Student Learning Experience from Renewable Energy Case Studies

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Abstract

Students' design projects at all levels are increasingly focused on the renewable energy sources and systems due to the increased emphasis in the U.S. on clean energy innovation, generation, manufacturing, and commercialization. Since many topics and issues related to the renewable energy systems have been investigated by well-equipped research teams all over the world, the educational effort for student learning should be focused on how students acquire useful knowledge in the physical and chemical principles and make meaningful contributions to the applications of renewable energy. This paper describes four completed "green energy" projects. The description includes a summary of the project requirements, design processes, and laboratory work. It also describes the interactions between faculty, staff, and students from different disciplines. A special emphasis is placed on understanding how to make interdisciplinary projects successful. During the past several years, our senior design capstone course teams have designed case studies such as wind energy turbines, fuel cell controllers, solar cell maximum power tracking controllers, and other similar projects. The paper also explores the students' motivation for undertaking an interdisciplinary project and looks at how they were able to remain motivated. Initial results show that students' motivation remained high as long as the project remained challenging. In addition, the interdisciplinary subject matter, laboratory techniques, and interactions between students, staff, and sponsors all played a role in the project success. Finally, the paper explores how participation in these interdisciplinary projects influenced students in their subsequent career choices.

1. Introduction

Society is increasingly calling for professionals across government, industry, business and civil society to be able to problem-solve issues related to climate change and sustainable development as part of their work[1]. The Energy Information Administration predicts that U.S. energy consumption will increase at a rate of 1.1 percent annually, but that U.S. energy production will only increase at a rate of 0.9 percent annually, from now through 2030[1-3]. These projections are based in part on current usage of renewable energy sources. Motivated by these energy security requirements and the desire to create a sustainable and safe environment, there is a growing need to transition gradually from fossil fuels to emerging and renewable energy sources. To narrow the gap between consumption and production, additional usage of energy sources other than fossil fuels is required. Moving towards addressing the energy needs of the future is supported by the U.S. Energy Policy Act of 2005, a long-term energy strategy that includes provisions for diversifying energy supplies, increasing residential and industrial energy efficiency and conservation, developing more efficient motor vehicles, improving the electric power infrastructure, and expanding reserve storage of petroleum[2].

A key ingredient to addressing such issues is equipping professionals with emerging knowledge and skills to address energy challenges in all aspects of their work. Engineering and engineering technology programs must offer a relevant and validated curriculum that prepares students for post-graduation success[4, 5, 7-9]. Courses that cover traditional subject matter in mathematics, the sciences, materials, engineering economics and related topics provide the foundation of knowledge upon which specific skill sets are added depending on emphasis. However, it is critical for engineering/technology to transition from theoretical work in the classroom and 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 theory and real world practice. Accordingly, the proposed senior projects should include elements of both credible analysis and experimental proofing such as design and implementation as discussed in ABET criteria[6, 7]. Additionally, the senior design courses can serve as an excellent culminating experience in the program of study when it focuses on research and design projects that have practical value to consumers or to industrial customers.

Undergraduate engineering or engineering technology curricula are facing a number of challenges including a rapid growth in what is perceived by the technical community to be a necessary foundation of knowledge, the realization that our workforce must be able to operate in a diverse global society and the recognition that the implementation of technology can have an enormous impact on the sustainability of our global resources. If our students are going to successfully function as professional engineers in the international corporate world of the 21st century, they must be equipped to be global engineers who are technically versatile, able to solve problems from a systems-level perspective, effective communicators, function in diverse ethnic teams and demonstrate social responsibility. Accordingly, our undergraduate curricula must keep evolving in order to provide the proper learning environment for students to develop these characteristics. Due to the unprecedented growth of renewable energy technologies and in the interest of keeping students abreast of the current scientific and technological developments and trends, we believed that it was important and timely to develop an undergraduate course on renewable energy. There also is a well-documented demand and need in offering program study, courses and training in the areas of renewable energy and power systems[15-20].

Equipping engineering students with the skills and knowledge required to be successful global engineers in the 21st century is one of the primary objectives of undergraduate educators. Enabling students to practice self-directed learning, to find solutions to design problems that are sustainable and to recognize that they are part of a global community are just of few of our educational goals. Self-directed learning can define an individual’s ability to practice life-long learning. It places the responsibility on the individual to initiate and direct the learning process and can enable an individual to adapt to change. Project-based learning provides the contextual environment that makes learning exciting and relevant. It provides an opportunity for students to explore technical problems from a systems-level perspective and to develop an appreciation for the inter-connectedness of science and engineering principles. In engineering technology, the model of a tetrahedron is often invoked to illustrate the bottoms-up connectivity of the fundamental principles associated with processing, structure and properties, which must be optimized to reach a desired performance of any system. In addition, a top-down tetrahedron can be envisioned with the need for sustainability guiding the balance between economic, societal and environmental factors, which also influence the choice of the optimum design solution for a project. For students to fully explore this paradigm, it is imperative that project-based learning experiences be integrated throughout their undergraduate education.

