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# Renewable Energy Integration in Electrical Engineering Programs

**Dr. Afsaneh Minaie, Utah Valley University**

Afsaneh Minaie is a Professor of Electrical and Computer Engineering at Utah Valley University. She received her B.S., M.S., and Ph.D. all in Electrical Engineering from the University of Oklahoma. Her research interests include gender issues in the academic sciences and engineering fields, embedded systems, machine learning, wireless sensor networks, and databases.

**Dr. Reza Sanati-Mehrizy, Utah Valley University**

Reza Sanati-Mehrizy is a professor of Computer Science Department at Utah Valley University, Orem, Utah. He received his M.S. and Ph.D. in Computer Science from the University of Oklahoma, Norman, Oklahoma. His research focuses on diverse areas such as: Database Design, Data Structures, Artificial Intelligence and Machine Learning, Robotics, Data Mining, and Computer Integrated Manufacturing.

## Renewable Energy Integration in Electrical Engineering Programs


### Abstract

Renewable energy or green energy is energy from renewable natural resources that are replenished on a human timescale. These sources of energy are considered sustainable because they are naturally replenished and have a lower environmental impact compared to fossil fuels. The transition away from fossil fuels and towards renewable energy technologies is now fully underway. The most widely used renewable energy types are solar energy, wind power, and hydropower. A large majority of worldwide newly installed electricity capacity is now renewable [1-4]. In 2022, renewables accounted for 30% of global electricity generation and are projected to reach over 42% by 2028 [5].

The recent rapid global growth in renewable energy production has given rise to a demand for engineers with experience in this area. It is recognized the need for a large, well-trained workforce that can conduct research and development projects in renewables. Currently, renewable energy courses are not well represented in undergraduate academic programs.

To prepare our electrical engineering students for the design and implementation of the renewable energy systems, we encourage them to choose a renewable energy capstone project. To satisfy the ABET requirements, students in electrical engineering programs are required to take a capstone course. This paper describes sample renewable capstone projects that students have done in this program.


### Introduction

Over the past decade, engineering education has undergone significant changes, shifting toward critical thinking, active learning, and hands-on problem-solving. Despite this progress, a growing skills gap persists in the engineering workforce due to the fast pace of technological advancement. Traditional education methods remain heavily theory-based and task-oriented, which limits students' ability to develop practical, transferable skills [6].

With the rise of emerging technologies like Artificial Intelligence (AI), Internet of Things (IoT), Augmented and Virtual Reality (AR and VR), Autonomous Systems, and Renewable Energy Technologies, the demand for skilled engineers is higher than ever. However, many recent graduates are underprepared to meet industry needs [7]. A 2019 survey of 600 Human Resource (HR) leaders found that 64% recognized a skills gap in their workforce—up from 52% the previous year. The most cited challenge was keeping up with the pace of technological change. Notably, 90% of employers indicated a willingness to hire candidates who demonstrate their abilities through certifications or specialized training, even without a formal degree [8].

The rapid global expansion of renewable energy has created a strong demand for engineers with relevant expertise, yet undergraduate programs still offer limited coursework in this area.

Renewable energy refers to energy that is generated from natural resources that are replenished over time and are considered sustainable and environmentally friendly. Unlike fossil fuels (coal, oil, and natural gas), which take millions of years to form and contribute to environmental degradation when burned, renewable energy sources are naturally replenishing and cause minimal or no harm to the environment. The main types of renewable energy sources are [1-4]:

- Solar Energy is harnessed from the sun's radiation. It can be captured using solar panels (photovoltaic cells) or through solar thermal systems that concentrate sunlight to generate heat.

- Wind Energy is generated by converting the kinetic energy of wind into electricity using wind turbines. Wind farms, both onshore and offshore, are the primary means of producing wind power.

- Hydropower (Hydroelectric Energy) generates electricity by harnessing the energy of flowing or falling water. The most common method is through dams on rivers, where the water's movement turns turbines to produce electricity.

- Geothermal energy is derived from the heat stored beneath the Earth's surface. This heat can be accessed by drilling wells and using steam or hot water to drive turbines that generate electricity or provide direct heating.

- Biomass energy comes from organic materials, such as wood, agricultural waste, and even algae. These materials can be burned directly for heat or converted into biofuels (such as ethanol and biodiesel) for transportation.

- Tidal and wave energy technologies harness the movement of ocean tides and surface waves to generate electricity. Tidal power plants utilize the rise and fall of tides to drive turbines, whereas wave energy systems capture energy from the motion of surface waves.

