Honors Thesis Work in Renewable Energy for an Undergraduate Student

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Abstract

Renewable energy has become an important area of research and development for both environmental as well as economic reasons. At the academic level, it is possible to introduce students to issues related to renewable energy. This paper discusses the effort one student has put in, as part of a thesis, to develop an economically feasible, self-sufficient, renewable energy system for a residential home in the Great Lakes region. The design of the system sought to use both wind and solar energy to supply energy to the home. The student was able to consider effects such as the design and capability of the wind turbine and solar panels to determine whether the design would be viable economically. After deciding that the initial system design would be too expensive, the student then considered other options to reduce the cost of the renewable energy system while still providing the necessary electrical systems that are used in a modern home. This included the development of a survey that was distributed to faculty and staff. The survey was used to determine the critical electrical loads that families in the Great Lakes region would require throughout the year. Successes and challenges of using thesis work as a teaching methodology for education in renewable energy will be discussed.

Introduction

Penn State Erie, The Behrend College offers an honors program (called the Schreyer Honors program) to those students who possess high academic ability and the desire to pursue research-oriented work within their curriculum. Students are required to take 14 semester credits of honors classes as well as write a thesis. Honors classes are either offered within the schedule, or students perform additional relevant work within a non-honors class to satisfy the honors credit requirement.

One student in electrical engineering technology (EET) was accepted into the honors program at the beginning of his junior year, based on his application and a clear record of academic achievement. As part of the thesis, the student and faculty advisor decided to look at the area of renewable energy. Specifically, the student thesis would focus on developing a renewable energy system for a home in the Great Lakes region that could be disconnected from the utility grid. Factors to be considered in the design included:

- Cost of the system
- Power and energy required throughout the year
- Use of different energy resources, namely wind and solar
- Consideration of energy storage, such as batteries

- Consideration of the climatic conditions in Erie, PA

Although a significant amount of research into renewable energy has taken place, renewable energy isn't a mature technology. Homes powered solely using renewable energy exist throughout the country, but are the exception rather than the rule. In the Great Lakes region, in particular, the gray winter months represent a primary drawback to developing a renewable energy system. The reduced available sunlight prevents solar from being considered as the sole source of energy for the home. It had already been determined at the start of the thesis work that for Erie, the amount of solar energy available peaked during the summer months. However, it had also been determined that the amount of available wind energy peaked during the winter months, based on information provided in [1]. Thus, it might be possible to develop a hybrid renewable energy system, where both solar and wind energy could be used in a complementary fashion to provide energy to a home throughout the year.

The student was then given the following tasks to develop his thesis over a period of four semesters:

- Determine the average energy usage of a home in Erie over the course of one year,
- Identify the amount of energy available in Erie due to solar and wind energy during the year, based on previous meteorological data,
- Propose a basic electronic system which uses both solar and wind energy to provide power to the home. Ensure that the system cost is minimized, with a goal of $10,000.
- Simulate the system, using a commercially available software package, to validate that various loads could be adequately supported,
- If time permitted, implement a scaled down proof-of-principle model of the system, and
- Record all of the work performed, write the thesis, and present conclusions.

The purpose of this paper is to document the progress made by the student, describe the difficulties encountered during the thesis work, and make some recommendations on what might be done differently in future theses.

Determining average energy usage of a home in Erie over one year

The student was introduced to the concept of a literature search in this portion of the thesis. The faculty advisor had already uncovered a number of references dealing with the development of a hybrid solar/wind energy system [2-6]. The student could then use the results of the literature search to analyze the papers and determine which of the references provided information about residential energy use. The student decided that [4] provided a preliminary baseline for the amount of energy usage, although the home selected would not be in the Great Lakes region. As will be discussed later, the value of approximately 12,000 kWh provided in [4] would need to be modified based on cost constraints.

