Promoting STEM with an Electric Energy System

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Abstract

The United States Air Force Academy (USAFA) has been designated as a demonstration Net-Zero Energy installation meaning it should attempt to generate as much energy as it uses. With a primary mission of education, USAFA has a unique opportunity to contribute to the Net-Zero Energy efforts while at the same time promoting Science, Technology, Engineering, and Math (STEM). Within USAFA, the Department of Electrical and Computer Engineering has developed a Green Energy Lab to further both faculty and student understanding of solar, wind, and other energy generation technologies and their applications. Over the last several years and including the current year, undergraduate senior capstone teams have designed and developed a highly mobile renewable/green energy system supporting the Net Zero goal. The system consists of an all-electric off-road vehicle with an off-road energy storage trailer that can store power generated from solar, wind, and mechanical sources. The complete system can be easily driven or carried to virtually any location or venue such as University Football games, graduation ceremonies, and other local energy related events. Being mobile, the system provides an opportunity for the exposure of green/renewable systems to primary and secondary school age children who are primary STEM targets. The system has been built with STEM outreach in mind and specifically allows for hands on demonstrations and fun experiments that can be done anywhere including school parking lots. As an engineering challenge, each year one of our capstone teams will take on the task of improving and expanding the capabilities of the system thus requiring the capstone students to acquire in-depth, hands-on knowledge of many different systems and engineering problems including multiple voltage levels, AC and DC power conversion, energy storage, power distribution, and economics of energy. This paper describes the energy system, the STEM outreach benefits, and the relevance to undergraduate engineering.

Introduction

During the last several years, numerous studies and articles indicate the United States, as a nation, has a serious shortage of young people entering into college degree programs and careers in STEM related areas[1,2]. Concurrently, there exists an increasing need for people who are knowledgeable in renewable energy technologies that drives the need for more young people to enter these career fields. Studies also indicate American students are falling behind other countries in primary and secondary school STEM abilities [3]. Obviously, there is a problem developing with numbers in STEM career fields and this paper illustrates one way that USAFA is incorporating mainstream green/renewable related technology into STEM outreach efforts providing hands-on motivation towards careers in green/renewable fields. Through the use of our newly established energy lab and by taking our highly mobile energy system to various venues, we are able to provide STEM outreach to local primary, secondary and post-secondary schools.

At USAFA, the Department of Electrical and Computer Engineering has developed a green/renewable Energy Lab to further both student and faculty understanding of current technologies and applications. First started in 2008, over 80 students and faculty have contributed to the design and implementation of a hands-on learning facility that includes two different types of solar arrays, an electric vehicle, a 7 kW mobile solar trailer, battery systems, energy data collection capability, and a host of small, safe, hands-on demonstrations. Since its inception, we have strived to maintain the concept of hands-on motivation, visibility, and appropriate levels of safety and supervision, to both faculty and students from USAFA as well as visiting elementary thru high-school classes. We believe this practice benefits the entire area of STEM promotion [4].

Our most recent addition, and the one that draws the most interest from young people, is our high powered electric off-road vehicle and energy trailer. Initially funded through an Office of the Secretary of Defense STEM grant, our senior capstone design teams have turned a discarded and non-functioning military electric vehicle into a fully functional mobile electric energy system using state-of-the-art technology. Our 2012/13 capstone team is currently designing and building an energy storage trailer to harvest solar, wind, and human mechanical energy. When complete, the system will be highly mobile and fully independent from commercial power. Easy setup and teardown facilitates off-campus demonstrations at diverse venues such as university football games, local schools, and local energy/STEM related events. The partially completed system has already been displayed at several Air Force football games as well as a local sustainability conference. Figure 1 below shows our electric off-road vehicle on display at the 2012 Colorado Sustainability Conference.

