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ALTERNATIVE ENERGY MECHATRONICS SENIOR DESIGN CAPSTONE PROJECT

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ABSTRACT

The field of Mechatronics has grown rapidly over the last 20 years. More corporations are requiring employees who have interdisciplinary knowledge and experience in both the electrical and mechanical engineering fields. Penn State recognized the need for individuals trained in these areas and developed a 4 year Mechatronics program. This program is a Bachelors of Science degree in Electromechanical Engineering Technology (BSEMET). In the senior year of the BSEMET program, students take a senior design capstone course EMET 440. This course provides an opportunity for students to work on an interdisciplinary real-life project and gives them first-hand knowledge of project management principles. Each student is given a budget of $1000.00 to complete the project and is required to justify expenditures. Student design teams are expected to meet with senior faculty advisors who monitor design progress and act as consultants. Having had courses covering electrical, mechanical, and computer control, students have chosen alternative energy applications such as wind energy and solar energy for their senior design capstone projects. This paper describes the success that Penn State has had in training students to complete senior capstone projects related to alternative energy applications.

KEYWORDS

Mechatronics, Alternative, Wind, Energy, capstone

1 INTRODUCTION

From Stockholm to Beijing, electromechanical systems and subsystems are replacing strictly electrical or mechanical systems in a wide range of products and processes. Hydraulic, pneumatic, and other mechanical systems once dominated applications that required speed, power, and reliability. These systems met the challenge and have proven themselves over many years of refinement. Things have changed rapidly even in the last 10 years. Hybrid electromechanical systems are finding their way into even the most staunch mechanical domains. Elaborate and costly drive trains, gear drives, and chain/sprocket systems are being replaced by synchronized servo drive systems allowing for more cost effective and flexible solutions.

The word Mechatronics was conceived in the late 1960's when the Yaskawa Electric Company of Japan had a vision for the integration of mechanical and electrical technologies [1]. Many Universities have adopted this term and are now offering degrees in Mechatronics. These programs all have one goal in common. They recognize a need for the graduate to be multidisciplinary in both skill and knowledge. Often, students are required to "put it all together" by taking a senior capstone design course. These courses allow students to exercise the training and knowledge received in an exciting and creative environment. The design, administration, and assessment of these courses is critical to achieving quality graduates.

2 PENN STATE'S EMET PROGRAM

2.1 PROGRAM HISTORY

Penn State has more than 100 years of history in technical training in Pennsylvania and has sought to remain up-to-date with the latest technology and programs in the fields of engineering and engineering technology. The Penn State Altoona College is one of 23 Penn State locations throughout Pennsylvania.

In the early 1990's, Penn State conducted research on a Mechatronics degree program. The title given to the program was Bachelor's Degree in Electromechanical Engineering Technology (BSEMET). The title Electromechanical was used instead of Mechatronics. The term Mechatronics was more familiar in European and Asian countries but not as familiar in the US. Informal surveys were conducted by Penn State and showed strong interest from students and industry leaders. This led to a formal survey in March 1993 for the Penn State Altoona service area. The results of this survey found that an overwhelming 94% of the survey respondents projected a need for graduates of a BSEMET type program over the next five years. In addition to that, these same companies projected that 70% of existing engineering positions were suitable for BSEMET graduates.

As a result of the strong interest from current engineering technology students and an overwhelming interest from industry, Penn State Altoona implemented the Bachelor's of Science degree in Electromechanical Engineering Technology Fall 1994 with the first class beginning in fall of 1995. The first graduates of the BSEMET program began entering the work force in spring 1997.

2.2 PROGRAM GOALS

The primary aim of the Electro-Mechanical Engineering Technology program is to provide graduates with the knowledge and skills necessary to apply current methods and technology to the development, design, operation, and management of electro-mechanical systems. The program is specifically intended to prepare graduates for careers in industries where automated systems are used and to prepare them both to meet current challenges and to be capable of growing with future demands of the field. Specific educational objectives of the program are to:

- Provide graduates with a broad knowledge of electrical, electronic, mechanical, instrumentation, machine technology, computer applications, and controls applicable to electro-mechanical systems.
- Prepare graduates who can apply technical knowledge to the development, operation, control, troubleshooting, maintenance, and management of electromechanical systems.