Identifying the amount of solar and wind energy available in Erie during the year

The student proceeded to obtain from the National Oceanic and Atmospheric Administration (NOAA) website [1] both solar and wind data for a five year period, from September 1996 through September 2001. The solar data contained on a daily basis the number of minutes of sunlight. Daily data for Erie, PA wasn't available on the website, so the student instead used data from a nearby city (Cleveland, OH, 100 miles away to the west). The student also looked at the daily sunlight data for Buffalo, NY, 90 miles away to the east, and found only minor discrepancies between the two cities. Therefore, the student felt comfortable applying sunlight data from Cleveland, OH to Erie, PA.

The wind data contained on a daily basis the average wind speed in miles per hour. The student was then able to build a spreadsheet that took the daily sun and wind information and, based on the size of the solar panel and wind turbine, could calculate the kWh energy available. By averaging the sum of the solar and wind energy over a 5-year period, the student was able to determine the average yearly kWh generated by the combined solar and wind energy.

To determine the amount of solar energy being generated, the student looked at a number of different manufacturers of solar cells, and decided on [7] to calculate the amount of power generated based on the amount of sunlight and the area of the solar panel. Multiplying the power available by the duration of sunlight yielded the energy available. A derating factor was also applied to account for the reduced sunlight at sunrise and sunset. Figure 1 shows the power produced by a solar panel with a surface area of 15,000 in^2 over the five year period from September 1996 – September 2001. As can be seen in Figure 1, the amount of energy being generated by the solar panel is highest during the summer months.

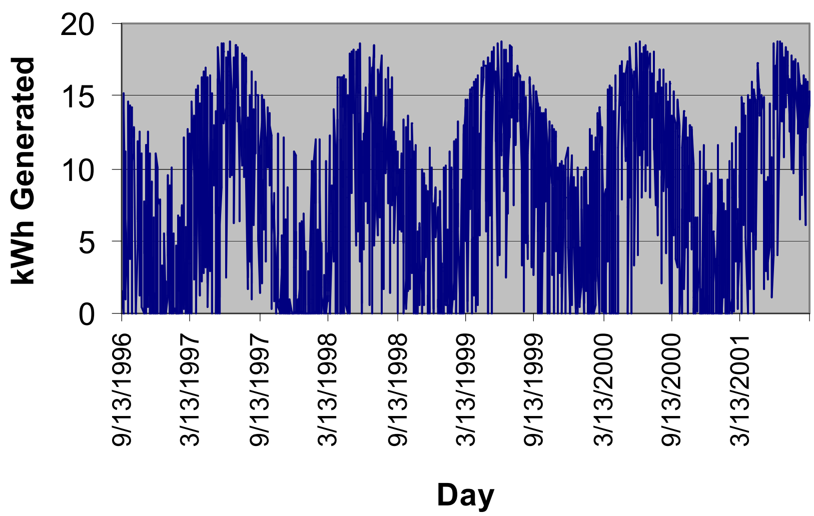

Figure 1. Calculated daily energy generated from a solar panel in Erie, PA

To determine the amount of wind energy generated, the student used information from Patel [8] to calculate the amount of power generated based on the size of the turbine blades and the average wind speed provided for a given day. The equation for the power generated was found from:

$P = 0.5\rho AV^3$, where

P = power generated, in Watts

ρ = air density, in kg/m^3
A = area swept by the rotor blades, in m^2
V= velocity of the air, in m/s

Using a 24-hour period, the student was able to provide the kWh available for that day. Constraints were applied to the data. For example, the minimum wind speed for the day needed to be at least 8 mi/h for the wind turbine to supply power. In addition, at very high wind speeds the wind generator can be damaged [4] and therefore needs to be reoriented away from the wind. Therefore, a limit was placed on the maximum amount of energy that could be supplied in any given day from the wind generator. Figure 2 provides the power produced by a wind turbine over the five year period from September 1996 – September 2001. The wind turbine chosen was a Bergey 1.5kW wind turbine [9] with a swept blade area of $8.04m^2$ and an assumed air density of 1.225 kg/m^3 [8]. As seen in Figure 2, the wind energy is maximized in Erie during the winter months.

