

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

Project number: Sddec20-16

Client: Dr. Venkataramana Ajjarapu

Advisors: Dr. Venkataramana Ajjarapu

Members:

Daniel Mendez – Chief Engineer (EE)

Benjamin Holt – Test Engineer (EE)

Samah Shabbo – Meeting Facilitator (EE)

Mohamed Adam – Meeting Scribe (EE)

Conner Makoben – Report Manager (EE)

Team Email: sddec20-16@iastate.edu

Team Website: <https://sddec20-16.sd.ece.iastate.edu>

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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 hybrid regeneration system
- System is safe, operable and functional.
- Generates energy from solar and wind sources efficiently.
- Capable of generating the maximum energy for varying temperature, irradiance, wind speed, and wind direction.
- 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.
- EE 459 Electromechanical wind energy conversion was used to understand wind turbines and their components.
- EE 475 Automatic control systems were used to understand control system analysis and design.

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 the work process flows of a project from idea to execution
- PV solar cell system - Understand how a PV cell functions and how generates energy
- 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

Table of Contents

1 Introduction	5
1.1 Acknowledgement	5
1.2 Problem and Project Statement	5
1.3 Operational Environment	6
1.4 Requirements	6
1.5 Intended Users and Uses	10
1.6 Assumptions and Limitations	10
1.7 Expected End Product and Deliverables	11
2. Specifications and Analysis	11
2.1 Proposed Approach	11
2.2 Design Analysis	12
2.3 Development Process	14
2.4 Conceptual Sketch	14
3. Statement of Work	15
3.1 Previous Work And Literature	15
3.2 Technology Considerations	15
3.3 Task Decomposition	15
3.4 Possible Risks And Risk Management	16
3.5 Project Proposed Milestones and Evaluation Criteria	18
3.6 Project Tracking Procedures	19
3.7 Expected Results and Validation	19
4. Project Timeline, Estimated Resources, and Challenges	19
4.1 Project Timeline	19
4.2 Feasibility Assessment	20
4.3 Personnel Effort Requirements	22
4.4 Other Resource Requirements	22

4.5 Financial Requirements	22
5. Testing and Implementation	23
5.1 Interface Specifications	23
5.2 Hardware and software	23
5.3 Functional Testing	23
5.4 Non-Functional Testing	23
5.5 Process	24
5.6 Results	25
6. Closing Material	26
6.1 Conclusion	26
6.2 References	26
6.3 Appendices	27

1. 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 Ajarapu has given us the space to exchange ideas and insight and has provided us with the mental tools and resources that allowed our team to design and develop this project in the first place. We are so grateful for every opportunity we had to be able to walk into your office, as we were 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 that is necessary to complete this project.

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

1.2 Problem and Project Statement

The goal of this project was to design and develop a new standalone hybrid renewable energy generation system that consists of both solar PV and wind regeneration subsystems. The regeneration system will serve as an educational tool for students in EE 452 to learn about clean energy in a safe lab environment.

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

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

After analyzing the current system, there was an area of opportunity for improving the learning about renewable energy generation in a lab environment. A solution we decided as a group was 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. The following figure is a proposed model that would be implemented in both the EE 452 lab and Coover Hall Courtyard.

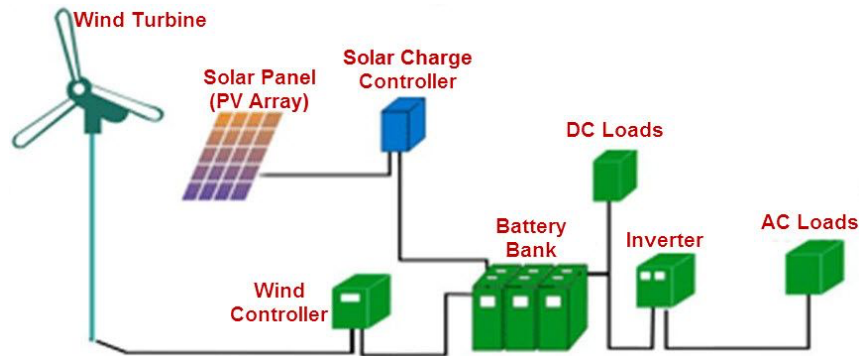


Figure 1: Hybrid regeneration system

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 the exception of the solar PV and wind turbine located outside of the lab. Since the solar panels and wind turbine 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 and wind turbines are constructed to be in outdoor environments and are resilient to these elements. Occasional cleaning of the panels and the turbine may need to be done in order to keep dust or debris off of the panels and turbine in case 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 to prevent any fire hazards or risk of electric shock to the users.

1.4 Requirements

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

Functional Requirements

- System: The system should be compact enough for efficient usability and storage in the lab.
- Generation: Solar cells should generate the maximum amount of power possible at varying temperatures and solar irradiance. Wind should generate enough power at varying wind speeds.

- Conversion: Conversion circuits should be able to convert from DC to AC or AC to DC 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: The system should be able to power multiple DC and AC loads. The system should have an electrical storage system to store excess power.

Non-Functional Requirements

- Clean energy regeneration: System should be able to generate clean energy using maximum power point tracking algorithms, controllers, inverters, battery bank.
- Safety: System adheres to IEEE, OSHA standards and safety best practices.
- Metering: Utilizing metering systems to monitor and prevent overvoltage/overcurrent.
- Validation: Rigorous testing and implementation to meet specifications
- Lab manual: Design lab experiments for students

Environmental Requirements

Availability of Sunlight:

- The solar panels should be in a centralized area away from walls where the maximum amount of sunlight can be achieved
- Ideal operating times for the EE 452 lab sessions would be in the during the spring and summer semesters

Availability of Wind Speeds:

- The wind turbine should be installed in an open area such as the Coover Hall Courtyard away from walls and at an appropriate height to achieve maximum power.
- Ideal operating times for the EE 452 lab sessions would be in the spring and summer.

Lab Environment

- The system should be small enough so that the lab bench would be able to have the system neatly and safely housed for students to have available and to conveniently use
- A Teaching Assistant shall be present at all times during the lab to ensure that students are using the safely and properly to prevent any damage to it, themselves, or others
- The system should have enough space for the necessary number of batteries, solar panels, and wind turbines to provide enough power to the lab bench in the future to avoid situations where there isn't enough power to complete the lab adequately.

Cost Requirements

The following is a bill of materials that would be sponsored and approved by the Iowa State University Engineering Department and will be ordered and received by ETG.

Type of equipment	Quantity	Cost
Solar panel	2	\$700
Wind Turbine	1	\$800
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
Light bulb bank	1	\$50
Resistor bank	1	\$50
inverter	1	\$200
Variable frequency drive	1	\$168
total		\$4848

Table 1: Bill of Materials

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.
- Wind Turbine - converts wind energy to electrical energy
- Buck/Boost Converter - DC to DC converter that can turn the output voltage to be higher or lower than the input voltage.
- Battery bank- Stores electrical energy at 24V DC.
- Inverter - converts DC power to AC power.
- DC Bus - interconnection for the hybrid system
- DC and AC loads - to study the behavior of the system. Equipment may include a resistor bank or brushless motor
- Metering system - used for monitoring the equipment to prevent any incidents

Software

The software that will be used is Simulink. Simulink is a function in MATLAB that allows the user to model and simulate the main components of the solar, wind, and hybrid system. This software will be vital to test and prototype the system as well as a safe option for studying the behavior of the system before implementing the hardware.

1.4.1 Constraints

- Geographical location: the solar panels and wind turbine need to be closest to the EE 452 lab which would be the Coover Hall Courtyard, however, due to being enclosed it would not deliver adequate wind speeds for the turbine as well as enough sunlight for the panels due to the high walls surrounding the equipment
- Use of lab: due to the COVID-19 pandemic, we are unable to work in a lab environment and would need to adhere to CDC guidelines
- Non-ideal climate: varying climate may produce inadequate results to produce enough power during lab time
- Energy efficiency: equipment is not up to spec which means the technology in the solar panels may have degraded efficiencies
- Power losses: equipment is not ideal, therefore, the results we produce from hardware may differ from the software implementation

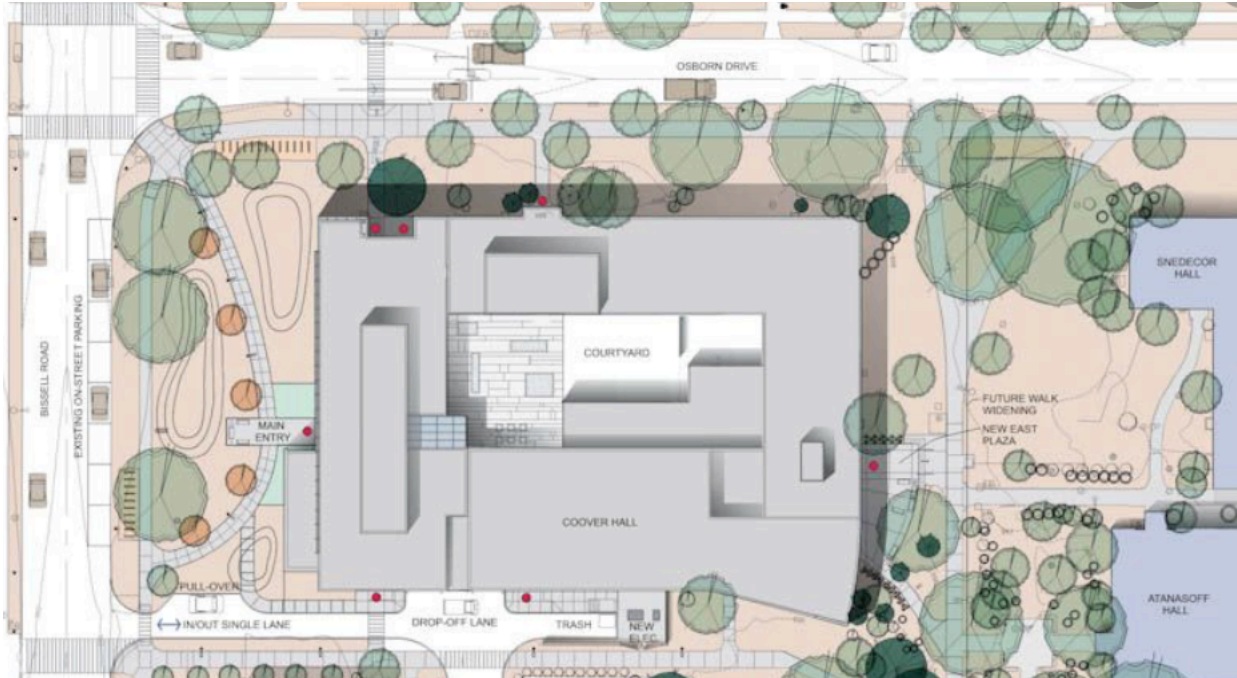


Figure 2: Plot Plan of Coover Hall

1.5 Intended Users and Uses

The end-users of this project will be the students participating 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 or use it as an opportunity to integrate clean energy across campus as part of the green initiative at Iowa State University.

1.6 Assumptions and Limitations

Assumptions

- The system will be placed on one lab bench that will be able to have the necessary equipment to complete the lab.
- The solar panel, wind turbine, and battery supply will be large enough to be able to generate enough power to the lab bench equipment so students will be able to effectively complete the lab.
- The system will be simple enough for students to operate 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 turbines adds up to a very high cost without the inclusion of the other parts that are critical which is currently out of our budget unless we can receive additional funds from the department.
- The amount of sunlight and wind speed 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 and wind turbines.
- The location of the solar panels may have shadows cast onto them from the walls of the courtyard. The location of the wind turbine may also have limitations due to the surrounding walls.
- Labs taking place during the evening hours may have varying experiences 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 proposed end product that the team will deliver at the end of the fall semester of 2020 will be a small-scale stand-alone hybrid PV solar and wind energy generation system model for EE 452 lab. The system will be used to conduct educational experiments as a part of the electrical machines and power electronics lab at 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 the experiment station to provide power stability during the lab. We will add to the existing system another PV solar panel, a 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 the ultimate benefit of redesigning the existing system. However, due to the COVID-19 pandemic, our team needed to reevaluate the implementation of our project. In order to adhere to lab and safety protocols from Iowa State University and the CDC guidelines, our group and client decided to delay our hardware implementation until further notice and focus our efforts in modeling the hybrid regeneration system as well as designing and developing a lab manual for the EE 452 lab.

2. Specifications and Analysis

2.1 Proposed Approach

Since the project has been started by a previous team, we needed to learn and understand what the group has accomplished before it was transitioned to our team. Our team has done the following to better inform ourselves of the status of the project and the path forward towards completing the project.

Safety

Before operating any equipment, we reviewed, as a team, the safety measures we need to take in regard to power systems. The standalone system works with high voltage, therefore, extra precautionary measures were needed before moving any equipment. These standards can be referred to in the “Executive Summary” section “Development Standards & Practices Used.

Research (Solar PV and Wind energy)

Our team began researching how a hybrid energy system functions. More specifically, how solar panels and wind turbines obtain energy and convert it into useful power. The team worked on a presentation that covered our research we completed that better prepared ourselves on how to design the system.

Transition Documents

Our team has obtained all documents that were left by the previous team. Key documents included weekly reports, design documents, datasheets 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 Solar PV, wind, 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 the Project Execution Plan

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

2.2 Design Analysis

After informing ourselves of the status of the project, we documented our findings that were useful in how we needed to create a path forward for the project.

Transition Documents

Our team 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 was 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 took very long to identify the concepts that were conveyed to learn. To mitigate this, we condensed the experiments so that they do not take very long while also keeping the learning aspect in mind.

