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Training Global Engineers: A Capstone Senior Design Project in Energy Harvesting and Sustainability

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Abstract

As the world of engineering becomes more global in character and practice, our instructional endeavors must follow suit and enable our graduates with the necessary skills to thrive in their career. Our task is to prepare students to be more effective in a global context as well as to be able to respond to today's challenges, giving them the competencies deemed important or even essential for global engineering work. Combined with these pressing needs are the current global considerations to conserve natural energy resources and convert to more sustainable methods of power generation.

This fortunate unique combination led to the development of a series of capstone projects in energy harvesting and renewable energy areas. One project though stands out, as it serves as a model of such interdisciplinary and integrated work: under authors supervision and advising, the student-team developed a hybrid wind and solar powered outdoor (street) lighting kit, aimed to be mostly off-grid, eco-friendly, eco-designed, being able to provide significant reductions in natural resource consumption and energy costs, more flexible installations, and a significant leap forward to becoming energy independent.

The paper aims at presenting the project technical aspects with a centering on lessons learned and instructional and educational aspects of developing this project.

Introduction

"Global Engineer" syntagm evolved into encompassing a wider understanding than before: it includes innovation and sustainability, environmental consciousness and business oriented, while serving the greater good in a multicultural environment. In the same way our curricula must evolve accordingly, integrating all these skills into homogeneous and well developed learning modules and activities. **Training students to be able to identify, formulate and solve emerging engineering problems of today's economic, social and environmental framework is a tremendous task and involves much more than a traditional engineering curricula.** Engineering programs across the nation, including our program in Engineering Technology, did incorporate courses and concentration in renewable energy, sustainability, green manufacturing and so on: this remarkably increased the competencies' quality of our students. However, the overarching integration of the knowledge acquired throughout the program's curricula is achieved through incorporating the capstone design component in undergraduate engineering education. The design experience develops the students' lifelong learning skills, self-evaluations, self-discovery, and peer instruction in the design's creation, critique, and justification, *contributing to the creation of the global engineer of today's world*.

Combined with these pressing needs are the current global considerations to conserve natural energy resources and convert to more sustainable methods of power generation. This fortunate unique combination led to the development of a series of capstone projects in energy harvesting and renewable energy areas. One project though stands out, as it serves as a model of such interdisciplinary and integrated work: under authors supervision and advising, the student-team developed a hybrid wind and solar powered outdoor (street) lighting kit, aimed to be mostly off-grid, eco-friendly, eco-designed, being able to provide significant reductions in natural resource consumption and energy costs, more flexible installations, and a significant leap forward to becoming energy independent. The project was developed also under the guidance of the relevant departments of our Philadelphia Streets Department. The system aimed at retrofitting the existing street lighting poles and working in conjunction with current LED technology that is to be implemented to reduce the electricity demand. Students used an integrated approach of two vertical axis turbines (Darrieus and Savonius) and a PV panel, building a fully functional prototype, amenable to wireless monitoring and further improvements for increased efficiency. *This unique combination proved to be able to provide 85% of the required operation power of a street-light. Combining the sustainable and relatively reliable nature of the power sources, the higher quality of light, and the reduction in fossil fuel consumption achieved, the retrofit kit may provide a great leap forward towards a more sustainable society.*

The paper aims at presenting not only the students achievements in terms of the project technical aspects but mostly will focus on the lessons learned and on the instructional and educational aspects of developing this project, embedded into the engineering design experience. The paper concludes with an assessment of our current work including how our findings are inspiring creation of situational prompts and activities for instructional uses.

Background

The United States Department of Energy has laid out a vision in 2011, which includes having the U.S. secure a leading role in clean energy technologies [1]. With current global considerations to conserve natural energy resources and convert to more sustainable methods of power generation, applied efforts need to be developed in order to integrate known methods of energy generation, and still be able to provide reliable results. Although traditional energy sources (such as fossil fuels) still meet most of our energy demands, the benefits of renewable energy have no match as being environmentally friendly while they are virtually inexhaustible. Sustainable development includes solving the sustainable energy resources problem [2]. "A sustainable energy system may be regarded as a cost-efficient, reliable, and environmentally friendly energy system that effectively utilizes local resources and networks." [3]. Renewable energy systems range from well developed and mature technologies to new and emerging technologies in need of further research and development. In terms of societal impact, renewable and sustainable energy systems will lead to an increase on energy independence, an advance in local and regional sustainable manufacturing industries, including increased research and development components of these industries; and to promotion of regional development of the workforce specialized in the renewable energy area with a direct impact in job creation. However, this growth created an even bigger gap between demand and supply in terms of skilled professionals in the area of renewable and sustainable energy systems, and energy conversion areas.

Educating students in controversial topics such as global warming, energy security, air pollution, ecological damage, reduce the carbon footprint and green-house emissions, just to name a few of them, will create a global and well rounded engineer [4]. This type of specialist will be able to identify and create solutions for these types of problems. Filling in the gap between the industry demand of specialized job skills and the current educational majors offerings at Philadelphia and surroundings local colleges and universities, our Drexel University, Engineering Technology

(ET) program offers a combined electrical and mechanical engineering technology major, with several courses related to renewable energy, energy conversion, green energy manufacturing and sustainability. Our main goal is to create a highly skilled professional workforce ready to "hit the ground running" after graduation and also having most of the qualities of a "global engineer", a critical thinker and an innovator which is in total agreement with ABET criterion c ("an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability"). Our ET program developed during the past 6-7years more and more courses oriented towards energy conversion and green energy and sustainability. As a result of this enhancement of our program, during past five years, we had an afflux of capstone project topics in the renewable energy area with a predilection towards wind and solar energy harvesting systems. During last academic year (AY), more that 50% of the capstone projects were in the green/renewable energy and sustainability fields. This coincides with a general trend of increased students' interest in developing sustainable systems and honing their acquired skills in sustainable energy systems development through our series of capstone design courses, which is more in tune with the aforementioned criteria.

