engineering from the University of Michigan.

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Will Wittig is an Associate Professor in the School of Architecture at the University of Detroit Mercy. He is also the Co-Director of the Masters of Community Development program, and is a founding partner of Crossings Architecture. Prof. Wittig teaches a masters level thesis studio as well as a required lecture course on ecological design, an elective design+build studio, and Introduction to Physical Development in the Community Development program. Prof. Wittig earned a professional Bachelor of Architecture from the University of Kansas, and a Masters of Architecture from Cranbrook Academy of Art.

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David Chew is a mechanical engineering student at the University of Detroit Mercy. He has had the opportunity to co-op with the Hydraulic Valve Division of Parker Hannifin in Elyria, OH. David will receive his undergraduate degree in August of 2008 and hopes to design thrill rides and roller coasters in the future.

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Krysten Dzwigalski is an undergraduate student in mechanical engineering at the University of Detroit Mercy. She is currently in her third year and plans to graduate in August of 2008. She has completed a co-op with Daimler Chrysler at Warren Truck Assembly Plant, and is currently working at TARDEC for the US Department of Defense. Krysten is also the President of the Engineering and Science Student Council.

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Chris Keimig is a student of mechanical engineering at the University of Detroit Mercy. He is an intern with DaimlerChrysler Corporation in the Vehicle Development department. He is involved with Alpha Phi Omega community service fraternity, Engineering and Science Student Council, Society of Automotive Engineers, and Pi Tau Sigma Mechanical Engineering honors society.

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Meghann Mouyianis is the Chemistry Storeroom Manager at the University of Detroit Mercy, where she maintains the supply of chemicals, laboratory equipment, and instruments. She has been involved in science education outreach programs through the Science and Engineering Fair of Metropolitan Detroit, FIRST Robotics, FIRST Lego League, Engineering Society of Detroit, Detroit Science Center, University of Detroit Mercy Chemistry Club, and Detroit Area Pre-College and Engineering Program. She is the chair of the Younger Chemists Committee of the American Chemical Society Detroit Local Section and is a member of Chemists Without Borders. Her research interests include inorganic synthesis/coordination chemistry and archaeological quantitative analysis. She earned her B.S. in Chemistry and secondary teaching certification from the University of Detroit Mercy and plans on working towards her M.S. in the fall.

Tim Rourke, University of Detroit Mercy

Tim Rourke is a junior at the University of Detroit Mercy. He is studying mechanical engineering and has been actively involved on campus through work study, undergraduate research, and the service fraternity Alpha Phi Omega. Tim is currently on the co-op rotation employed at Hitachi Automotive Products, where he is an intern for the electro mechanical group, working on throttle bodies and direct injection systems.

A Student-Centered Solar Photovoltaic Installation Project

Introduction

In light of the growing recognition that the country must accelerate efforts to develop alternatives to oil, the U.S. government has offered incentives for installation of alternative energy systems. One incentive program administered by the State of Michigan Energy Office called for organizations to install and demonstrate large scale (10 kW or larger) solar photovoltaic systems for purposes of public education. The College of Engineering & Science at the University of Detroit Mercy applied for and was awarded such a grant in 2005. The project had two objectives: first, to demonstrate that photovoltaic solar energy generation can be seamlessly incorporated into existing architecture; and second, to inform and educate a wide-ranging target audience about the technology and issues surrounding photovoltaic systems.

State funds were restricted to equipment, supplies, and materials. In order to minimize additional costs, the faculty team decided to purchase a PV system that required minimal support structure and building modification, and to use volunteer faculty and student labor to accomplish the installation. In spite of the time commitment, the experience provided invaluable benefits in terms of student-faculty relationships, student learning, and fostering interdepartmental collaboration.

The remainder of the paper describes the system we installed, the installation process, student learning which took place, and preliminary system performance data.

System description

The photovoltaic system is a 10 kW Uni-Solar “Premier Solar Flat” system, consisting of seven 6.1 m × 5.2 m horizontally mounted self-ballasted assemblies that feed an inverter which in turn provides AC power directly into the building’s electrical system. The pre-engineered system uses triple junction amorphous silicon alloy technology designed and manufactured by United Solar Ovonic. We decided to install a 10 kW system because we wanted to minimize costs and 10 kW was the smallest supported by the grant.

Each assembly consists of 11 of Uni-Solar’s 136 W photovoltaic laminates. Each flexible laminate strip is approximately 0.41 m wide and 5.5 m long, and is durable enough to walk on. The laminates are attached to standing seam metal roofing assemblies with a “peel-and-stick” adhesive. Each laminate is rated at 33 VDC and 4.1 A. Within each of the seven assemblies 11 laminates are connected in series to generate 363 V and 4.1 A. The seven assemblies are connected in parallel to give a nominal DC output of 28.7 A at 363 V. The DC power is directed into a Xantrex 10 kW 60 Hz sine wave inverter to generate 208 VAC 3-phase power. The AC power is delivered to the building’s electrical system through a 10 kVA, 208 V “wye” isolation transformer. Since the system is rated at 10 kW peak for the DC power, the 10 kVA transformer is operating below the rated value under normal conditions.