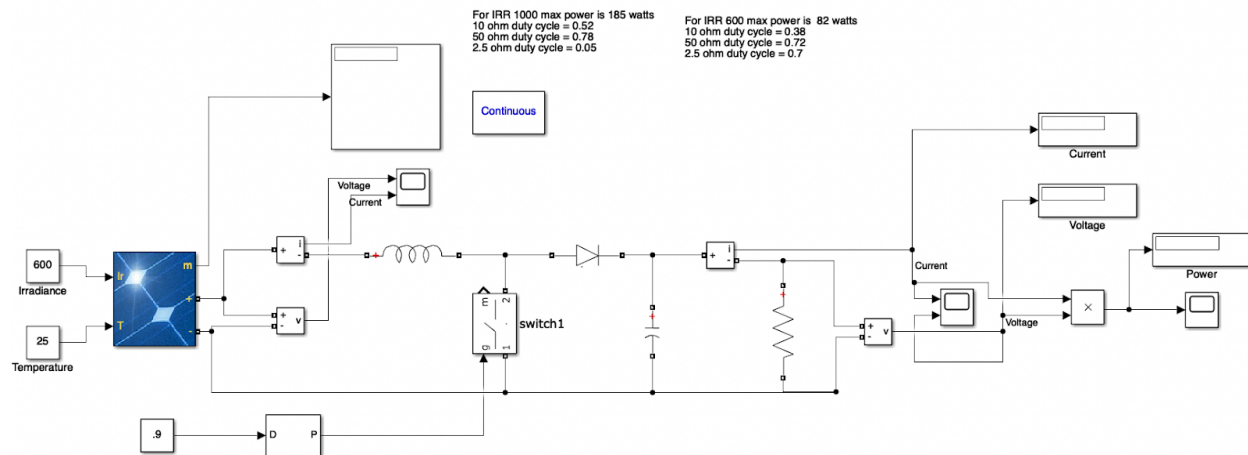


Figure 2.2: Modeling of MPPT behavior without algorithm

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 was not functioning. We found the DC output when switched to MPPT was not functioning. In addition, the wiring was not well organized and needed to be fixed.



Figure 2.2.1: MPPT within panel not functioning

Identify the Project Execution Plan

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

2.3 Development Process

The team used a corporate project management structure that follows a project from FEL-1 to Project Execution.

2.4 Conceptual Sketch

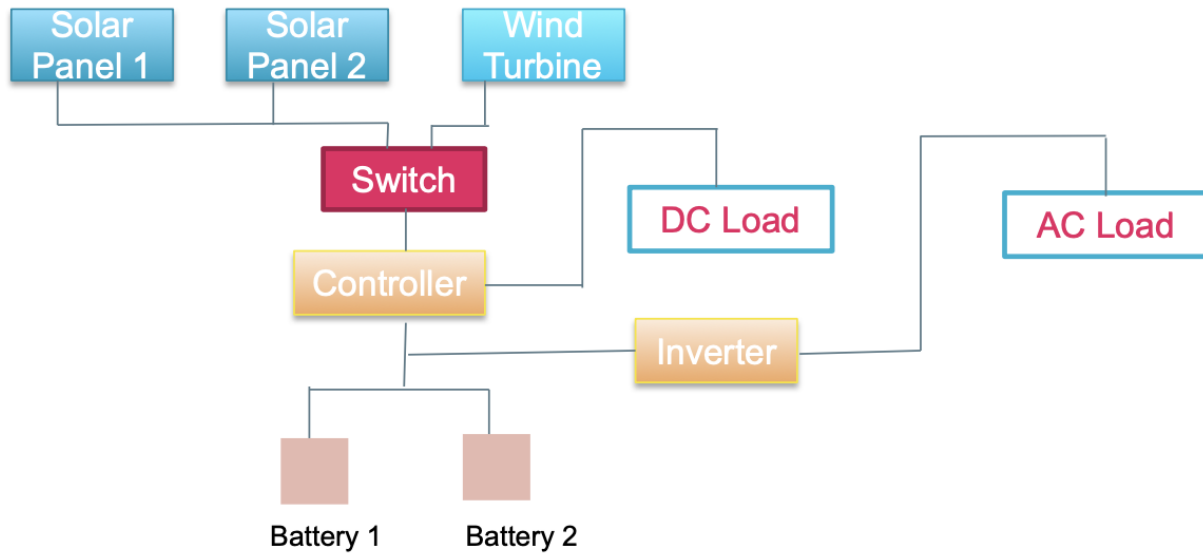


Figure 2.4: Conceptual Sketch of equipment

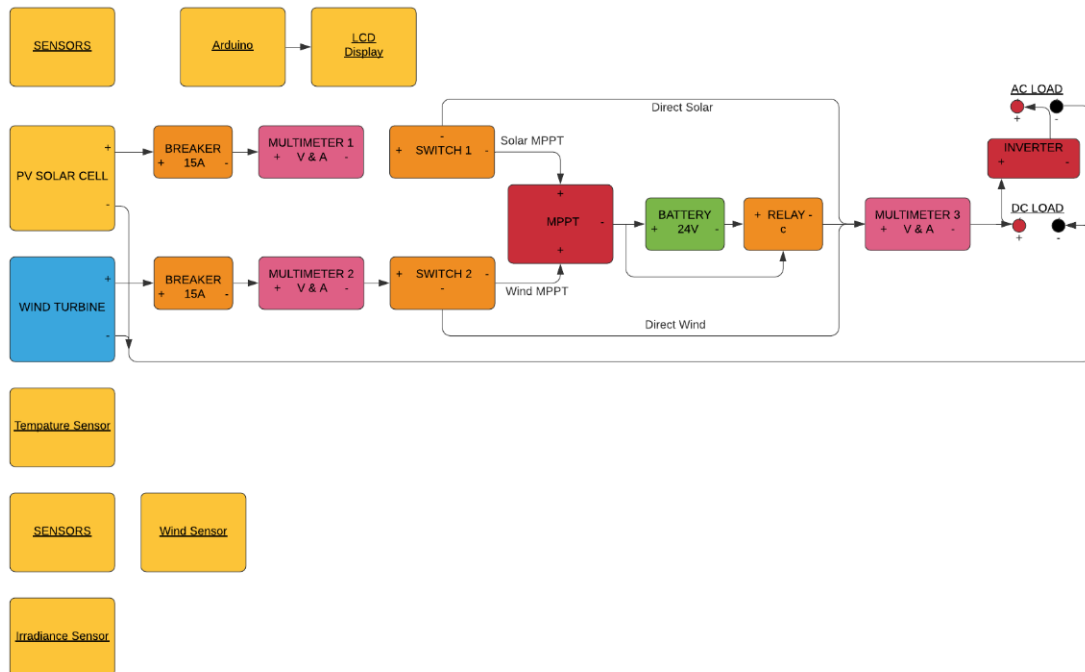


Figure 2.4.1: Detail Design

3. Statement of Work

3.1 Previous Work and Literature

After researching the type of stand-alone system we would like to design and implement for lab use, we noticed that there is no such system one can buy and equip in a lab setting to study clean energy. However, one can purchase each piece of equipment separately to compose a system according to the specifications the user would like or need. This is a gap our group can fill because we can design, build, and operate a solar PV and wind regeneration system that meets lab use standards and safety precautions. This is also an advantage to our group because we can standardize our end-product to market as a system for lab use or as a standalone regeneration system that provides power for equipment on a small scale such as a motor or battery storage to then power a room with a light source. In addition, providing clean energy so that we are not releasing toxic chemicals to our environment that prove to be detrimental.

3.2 Technology Considerations

Data technology

- Data is stored and displayed using 2 libraries (GFX and TFT LCD).
- A TFT LCD screen displays the irradiance and temperature.
- MPPT Sensors
- Microsoft Office for creating and editing documents
- Internet and other sources for data collection

Scheduling Technology

In our project, we used the Gantt chart in Excel for time schedules. It helped the group to manage, plan, and track the project.

Design Technology

The software that is used in this project for the design is Simulink in MATLAB. The programs allowed us to design and simulate the hybrid system. It can simulate the amount of voltage and current across each component of the resistor bank and be able to see the power consumption when each load is connected as well as the amount of solar/wind energy needed to power that load.

Communication Technology

Our group uses university e-mail and group texting for communication. We also use the university website Cybox and google drive for sharing our work and to organize the project documents. Due to the COVID-19 pandemic, we needed to transition to a remote environment where we utilized Zoom to facilitate meetings and updates with our team members and client.

3.3 Task Decomposition

The five tasks that our project has been divided into are: create an updated lab manual, performing research and cost analysis of the new hardware system, create a Simulink model and simulation for a wind turbine and hybrid system, and centralizing the documentation of the stand-alone system.

The updated lab manual will build upon the work of the last senior design team's lab manual and incorporate new experiments with both Simulink and the hardware that may be more useful, beneficial and less repetitive. This lab should also be able to be completed by the EE 452 lab students within the given three-hour lab time in the Coover 1102 lab.

Research and cost analysis were performed on the necessary parts that needed to be ordered for the new hardware design that was planned to be built in the fall. This cost analysis and parts list gave us a complete estimate of the total cost and the exact parts that should have been ordered and ready for construction for the fall semester. This also helped aid in the documentation of the overall project for future replication of the design.

The Simulink simulation for the wind turbine allows for students to input different wind speeds and other variables in order for students to use this in the lab experiments similar to the currently existing solar simulation created by the other design team. This simulation also aids in the students' understanding of wind generation and will help them when working with the wind generation portion that was planned to be added into the next hardware design.

The modeling of the hybrid system was also completed in Simulink. The hybrid model ties together both generation sources, a battery and inverter to function as a full system. It allows for students to turn off various elements such as wind, solar, or both to see how the system reacts. This will also help the students understand a hybrid system that will benefit them when they test the hardware portion of the model in the future.

The centralization of the documents and circuitry of the current and new solar PV system was important to provide for a solid overall understanding of the hardware and how it works. This also aided in the design of the new system that was built based on certain aspects of the currently existing design. This documentation will also prove to be critical in the future if the ECpE Department chooses to replicate or create more hardware systems to be used across campus as part of Iowa State's initiative towards a greener campus.

3.4 Possible Risks And Risk Management

COVID-19 - Due to the pandemic, the group needs to adhere to CDC guidelines to prevent transmission of the virus to other team members as well as students and faculty.

Material availability - this was a possible risk due to our planned materials being out of stock or no longer a continued product. The risk was planned to be managed by having multiple options for each component in case such an event occurs. This would have changed the design constraints of the system if another component is bigger or requires more inputs.

Shipping & Delivery issues - this was a risk because it could have hindered the entire hardware build process of the project. If shipping took up to a month to receive components, then adequate time would be needed to be used in order to receive the components at the start of the fall semester. The possibility of damaged items upon delivery could setback the build process due to new components needed to be reshipped. A way we planned to manage this risk was by working with the vendor to discuss the lead time and find the equipment that meets our time constraints.

Lab Access - the university moving all classes online and shutting down campus possessed a risk to our ability to work on our project in the lab. Since our project cannot be removed from the lab our ability was hindered in the hardware aspect of the project. In order to manage this risk, we did everything we could that didn't involve hands-on testing. We did this by planning and simulating the project online.

Wind turbine location - Another risk to our project was our wind turbine location due to it being located in the Coover courtyard. Since this turbine spins it can be a risk to others and since the courtyard is open to the public our location needs to be the safest option. This safety risk was managed by finding a location that would be out of reach to the public. However, there was another risk of the building and grounds department not approving the location.

3.5 Project Proposed Milestones and Evaluation Criteria

There are six major milestones we are targeting for our project as listed below.

Milestone	Mitigation Steps for Completion
Centralizing documentation for Solar PV and Wind Generation System	<ul style="list-style-type: none"> • Plot plan: a drawing that shows where the equipment is located • Loop sheets: drawings that show all connections of the system • Equipment manuals: reference documentation for troubleshooting • Datasheets: reference documentation for troubleshooting and equipment purchase/comparison • Standard Operating Procedure (SOP): procedure to show how equipment functions and safety precautions when operating equipment
Design and Develop Lab Experiments	<ul style="list-style-type: none"> • Research solar PV and wind generation to understand the system • Consider safety for users • Create lab experiments for Solar PV circuit using panels and MPPT • Create a lab experiment for Solar PV using Simulink • Create lab experiments for wind circuit • Create a lab experiment for wind generation using Simulink • Create lab experiments for hybrid circuit • Create lab experiments for hybrid generation using Simulink • Learning goals to guide students • Solution manual
Wind Turbine Simulation Model	<ul style="list-style-type: none"> • Develop a simulation model of a wind turbine on Simulink • Ensure theory matches with equipment that will be in place
Hybrid Regeneration system and model	<ul style="list-style-type: none"> • Develop a simulation model of the hybrid system on Simulink • Ensure theory matches with equipment that will be in place
Research, Cost Analysis, and Purchase of equipment	<ul style="list-style-type: none"> • Research equipment that meets our design specifications and safety precautions • Develop budget and cash flows chart of purchased equipment and resources • Develop bill of materials • Work with vendors to ensure equipment can be delivered to campus • Purchase equipment within budget to implement for project • Retrieve purchased equipment and document what is being used and not used
Execution of Project	<ul style="list-style-type: none"> • Review safety precautions before handling equipment • Execute project equipment according to design schedule • Ensure all equipment connections are properly connected in the correct places
Safety and Operability Testing	<ul style="list-style-type: none"> • Loop test each connection • Isolate each piece of equipment to test functionality • Attach meters to analyze voltage, current, and load • Make changes according to findings • Use lab experiments to see functionality of equipment and compare simulation vs hardware

Table 3.5: Milestone Criteria

3.6 Project Tracking Procedures

Our group used a Gant chart to track our progress of each large milestone and each small milestone within those accomplishments. This proved to organize our project execution in addition to following a set schedule to meet our deadlines.

3.7 Expected Results and Validation

The desired outcome consists of equipping the EE 452 lab with a new standalone hybrid renewable energy generation system that will be composed 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.