Figure 1. USAFA Electric Off-Road Vehicle on Display

Need for GREEN and a Push for STEM through Outreach

Most people would agree the United States is not producing sufficient high school and college graduates in STEM career fields and that many of our students are lacking mastery of basic sciences. How then can we, as a nation, a corporation, a school, or as individuals, help to increase the number of students enrolling in STEM related programs or fields? Clearly the rewards are there but for whatever reasons, our schools are not graduating enough young people into these technical areas [1]. One thought is that we might not be doing a good job of reaching students outside of those who are inherently driven. We, as educators, can take STEM to the students and help them better understand and not fear or shy away from it.

Because we at the USAFA are an all undergraduate institution, our efforts are not always focused towards cutting edge academic research but rather, on ways to improve teaching and promote learning. These efforts, when coupled with our EES and Energy lab, provide both the expertise and tools needed to produce the very STEM outreach needed to motivate our young people.

Since the energy lab's inception, we have been able to provide tours, give green energy demonstrations, provide materials and occasionally student helpers, to over 500 elementary thru high school students. These new capabilities have contributed to the overall STEM efforts taking place in our local community schools. We recognize that not every student attending school is interested in a STEM related degree, however, we also recognize that there may be many students interested in a STEM degree but simply have not expressed those feelings or decided to go in a STEM direction. One of our goals then, is to nudge some of those students towards a STEM degree program. Below is a small sampling of some

demonstrations, hands-on activities, and other activities we think are helpful to students as they learn and think about their future.

Example #1 -- A fourth grade class spent two hours with our faculty learning about solar energy. Preplanned with their fourth grade teacher and a USAFA faculty member, the two hour session at the USAFA included some initial question and answer time with the students, a short tour of a large, fully operational, solar powered battery system, a discussion of some pros and cons of electric vehicle systems, and ended with 45 minutes of outside time with motors, multi-meters, wires, and solar panels. For the hands-on activities, the class broke into groups of 2-3 students and were provided a multi-meter, a 25 W solar panel, a small DC motor, and instructions as to how to hook up the panel to the motor in order to make it spin. On their own initiative, several groups combined their panels to create higher voltages and currents thus learning about series and parallel circuits. They also learned things like how varying the sun angle affected the motor speed. Overall, a very beneficial and satisfying day for both students and faculty.

Example #2. During a heavily attended Air Force versus Navy football game, the electric vehicle and energy trailer were setup on the food concourse inside the stadium gates. Despite it being a cold day, there were many people, both young and old, that were captivated by the static display and came by to ask questions. A related event was at an engineering department tailgate at which the vehicle was able to be driven around the parking area by many different people sparking several discussions about electric vehicles and their use. Seeing a silent, military-style (but painted Air Force Blue), all electric vehicle pull up and take people for silent, but very fun rides is one of the best motivators.

Example #3. Tours. Even high school students enjoy a tour of a local 6 MW solar array, especially when the tour is given by students only a few years older than themselves. The large 6 MW solar array that sits adjacent to the south gate entrance at the USAFA is an impressive site from the highway, but it gave the high school students a whole new perspective after being up close and personal with it.

Example #4. Three students from the USAFA took an entire morning out of an academic school day to provide a renewable/solar demonstration to a local elementary school. Our senior undergraduate students executed, on their own, both the presentation and demonstration pieces to over 300 kids.

Example #5. The most recent opportunity for outreach came as an invitation to a local conference. Our electric vehicle came as an invited guest to the 2012 Colorado Clean Cities Exhibition and Conference. Although not a typical STEM outreach venue, this conference allowed industry leaders some insight to our current activities in this arena.

Several additional examples/demonstrations are briefly described to give other ideas:

- An electric space heater powered directly by a larger panel. Demonstrates that AC is not always needed for resistive heating.
- Operational, high voltage, lithium-ion battery system. Hands-off but it does have a high “That’s Really Cool” rating.
- Multi-meters and cables to show topics like open circuit voltage and short circuit current.