Senior Design Course Sequence Overview

Although our students receive an integrated theoretical and experiential learning throughout our curricula it is crucial for engineering/technology to transition from classroom work towards a more comprehensive experiential learning with applications of technology and design. *The main objective of senior design courses in engineering and engineering technology curricula is to bridge the gap between academic theory and real world practice. As discussed in the ABET criteria* [5] *senior capstone projects should include elements of both credible analysis and experimental proofing*. For the ET program at Drexel University, the senior design course is a year-long educational journey (three quarters) that takes an idea generated by a student or an industrial sponsor and culminates in a product. This course is an excellent capstone experience, which requires both teamwork and individual skills in solving a modern industrial problem. Senior design projects seminars in fall, winter and spring quarters bring the students, faculty, and industrial partners together to see the student's results and to give them the additional experience of public presentation of their work.

For an engineer in industry, a project is a sequence of tasks required to reach an objective. Typically, the objective is to design a device or process that has value to a customer (user). The project begins by defining a performance problem associated with an application and ends with a design solution. The problem drives the learning required to complete the project. Managing the project requires the engineer to demonstrate effective teamwork, clear communication and the ability to balance the social, economic and environmental impacts of the project. Moreover, this approach provides a context that makes learning the fundamentals more relevant and, hence, results in better retention by students.

This project is an underway project for capstone Senior Design Project, performed by a team of four students in the ET department. Senior Design Project is a sequence of three-quarter capstone project design courses required for all the BSET majors. The course focuses on planning, development, and implementation of an engineering design project, which includes formal report writing, project documentation, group presentations, and project demonstrations. The goal of these courses is to demonstrate the ability to manage a major project involving the design and implementation of products with a mixture of electrical and mechanical elements as a member of a product innovation and/or development team. In these project-based courses, the students are expected to effectively manage their time and team efforts to produce a working prototype of a product in three ten-week quarters. Progress and formal reports, and oral presentations constitute integral components of this course sequence. Before beginning the projects, student teams are provided adequate training in project formulation and resource analysis, performance goals and team expectations, public presentations of project work, and individual project supervision.

All capstone projects, this one included are assessed at the end of each quarter using performance indicators stemmed and mapped to the a-k ABET-ETAC criteria. Some of the performance indicators that are included in the evaluation of our capstone projects are as follows:

- Demonstrates ability to apply knowledge and techniques of the discipline.
- Demonstrates mastery of the techniques and skills of the discipline
- Demonstrates mastery of modern tools used in their discipline
- Demonstrates an ability to apply knowledge of science to engineering technology problems.
- Demonstrates an ability to apply a knowledge of engineering and technology to engineering technology problems
- Demonstrates an ability to identify system, component, or process requirement
- Demonstrates an ability to define an optimal, realistic, and technical approach that meets requirements in terms of technical, economic and societal criteria with realistic deadlines.
- Identifies problems that are suited for technical solution.
- Produces practical solutions based on meeting requirements of analyzed problem components.
- Presentations clearly describe goals, methods and solutions
- Responds to questions, comments and criticism in a clear and appropriate manner in oral interactions
- Identifies both potential and adverse impacts of engineered systems on society and the environment.
- Develops and evaluates alternative designs to minimize adverse environmental and societal impacts

These performance indicators are further detailed using a Likert type scale with an equivalence to the letter grading systems as follows: a score of 5 would be an A (≥ 90%); 4 would be a B (performance between 80% and 90%, and so on with 1 representing an F letter grade (< 60%). *The performance of the team is presented in the Assessment section of this paper.*

Student-team Project Description: Technical and Educational Aspects

This section covers mainly the technical aspects of the project as developed by the students. However, we would like to draw attention upon several educational aspects of the project: interdisciplinary nature: both electrical and mechanical engineering problems being approached; the global perspective: *students are approaching a project that has the potential of serving several communities, in an affordable and sustainable way; technical merit and innovative nature of the system; long term approach: students studied the viability of the system on a long* *term basis. This practical, real-world approach is essential for educating and training future "iEngineers" or "Global Engineers". Their generation as well as future generations are more and more connected to real world needs and issues. This project proves their shear interest in the field and their commitment to finding solutions to today's challenges.*

In many places throughout the local area of Greater Philadelphia area we notice the use of solar panels on streetlights and construction signs; we also see the use of wind turbines mainly on structures to generate electricity (such as those on Lincoln Financial Field). In areas where considerable seasonal changes occur, the change in weather throughout the year does not provide a consistent energy source with respect to solar or wind energy. What our student team has developed is a Solar/Wind hybrid power system, specifically designed to retrofit current street lighting poles and work in conjunction with LED (Light Emitting Diode) technology, which is slowly being adopted by the city to reduce the demand on current electrical services. This system has the potential to benefit both the City of Philadelphia by reducing yearly power consumption as well as PECO Energy by reducing their grid demand. The system is capable of providing sustainable power throughout the year by capitalizing on the high solar insolation in the late spring and summer months, as well as the greater atmospheric pressure variations that occur in the spring, fall, and winter months. Initially the system will be able to accommodate around 85% of the required power necessary on average. The system has the ability to become more efficient due to its modular structure system is modular and upgrades become as simple as switching out components. With the system implemented across the Greater Philadelphia area, for example, it will be able to provide significant reductions in natural resource consumption and energy costs, more flexible installations, and a significant leap forward to becoming energy independent.