There are three ways we can confirm our solutions work:

1. Ensure the safety of our clients, users, and a team that maintains the system at all times
2. Our simulation models match the data of the hardware when experimenting
3. The students obtain new knowledge on clean energy (solar PV and wind)

4. Project Timeline, Estimated Resources, and Challenges

4.1 Project Timeline

The project was planned to be completed within the two-semester time frame by attempting to divide the work up and target which tasks should be completed first before the project can progress. The project schedule was only a tentative schedule consisting of estimated time frames and member allocation. This chart was subject to change when problems arose and when some tasks prove to require more assistance from other members than anticipated. An example of this was when we needed to restructure the schedule due to the pandemic where plans for hardware implementation needed to be postponed per CDC guidelines regarding crowds. There were also new tasks that were realized and addressed before progressing along the way; however, by appropriately designating these tasks amongst team members they were dealt with on time without issue.

The timeline below consists of the estimated time frames for each month that each task was worked on and brought to or near completion. This timeline was proposed based on the major tasks that need to be completed. Smaller tasks that needed to be done along the way were distributed to members who were able to complete them so progress can resume. The first task presented involved researching both solar and wind generation and reviewing the last senior design team's documentation to gain more knowledge on the current system. After this had been completed, new changes, modifications, and additions were made as necessary through the testing of the system so it would be prepared and ready for the EE 452 lab near the end of the semester. Some additions that needed to be made were a Simulink simulation modeling wind generation and also adding a small wind turbine into the new hardware system that was considered and researched. Also mentioned in the schedule is a cost analysis and the construction list of parts that were planned to be ordered to build the new system with the addition of wind. This would have helped with ordering parts at the end of the semester so that they could be on hand at the beginning of or during the second semester for the development of the new

system. A new lab manual was also made to include new and updated experiments for the lab that better-benefited students.

Once the Fall 2020 semester began, we planned on the design and construction of the new system. During this design and build process, it would be critical to have the process documented accurately with many details. This would be important if the ECpE Department chooses to replicate the system in the future for other lab benches or to make repairs if needed. While building the new system it would also be critical to test it and perform necessary troubleshooting, so that problems would be caught before reaching the end product and discovering that it does not work. Once the system is complete and operational, the new lab manual could then be completed and tested to determine if the system and overall lab will meet the needs of students and the department. However, those planes needed to be postponed until further notice due to the increased number of cases.

Small Scale Stand Alone Hybrid Solar PV and Wind Energy Generation System for EE 492 Lab

Company Name		ISU Senior Design												
Project Team		DRM, BH, SS, MA, CM	Project Start	1-Jan-20										
			Project End	20-Nov-20	12-Apr-20			18-Apr-20						
					14	15	16	17	18	19	20	21	22	23
TASK	Assigned To	Progress	START	END	T	W	T	F	S	S	M	T	W	T
Phase One														
Solar PV and Wind Generation Research	TEAM	100%	15-Jan-20	20-Nov-20	1	1	1	1	1	1	1	1	1	1
Test Solar Hardware	DRM/BH	100%	22-Jan-20	10-Feb-20										
Test Solar PV Simulations	TEAM	100%	11-Feb-20	18-Feb-20										
Design and develop Solar PV lab manual	CM	100%	19-Feb-20	10-Mar-20										
Model Wind Turbine Simulation	BH	100%	24-Aug-20	14-Nov-20										
design and develop wind turbine lab manual	BH	100%	24-Aug-20	14-Nov-20										
Solar PV and Wind system integration model	DRM	100%	7-Sep-20	14-Nov-20										
design and develop hybrid lab manual	DRM	50%	7-Sep-20	14-Nov-20										
Phase Two														
Approval from Building manager	DRM	100%	31-Aug-20	15-Sep-20										
Bill of materials	SS	80%	31-Aug-20	15-Sep-20										
Equipment review	TEAM	60%	7-Sep-20	15-Sep-20										
Order and receive equipment	TEAM	0%	8-Sep-20	27-Sep-20										
Centralize documentation	TEAM	0%	28-Sep-20	4-Oct-20										
Phase Three - Execution of Building the system														
Build solar module	DRM/BH	0%	5-Oct-20	11-Oct-20										
build wind turbine module	MA/SS	0%	12-Oct-20	18-Oct-20										
build panel	CM/BH	0%	19-Oct-20	25-Oct-20										
integrate systems together	TEAM	0%	26-Oct-20	8-Nov-20										
Phase Four - Final Checks														
develop standard operating procedure	DRM	0%	9-Nov-20	15-Nov-20										
develop hazard analysis document	BH	0%	9-Nov-20	15-Nov-20										
finalize lab manual	CM	0%	9-Nov-20	15-Nov-20										
QA/QC check	MA/SS	0%	9-Nov-20	15-Nov-20										
Final Presentation	TEAM	0%	16-Nov-20	20-Nov-20										

Note: Phase three and four were postponed due to covid-19 pandemic

Figure 4.1: Project Execution Schedule

4.2 Feasibility Assessment

Design and implementation of small-scale stand-alone hybrid PV solar and wind energy power system projects will serve as an educational tool for students to learn about renewable energy in EE 452 lab. Clean energy is an alternating focus of energy to replace the classic types of energy production that have serious damages to the environment. So, the project will encourage students to study and practice all the aspects of renewable energy from a design perspective. The platform that the project will provide

for EE 452 lab consists of one station to allow sufficient practical opportunities. EE 452 course focuses on electric machines and power electronics that represent the base of power system design and generation. Therefore, the project is so important in areas of redesign and implementing a system that produces more power to the lab by adding a wind turbine and another PV solar panel to the existing design.

As the students used to perform labs in the previous semester by using the existing design, the new design will solve the problems of power supply stability, the relation between the student's numbers and experiment station number, and the variety of clean energy resources to help students learn more about renewable resources. Power supply stability depends on the weather conditions when the system is not big enough to generate and store enough power during the lab day. Even though students conduct the lab during the mid-day because in Winter the sun irradiance is too low. So, the new design will provide stability to the system in areas of increasing the capacity of energy harvesting and the ability to store energy in batteries. Also, with a hybrid system, the weather conditions will not affect the power supply stability because wind and sun energy will work together. The capabilities of the new design will solve the limitations of the existing design and provide enough stations and a safe lab environment for EE 452 students.

The project tasks plan has been achieved as the project timelines. For the spring semester, the group focused on redesigning the system and ordering the new components for the system extension. The redesigning part consists of hardware configuration and modeling in addition to cost analysis. The configuration of the hardware was completed before the spring semester shutdown. The modeling of the PV solar was also achieved before the end of the spring semester. The simulation of a wind turbine was a real challenge in the project, but the group worked really hard on it. For wind turbine modeling, most simulations were for big scale projects. The modeling of small wind turbines was the project's foreseen challenge, but the group overcame the issue during the fall semester of the project's design.

4.3 Personnel Effort Requirements

Name	Major Milestone	Tasks	% Complete
Daniel Mendez	Responsible for all engineering and technical disciplines that the project involves as well as designing hybrid model	Prepare engineering project tasks	100%
		schedule the tasks	100%
		coordinate and monitor project controls	100%
		ensure project is within standards and regulations	100%
		QA/QC documents	see note 1
		weekly interactions with client to meet needs and requirements of project	100%
		perform overall quality control of work that includes budget, schedule, plans, personnel and report regularly on project status	80%
		assign responsibilities and mentor team project	100%
		communicate effectively with project manager and project participants to provide assistance and technical support	80%
		review engineering deliverables and initiate appropriate corrective actions	80%
		develop simulation model of wind turbine on Simulink	100%
		ensure theory matches with equipment that will be in place	100%
Benjamin Holt	Centralizing documentation for Solar PV and Wind Generation System as well as designing and developing wind turbine model and lab manual	Plot plan: drawing that shows where the equipment is located	100%
		Loop sheets: drawings that shows all connections of the system	see note 1
		Equipment manuals: reference documentation for troubleshooting	see note 1
		Datasheets: reference documentation for troubleshooting and equipment purchase/comparison	see note 1
		Standard Operating Procedure (SOP): procedure to show how equipment functions and safety precautions when operating equipment	see note 1
		develop simulation model of wind turbine on Simulink	100%
		develop lab simulation manual	100%
		ensure theory matches with equipment that will be in place	100%
Conner Makoben	Design and Develop lab Experiments	research solar PV and wind generation to understand system	100%
		consider safety for users	100%
		create lab experiments for Solar PV circuit using panels	80%
		create lab experiments for Solar PV circuit using MPPT	80%
		create lab experiment for Solar PV using Simulink	80%
		learning goals to guide students	60%
		solution manual for solar pv model	100%
Mohamed Adam	Wind Turbine Simulation Model	develop simulation model of wind turbine on Simulink	100%
		ensure theory matches with equipment that will be in place	100%
Samah Shabbo	Research, Cost Analysis, and Purchase of equipment	research equipment that meets our design specifications and safety precautions	100%
		develop budget and cash flows chart of purchased equipment and resources	100%
		develop bill of materials	100%
		work with vendors to ensure equipment can be delivered to campus	see note 1
		purchase equipment within budget to implement for project	see note 1
		retrieve purchased equipment and document what is being used and not used	see note 1
All group members	Execution of Project	review safety precautions before handling equipment	100%
		execute project equipment building according to design schedule	80%
		ensure all equipment connections are properly connected in the correct places	100%

note 1: tasks are on hold because it requires the responsible user to work in the lab. Due to the coronavirus outbreak, the responsible person can not access the lab and document the specifications of the equipment

Figure 4.3: Personnel Efforts Requirements

4.4 Other Resource Requirements

The main project resources will be in the power electronic drives lab. This lab contains electrical measurement tools, electrical kits, and computer terminals. It is used mainly by students taking EE 452. There are spare components that are available near the system that our team will be able to utilize if necessary

4.5 Financial Requirements

The design team adheres to one financial resource: The Department of Electrical and Computing Engineering. However, our design team will be responsible for cost analysis and working with The Department of Electrical and Computing Engineering for approval of equipment purchase.

5. Testing and Implementation

5.1 Interface Specifications

The interfacing between software/hardware in our project was by simulating the operation of our design and testing it before we built the hardware module. We used the program Simulink in MATLAB to do our testing. We used simulations to imitate the key characteristics and behaviors of the system. We also simulated and tested all of our model's core components for our project. For example, we were capable of simulating and testing the MPPT, solar PV system module, wind turbine system, and hybrid model.

5.2 Hardware and Software

Software:

For software testing, we used MATLAB's Simulink. Simulink is a MATLAB graphical programming environment for modeling, simulating, and analyzing multidomain dynamical systems. Using Simulink, we were able to test I-V curves and measure the voltages and currents of each system's components to verify functionality.

Hardware:

For the hardware testing, we planned to use a digital multimeter. The multimeter was planned to be used as an electronic measuring instrument to measure voltage, current, and resistance. Using the digital multimeter, we planned to be capable of measuring the open-circuit voltage, the short circuit current, the operating current of the regulator, and any circuit breaker or fuse.

5.3 Functional Testing

When testing out our system we used these types of functional testing to review our system for any issues.

- **Unit testing** - We did unit testing to see if both our solar, MPPT, and wind simulation components worked on their own before implementing them into one complete model.
- **Integration testing** - We tested integrating an MPPT module in Simulink on MATLAB to see if it replicates an actual solar MPPT. We also integrated a wind turbine into Simulink to see if a hardware version would work well with our system.
- **System testing** - We tested the system by running it through multiple lab experiments to test out different aspects to see if they matched expected simulation values. For more information on what lab experiments were conducted, refer to the appendix.
- **Acceptance testing** - We completed acceptance testing by comparing our hardware values to our simulation values to see if they are similar within the acceptable tolerance range.

5.4 Non-Functional Testing

During the testing of our system, we also used the following non-functional testing methods.

- **Performance testing** - We tested the performance of our system by using different load resistances in order to see how much loss occurs in the system. We did this by comparing the input and output voltages from different loads.
- **Security testing** - We tested the security and safety of our systems by having someone that is not familiar with our current system try and access it to see any potential flaws.
- **Usability testing** - We used the EE452 ta to give us feedback regarding the usability of our project's lab experiment. We gained feedback from EE452 students after they complete our lab portion of our project this semester.
- **Compatibility testing** - We tested our systems compatibility by trying out multiple different loads that would represent applications in different environments. We also could have changed our source components with other models to see if the system functions. However, this wouldn't be feasible due to the high cost of source components.

5.5 Process

Before we began testing equipment on the current standalone system, we needed to understand the specifications and limits of the equipment in order to ensure the safety of all users. Once the team was well informed on the equipment we were operating, we began isolating different areas of the system to test the functionality of the equipment. This involved loop checks, voltage, current, and power metering using multimeters. In addition, we simulated the equipment using MATLAB to observe and predict the behavior of the equipment to understand the correct operating parameters of the system.

We used the following flow diagram to complete tasks regarding each piece of equipment. This involved various metering of the equipment to ensure that there is no overcurrent or overvoltage flowing through the system to prevent equipment damage or an incident. The result of using this flow diagram insured the safety of all users to prevent any type of electric shock. We noted that various areas of equipment were isolated for testing purposes in order to observe the performance of the equipment.