2. MET421/422/423 Courses Structure and Organization

From the very beginning, this course sequence was organized following the ABET guideline for capstone and/or senior project design courses. The senior design class is organized in a very structured form.

1. **Teams**: All students have to work in teams of three or four. We consider this to be the optimum team size. A team of two may result in distress in cases where one of the students was not able to do his or her share of the work, while for teams larger than four may have difficulties to choose projects which were challenging enough for such a big group of students and still could be finished within three-quarter time frame.
2. **Self and Peer Review**: A very simple self and peer review system has been introduced. The students must evaluate their own and their team members' performance on a scale of 5. The main challenges we faced were that we never had anything similar to this and were inexperienced in how to adequately give feedback to the students.
3. **Industrial Advisors:** Some of the department's advisory board members are also serving as industry advisors for the senior design class. They are reviewing reports, listen to presentations and give feedback on those and are also serving as judges for the Senior Design presentations.
4. **Reports and Presentations**: All teams must hand in a proposal, two term design reviews, and a final report. Various faculty and industry advisors review all these reports and the students are provided feedback on their projects and reports. All teams must also present their proposals and first quarter design review. On the Friday before Final Exam week, in the spring quarter all teams show their prototypes. The audience for these presentations is the class, faculty members and some of the industry advisors. The teams are judged on the projects' technical content and presentation style. These ratings have a two-fold purpose: they will be used as a part of the students' final grades and for a ranking of projects and teams. The winning team receives an award and members' names will be engraved on a plaque.

3. Samples of Senior Design Projects in Renewable Energy

For the last two years, our focus shifted towards incorporating renewable energy topics in our senior project design courses[18-20, 30, 31]. In the first quarter in the project design course sequence we assigned to our students the project topics related to renewable energy, power systems or other engineering topics. These projects are a good example of multi-disciplinary cooperation of different engineering disciplines as well as providing valuable hands-on experience to the students. In addition to providing useful lessons in teamwork and project management, the project will provide a working demonstration of a wind and solar energy system[30,31]. For the last two years our focus shifted towards incorporating renewable energy concepts in our senior design courses. Two examples of senior projects are presented in the following subsections of this paper. During the first month of the fall quarter section of the course, each team is given partial specifications for the project. Each team demonstrates the finished project to the entire class and then a written report summarizing the project is handed in as part of the senior project design course. This process synthesizes all of the basic materials in the core courses and can also be used as part of the requirements of the senior project requirements for each student. Examples of the renewable energy senior design projects included in this course are:

1. Micro Wind Power with a Savonius Rotor

2. High Efficiency Charger for Photovoltaic Power Systems
3. Indoor Solar Harvesting Energy for Sensor Network
4. Solar Cell Surface Imaging for Quality Measurement

The design also includes test models of the prototypes, which can be tested and operated. The nest sections will discuss two of the project listed above. To enhance the hands-on experience this course was restructured as a project based course. Students are required to analyze, design, simulate or built a completely functional system, as an end-of-term project, selected from a list proposed by the instructor. The goal of the project is to explore and enhance students understanding of the fundamental power conversion principles, power circuit simulation capability and hands-on demonstration of circuit prototyping

Project 1: Micro Wind Power with a Savonius Rotor

A micro-wind turbine-based power supply (low-power range) using a vertical axis Savonius type rotor was proposed in this project (as seen in Figure 1). The project involves: wind potential estimates, turbine rotor selection, design of the electronics and controls of the system, system test and performances estimates. This project will be included in the renewable energy course experiments. The Project Goals are to 1. Generate a useable amount of electric power, 2. Demonstrate turbine in a visible location on campus, and 3. Evaluate Drexel campus potential for wind power generation. The Design Goals are required to safely charge battery, broaden range of usable wind speeds, maximize system efficiency, and synchronized data acquisition

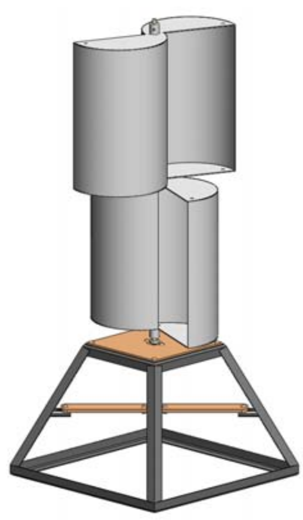


Figure 1: 3D CAD drawing of the Savonius rotor and support system

Design Considerations include Generators vs. Alternators, starting Torque, Direct-Drive vs. Gear-Drive, and Power Curves. The rotor design that was implemented for this project is a type of Savonius rotor (a vertical axis wind turbine). These vertical axis wind turbines can be placed in areas without much room. They can be built at locations where taller structures are prohibited.

