



Portable Photovoltaic Laboratory for In-Service Teacher Workshops

Prof. Kenneth E. Dudeck, Pennsylvania State University, Hazleton Campus

Kenneth Dudeck is an associate professor of Electrical Engineering at the Pennsylvania State University located in Hazleton, Pa. He has been teaching Electrical, Computer, and Electrical Technology Engineering Courses for the past 25 years.

Dr. Wieslaw Grebski, Pennsylvania State University, Hazleton Campus

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Abstract

This paper describes the design and development of a sustainable energy workshop that features a mobile photovoltaic laboratory for the purpose of providing an outdoor learning resource. The portability of this laboratory was achieved by the design and construction of custom utility carts used for the mounting of the photovoltaic panels and the supporting instrumentation. The workshop also included a demonstration fixed solar thermal system used to generate hot water, as well energy auditing techniques.

The instrumentation outlined in this paper was used in the delivery of two separate workshops that were offered to 8 -12 grade teachers as part of their Act 48 in-service workshops. The objective of these workshops was to expose teachers to the concepts of renewable energy resources and empower them with teaching materials that they could use in their classrooms to increase student awareness and excitement in renewable energy industry.

Additionally, this paper also provides details regarding the content, pedagogical outcomes, and assessment results of the developed workshops that used this instrumentation.

Background

Without a doubt, the greatest national challenge facing the United States and the rest of the world is how to manage the continually rising demand for energy in the face of dwindling fossil energy based resources. Obviously a multipronged approach that incorporates conservation as well as development of renewable energy resources must be vigorously pursued in order to find a solution to this dilemma. The entire public must be vested towards making a transition from a fossil fuel based society to one that utilizes a far greater amount of renewable energy resources. According to Elder (2009) “Higher education has a critical role to play in this transition, much as it did during the space race of the 1960s. Our colleges can - and must - help students understand the complex connections and interdependencies among our environment, energy sources, and economy - all of which underpin the green movement.”^[1]

The present situation is very similar to the 1960’s when the entire country was unified towards placing a man on the moon. The space race grew out of the fear of space domination by an adversary whose intentions were unclear. Today we are faced with the potential threat of running out of energy, which is the life blood of a modern society. Now, just as then, bright young engineers and scientists are needed to achieve the goal of sustainable energy independence. In the 1960’s there was a certain glamor associated with astronauts and rockets

that made high school students want to study science and engineering and ultimately work in the space program or something closely related. Today more than ever, K-12 students need to be attracted towards the STEM programs, especially those who have the interest to deal with energy issues. Many teachers are working to integrate energy related topics into their curriculums and involve students in “a community based sustainable energy project that will give them the opportunity to make a difference in their local community and the world”.^[2]

At the university level, various “Energy Engineering” programs have begun to emerge to address the anticipated shortage of energy engineers. In a 2009 industry survey by the Center for Energy Workforce Development^[3], it was found that over half of engineers engaged in power generation could leave their jobs by 2015, due to retirements and other attrition. This anticipated shortage of traditional energy engineers, along with the growth and interest in renewable energy represented an opportunity for the development of a relatively new BS in General Engineering with Alternative Energy and Power Generation Option^{[4],[5]}. At Penn State Hazleton, this program will graduate its first class of engineers in the Spring of 2014.

In order to help promote the program, it was decided that the campus would develop two workshops geared towards secondary education STEM teachers that would introduce them to renewable energy topics as part of their annual continuing education requirement (ACT 48), and provide them with lessons that they could bring back to their respective schools. These workshops would help achieve two major goals: raise general awareness about renewable energy and promote the new program at Penn State.

A grant was received from the Pennsylvania Environmental Protection Agency that provided funding to build three mobile photovoltaic systems that were mounted on carts to provide a portable solar energy laboratory platform. These carts provided the cornerstone of the two workshops. During the first workshop, the teachers were involved in testing the electrical integration on the workbench which yielded valuable details concerning the final cart design. The second workshop actually used the carts out in the field to provide remote electrical power. One of carts was used to provide electrical energy for a circulation pump used in a roof mounted solar thermal hot water system. The grant also provided funds to build a mock roof section and purchase this solar thermal water heating system. Details about the solar carts and workshops are contained in the sections that follow.

Photovoltaic Solar Carts

The solar carts were designed and fabricated using 1.25 inch aluminum “L” stock to construct the frame. The frame would support two 21x41 inch solar panels as shown in Figure 1.