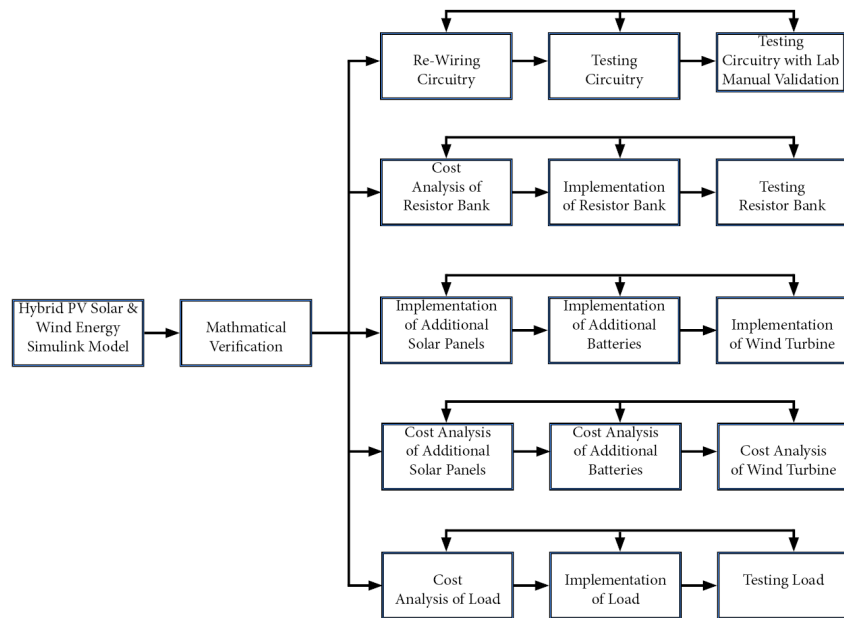


Figure 5.5: Proces

5.6 Results

Throughout the Spring and Fall semesters, we had several accomplishments, but there were also things that will be postponed due to the COVID-19 pandemic that hindered the team to work on the hardware implementation. Nonetheless, these accomplishments for the fall semester are listed below as well as progress updates and details.

Results, Achievements, and Updates:

- Created an updated lab simulation manual for the current EE 452 course that consists of solar PV, wind, and hybrid regeneration lab experiments
- A prototype lab simulation was successfully completed by lab groups in EE 452
- Further explored the possibility of adding a wind turbine into both the hardware and software experiments
- Communicated with the building manager on the possibility of adding a wind turbine into the Coover courtyard
- The turbine cannot be any higher than the walls of the Coover building but is recommended that the turbine is not located any higher than 10 feet for optimal safety
- Created a new list of materials needed for the new hardware system to be designed and built for next semester
- Given a general idea of the overall cost of the new project and what materials will need to be ordered
- Took wind measurements in the Coover courtyard to determine whether or not a physical wind turbine would be feasible
- Determined that wind speeds in the courtyard can meet the requirements of the turbines, but the consistency of the wind may be an issue
- Began designing and constructing ideas for the new hardware system as well as creating a more in-depth Simulink simulation to better model the hardware and MPPT
- Optimized versions of the Simulink models were developed to have a built-in logic block to automatically determine the duty cycle input of the DC to DC conversion circuit which will then give the maximum power point at the output based on the input parameters
- Studied the currently existing hardware system to gain a better understanding of how it works and what can be improved upon when building the new system
- Reevaluated new hardware that will be built by the next team

From these tasks and accomplishments, we were able to gain a better understanding of Simulink as well as solar PV and wind hybrid systems which we previously had very limited knowledge of prior to this project. We were also able to learn more about the current hardware system by studying its documentation and performing experiments with it prior to the transition of online classes.

Throughout the second semester, we completed almost all of our tasks. However, there still needs to be work done on building a hardware system and optimizing the current models for future use. Our Completed tasks for the spring semester are listed below:

- Finalized hardware block diagram design
- Created a wind turbine model that is simulated in Simulink
- Created a combined hybrid model that connects solar and wind into one system in Simulink
- Added an AC inverter and battery charge controller system to the hybrid model
- Developed lab experiments for the wind turbine model

- Developed lab experiments for the hybrid model

Refer to the appendix to view the lab manuals

6. Closing Material

6.1 Conclusion

Work that was completed for this project consists of research into solar and wind hybrid systems, studying and experimenting with the current hardware system and simulations, recreating a new lab manual for this current semester's EE 452 students, research and modeling of a wind turbine simulation and considered how one could be implemented into the hardware system.

The goals for this project were to create a safe, effective, and replicable lab for the EE 452 students to use to help them learn about and gain experience with solar, wind, and a hybrid system between the two. To accomplish this, we worked on studying the current system, simulations, and learning on how to improve them to create this better learning experience for future students.

This is why it was best to take the time to review the previous design team's materials to search for flaws or improvements that could be made and while doing so we also gained more knowledge on how we could expand their work to include the wind turbine and be more compact, less complex, and safer. Compared to starting from scratch, this approach is much better because it allows for us to have something to work with and base the new design on, which saved us a considerable amount of time.

6.2 References

Senior Design Team sddc 19-20. "Design and Implementation of a small scale stand alone Hybrid Solar PV and Wind Energy Generation system". Iowa State University . EE 491. <http://sddc19-06.sd.ece.iastate.edu/docs.html> . April 2020.

Rim, Ben Ali. Horst, Schulte. Abdelkader, Mami. "Modeling and simulation of a small wind turbine system based on a PMSG generator." *ResearchGate GmbH*, ResearchGate GmbH, June 2017, https://www.researchgate.net/publication/317824431_Modeling_and_simulation_of_a_small_wind_turbine_system_based_on_PMSG_generator. April 2020.

Mohammed, Husain. Abu, Tariq. "Modeling and Study of a Standalone PMSG Wind Generation System Using MATLAB/SIMULINK." Horizon Research Publishing, 2014, <http://www.hrpub.org/download/20140902/UJEEE2-17102390.pdf>. April 2020.

6.3 Appendices

Deliverable	FEL 1	FEL 2	FEL 3	Detailed Design
Purpose	project ideas, define alternatives	evaluate alternatives	define the facility to	Design for project execution
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				

Figure 6.3: QA/QC Documentation

Lab experiments

EE 452 Standalone PV Systems Lab Manual

Objective:

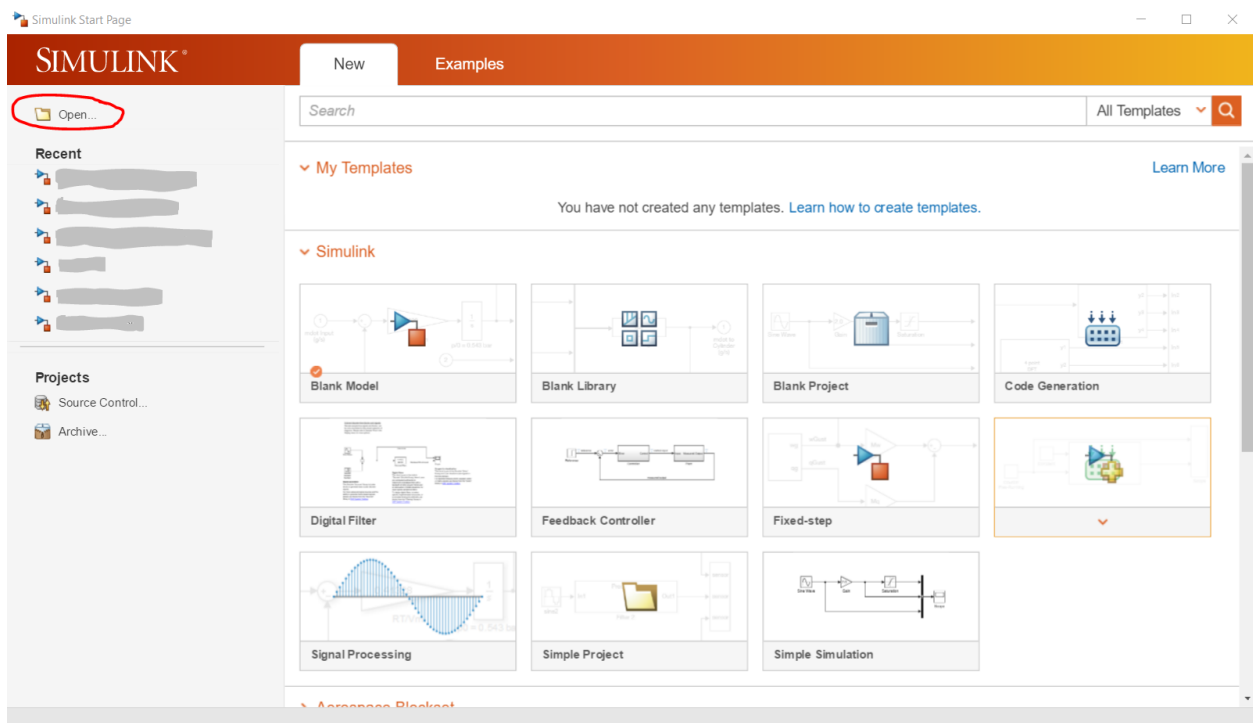
The objective of this lab is to give a better understanding of how power is generated by solar energy through varying levels of irradiance, temperature, and load resistance through Simulink. You will also be using this simulation to determine the load resistance at which maximum power point tracking can be achieved during different levels of temperature and sunlight.

Feel free to use the provided template for this lab to reduce the time needed to create the necessary tables for your data.

Part 1:

For this part of the lab you will be simulating the basic characteristics of photovoltaic (PV) cells based on changes in temperature of the environment.

1. Download the “Resistive_Load_Only.slx” file and open this in Simulink.
 - a. This can be done by first opening MATLAB, then Simulink, and then from the “Simulink Start Page” window click on the “Open...” option and navigate to where the .slx file was saved and select it.



2. Once the file has been successfully opened in Simulink, you can then begin to study how this basic model works. The two constant blocks on the left side are what will be used to change the irradiance (W/m^2) and temperature ($^{\circ}\text{C}$). The resistor that is labeled “Load” will be adjusted and used to model the resistive load.

3. Start the simulation by keeping the irradiance at $1,000 \text{ W/m}^2$, the load at 10Ω , and vary the temperature at 0, 10, 25, 50, 100, and 200°C . You can also set the simulation run time to 0.1 to reduce the load time for each simulation.

a. While you are conducting the simulations, be sure to collect data on the current and voltage outputs on the display and calculate the power.

Deliverable 1:

Discuss any trends and observations you make based on the effects of varying temperature and why these might be happening. What temperature gives the maximum power output? Also include in your report a table with your recorded output voltages, currents, and power at each temperature increment.

Part 2:

This next part of the lab will use the same Simulink file, but instead you will now observe the effects of changing irradiance instead of temperature.

1. To begin, set the temperature to 25°C and keep the resistor to 10Ω and vary the irradiance at 0, 10, 25, 50, 100, 250, 500, and $1,000 \text{ W/m}^2$.

a. Similar to Part 1, record the output currents and voltages and calculate the power.

Deliverable 2:

Discuss any trends and observations you make based on the effects of varying irradiance why these might be happening. What level or irradiance gives the maximum power output? Also include in your report a table with your recorded output voltages, currents, and power at each level of irradiance.

Part 3:

This part of the lab is similar to Parts 1 and 2 where you will be setting the irradiance to $1,000 \text{ W/m}^2$, the temperature to 25°C and then testing with resistance values of 1Ω , 2Ω , 3Ω , 4Ω , 5Ω , 7.5Ω , 10Ω , 15Ω , 20Ω , 50Ω , 100Ω , and 200Ω .

1. Be sure to record the output current, voltage, and power and then create a plot for Voltage vs. Current and Current vs. Voltage with voltage on the x-axis.

a. Use these plots to help estimate the load resistance value which draws the maximum power.

i. Based on the given resistance value that you found to achieve the maximum power, run the simulation a couple more times with a different resistance value close to what you found and try to find the resistance value for achieving the true maximum power.

Deliverable 3:

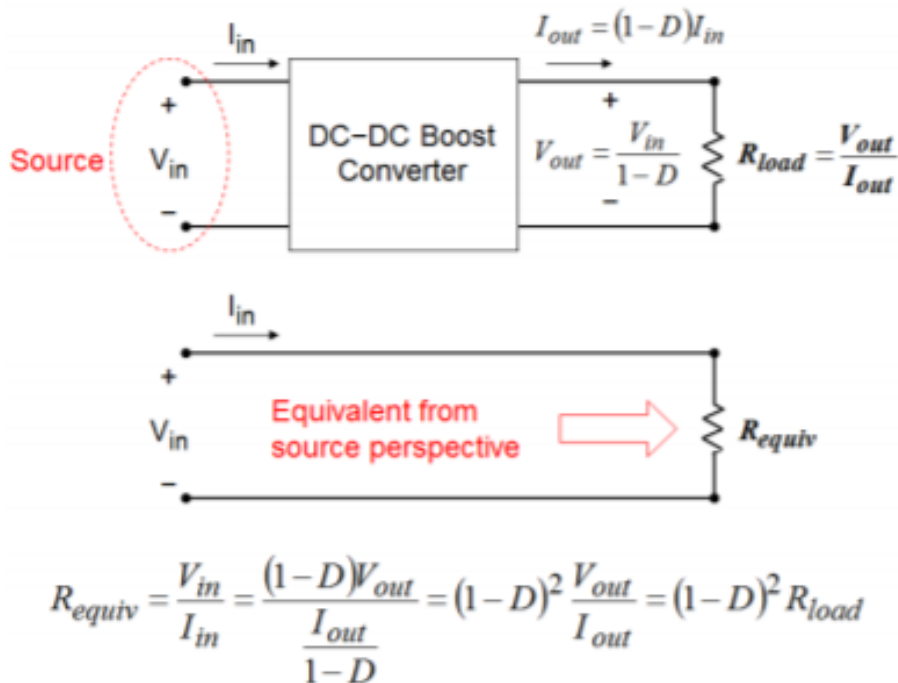
Discuss what trends you noticed when changing the load resistance. What resistance value did you find that drew the most power from the PV array and how much power were you able to achieve?

Part 4:

This next part of the lab will involve a different Simulink model and will work by using a boost converter with a variable duty cycle to find the maximum power point of a similar model you have been using. This model differs in that it has a boost converter connected to the PV array to model a different circuit that can be used to achieve the maximum power point.