- Hydrogen can be used as an energy carrier. Green hydrogen is produced using renewable energy sources (such as wind, solar, or hydro) to split water into hydrogen and oxygen through electrolysis. The hydrogen can then be stored and used in fuel cells or combustion processes [1 - 4].

The following are some of the advantages of renewable energy:

- Sustainability - Renewable energy resources, such as sunlight, wind, and water, are naturally replenished, making them sustainable over the long term.
- Environmental Protection - Unlike fossil fuels, renewable energy sources generate little to no pollution, helping reduce greenhouse gas emissions and combat climate change.
- Energy Independence - By relying on locally available resources, countries can reduce their dependence on imported fossil fuels and improve energy security.
- Economic Growth - The renewable energy sector creates jobs in manufacturing, installation, and maintenance of renewable energy systems.
- Reduced Energy Costs - Over time, the cost of producing renewable energy has dropped significantly, making it more affordable for consumers and businesses.

- Health Benefits - Reducing the use of fossil fuels cuts air pollution, which can lead to fewer respiratory and cardiovascular diseases, as well as fewer premature deaths [1-4].

Renewable energy represents a key solution to addressing climate change, reducing reliance on fossil fuels, and promoting a cleaner, more sustainable energy future. As technology advances and more investments are made in infrastructure and energy storage, renewable energy will continue to grow, offering a cleaner, more efficient way to power our world.

As a green renewable energy source, solar energy is crucial to the future of renewable energy production. Solar energy is the energy harnessed from the sun's radiation, which can be converted into electricity or heat. It is one of the most abundant, sustainable, and environmentally friendly sources of energy available today. Solar energy can be used in various ways, from generating electricity to heating homes and water.

The two main ways to harness solar energy are photovoltaic (PV) and solar thermal systems. Solar thermal systems use mirrors or lenses to concentrate sunlight onto a receiver, which then heats a fluid (usually water or oil). This heat can be used directly for heating or to generate electricity via a steam turbine. Photovoltaic solar panels convert sunlight directly into electricity using semiconductors (typically silicon). When sunlight hits the surface of the PV cells, it excites electrons in the semiconductor material, creating an electrical current. Inverters convert the direct current (DC) electricity generated by the solar panels into alternating current (AC), which is the form of electricity used in homes and businesses. The solar panels are used at the residential rooftops, commercial and industrial buildings, utility-scale solar farms, and portable and off-grid solar systems [15].

Solar energy is a cornerstone of the renewable energy future. It offers significant environmental, economic, and societal benefits, including reducing carbon emissions, lowering energy costs, and enhancing energy independence. Despite challenges like intermittency and high initial costs, advancements in technology and supportive government policies are making solar energy more affordable, efficient, and accessible. With continued growth in the adoption of solar energy, it is poised to play a critical role in the global transition to a more sustainable and clean energy future.

Solar energy usage in the U.S. has grown rapidly in recent years, thanks to declining costs, supportive government policies, and growing awareness of environmental issues. As of the end of 2023, the U.S. has over 200 gigawatts (GW) of solar energy capacity installed across the country [12]. This makes the U.S. one of the largest solar energy markets in the world. The U.S. solar market has been growing at an average annual rate of about 20% since 2010. Solar energy accounted for around 4.8% of total electricity generation in the U.S. as of 2023. This share is expected to increase significantly over the next decade, especially with further expansion of solar power, both in residential and utility-scale systems. Solar is projected to grow to around 10-12% of total U.S. electricity generation by 2030, depending on the pace of new installations and the development of energy storage and grid infrastructure. As of 2023, utility-scale solar power plants contribute to around 60% of the total installed solar capacity in the U.S., with significant projects in states like California, Texas, and Nevada. The largest solar farm in the US includes projects like: Copper Mountain Solar Facility in Nevada (802 MW), Mount Signal Solar in California (800 MW), and Harquahala Solar Project in Arizona (300 MW). The rise of residential solar systems means more homes are generating their own electricity, often with the ability to send excess energy back to the grid through net metering programs. This helps reduce the demand on traditional power plants and contributes to a more decentralized grid. As more solar energy is integrated into the grid, grid operators are investing in smart grid technologies, energy storage systems (such as batteries), and demand-response programs to help manage variability and ensure a reliable power supply. Solar energy is expected to play a critical role in the U.S. transition to a cleaner energy future. By 2030, solar capacity is projected to exceed 500 GW, making it a central part of the country's energy mix. Solar energy could contribute 20-30% of U.S. electricity generation by 2040, especially as costs continue to fall and energy storage solutions improve. The solar industry has created over 250,000 jobs in the U.S. as of 2023. This includes jobs in manufacturing, installation, maintenance, and other sectors. Solar jobs have been growing at a rate that outpaces the average for the broader energy sector. Between 2010 and 2020, solar industry jobs grew by 167%, while overall jobs in the energy sector grew by about 24% [9-15].

