Wind-Powered Building

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CONCEPT OF OPERATIONS

REVISION – 1
12 February 2022

CONCEPT OF OPERATIONS
FOR
Wind-Powered Building

TEAM 07

APPROVED BY:

Colton Boos 04/30/22
Project Leader Date

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Draft	2/9/2022	Peter Zha		Draft Release
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1. Executive Summary

Tall buildings, offices, and high-rises are commonplace in urban environments. In particular, strong winds can be found at the top of these structures, which is usually left unharvested. Our aim is to harness the power of the wind and take advantage of this form of energy that is readily available to us. Through The Wind-Powered Building, we will implement electricity generation at a local level. By powering part of the building's electrical systems with renewable energy, this will save money for electricity producers and consumers, along with helping preserve the environment around us.

2. Introduction

The Wind-Powered Building will harness mechanical energy from the wind and convert it into electrical energy. By integrating a wind turbine into the building's structure, the electrical energy produced will shed part of the electrical load a building consumes. This results in a reduced usage of fossil fuels and a step towards using only renewable energy sources for the future of the environment.

2.1. Background

Buildings receive their power through the electrical grid, and typically electricity generation is produced from fossil fuels. While the electrical grid does implement renewable energy sources for some electrical generation, it is not enough. Coal is the largest source of electrical generation as well as the biggest contributor to climate change [1]. Furthermore, wind power is commonly captured through large scale wind farms, which may consist of hundreds of individual wind turbines. Wind farms, in addition to other forms of electricity production, are typically at remote locations and their power is carried by transmission lines to higher density populations [2].

By implementing wind-power closer to the consumer, there is no transmission network involved. Additionally, with this method of power generation, wind turbines will be able to take part of the building's electrical load off the grid, and away from nonrenewable fossil fuels.

2.2. Overview

Our system will be deployed to capture wind energy on the top of a building, and in turn, deliver power to that same building. Power will be stored into battery reserves and be used immediately as well as for the future. In cases of when the battery is full there will be a charge controller to change the flow of power onto a dump load. A system of power conversions will be implemented on the input and output of the battery to deliver power to the building.

A monitoring system will also be set up to observe the power intake and outtake of our wind powered system. The monitoring system will be able to display the status of the batteries and assist in tasks such as changing the flow of power to the batteries or the dump load.

2.3. Referenced Documents and Standards

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[3] “Design and Construction of a Wind Turbine Dump-Load Charge Controller.” Warlock, Warlock Engineering, https://www.warlock.com.au/dumploadcontroller.htm.

[4] Analyst, James Gignac Lead Midwest Energy, et al. “Wind Turbine Blades Don't Have to End up in Landfills.” The Equation, Union of Concerned Scientists, 7 Dec. 2021, https://blog.ucsusa.org/james-gignac/wind-turbine-blades-recycling/.

[5] “Wind Turbine Dump and Diversion Loads: What They Do and How to Choose the Right System.” Windy Nation, https://www.windynation.com/jzv/inf/wind-turbine-dump-anddiversion-loads-what-they-do-and-how-choose-rights#:~:text=The%20charge%20controller%20constantly%20monitors%20the%20voltage%20
of%20the%20battery%20bank.&text=Once%20the%20battery%20bank%27s%20vol ta ge,to%20charging%20the%20battery%20bank.

[6] “Charge Controller.” The Back Shed, https://www.thebackshed.com/windmill/articles/TL084-Controller.asp.

[7] “How To Charge a Lead Acid Battery” Power Sonic https://www.power-sonic.com/blog/how-to-charge-a-lead-acid-battery/

3. Operating Concept

3.1. Scope

The Wind-Powered Building will consist of an outlet for distributing and deploying power for appliances. While the entire system is a scaled down version of large wind turbines connected to the power grid, our system will charge battery storages instead. The wind turbine used will be pre-assembled and will not be part of the components designed for the project. Subsystems connected to the wind turbine will be designed and fabricated to control the power output generated by the wind turbine and power input into the building. An additional subsystem will monitor, control, and display further aspects of The Wind-Powered Building.

3.2. Operational Description and Constraints

The Wind-Powered Building will be used to power basic electrical loads that plug into AC, as well as lighting systems that run off DC. The AC power output into the building will imitate a standard electrical outlet in a residential home, therefore, voltage, current, and power readings will be compared with that of a typical home outlet. The turbine itself will be chosen as an individual unit designed to power small appliances, including:

- Laptop and cellphone chargers
- Small monitors
- LED Lighting

Small household appliances will benefit the most from the system, as they draw a smaller amount of power from the battery. When maximum charge of the batteries is reached, the dump load drawing power away from batteries must be sufficiently large enough to consume all power produced by the wind turbine. Due to the limited budget of $400, additional batteries may not be available to substitute for a dump load. There will be a limited amount of power generated due to the costs of the wind turbine and batteries. The Wind-Powered Building will only be tested under windy conditions. The use of artificial wind by fans shall be used to simulate these testing conditions as well.

3.3. System Description

The Wind-Powered Building consists of five key subsystems, with four of these involving power conversion and delivery. The wind turbine will generate power and deliver this to a battery bank. The battery bank will deliver power to the building, including alternating current and direct current. The bulk of our subsystems lies within this flow of power from the source to the destination.

Rectification and Conversion Subsystem: The wind turbine will output three-phase alternating current (AC). However, direct current (DC) is needed to charge the battery bank. The rectifier will take the wind turbine’s AC and output DC. The converter will take this DC voltage and convert it to a DC voltage appropriate to the batteries’ specification for charging.

Inversion and Conversion Subsystem: The batteries will output DC and after this, the power will split into separate paths for use in the building. The first path involves the use of an inverter to take the DC from the battery and output AC. This can be used in the building to power AC loads. The second path will lead to the building's lighting system which requires the use of DC. To achieve the specific voltage used by the lighting system, the converter will take the batteries' power output and convert it to that specified DC voltage.

Charge and Switch Controller Subsystem: The charge controller comes before the battery bank where it changes the flow of power from one battery to the other. After one battery is fully charged, the charge controller will automatically start charging the other battery. The charge controller also serves as a safety measure for the batteries. When both batteries are fully charged, the charge controller will divert electricity to a dump load. It is not safe or efficient to continue charging a full battery, and it is important for the wind turbine to always have an electrical load connected.

The switch controller comes after the battery where it utilizes the proper flow of power. The switch controller automatically connects the appropriate battery to the inverter and converter. While one battery is charging, the switch controller will connect the other battery to the building. Its job is to prevent the simultaneous charging and discharging of one battery.

Monitor Subsystem: The monitor is the central intelligent hub of the Wind-Powered Building, and it serves two major functions. The first is the collection and display of data. By collecting the building's power consumption and status of the battery bank charge levels, we can output this on a website. The second function involves the use of this data to control aspects of The Wind-Powered Building. Since the monitor will read the batteries' charge levels, it will send appropriate signals to the controller. The monitor is programmed to read states of the charge controller, and this will determine the state of the switch controller.

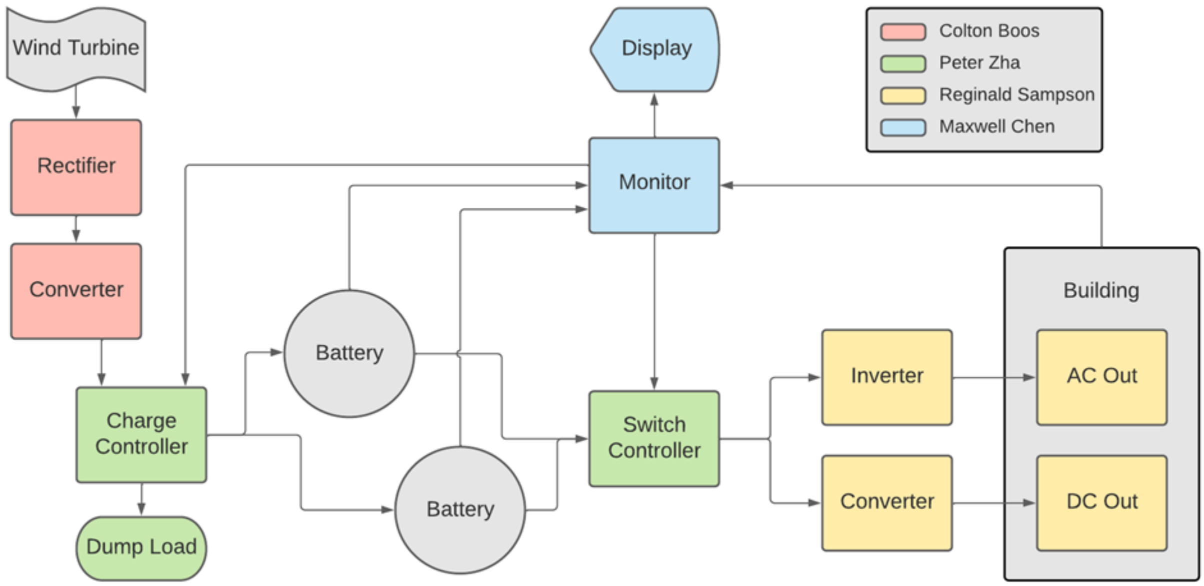

Figure 1. Wind-Powered Building Block Diagram

3.4. Modes of Operations

Charging: The charging mode features two processes involving the battery bank. While a battery is being charged through the wind turbine, it shall not be connected to any electrical load. The Wind-Powered Building shall be supplied by the battery not being charged. For example, when the first battery is being charged, the second battery will provide power to the building. The charge and switch controllers are managing this flow of power.

Fully Charged: When the battery bank is fully charged, the flow of electricity will be diverted away from these batteries. The charge controller will connect the power generated by the wind turbine to a dump load. In this mode, The Wind-Powered Building shall continue consuming power if needed and once the battery drops below a specified threshold, the mode will change back to charging.

3.5. Users

Individual consumers and larger entities will equally benefit from The Wind-Powered Building. In smaller applications and residential use, the wind turbine may provide adequate power to allow off-grid use, especially in conjunction with those already using alternative methods such as solar power. In larger applications, the wind turbine may be added to a building with existing electrical grid connections. In both cases, installation of the wind turbine and sequential subsystems will require basic knowledge of power systems. The user must understand how to safely connect resistive loads and wire terminals, as well as how to interpret voltage and power readings.

3.6. Support

Support for the users will be provided through manuals created by the team. Potential hazards and safety precautions will be clearly stated. Basic troubleshooting steps will also be listed to provide users with solutions for common issues found within each subsystem.

4. Scenario(s)

4.1. Renewable Energy

Areas with emission standards may be looking for renewable energy sources to reduce their emissions of CO2 and greenhouse gasses. The Wind-Powered Building will generate electric power by harnessing wind and utilizing a renewable energy. Wind is an infinite source of fuel and is only limited by the capacity of the battery used to store the power generated.

4.2. Optimizing Cost of Energy

Buildings that require expensive fuel sources or experience high power losses may need a new cost-effective system to generate power. The Wind-Powered Building will harness wind, a free fuel source, to generate its power. The cost saved in the long term will pay for the initial construction of the wind turbine system and on-going maintenance of the system. Additionally, The Wind-Powered Building will monitor its power usage and switch between wind and grid generated power.

4.3. Independent Power Source

Remote geographical regions may be dependent on imported fuel sources to generate power to their buildings. The Wind-Powered Building will focus on using wind as a local and independent fuel source. Usage of nearby sources of energy will not only decrease costs, with less reliance on importing fuel, but also help promote environmentally friendly operations.

5. Analysis

5.1. Summary of Proposed Improvements

The Wind-Powered Building aims to bring an alternative source of energy in a changing time where more people are moving towards renewable energy sources. Wind-generated energy seeks to replace fossil fuel-based energy sources, and the Wind-Power Building serves as a model for future renewable energy solutions. The project places greater emphasis on tweaking individual subsystem components for better performance overall, leading to more efficient and sophisticated wind-powered systems.

5.2. Disadvantages and Limitations

The complete Wind-Powered Building will be limited by operational capacity and battery requirements. Subsystem components cannot exceed maximum capacity requirements for voltage, current, power, and energy consumption [3]. Overcharging the battery for long periods of time can result in permanently reduced battery capacity [4]. The wind turbine will not output power in times where there is no wind. The battery will provide needed power during this time. In times where there is no wind and the battery is drained, the building and its systems will be powered by the grid.