- Prepare graduates who can communicate effectively and work collaboratively in multi-discipline teams.
- Prepare graduates who are productive professionals in technical careers and who continue to adapt to changes in the technical fields.

2.3 FACILITIES

The primary facility for students enrolled in the BSEMET program is a 15,000-square-foot engineering building that has two state-of-the-art classrooms and five engineering laboratories. In the CAD/CAE lab students are trained in the use of AutoCAD and ProEngineer. Students engage in engineering design and learn to create solid models. A Stratasys Dimension Rapid prototype machine using fuse deposit modeling (FDM) creates a three dimensional plastic part that provides real world feedback. A machine shop/chemical laboratory is used for general machining; foundry; chemical etching and printed circuit board fabrication. There is a manufacturing laboratory for robotics; programmable logic controllers; computer numerical control; CAD/CAM; flexible manufacturing systems; and computer-integrated systems. A project laboratory allows students to build projects and includes a four-ton hydraulic equipment lift; access to the exterior; space for the design and construction of student projects, and benches with variable power supplies. A controls laboratory is used to facilitate digital I/O and automatic control hardware experimentation; pneumatic/hydraulic technology; stepper/servo motor technology; and temperature, pressure, flow, and volume process control stations; Finally, a communications laboratory is used for data/information transfer and control; data communications; fiber optics; and networking.

2.4 INDUSTRY SERVED

Program graduates from the EET, MET, and BSEMET programs were surveyed in December, 1999 and January, 2000 to determine the graduates' satisfaction with their programs, employment status, job titles and responsibilities, helpfulness of their education, initial and current salaries, and further educational plans. A full report summarizing this information from graduates and employers is presented under a separate cover. This report is based on the responses of 29 alumni of BSEMET from Altoona (27) and New Kensington (2), and 10 employers (9 of Altoona graduates; 1 from New Kensington).

The major findings of the 1999-2000 survey of BSEMET graduates and employers include:

- 96.5% of respondents were employed in Engineering Technology or Engineering.
- The most common job title for initial jobs were Project Engineer (17.8%) and Engineer (17.8%) followed by Manager or Supervisor (14.3%), Designer (14.3%), and Process Engineer (14.3%). Almost half had initial salaries of $40,000 or more (48.2%).
- Manager or Supervisor (31.2%) was the most common title of current positions followed by Project Engineer (25%). The current salaries of most respondents (78%) was over $40,000.

3 CAPSTONE COURSE EMET 440

The electromechanical engineering technology baccalaureate program at Penn State Altoona includes a senior capstone design course, Electromechanical Engineering Technology 440 (EMET 440), currently one (spring) semester (fifteen weeks) long, earning three credits. The PSU catalog entry for the course (http://cede.psu.edu/StudentGuide) reads:

> EMET 440: Electro-Mechanical Project Design (3 credits). Planning, development, and implementation of an electro-mechanical design project which includes formal report writing, project documentation, group presentations, and project demonstrations

3.1 GOALS AND OBJECTIVES

The goal of EMET 440 is to demonstrate the ability to manage, as a team, a major project involving the planning, design, development, and implementation of a process or product. This project will be interdisciplinary including electrical, mechanical, and computer control elements. Students are required to select projects that are have strong electronics, mechanics and computers/microprocessor elements. Typical projects from past course offerings include: electromagnetically-levitated trains, obstacle-avoiding or path-following robots, a multi-legged walking robot, an electric passenger vehicle and infrared-sensing paintball-armed radio-controlled battle tanks.

3.1.1 Class structure

The structure of the senior capstone course EMET 440 is very different from a traditional design course. The faculty supervisor for the course plays the role of an engineering manager more than a teacher addressing a class. Each student is given a budget of $1000.00 to complete the project and is required to justify expenditures. Each week, the faculty supervisor meets individually with a student team. The goal of the meeting is to review the progress students have made over the past week in their project and to provide an opportunity for extended design review.

