Small-Scale Stand-Alone Hybrid Solar PV and Wind Energy Generation System for EE 452 Lab

Project number: Sddec20-16

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Executive Summary

Development Standards & Practices Used

- IEEE Guide for Insulation Maintenance of Electric Machines
- https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7740867
- IEEE Guide for terrestrial Photovoltaic Power Systems Safety https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=752491
- IEEE Guide for Selecting, Charging, Testing, and Evaluating Batteries in PV Systems https://standards.globalspec.com/std/1689699/ieee-1361
- IEEE Guide for Array and Battery Sizing in Stand-Alone PV Systems https://standards.ieee.org/standard/1562-2007.html

Summary of Requirements

- Design and develop solar PV and wind regeneration system
- System is safe, compact and easy to use
- Generates energy from solar and wind sources efficiently.
- Capable of generating the maximum energy for varying temperature, irradiance and wind speed.
- Ability to support both AC and DC loads.
- Contain a storage system for excess energy storage.
- Develop lab experiments that enhance the learning opportunities regarding solar and wind generation

Applicable Courses from Iowa State University Curriculum

- EE 201 & EE 230 Electric circuits and systems were used in the circuit design and analysis aspects of the project.
- EE 224 & EE 324 Signals and systems were used in the Simulink simulation aspect of the project.
- EE 452 Electrical machines and power electronics were used to understand electrical loads and their control circuits.

New Skills/Knowledge acquired that was not taught in courses

- Team management - Practicing good communication among ourselves has allowed us to accomplish important tasks
- Project management - We learned how to break down a project from a design and development phase to a project execution plan using effective communication, budgeting and technical skills that each of our group members have obtained
- PV solar cell system - Understand how a PV cell functions and how it plays a role in energy regeneration
- Safety - Solar energy can pose a variety of hazards such as arc flashes and electric shock. Reading and taking precautionary measures allow for safe use of the system

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Introduction

1.1 Acknowledgement

We would like to express our sincere gratitude to our professor of the project (Small-Scale Stand-Alone Hybrid Solar PV and Wind Energy Generation System for EE 452 Lab) for engaging our team in redesigning how we learn about clean energy in a lab setting. Dr. Venkataramana Ajjarapu has given us the space to exchange ideas and insight and have provided us with the mental tools and resources that allow our team to design and develop this project in the first place. We are so grateful for every opportunity we have to be able to walk into your office, as we are able to walk out of it feeling more knowledgeable than the time before.

We would like to express our appreciation to our colleague, Pranav Sharma, who takes time out of his day to sit in our weekly meeting and answer questions for this project. Your assistance and contributions have given the team insight and continue to be the driving force in the work that is necessary to drive this project to completion.

Lastly, we would like to express our appreciation to the previous students for the hard and organized work they have done that made our learning more valuable.

1.2 Problem and Project Statement

The goal of this project is to design and develop a new standalone hybrid renewable energy generation system that will consist of both solar PV and wind energy. The regeneration system will serve as an educational tool for students to learn about clean energy in a safe lab environment.

The current system in the lab is limited to a few capabilities for the following reasons:

1. The standalone system is equipped with solar PV energy as an input and limits the opportunity for students to learn about wind generation
2. The current system is not sized optimally that can be stored in a shelf after use.
3. The system has safety hazards that are potentially dangerous to the user. Some of those include loose wires and connections do not have safety measures such as relays to prevent overcurrent.
4. The system is not equipped with various AC and DC loads to experiment with and limits the education for the student.
5. Lastly, there is only one system that provides limited learning opportunities for everyone to get hands on experience.

After analyzing the current system, there is an area of opportunity for improving the learning about renewable energy generation in a lab environment. A solution is to build a new hybrid standalone system that allows students to gain hands on experience working with solar PV and wind energy in addition to learning how it is used to generate maximum power under changing weather conditions.

We hope to have a functioning standalone system that is safe for the user and enhances the learning environment.

1.3 Operational Environment

The environment of our project is primarily indoors in the Coover 1102 lab with exception to the solar panels located outside of the lab. Since the solar panels will be stationed outside, they will be exposed to various climate changes such as freezing and/or hot temperatures, rain, snow, and hail. These elements are not much of a concern as the panels are constructed to be in outdoor environments and are resilient to these elements. Some occasional cleaning of the panels may need to be done in order to clean any dust or debris off of the panels if they get dirty.

The control system will be located in an indoor lab. This system should be able to withstand use by students at least once a semester and should be able to last many years without maintenance or repairs. The system should also be dry and safe as to not allow for any fire hazards or risk of electric shock to the users.