Vertical axis wind turbines can be located close to the ground. This makes the moving parts of Savonius rotors easier. The blades of a savonius rotor are shaped with two or more half cylinders. The concave side of one of the half cylinders faces the wind and the convex side of faces against the wind. Vertical axis wind turbines require lower wind speed to startup than a horizontal axis wind turbine. These wind turbines can start creating electricity at wind speeds of 6 mph.

A two cylinder Savonius rotor system was chosen during the design process of this project for the reasons of having better efficiency, less vibration and very stable design. This system was assembled with two blades perpendicular to one another. As the blade spins one catches the wind as the other blade is facing against the wind. The Savonius rotor blades are shaped like two half cylinders. The profile of the rotor blades were fabricated out .100 inch 6061-T6511 aluminum. This material was selected because of being light weight and very strong. The T6 temper 6061 has an ultimate tensile strength of at least 38,000 psi and yield strength of at least 35,000 psi. The shape was machined by a 2-axis CNC vertical milling machine. The shape was machined in two operations. In the first operation all four plates were placed in a vice one on top of each other and three holes (ø.500 and two ø.375) were drilled through all four pieces. These four plates were bolted to a milling fixture that was created using these three holes. Using this fixture shape of the blades can be cut without stopping the milling machine. All four blades being machined at the same time will assure that these four blades will be exactly the same as shown in Figure 2.

Figure 2: The Savonius rotor and support system

The team was able to complete most of the project at the end of the winter term, and only had the electronics left to work on at the beginning of the spring quarter. The last part the system electronics, monitoring and control were finished during the winter quarter, while the entire project would have been completed during the first weeks of the spring term. The prototype was fully built and tested in front of team and advisor, at various locations and weather conditions. What started out as a few sketches in a notepad at the beginning of the school year was made into a fully working model. There were no major problems during the entire built. All the original thoughts and ideas in this project were not hindered whatsoever. The team didn't have to settle for second best or completely change the entire design, as building the idea conceived in the fall term proved to be fully accomplishable.

Project 2: High Efficiency Charger for Photovoltaic Power Systems

This project consisted of the design, implement, test, and build an improved Maximum Power Point Tracker (MPPT) system for a Photovoltaic (PV) module to charge a laptop battery, or other small electronics. When a PV system is operating at maximum power point, it can generate more energy without needs for the increase of the system size and complexity. In order to maximize the power output of a PV module, the area under the I-V operating curve in a MPPT system is continuously adjusted so the power output is maximized. When the voltage from the PV system is altered due to elements such as load operation, temperature, or solar irradiation, the charge controller will move the operating point as to maximize power output. The PV system for this project is used to provide power for electronic devices enabling them to operate in remote locations or areas without access to the power grid. This design combines a high-efficiency (≈95%) SMPS circuit with an analog power-conversion optimization loop. We selected a 20 Watt portable photovoltaic panel. We insured that our system will be portable and light or to be incorporated in innovative outdoor facilities. There are an increasing number of portable electronic devices being made, and they will require an increase in energy supply. It is very well known that the conventional fossil fuel used to generate electrical energy is polluting the environment and becoming scarce. In order to overcome these major issues, the need for alternative energy brought forward the use of nonpolluting photovoltaic modules. PV modules are designed to transform the free solar energy to electrical power.

During the spring term, our group has successfully maintained progress by clearly stating all design goals for this quarter. Last term we held weekly design meetings that allowed us to make changes to our original design and finalize the proposal stage of our project. At this point in time we have built our MPPT prototype; as well as the mounting details for the enclosure. Initial prototype analysis and testing began early in the spring term. During the acquisition of the material necessary to assemble our prototype, our team had to adapt the design to the resources currently available and at a feasible cost. Our group has consulted with our advisor and Drexel staff to help correctly assemble our circuit. All additional comments or ideas they have made are presented in this report and will be illuminated in our final design. This report will discuss all the parts and procedures we used to build our MPPT prototype.