- Functioning vehicle horn. Simple but very motivational for children in pre-school to second grade.
- Electric Vehicle low-speed governor. Allows anyone to take the vehicle for a short ride without fear of accelerating beyond their, or our, comfort level.
- Static displays and "pass-around-items" such as batteries to compare (lithium, lead acid, nicad, etc.)
- Renewable/Green energy flyers describing the EES.

Clearly, the above efforts support both STEM outreach as well as promoting renewable energy. The proverbial two birds with one stone.

The Electrical Energy System (EES) and its Systems

The EES is our main STEM outreach attraction. The system is still under development by both faculty and students, but when completed, will be a highly mobile, electric supply and generation system capable of supplying 18 kWh of energy to multiple consumers at multiple voltages. The system will contain at least one electric vehicle but could easily contain several. The system will have the capability to charge the electric vehicle using a standard 120 V or 240 V grid connection but will also be designed to be fully self-sufficient providing its own energy through deployable solar, wind, and mechanical means. A description of the system follows.

A. Vehicle Mechanical. A dune-buggy style off-road steel tube chassis provides the basic framework for the system. With few side or top panels, nearly all components are visible and easily accessible with minor effort. People interested in the mechanical aspects of the vehicle can clearly see how things are connected and how they work. The vehicle has up to 1500 lbs. of towing capability, and can haul our off-road trailer which houses the energy harvesting and storage system.

B. Vehicle Electric. We use a 325V LiFePo battery system to power a three-phase AC motor via a high power DC-AC converter/controller. In addition to the high voltage system, the vehicle also uses a standard 12V system for lights and ignition.

C. Energy Harvesting and Storage System. Housed in an commercial-off-the-shelf off-road trailer, this portion of the EES is currently at the prototype stage and plans to harvest energy from a combination of solar, wind, and human mechanical means, and then stores that energy in a large, 18 kWh battery bank.