1. Similar to Part 1, download the “MPPT_LAB.slx” file and open it in Simulink.
 - a. Once the file has been opened, take some time to analyze it and try to understand how it is working and what might be happening within the model.
- i. This simulation will focus on something called impedance matching which is done by the boost converter.
 - ii. This impedance matching circuit is also used to maintain the maximum power point and the device which performs this task is called Maximum Power Point Tracking or MPPT. This device works by using a DC-DC conversion circuit such as the boost converter along with a logic circuit in order to continuously alter the duty ratio depending on the voltage and current being output by the PV array to maximize the power output at all times.
2. To begin, set the irradiance to 1,000 W/m², the temperature to 25°C, and the load to 50Ω.
 - . Then by using the resistance value you found in Part 3 which gives the most power output, set that equal to R_{equiv} and use the following figure and equations below to calculate the duty cycle which should achieve the maximum

Impedance matching



power.

3. Once you have a general idea of what duty cycle should achieve the maximum power, run the simulation several times while varying the duty cycle and be sure to include the value you found in the last section (Part 4.2) in your data, and record the voltage, current, and power output of the system.

Deliverable 4:

With the irradiance and temperature having been unchanged, what is the duty cycle needed to achieve the maximum power output? Based on the data you recorded for the changing duty cycle, what trends or observations did you notice? Also create a plot showing the Power vs. Duty

Cycle to help visualize where the maximum power point can be achieved with the variables tested.

EE 452 Standalone Wind Systems Lab Manual

Objective:

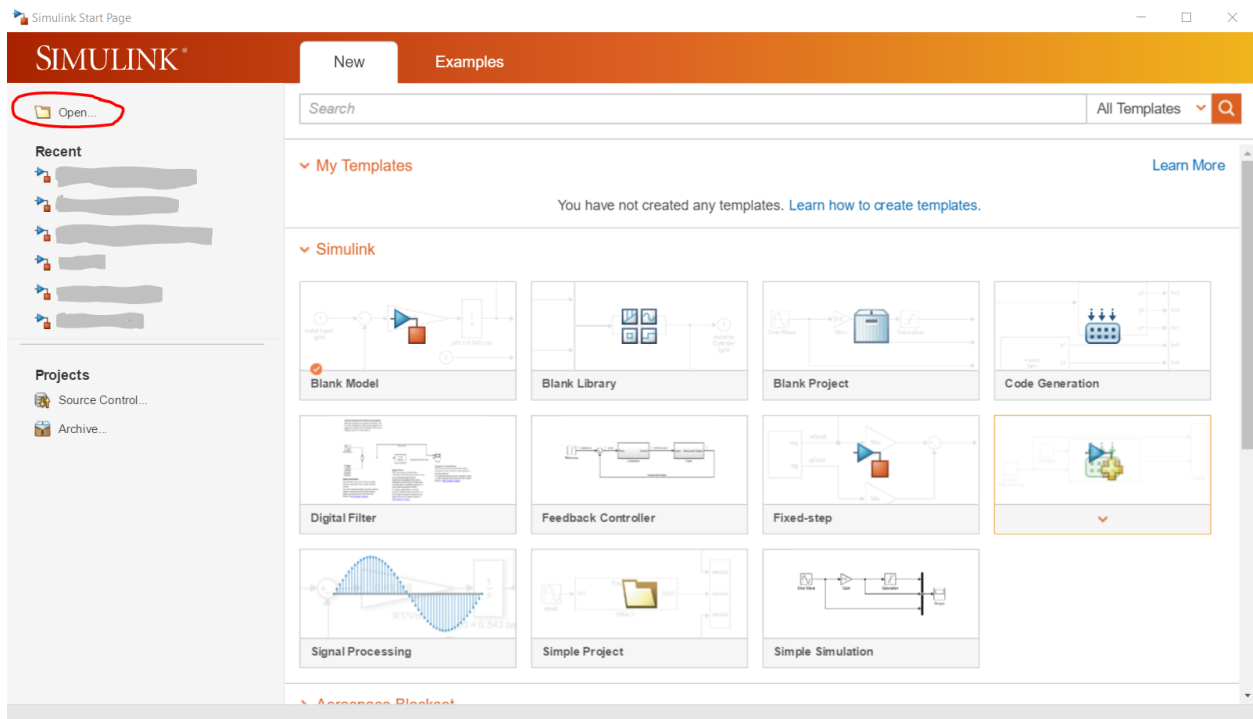
The objective of this lab is to give a better understanding of how power is generated by wind turbines through varying levels of wind speeds, pitch angles, and load resistances through Simulink.

Feel free to use the provided template for this lab to reduce the time needed to create the necessary tables for your data.

Part 1:

For this part of the lab, you will be simulating the basic characteristics of a wind turbine based on changes in wind speed.

1. Download the “Wind_Turbine.slx” file and open this in Simulink.
 - a. This can be done by first opening MATLAB, then Simulink, and then from the “Simulink Start Page” window click on the “Open...” option and navigate to where the .slx file was saved and select it.



2. Once the file has been successfully opened in Simulink, you can then begin to study how this basic model works. The two constant blocks on the left side of the wind turbine block are for

adjusting wind speed (m/s) and pitch angle (deg). The resistor is used to represent the load and will be adjusted in part 3.

3. Set the load resistance to 525 ohms and pitch angle to 0 degrees and set the simulation time to 2 seconds. Vary the wind speeds at 8, 9, 10, 11, 12, 13, and 14 m/s.

For each simulation record the following variables

- a. Load voltage, current, and power.
- b. Wind Turbine torque, Generator speed, and input power. $P=T \cdot \omega$
- c. 3-phase generator instantaneous power

The 3-phase instantaneous power can be found by using the signal statistics measurement tool in the three-phase scope to measure the voltage and current RMS values of phase A. Then use $S=3 \cdot |V_{rms}| \cdot |I_{rms}|$ to calculate the power produced from the generator.

Wind turbine equations (For Reference)

$$T=P/\omega$$

$$\text{Wind turbine power } P=0.5 \rho A C_p(\lambda, \beta) V_w^3$$

$$\text{Air density } (\rho) = 1.225 \text{ kg/m}^3$$

$$\text{Rotor area } (A) (\text{m}^2)$$

$$\text{Maximum power coefficient } (C_p(\lambda, \beta)) \text{ 59.3\% Betz limit}$$

$$\text{Wind speed } (V_w) (\text{m/s})$$

$$\text{Pitch angle } (\beta) (\text{deg})$$

$$\text{Tip speed ratio } (\lambda) = \omega R / V_w$$

$$C_p(\lambda, \beta) = c_1 (c_2 \lambda^{-3} - c_3 \lambda^{-4}) e^{-c_5 \lambda} + c_6 e^{-c_4 \lambda}$$

$$c_1 = .5176, c_2 = 116, c_3 = .4, c_4 = 5, c_5 = 21, c_6 = .0068$$

$$= 1 + .08 \lambda^{-0.0353} + 1$$

Deliverable 1:

Discuss any trends and observations you make based on the effects of varying wind speed and why these might be happening. What wind speed gives the maximum power output? Include in your report a table with your recorded values from above at each wind speed increment. Does the power at the turbine, generator, and load make sense in terms of power loss?

Part 2:

The next part of the lab will use the same model to find the effect of changing the pitch angle of a wind turbine.

1. Set the load resistance to 525 ohms and wind speed to 10 m/s and set the simulation time to 2 seconds. Vary the pitch angles to 0, 1, 2, 3, 4, 5, 8, and 10 degrees.

For each simulation record the same values as part 1.

$$\text{Wind turbine power } P=0.5 \rho A C_p(\lambda, \beta) V_w^3$$

$$C_p(\lambda, \beta) = c_1 (c_2 \lambda^{-3} - c_3 \lambda^{-4}) e^{-c_5 \lambda} + c_6 e^{-c_4 \lambda}$$

$$c_1 = .5176, c_2 = 116, c_3 = .4, c_4 = 5, c_5 = 21, c_6 = .0068$$

$$= 1 + .08 \lambda^{-0.0353} + 1$$

Deliverable 2:

Discuss any trends and observations you made based on the effects of varying pitch angles and why these might be happening. What pitch angle gives the maximum power output? Include in your report a table with your recorded values at each pitch angle.

Part 3:

This final part of the lab will be about finding the effect of load resistance on power and generator speed.

1. Set the wind speed to 10 m/s and the pitch angle to 0 degrees. Now vary the load resistance values to 350Ω , 340Ω , 375Ω , 400Ω , 425Ω , 450Ω , 500Ω , 550Ω , and 330Ω . For each simulation record the same values as part 1.
 - a. Plot the load voltage vs load current to estimate which resistance draws the maximum power. Now test resistances close to your estimate to find the exact resistance.

Deliverable 3:

Discuss what trends you noticed when changing the load resistance. What resistance value did you find that drew the most power from the wind turbine and generator? What was the maximum power were you able to achieve at that resistance?

Simulation of Solar PV-Wind Hybrid Energy System

Introduction

Renewable energy is getting a lot of attention due to the scarcity and bad environmental impact of conventional sources of energy. Wind and solar PV energy are two leading sources of clean energy. The goal of this lab is to study a small-scale stand-alone hybrid model consisting of wind and solar PV energy that will be modeled in MATLAB/SIMULINK. Before continuing to the lab simulations and deliverables, familiarize yourself with the equipment utilized in a hybrid model and begin to draw connections in understanding why they are integrated into the system.

The integration of different energy sources and energy storage systems have been one of the new trends and renewable energy technology. One of the most common ways is a stand-alone wind with solar photovoltaic hybrid combination due to its adaptability of seasonal changes. In the following model, the wind and solar systems are inter-connected with individual DC-DC converters, a battery bank, DC load, and a full-bridge inverter to supply AC power to a load.

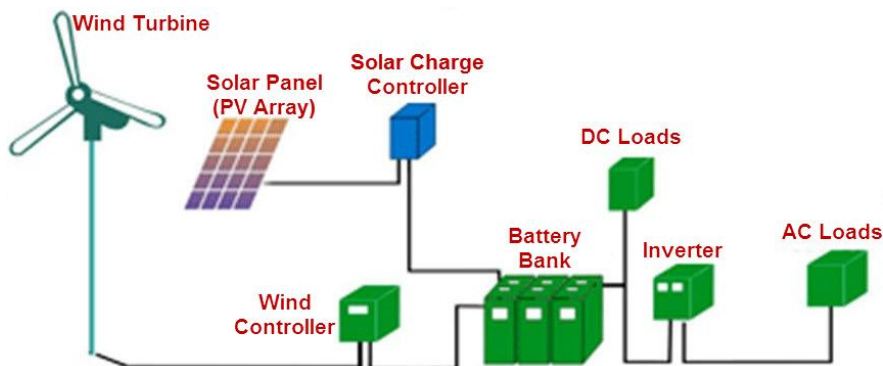


Fig 1: Schematic diagram of hybrid energy system

The proposed hybrid energy system consists of a PV array and induction generation driven wind energy conversion system meeting a common load. The PV system consists of PV arrays and corresponding DC/AC converter modules. Generally, according to the sunlight conditions, the maximum power point tracking control mode is adopted for PV system which aims to maximum utilization of solar energy. A full bridge inverter is used to connect the load to the hybrid system. Batteries are used to store the power when the power production exceeds the demand. The supply from the battery is needed during peak hours when power demand is higher than the production.

Renewable energy systems

Solar PV

This section presents the mathematical models of solar PV, wind and power electronic converters used in the hybrid system. You may also refer to material in the previous labs.

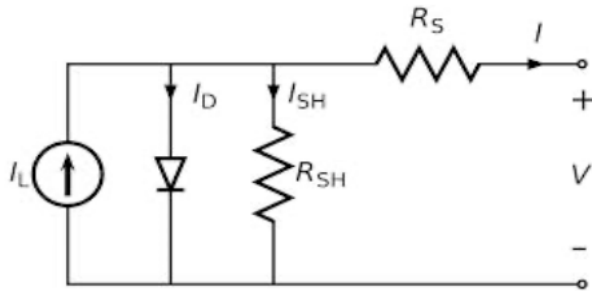


Fig 2: Solar PV cell

A PV system consists of PV arrays. When exposed to sunlight, photons which have energy greater than the band gap energy of the semiconductor are absorbed and create an electron hole – where a pair is proportional to the incident radiation. The output current is calculated as:

$$I = I_{pv} - I_0 \frac{V}{AV_t} - 1$$

One may model the current voltage characteristics of a solar cell as follows:

$$I = I_{pv} - I_0 \frac{V}{AV_t} - 1$$

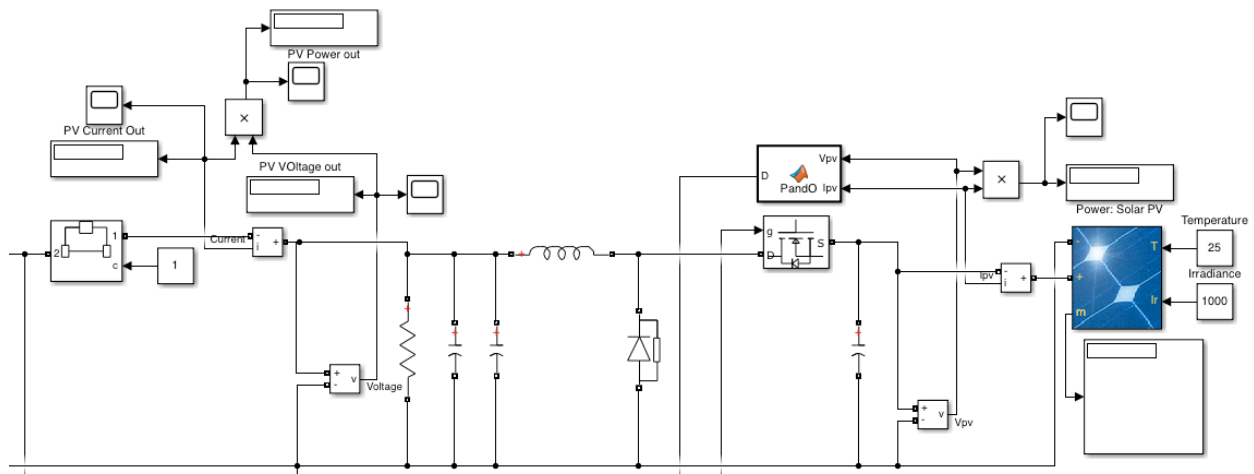


Fig 3: Solar PV array with a buck converter, mppt, and load

Wind

The wind turbine rotor consists of three blades mechanically coupled to a permanent magnet synchronous generator. The power obtained from the wind turbine is calculated as follows:

$$P_{\omega} = \frac{1}{2} C_p \rho A V_{\omega}^3$$

Where

ρ : air density (1.225 kg/m³)

C_p : power coefficient

V_{ω} : wind speed in m/s

A: area swept by the rotor.