5.3. Alternatives

There are a few different configurations for the Wind-Powered Building. The location of the wind turbine can be varied by placing it lower on the building, or even placing it on the ground. However, because stronger winds are located at higher elevations, this solution could raise problems for this alternative. Wind turbines that are placed lower will lead to more intermittency of power generation in conjunction with less overall power output. A different alternative would be increasing wind power generation to provide more power to the building and decreasing the load to the grid. Larger energy storages and bigger wind turbines are needed with this approach, but battery banks are resource intensive and would also require higher initial costs to set up.

5.4. Impact

Providing renewable energy through wind power has considerable benefits to our environment; however, there are some drawbacks to consider. Wind turbines can cause noise pollution due to its mechanical system, and they can be a visual nuisance as well. Additionally, they can harm local wildlife, including birds and bats that fly into spinning turbine blades. Wind turbines can have a long lifespan, but when they are decommissioned, their blades will need to be recycled and reused, or risk filling up landfills even more [5]. Routine maintenance will be required in frequent intervals to keep the turbines optimized.

Wind-Powered Building

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FUNCTIONAL SYSTEM REQUIREMENTS

REVISION – Draft
22 February 2022

FUNCTIONAL SYSTEM REQUIREMENTS
FOR
Wind-Powered Building

PREPARED BY:

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Author Date

APPROVED BY:

Colton Boos 04/30/22
Project Leader Date

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John Lusher, P.E. Date

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T/A Date

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Draft	02/22/2022	Colton Boos		Draft Release
1	04/30/2022	Colton Boos		Revision 1

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1. Introduction

1.1. Purpose and Scope

The Wind-Powered Building is a new power system designed to be an easy way for people to integrate the power of wind energy into their buildings, reducing the usage of fossil fuels and promoting the usage of green energy. Our system is designed to be quite simple to allow for implementation into a variety of buildings. It has also been designed in a fashion that will allow the user to easily monitor the system. Figure 1 shows a general outline of the system with its various components.

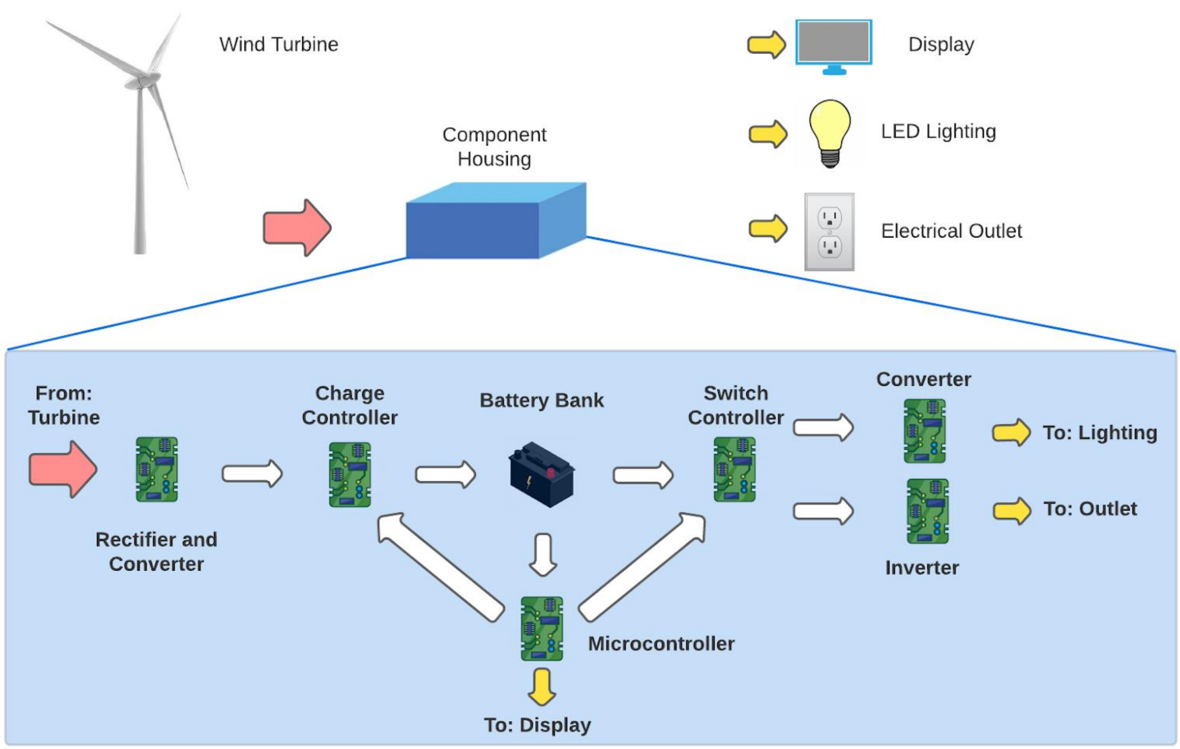

Figure 1. Wind-Powered Building Conceptual Implementation

The system converts energy generated by the wind turbine into usable energy for the building. This is achieved through the usage of a rectifier and converter to convert and lower the power into usable state to be stored in the batteries. Once the energy is stored in the battery it is then sent to be used by the building with an inverter and converter to convert the power into either AC or DC power based on the appliances used by the building.

The system also has a monitoring system that will track the battery levels of both batteries. Using this information, the monitoring system will then manage the switch controllers to control which battery is being used and which battery is being charged. This includes the small chance that both batteries are fully charged in which case the dumpload will be utilized as a safety measure. In addition to these functions the monitoring system will also be able to provide useful information to the user such as power generated by the wind turbine and the power consumption of the building on the entire system.

1.2. Responsibility and Change Authority

The team leader, Colton Boos will hold the responsibility of ensuring that the project requirements are met. The project sponsor, Wonheok Jang and team leader, Colton Boos possess the authority to make changes to the specifications and requirements of the system.

Subsystem	Responsibility
Rectification and Conversion	Colton Boos
Inversion and Conversion	Reggie Sampson
Charge and Switch Controller	Peter Zha
Monitor System	Maxwell Chen

Table 1. Subsystem Ownership

2. Applicable and Reference Documents

2.1. Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Document Number	Revision/Release Date	Document Title
IEEE 2760	2020	IEEE Guide for Wind Power Plant Grounding System Design for Personal Safety
IEEE 2030.2.1	2019	IEEE Guide for Design, Operation, and Maintenance of Battery Energy Storage Systems, both Stationary and Mobile, and Applications Integrated with Electric Power Systems
IEEE 1834	2019	IEEE Standard for Technology Supervision Code for Wind Turbine Rotor Systems
IEEE 60076-16	2018	IEC/IEEE International Standard - Power transformers - Part 16: Transformers for wind turbine applications
IEEE C57.12.01	2020	IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers
NEC 210	2020	National Electrical Code, Branch Circuits

2.2. Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/Release Date	Document Title
IEEE C37.30.2	2015	IEEE Guide for Wind-Loading Evaluation of High Voltage (>1000V) Air-Break Switches

2.3. Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable report are considered to be for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

3. Requirements

3.1. System Definition

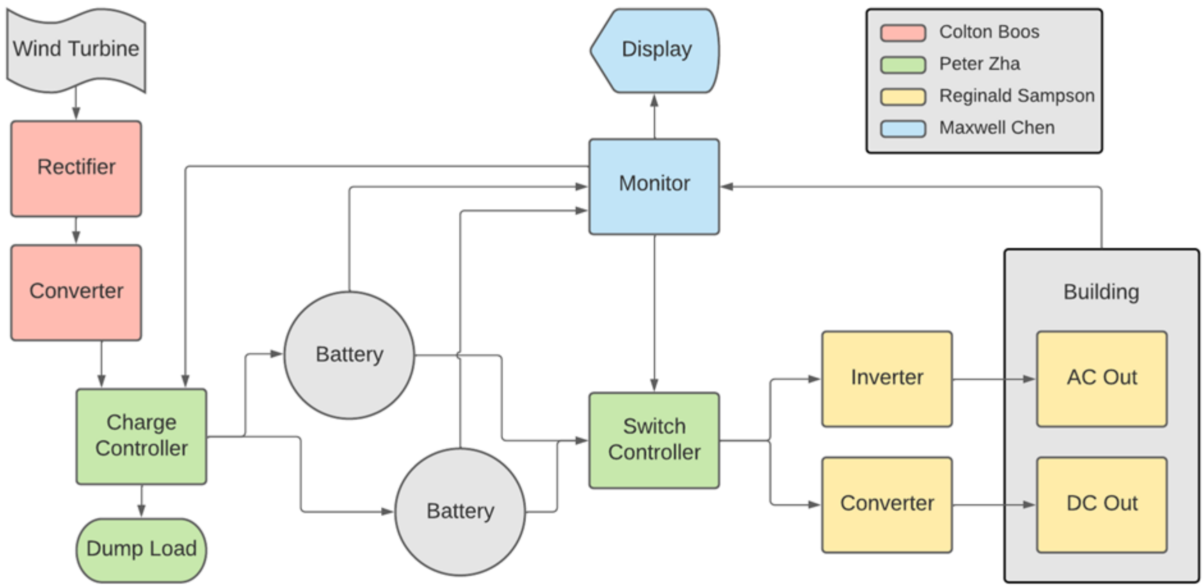

Figure 2. Wind-Powered Building Block Diagram

The Wind-Powered Building will be supplied by electricity through this flow of power. The wind turbine will generate power and store this into the battery bank. One subsystem is involved in this path. Rectification and Conversion subsystem will convert power to meet the batteries' specifications. After this, the battery will supply power to the building with another subsystem involved in this path. Conversion and Inversion subsystem will convert the batteries' power into DC and AC respectively. A switching subsystem will be in place before and after the battery bank. This is in charge of what battery to charge and what battery to power the building. Separately, a Monitor subsystem will observe the batteries' charge and power consumption of the building, and display the information onto a website.

3.2. Characteristics

3.2.0. Functional / Performance Requirements

3.2.0.1. Energy Storage

The Wind-Powered Building shall take the energy produced by the wind turbine and store this into the battery bank. The system shall charge two batteries, each with 7Ah capacity.

> *Rationale: Due to the nature of wind power being intermittent, energy storage is needed to provide the building with constant electricity, including periods the wind turbine may go without producing power.*

3.2.0.2. Power Output

The Wind-Powered Building shall provide two forms of electrical output: AC and DC. Further details are elaborated in *Electrical Characteristics* below.

> *Rationale: This is the core system performance requirement. The Wind-Powered Building will provide two different forms of electrical output, AC and DC, due to how different appliances in the building require either AC or DC power.*

3.2.0.3. Frequency of Measurement

The Wind-Powered Building monitoring system checks the status of the battery every couple of seconds to ensure it has an accurate reading.

> *Rationale: The monitoring system should be consistently checking the status of the battery in order to ensure that the batteries are not going over capacity or that there is no power source to output to the building.*

3.2.1. Physical Characteristics

3.2.1.1. Mass

The mass of the wind turbine shall not exceed individual building safety standards in regards to rooftop appliances.

> *Rationale:* The wind turbine should not damage the roof of the structure supporting it, and likewise must have a stable foundation on which to stand.

3.2.1.2. Structure

A majority of the components will be internal inside the building however the wind turbine needs to be securely placed on the building.

> *Rationale: The wind turbine will be susceptible to the various weather conditions so it needs to be placed securely in order to ensure that any incidents do not occur.*

3.2.1.3. Mounting

The Wind-Powered Building and all its subsystems properly mounted shall be captured in the Wind-Powered Building ICD.

> *Rationale: Properly mounted subsystems of the Wind-Powered Building and their connections include thermal and electrical components.*

3.2.2. Electrical Characteristics

3.2.2.1. Inputs

a. The presence or absence of any combination of the input signals in accordance with ICD specifications applied in any sequence shall not damage the Search and Rescue System, reduce its life expectancy, or cause any malfunction, either when the unit is powered or when it is not.

b. No sequence of command shall damage the Search and Rescue System, reduce its life expectancy, or cause any malfunction.

Rationale: By design, should limit the chance of damage or malfunction by user/technician error.

3.2.2.1.1. Power Production

a. The maximum peak power of the system shall not exceed 800 watts.

Rationale: This is measurement corresponds with the power output of the wind turbine to be connected with the combined subsystems.

3.2.2.1.2. Input Voltage Level for Rectification

The input voltage level for the rectification circuit of the Wind-Powered Building shall be 12V AC.

Rationale: The wind turbine will output a specified voltage, and this will feed directly into the rectifier.