The primary objective of institutions of higher education is to facilitate students to reach their utmost academic potential. Educational excellence requires exposing students to the current edge of research. To ensure that student projects are along the same trajectory that the industry is moving, educators must continually introduce emerging techniques, practices, and applications into the curriculum. The field of renewable energy is growing rapidly, and there is increasing interest in providing undergraduate students with a foundation in this area. It is essential to prepare students for the growing demand for sustainable energy solutions. This paper presents the details of sample projects that our undergraduate electrical engineering students have done in their senior capstone course in renewable energy.

## Background Information

Utah Valley University (UVU) is a large regional institution serving over 46,000 students in Utah County, the state's second-largest county. UVU is regionally accredited by the Northwest Commission on Colleges and Universities. The university has a dual mission: it offers 91 bachelor's degrees and 11 master's degrees as a comprehensive university, and it also provides 65 associate degrees and 44 certificate programs as a community college. To fulfill its community college mission, UVU maintains an open-enrollment policy. The university serves a diverse student body, with 38% of students being low-income and 41% being first-generation. Additionally, UVU has a significant population of non-traditional students, including 29% who are older than the typical college age, 35% with spouses [16], and 19% with children under age 12 [17]. Despite relatively low tuition, 36% of degree-seeking students attend part-time. These factors contribute to the university's overall graduation rate of 33% (as measured by the national IPEDS standard for completions in 150% of normal time) and a 70% one-year retention rate for baccalaureate degree-seeking students. About 80% of UVU's students will remain in their communities and pursue employment in this region [18, 19].

## Electrical and Computer Engineering Department

To address a critical workforce demand in the region, UVU launched new bachelor's programs in Electrical, Civil, and Mechanical Engineering in Fall 2018. These joined existing Computer and Pre-Engineering programs to form the Engineering Department, which grew rapidly—from 300 students in its first semester to over 900 by 2023.

In Fall 2024, the department was reorganized into two: Mechanical and Civil Engineering, and Electrical and Computer Engineering (ECE). The ECE Department now serves over 250 students and offers ABET-accredited programs in Electrical and Computer Engineering.

**Electrical Engineering Capstone I and II Courses**

Capstone design project courses serve as a culminating experience for graduating senior students, providing them the opportunity to apply and demonstrate the knowledge and skills acquired throughout their studies. At Utah Valley University (UVU), electrical engineering students complete a two-semester capstone design sequence as part of their graduation requirements. These courses are structured around independent student projects that challenge students to design, build, and troubleshoot fully functional systems. The primary goal is to engage students in solving complex, real-world problems by utilizing the technical competencies developed during the first three years of the curriculum. Capstone projects not only reinforce professional skills but also help prepare students for careers in industry, making them a vital component of the electrical engineering curriculum.

The primary objectives of senior projects are to simulate industry-relevant project development and to build expertise in four key areas:

- Teamwork
- Project Management
- Research & Development
- Communication

These are the most important skill areas to the success of an engineer.

**Capstone I Course (ECE 4900)**

The course description for ECE 4900 is as follows:

This course focuses on team-oriented design projects and technical writing by incorporating group projects, oral presentations and written reports. Incorporates engineering standards and realistic constraints including economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political. Emulates the problems encountered by engineers working in commercial, industrial, and governmental entities.

**The Course Objectives for this course is as follows:**

- Plan an engineering project involving multiple tasks
- Design electrical systems that meet defined constraints
- Communicate technical information on writing
- Identify business issues related to technology
- Explain the impact of engineering on societal issues
- Analyze the economics of designing and manufacturing the engineering artifact

Capstone I is the first course in the two-part senior design sequence. In this course, students complete several key milestones:

- Team formation

- Project proposal and approval
- Project planning
- Procurement of hardware components
- Proof of concept for critical circuits
- Preliminary Design Review (PDR)

The topics covered in this course are as follows:

- Engineering design methodology
- Project selection and need Identification
- Requirement specification development
- Concept generation and evaluation
- Team dynamics and collaboration
- Ethics and legal considerations in engineering
- Basics of Engineering Economics

Each team meets weekly with a faculty advisor to review progress, troubleshoot challenges, and provide regular status updates. Students are expected to commit approximately 10 hours per week, totaling 150 hours over the semester. A final letter grade is awarded based on project performance, participation, presentation, weekly and final reports, and milestone completion.

This course is offered every fall semester. The prerequisite for this course is Embedded Systems I and University Advanced Standing.

**Capstone II Cours (ECE 4950)**

The course objectives for this course are as follows:

- Design an electrical system or process to meet given specifications with realistic engineering constraints
- Use effective team processes, communication, and conflict resolution skills
- Implement an electrical system
- Troubleshoot an electric system
- Present the design project results orally and in writing format

Capstone II is the second course in the senior design sequence required for graduation. The course requires the completion of the following major milestones:

- Fulfillment of proposal commitments
- Functional project demonstration
- Completion of documentation and poster
- Final Design Review
- Submission of an abstract to a conference (if accepted poster presentation)
- Developing a poster for presentation at a college wide design expo (CET Expo)

Capstone I (ECE 4900) is a prerequisite for this course. Capstone II does not have a scheduled lecture component. Instead, students meet weekly with their faculty advisor to review progress and receive guidance.

The primary outcome of Capstone II is a comprehensive written project report. This document must thoroughly describe the project, providing sufficient detail and clarity so that someone with a general background in electrical engineering—but no prior knowledge of the specific project—can fully understand the work.

In addition to the written report, students will deliver a formal oral presentation to an audience that may include faculty, students, industry professionals, and members of the public. This 30-minute session (which includes time for setup and teardown) will require students to:

- Present their project at a level suitable for a general engineering audience.
- Demonstrate any functional systems or components.
- Answer questions regarding their design, implementation, and results. [20]

**Integration of Renewal Energy Education in Electrical Engineering Program at UVU**

Today's engineering students are required to learn in an environment of continual technological change and innovation. To meet this challenge and prepare them for the future workplace environment, students are trained to be content experts, highly skilled problem solvers, and team players. To prepare students for the 21st-century workplace challenges, instructors are striving to create learning activities that help them to develop content expertise, problem solving and teamwork skills. To prepare our electrical engineering students for the renewal energy experience, which serves as a critical element of their education, we offer an elective senior level course called Smart Power Grids (ECE 4260). However, since this is an elective course not all the students are exposed to the topic. This elective course on renewable energy is not enough to teach the students the skills that they need. For our capstone courses students have the option of selecting the area that they would like to do their project in. Recently, some of our students have selected to work in renewable energy and the following are sample projects in renewable energy.

**Maximum Efficiency Solar Tracking Using Image Processing Project**

The purpose of this capstone project was to investigate the details of implementing a solar tracking system to help increase the output power of a solar panel. A Team of three electrical engineering worked on this project for two semesters. The idea for the project came from the students and the faculty mentor. The funding for the project was provided by the Smith College of Engineering and Technology. The students surveyed the existing literature in solar trackers and developed their own design, with the objective of increasing tracking efficiency.

They designed a dual axis solar tracking device to increase the generated power from the solar panel. The solar tracker was equipped with two different algorithms to help track the sun. The first method was to simply use four photoresistors to accurately determine the position of the sun in the sky. The system was then moving the solar panel into a position orthogonally to the sun to try to maximize the output power. The second method was to take advantage of an image processing system to track the Sun's position accurately. It was found that both methods can track the sun reliably with the photo resistor method having a wider field of vision than the camera [21].

**System Design and Construction**

Figure 1 shows a system block diagram of their design

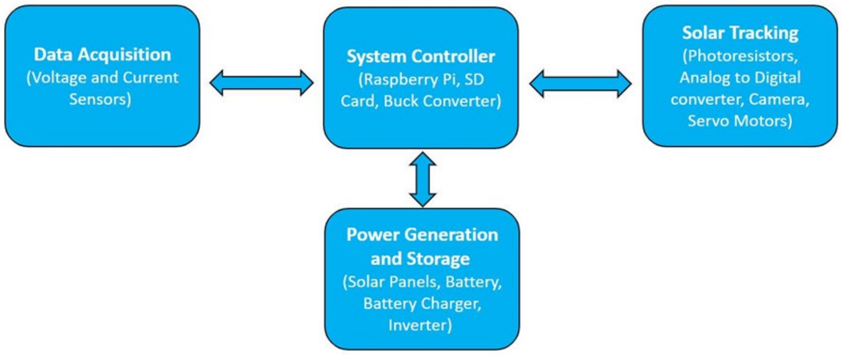


Figure 1: System Block Diagram [21]