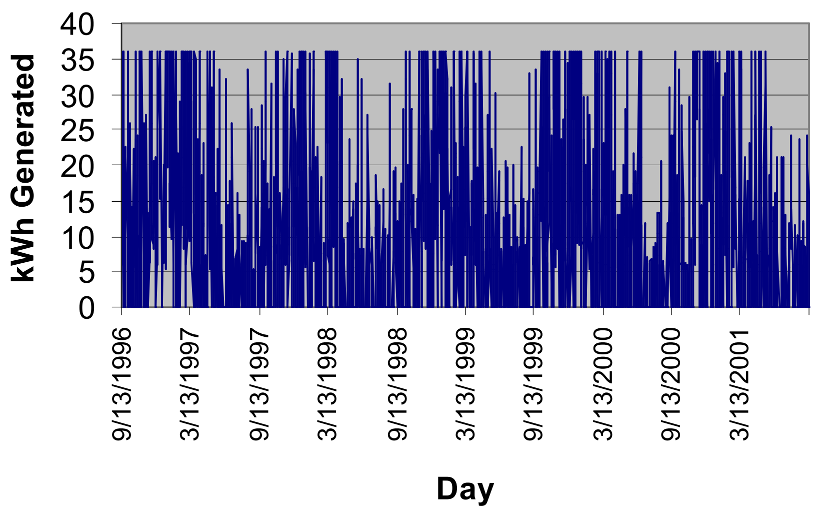

Figure 2. Calculated daily energy generated from a 1.5kW wind turbine in Erie, PA

Proposal of a basic electronic system with a cost goal of $10,000

The basic design of the hybrid solar/wind system is provided in Figure 3. It includes, in addition to the solar panel and wind turbine, the following components:

- a rectifier for converting ac to dc from the wind generator,
- a battery for backup energy when there is both minimal solar and wind energy available
- a dc bus to integrate the system
- various loads

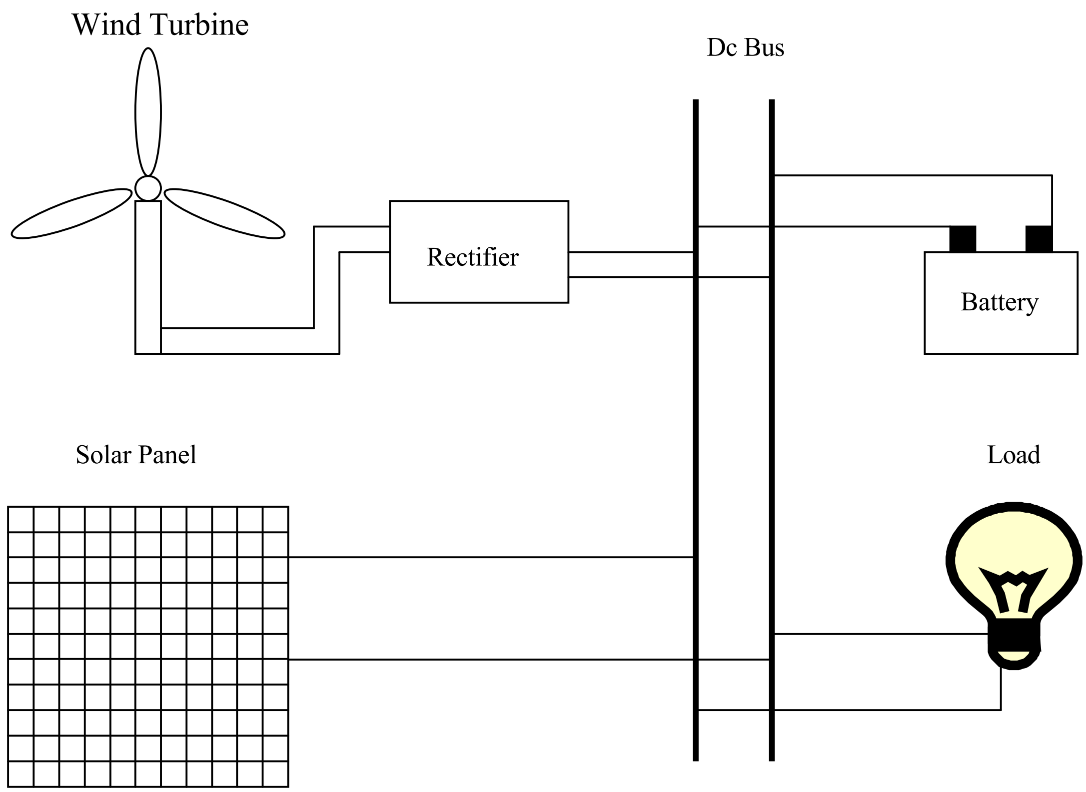

Figure 3. A basic system design for supplying solar and wind energy to a residential home