The amount of aerodynamic torque (n-m) is given by the ratio of the power extracted from the wind power and turbine rotor noted:

$$T_w = P_{\omega} w_{\omega}$$

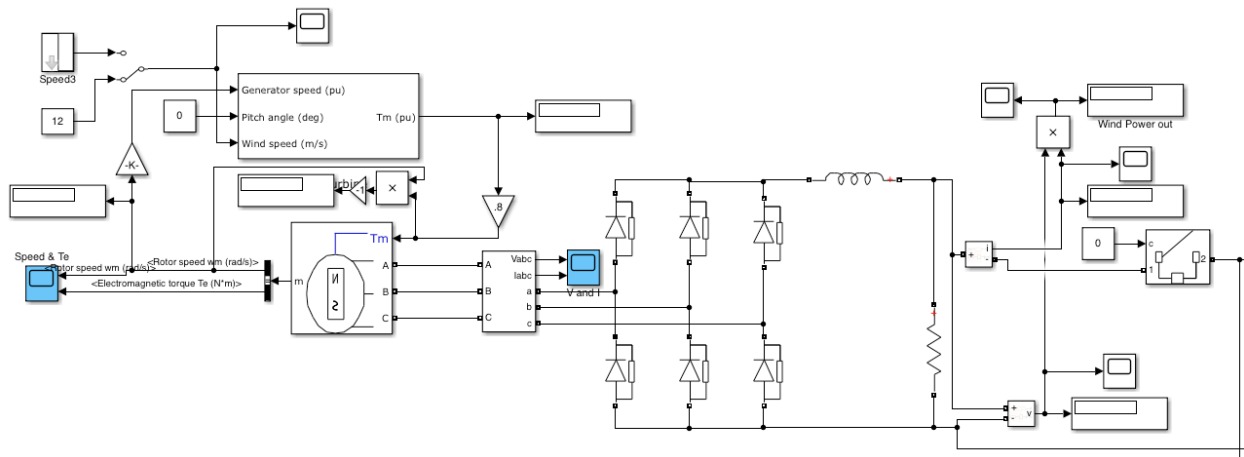


Fig 4: Wind turbine model with PSMG, rectifier, and load

Battery

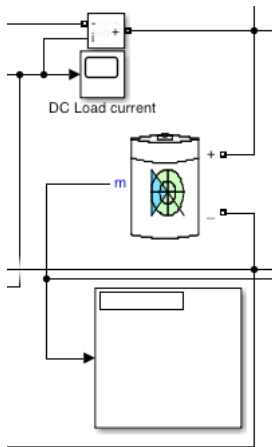


Fig 5: Battery

The storage capacity of a battery at any given time (t) can be calculated as follows:

$$C_{bat}(t) = C_{bat}(t - 1) + P_{pv}(t) + P_{wg}(t) - P_{load}\eta_{cad}^{\Delta t\eta_b}$$

Where:

$C_{bat}(t)$ and $C_{bat}(t - 1)$: battery capacity at time t and t-1

$P_{pv}(t)$: photovoltaic power

$P_{wg}(t)$: wind turbine power

P_{load} : load power

$\eta_{cad}^{\Delta t\eta_b}$: battery and converter efficiency

DC-DC Buck Converter

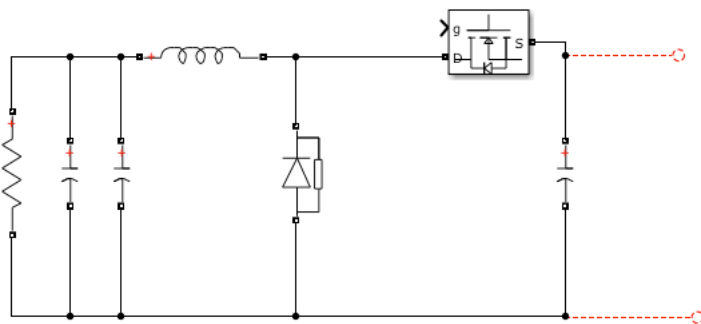


Fig 6: DC-DC buck converter

A DC-DC converter is used to step down the rectified voltage. In the circuit, the gate receives a pulse from the PWM generator. In the figure above, we observe the DC input voltage source, inductor, control switch, diode, capacitor and a load resistance. A buck converter

operates in a continuous mode if the current through the inductor does not fall to zero during the cycle change. It operates as follows:

- When the switch is closed, the voltage across the inductor is:

$$V_L = V_i - V_o$$

The current through the inductor rises linearly. As the current through the diode is reverse biased by the voltage source V , no current flows through it.

- When the switch is opened, the diode is forward biased. The voltage across the inductor is:

$$V_L = -V_o$$

And inductor current decreases.

Full bridge inverter

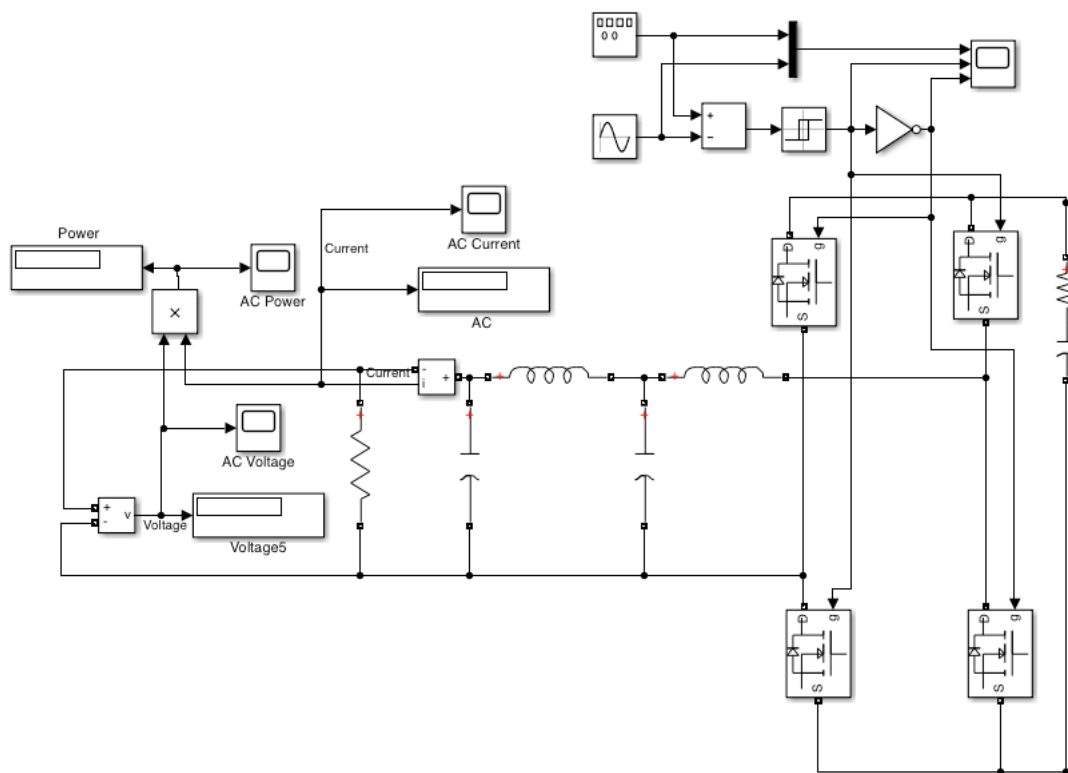


Fig 7: Full bridge inverter

P&O Control for MPPT

The Perturb and Observe method is used primarily for tracking the maximum power point (MPP) in the solar PV subsystem. The algorithm is implemented by a minor disturbance (perturbation) to cause the power variation in the PV module. The output power of the solar PV is continuously measured and compared to the previous power. If the output power increases, then the same process. If not, the disturbance is reversed. For a solar PV subsystem, the PV voltage is increased or decreased to check whether the power is increased or decreased. When

there is an increase in voltage, this leads to increased power, which means the operating point of the PV is on the left side of the algorithm as noted in the figure below. Therefore, more disturbances are needed to shift it towards the right to reach maximum power point. The maximum power point tracking is inter-connected to the battery to monitor the battery voltage. When the battery is fully charged, it stops charging by turning on the DC-DC converter where the duty cycle is increased to extract maximum power from the PV.

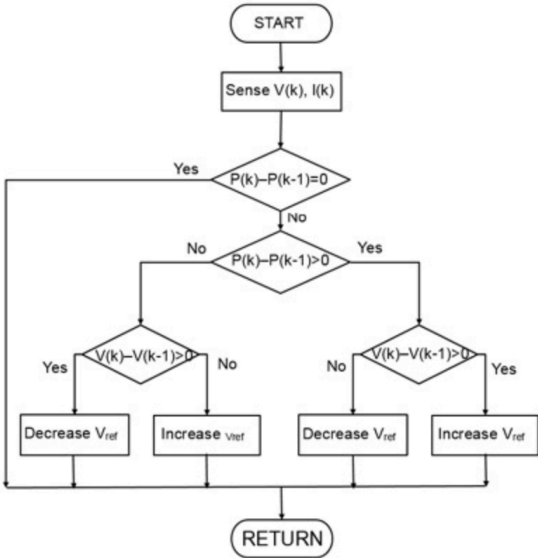


Fig 8: P&O Algorithm

Lab Case Study

A hybrid system has the capability of producing 2039 W when simulated. The parameters of the DC and AC loads are connected to the hybrid system. Below are 4 case studies to study the behavior of a hybrid system under various conditions. In a real application, some of those conditions include varying parameters such as wind speed, wind direction, temperature and irradiation.

Open the Simulink file: hybridmodelcasestudy.slx

Case 1: Hybrid system

In the case both wind and solar PV system are used to meet the demand, a DC/DC buck converter is combined with an inverter to get the output voltage of 404 V. Below is the hybrid system with a DC load of 500 ohms and an AC load of 1100 ohms. And operates with a wind speed of 12 m/s, irradiance at 1000 W/m², and 25 C.

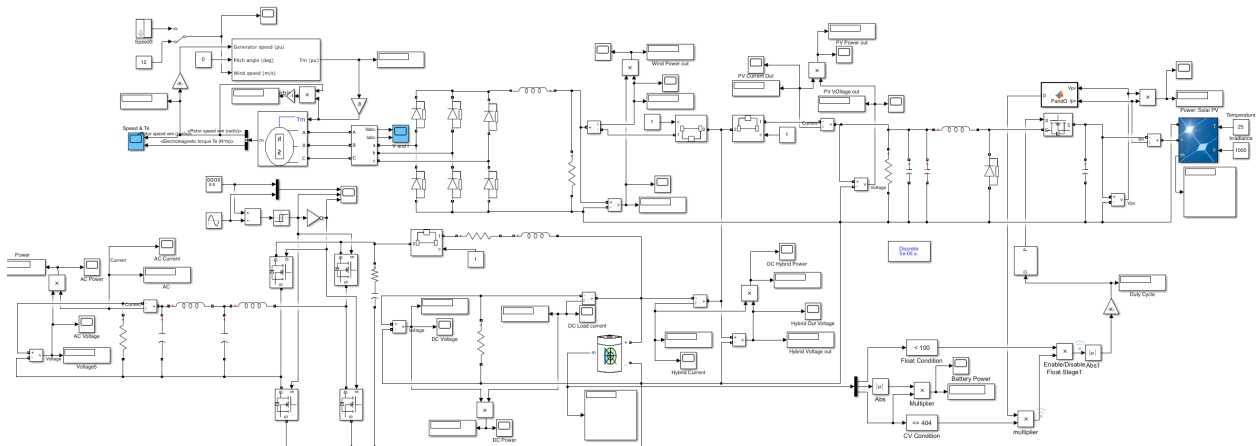


Fig 8: hybrid model

Run the simulation and record your observations

System	Voltage (V)	Current (A)	Power (W)
Wind			
Solar			
Hybrid			
Battery			
DC load (500 ohms)			
AC Load (1100 ohms)			

Obtain voltage, current and power data from DC and AC Loads

DC:

AC:

Case 2: Wind System

In some scenarios, there may be times where the solar PV subsystem may not be able to generate power due to low irradiance. In this case, we will study how the hybrid system functions without the solar PV subsystem.