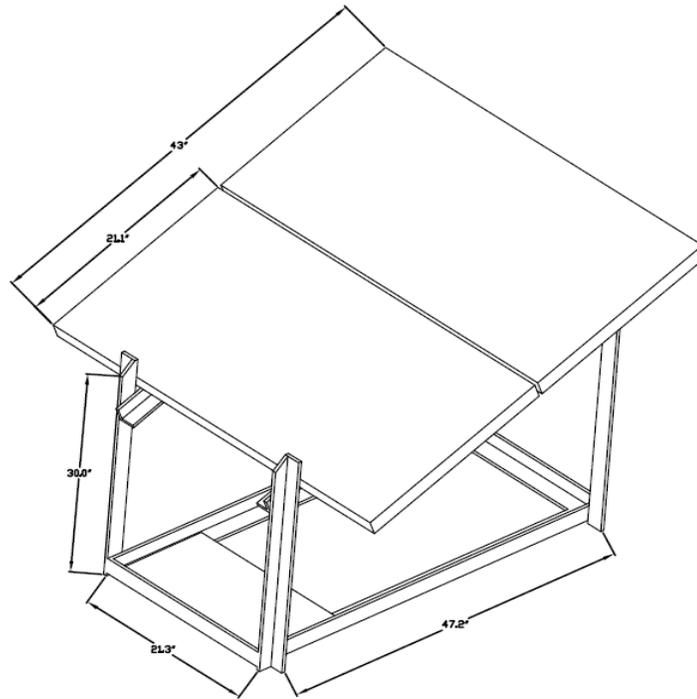


Figure 1 – Portable Cart Structure Used to Support Two Hinged Solar Panels

The base of the cart is welded together and has four casters located in each corner for easy transportation. The four vertical posts are connected with bolts and wing-nuts to the four corners of the base. The two solar panels are hinged together and rest on support rails beneath the panels which are not visible in Figure 1. Each of the two support rails are connected to two of the vertical posts by bolts and nuts. In this manner, each side of the cart can be disconnected from the base and folded into one long element. The two solar panels fold toward each other which protect the PV side from damage when not in use. The folded panels then can be connected to the welded base by latch connectors, forming a single attaché case with the side elements stored inside as shown in Figure 2.



Figure 2 – PV Mobile Carts in Attaché Storage Configuration

In addition to the carts themselves, the mobile PV laboratory has the following electrical components:

- two 12VDC/80W solar panels , connected in parallel (12VDC/160W total array power)
- one 200W 12VDC/120VAC power inverter
- one 240W battery charge controller
- one 12VDC (18Ahr) deep cycle sealed battery.

The fully functional assembled cart is shown in Figure 3 providing power for a 120 W circulation pump for a solar thermal water heating system. The photograph shown in Figure 3 was taken during the second of two workshops on May 11, 2012. Approximately at 12pm, while the sun was high in the sky, the workshop participants measured the voltage from the array at 12.4VDC. The DC current from the array was measured at 13.2A which netted a total of 163W of array power. The power from the array was used to charge the marine battery and the battery power was feed into the 200W inverter. The power from the inverter was used to run the circulation pump for the solar water heater. The AC current for the pump was measured using a clamp-on current meter and observed to be approximately 0.95A at 120VAC, or 114 W .



Figure 3 – Solar Cart Providing Power to a Pump for a Solar Water Heating System

Workshop Details

Two separate Act 48 workshops were developed and conducted at Penn State Hazleton that focused on middle school and high school teachers (grades 8-12). Both workshops included information about all the different forms of renewable energy as well as home energy auditing. Attendees used a “Kill-a-Watt” energy usage monitor to record energy consumption of various household items. They also used a thermal leak detector to measure potential sources of thermal heat loss.

The first workshop was offered in the Fall of 2011, at which time the carts were not completed. So the attendees connected the electrical equipment that would be eventually used for the photovoltaic carts: solar panels, charge controller, battery, and power inverter, on a bench top near a window to verify the electrical integration of these components in the final cart design.

The second workshop was offered during the Spring of 2012, at which time the carts were fully functional. Also by that time, a roof section was built to support a solar thermal water heater array and the solar carts were used to provide power to the pump as shown in Figure 3. Also during the second workshop, an additional module was conducted that introduced photovoltaic system sizing requirements. Students were able to design a stand-alone PV system for a specified electrical load by specifying the required components needed for the PV system to satisfy the given load requirement.