The roof assemblies lie horizontally on the flat roof of the engineering building, and are ballasted with rectangular paving stones. The system is UL-listed and approved for wind loadings. There are distinct advantages to using the self-ballasted horizontal roof assemblies. First, the engineering building at UDM is over 75 years old and its design is part of the traditional character of the campus. The building has undergone significant interior and exterior renovation over the past several years, including the installation of a vinyl-membrane roofing system. This roofing system is currently under a twenty year manufacturer's warranty which would be voided by any roof penetrations. The self-ballasted assemblies we installed require no roof penetration. The second advantage is cost; raising and tilting the array would require a significant infrastructure. Our estimates indicated that the infrastructure could have added 40% to the total cost, which would have been several tens of thousands of dollars. The energy gain for a tilted array is about 20%.¹ With our estimated annual energy output of about 10,000 kWh and with the cost of electricity being about 0.01\$/kWh the payback period for the additional expense of a tilted array is longer than the expected lifetime of the project. Thirdly, use of a horizontal array resulted in no alteration to the physical appearance of the building. The array is invisible from the ground. Finally, the assemblies were easy to install. Figure 1 shows the positioning of the assemblies on the engineering building roof.

Figure 1. Locations of the seven PV assemblies and display.

A disadvantage of a horizontal array is that the power output will be slightly reduced when compared to an array that is tilted at the optimum angle. That said, amorphous silicon technology is less sensitive to tilt angle than crystalline photovoltaic technology. United Solar Ovonic cites data¹ showing that horizontal amorphous arrays delivered a time-integrated power (energy) that was comparable to that of the competing tilted crystalline glass-framed modules (the same study also demonstrated that amorphous arrays delivered more energy than crystalline arrays when both arrays were at the same tilt angle).

The data acquisition system, designed and assembled by United Solar Ovonic, is internet-based and includes a touch screen terminal, a web camera, and a weather station. The system logs data every five minutes for the following variables: solar irradiation, air temperature and windspeed, DC voltage and current, inverter output AC voltage and current, DC and AC power, and daily and cumulative energy output. The camera resides on the east wing of the engineering building and provides real-time video of four of the assemblies with the University's clock tower in the background.

Figure 2 shows photographs of the completed PV assemblies on the roof of the engineering building east wing, along with the inverter, data acquisition and breaker boxes, isolation transformer, and circuit breaker box located in the manufacturing systems lab directly below the east roof.

The cost for all components, tools, and installation services (including crane rental and electrician) came to \$73,000. This figure does not include donated labor or costs for the lobby display.

Top: Four assemblies installed on the east wing of the engineering building.

Left middle: Isolation transformer and circuit breaker panel in the foreground; inverter in the background.

Left bottom: Inverter (white); DC and AC disconnects (gray boxes on either side of the inverter); data acquisition box (above inverter).

Figure 2.

The data display panel and video output are located prominently in the lobby of the Engineering Building (see Figure 3). The text on the display describes how solar photovoltaic systems work, and lists the advantages of solar power (see Figure 4). A 20-minute long PowerPoint slideshow cycles continuously. The slideshow presents current energy issues, highlights the role of solar energy, describes how the amorphous silicon panels installed at UDM work, and presents photographs of the installation process. Additionally, a pushbutton demonstration shows how a flexible laminate solar cell powers a toy motor when a light is turned on.

The website for the installation is <http://eng-sci.udmercy.edu/solarpower/index.html>. The home page for the website is seen in Figure 5. Links to the webcam image and data display are included. Other links go to slideshows describing solar energy and showing photographs of the installation.

Figure 3. The solar energy display in the engineering building lobby.

10 kW SOLAR PHOTOVOLTAIC DEMONSTRATION PROJECT

HOW DOES IT WORK?

The Sun transports energy to Earth in the form of electromagnetic radiation. A portion of this radiation is visible light that shines on the surface of the solar panel. The front surface of the panel has a thin film which reduces the amount of reflected light. The light from the Sun that is not reflected is absorbed inside the active region of the device. The active region in a solar panel consists of several very thin layers, some only a few atoms thick, of various types of semiconducting materials. The absorbed light generates equal amounts of positive and negative electric charge inside the semiconductor and a built-in electric field drives the charge through the circuit as direct electric current. The direct current (DC) is supplied to an inverter that converts it into alternating current (AC). The alternating current is supplied to the existing electrical power grid of the building thus reducing the need for external power generation.