Flip the breaker off on the solar panel side and run the simulation

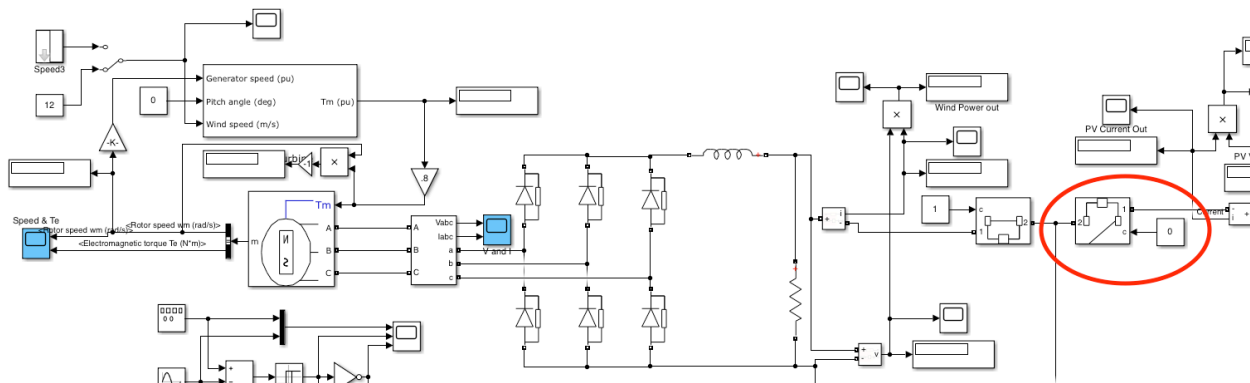


Fig 9: wind model

Run the simulation and record your observations

System	Voltage (V)	Current (A)	Power (W)
Wind			
Solar			
Hybrid			
Battery			
DC load (500 ohms)			
AC Load (1100 ohms)			

Obtain voltage, current and power data from DC and AC Loads

DC:

AC:

Case 3: solar PV system

In some scenarios, there may be times where the wind subsystem may not be able to generate power due to low wind speeds. In this case, we will study how the hybrid system functions without the wind subsystem.

Flip the breaker off on the wind turbine panel side

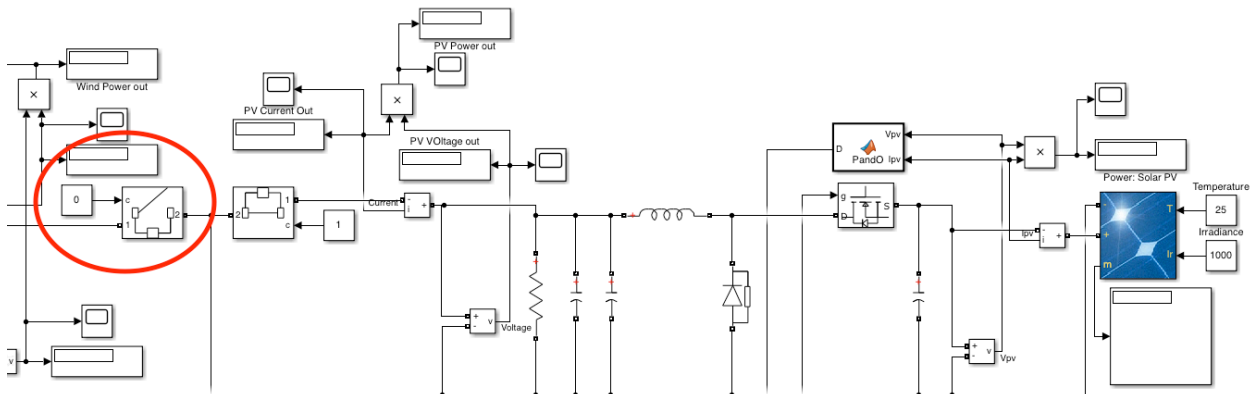


Fig 10: solar PV system

Run the simulation and record your observations

System	Voltage (V)	Current (A)	Power (W)
Wind			
Solar			
Hybrid			
Battery			
DC load (500 ohms)			
AC Load (1100 ohms)			

Obtain voltage, current and power data from DC and AC Loads

DC:

AC Loads:

Case 4: Battery storage system

In some scenarios, there may be times where both wind and solar PV subsystems may not be able to generate power due to poor conditions. In this case, we will study how the hybrid system functions without the solar PV and wind subsystem.

Battery Specifications

Parameter	Nominal Voltage	Capacity
Rating	202 V	100 Ah

Flip the breaker off on the wind turbine and solar PV panel sides

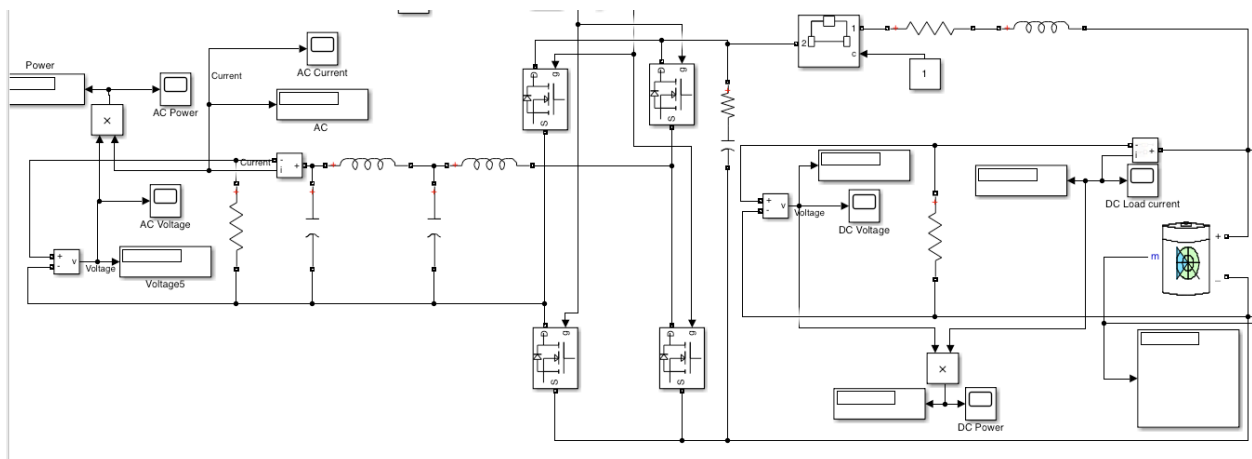


Fig 11: battery storage system

Run the simulation and record your observations

System	Voltage (V)	Current (A)	Power (W)
Wind			
Solar			
Hybrid			
Battery			
DC load (500 ohms)			
AC Load (1100 ohms)			

Obtain voltage, current and power data from DC and AC Loads and battery.

Battery power:

If the battery has a charge capacity of 100Ah, how long will the battery take to dissipate into the DC and AC loads?

We note that In the case that PV and wind are not able to provide any power, the battery system can provided power over the span of time.

Record What you have learned below:

Lab Case Study (SOLUTION)

Note: this lab manual serves as a testing implementation for our system

A hybrid system has the capability of producing 2039 W when simulated. The parameters of the DC and AC loads are connected to the hybrid system. Below are 4 case studies to study the behavior of a hybrid system under various conditions. In a real application, some of those conditions include varying parameters such as wind speed, wind direction, temperature and irradiation.

Open the Simulink file: hybridmodelcasestudy.slx

Case 1: Hybrid system

In the case both wind and solar PV system are used to meet the demand, a DC/DC buck converter is combined with an inverter to get the output voltage of 404 V. Below is the hybrid system with a DC load of 500 ohms and an AC load of 1100 ohms. And operates with a wind speed of 12 m/s, irradiance at 1000 W/m², and 25 C.

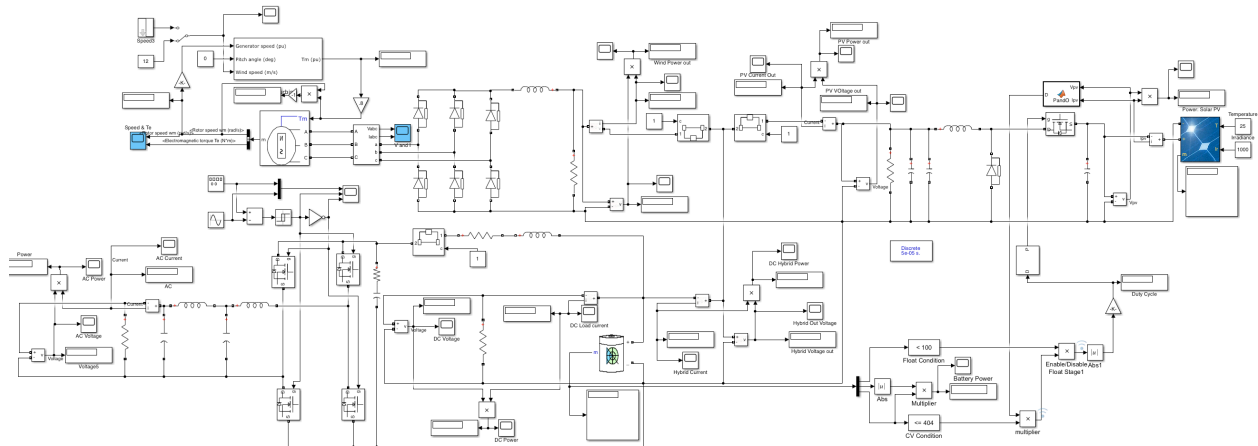


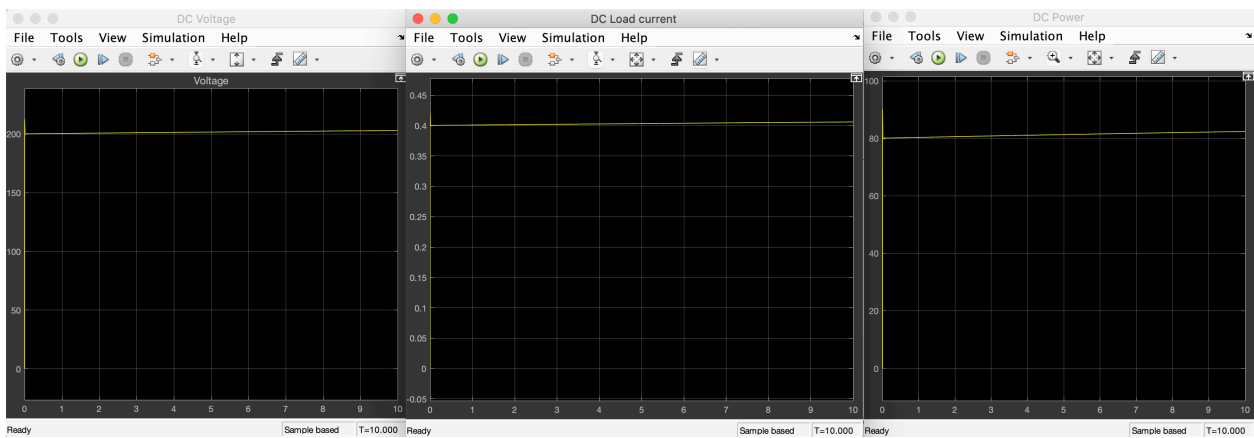
Fig 8: hybrid model

Run the simulation and record your observations

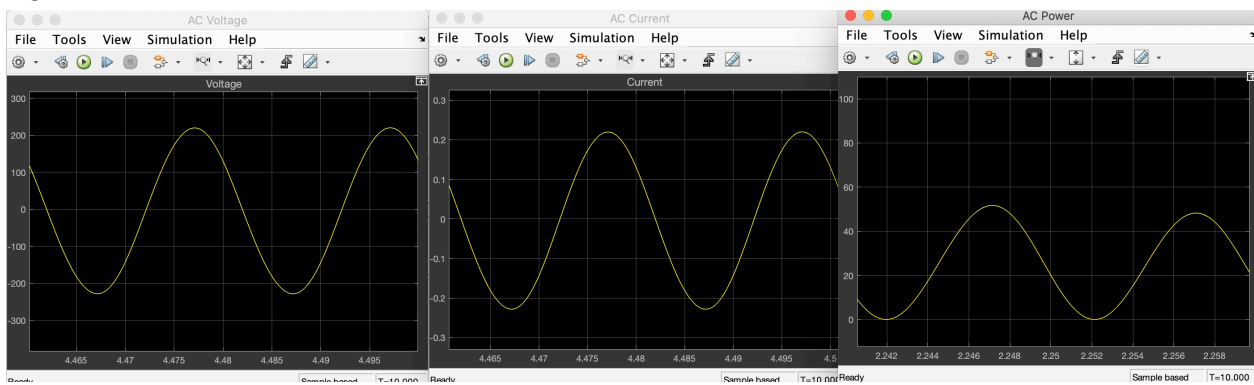
System	Voltage (V)	Current (A)	Power (W)
Wind	203	2.177	442
Solar	203	7.866	1597
Hybrid	203	10.04	2039
Battery	203	9.43	1921
DC load (500 ohms)	203	0.406	82.42
AC Load (1100 ohms)	203	0.175	35.525

Obtain voltage, current and power data from DC and AC Loads

DC:



AC:



Case 2: Wind System

In some scenarios, there may be times where the solar PV subsystem may not be able to generate power due to low irradiance. In this case, we will study how the hybrid system functions without the solar PV subsystem.