Final Design of Prototype Circuit

The Switching Mode Power Supply (SMPS) with analog power conversion optimization loop circuit solves the problem of inefficiency caused from connecting the load directly to the solar panel. The prototype contains the SMPS integrated circuit manufactured by Linear Technology, LTC-1149, one CMOS dual channel operational amplifier, LMC6062, and one triple-pole single-throw analog switch, HEF4053B (see Figures 3 and 4). When the battery is discharging, the SMPS will drive the switching semiconductor IRF9Z34 at a duty factor of 1 bringing the operational point of the circuit to a low power output. By adding the analog power conversion optimization loop the input voltage is dithered by approximate +/- 1V by continuously changing the duty cycle by +/- 10%. The DC error signal resulted from the 50Hz dithering circuit is integrated by one channel of the operational amplifier and the loop is closed through the second channel. There are three distinctive operation types for this model:

1. If $V_{IN}<V_{MPPT}$ then the operating point is on the rising side of the IV curve, and the first channel of the operational amplifier will decrease the duty cycle, increasing $V_{IN.}$
2. If $V_{IN}>V_{MPPT}$ then the operating point is on the falling side of the IV curve, and the first channel of the operational amplifier will increase the duty factor and decrease $V_{IN.}$
3. When battery is completely charged, the second channel of the operational amplifier saturates setting the SMPS IC into constant voltage regulation mode.

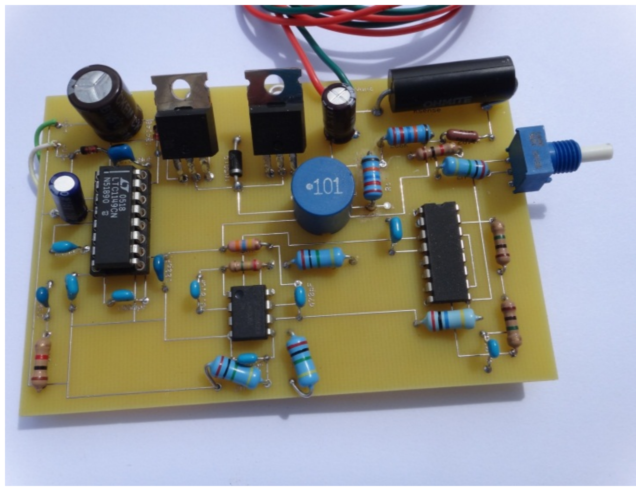


Figure 3: Maximum Power Breadboard

The analysis and the set of tests performed on this prototype concluded that it is more efficient than connecting the battery directly to the solar panel.

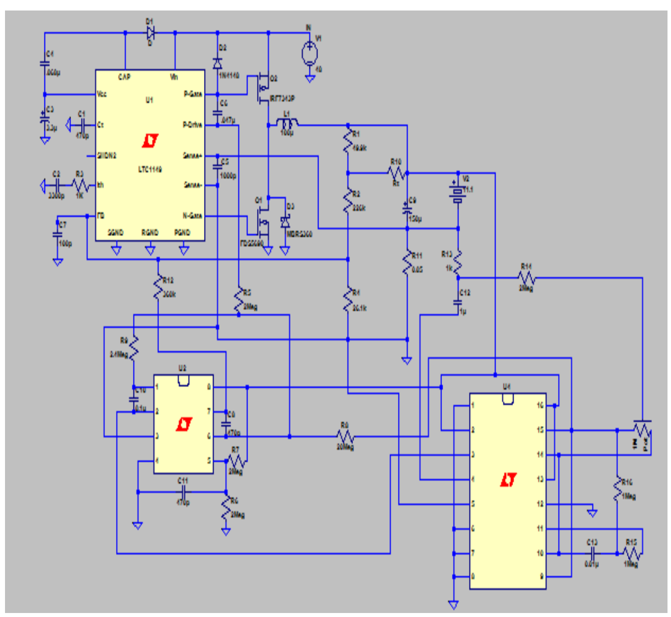


Figure 4: Circuit Diagram

The second prototype is using a wide voltage range Buck-Boost controller integrated circuit LM5118, manufactured by Texas Instruments. The main advantage of this design is the ability of the controller to work with a wide range of input voltage values while maintaining the output voltage, transitioning smoothly from buck to buck-boost operation mode. The LM5118 uses current mode control utilizing an emulated current ramp, method that reduces noise sensitivity of the pulse-width modulation circuit. The operating frequency is user programmable from 50kHZ to 500kHz. There are two districted modes of operation:

1. When $V_{In} > V_{Out}$ the controller operates in buck-mode having active the high-side MOSFET. The transfer function for this mode is:
   $V_{Out}/V_{In}=D$, where D is the duty factor.
2. When $V_{In} \leq V_{Out}$ the controllers enters the buck-boost mode having both MOSFETs active for the same interval of time. The transfer function for this mode is:
   $V_{Out}/V_{In}=D/(1-D)$

The design has faults protection features like current limiting and thermal shutdown making it a versatile safe to use circuit.