ADVANTAGES OF SOLAR POWER:

RENEWABLE: inexhaustible energy source.

FREE: once the system is in place, electrical energy is free.

ZERO EMISSIONS: no pollution or byproducts.

AVAILABLE: sunlight is present everyday, everywhere.

DISTRIBUTABLE: produces power right on site.

RELIABLE: no moving parts.

SILENT: zero noise pollution.

SUPPLY AND DEMAND CORRESPONDENCE: system is most productive in summer months when air conditioning loads are highest.

UNOBTRUSIVE: flat panels or solar shingles blend unassumingly into existing architecture.

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Faculty Coordinators: Arthur Haman, Robert Ross, Mark Schumack (College of Engineering & Science) and Will Wittig (School of Architecture)

Student Team Leaders: Dave Chew, Krysten Dzwigalski, James Hadley, Chris Keimig, Mehgann Mouyianis and Tim Rourke

Figure 4. Text for the engineering lobby display.

Figure 5. The solar website at <http://eng-sci.udmercy.edu/solarpower/index.html>.

Overview of the installation process

The five-member implementation team consisted of faculty members from mechanical engineering, physics, and architecture, along with the College's associate dean of operations and the university's Facilities Operations Manager. After receiving funding in August 2005, the team met to determine location of the seven PV assemblies and tie-in to the building's grid, and to complete specifications for ordering the PV assemblies, inverter, connection boxes, transformer, and data acquisition system from United Solar Ovonic. A core team of five students was chosen by faculty to be trained by United Solar Ovonic on how to assemble, install, and wire the assemblies. Later another student joined what came to be known as the Student Leadership Team, consisting of five students from engineering and one from chemistry. In September, a College-wide informational meeting was held in which an additional 17 students were recruited to assist in the installation effort.

The main tasks for assembling the PV system were 1) laying the laminates in the 77 roofing trays, 2) attaching and wiring the junctions boxes to the trays, 3) assembling the seven tray support structures on the roof, 4) attaching the trays to the support structures, and 5) wiring the assemblies. Working on average two full days per week, students and faculty completed the first four activities over a period of about three weeks in October. Engineers from United Solar Ovonic were on hand for two of the workdays to supervise and assist. Thankfully, unseasonably warm and sunny fall weather made for some delightful afternoons on the roof of the engineering building.

Wiring the seven assemblies to the combiner box, installing and wiring the inverter and disconnects, and connecting the data acquisition system all occurred from November 2005 through January 2006. These tasks were accomplished mainly by faculty, the Student Leadership Team, and engineering technicians. Final connections were made by the University electrician, and the system began supplying power to the building grid in late April. Due to some problems with the computer readout for the data acquisition system, it was not until July that we began logging performance data.

Figures 6 through 10 show photographs chronicling the installation process.

Figure 6. Laying the laminate in the roofing tray in the engineering highbay.

Figure 7. Attaching the junction box to the bottom of the tray.

Figure 8. Hoisting the trays to the engineering building roof.

Figure 9. Assembling the tray supports on the roof.

Figure 10. Attaching the trays to the support structure.

Will Wittig, the team's architecture faculty member, designed the layout for the informational display. The PowerPoint presentation for the display was designed by Wittig and Robert Ross (the team's physics faculty member). Wall space was designated for the display in a prominent location in the engineering building lobby, and construction of the display was accomplished in August and September by an engineering technician, with vinyl lettering installed by a local print shop.

An opening ceremony for the PV system was held on October 20, 2006, with attendees from the University administration, state government, United Solar Ovonic, a local high school, and the UDM student body. The six student leaders were recognized and awarded certificates at the event.

Material related to the PV system has been introduced into the curriculum of two physics courses, an engineering course, and an architecture course. One of the physics courses, Introduction to Physics (PHY110), is a two credit summer enrichment course for high school students as part of the university's Uninitiates Introduction to Engineering (UNITE) program. Additionally, the solar panels are topics of discussion in the middle- and high-school Detroit Area Pre-College Engineering Program (DAPCEP) classes held throughout the year at UDM. The PV system is also highlighted in the University's virtual tour for prospective students. These venues, in addition to the ongoing visits to the lobby display and website and occasional walking tour of the system, ensure that the public demonstration aspects of the project are fulfilled.

Student learning

The leadership experiences gained by students during the project were invaluable. A project of this magnitude introduced many teaching opportunities relative to working as a group, problem solving, giving and following instructions, and project and time management. Student leaders took charge of coordinating the assembly efforts of the other student volunteers, a responsibility that taxed their people- and materials-management skills. Installation of the solar assemblies was conducted in the midst of an academic term, impressing upon the students the importance of creating a schedule and following it to enable successful completion of a project in a timely manner. Part of an engineering education is to prepare students for their professional lives, and the solar array project offered a hands-on approach for achieving that objective. Additionally, the student leaders found this project an opportunity to confirm their career choices to be engineers.