Flip the breaker off on the solar panel side and run the simulation

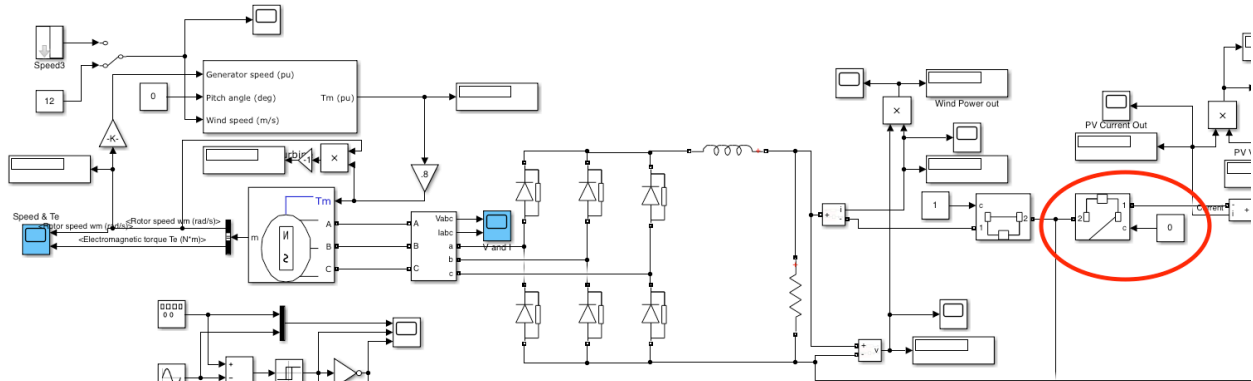


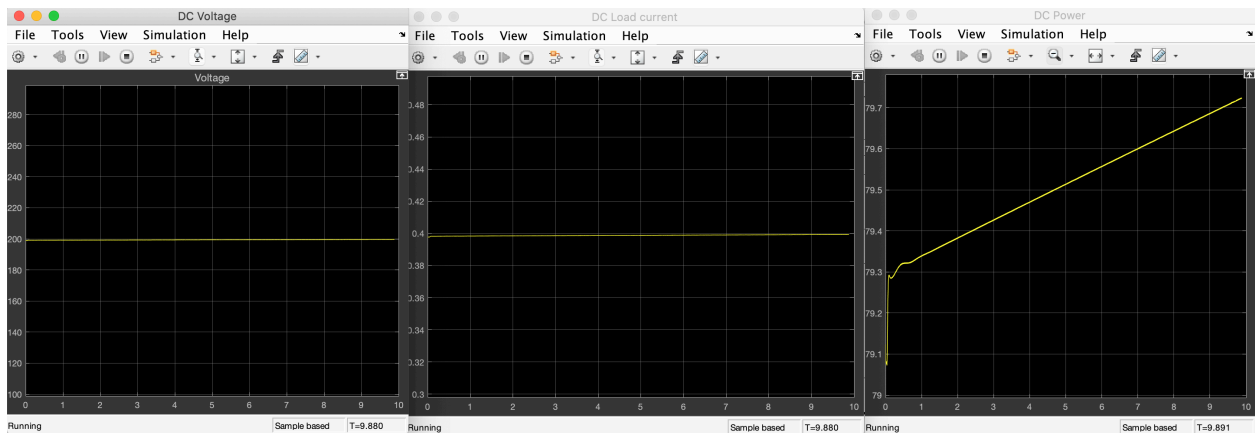
Fig 9: wind model

Run the simulation and record your observations

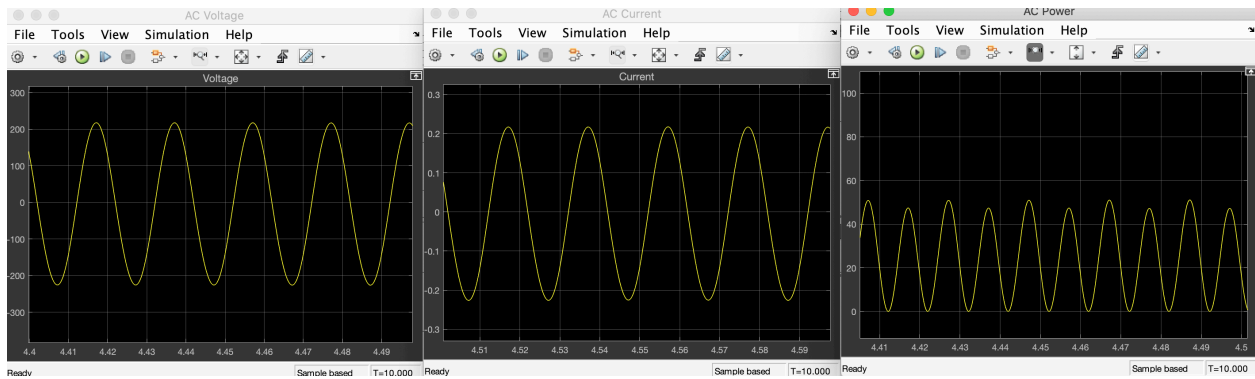
System	Voltage (V)	Current (A)	Power (W)
Wind	199.7	2.2	439.3
Solar	0	0	0
Hybrid	199.7	2.2	439.3
Battery	199.7	1.63	325.4
DC load (500 ohms)	199.7	.399	79.73
AC Load (1100 ohms)	199.7	.1717	34.17

Obtain voltage, current and power data from DC and AC Loads

DC:



AC:



Case 3: solar PV system

In some scenarios, there may be times where the wind subsystem may not be able to generate power due to low wind speeds. In this case, we will study how the hybrid system functions without the wind subsystem.

Flip the breaker off on the wind turbine panel side

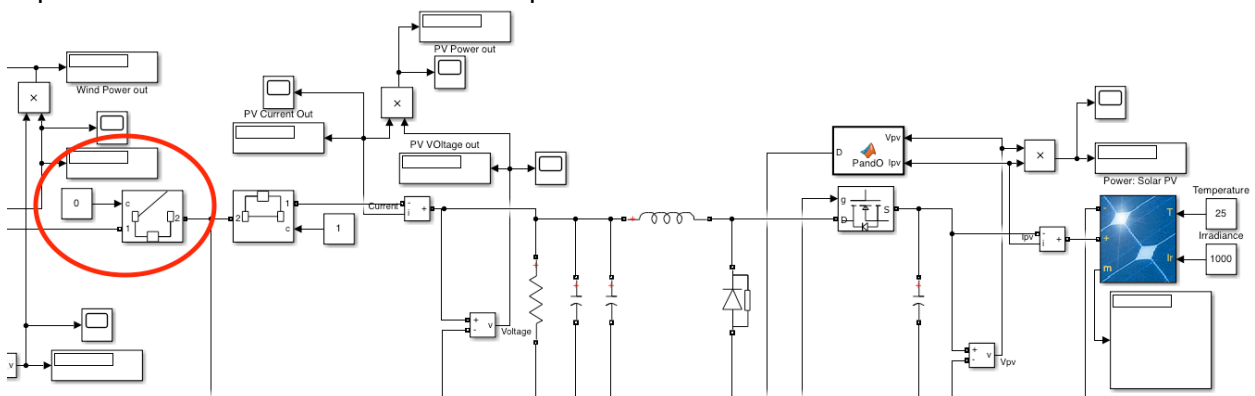


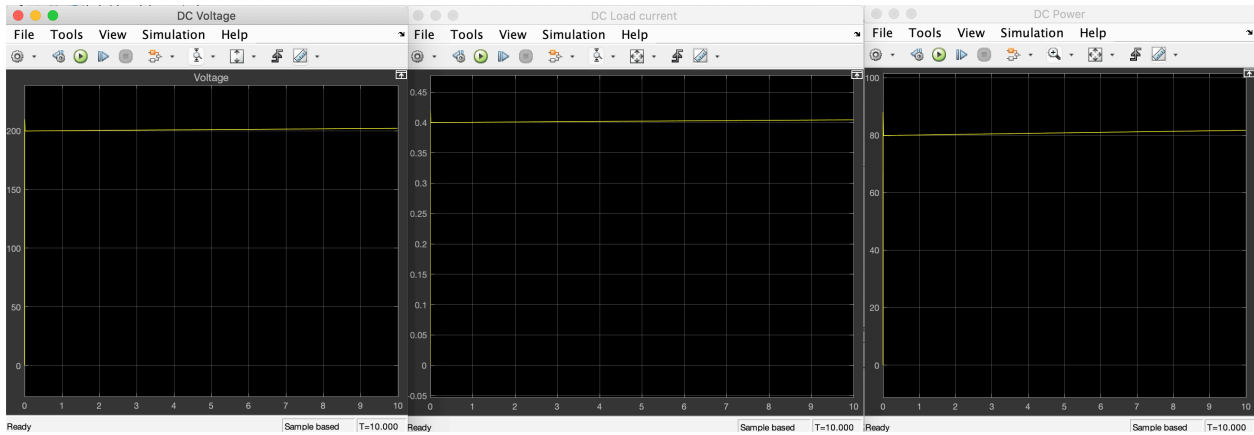
Fig 10: solar PV system

Run the simulation and record your observations

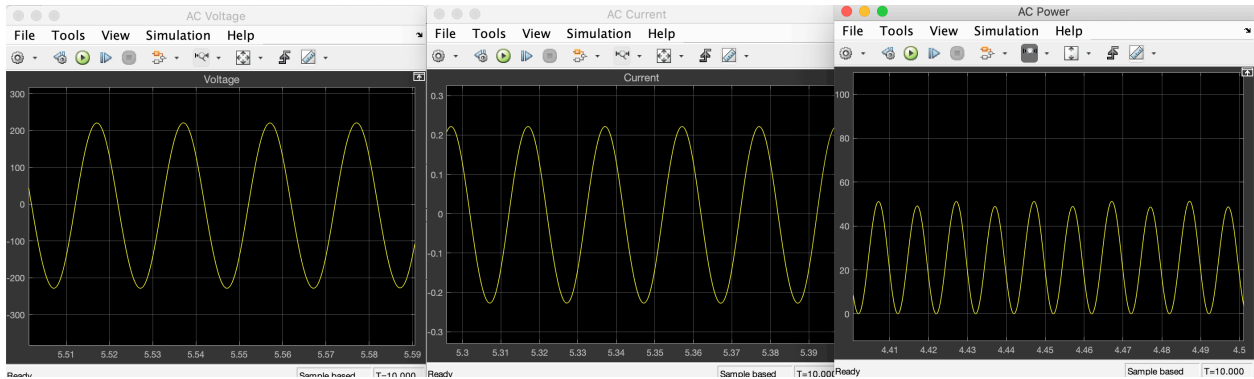
System	Voltage (V)	Current (A)	Power (W)
Wind	0	0	0
Solar	202.1	7.967	1590
Hybrid	202.1	7.967	1590
Battery	202.1	7.29	1473
DC load (500 ohms)	202.1	.4042	81.7
AC Load (1100 ohms)	202.1	.174	35.3

Obtain voltage, current and power data from DC and AC Loads

DC:



AC Loads:



Case 4: Battery storage system

In some scenarios, there may be times where both wind and solar PV subsystems may not be able to generate power due to poor conditions. In this case, we will study how the hybrid system functions without the solar PV and wind subsystem.

Battery Specifications

Parameter	Nominal Voltage	Capacity
Rating	202 V	100 Ah

Flip the breaker off on the wind turbine and solar PV panel sides

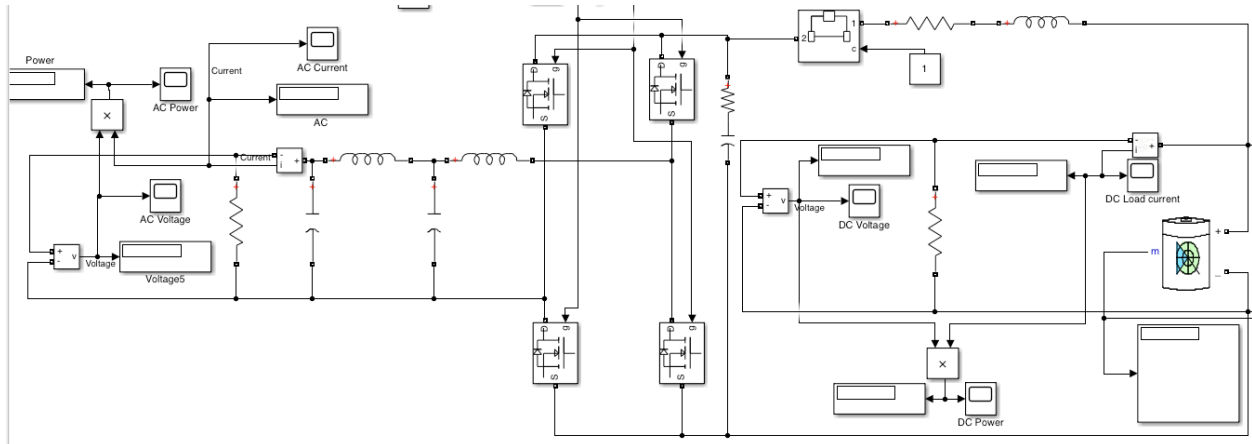


Fig 11: battery storage system

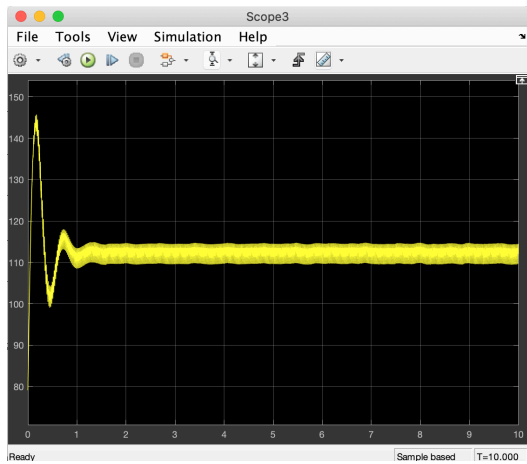
Run the simulation and record your observations

System	Voltage (V)	Current (A)	Power (W)
Wind	0	0	0
Solar	0	0	0
Hybrid	0	0	0
Battery	198.8	0.5681	113
DC load (500 ohms)	198.8	.3977	79.07
AC Load (1100 ohms)	198.8	.17	33.93

Obtain voltage, current and power data from DC and AC Loads and battery.



Battery power:



If the battery has a charge capacity of 100Ah, how long will the battery take to dissipate into the DC and AC loads?

$$0.72 \text{ A} \times h = 100\text{Ah}$$

$$100/0.72$$

$$H = 138.88 \text{ hrs}$$

We note that In the case that PV and wind are not able to provide any power, the battery system can provided power over the span of time.

Record What you have learned below: