Curriculum Development in Renewable Energy and Sustainability

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For 13 years, Dr. Zilouchian served as the Associate Dean of Academic Affairs and the Assistant Dean for Graduate Studies at FAU's College of Engineering and Computer Science. His sustained contributions and research projects total more than $9M with funding sources from the U.S. DOE, the National Science Foundation (NSF), The Florida Board of Governors (BOG), Florida Power and Light (FPL), Motorola Inc., The School Board of Broward County Florida, JPMorgan Chase Foundation, and others.

Dr. Zilouchian's accomplishments at Motorola Inc. include automation, process control, and computer vision inspection projects. His research accomplishments at FAU include developing national models in STEM education across institutions, algorithm developments related to maximum power point tracking for solar systems, water management of proton exchange membrane fuel cells, computer modeling investigations in battery technology; and, applications of soft computing (neural network, fuzzy logic, and genetic algorithms) methodologies to several industrial processes including desalination, oil refineries, jet engines, and robot manipulators.

Dr. Zilouchian awards include: the distinguished FAU Presidential Leadership Service Award in 2017 for his contribution to research and community engagement, FAU College of Engineering Dean's Awards twice, and Excellence in Undergraduate Teaching twice. He has published one book and more than 165 book chapters, scholarly journal papers, and refereed conference proceedings. He has supervised more than 20 Ph.D. and MS students to completion during his tenure, and taught more than thirty (30) different courses related to computer and engineering technology. He is active in several professional societies and editorial boards and is a senior member of IEEE and ASME and ASEE and AHSIE.

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Abstract

This paper presents the development and curriculum implementation of a combined alternative energy course for both mechanical engineering and electrical engineering programs at the College of Engineering and Computer Science at Florida Atlantic University (FAU). The course contents and hands-on activities are divided into several sections, including PV (photovoltaic engineering), H2PEM (Proton Exchange Membrane hydrogen fuel cells), wind energy technology and solar energy assessment. The impact of these technologies on a future hydrogen economy, the impact on smart grids, and job creation are also introduced. The curriculum draws heavily on the experience and background, both theoretical and field experience, of the instructors including NSF and DOE grants that allowed the design and implementation of a certified hydrogen development laboratory, and development of instructional materials for PEM training. The curriculum integrates key topics such as MATLAB^R and SIMULINK^R modeling and simulation of critical components including PEM Fuel Cells, PV with storage and grid integration.

Aside from lectures, the course relies heavily on project-based learning. The students are divided into teams to propose, design, and implement realistic, hands-on projects. When there is an opportunity for a large-scale project such as Project 1 discussed in this paper, the entire class participates with sub-disciplines organized around a specialty such as structural design or electrical interconnect of solar energy with the local utility. Safety and NEC (National Electrical Code) compliance are also discussed to satisfy course objectives. In summary, the class project is managed to mirror real world project implementation treating the class as design-build entity and sub-groups as sub-contractors. During the implementation phase of the project, the students are also made aware of the need for diversity and inclusion at every level, from the design phase to the assembly and construction phases.

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I. Introduction

The population of the United States is projected to increase from the current level of 335 million to 458 million by the year 2050 under the assumption of high international migration [1]. Currently, 24% of all energy consumed comes from renewable sources, including solar, hydroelectric, biofuels, and biomass, according to the latest data from US Energy Information Administration [2].

According to a study by Management Information Services Inc., a Washington, D.C. research firm that has been tracking green jobs for the past three decades, the new industries of environmental management and protection have already created 7.8 million jobs and are estimated to create 18.3 million additional jobs, thus significantly impacting the economy by 2030 [3]. In addition, the State of Florida will outpace the national economy, and its unemployment is expected to fall due to the state's robust economy (Institution for Economy Forecasting at UCF)[4]. In the past, environmental jobs were mostly about regulatory compliance; now, they are supporting a wide variety of initiatives, including sustainability, water processing, and alternative energies.

As of 2021, the transportation sector accounts for the largest source of pollution in the United States of America (EPA). To combat this and ease the strain on planet Earth, many automotive companies, with government support, have announced an accelerated roll-out of electric vehicles (EVs). While Tesla currently is the most well-known and arguably most successful to date, all major legacy manufacturers, as well as several new start-ups, are looking to make a splash in this market. Demand for lithium has exponentially increased as the auto companies' race to develop EVs. Growth in the number and size of batteries for EVs could comprise more than 90% of lithium demand by 2030[5]. Additionally, the new bill recently passed by the Senate and the House [6] will create the needed platform for the further development of EVs. It will create the green workforce needed in manufacturing and building the supply chains critical for EV production[7]-[10].