Unfortunately, the student had not yet taken a course in power electronics prior to devising this system, so components such as dc-dc converters and dc-ac inverters were not included in this design. The dc-dc converter would likely be needed to ensure that power from both the solar panel and the wind generator was at the same voltage as the dc bus. The inverter would be needed to convert power from the dc bus to ac to supply the necessary loads in the home. However, the system of Figure 3 provided the student a basic understanding of how one might integrate the energy generated by the hybrid power system.

The student then used a spreadsheet program to attempt to size the system based on the 12,000kWh value determined from [4]. In this spreadsheet, the student looked at different manufacturers of solar panels to identify both the cost and power density of solar cells (see [9] for some examples of cell power density and cost). Sizing of the solar panel and wind turbine was based on whether the associated battery banks would be forced to discharge more than 50% at any time. Unfortunately, a potentially viable system would require the following components:

- A 15,000in^2 solar panel, at an estimated minimum cost of $3,900
- A 1.5kW wind turbine with a supporting structure, at an estimated cost of $6,200
- A battery bank capable of storing 1,500kWh, at an estimated cost of $1,800 (see [8]).
- Extra costs for inverters, rectifiers, connectors, wire, and other miscellaneous components (not totaled)

Since the total cost of the hybrid system was going to exceed the goal of $10,000, a different strategy was developed. The advisor and student decided to focus on the critical loads that would be necessary in a residential home in Erie, PA. This would allow the student to be able to resize the system such that the annual kWh loads would be reduced to a level which would make the cost of the hybrid system viable. To determine what constituted a critical load, the student developed a survey which was distributed to faculty and staff at Penn State Erie, the Behrend College. The survey provided a list of typical electrical loads in a residential home (see Table 1). For each load, the subject was given the option of ranking the criticality of the load (from "definitely could live without" to "definitely could not live without"). The results from the survey were tabulated, and the Table 2 results show what were deemed to be critical loads in the Erie, PA region:

Table 1. List of electrical items used in a typical residential home

Kitchen	**Entertainment**	**Cleaning**	**Bathroom**	**Miscellaneous**
Dishwasher	TV	Vacuum	Hair dryer	Inside lights (10 lights)
Electric range	VCR	Washing machine	Curling Iron	Heating
Electric oven	Computer	Dryer	Shaver	Hot water heater
Refrigerator	Video game systems			Central Air-conditioning
Microwave	Stereo			Outside lights
Toaster	Clocks/Radios			Dehumidifier
Mixer	Answering machine			
Trash compactor				

Table 2. List of critical loads

Critical Loads
Refrigerator
Clocks/Radios
Vacuum
Washing Machine
Dryer
Inside Lights (10 lights)
Heating
Hot Water Heater
Computer

The student then began to size how much energy would be consumed by each of the critical loads over the course of one year. Using an undergraduate research grant, the student purchased an electrical watt-meter that could also measure energy consumption. For example, he was able to measure the energy consumption of his refrigerator where he lived, and measured 11.5kWh of energy usage in 167 hours of operation. This would correspond to 603kWh over the course of one year. The student also began to search manufacturers' websites to determine the energy consumption of some of the critical loads. For example, he found that a new refrigerator of similar size would consume only 509kWh per year.