The materials presented to the teachers, as well as the hands-on experiments, were developed to comply with the Pennsylvania Department of Education Standard Aligned System subject areas in *Science and Technology and Engineering Education* as well as *Environment and Ecology*. Organizing categories within Subject Area 3, *Science and Technology and Engineering Education*, included *The Scope of Technology*, *Technology and Society*, and *Technology and Engineering Design* for grade levels 8 and 10. In addition the workshops presented materials and experiments related to Subject Area 4, *Environment and Ecology*, which included standards from *Natural Resources* for grade levels 10 and 12 and *Humans and the Environment* for grade level 12. More detailed information related to the Pennsylvania Department of Education Standard Aligned System is available at <http://www.pdesas.org/Standard/StandardsBrowser>.

The teachers who participated in the workshop were provided with hands-on activities and experiments in the areas of energy auditing as well as solar thermal and photovoltaic systems. Additionally they had the option to borrow the equipment, including the mobile carts, for demonstration use in their classrooms. By developing a lending schedule, all the workshop participants had the opportunity to utilize the equipment in their classrooms on a rotating basis.

Workshop Assessment Details

The assessment of the workshops was conducted by asking each participant to complete a pre- and post- workshop evaluation form. There were a total of 13 collected evaluation forms. The pre-workshop questionnaire asked participants to rate their general knowledge in the various topic areas of renewable energy using a 1 (low) to 5 (high) point scale. Using the same scale, the questionnaire also asked the participants to rate the *relevance* of two stated workshop learning objectives which are listed below.

- To teach students topics related to sustainable forms of energy, for example, wind power, solar photovoltaic, solar thermal and energy efficiency.
- To teach students to perform an energy audit for a residential setting and create an energy saving plan based on the energy audit.

The post workshop evaluation asked the participants to again rate their knowledge in the topic areas addressed during the workshop and then rate the effectiveness of the workshop in achieving the stated learning objectives. In this manner the effectiveness of the workshop in each area could be evaluated. The questionnaire also asked each participant to rate the overall quality of the workshop and to provide individual comments.

The average results for Pre- and Post-Workshop Knowledge Areas from 13 samples of the evaluation forms, along with the percent change, are shown in Table 1. The relevance in the pre- and effectiveness in the post- workshop learning objectives are also shown in Table 1.

Knowledge Area	Pre-Workshop	Post Workshop	% Change
PV Cells and Solar	2.77	4.69	38.5%
Wind Turbine	3.08	3.92	16.9%
Solar Thermal	2.77	4.38	32.3%
Hydrogen and Fuel Cells	2.69	3.62	18.5%
Biofuels	3.31	3.85	10.8%
Objective #1	4.77	4.85	-
Objective #2	4.23	4.69	-

Table 1 – Pre-and Post- Workshop Renewable Energy Knowledge Areas

The results of total evaluation of the workshop quality are summarized in Table 2.

Post-Workshop Assessment	Average
Topic Relevance	4.85
Level of Information	4.92
Level of Detail	4.85
Knowledge of Presenters	5.00
Presenters Clarity and Professionalism	5.00
Workshop Effectiveness	4.92
Time Length	5.00
Location and Facilities	5.00

Table 2 – Workshop Quality Results

The results of questionnaires appear to indicate that the participants gained valuable knowledge in each of the listed topic areas showing a percentage increase ranging from 10.8% to 38.5%. It should be noted that a significant amount of the participants were biology teachers who had a high degree of prior knowledge in biofuels. It should also be noted that the topics that were emphasized the most, photovoltaic, solar thermal, and energy auditing, received the highest percent increase in gain knowledge.

The seminar evaluations appear to indicate that the workshop experience itself was of great value to the participants. Some of the open comments from the evaluation forms were: “excellent job”, and “great introduction to alternative energy for use in STEM-based curricula”. Many of the participants appeared to really value the hands-on activities using the instrumentation listed in this paper. Some of the comments in this regard were: “I plan on borrowing the thermal leak detector for my class”, “I can now truly communicate the use of solar power to my students, the

visuals outside were amazing!” and “Am glad to know I can borrow these carts for demonstration at my school!” As expected, the topic areas that included the hands-on activities received the largest percent knowledge gain.

Conclusion

The format of this workshop, especially the use of the related instrumentation, appears to have been quite effective and well received. While this renewable energy workshop focused mostly on photo voltaic and solar thermal technologies, energy sustainability includes other types of viable renewable energy resources such as wind, biofuels, geothermal, fuel cells, and hydroelectric. Depending on the solar resource available, which is location dependent, solar energy is not always the most efficient form of renewable energy to consider. In order to offer a more comprehensive perspective, further work is being considered to develop similar workshops using the same format with the appropriate instrumentation focusing on these other renewable energy resources.

Bibliography

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