3.1.2 Team Environment

Working in a student team environment is one of the more challenging tasks the faculty advisor engages in. Teams of two students are most typical. When the teams have three or more involved often the quality of the work diminishes and it is more difficult to supervise progress of each member. The faculty advisor often discusses team related issues and acts as a mentor and coach to provide direction and guidance during points of tension between team members. The faculty advisor also monitors team activity to ensure that energetic individuals do not get carried away and do everything themselves.

4 ALTERNATIVE ENERGY APPLICATION – WIND ENERGY

4.1 WIND ENERGY PROJECT

The overall goal of the project is to design and build a wind turbine, place it into service on campus, and tie the power output to the power grid. This project is to be carried out by teams of EMET students – possibly over consecutive years

4.1.1 Project Requirements and Restrictions

The performance goal for the project was to construct a generator capable of producing a reasonable quantity of energy relative to typical home use of 9400 kW-hrs per year. Given that the average wind speed near our campus is 11 mph, it was determined that approximately 2250 kW-hrs per year would be produced by a 1 kW generator. Given the budget constraint of $1000, a small wind turbine size was necessary; an electrical power output of 1 kW was targeted.

Another aspect of the desired performance is the ability to operate either as an isolated power system, or connected to the power grid. This will require additional power electronics, as shown in the block diagram of Fig. 1.

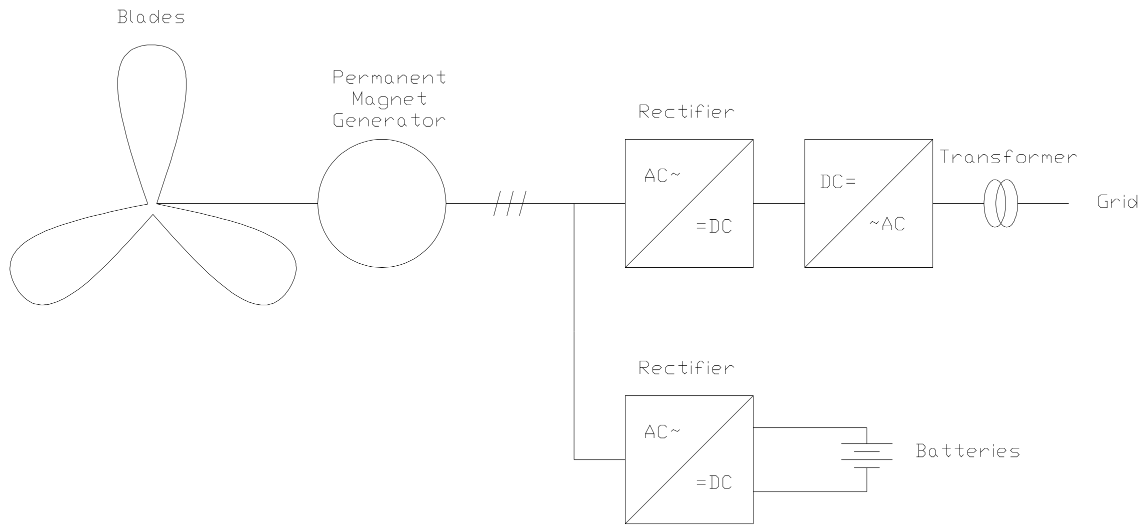

Fig. 1. Block diagram of the wind energy project

Another important aspect of the project related to performance is the location, or siting of the turbine. Ideally the system would be located in an area where there are no physical obstructions. On our campus, however, trees and buildings complicate the site selection process. Following small wind turbine siting guidelines, we determined that the turbine should be placed approximately 30 feet above the highest tree in the area. We chose a rather remote location behind the engineering buildings where there is ample room for the tower and guy wires. The highest tree in this area is about 70 feet high, and due to this we have concluded that our tower will be about 100 feet high.
Zoning issues were investigated, and it was determined that a building permit would be required since the tower was over 20 feet high.

4.2 DESIGN

After establishing the performance objectives of the project, the student team reviewed several micro wind turbine projects that had already been completed. From this review, the design a standard 3-blade turbine of 8-foot diameter was determined to be appropriate for the project needs. The speed at maximum output power is 600 RPM. The turbine blades are shown in Fig. 2.