Many cities such as Philadelphia and the surrounding areas are undertaking pilot projects to convert streetlights from high-pressure sodium (HPS) bulbs to more efficient Light-Emitting Diodes (LED). Because LED technology is about 30% more efficient than the HPS luminaries, utilizing renewable energy technologies is now a viable option [6]. In evaluating the current local market, while there is an increasing use of solar panels for streetlights and construction signs, and wind turbines used on structures, the use of a hybrid system is rather scarce in the urban area of Philadelphia. A thorough market analysis revealed that while there are companies producing hybrid wind and solar systems, these are for new construction and are rather expensive, running around $15,000 per pole [7]. The concept design of our students incorporated a hybrid design to install on existing street light structures, to significantly reduce the cost per unit, along with the ease of implementation and simplicity of the system designed to further increase savings from installation and maintenance. The design incorporated an improved Savonius and Darrieus wind turbine combination at the high point of existing streetlight structures, combined with solar panel as a hybrid power source to specifically provide energy to a streetlight in a retrofit package. The photovoltaic panel is the main power source and is complimented by the integration of the wind turbine to improve the capability of providing consistent sustainable energy throughout the year. The end result is a system that significantly reduces the needed power from the grid, which has a multitude of benefits, such as reducing the annual cost for providing a safely lit environment while reducing the demand placed on the electric company.

As can be easily seen, students tackled an ambitious project that addressed a real stringent need of the community, approached it in the real business model, discussing the project potential with the appropriate stakeholders (City Hall representatives), and choosing an optimal solution for the constraints presented, including addressing the sustainability issues. As a matter of fact, the entire solution was approached around sustainability, care for environment and meeting the community needs. This approach has been nurtured in several other courses in our curricula, all of them being laboratory integrated combined with project-led learning and practicum oriented learning (Thermodynamics and Heat Transfer Analysis, Energy Conversion, Power Electronics). The knowledge acquired during these courses and other courses in our curricula is put together in creating their design solution for the chosen system. While in respective courses students are asked to design components and/or subsystems, mainly guided by their instructor, during senior design sequence courses students are asked to create their original system with minimal input from the adviser, this endeavor being a showcase of their overall engineering skills, allowing us to evaluate not only their preparedness for real jobs but also our curricula as well. The success of our students is the measure of our success. In the figure below, we represent the major project based learning courses that require students to design a system, a component or a subsystem of an engineering system.

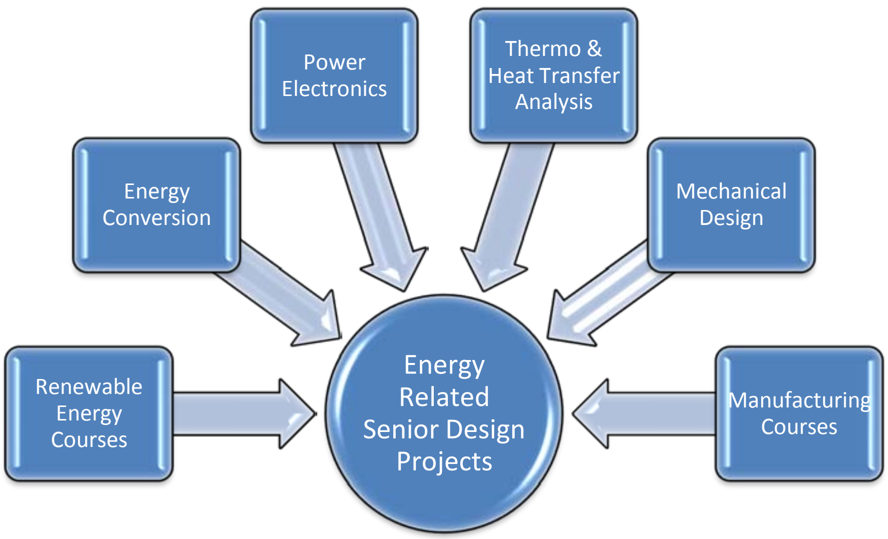

Figure 1 Project-Based Learning courses are feeders for capstone projects

Problem Statement: Creating a sustainable, environmental friendly system that incorporates both electrical and mechanical engineering technology knowledge

In today's world of heightened concerns regarding climate change as well as the uncertainty associated with fuel costs, the need to develop technologies that will assist in reducing this burden is of ever-increasing importance. One area that we have identified is that of street lighting. In the city of Philadelphia there are over 100,000 streetlights that range in power consumption from 100 Watts to 250 Watts, and up to 400 Watts on highway lighting. The cost to power these lights is in the millions of dollars annually. With the advancement of LED technology it is now feasible to consider the option of using renewable energy technologies as a street light power source. LEDs reduce the needed power necessary while still providing an equivalent amount of lumens, as well as a higher color rendering index or CRI. Taking this into consideration, the question was asked, "could a system be developed that would be able to provide the necessary power using current wind and solar technology?" Historically, renewable technologies have not been efficient enough to be of much use in small-scale applications, but with the reduced demand due to LED technology and the advancements in solar and wind power collection, we believe it is a viable option.