1.4 Requirements

There are various requirements that need to be met in order to achieve a safe and functional project:

Functional Requirements

- System: System should be compact enough for efficient usability and storage in the lab.
- Generation: Solar Cell should generate the maximum amount of power possible at varying temperatures and solar irradiance.
- Conversion: Conversion circuit should be able to convert from DC to AC power with minimal losses. The system's voltage should be able to increase or decrease in order to match the voltage rating of the load.
- Load: System should be able to power multiple DC and AC loads. System should have an electrical storage system to store excess power.

Environmental Requirements

Availability of Sunlight:

1. The solar panels should be in a centralized area away from walls where the maximum amount of sunlight can be achieved
2. Ideal operating times for the EE 452 lab sessions would be in the springtime during the afternoon hours

Lab Environment:

1. The system should be small enough so that each lab bench would be able to have the system neatly and safely housed for students to have available and to conveniently use
2. A TA should always be present during the lab to ensure that students are using the system properly and will not cause any damage to it, themselves, or others
3. The system should have enough space for the necessary number of batteries and solar panels to provide enough power to each lab bench in the future to avoid situations where there isn't enough power for all lab groups to complete lab

Cost Requirements

Type of equipment	Quantity	Cost
Solar panel	2	$700
breaker	1	$20
multimeter	2	$20
relay	2	$40
mppt	1	$243
Mppt sensor	1	$143
Battery block	2	$260
microcontroller	1	$20
Buck converter	1	$10
Ac motor	1	$200
Light bulb bank	1	$50
Resistor bank	1	$50
inverter	1	$200
Variable frequency drive	1	$168
total		$2,124

Circuit Design Requirement

Hardware

- Array Panel - converts solar energy to electrical energy
- MPPT - Maximum power point tracking allows for the maximum power to be produced.
- Buck/Boost Converter - DC to DC converter that can turn the output voltage to be higher or lower than the input voltage.
- Battery - Stores electrical energy at 12V DC.
- Inverter - converts DC power to AC power.

Software

The software that will be used is Simulink. Simulink is a function in MATLAB that allows the user to simulate the main component of the PV system as well as the voltage, current and the power consumption across the circuit.

1.5 Intended Users and Uses

The end users of this project will be the students in EE 452. They will be using this project as a part of a lab to learn more about solar and wind energy generation and efficiency with both AC and DC loads. The system should be easy for a student to understand and use without complications or any additional assistance aside from what instructions are given within the lab manual. The documentation of the overall project and its design should also be highly detailed so that the ECpE Department would be able to replicate the project in the future or make repairs if needed.

1.6 Assumptions and Limitations

Assumptions

- The system will be replicable so that each lab bench will have the necessary equipment to complete the lab.
- The solar panel arrangement and battery supply will be large enough to be able to generate enough power for each lab bench to be able to effectively complete the lab.
- The system will be compact enough to fit at each lab bench without causing too much clutter and allowing students enough space to work.
- The system will be simple enough for students to understand and use with a clear lab manual guiding them through the lab and how to use the equipment.
- The system will have displays showing the current and voltage being generated within the system for students to easily read.
- The Simulink model will be provided for students to download and experiment with as a part of their lab before using the hardware.

Limitations

- The cost of the solar panels, batteries, and wind turbine add up to a very high cost without the inclusion of the other parts we need which is currently out of our budget unless we can receive additional funds from the department.

- The amount of sunlight on a given day that this lab takes place could affect the experience of the students during the lab in that not enough power may be being generated from the solar panels.

- The location of the solar panels may have shadows cast onto them from the walls of the courtyard.

- Labs taking place during the evening hours may have a varying experience due to the lack of sunlight.

- The efficiency of the wind turbine may not be high due to it being powered manually by a box fan in the lab.

1.7 Expected End Product and Deliverables

The end product that the team will deliver at the end of fall semester 2020 will be a small-scale stand-alone hybrid PV solar and wind energy generation system for EE 452 lab. The system will be used to conduct educational experiments as a part of electrical machines and power electronics lab in Iowa State University. The previous senior design teams delivered a system containing various capacitive, inductive, and resistive loads as AC and DC loads needed in the lab.

Our team will work on redesigning the system by adding more PV solar panels and a wind energy turbine to perform like a hybrid system for maintaining more power supply to increase the experiment stations and power stability during the lab. We will add to the existing system another PV solar panel, wind energy turbine, and two more batteries. The end product deliverables will include modeling and test results showing the performance of the system. In addition, all the instructions and documents to be used in lab manuals. Also, our major deliverable will emphasize the system safety and reliability aspects to give the client ultimate benefit of redesign the existing system.

2. Specifications and Analysis

2.1 Proposed Approach

Since the project has been started by a previous team, we needed to understand what the group has accomplished before it was transitioned to our team. Our team has done the following:

Safety

Before we moved anything on the system, we reviewed, as a team, the safety measures we need to take in regard to high voltage systems. These standards are referred to in the "Executive Summary" section "Development Standards & Practices Used.