Fig. 2. Turbine blades for student wind energy project

With the blades selected, the most important aspect of the project is the design of the electric generator. A permanent magnet generator was selected due to ease of construction and relatively low manufacturing cost. To match the relatively low rotational speed with power requirements, a disk-type machine is generally preferred in wind turbine applications to avoid gearing between the turbine and generator. With this in mind, a 12-pole dual-rotor axial flux generator design was selected. The generator consists of two rotor disks sandwiched around an ironless stator containing the phase windings. The NeFeB permanents magnets are arranged on both rotor plates to form a 12 pole machine. One half of the dual rotor assembly is shown in Fig. 3.

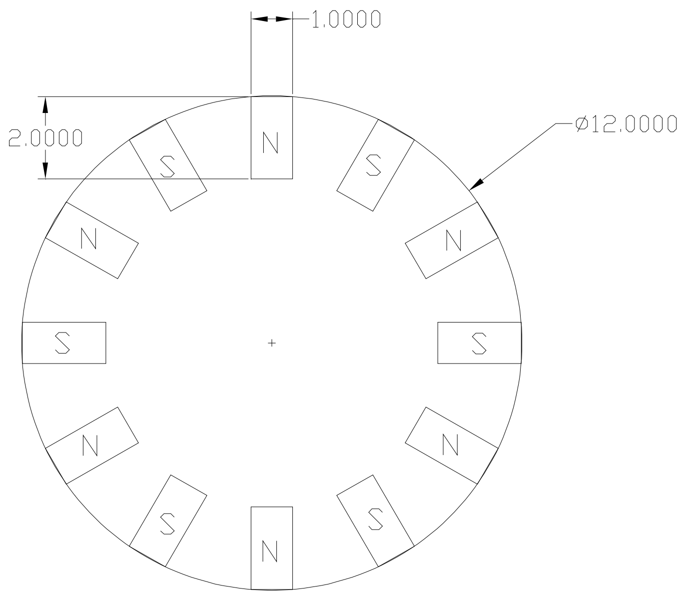

Fig. 3. Arrangement and dimensions (inches) of rotor.

The dimensions of the air gap and magnets were selected based on several criteria. First, to keep magnet cost to a reasonable level, a standard magnet size (dimension shown in Fig. 3) was selected. In addition, to optimize the use of the magnets, it is desirable to operate them near their maximum energy product. In lieu of time-consuming finite element analysis of the magnetic system, an approximate magnetic equivalent circuit, as shown in Fig. 4, was used to determine the magnetic set point of the system and the air gap dimensions. [Fitzgerald et al., 1990]

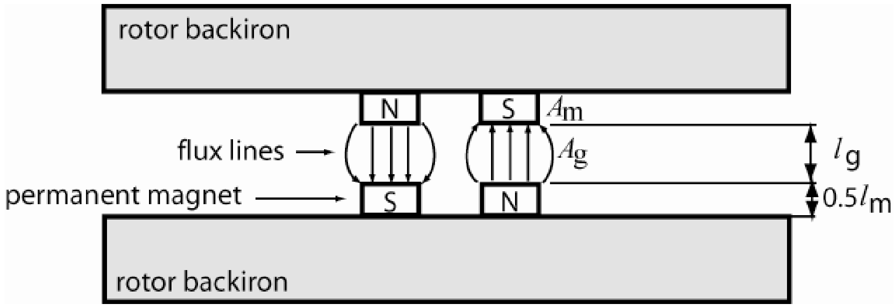

Fig. 4. Magnetic circuit for generator pole pair.

Applying Ampere's law around the flux path of a single pole, as shown in Fig. 4, the mmf of the flux path in the absence of external excitation is:

$$H_g l_g + H_m l_m = 0 \ , \tag{1}$$

where H_g and H_m are the magnetic field intensities of the air gap and magnet respectively. Similarly, l_g and l_m are the length of the physical air gap and the magnet pair thickness (0.5 inch per magnet, or 1 inch per N/S pair), respectively.

The flux in the magnetic circuit must be constant in the loop so that

$$B_g = \frac{A_m}{A_g} B_m \ , \tag{2}$$

where B and A are the magnetic flux densities and cross-sectional areas, respectively of the magnet and air gap.

Combining (1) and (2) , we gain a representation for the operating point of the magnetic system based on the cross-sectional area and length of both the magnet and gap.

$$H_m = \frac{-B_m}{\mu_0} \frac{A_m}{A_g} \frac{l_g}{l_m} \tag{3}$$

Given the Neodymium magnet's residual flux density 1.2 T and coercivity of 950,000 A/m , we can describe the magnet B-H curve by:

$$H_m = \frac{B_m - 1.2}{\mu_0} \tag{4}$$

The simultaneous solution of (3) and (4) yields the magnetic set point in the absence of external mmf sources. Given the magnet dimensions, and assuming that the air gap cross-sectional area is 50% larger than the magnet due to fringing, the length of the gap is selected to be equal to the magnet thickness so that the magnetic set point is near the maximum energy product. With $l_g = l_m$ and $A_g = 1.5 A_m$, the permanent magnet flux density is 0.72 Tesla, and the air gap flux density is approximately 0.5 Tesla.

With the air gap flux density set point determined, the stator coils may now be designed. The desired generator output voltage is approximately 50 V rms. The air gap flux density may be described mathematically by:

$$B_g = 0.5\sin(\omega t), \qquad (5)$$

where ω is the electrical frequency (377 rad/sec. at 600 RPM). Faraday's law can be used to determine the number of turns required to produce the desired voltage:

$$e = NA_{coil}\frac{dB_g}{dt}, \qquad (6)$$

where e is the peak voltage output of the generator, N is the number of coil turns, and A_{coil} is the cross-sectional area of the coil. From (6) it was determined that 220 turns would generate 80 volts peak, or 56 v (rms). Each phase of the generator consists of 6 coils of 220 turns each connected in parallel, so each coil must be capable of carrying 1 A to meet the desired VA rating of the machine. Therefore, 21 Gauge wire was used to form the coils. Given the parallel configuration the six coils constituting a phase, the total phase current rating is 6 A.

Another important design factor is to determine the loads affecting the turbine. The area surrounding the site consists of several buildings as well as pedestrian walkways. For this reason, the tower needs to be stable such that no harm can be done to students or the buildings. We have conducted an analysis regarding the loads on the turbine to ensure the proper security of the turbine to the tower and from the tower to the ground.

4.2.1 Test and Verification

The generator will be tested by connecting a DC motor to the generator shaft to act as prime mover. At a speed of 600 RPM, we expect to see a balanced 3-phase voltage of 56 vrms line-to-neutral at the output. However, given the approximations used to design the magnetics, provisions have been made to adjust the air gap length to make small adjustments to the air gap flux density, and therefore to the output voltage magnitude. Once the output voltage is verified and adjusted as necessary, the generator will be loaded by a resistive bank to a level of 1 kW. The load test will verify acceptable thermal characteristics of the generator design.

4.2.2 Budget

A total of $1500 dollars was provided to complete the project - including all materials necessary to erect the turbine. The total rotor cost was $230, where $130 dollars was spent on the 24 neodymium magnets, and $100 for the 5/8 inch steel plate for the rotor backiron. The stator cost was $100 for the stator coil wire. Approximately $200 was spent on steel pipe to construct the alternator mount. The slip ring that we purchased was $90. Pipe for the tail frame was $100. The tower and guy wires will cost approximately $400. Batteries, rectifier and transformer for the system will cost about $300. When everything is purchased we expect to be just within our $1500.

5 CONCLUSION

This paper describes activities and work related to a wind energy senior capstone course project. There are a variety of other alternative energy application projects this semester. These include two hybrid vehicle projects, a bio-diesel project, and a small scale fuel cell project. Students are very interested in alternative energy and programs like Penn State Altoona's BSEMET program are good resources in providing the knowledge and training to meet the demands of society.

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7 AUTHORIZATION AND DISCLAIMER