Problem statement as well as students conceptual design is focused to solve several pressing issues by one integrated system: light pollution, sustainable energy, aesthetically pleasant, cost efficiency, increased safety.

Conceptual Design:

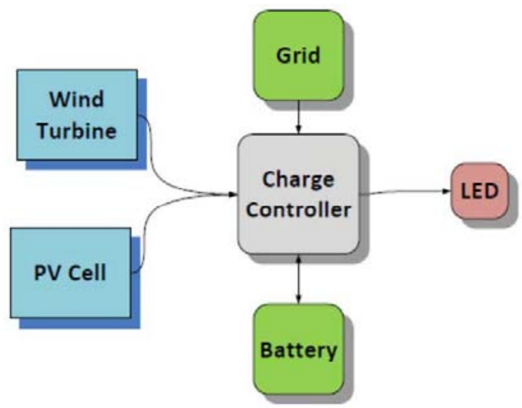

Figure 2 System Block Diagram

Figure 3 Hybrid Wind and Solar Integrated Kit

Mathematical Modeling

The following equations were used throughout our testing, and are noted respectively in the paper where used.

Savonius torque [8]

$$T_S = C_{T,S}\rho_{air}A_S d_S \bar{v}^2$$

Darrius torque [9] [10]

$$\tau_D = \frac{1}{4}C_{T,D}\rho_{air}h_D d_D^2 v^2$$

Equation 1 - Power output of the turbine; applies to Savonius, Darrius and combined system [11]

$$P = \left(\frac{2\pi\omega}{60}\right)\tau$$

PV panel efficiency calculation, based on energy output and solar radiation [12]

$$E_{daily} = A\eta\left(\frac{H_{avg}}{365}\right)PRt$$

Cost savings calculation

$$Cost\ Savings\ = (Demand\ Reduction\ x\ Hours\ x\ Energy\ cost) + (Number\ of\ Poles\ x\ Distribution\ Cost)$$

Photovoltaic Panel Results:
For the assembly, students chose the SolarLand 70W PV panel; model SLP070-12U, for its polycrystalline construction. Polycrystalline panels are constructed as several crystals wired together, and while they are less efficient and more susceptible to reduced efficiencies at higher temperature, they are also less costly to produce, less subject to shading efficiency reductions, less likely to completely fail if damaged, and easier to replace should damage occur [13]. The panel outputs a maximum of 70W, enough to give 75% of the battery's full required charge. Since the manufacturer's specifications do not provide for an efficiency of the solar panel, the primary objective was testing the efficiency.

Using historical data for Philadelphia International Airport, the expected solar radiation was calculated to be 5.0 $kWh/m^2/day$) [12]. The maximum expected average hourly power output of the photovoltaic panel operating 12h a day is 215 W [14]. This baseline was compared to our output, measured through the charge controller. A graph of our output over time is shown below in Figure 4.

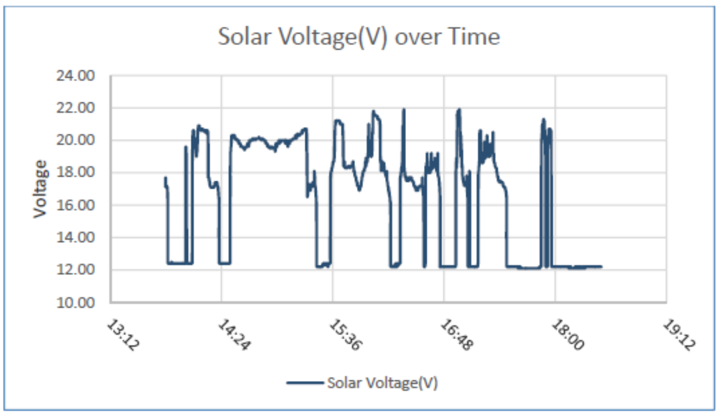

Figure 4 - A graph of solar panel's output over time in Mt. Airy

By calculating the average power output, and using PV panel efficiency calculation, based on energy output and solar radiation, it was found that the solar panel is producing on average 18.05W/hr, which equates to an efficiency of (8.40 ± 0.13)%, far below the expected efficiency of 14% to 20% for polycrystalline panels [13]. However, we believe this deviation is because the output was measured through the charge controller. Because the charge controller uses pulse-width modulation (PWM) and regulates the power going to the battery, and because our battery was nearly fully charged (consistently reading in the 11.3 V range), we were not able to see how our PV panel would output power in its ideal circumstances.

Savonius Turbine Results:
Typically, the Savonius turbine is a half barrel design with efficiencies around 13 to 15% [15]. Our designed turbine is a modified profile where the inner part of the blade straightens out allowing for a better flow of air. Figure 5 below shows the efficiency curve of the turbine. Due to the resistance of the alternator, a lower efficiency is seen at first. Once spinning, the efficiency slowly increases with its peak around 10 to 12 mph. At higher wind speeds, the drag begins to

slow down the turbine, creating slower rotations per minute, thus lowering the efficiency. This average increase in efficiency will provide slightly more power generation then standard turbines used.