Project conclusion and student evaluation

During the fall semester of his senior year, the student decided to terminate work on his undergraduate thesis project. A number of factors contributed to this decision. They include:

- Time constraint – The student felt that there wasn't sufficient time to simultaneously work on the thesis while also maintaining excellence in his schoolwork and being involved in extracurricular activities, such as student government and his fraternity. He was also concerned about making satisfactory progress on his capstone senior design project. This team project requires the students to define, design, build, test and present their results of an industrial-based system.
- Structural constraint – The honors program provides three options to complete the 14 credits required of the honors thesis. The first option includes courses which are offered with an honors designation. In such a course, all students perform the same amount of work. Unfortunately, none of the technical courses in the student's major had such a designation. The second option was then to transform a non-honors class in his major to have an honors option. This required the student to work with the specific instructor to perform additional work that was not required of the other students. The third option was to take an independent study as an honors designation. This option focuses the student on his thesis, but does not have the rigor normally associated with a structured class. The student took an independent study during the fall semester of his junior year, and made reasonable progress. However, he took no classes with an honors designation in the spring semester, and made significantly less progress. He finally decided to terminate the thesis during the fall semester of his senior year.
- Time lost due to outside circumstances – The student spent a significant amount of time resolving hardware and software issues to be able to proceed with the project. For example, the student was able to purchase a kit to build a solar panel from his undergraduate research grant. This panel was intended to represent the solar panel in the scaled-down proof-of-principle model. However, some of the cells arrived broken and it was difficult to get the broken cells replaced by the manufacturer. The student also spent time trying to learn a software package for simulating his proposed system. However, the software was difficult to work with, and the entire software package had been inadvertently deleted by the time the student returned to school from summer break.

Overall, the student felt that the thesis could have been completed if not for the constraints listed above. The student enjoyed working on the project and was looking forward to some of the power electronics design that might have occurred. However, because the thesis began to include a large number of different topics to study (.e.g., power electronics, software simulation, hardware construction, etc.), it became difficult for the student to master all of the different areas required to complete the thesis.

Recommendations for future work involving an undergraduate honors thesis

Based on the results obtained from this thesis, and discussions with the student, a number of recommendations can be made:

1) Reduce the focus of the thesis. Although the design of hybrid solar/wind energy system involves many areas, it is impractical to have one student work on all of these areas as part of one thesis. An alternative would be to have the student focus on just one area of the system, and then have succeeding honors students work on different areas to develop the overall system.
2) Have a defined plan for each student who goes through the honors program. This includes defining up front which classes would be used for the honors option, how those classes would be structured to support the thesis work, and whether an independent study would be preferable for development of the thesis.
3) Consider the type of work up front. Some programs, such as technology programs, are more hands-on and lend themselves to thesis work which is more applied. Other programs may want to focus on either design or software. In any event, the thesis should define up front whether the focus will be mostly on hardware, software, or design. By requiring the student to focus on multiple areas, it is more likely that the student will not satisfactorily complete any one area and may become frustrated with the overall process.
4) Consider the time spent in and outside of class. The student will likely consider his thesis to be of secondary importance, when compared with maintaining a high grade point average, or being involved in organizations on campus. The faculty member needs to ensure that the student understands the time required to complete an honors thesis. If the student has a large class load and other time constraints outside of class, then either the student will need to reduce the other time constraints or reconsider pursuing the thesis.

Conclusion

In this paper, an economically feasible, self-sufficient, renewable energy system for a residential home in the Great Lakes region has been researched as part of an undergraduate honors thesis. This system uses both wind and solar energy to supply energy to the home. The student looked at both the design and the cost of the system, and determined that the system was too expensive. The student then considered other options to reduce the cost of the renewable energy system, and developed a survey to ascertain the most critical loads in a residential home. Although the student enjoyed working on the thesis, he was unable to complete it, based on constraints such as time and course structure. A number of recommendations were then made to improve the thesis process for succeeding students, including a more focused research topic and a well-developed course plan for the duration of the thesis.

References

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Biographies

ROBERT S. WEISSBACH received his Ph.D. in electrical engineering from Arizona State University in 1998. Since August 1998, he has been an assistant professor of engineering in the Electrical Engineering Technology department at Penn State Erie, the Behrend College, where he is currently the program chair. His research interests are in flywheel energy storage systems, power electronics and power systems.

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