Transition Documents

Our team has reviewed all documents that were left by the previous team. Key documents included weekly reports, design documents, data sheets for equipment and MATLAB files.

Simulink

Our team has simulated various lab experiments that were part of the deliverables for this project to get a better understanding of how the standalone system shall work. This consisted of simulations of PV cells and their functionality.

Hardware Check

Once simulations were complete, we reviewed the system in its current state to understand its functionality. We tested various pieces of equipment where we found areas of improvement.

Identify Project Execution Plan

We developed a detailed project execution plan that will guide us towards completing the project. Please refer to the Appendix for more details.

2.2 Design Analysis

Transition Documents

Our team has reviewed all documents that were left by the previous team. We noticed some of the specifications of the equipment were left out. Key documentation was missing such as schematics, PFDs, safety procedures, manuals. This is an area of improvement to document all specifications regarding the equipment.

Simulink

Our team has simulated various lab experiments that were part of the deliverables for this project to get a better understanding of how the standalone system shall work. We noticed that some of the lab experiments take very long to identify the concepts that are conveyed to learn. To mitigate this, we will condense the experiments so that they do not take very long but also keep the learning aspect in mind.

Hardware Check

Once simulations were complete, we reviewed the system in its current state to understand its functionality. We tested various pieces of equipment where we found that some of the equipment is not functioning. We found the DC output when switched to MPPT is not functioning. In addition, wiring is not well organized and needs to be fixed.

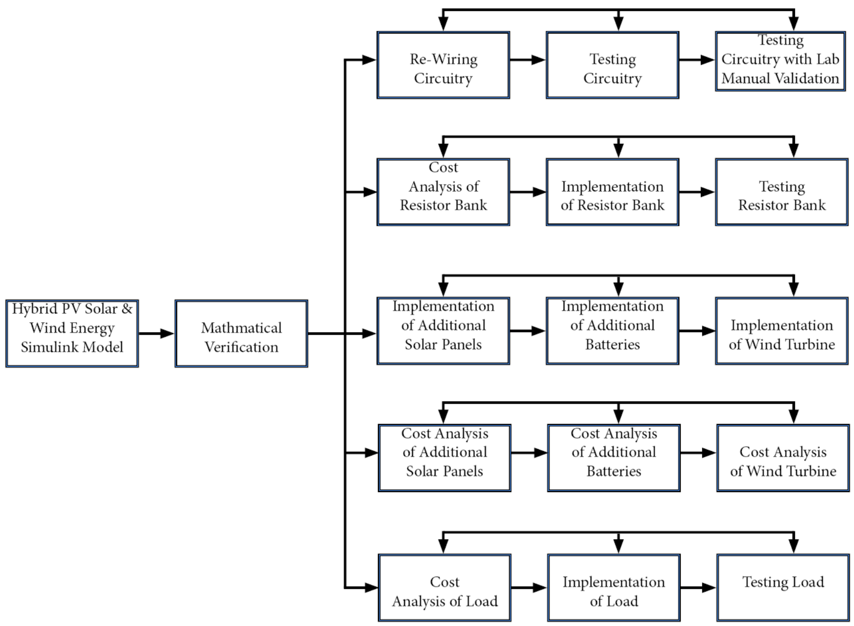
Identify Project Execution Plan

We developed a detailed project execution plan that will guide us towards completing a new standalone system. Refer to Appendix for more details.

2.3 Development Process

The team will be using a corporate project management structure that will follow a project from FEL-1 to Project Execution.

2.4 Conceptual Sketch



6.3 Appendices

Any additional information that would be helpful to the evaluation of your design document.

If you have any large graphs, tables, or similar that does not directly pertain to the problem but helps support it, include that here. This would also be a good area to include hardware/software manuals used. May include CAD files, circuit schematics, layout etc. PCB testing issues etc. Software bugs etc.

Deliverable	FEL 1	FEL 2	FEL 3	Detailed Design
Purpose	project ideas, define alternativ	evaluate alternatives	define the facility to	Design for project exe
Drawings				
Process Flowsheet				
P&ID drawing				
Key Plan/Site Plan				
General Arrangements				
Details				
Electrical Schematics				
Cable Schedule				
Instrument Loop Drawings				
Piping Line List				
Vendor Information/Drawings				
Shop Drawings				
Other				
Design Calculations				
Scope of Work/Report				
Equipment List				
Instrument List				
Process Hazards Review				
Soils Investigation Report				
Equipment Quotations				
Lifting Device Certification				
Specifications				
Cost Estimate				
Approvals				
TSSA				
ESA				
Building Permit				
Excavation Permit				
Buried Services Locates				
Insurance Underwriter				
Min if Natural Resources				
Project				
Engineering(% of Total Eng)				
Approx Eng Hours				
Estimate Method				
Estimate accuracy				