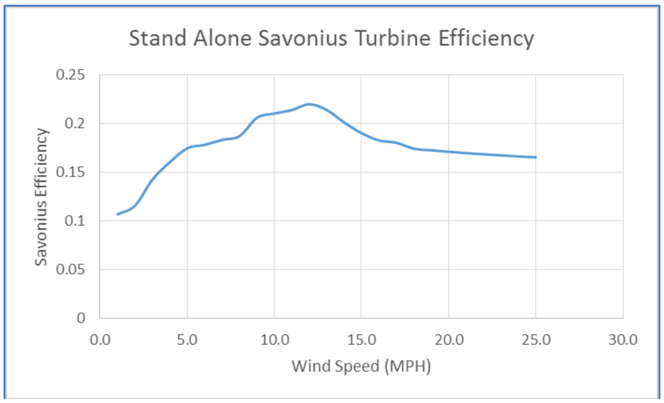

Figure 5 - Change in Savonius efficiency with change in wind speeds

An improvement can de later made by using a lighter material such as the carbon fiber to increase efficiency due to a weight reduction of approximately 2 pounds, allowing for an easier start-up. A 2% increase in efficiency at the turbine's peak would result in an extra 3 RPM or approximately 40 RPM to the alternator after passing through the 12.5:1 gearbox.

Darrieus Turbine Results:

The Darrius consisted of 3 PVC blades mounted with aluminum supports, for a total weight of approximately 13lbs. The blades were machined from PVC material to match NACA 012 profile, using CNC equipment. And the aluminum supports were machined using basic machining skills and equipment. The assembly of the Darrieus turbine is very simple and can be achieved with just one person. The unit was tested as an individual component to determine actual performance with no additional restrictions, except for the turntable bearing that was used to support the structure. The Darrieus turbine was attached to a support rig, and wind was applied from 5mph up to 20mph incrementing by 3mph each time data was recorded. The wind speed was recorded using an anemometer, and the wind was applied by using an industrial fan. The fan was able to produce adequate laminar flow acting on the turbine. During the testing at each of the wind speeds shown in Table 1, the orientation of the wind acting on the blades was changed from 0, 90, 180, and 270 degrees, with 0 degrees being the wind hitting the blade directly. There was a difference in the time it took the unit to get to idle rpm, but the difference was not considerable compared to all the positions at 0 degrees. Based on the results reflected in Table 1, the Darrieus turbine output the maximum RPM at a wind speed from 14-17 mph. At higher speeds the wind starts to affect the opposite blades in which the tangential force is being applied, and the performance of the Darrieus starts to decrease.

Wind Speed (mph)	Acceleration Time (sec)	Rotations per Minute(rpm)	Deceleration Time (sec)	Torque (Nm)	Power (Watts)
5	270	14	240	8	4
8	225	21	270	21	18
11	180	29	300	40	47
14	165	34	360	66	97
17	150	34	360	97	173
20	120	33	360	135	283

Table 1 - Darrius turbine results from testing. Torque and Power were calculated

Combined System Results:
The combined turbine is the most essential addition to the system since it creates the extra power. By testing the two turbines separately, we saw that at lower speeds, both turbines produced approximately the same amount of power. As speeds increased, the Savonius turbine increased in RPM, but the power created decreased due to the increased drag through the turbine. Unlike the Savonius, the Darrius turbine does not increase too much in RPM, but the power the turbine generates greatly increases. When the two turbines are combined, we see that the efficiency of the combined turbine falls in between that of each individual turbine. Figure 6 below shows that at slower speeds, the Savonius does most of the work, allowing for quick start up and more power generated, while the Darrius provides resistance dragging down the combined efficiency. As the wind speeds increase, the Darrius begins applying the needed power while the Savonius' increased drag pulls down the combined systems efficiency. Using Savonius torque, Darrius torque, and Equation 1 - Power output of the turbine; applies to Savonius, Darrius and combined system, we found the combined turbines average efficiency to be 19.36%.

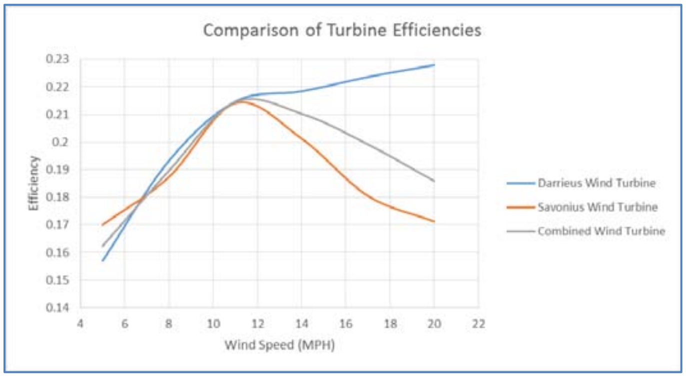

Figure 6 - A comparison of both individual turbines vs the combined turbine used in our kit

Discussion of Overall Solution:
Overall, we found our system to be a success. Our turbine efficiencies resembled what was read in earlier literature research with the combined efficiency falling somewhere in between the two. The kit developed would be amenable for city use, but ideal for surrounding suburban areas where buildings do not obstruct the sun from the solar panel. It met or came close to all of the design requirements stated above. With the intended materials, the combined turbine will look miniscule on top of the 30-ft poles, while the PV panel is already widely in use. The cost was kept low by using readily available materials and components needed for the build. As stated before, we fell short of being able to completely power the streetlight, but we come close to providing the power need in our time testing.

Testing Procedures:

Charge Controller and PV Panel Testing:
Our testing for the photovoltaic panel, charge controller, and battery occurred in several stages. First, we tested the battery and the charge controller in an ideal conditions setting. We had to test these two components together due to the design of the charge controller; it must be connected to a DC power source (in this case, a battery) to function properly. Using an Agilent 6623A DC power supply, as well as a Fluke 87V RMS multimeter and an Agilent 34401A digital multimeter connected as an ammeter and a voltmeter, respectively, we tested the current and voltage from the battery to the charge controller, and from the charge controller to a variable resister acting as a load. A picture of our setup in the lab is shown below in Figure 7.

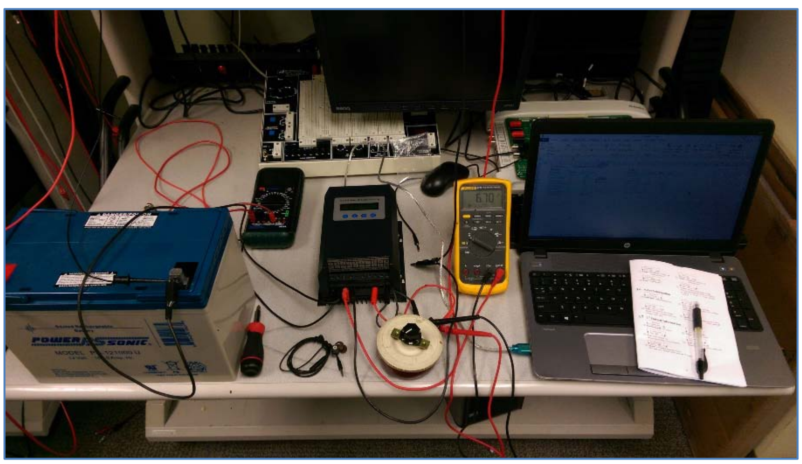

Figure 7 - Picture of our testing setup in the lab

It should be noted that the external ammeters and voltmeters are merely for our own visual reference in testing the equipment. All the data we acquired was obtained through an RS232-USB connection from the charge controller to our testing laptop. We specifically chose a model with an external connection so we could monitor and record all the tested parameters. After we connected all the components, and a variable resister to the output, we ran the testing with a constant 17.2 VDC to simulate the connection of the photovoltaic panel. We then let the testing under ideal conditions take place for half an hour, and finally, we downloaded all the historic data (using the provided charge controller software) into a spreadsheet to analyze the results. Once lab testing is completed, we moved the entire setup to real-world settings. Our first location was in Mt. Airy, and after setting up the system in this location, we ran two different real-world tests for a minimum of 4 hours. The reason we ran tests in the real-world conditions longer than lab conditions is because we wanted to determine how much variability we had in our setup, and under ideal conditions, we didn't expect any variation. We repeated the testing in Broomall as well, in the same manner.

Wind Turbine Testing:
The main purpose of testing the turbines was to determine the amount of power and RPM developed by each turbine to obtain their respective efficiencies. We expect to see an increase in power generated by each turbine as well as an increase in the rotational speed of the turbine. A testing platform was built in order to receive consistent data as varying winds, generated by a fan, move across the turbine. The testing procedure outline includes creating a controlled wind flow with a speed of 3mph impact the front of the turbine. Initially the turbine should be completely stopped using hand or brake and then released immediately start a stop watch to time the duration of turbine startup. Using a tachometer, monitor the amount of RPM produced by the wind turbine. These steps were repeated at wind speeds of 5, 8, 11, 14, 17, and 20 mph respectively. Same testing procedure was applied to the Darrius wind turbine and again for the combined wind turbine.

Cost Analysis:
After our testing had concluded, we found that we would be able to reduce the power demanded by the grid to 90 W per light. The demand reduction, DR, also includes the watts saved by the installation of the new ballast. If the lamps run for an average of 12 hours per night, from 6 pm to 6 am, for 365 days a year, we calculate the annual amount of usage to be 4380 hours. As stated by PECO Energy in their November 2014 tariff, the cost of power for street lighting is $0.07 per kWh with a distribution cost of approximately $205 per light pole per year [16]. Using this information and Cost savings calculation, we can find our cost saving to be approximate $233 per year [17].

Environmental and Societal Impacts:
One of the goals of this project is to reduce the demand energy providers need to produce in order to feed the grid. This will allow these providers to appropriately budget the demand needed into other customers such as homes or businesses. By reducing the demand, energy producers will not need to generate as much power, reducing fuel consumption. The less fuel that is burned means less carbon emissions being produced. Also, the waste that is accumulated from these plants will be lessened, further cleaning up the environment. Less pollutants and waste water will find its ways into streams, rivers, and landfills creating a healthier ecosystem. With technology constantly improving, when it comes time to replace our components, newer, more efficient parts will be available.

Our system is able to provide sustainable energy which increases the energy production reliability of the kit. Solar power will not fluctuate largely in a given year. As with solar, there will always be atmospheric pressure differentials creating wind to rotate the wind turbine. The kit will never see large shortages of fuel, allowing constant year round energy production without being compromised. With the great advantages of sustainable energy, communities may take pride in the contribution of green energy. This may prompt individuals to also participate in using other forms of sustainable energy in their homes, again decreasing pollutions and power needed by the grid. Street lighting is essential for populated area. A well-lit area gives most people a sense of security, by being able to see what is around them at night. Since street lights are required in most cities, they are often installed in large groups or quantities depending on the area needing to be lit. To promote the kit and its potential for being environmentally friendly, it needs to fit in with the people of these cities. Using the LED lights, a white light will be emitted, reducing the amount of glare going into residencies and providing clearer illumination of the street. LED lights also have a longer operating life than that of the current HPS bulbs used. This will reduce potential waste from being added to local landfills. The kits will also reduce the cost these towns or cities have to pay, allowing them to invest in other projects such as improving roadways or local schools. Lastly, because most of the components in the kit have a long operating life with proper maintenance, replacements will be far and few between.

Conclusions and Future Considerations of the Student Capstone Project:

In conclusion, the Hybrid Wind Solar Outdoor Lighting kit was a success. Even though the kit was unable to completely remove the poles from needing grid power, it produced enough that it will only need grid assistance once every few months. The PV panel supplied the necessary power that was expected while the combined turbine exceeded expectations by having a good efficiency and a great power output from the alternator. Extra precautions were taking in the design of the turbine to be able to withstand normal static forces developed by high speed winds. The kit as a whole was easy to install to a simulated light pole and only needed two people to successfully attach it. Due to the height of the light pole, the combined turbine and solar panel will look relatively small which will make it easier for the community to except the kits being installed in their towns. The kit proved cheap enough that a power generation and distribution companies can invest and get there return within 9 to 10 years while reducing the amount of work the grid and equipment have to provide. In the future, if the considerations listed below are included in the kit, companies may gain more of an advantage such as real time statistics of the kit such as power level of batteries and amount of power generated. Larger PV panels may also be supplied as the efficiency of the panels continues to increase with new technologies. Figure 8 depicts our prototype during testing.

Figure 8 Prototype of the Integrated Wind and Solar Kit

Inverter and Grid Tie-in

The first consideration for future designs we would like to put forward is a method of tying the system into the existing power grid. As of now, the system we have designed is a completely off-grid solution that runs the light source on DC power. Our original design included an inverter that runs the light from AC power. This inverter would monitor the battery current and power output, and would switch to grid-provided AC power when the battery current and power drops to levels unable to power the light. We included this in our original designs as a fail-safe, to ensure the light would be constantly on, however, we were unable to find an inverter that suited our needs.

Advanced Charge Controller

Another consideration for our future designs is an alternate setup of our charge controller. The charge controller we used is the LHLM06-02/24, which comes equipped with an RS232 output. Using an RS232-USB link cable, we were able to acquire historical data from the charge controller and analyze these data sets; however, in order to acquire this data, we would need to manually plug in a laptop periodically. This would be a time-consuming endeavor on a larger scale, but there are alternate solutions. A more advanced alternative for the charge controller is to purchase the model with a USB link, and to connect it to an Arduino with output capabilities that can transmit the data over public Wi-Fi frequencies.

Learning Assessment and Conclusions

On a quantitative level, students have been assessed rigorously during the course of the senior design sequence. For the performance indicators related to their ability to design an engineering system using modern tools and techniques (ABET-ETAC criteria “a” and “b”) for both of them students obtained a 4.5 score out of 5. Also students received scores between 4.0 and 4.4 out of 5 for performance indicators related to their demonstrated ability to identify system, component, or process requirement, to define an optimal, realistic, and technical approach that meets requirements in terms of technical, economic and societal criteria with realistic deadlines. The project scored 4.5 out of 5 for the performance indicators related to their ability to identify problems that are suited for technical solution and to producing practical solutions based on meeting requirements of analyzed problem components. These scores are closely related to the scores that individual students in the team received for their project-based learning courses preceding senior design sequence. The team was composed of two electrical technology and two mechanical technology major students. In average students scored between 3.8 and 4.7 in the specific course performance indicators similar to senior design performance indicators. That means that students’ performance in criteria such as “... ability to define an optimal, realistic and technical approach that meets requirements ...” was similar or better during the capstone endeavor when compared with their performance in a course that evaluated the same Student Learning Outcome for the students.

Since our ET curricula is an integrated mechanical and electrical engineering technology (with some students being either in industrial or biomedical ET concentration), students have the opportunity to be trained in more than one concentration, graduating with skills from both concentrations.

Teaching renewable energies methodologies accompanied by real system’s data increased the comfort, competitiveness, and confidence of the students not only qualitatively, but also quantitatively. It was also observed a positive impact on student’s simulation skills.

The design experience develops the students’ lifelong learning skills, self-evaluations, self-discovery, and peer instruction in the design’s creation, critique, and justification. Students learn to understand the manufacturer data sheets, application notes, and technical manuals and component specifications. The experience of teamwork, prototype design and test, which would be difficult to complete individually, gives the students a sense of satisfaction and accomplishment that is often lacking in many engineering courses, not including projects. Furthermore, the design experience motivates student learning and develops skills required in industry. The students were able to make satisfactory estimations and calculations of these projects. Their results reflect that they have understood well all the basic ingredients of the modeling techniques and design of the renewable energy systems. Our experience with the incorporation of renewable energy topics in the senior project design courses demonstrated that the abstract knowledge acquired by the students during their first three years of studies was put into practice. The students also gained extensive knowledge of power electronics, generator and mechanical components of renewable energy sources, their characteristics, environmental and structural constraints, separating different aspects of the project, such as generator or converter type, its parameters and characteristics, and what are the final outputs and its relationship to the load, etc.

The key element to the success was the interdisciplinary team work and the efforts of the faculty to continually instruct the students on the completion of their projects. The lessons learned from this type of projects lead us to believe that they are very attractive and favorable for students. Finally, they may represent one of the ways to enhance engineering education in our college.

References

[1] Energy.gov, "Secretary Chu Unveils the 2011 Strategic Plan," 12 May 2011. [Online]. Available: http://energy.gov/articles/secretary-chu-unveils-2011-strategic-plan. [Accessed 1 October 2014].

[2] R. Hinrichs-Rahlwes, "Renewable energy: Paving the way towards sustainable energy security: Lessons learnt from Germany," *Renewable Energy,* vol. 49, pp. 10-14, 2013.

[3] A. Hepbasli, "A key review on exergetic analysis and assessment of renewable energy resources for a sustainable future," *Renewable and Sustainable Energy Reviews,,* vol. 12, no. 3, p. Pages 593–661, April 2008.

[4] T. C. Kandpal and L. Broman, "Renewable energy education: A global status review," *Renewable and Sustainable Energy Reviews,* vol. 34, p. Pages 300–324, 2014.

[5] R. a. R. B. Felder, "Designing and Teaching Courses to Satisfy the ABET Engineering Criteria," *Journal of Engineering Education,* vol. 92, no. 1, pp. 7-25, 2003.

[6] General Electric, "Street Lighting Comparrison IND HPS LED 2152011 [Compatibility Mode]," 28 February 2012. [Online]. Available: https://ewh.ieee.org/r2/delaware_bay/0311/Street%20Lighting%20Comparrison%20IND%20HPS%20LED%202152011%20%5BCompatibility%20Mode%5D.pdf. [Accessed 26 October 2014].

[7] Illumient Co., "Illumient - Smart Off-Grid Lighting," 2013. [Online]. Available: www.illumient.com. [Accessed 18 November 2014].

[8] Shenzhen TIMAR Scenery Energy Technology Co., "Shenzhen Timar Scenery Energy Technology

Co.," 2015. [Online]. Available: htt;%3A%2F%2Fshenzhen-timar.en.ywsp.com%2F. [Accessed 1 March 2015].

[9] NREL, "NREL: Dynamic Maps, GIS Data, and Analysis Tools - Wind Maps," 3 September 2013. [Online]. Available: https://www.nrel.gov/gis/wind.htm. [Accessed 20 November 2014].

[10] M. F. Voneschen, "How to Build an Enegy Generator with an Old Oil Barrel without Oil," Amics21, 19 August 2008. [Online]. Available: http://www.amics21.com/laveritat/savonius_generator_english.pdf. [Accessed 14 November 2014].

[11] L. Turner, "Making a Simple Savonius Wind Turbine," [Online]. Available: http://www.macarthurmusic.com/johnkwilson/MakingasimpleSavoniuswindturbine.htm. [Accessed 1 March 2015].

[12] S. McFadyen, "Photovoltaic (PV) - Electrical Calculations," 11 July 2013. [Online]. Available: http://myelectrical.com/notes/entryid/225/photovoltaic-pv-electrical-calculations. [Accessed 5 November 2014].

[13] W. Khan, "PV: Types of Solar Panels and Which One is the best PV panel," 8 October 2014. [Online]. Available: http://www.electricaltechnology.org/2014/10/pv-types-of-solar-panel-best-pv-panel.html. [Accessed 8 November 2014].

[14] SolarLand, Inc., *SLP070-12U Manufacturer Specifications,* 2013.

[15] M. Barnard, "What Is the Future of VAWT (Vertical Axis Wind Turbines)?," Quora, 13 September 2014. [Online]. Available: http://www.quora.com/What-is-the-future-of-VAWT-Vertical-Axis-Wind-Turbines. [Accessed 6 May 2015].

[16] PECO Energy, "Rates and Pricing," 1 May 2015. [Online]. [Accessed 10 May 2015].

[17] B. Capehart, W. C. Turner and W. J. Kennedy, Guide to Energy management, 5th ed., Lilburn, Georgia: The Fairmont Press, 2008.

[18] P. Jennings, "New directions in renewable energy education," *Renewable Energy,* vol. 34, no. 2, pp. 435-439, 2009.

[19] L. Shi and M. Y. L. Chew, "A review on sustainable design of renewable energy systems," *Renewable and Sustainable Energy Reviews,* vol. 16, no. 1, pp. 192-207, 2012.

[20] National Renewable Energy Laboratory, "Best-Researched Cell Efficiencies," 27 April 2014. [Online]. Available: http://www.nrel.gov/ncpv/images/efficiency_chart.jpg. [Accessed 5 May 2015].

[21] SolarLand, Inc., *SLP100-12U Manufacturer Specifications,* 2013.