The approach that was used in this design was to use a hybrid system using both image processing and photoresistors to track the sun. In the image processing approach, they used a camera to take an image of the sky and used OpenCV library to identify the location of the sun. For the photoresistor approach, they placed the photoresistors strategically to find where the sun is most intense and estimated where the sun is. Once the sun was located relative to the solar panels the panels was moved in a way to absorb the maximum light. Figure 2 shows the bock diagram of the System Controller. A block diagram of the Data Acquisition system is shown in Figure 3 [21].

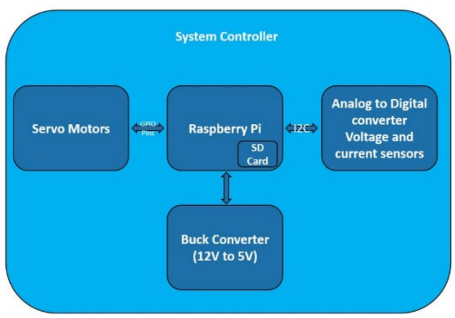


Figure 2: Block Diagram of the System Controller [21]

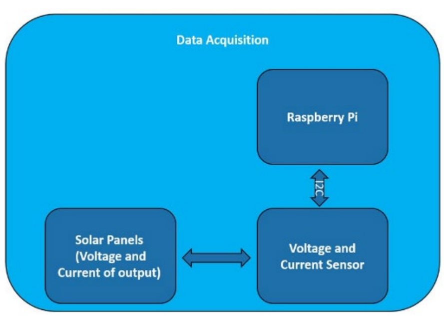


Figure 3: Block Diagram of the Data Acquisition System [21]

The power that was generated by the solar panels was measured using voltage and current sensors that were connected to the solar panels. Figure 4 shows the block diagram for the power generation and storage block [21].

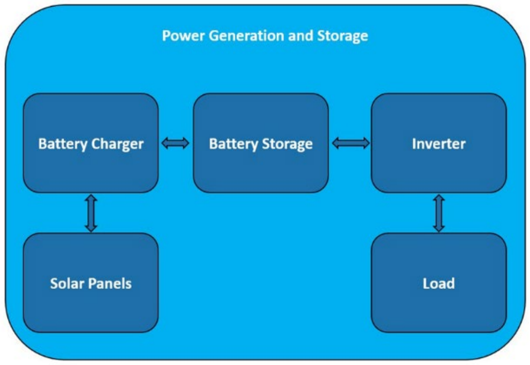


Figure 4: Block Diagram of the Power Generation and Storage [21]

Figure 5 shows the block diagram for the Solar Tracker. This block includes everything that was needed to track where the sun was and moved the solar panels so that they could receive the maximum amount of sunlight. The camera along with the photo resistors was used to track where the sun is located, and the servo motors were used to move the panels [21].

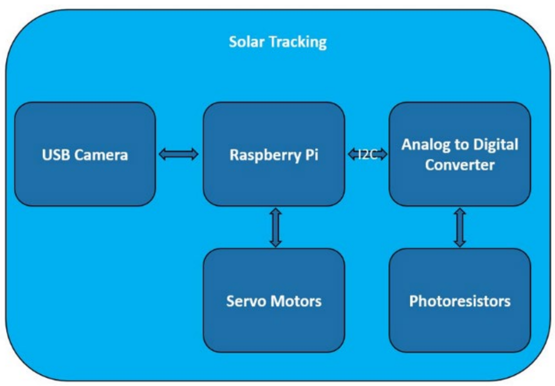


Figure 5: Block Diagram of the Solar Tracker [21]

A prototype of the design (Figure 6) was built to test the effectiveness of the two techniques. In the process of designing the prototype students learned a plethora of technical skills such as 3D design and printing, soldering, welding, and circuit design. The components of this prototype were a combination of off-the-shelf parts for the electronics running the system, a designed base to prevent tipping, and a dual axis designed head which provided the movement required for maximum energy harvesting [21].

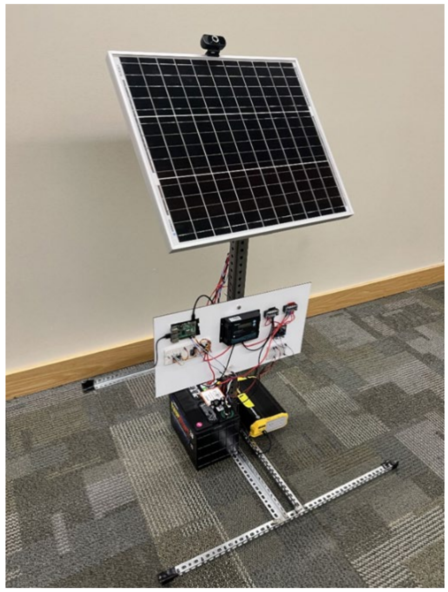

Figure 6: Design Prototype [21]

The project presented here provided an excellent opportunity to investigate many of the key skills developed in an undergraduate electrical engineering program. Mechanical modeling programs such as SolidWorks played a vital role in the design and manufacturing of the prototype.

This project was successful and the students' comment after finishing their project was positive and they said that "much was learned in this project."

**Mobile Security System Project**

The goal of this capstone project was to develop a cost-effective, portable security system powered by solar energy, specifically designed for off-grid or hard-to-wire locations like golf courses, parks, and construction sites. The goal was to offer an alternative to the high cost of installing permanent power lines, as faced by Spanish Fork Golf Course. A team of three electrical engineering students worked on this project over the course of two semesters. Funding for the project was provided by the students themselves [22].

The students developed a portable, solar-powered security system to enable easy relocation and real-time monitoring in remote locations. Their system utilized a Raspberry Pi to manage core functions, powered by a lithium-ion battery charged via a mono-crystalline solar panel with an efficiency range of 15–17%. Temperature regulation was achieved through a fan controlled by onboard sensors, and motion detection activated a camera to record video footage. This data was transmitted to a Swift-based application, which interfaced with Python scripts on the Raspberry Pi to provide users with access to motion history, voltage, current, and power metrics. Figure 7 illustrates the block diagram for their design [22].

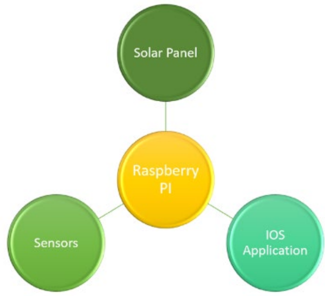


Figure 7: Mobile Security Block Diagram of System [22]

Figure 8 shows the system diagram for their design.

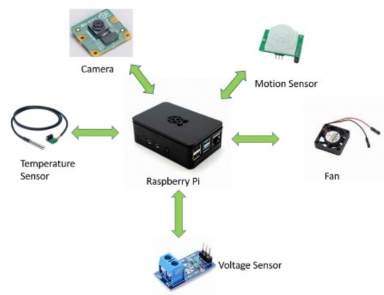


Figure 8: Mobile Security System Diagram [22]

The solar panel that was used in this project is shown in Figure 9.

Figure 9: Lion Energy 100W Solar Panel

The chosen solar panel for the project was the Lion Energy 100 W model, which generates 100 watt-hours (Wh) of power. This output was sufficient to power the system throughout the day and recharge the battery. The panel was highly durable, capable of withstanding both summer and winter conditions, and was designed for long-term use with high efficiency to maximize energy production [22]. The final design is depicted in Figure 10.

Figure 10: Final Design [22]

This project was successful and the students' comment after finishing their project was positive.

## Conclusion

This paper discussed recent sample senior design projects in renewable energy completed by undergraduate electrical engineering students. The senior design course is structured around independent student-led projects, which students often find both demanding and rewarding. They are required to design, build, and troubleshoot a fully functional system, applying the technical skills and knowledge acquired throughout their academic journey. These projects foster self-directed learning, encouraging students to develop problem-solving skills, troubleshooting issues, research solutions independently, and interpret complex or poorly documented materials. Feedback from students and their final presentations reflect a strong sense of accomplishment and increased confidence in their engineering capabilities. Senior capstone design projects continue to serve as a vital component of electrical engineering education and align with the standards established by the Accreditation Board for Engineering and Technology (ABET). Overall, students' feedback and their final project presentation indicate that they have pride in their project accomplishments and have gained confidence in their engineering abilities.

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