On the other hand, the technical and scientific challenges associated with the production of reliable energy sources for the nation in a short 30-year period are enormous tasks, especially when combined with strategic and recent economic concerns.

It is clear that as part of the mix of energy sources necessary to deal with these challenges, alternative energy sources will play both a critical and central role in addressing these demands. The US Department of Energy, as well as many national laboratories and academic institutions, have been aware of the importance of alternative energy sources for some time. Recently, the energy industry, especially car manufacturers, transportation experts, and even utilities are paying attention to alternative and sustainable sources of energy for the future[10]. As an example, currently, the auto industry employs 4.7 million people in the United States (Bureau of Labor Statistics). Many of these jobs are held in both the manufacturing and supply of parts to the manufacturing process. Electric vehicles require far fewer parts than traditional Internal Combustion Engines (ICE). Many ICE's contain hundreds of complex parts while some EVs operate with fewer than 17. A recent report published by the State of California has estimated that nearly half of all the technicians in the state will lose their jobs as less maintenance is needed on EVs. These job losses will have the greatest impact on minorities, women, and those with lower education credentials.

Universities around the nation need to play an even more important role in addressing the transition from fossil fuels to sustainable sources of energy, as well as the educational aspects and green workforce development. Their role includes a wide range of tasks that include public education requirements at one end of the spectrum to specific recruitment, mentoring, and retention of highly qualified students at the other end of the spectrum.

There are number of renewable course developments [11]-[13], and program integration initiatives during the last ten years. They cover various aspects of the development of renewal energy. In addition, both the new development programs and certifications address the needs associated with renewable energy and sustainability [14]-[17].

The primary goal of the proposed course is to address the concept of "green" workforce development as it relates to education, training, and, to some extent, the public ~~information~~ dissemination of information related to renewable energy and sustainability by integrating these trends directly into the course curriculum. The students will learn about all forms of renewable energy including solar, wind, fuel cell, biofuels, geothermal, and other clean-energy-related technologies as well as the underlying foundations of sustainable design and implementation. The students will participate in several experimental lab studies as well as computer model simulations to aid them in understanding complex and large-scale systems. Issues of specific interest to engineering students including power management and hybrid control of the systems will be covered in greater depth. In addition, students will be made aware of the impact that human activity has on the environment, and how politics and business interests influence the way technology is developed and delivered to the market.

The paper is organized into the following sections. Section one is the introduction. In section 2, the course objectives are briefly outlined. The course topics are presented in this section also. The project's relatedness to critical alternative energy topics will be discussed in this section also. In section 3, several course sample projects will be discussed. Section 4 will discuss the assessment outcomes related to the hands-on project. Section 5 presents the conclusions and next steps.

II. Course Development, Objectives, and Outcomes

The course has been designed to provide a foundation to engineering students in several energy-related areas including:

(a) Conventional energy source technologies and their promise, advantages, and disadvantages

(b) Renewable energy source technologies and their promise, advantages, and disadvantages.

(c) A general background in solar energy technologies including solar thermal, solar photovoltaic, concentrating thermal, and combined thermal-photovoltaic technologies.

(d) Basic economic principles and the future "hydrogen economy"

(e) Greenhouse gases, global warming, and carbon credits

The following list identifies the course objectives and outcomes:

<u>Course Objective 1</u>: *Understand issues related to conventional sources of energy.*
The course topics below relate to this objective:

- The global and regional sources of fossil fuels.
- Past, present, and future forecast of fuel productions including oil, coal, and natural gas.
- The basics of electrical generation.
- The underlying rationale that explains why conventional sources of energy have dominated the electrical generation and transportation industry and other relevant industries.
- Current trends aimed at shifting from the fossil fuel-based economy to the hydrogen base economy in the short term.

<u>Course Objective 2</u>: *Understand the history and future of Alternative Energy Technologies*
The course topics below relate to this objective:

A short history and technical aspects of alternative sources of energy including PV, hydro, nuclear, and other renewal sources of energy.

- Advantages/disadvantages, and scientific challenges of the renewal and sustainable energy technologies.
- A comprehensive cost analysis of different renewal and sustainable energy technologies.
- The environmental impact of alternative and renewable sources of energy.

<u>Course Objective 3</u>: *Solar energy technologies and the potential impact on the power grid*

The course topics below relate to this objective:

- Solar thermal: current and future
- Solar PV: current and future
- The basic principles of photovoltaics and PV system components
- Predictive tools for assessing solar generation for load management
- Solar energy storage: current and future
- Explain how power flows in the grid are controlled.
- Interaction between the utility and small to medium solar generators

- Interaction between the grid and large-scale solar generators

<u>Course Objective 4</u>: *Understand the technical issues related to fuel cell*

The course topics below relate to this objective.

- Advantages/disadvantages of scientific challenges of the PEM fuel cell technology
- Evaluation of fuel cell stacks under various operating conditions.
- Effects of humidification, water management, and heat management on the performance of the PEM fuel cells.
- Assess innovative technologies in modeling, control, and chemical testing related to fuel cells, and the use of interactive learning for the design and fabrication of reliable FC.
- Scientific and industrial evidence related to the future of FC for energy-related applications.

<u>Course Objective 5</u>: *Greenhouse gases, global warming, and carbon credits*
The course topics below relate to this objective.

- The environmental impact of present conventional energy sources.
- Scientific evidence of comparative polluting effects of various fuel sources and global warming.
- Impact of carbon credit for the energy industry sectors.
- Environmental issues with large scale solar installations
- Environmental problems with current energy storage.
- The cost-benefit analysis of distributed generation sources, including direct costs and indirect costs related to external sources.

III. Organization of Course Learning Sessions

The course activities have been sub-divided into two distinct parts: Course lecture and research/authentic hands-on project:

***<u>III.1 Course Lectures and Presentations</u>*- ** Lectures for the course are presented in one session (1.5 hr.) each week and follow the outline below:

• Energy, sources of energy, and energy conversion

Basic energy equations, fossil and renewable sources, a review of thermodynamics: first and second laws, units, work, energy, and heat

•Greenhouse gases and global warming, the Paris accord, and carbon credit
•Overview of conventional Energy source technologies and their promise, advantages, and disadvantages:

- nuclear fission and fusion
- coal, clean coal, and syn-fuel
- oil and gas

•Overview of renewable energy source technologies and their promise, advantages, and disadvantages:

- ethanol and methane
- solar thermal and solar photovoltaic
- hydrogen
- hydroelectric and micro-hydro
- wind, wave, and tidal
- other exotic sources

• Conversion technologies and efficiency:

- Steam power, diesel, and gas turbines
- Electric transportation
- Fuel cell technologies, types of fuel cells (PEM, SOFC, other)
- Solar thermal principles
- Solar photovoltaic principles: basics and system design
- Wind and hydro power

• Basic economic principles and impact of solar, fuel cell, and other renewal sources of energy[2]:

- Cost benefit analysis
- Risk assessment and system efficiency
- Power management strategy of several energy sources

III.2- Research/Hands-on Project: Students are given an initial assignment to develop a proposal by conducting research on a topic of their interest, within guidelines set by the instructor. Once the proposals are approved, students can team up with one or 2 other students with similar interests and develop a "team" project proposal. Frequent interaction and short presentations by all members of every team ensures an equitable division of responsibilities by team members.
Open-ended design problems are encouraged so that students can practice their decision-making skills in group settings. For example, the project could be the design of a fuel cell system for a specific application (i.e., backup power) requiring multiple calculations to predict operational performance (i.e., short power outage, low fuel resource, etc.). As another example, the project can be research work related to the application of fuel cells in the automobile industry. Written reports are also required for all teams, and weekly project updates keep track of each team's

progress. Final reports and presentations are also graded not only for creativity and results, but also a fair distribution of tasks in every category of project implementation.

The students may also participate in the computer model simulations using MATLAB and Simulink instead of doing a hands-on project. Such activities support their understanding of different systems (e.g., PEM, charge and dis-charge of the battery or the PV model using non-linear elements and plot the characteristics of PV systems modeling, simulation of specific systems such as power management of several different power sources or control of a power system). When carried out by the student team, they are likely to have a better understanding of the operation and processes of large scaled systems.

IV. Sample of Students Projects

In this section, three recent student team projects are presented. These projects are sponsored by a research institution, a wildlife sanctuary, and an industrial partner. [UNIVERSITY] and are expected to serve as a focal point for university-industry educational partnerships for renewable energy workforce development.

IV.1- Project #1: HBOI-30 kW Solar Project (Supervisor-Dr. Abtahi)

Harbor Branch Oceanographic Institute(HBOI)-30 kW installation project was implemented to lower the maintenance cost of the Aqua-farming research facility at HBOI. The facility is an energy-intensive operation with an array of water pumps for fish breeding and feeding tanks, thermal control devices, chemical and physical scrubbers, and numerous controllers and accessories. The 30 KW solar photovoltaic (PV) system is only a fraction of the electric demand; however, it does reduce the operational cost of the facility. It is also designed to allow seamless expansion of the solar array when additional funding becomes available, with the ultimate goal of providing 100% of the power requirements with solar PV energy.

(a)Project Background

In the spring semester of 2019, Dr. Paul Wills , a Research Professor at HBOI approached the author with a proposal to fund the design and installation of a 30 kW PV solar power system in order to help lower the electricity demand of an aquafarming facility. His offer was conditional on a budget limit of $30,000 and completion of the bulk of the project by the end of the summer semester. Always eager to engage our engineering students with real-life projects, we made plans to adapt the 2019 Summer Solar Engineering class to the design and implementation needs of this project.

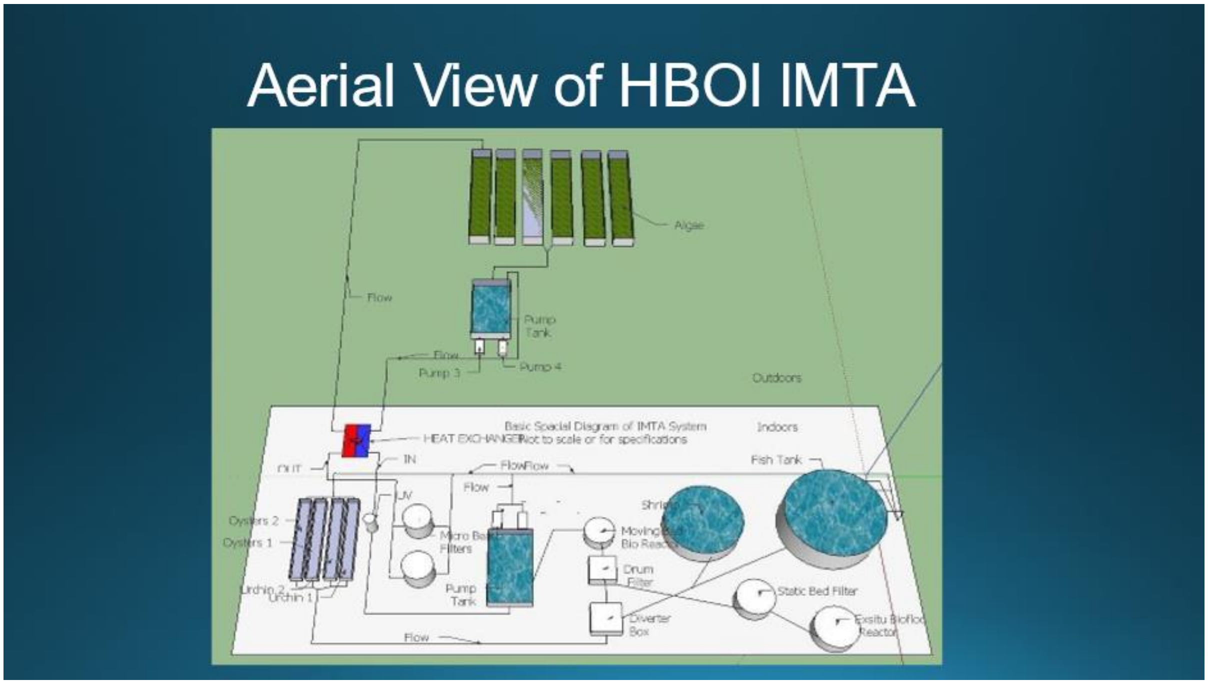

Figure 1- *Project #1 Prototype Phase*

(b) Project Design and Construction

We organized an initial site visit by the class to develop the BOD (Basis of Design) for the project. The HBOI offered us a 4' deep concrete foundation that had been used for a previous research project. Using the foundation for the layout for the solar array, the design process began. Using a design-build management scheme prevalent in industry, the design process was sub-divided into specialty groups such as structural, electrical, fabrication, procurement, etc. The students were fully engaged in every aspect of the project. Those with construction experience took on more of the installation tasks but still participated in student teams involving structural analysis and solar design optimization. Advanced tools were used such as ANSYS[c] (for structural) and National Renewable Energy Laboratory (NREL)'s open-source solar optimization tools such as HOMER, along with analytical methodologies.

The final system design was a 30,720-Watt grid-tie PV system with 96 solar panels, each generating 320-watts arranged in 4 sub-arrays of 24 panels each, connected to 6 inverters converting DC (Direct Current) solar power to 3-phase 208 VAC, alternating current. The output of the inverters was then fed back and tied to the main electric panel serving the aquafarming facility. All NEC (National Electrical Code) and UL protocols (such as UL 1741) were introduced to the students. To ensure students' safety and as per requirements of Florida Building code and local authorities, the final connections of the high voltage lines were made by a senior electrician. Connection to the local utility FPL was subsequently finalized after inspections by Licensed Electricians and FPL.

Students were involved in every aspect of the project including the permitting requirements of the University's facilities division.

Figures 2 and 3- *Project Implementation*

Figure 4*: Student work on the Solar Project*

IV.2-Project #2 Solar-Powered Cooler Project(Supervisor- Dr. Zilouchian)

In this project, the design and implementation of a solar-powered cooler were carried out by two students in the spring 2022 semester. Students were interested in the project due to its potential market trend in the State of Florida and beyond. Consumers may utilize the solar-powered cooler to replace the regularly needed ice or to connect to the grid network in case of a hurricane blackout for an extended period. Therefore, sustainability has become the prominent trend for such a small-scale system [18]-[21].

Project Design and Construction

The students initially proposed to design and construct the cooler using plastic bins for exterior walls. However, since the system was a prototype student project with a limited budget, the wood exterior was chosen as the preferred material to construct the cooler. An old 1.6 cubic ft mini refrigerator was stripped of its parts and used as the base of the system design. System components including the solar panel, DC to AC inverter, charge controller, power regulator, and backup battery for energy storage were assembled to carry out the task. In addition, two large plastic bins were utilized: one as a cooler, and the second one as a cover for all the connected wiring and electric components.

Figure 5: *Solar-Powered Cooler Project*

The system was designed and constructed to be fully portable with its built-in wheels and handlers as shown. The compressor, condenser, inverter, evaporator, coils, evaporator fan, temperature controls, and defrost heater have been situated to function together. The coils were on the outer layer of the top bin radiating. A single solar panel was used to collect the sunlight to provide the needed power for the cooler and charge the battery. The project was tested for an extended number of days. The system performed according to design specifications. The total cost of the project including the frame, solar panel, investor, charge controller, battery storage, and cooling section was $182. The project provided student team with a great experience from both design and implementation viewpoints for a small-scale system with potential marketability shortly.

Several other projects were designed and carried out in both solar classes. Due to space limitations, the other projects are not described in this paper.

Project #3-Modeling of PEM Cruise Control (Supervisors Drs Zilouchian and Abtahi)

Students in the course have the option to participate as a team to model a renewal energy device instead of hands-on projects. For example, student teams did work in the modeling and simulation of PEM fuel cell systems as well as large-scale power management systems. In this sub-section, the modeling and simulation of a fuel cell cruise control are presented. It is expected that all team members will actively participate in the construction of Simulink models and analysis of the simulated results.

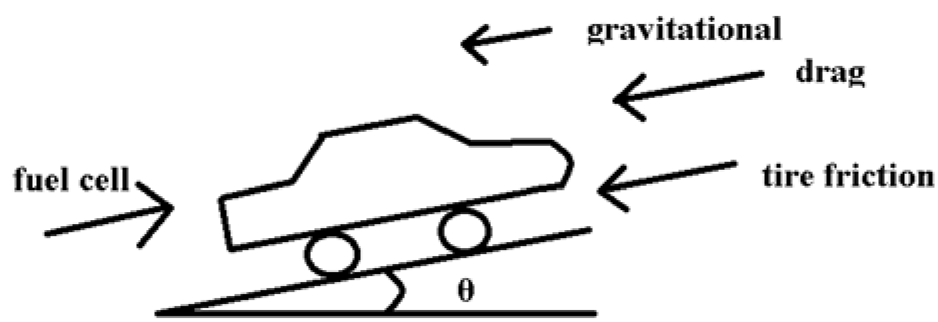

Figure 6: *Free Body-Diagram of Cruise Control*

The student builds a Simulink model for a cruise control system for a fuel cell vehicle. In doing so, students were reminded that the proposed project needed to be decomposed into different subsections in order to carry out the tasks. The student team designed a PEM fuel cell model in the first phase of the project. Next, the team designed a PID controller to achieve the desired simulation results. Below are the steps taken by the student team to complete the modeling and simulation of the system:

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1) Construction of a simple PEM Fuel Cell Stack Voltage Model.
2) PEM Modeling due to the Ohmic losses.
3) Modeling Due activation of the anode and the cathode.
4) Modeling as the results decrease in the concentration of oxygen and hydrogen.
5) Stock Voltage Model Analysis and simulation using Phases 2-4.
6) Construction of Cruise control model.
7) Modeling and simulation of the system using a PID controller.

Below are the Simulink model and simulation results as carried out by the student team. In the above model, a PID controller is utilized to control the input pressures to maintain a fixed velocity for the car. Due to space limitation, the detail of the project is not presented here.

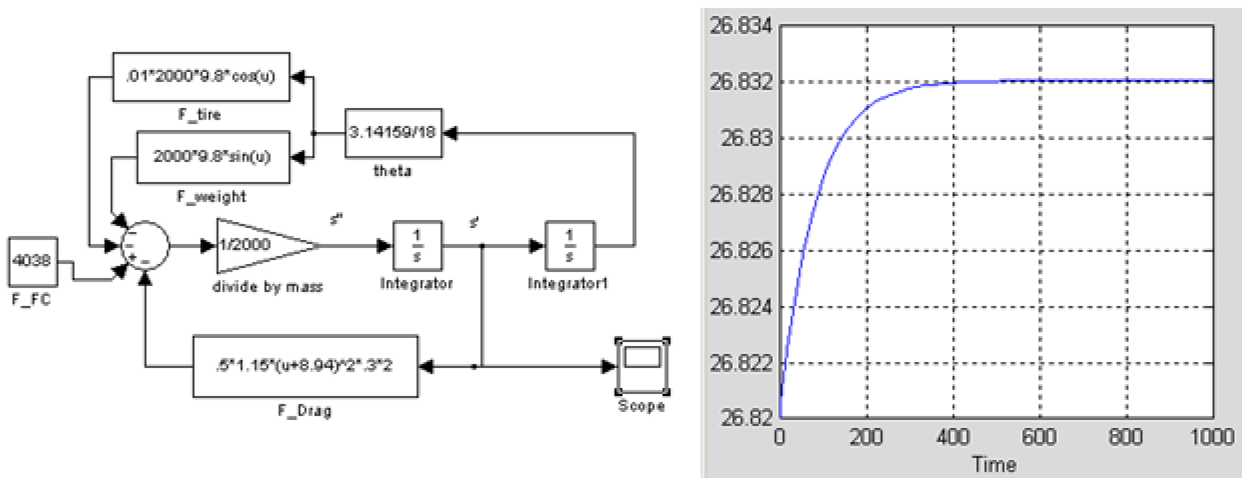

Figure 7 *Simulink Model for Cruise Control System*

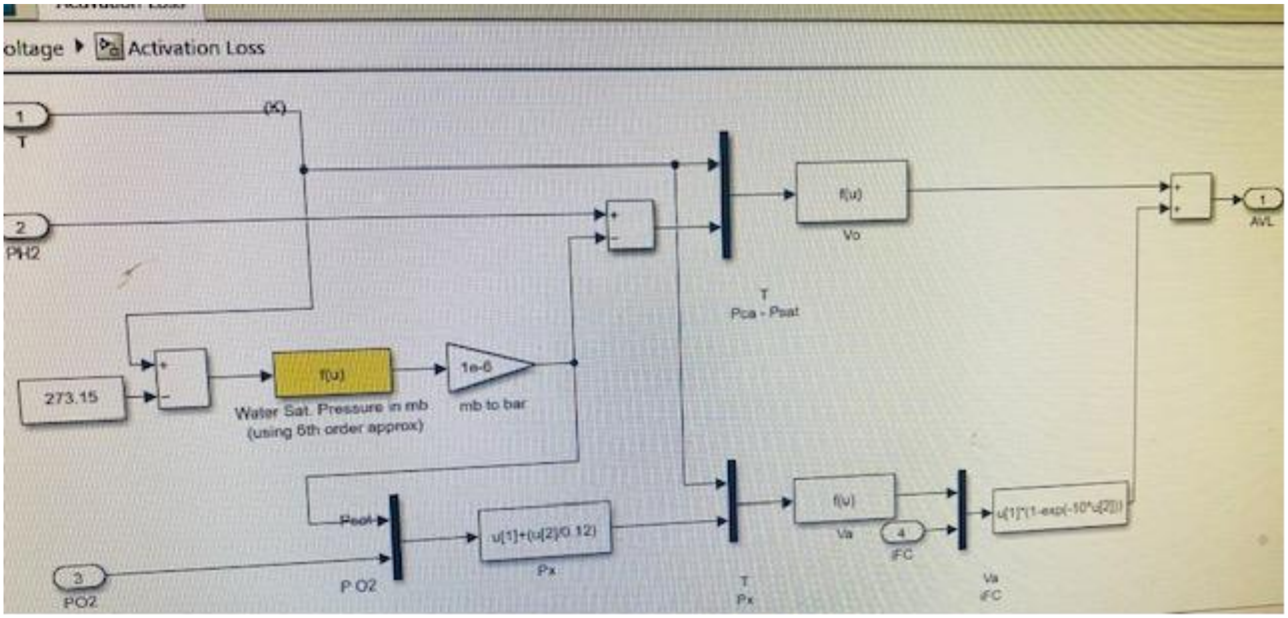

Figure 8*: Example of Sub-system PEM Model*

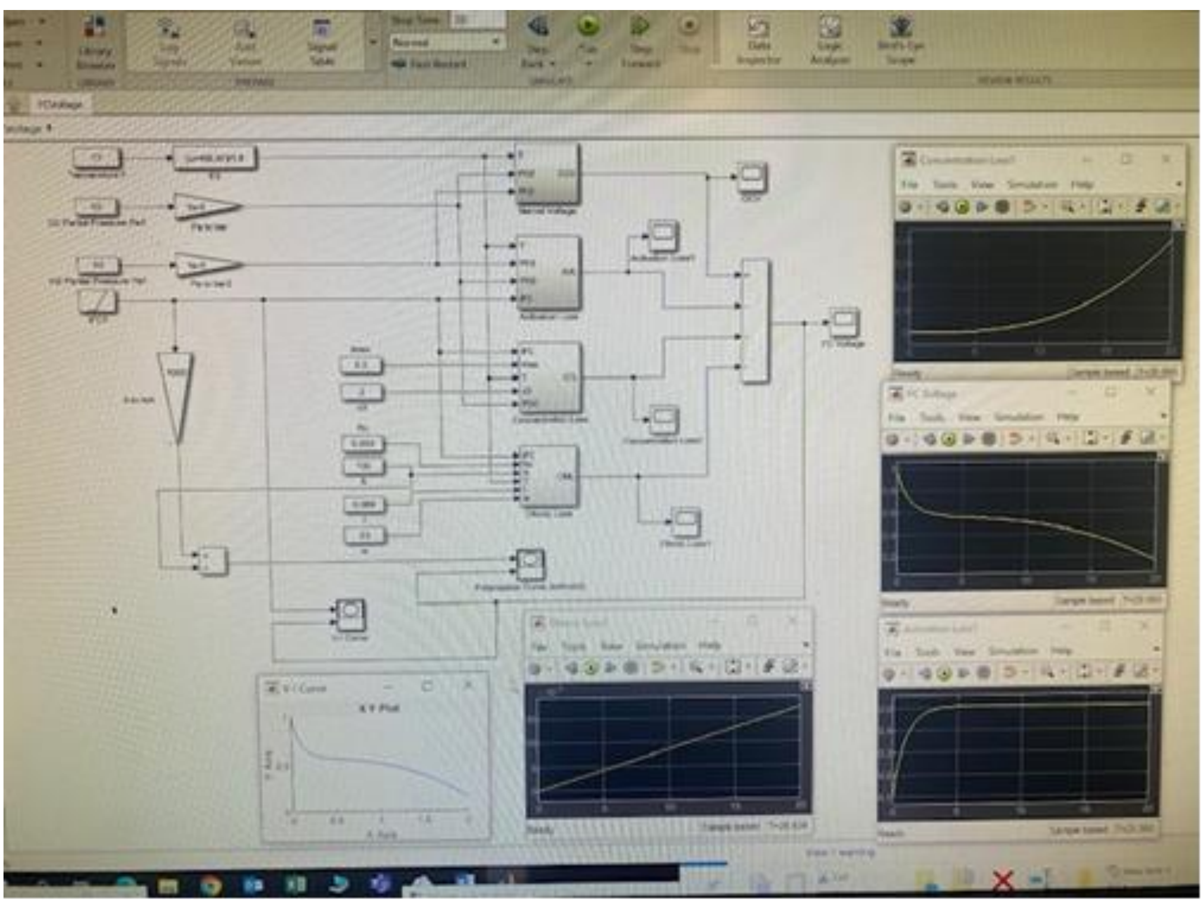

Figure 9*: PEM Simulink Model with Simulation Results*

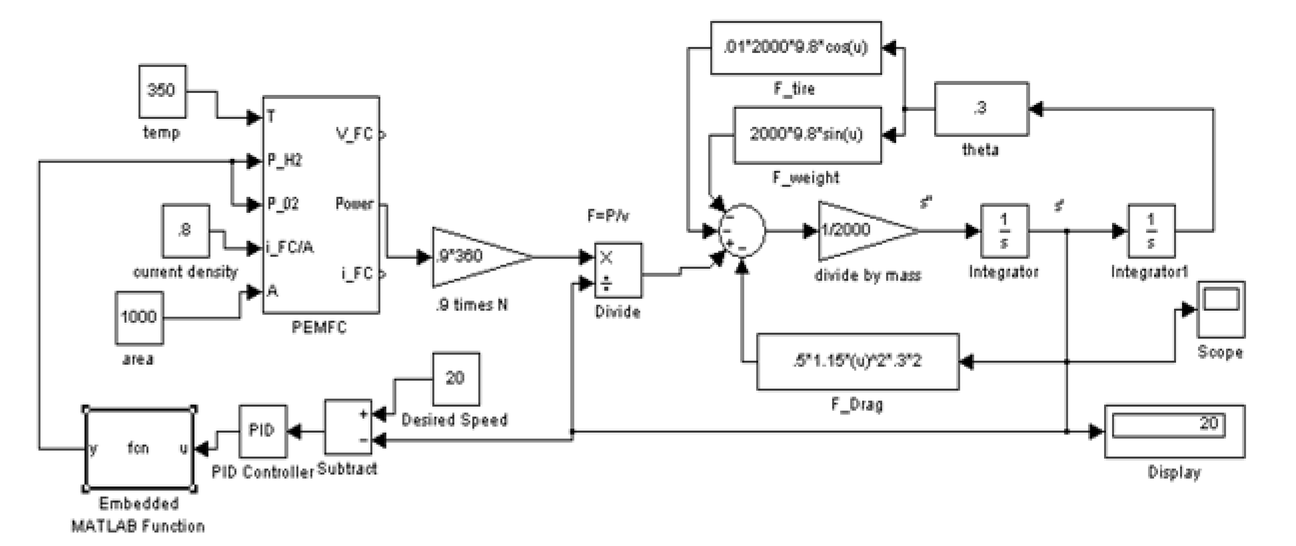

***Figure 10**: Simulink Model of PEMFC Cruise Control with PID controller*

V. <u>Course Assessment</u>

The proposed course curriculum was evaluated in terms of student learning outcomes and the overall impact on students and was based on a variety of measures, including quantitative and qualitative measures, informal assessments, and anecdotal records. Quantitative and qualitative assessment of the course centered on student engagement, student learning outcomes, and student satisfaction. Student engagement was assessed by observing student participation in hands-on group activities in the course. Student learning outcomes was assessed by reviewing student understanding of the material presented in the course. Students were enthusiastic and actively participated in hands-on activities, lectures, and Simulink modeling. They were eager to participate in group activities, ardently asked questions and energetically engaged in lectures and discussions. The hands-on approach to learning used in the course especially for the project #1 has proven to be an effective method of engaging engineering students, increased their interest in renewable energy topic and careers. The Simulation models of PEM fuel cells provided students with depth understanding of the subject matter. Students expressed positive feedback regarding the course and indicated that they had learned a great deal and enjoyed their hands-on experience in the course.

VI. Summary and Learning Course Outcomes

The conceptual design and development of the course provided undergraduate students with advanced technical training to find ***solutions*** to current energy and sustainability problems. Understanding human, environmental, economic, and energy issues and modeling to predict the future, as well as having the skills to identify and resolve related problems are critical to national energy independence and local and global sustainability. The proposed course has accomplished the following outcomes:

- Familiarized students with the design, testing, and implementation of alternative energy technologies including equipment, software development, and testing.
- Supported student acquisition of the knowledge, skills, and dispositions necessary to engage in energy-sustainable development.
- Introduced students to the utilization of emerging technologies in industrial communities, but not yet utilized in the university environment.
- Created a focal platform for interdisciplinary learning as well as presented a balance between theoretical, hands-on experience, modeling and simulation in undergraduate instructional activities related to alternative energy.
- Established a vehicle for the development of undergraduate research and implementations of senior projects related to alternative energy technology.

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