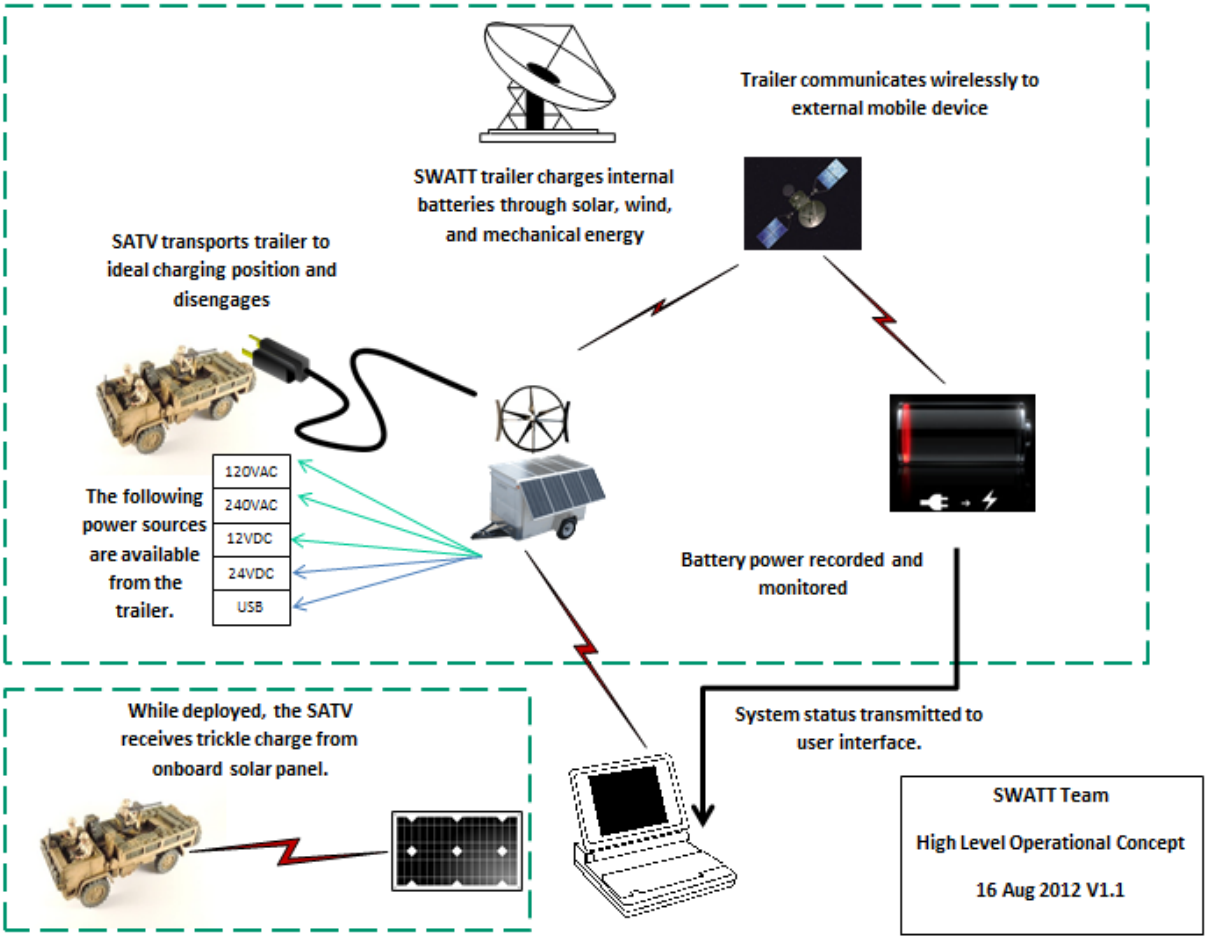

Figure 2. Operational View of our Electric Energy System

The EES currently is being designed, piece by piece, through a multi-year senior capstone design team concept. The 2012/13 team is focusing on the trailer design and implementation. The 2010/11 team focused on rebuilding and testing an electric off-road vehicle. In 2009/10, the team developed an in-place 7 kW solar array complete with battery storage as a prototype.

Relevance to Undergraduate Engineering

There are a many commercial electric vehicles, educational pieces of equipment, online resources, etc., however there are few that provide undergraduate students with both an engineering education and a chance to do real engineering. Our EES provides both. Through our capstone course, students have an opportunity to directly design and contribute to the overall system. USAFA does not have access to graduate students and although we can do long distance collaboration with the Air Force Institute of Technology, we generally consider our projects to be at the undergraduate level.

Senior Capstone Design teams are nearly all multi-disciplinary consisting of students from many majors including electrical, computer, mechanical, systems engineering, and management. The majority of our

students are aware of and increasingly interested in those technical areas that focus on renewable and green energy and hence come to us well motivated to learn.

Because the EES and subsystems are so relevant in today's society, teams can immediately see the relevance and quickly want to find ways to improve the system. With no graduate students to get in their way, our students have to quickly come together as a group to solve their particular problem.

As an example, the 2012/13 group of 8 students had several challenges to overcome to support the energy harvesting and storage portion of the EES.

- Find a way to combine multiple generation sources
- Learn about and use a modern lithium battery system
- Work within a predefined budget

Feedback sessions near the middle of the second semester indicated the students felt they were learning a significant amount about real engineering. Things like schedule setbacks, parts breaking, tinkering taking to long, etc., all contributed to the overarching learning objectives.

Conclusion.

Hands-on learning is awesome. Students get to touch and feel how parts go together to create a greater design. They can experience the agony of defeat when their $300 inverter breaks and now they must find a work-around. They can experience the thrill of victory when a battery/solar system actually powers something real like a space heater during a cold, outdoor football game demonstration. Without even knowing it, students are taking part in STEM activities both for themselves and also for the people they demo their project to. Excitement grows as the project matures and everyone can see real results.

So how effective have our STEM outreach efforts been? That's a tough question to answer on a small scale, however, we hope to one day have a student in our energy classroom tell us he or she saw the EES system at a football game when they were little and it motivated them towards a career in energy.

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