Much of the leadership experience was gained through problems experienced throughout the installation. From delayed deliveries to the receipt of defective parts, all types of setbacks were encountered. Students had to be flexible in their working hours, learn new skills "on the fly," and, most importantly, exercise patience. For instance, a crane was hired to transport the crates containing the finished trays to the building roof. However, when students and faculty met at the appointed time and place to help move the trays, the crane operator was nowhere in sight. Instead of postponing the effort, the team devised a way to lift the trays to the roof with ropes and muscle-power. The overcoming of this problem kept the project on schedule and fostered a can-do attitude that resulted in the lifting of not only the trays but also the team's spirits.

As for engineering knowledge, students were able to learn about the benefits of solar power from their training at United Solar Ovonic and from discussions with faculty during the course of the installation. They became familiar with the environmental and economic advantages of using solar energy, in addition to learning how factors such as time of day, season, and location affect solar resources. Hands-on experience with drilling, metal cutting, soldering, wiring, and other manufacturing techniques enhanced their practical skills.

Preliminary data analysis

Figures 11, 12, and 13 show several performance measures for August 4, a typical sunny summer day (the jagged behavior of the curves in the afternoon is probably due to sporadic cloud cover). After nearly a year of collecting data, we are currently in the process of initiating a study to thoroughly examine the performance of the system. What follows below is a brief presentation of preliminary results.

Figure 11 shows that the system produced a maximum DC power slightly above the rated 10 kW. Ignoring the sporadic afternoon power peaks, the figure implies a maximum power occurring at around 2 PM. When correction for daylight savings time is made, this results in an equivalent solar time of 12:20 PM (see reference 2 for solar time calculation methods), close to the expected value of solar noon for the time of maximum power output. The average efficiency for the panels, defined as the ratio of DC power output to the solar irradiation, was 6.7% for the day. This efficiency value was calculated based on the active area of the solar panels (174 m²). If we instead use the total footprint of the panels (i.e., the roof area covered by panels and support structure, 211 m²) an average efficiency of 5.5% is obtained. Figure 12 shows DC and AC power output, along with the inverter efficiency (defined as the ratio of AC to DC power output). From about 9 AM to 6 PM the inverter efficiency ranged between 65% and 80%. The integrated average efficiency, obtained by taking the ratio of AC energy output to DC energy input for the day, was 74%. This inverter efficiency appears low, and remains a subject for further investigation. Figure 13 shows the variation in system voltage and current throughout the day. As expected, the voltage remained relatively steady at near the rated value of 363 VDC, and the current peaked near the rated value of 29 amps.

From the time the system came online at the end of April 2006 through February 2007, the system generated a total of 8700 kWh. This yields an average monthly energy output of 870 kWh, which, if extrapolated for the entire year, yields slightly over the expected annual output of 10,000 kWh.

Figure 11. Daily solar irradiation, DC power output, and efficiency values for August 4, 2006.

Figure 12. DC power output, AC power output, and inverter efficiency for August 4, 2006.

Figure 13. DC voltage and current output for August 4, 2006.

Conclusion

This project had two objectives: first, to demonstrate that photovoltaic solar energy generation can be seamlessly incorporated into existing architecture; and second, to inform and educate a wide-ranging target audience about the technology and issues surrounding photovoltaic systems. As demonstrated by the successful installation and operation of the system, and by the ongoing wide exposure given to students and members of the public, the objectives have been met. Due to the long-lasting nature of the solar panels themselves, the presence of the permanent display kiosk in the engineering building lobby, and the online presentation of the system, the PV demonstration project promises to be a highly visible educational venue for years to come. Another significant outcome of the project was the learning experience for the student volunteers, in terms of both leadership and technical skills obtained.

Acknowledgements

Contributing largely to the project's success (and relatively low budget) was the enthusiastic participation of student volunteers. The student leaders were David Chew, Krysten Dzwigalski, James Hadley, Chris Keimig, Meghann Mouyianis, and Tim Rourke (five of these are co-authors of this paper). Other student volunteers included Dominick Aleardi, Eli Kafar, Godwin Bibah, Elizandro Lopez, Carl Bolofer, Christopher Payne, Jake Filipic, Casey Stein, Jessica Gasior, Amy Szewczyk, Elizabeth Hardy, Laura Uschold, Andrea Hooper, Jason Wah, Keyur Patel, Carel Minjeur, and Andy Wakeland. We are also grateful to United Solar Ovonic for the

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