Testing

We simulated the SMPS part of our circuit using *LTspiceIV* software provided by Linear Technology. Since the analog switch IC HEF4053B or any similar IC was not available in software's component library, the simulation of the operation amplifier and analog switch part of the circuit is not present**.** We attempted simulating the circuit using *Multisim* software but the SMPS LTC1149 or any similar IC was not available in the library. The schematic for the simulated circuit is presented in Figure 5.

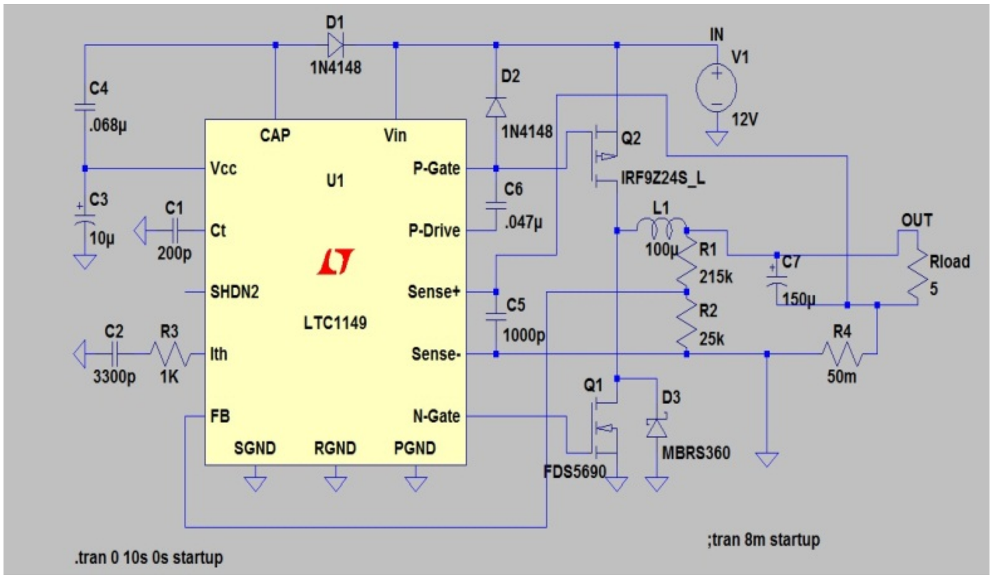


Figure 5: LTC1149 Simulation Schematic

After building the protoptype circuit we tested the system (Figure 6) and measured various signals using digital multimeter and an osciloscope. During testing procedures we changed the value of the resistor's network which determine the output voltage in order to obtain the desired output signal.

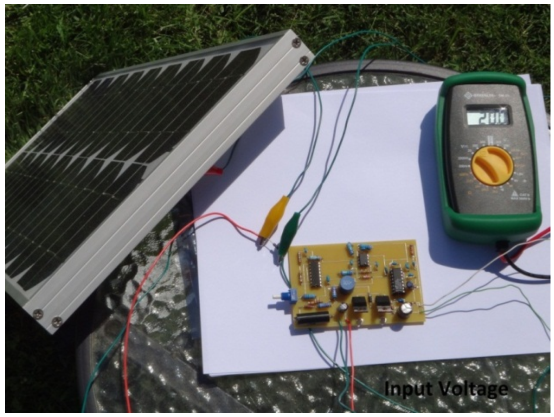


Figure 6: Input and Output Voltage Test Results

At 12 volts input voltage from the solar panel, 11.1V was measured at the output charging the battery. 10V was measured at VCC output pin of the LTC1149 integrated circuit. At P-Gate we measured 1.62Volts and 0 volts at N-Gate pins, with setting shown in Figure 5. The feedback voltage at V_{FB} pin of the IC was 1.14V. Measured signals during testing procedures are listed in Table 1.

Table 1: MPPT Test Measurement

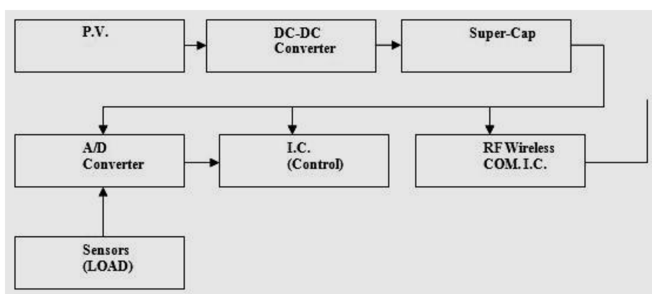
MPPT Test Measurements			
V_{IN} (V)	12.0	16.0	20.0
V_{OUT} (V)	11.1	11.1	11.3
V_{P-GATE} (V)	1.6	1.4	1.2
V_{N-GATE} (V)	0	0	0
V_{FB} (V)	1.6	1.2	1.1
I_{OUT} (mA)	11.3	11.5	11.7
P_{OUT} (mW)	125.4	127.6	132.2

The conclusion of our test measurements is that the MPPT circuit design is 26% more efficient than connecting the load directly to the solar panel.

Project 3: Indoor Solar Energy Harvesting for Sensor Network Nodes

In today's world there is a broad and growing spectrum of wireless network systems for commercial, industrial and military applications. These systems include everyday technology we use such as wireless Internet, cell phone networks, two-way radios, GPS systems and advanced sensor technology. Wireless communication can also be used to remote monitor physical or environmental conditions, such as, light intensity, temperature and pressure changes, or sound and vibration. This type of technology, called wireless sensor networks (WSN's), can monitor systems from a remote location where wired connections are not convenient. The network nodes pass along the data through the network to a main location. Each node is connected to sensors to monitor given conditions. Every node also has several other parts: A radio transceiver, a microcontroller, a circuit for interfacing with the sensors, and an energy source, usually a set of alkaline batteries. The use of batteries severely limits the life of the WSN, as batteries will need to be replaced over time. To combat (overcome) this problem, the use of a solar energy-harvesting unit can be used in place of the batteries or in combination with the storage energy units. Doing such, allows the WSN's to be functional all the times and eliminates the frequent replacement and charging of batteries.

Indoor solar energy harvesting units can extract energy from indoor lights such as 34W fluorescent bulbs, which are always on in hospital and office hallways. Mono-crystalline solar cells can be used to power wireless network nodes. The energy scavenged from the lights can be also stored in an energy storage device such as a set of super-capacitors with a battery backup source for a later use. The objective of our project was to create a WSN power supply system in which solar cells can scavenge energy from indoor lighting (energy harvesting unit) and eventually to store the energy (storage module) for the use of sensor network nodes. With a proper system design and seizing we are aiming to extract enough energy from indoor lighting sources, to power wireless sensor network nodes. Figure 7 shows the system block diagrams, while the Figure 8 shows the physical implementation of the indoor solar harvester.



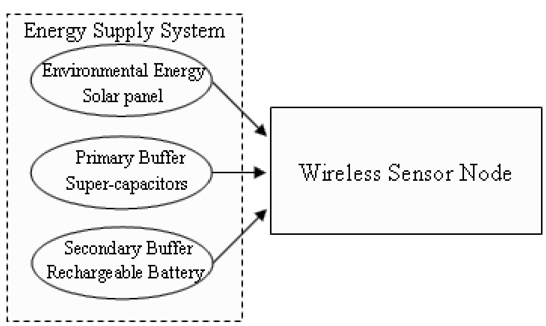


Figure 7: WSN bolck diagram and the indoor solar harvester diagram

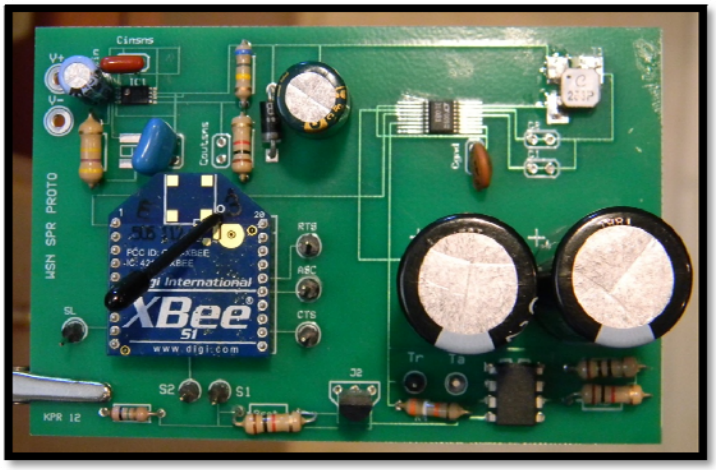


Figure 8: Module PCB with soldered components

Project 4: Automated Solar Cell Surface Roughness Measurement System

Renewable Energy includes solar energy, hydro power, wind energy, biomass, etc. Solar energy is one of the most popular and widely used types of renewable energy. The applications of solar energy science and technology range from grid electricity generation to running small embedded appliances. The abundance of sunlight delivers tremendous amounts of power to the surface of the earth. Solar cell conversion efficiency is determined by the various factors involved with the collection and conversion from light energy to electrical energy. Thus, the quality of solar cells is a crucial factor in determining their efficiency. The objective of this project was to eliminate the required resources it takes to maintain a WSN. With the use of PVs and ultra-capacitors, the team succeeded to provide a product that can harvest ambient energy from indoor (or outdoor) lighting to continuously power WSN nodes. The PV's is used to scavenge ambient energy from indoor lighting or direct sunlight, convert the light energy to electrical energy, and store the energy in low cost, super-capacitors. The embedded energy harvesting system and super-capacitors replace the use of batteries, thus eliminating the typical maintenance that batteries require. However, the team decided to include batteries as a backup to the harvesting system, to increase the lifetime and reliability of the system. However the batteries are used only in emergency situations. This developed and designed system significantly reduces the tedious maintenance required due to the short life cycle of batteries, thus making the system cost effective, self-sufficient and reliable. In turn, the system will relay data to a host computer, to monitor the conditions of a particular environment. This provides an alternative method of powering WSN nodes that do not require the regular maintenance that current battery operated systems do.

Figure 9 shows the architecture of the remote surface roughness measurement system. The PC-based remote inspection system is composed of a YK250X 4-axis SCARA robot, RCX 140 controller, a F1010-700 1-axis robot, SR1-X robot, a laser check sensor, an IP Surveillance camera, and an Allen Bradley PLC controller. The laser check sensor has a built-in processor which allows it to perform real-time algorithms, along with live monitoring capabilities. The process is designed to be Ethernet-based using TCP-IP communications. After a successful TCP handshake, images and extracted measurements can be sent back and forth remotely between the servers and clients. The laser check sensor is programmed with necessary algorithms to calculate the various surface roughness parameters. In the LabVIEW-based graphic user interface (GUI), statistical quality algorithms for remote measurement are calculated. The controller communicates with the robot to instruct it to perform the required operations.

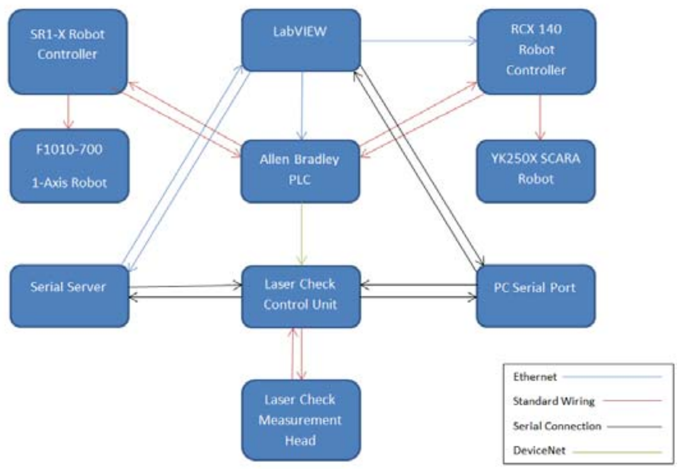


Figure 9: Automated surface roughness system diagram

Robotic Workcell

Utilizing robots in the process of performing surface roughness scanning allows for both full automation as well as precise and repeatable measurements. The two robots used in this cell are the Yamaha YK250X SCARA 4-axis robot and the Yamaha F1010-700 1-axis robot. The measurement head of the Laser Check system is mounted to the tool arm of the SCARA robot. The piece to be scanned is mounted to the 1-axis robot. The scan is performed by incrementing the 1-axis robot in what shall be designated as the y-axis i number of times. Once completed, the 1-axis robot moves back to its initial position and the SCARA robot increments in what shall be designated as the x-axis, and the 1-axis robot begins its incrementing cycle again. This process repeats $j+1$ times, j being the number of increments the SCARA robot makes. This produces a 2D array or matrix of data: $M_{i+1,j+1}$, which can later be used to plot a 3D graph. The robotics workcell can be seen in Figure 10.

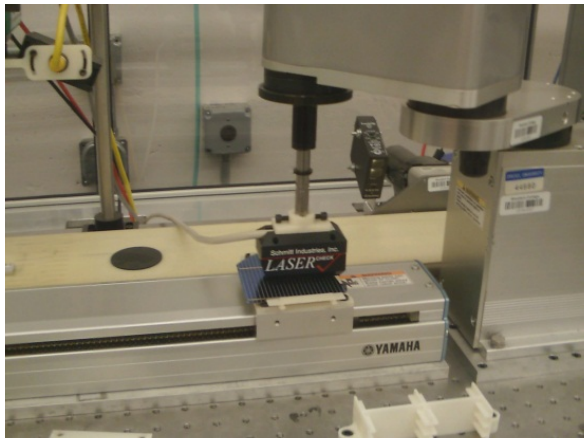


Figure 10: Robotic workcell for solar cell surface roughness measurement

LabVIEW Program

To initiate a connection, a configuration block specific to the type of connection is used. Once the connection is established, TCP/IP or Serial Read/Write blocks are used to issue a call for data to the Laser Check system and read the data that comes in. To control the flow of incoming data, so that data is not erroneously read twice or skipped over, a case structure is employed, which is triggered by the falling edge of the laser trigger in the PLC. This essentially allows the program to read the data only right after the laser turns off. The data that flows in comes in the form of an ASCII string. To convert this into a floating point value, the string is parsed and header and footer values are removed. The remaining value is then converted to a float value using a type cast function. This data is then sent along and placed into a 2D array that is a set of 1D arrays that represent each scan along the face of the material. This array is then sent to the 3D graph and table on the front panel, as well as to an external spreadsheet file. The connections between the program and the robots are made through both the PLC and through Telnet communication using TCP/IP. The 1-axis robot's controller does not support an Ethernet connection, and as such, the program is initiated by connecting to the PLC via Ethernet and flipping a control bit, which initiates the 1D scan. The SCARA robot's controller does support Ethernet, and is connected to directly using TCP/IP.

Surface Roughness Measurement of Solar Cells

The one-axis robot positions the solar cell precisely under the sensor. The controller can be externally triggered by one of the robots or a controlling software package. The surface of the cell is scanned by stepping the one-axis robot in 1 mm increments; the surface roughness data is then captured by the controller. This setup can be incorporated with the blob analysis vision system to encompass a fully-developed quality control procedure to evaluate the efficiency of solar cells. Figure 11 shows how multiple SCARA robots can help in constructing surface profiling through the use of LabVIEW program.

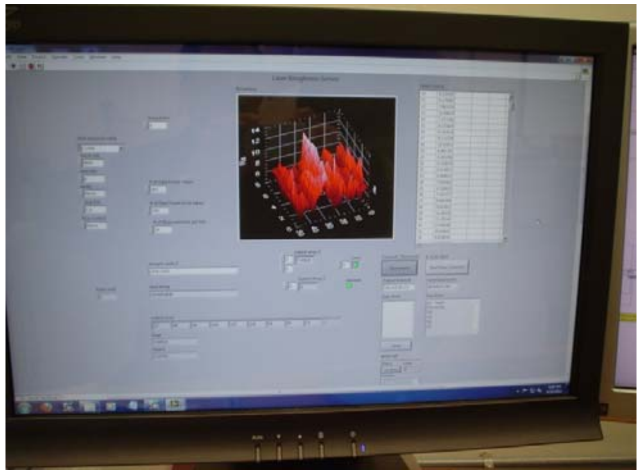


Figure 10: LabVIEW serial and Ethernet front panels interface for surface profiling

There are minor differences between both front panels, which can be seen on the left side of each. These differences are due to variations in connecting and reading from the serial connection either locally or via Ethernet. The two buttons on the right are responsible for connecting to the robots and subsequently running their programs. The graph in the middle of the screen plots a visualization of the incoming height/roughness data, and the table next to it displays the raw numerical data as it comes in.

Conclusions

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. The experience, which would be difficult to complete individually, gives the students a sense of satisfaction and the accomplishment that is often lacking in many engineering courses, using traditional teaching approaches. Furthermore, the design experience motivates student learning and develops skills required in industry. This paper describes renewable energy innovations for the enhancement of undergraduate level teaching of a capstone senior design course integrated with emerging technology. Due to the increasing importance of reduction of greenhouse gas emissions, renewable energy is an appropriate topic for the Engineering technology curriculum. We described several senior design projects that gave students hands-on experience with renewable energy issues and modern methods such as power electronics, machine vision, image processing, and robotics. 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 in these projects learned about identifying a problem, gain knowledge of system components, parts and electronics, their characteristics, environmental and structural constraints, economic aspect of the project. The senior design projects at Drexel University address this issue and encourage students to investigate in possible methods for building solar energy efficient systems. These projects are an introductory step to a larger scale mission to develop tomorrow's renewable energy industry.

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