3.2.2.1.3. Input Voltage Level for Converter

The input voltage level for the converter circuits shall be +12V DC.

Rationale: Rectifier output voltage feeds into first converter, battery bank output voltage feeds into second converter, both consist of 12 volt DC.

3.2.2.1.4. Input Voltage for Battery Bank

Each battery shall be supplied with an input voltage of +15V DC for charging.

Rationale: Constraint due to the input voltage specified by the battery manufacturer for cyclic charging.

3.2.2.1.5. Input Voltage for Microcontroller

The input voltage for the microcontroller should not exceed +5V DC.

Rationale: Constraint due to the input voltage specified by the microcontroller manufacturer.

3.2.2.2. Outputs

3.2.2.2.1. Power Consumption

The power consumed by devices connected to the system shall not exceed 900 W

Rationale: Limited battery capacity cannot support higher power output.
Diagnostic Output

3.2.2.2.2. Inverter Voltage Output

The output voltage from the inverter connected to the building shall be equivalent to a nominal voltage of 120V RMS.

Rationale: A typical household outlet outputs 120 V, so the Wind-Powered Building should imitate this output when used to power household appliances.

3.2.2.2.3. Converter Voltage Output

The output voltage of the converter connected to the building shall be equivalent to +12VDC

Rationale: This is a constraint due to the input voltage for the LED lighting system used in the building.

3.2.2.2.4. Display/Website Output

The Wind-Powered Building shall gather information on power consumption of the building as well as the charge levels of the battery bank and present this information on a website according to the Monitor subsystem.

Rationale: Includes information pertinent to users of the Wind-Powered Building.
Connectors

3.2.2.3. Wiring

The wiring for the Wind-Powered Building subsystem shall be completed according to NEC 210 standards.

Rationale: Conform to National Electrical Code standards for safe wiring.

3.2.3. Environmental Requirements

The Wind-Powered Building shall be designed to withstand and operate in the environments and laboratory tests specified in the following section.

Rationale: The Wind-Powered Building will need to function in outdoor environments due to the nature of harnessing wind energy from a wind turbine.

3.2.3.1. Wind Speed

The Wind-Powered Building shall withstand and operate at wind speeds ranging from 5mph to 90mph.

Rationale: The wind turbine will need sufficient wind speed to output power while wind speeds too strong will contribute to the degradation of the wind turbine.

3.2.3.2. Altitude

The Wind-Powered Building shall withstand and operate at altitudes ranging from 20ft to 3,000ft compared to the altitude of ground level.

Rationale: Higher altitudes are associated with more turbulent winds which may contribute to the degradation of the wind turbine. Altitudes lower than 20ft compared to ground level is associated with lower wind speeds and insufficient power generation.

3.2.3.3. External Contamination

The Wind-Powered Building shall withstand and operate in environmental contamination such as smoke and smog. The system shall withstand and operate in environmental contamination such as dirt and dust excluding cases where extreme contamination causes the wind turbine to cease functioning properly. The system shall withstand and operate in environmental contamination such as wildlife and its corresponding interactions not including cases where the wind turbine may be damaged or impeded by wildlife.

Rationale: The Wind-Powered Building may be implemented in a variety of regions and the wind turbine must withstand and function in corresponding natural contaminations. For urban areas, smoke and smog are common contaminants. For more rural areas, dirt and dust are common contaminants. Both areas are associated with wildlife interactions.

3.2.3.4. Thermal

The Wind-Powered Building shall operate in temperatures ranging from -40°F to 120°F.

Rationale: This range includes the temperatures for a region where the customer may implement the Wind-Powered Building due to the operating temperature of the wind turbine.

3.2.3.5. Rain

The Wind-Powered Building shall withstand and operate in rain not exceeding 1” per hour.

Rationale: Extremely heavy rains may impede the production of sufficient power and will contribute to the degradation of the wind turbine and its blades.

3.2.4.6 Humidity

The Wind-Powered Building shall withstand and operate in humidity ranging from 0% to 90%

> *Rationale: Higher humidity is associated with faster corrosion of the wind turbine and will shorten the lifespan of the system.*

4. Support Requirements

The Wind-Powered building does not require any extra resources or materials other than power to the monitoring system. The system will include a display to showcase information on the system such as the battery capacity, power generated, and power usage. As typical with any power system, the subsystems should be checked on and maintained regularly to ensure that they are functioning properly.

Appendix A: Acronyms and Abbreviations

AC	Alternating Current
Ah	Ampere-hour
DC	Direct Current
Ft	Feet
LCD	Liquid Crystal Display
LED	Light-emitting Diode
mph	Miles per Hour
RMS	Root Mean Square
V	Volt
W	Watt

Appendix B: Definition of Terms

Charge Controller	Mechanism used to control what battery is being charged and operation of the dump load.
Monitoring System	System that monitors the capacity of the battery along with the amount of power generated and used in the system
Switch Controller	Mechanism used to control what battery is being used by the building
Battery Bank	Composed of two 7.2Ah Sealed Lead-Acid Batteries

Wind-Powered Building

Reginald Sampson
Maxwell Chen
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Peter Zha

INTERFACE CONTROL DOCUMENT

REVISION – 1
30 April 2022

INTERFACE CONTROL DOCUMENT
FOR
Wind-Powered Building

PREPARED BY:

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Author   Date

APPROVED BY:

Colton Boos   04/30/22
Project Leader   Date

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John Lusher II, P.E.   Date

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T/A   Date

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Draft	02/22/2022	Colton Boos		Draft Release
1	04/30/2022	Colton Boos		Revision 2

Table of Contents

1. Overview

The Interface Control Document (ICD) for the Wind-Powered Building will provide more information on each of the four subsystems discussed in the Concept of Operations and the Functional Systems Requirements. The ICD will include specific information on the physical, thermal, electrical, and communication interfaces of the subsystems.

2. References and Definitions

2.1. References

Heat Dissipation of the TriStar & TriStar MPPT Controllers inside Enclosures
2014

Safety Requirements for Board-Mounted DC/DC Converters
November 2011

2.2. Definitions

AC	Alternating Current
Cm	centimeter
LCD	Liquid Crystal Display
V	Volt

3. Physical Interface

3.1. Weight

3.1.0. Weight of Inversion and Conversion Subsystem

The weight of the inversion and conversion subsystem shall be less than 2 pounds. Majority of the weight will be contributed by the PCB, heatsinks, a transformer and the three prong outlet.

3.1.1. Weight of Rectification and Conversion Subsystem

The weight of the rectification and conversion subsystem shall be no more than 1 pound. Both circuits consist of electrical components placed onto a PCB and by nature it will not be heavier than 1 pound.

3.1.2. Weight of Charge and Switch Controller Subsystem

The weight of each charge controller shall be within 1 to 3 pounds. Each charge controller consists of PCBs, heatsinks, switch relay solenoids, cooling fans, and the housing to protect the subsystem.

3.1.3. Weight of Monitor Subsystem

The weight of the monitor subsystem will only be a couple of grams as it is only composed of the microcontroller, internal wirings, and the housing for the system.

3.2. Dimensions

3.2.0. Dimension of Inversion and Conversion Subsystem

The dimensions of the inversion and conversion subsystem shall be 25 x 13 cm. These dimensions are the upper limit and may be subject to decrease if the PCB development requires less space or increase if a housing for the PCB is created.

3.2.1. Dimension of Rectification and Conversion Subsystem

The total area enclosed by the rectification and conversion subsystem shall be no bigger than $250cm^2$ as the dimensions would be 25 x 10 cm. The subsystem can be decreased to a smaller dimension but it will not be bigger than proposed.

3.2.2. Dimension of Charge and Switch Controller Subsystem

The dimensions of each charge controller shall be approximately 30 x 12 x 7 cm in volume. These dimensions may be smaller depending on the layout of the PCB.

3.2.3. Dimension of Monitor Subsystem

The size of the monitor subsystem at most will be around 5.5 x 17cm which is the size of a breadboard. This is to house the microcontroller and resistors that are needed for the input and outputs of the system. The size can be further decreased in the future if needed.

3.3. Mounting Locations

The entire system, excluding the wind turbine, shall be mounted on a sturdy wall inside the building supporting the wind turbine. The devices should be mounted in a location away from potential electrical hazards, and should accommodate enough wiring to and from the turbine so the wires do not have to be strained. All subsystems should be mounted in the same room so that maintenance may be readily performed.

4. Thermal Interface

The charge controllers, utilizing power electronic circuits will require heatsinks to dissipate the heat generated by MOSFETs used in the circuits. Computer fans shall be mounted to aid in the cooling alongside the heatsinks.

5. Electrical Interface

5.1. Primary Input Power

Input from the wind turbine will be 3-phase VAC.

5.2. Microcontroller Input Power

The microcontroller part of the monitor subsystem will be supplied with a separate battery supply with input up to 5V for the micro usb port and inputs between 7 and 12V for the VIN port.

5.3. Video Interfaces

The monitor subsystem will display information to a website hosted by the microcontroller that will be accessible to those on the same network.

5.4. User Control Interface

User interaction with the system will involve push buttons on the switch controller and monitor subsystems.

6. Communications / Device Interface Protocols

6.1. Microcontroller Input and Output

The microcontroller we are using has a wide range of input and outputs. It consists of multiple ADC (Analog to Digital Converter) inputs that can be utilized to read signals from the battery with a voltage range of 0 to 3.3V. The microcontroller also has two DAC (Digital to Analog Converter) ports that can output up to 3.3V, which will be used to control the switch and charge controllers as needed.

6.2. Display/Website Monitor

The microcontroller will host a local website that will display the information on the battery status and power consumption and usage of the building. Users on the same network will be able to access this website.

Wind-Powered Building

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EXECUTION PLAN

	Jan 31	Feb 7	Feb 14	Feb 21	Feb 28	Mar 7	Mar 14	Mar 21	Mar 28	Apr 4	Apr 11	Apr 18	Apr 25	Apr 30
ConOps Report														
Research and Identify Parts														
Conceptual Subsystem Designs														
FSR, ICD, Execution and Validation Plans														
Midterm Presentation														
High Level Subsystem Designs														
Simulate and Develop Converter														
Simulate and Develop Inverter														
Simulate and Develop Rectifier														
Develop Battery Monitor														
Calculate Power Usage and Generated														
Develop theory for charge controller														
Status Update Presentation														
Develop Local Website for System Monitor														
Finalize calculations for charge controller														
Test switching for charge controller														
Prepare Output Signal for Switch Controller														
Develop Boost Converter														
Final Presentation														
Connect Rectifier and Converter														
Final Demo														
Final Report														

Completed
In Progress
Behind Schedule

Wind-Powered Building

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VALIDATION

Subsystem	Validation Requirements	Status
Inversion and Conversion Subsystem		
DC-AC Conversion	12VDC is converted to 12VAC	Completed
Transformer Step-up	Transformer output is 120VAC given 12VAC input	Completed
Inverter Output	Connected outlet outputs 120VAC	Completed
Converter with battery	Circuit elements function properly with battery voltage	Completed
Converter Output	Output meets DC voltage requirements of LEDs	Completed
Rectification and Conversion Subsystem		
AC-DC Conversion	2-15VAC is rectified to corresponding DC with < 0.2 V output ripple	Completed
DC-DC Conversion	4-15VDC is converted to 15VDC	Completed
Connect Rectifier and Converter	Voltage output 15 VDC	Completed
Charge and Switch Controller Subsystem		
Charge controller circuit validation	Conceptual circuit matches with parameters	Completed
Input/Output	Switch correctly transfers input power to output	Completed
Load Capacity	circuit can withstand expected load of input and output	Completed
Switch Validation	The switch correctly switches between outputs	Completed
Monitor Subsystem		
Battery Capacity Monitor	System is able to successfully track the capacity of the battery	Completed
Display Power Generated and Power Usage	System is able to display the power generated from the Wind Turbine, and the power used by the building	Completed
Website for System Monitoring	Website is accessible and cleanly displays information about the entire system	Completed
Output Signal for Switch Controller	System will have triggers for specific cases of when each battery should be used or charged. Further implementation will be done in 404	Completed

Wind-Powered Building

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SUBSYSTEM REPORTS

SUBSYSTEM REPORTS
FOR
Wind-Powered Building

PREPARED BY:

____
Author Date

APPROVED BY:

Colton Boos 04/30/22
Project Leader Date

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John Lusher II, P.E. Date

____
T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
Draft	04/30/2022	Colton Boos		Draft Release

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1. Introduction

The Wind-Powered Building project focuses on the power systems that convert, monitor, and store the power generated from a wind turbine to be delivered to an individual home. Each subsystem divides the overall system into relevant, manageable portions that each serve a different purpose. The rectifier and converter, the charge and switch controllers, the inverter and converter, and the monitor subsystems each manage a portion of the power delivery system. This system also features the use of two batteries for simultaneous charging and discharging, allowing for more efficient power gathering and delivery. Thorough validation testing was conducted on each subsystem to verify the working principles of each system in preparation for future system integration.

2. Rectification and Conversion Subsystem Report

2.1. Subsystem Introduction

The Rectification and Conversion Subsystem is designed to transfer the energy generated by the wind-turbine into a more usable form. This subsystem is crucial for charging the battery bank and was designed around those specifications. The wind-turbine will generate electricity when wind speeds are high enough, and this subsystem will be operating during those times.

2.2. Subsystem Details

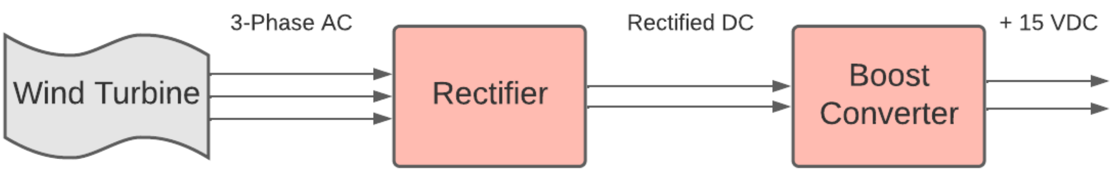


Figure 1. Rectification and Conversion Subsystem Block Diagram

The Rectification and Conversion Subsystem involves two circuits: a three-phase rectifier and a boost converter. These circuits are connected in series and were designed with that in mind. The goal of this subsystem is to charge the battery bank, however, the overall output passes through a separate subsystem prior to the bank.

2.2.0. Three-phase Rectifier Details

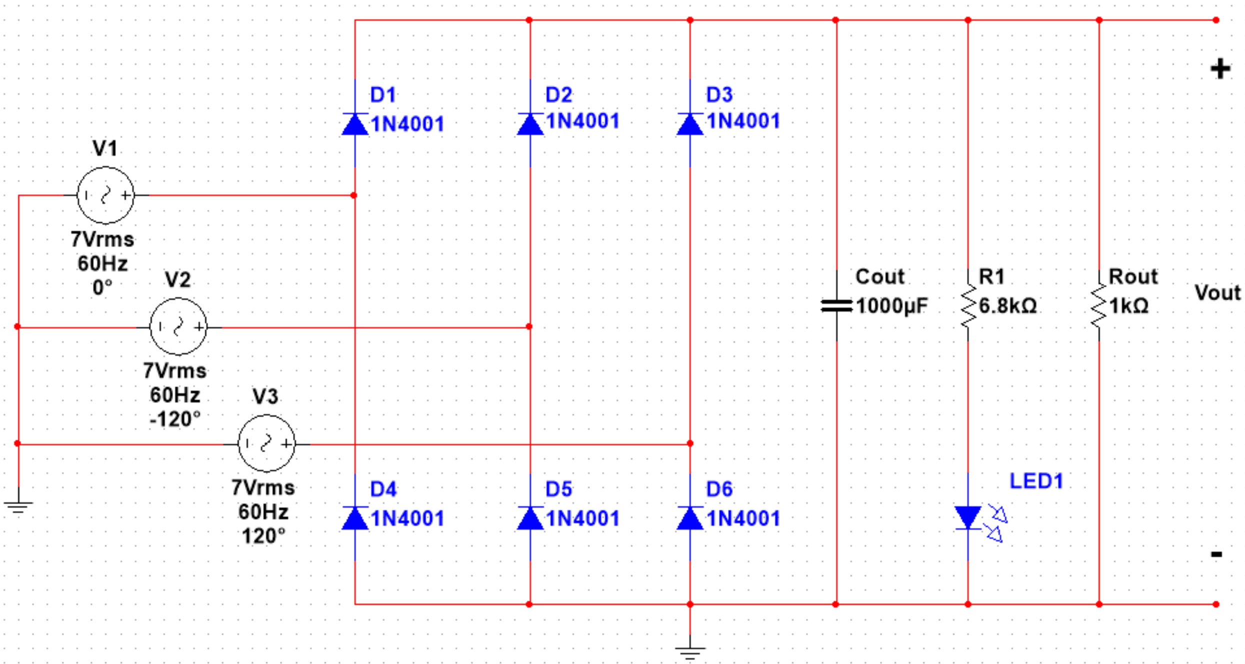


Figure 2. Schematic of Three-phase Rectifier

Considering the flow of power, from energy generation to electrical output, the three-phase rectifier is the first circuit in this path. It is directly connected to the wind-turbine and is where the circuit receives its inputs. Three identical AC voltages make up this input, each one being 120 degrees out-of-phase with one another. Through a network of diodes, the circuit will rectify the input and achieve a DC output. The output power will fluctuate with respect to the wind speed, and a range of voltages will be passed onto the next circuit in this subsystem. There is an associated output voltage ripple with this rectifier, which was minimized with the use of a large enough capacitor.

2.2.1. Boost Converter Details

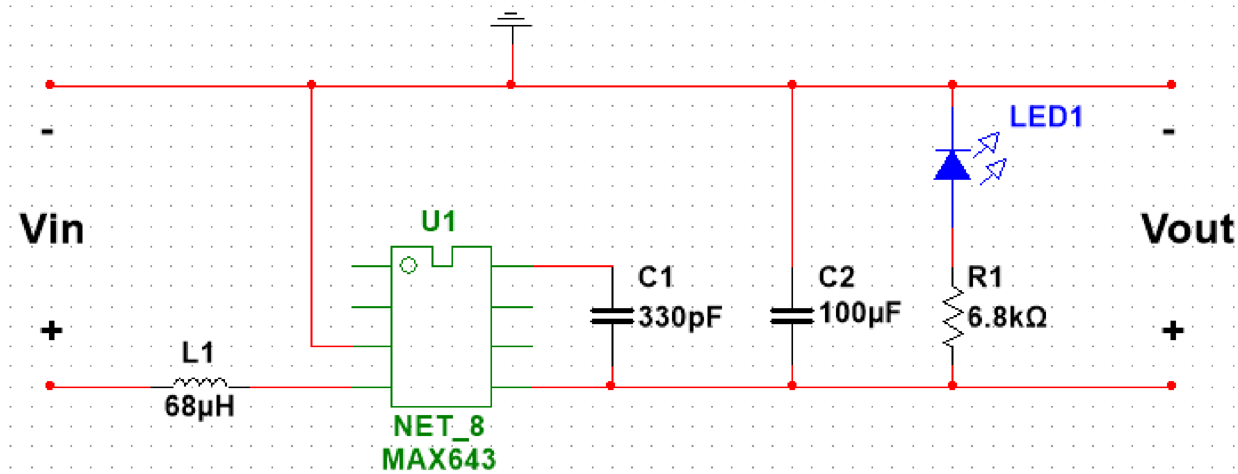


Figure 3. Schematic of Boost Converter

The goal of this boost converter is to take in a variety of input voltages then proceeds to output a constant voltage. Through experimentation, a boost topology was chosen since the wind-turbine will be generating voltages less than that of charging the battery. For the input, this circuit was designed around receiving a wide range of voltages from the rectifier. For the output, this circuit was also considered around specifications for charging the battery bank given by the manufacturer. The batteries will be charged using the constant voltage method and a range of 14.6V to 15V is specified. I elected to use the MAX643 voltage regulator which has an output voltage of 15V. The upper limit of charging the batteries were chosen by considering losses and voltage drops across the system. This regulator was also chosen for flexibility as it allows the use of a resistor divider and feedback pin to set the output voltage if it ever needs changing.

2.3. Subsystem Validation

This subsystem was thoroughly tested and validated according to criteria specified in Table 1 below. The three-phase rectifier was first designed and simulated in Multisim where it was then implemented on a breadboard and subjected to preliminary testing. After this, the circuit and all its components were soldered onto Perfboard, where final testing was applied.

For the boost converter, there was no simulation due to the absence of the MAX643 voltage regulator and its libraries on Multisim and other platforms. Starting from the implementation on breadboard, it was verified to be working properly before moving on. After this, the circuit was soldered onto Perfboard. From here, a multitude of tests were performed, and the bulk of the data gathered lies in this aspect.

Test Name	Criteria	Methodology
Rectification with Output Voltage Ripple	Ripple < $0.2V_{pp}$	Apply various input voltage amplitudes and measure V_{pp} of output voltage
DC-DC Conversion with Load	15V output with $\pm$ 1% tolerance	Apply various input voltages and measure output voltage
Serial Test	15V output with $\pm$ 1% tolerance	Connect rectifier and boost converter in series

Table 1. Validation Plan

2.3.0. Three-phase Rectifier Validation

Once the rectifier was simulated, the first test performed was measuring the output voltage ripple. After the final circuit was built on Perfboard, experimental data was gathered. Both tests are shown in the following Figure 4.

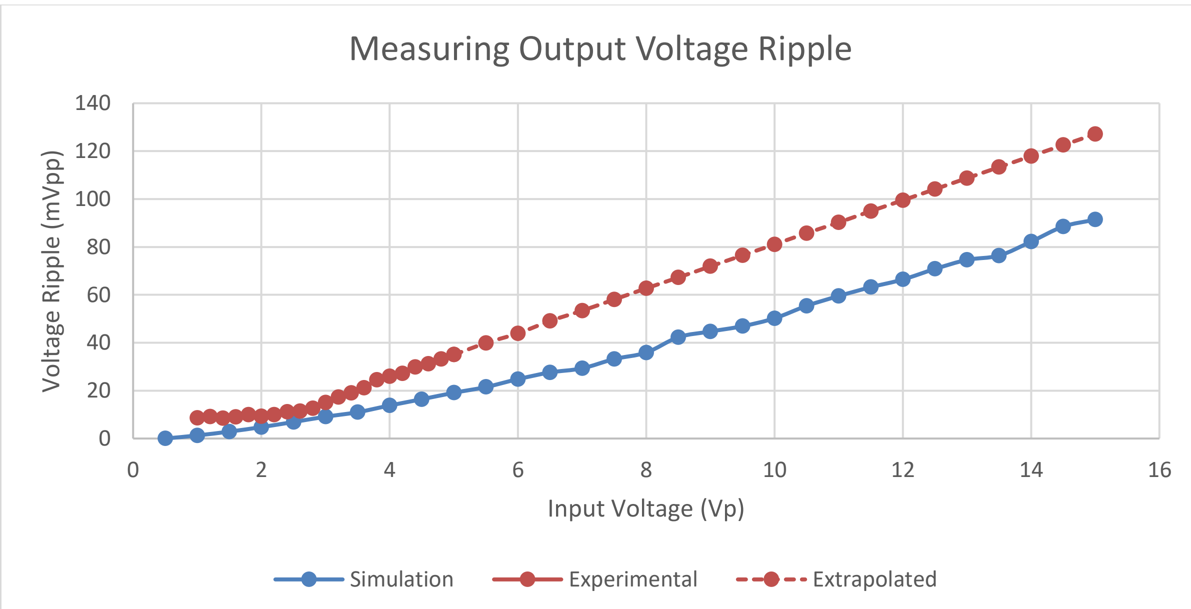


Figure 4. Validation of Output Voltage Ripple

Starting with the simulated data, a three-phase voltage source was varied from 0.5V to 15V in 0.5V increments; the voltage ripple was measured at the output. Experimental data was gathered using the Analog-Discovery 2, however, this machine has a maximum input voltage amplitude of 5V and can only support two waveform inputs. Due to this, the voltage ripple at the output will be affected and is the reason for the difference among the two cases. Using the extrapolated data from the experimental results, our validation criteria is still satisfied and shows that the circuit can perform under less-than-ideal circumstances.

Moving on, we can use the same process above, but instead measure the rectified output voltage as seen in Figure 5. The simulated and experimental results match up very closely and the expectation is for that to continue. It is a linear relationship, therefore we can calculate the DC voltage given any input amplitude by $V_{DC} = \frac{\sqrt{3}}{2} V_p$.

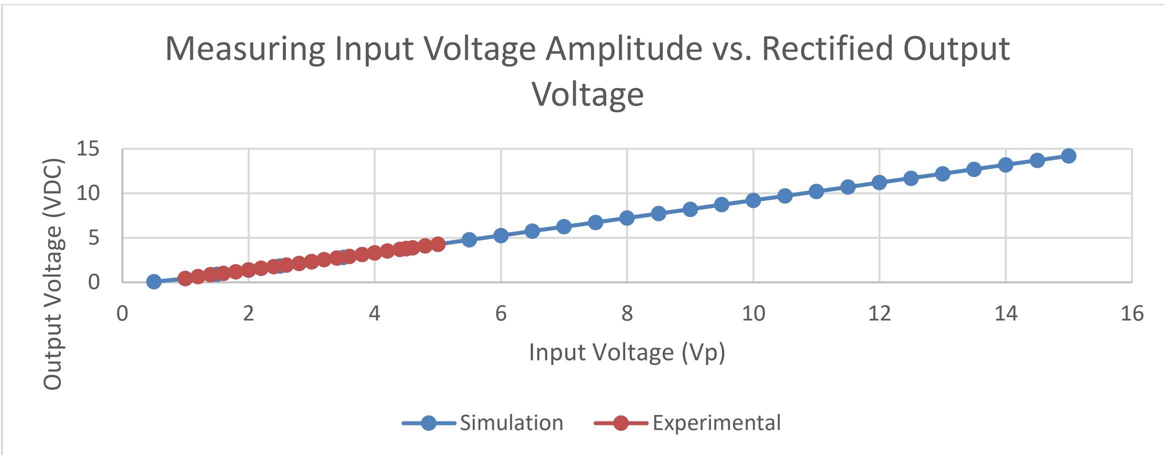


Figure 5. Relationship between Input Voltage Amplitude and Output Voltage

2.3.1. Boost Converter Validation

For the boost converter, all data presented in this section was gathered at the final stage when the circuit was on built on Perfboard.

The output of the boost converter was validated by a DC power supply and a DC load machine. The input was fed from the power supply by varying the voltage from 2V to 15V in 0.5V increments. The output was measured directly by the load machine while it drew a specific amount of current. By doing so, this is a good way to simulate the result of charging a battery. Eight different load currents were tested to see how the output voltage changed with respect to the input voltage. In total, as the load current increases, it requires a higher input voltage to supply a constant 15V. This is shown in Figure 6 below.

Another way to visualize this data is in Table 2 where we can more closely examine the output voltages that are desired. By focusing on the specified output of 15V with $\pm$ 1% tolerance, this corresponds to a range of acceptable voltages of 14.85V to 15.15V. Input voltages are given in the left column, while load currents are specified in the top row. Therefore, each entry in the Table 2 corresponds to a measured output voltage. The entries that satisfy our validation requirement are highlighted in green. There are a wide range of valid entries that show exactly how much input voltage we need to supply a certain load current.

Using the same methodology with the DC power supply and DC load machine, we can also see the effects of input current given in Figure 7. It takes a higher input current to supply an increasingly higher load current. Due to the IC overheating, any input current over 0.65A was cut off, which affected data collection for the load current of 400mA.

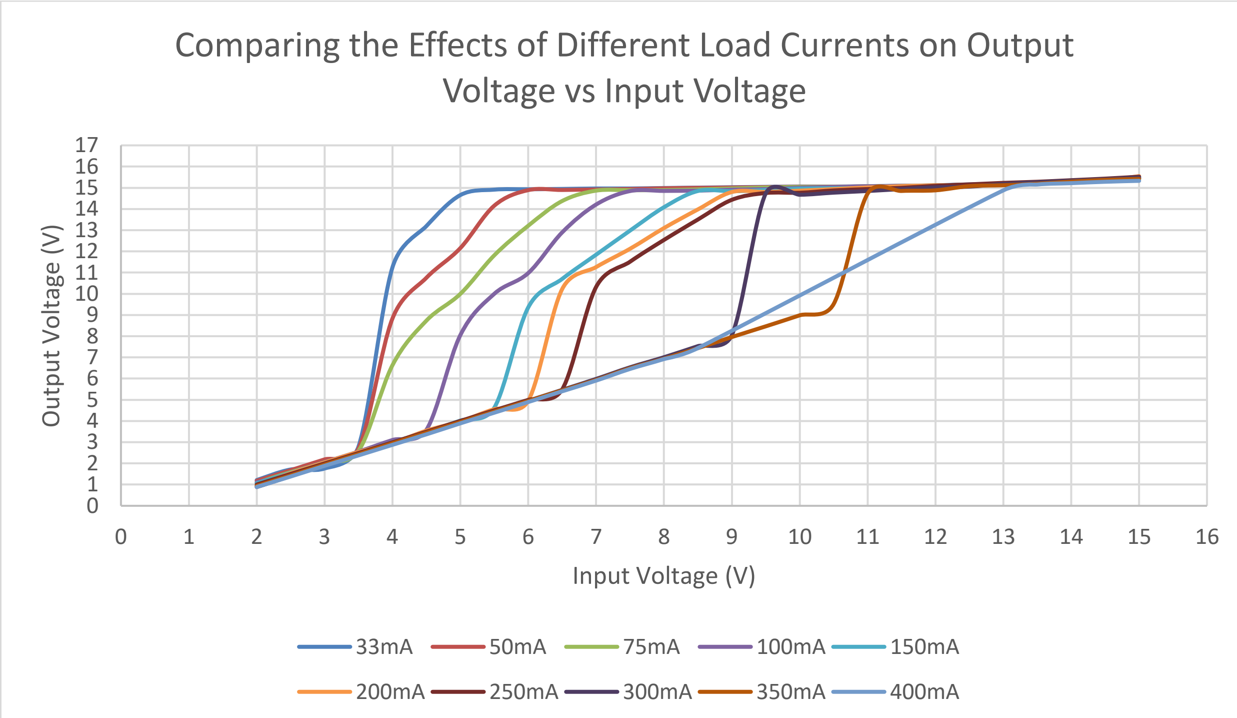


Figure 6. Validation of Boost Converter with Load

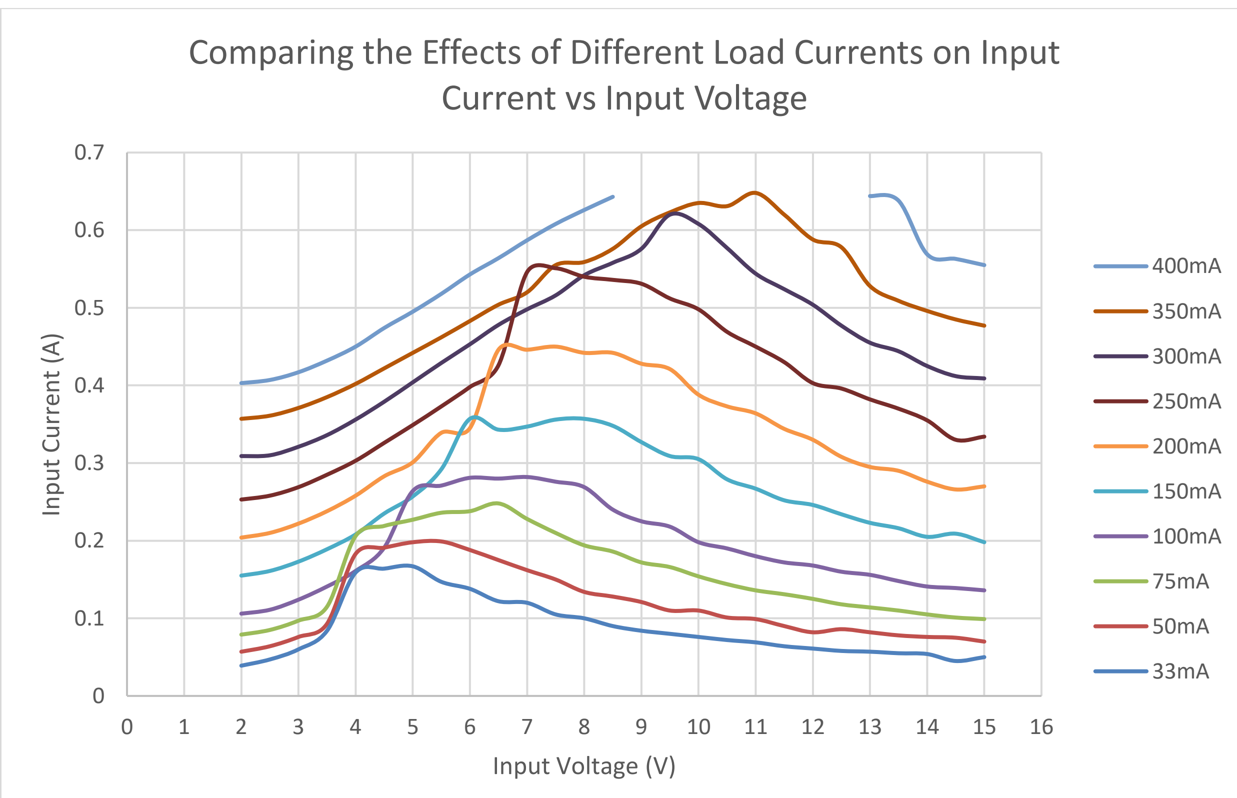


Figure 7. Effect of Input Current with Load

		Load Currents (mA)									
		33	50	75	100	150	200	250	300	350	400
Input Voltage (V)	0.5	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0
	1.5	0	0	0	0	0	0	0	0	0	0
	2	1.213	1.18	1.091	1.11	1.061	0.934	1.002	0.885	0.939	0.888
	2.5	1.712	1.68	1.587	1.506	1.56	1.541	1.502	1.396	1.435	1.382
	3	1.76	2.189	2.04	2.052	2.054	2.045	1.998	1.912	1.947	1.886
	3.5	2.796	2.705	2.593	2.556	2.502	2.541	2.49	2.416	2.443	2.377
	4	11.248	8.835	6.631	3.104	2.994	2.957	2.991	2.911	2.95	2.876
	4.5	13.195	10.756	8.733	3.586	3.49	3.544	3.495	3.424	3.449	3.37
	5	14.655	12.155	9.995	8.05	4.02	3.982	4.002	3.933	3.95	3.889
	5.5	14.912	14.156	11.815	9.999	4.625	4.559	4.503	4.447	4.449	4.391
	6	14.929	14.89	13.209	10.976	9.357	4.951	4.995	4.953	4.948	4.895
	6.5	14.944	14.897	14.376	12.896	10.702	10.223	5.489	5.467	5.445	5.401
	7	14.966	14.919	14.866	14.21	11.844	11.26	10.32	5.983	5.937	5.905
	7.5	14.966	14.939	14.883	14.846	12.98	12.123	11.512	6.531	6.49	6.455
	8	14.988	14.976	14.89	14.853	14.083	13.1	12.539	7.006	6.94	6.922
	8.5	15.007	14.995	14.922	14.866	14.848	13.98	13.503	7.53	7.436	7.439
	9	15.025	15.01	14.966	14.912	14.836	14.8	14.433	8.05	7.96	-
	9.5	15.042	15.03	15.01	14.939	14.893	14.804	14.753	14.74	8.466	-
	10	15.06	15.047	15.037	15	14.961	14.866	14.765	14.672	8.985	-
	10.5	15.056	15.049	15.044	15.039	14.978	14.937	14.875	14.77	9.518	-
	11	15.074	15.066	15.064	15.064	14.993	15.017	14.939	14.848	14.724	-
	11.5	15.096	15.088	15.083	15.083	15.059	15.074	14.998	14.939	14.851	-
	12	15.115	15.11	15.108	15.105	15.098	15.115	15.091	15.02	14.88	-
	12.5	15.16	15.147	15.142	15.142	15.135	15.122	15.16	15.056	15.078	-
	13	15.186	15.174	15.174	15.176	15.174	15.164	15.23	15.181	15.12	14.88
	13.5	15.235	15.223	15.22	15.218	15.215	15.213	15.284	15.262	15.191	15.152
	14	15.286	15.274	15.259	15.272	15.277	15.269	15.357	15.338	15.291	15.218
	14.5	15.345	15.335	15.33	15.343	15.345	15.34	15.431	15.409	15.374	15.284
	15	15.453	15.46	15.423	15.46	15.458	15.546	15.521	15.489	15.418	15.328

Table 2. Validation of Boost Converter Output Voltage with Tolerances

2.3.2. Serial Connection Validation

With the rectifier and boost converter connected in series, we can test the output voltage of the subsystem. Again, using the Analog-Discovery 2, we can apply two input waveforms to the rectifier while measuring output voltage of the boost converter. Once an input voltage amplitude of 1.8V is applied, the boost converter is activated and starts outputting 15V. This 15V is carried all the way up to the maximum input amplitude of 5V. It is also well within the $\pm$ 1% tolerance once the boost converter turns on. Higher input voltage amplitudes will continue to produce 15V at the output of the boost converter, but such tests cannot be performed with the limitations of the Analog-Discovery 2.

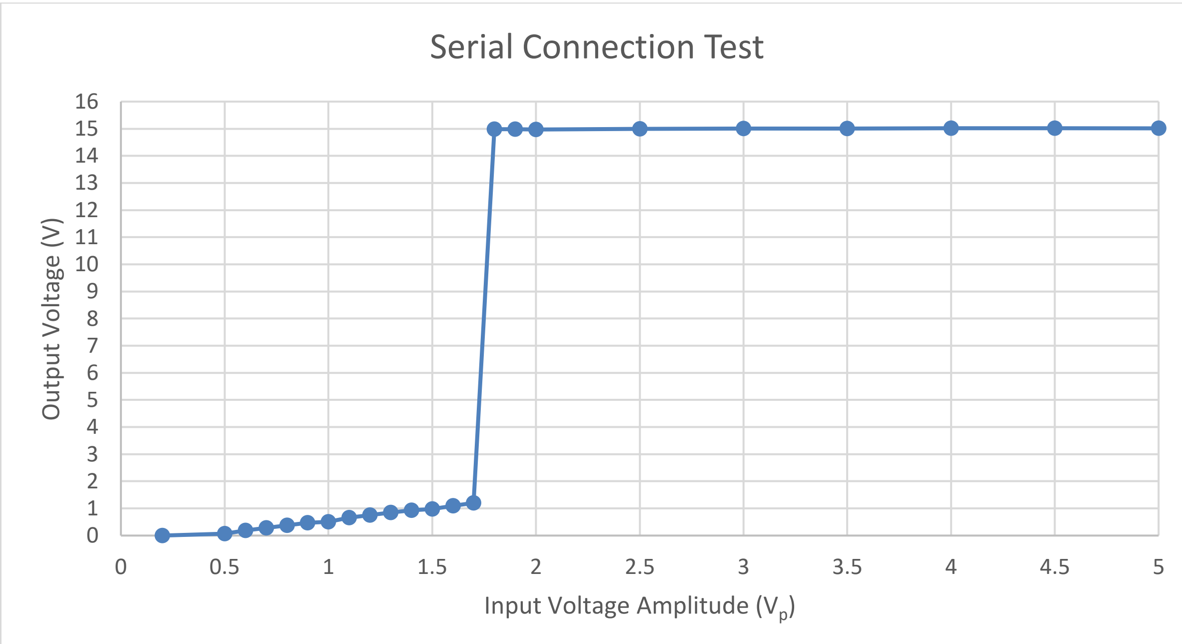


Figure 8. Validation of Serial Connection

2.4. Subsystem Conclusion

Each of the circuits built were shown to have worked and are verified against the validation criteria. With the rectifier, I've shown that there is minimal output voltage ripple and less than the 200mV$_{pp}$ requirement along with the linear relationship between input voltage amplitude and rectified output voltage. For the boost converter, I've compared the effects of eight increasing load currents while measuring output voltage and input current. There are multiple options that satisfy the output voltage of 15V $\pm$ 1%. By electing to charge the batteries with a specific amount of current, we know exactly how much input power is needed. Finally, when both circuits are connected in series, it is shown that the validation requirement is met again.

3. Charge and Switch Controller Subsystem Report

3.1. Subsystem Introduction

The charge and switch controller subsystem is designed to divert power to and from the batteries to prevent overcharge and output control. The overall power system will be unique in that there will be two batteries in use simultaneously, so the working principle of a typical charge controller system will require slight modification. The charge controller subsystem is focused on switching between the two batteries in order to prevent over charging of each. The second switch determines which battery to draw the output power from. The overall system allows one battery to charge and the other to discharge simultaneously, making the overall power system more efficient than a one battery system. Eventually the charge and switch controller system will be combined with the Monitor Subsystem, which will control the switches based on a signal output from a microcontroller. “After deliberation with the sponsor, the switch controller will simply be achieved through gate-driven logic”

3.2. Subsystem Validation

The charge controller will make up the bulk of the implementation for this subsystem, and as such warranted the most research. A circuit borrowed from an online resource was used for the implementation because its design closely matched the specifications required for charging the batteries purchased. This circuit is based on self-regulated switching, which means it does not rely on an external signal to drive the switch. The key components of the circuit are the 12V SPDT (single pole double throw) relay and TL7808 operational amplifiers. The operating principle for the circuit is the use of the operational amplifiers as comparator switches. The default connection for the combination relay will divert incoming power from the wind turbine to the battery. This voltage will also be fed into the first two amplifiers, which have two comparator configurations: the first has a reference voltage set high, so that when the input voltage exceeds it the resulting output should trigger the relay and divert to the dump load. Practically, this means that the battery is fully charged, so according to the battery specifications, this high reference voltage will be at 15V. The second comparator will have a reference voltage set low, so that when the input voltage drops below it, the relay will switch off, diverting the current flow back to the batteries. In accordance with battery specifications, the low reference voltage will be around 10.5V.

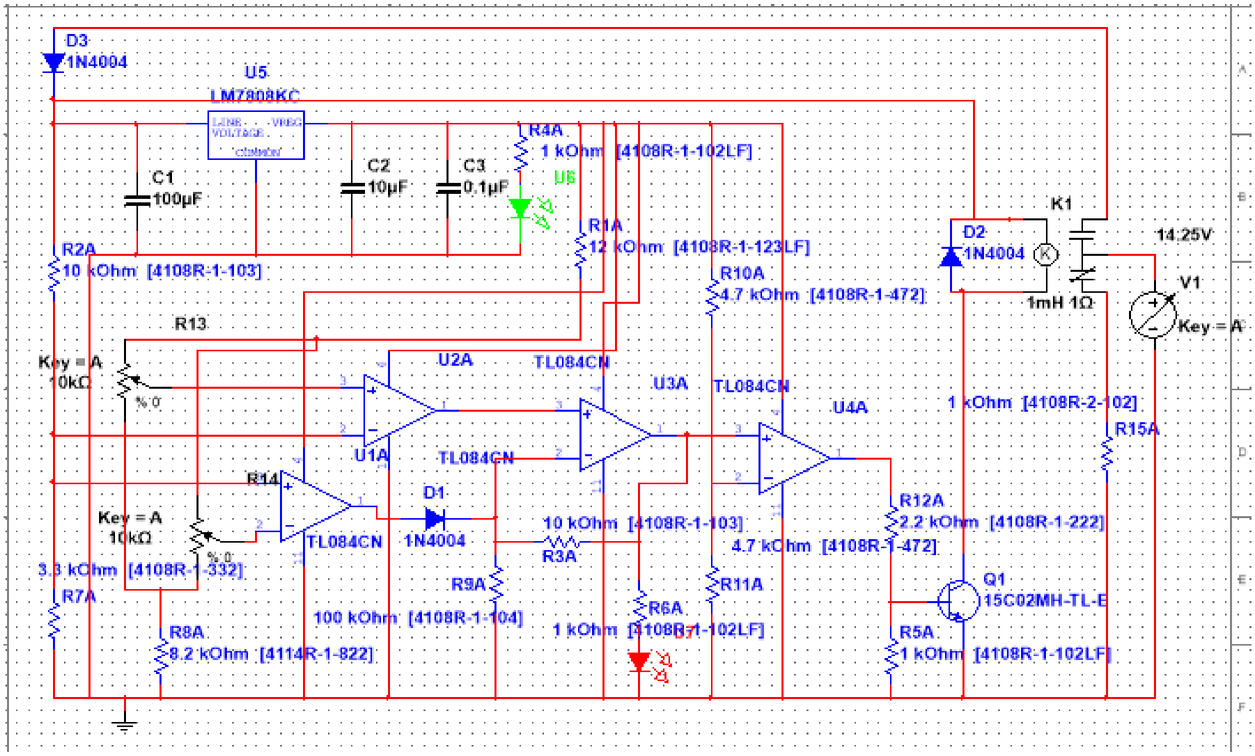


Figure 9. Schematic for Charge Controller

The primary goal of validation for the charge controller is to confirm that the relay will properly switch when the input voltage exceeds the high reference voltage and drops below the low reference voltage, and the voltage of the comparator output is used to confirm this operation. For validation, a couple of changes were made to the borrowed circuit. Firstly, the dump load was to be replaced with the second battery, as the operation between two batteries was more important than the presence of the dump load. Secondly, the potentiometers used to adjust the reference voltages were changed from 10k to 100k in order to allow greater variability on the reference voltages values.

Switching was eventually accomplished but at a low voltage setting with 5V input due to the low-current limitations of the breadboard the circuit was built on. The low reference was set to 2.00V while the high reference was set to about 0.4V, so as Vin exceeds 2.00V, the output on the comparator affecting the relay, Opamp3, should be high.

Vin (V)	Opamp2 Out (V)	Opamp1 out (V)	Opamp3 out (V)	Opamp4 -in (V)
1.5	2.68	2.64	0.59	2.02
3.3	0.042	2.47	2.37	1.92

Table 3. Comparator Voltage Measurements Confirm Successful Switching Behavior

However, several issues arose that required changes before this conclusion could be reached. Firstly, the relay did not switch with changing input voltage, and it was soon discovered that the voltage regulator output increased directly with the input voltage.

Vin (V)	VregOut (V)	Comparator Vin (V)
5	4.078	1.08
6	4.945	1.32
7	5.854	1.56
8	6.778	1.81
9	7.711	2.05
10	8.646	2.27
10.5	9.109	2.38
11	9.582	2.5
11.5	10.054	2.65
12	10.523	2.77
12.5	10.993	2.89
13	11.465	3.02
13.5	11.936	3.13

Table 4. Observation of Voltage Regulator Output Increasing with Input Voltage

This was unexpected behavior as the voltage regulator used was rated at 8V, so the output should not have exceeded 8V. The regulator was swapped a couple times, but the problem persisted. This in turn affected both low and high reference voltages, since they were directly related to the regulator output. This essentially locks the ratio between input voltage and reference voltage, and the only way to modify the output of the comparators was to adjust the reference voltages.

The issue with the input voltage was also an opportunity. The input voltage to be compared against the reference voltages was removed from the input and replaced with an external voltage source. This modification much more closely matched the intended goal of switch control being driven by an external signal provided by the Monitor Subsystem.

A second issue regarding the reference voltages also hindered the expected functionality of the circuit. The high reference voltage apparently had no effect on the relay switch, and by solely adjusting the low reference voltage the relay was able to switch on and off. Each combination of high and low was tested with a test voltage of 7V, and a fixed comparator input voltage of 1.04V. Here VrefLow represents the low reference voltage while VrefHigh represents the high reference voltage.

VrefLow (V)	VrefLow > VrefHigh	Opamp2 out (V)	Opamp1 out (V)	Opamp3 out (V)	Opamp4 -in (V)
3.38 adjust to 0.99	Vin > VrefLow(only)	N/A	N/A	N/A	N/A
VrefHigh (V)	Vin > VrefHigh(only)	2.724	2.657	0.63	2.04
0.45	Vin > both	0.011	2.504	2.407	1.93
VrefLow (V)	VrefLow < VrefHigh	Opamp2 out (V)	Opamp1 out (V)	Opamp3 out (V)	Opamp4 -in (V)
0.411	Vin > VrefLow(only)	0.023	0.014	2.405	1.934
VrefHigh (V)	Vin > VrefHigh(only)	N/A	N/A	N/A	N/A
3.21 adjust 0.928	Vin > both	0.018	2.503	2.385	1.926

Table 5. Thorough Comparison of VrefLow and VrefHigh Behavior

Using logic analysis, the only time the output of amplifier 3, and therefore the relay, is affected is when VrefLow drops below the comparator input voltage. There appears to be no effect on the output whether VrefLow is greater or less than VrefHigh, or whether VrefHigh is greater than the comparator input voltage. Interestingly, at higher input voltages such as 12 V, the comparator output operates closer to its expected behavior, and adjusting both the value of VrefHigh and VrefLow appears to control the output; a low VrefLow and high VrefHigh yields a high output, and a low VrefHigh yields a low output. However, this behavior was not consistent, and subsequent tests did not yield the same results.

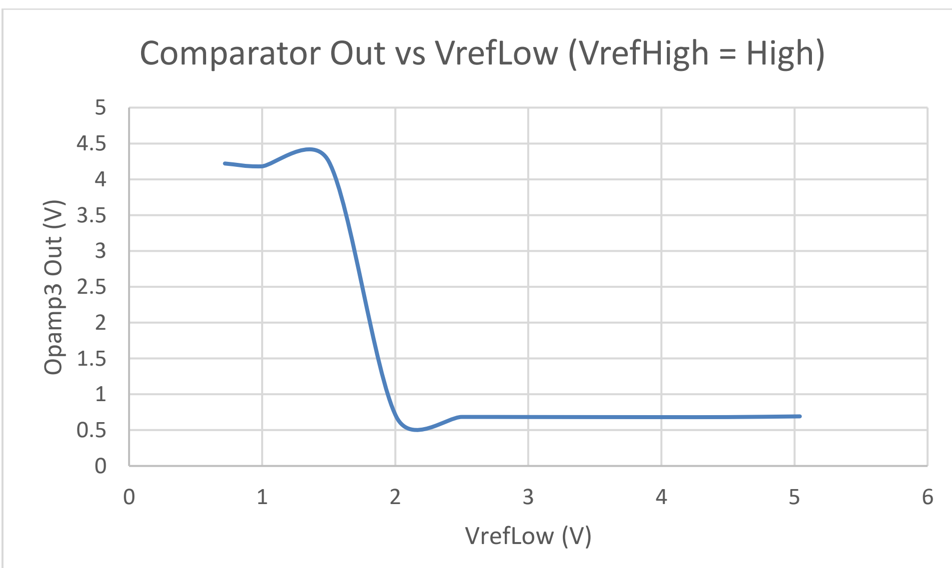


Figure 10. VrefLow Effect on Output with VrefHigh Set High

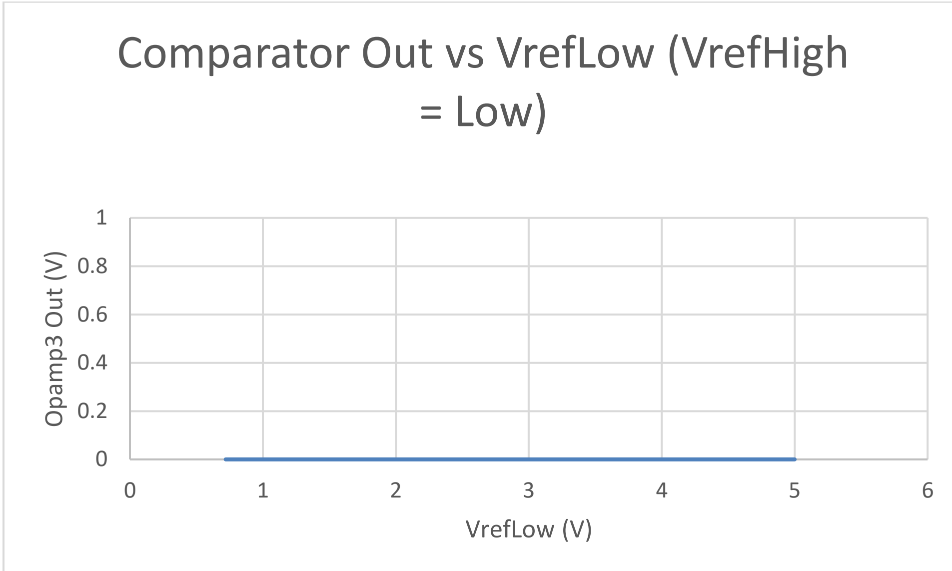


Figure 11. VrefLow Effect on Output with VrefHigh Set Low

3.3. Subsystem Conclusion

Initially the expected behavior of the circuit did not operate correctly, and thus necessary changes were made in order to better operate its behavior. The modifications to the reference voltages and switching signal input were simple but effective solutions to operate the circuit as intended. Validation tests confirmed successful switching of the relay and correct output behavior of the amplifiers. Though results appeared different at higher input voltages, the behavior was mostly inconsistent and firm conclusions could not be drawn. After reviewing the demonstration, the professor’s advice was to swap out comparators and relays for transistor-based switching for more proper integration with the other subsystems.

4. Monitor Subsystem Report

4.1. Subsystem Introduction

The Monitor Subsystem is designed to monitor the battery life of the Wind-Powered Building providing valuable information to the user through a website the user will be able to access on the network. In addition, this subsystem will also be in charge of controlling the Charge and Switch Controller Subsystem sending a signal to control which battery will be charged by the wind turbine and which battery will be used to power the building.

4.2. Subsystem Details

The Monitory Subsystem utilizes an ESP32 microcontroller to read in inputs from a power a source. This microcontroller is equipped with multiple ADC (Analog to Digital Converter) ports allowing it take in inputs from the two batteries that are in our system. It also comes equipped with two DAC (Digital to Analog Converter) ports which is a sufficient amount to output a signal to the Charge and Switch Controller Subsystem. Finally, the microcontroller is equipped with Wi-Fi and Bluetooth capabilities which will be used to host a local website for the user to access.

The ADC ports on the microcontroller are only able to take in voltages between 0 and 3.3V. Because of this voltage dividers must be utilized to step down the voltage from our battery which can range from 10 up to 14V. Furthermore, the ADC ports have trouble detecting voltage differences at very low and very high voltages, however this should not be an issue since to optimally charge the battery we do not want to charge the battery when it is almost dead or likewise keep charging it when it is almost full. The DAC ports can only output voltages between 0 and 3.3V, which will be a restriction on the design of the Charge and Switch Controller Subsystem. Using the information received from the ADC ports the microcontroller will output a signal using the DAC ports to the Charge and Switch Controller Subsystem telling it which battery to charge and which battery to use. This is something that will be worked on more later as it involves integration of subsystems, however preparations have been made to allow for easy integration.

Utilizing the Wi-Fi and Bluetooth capabilities a local website will be hosted by the microcontroller. This website will display information on the statuses of the two batteries as well as other information such as the power usage and generated by the Wind-Powered Building. A user on the same network can access this website through the IP-Address of the microcontroller.

A PCB will be added at a later date to replace the breadboard that currently houses all the components of the subsystem.

4.3. Subsystem Validation

Validation for the battery monitor portion was done by inputting various voltage levels into the microcontroller. Using a power supply various voltage levels were tested on the microcontroller. Print statements outputting to a console were written in the code to see if the microcontroller was reading the voltage levels properly. First lower voltages were tested to see if the microcontroller was reading properly. Afterward higher voltage levels up to 14V were tested to see if the voltage divider was function as intended.

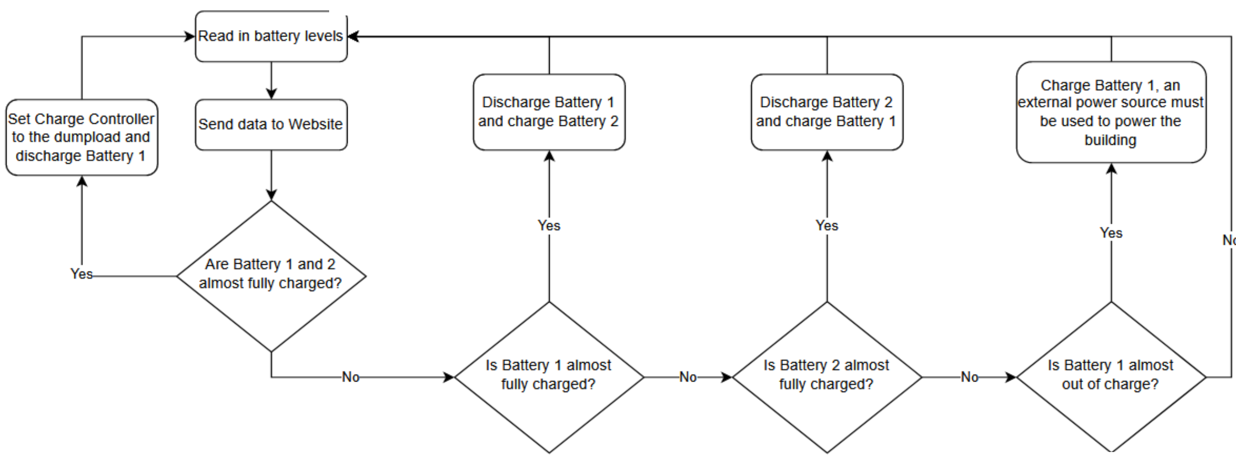
In preparation for integration with the Charge and Switch Controller Subsystem code was written that will trigger print statements to the console when either battery reaches a certain threshold. These print statements will later be replaced to instead send a signal to the Charge and Switch Controller Subsystem. The figure below shows the print statements outputted to the console during testing.

Figure 12. Console Output

```
10:44:20.480 -> Battery 1: 0.00%
10:44:20.480 -> Battery 2: 91.65%
10:44:20.480 -> Battery2 is almost fully charged, now being used to power the building
10:44:20.480 -> Battery1 is almost out of power, now charging with the wind turbine
10:44:20.480 -> Power Generated: 10.99
10:44:20.480 -> Power Consumed: 0.00
```

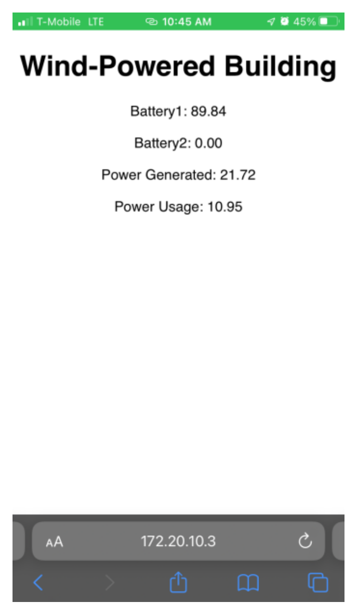
The flow chart in Figure 13 shows the logic used when determining which battery should be charged and used

Figure 13. Flow Chart of Battery Management



Validation for the website was done by yet again using a power supply to test various voltage levels on the microcontroller. The website was then checked to see if the correct information was displayed. Furthermore, while testing various voltages the website was also checked to ensure that the values were updating properly. On the side in figure X is a picture of the current website on a mobile device displaying information to the user.

Figure 14. Mobile Website



4.4. Subsystem Conclusion

Currently the Monitor Subsystem is functioning properly, being able to track level of both batteries and displaying that information onto the website. Some aspects will need to be further tested once integration begins with outputting voltage to the Charge and Switch Controller Subsystem. Finally further improvements can be made to the website UI for a cleaner and more user friendly look.

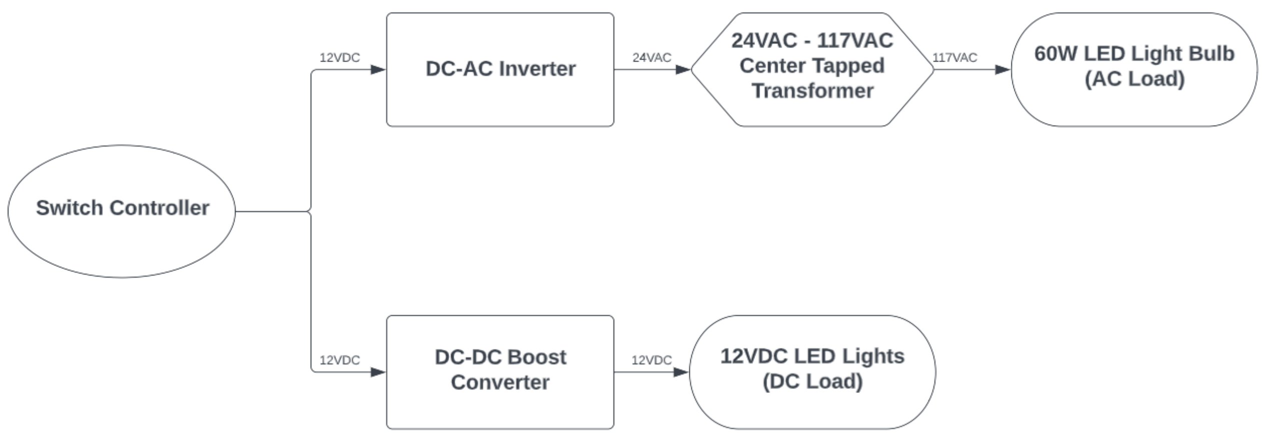
5. Inversion and Conversion Subsystem Report

5.1. Subsystem Introduction

The inversion and conversion subsystem is designed to supply power to the building, to both a DC and AC load. The subsystem is powered by a battery which stores the wind power generated by the wind turbine. The inverter and converter were tested to validate their capability to power the building's loads.

For both the inverter and converter circuits, I do not have working simulations or schematics due to no database having a CD4047 or LM2577 model in their library. I am working to find a program that allows me to design both because it is necessary to optimize andimplemt the circuits further.

Figure 15. Block Diagram of Inversion and Conversion Subsystem



5.1.0. Inverter without Transformer and Load

5.1.0.1. Operation

For the inverter, a CD4047 low power inverter is used in astable multivibrator configuration. The inverter outputs two alternating square waves to drive the IRFZ44 MOSFETs, so that only one is on at a given time. By repeatedly driving one MOSFET while the other is off, current is pushed and pulled through the windings of the transformer's secondary side. Ideally supplying the transformer's secondary winding with 24VAC (-12-0-+12) at around 60 Hz.

5.1.0.2. Validation

Test	Criteria	Methodology

Inverter without transformer or load	24VAC output with 1% tolerance	Apply input voltages ranging from 10.5-14.7V and measure the output voltages at the MOSFETS drain
Inverter with transformer or load	117VAC output with 1% tolerance	Apply input voltages ranging from 10.5-14.7V and measure the output voltages at the transformer's primary terminal
Light Bulb Test	Light bulb turns on	Apply input voltages ranging from 10.5-14.7V and check if the light bulb turns on

Table 6. Inverter without Transformer and Load Validation Plan

To validate the inverter circuit, the circuit was first tested without the transformer or LED light bulb connected to the output. The output voltage of the inverter circuit was measured at the gate of both IRFZ44 MOSFETs with the positive end of the voltmeter probe connected to the drain and the negative end of the probe connected to the supply voltage (V+) of the inverter circuit. The input voltages that the output voltage was measured for ranged from 10.5-14.7V. The output voltage was measured over this specific range because the discharge voltage of the battery supplied to the converter has a minimum of 10.5V and maximum of 14.6V. The measured output voltages of the inverter circuit without the transformer and LED light bulb are displayed in Figure 16. The inverter was validated that it could produce 12VAC at its output when supplied with input voltages closer to the upper bound of the input voltage range. However, as the input voltages decreased the output voltage also decreased.

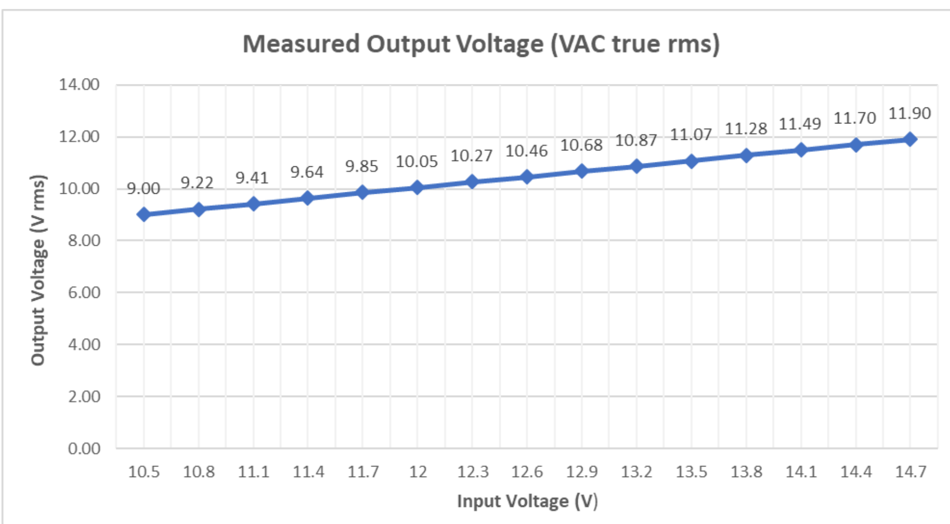


Figure 16. Inverter without Transformer or Load Measured Output Voltage

Input Voltage (VDC)	Current Draw (A)
10.5	0.992
10.8	0.991

11.1	0.991
11.4	0.991
11.7	0.991
12	0.99
12.3	0.99
12.6	0.989
12.9	0.989
13.2	0.988
13.5	0.988
13.8	0.988
14.1	0.988
14.4	0.987
14.7	0.987

Table 7. Current Draw of Inverter without Transformer or Load

To complete validation for the inverter circuit when the transformer and LED light bulb are disconnected, an oscilloscope was used to measure the waveform output at the drain of both IRFZ44 MOSFETs. In Figure 17 and Figure 18, the waveform is shown along with the frequency and peak to peak voltage. With both MOSFETs outputting a voltage ranging from 12.7-12.9VAC at a frequency of 60 Hz, the criteria needed to validate the output of the inverter circuit was confirmed.

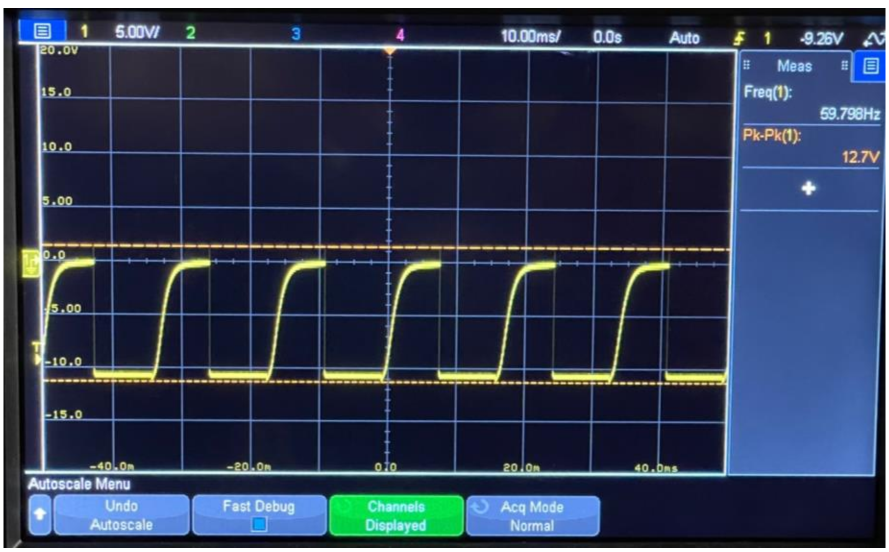


Figure 17. First IRFZ44 Output Voltage and Frequency

Figure 18. Second IRFZ44 Output Voltage and Frequency

5.1.1. Inverter with Transformer and Load

5.1.1.1. Operation

For the transformer, a 24VAC to 117VAC center tapped step-up transformer was used. Each of the transformer's two 12V terminals are connected to drain (output) of the IRFZ44 MOSFET's individually. The transformer's 0V terminal on the secondary side is connected to the supply voltage (V+). On the primary side of the transformer, a 510VAC varistor is placed between the 117V and 0V terminals to reduce voltage spikes. Additionally, a 60W LED light bulb is connected to the transformer's primary side 117V and 0V terminals. The function of the transformer is to step-up the inverter's 24VAC output to about 117VAC at 60Hz, supplying power to the LED light bulb.

5.1.1.2. Validation

Test	Criteria	Methodology
Inverter with transformer or load	117VAC output with 1% tolerance	Apply input voltages ranging from 10.5-14.7V and measure the output voltages at the transformer's primary terminal
Light Bulb Test	Light bulb turns on	Apply input voltages ranging from 10.5-14.7V and check if the light bulb turns on

Table 8. Inverter with Transformer and Load Validation Plan

Since validation for the output of the inverter circuit was already completed the final steps for validation were to connect the output of the inverter to the secondary terminals of the transformer and then connect the primary terminals of the transformer to the LED light bulb. After these were connected testing of the AC output voltage was conducted by using a digital multimeter to measure the 117VAC and 0VAC terminals of the transformer using clamp cables. In addition, the LED light bulb was tested at the same time to check that it worked when supplied by the transformer output.

Input Voltage (VDC)	Inverter Output (VAC)	Transformer Output (VAC)
10.5	9	90.16
12	10.05	102.75
14.7	11.9	125.92

Table 9. Transformer Output at Boundary Input Voltages

As shown in Table 9, because of safety concerns I measured the transformer's output voltage at the upper and lower input voltage bounds and the ideal 12V input voltage. The data confirmed that the inverter connected with the transformer and LED light bulb met the validation criteria, but at the upper input bound as mentioned previously.

Input Voltage (VDC)	Inverter Output (VAC)	Transformer Output (VAC)	Light Bulb
14.7	11.9	125.92	On
14.4	11.7	113.34	On
14.1	11.49	103~112	On
13.8	11.28	103~112	Off

Table 10. Input Voltage Range for Powering Light Bulb Load

In Figure 19, a picture displaying the LED light bulb lighting up when supplied by the transformers output. This validates that the inverter passed the validation test checking that the LED light bulb turned on. Additionally, the transformers output voltages that could power the LED light bulb are shown in Table 10, providing us with the ideal input voltage range of 14.7-14.1VDC needed by the inverter to turn on the light bulb.

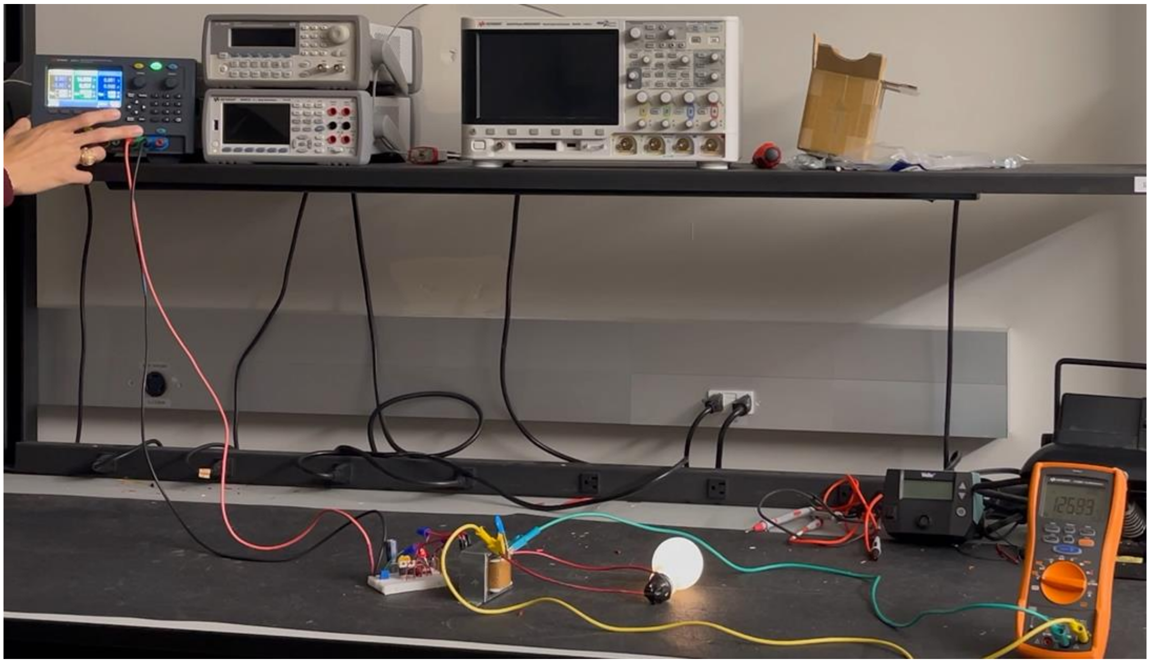


Figure 19. Picture of Inverter Powering LED Light Bulb Successfully

5.2. Converter

~~5.2.1.~~5.2.0. Operation

For the Converter, a LM2577-ADJ step-up regulator IC is used. The function of the converter is to output a voltage ranging from 12 to 24VDC when supplied an input voltage ranging from 10.5 - 14.7V. A 100K variable resistor is implemented to allow for the output voltage to be adjusted.

~~5.2.2.~~5.2.1. Validation

Test	Criteria	Methodology
Converter without load (output lower bound)	12VDC output with 1% tolerance	Apply input voltages ranging from 10.5-14.7V and adjust variable resistor for desired 12VDC output and measure the output voltages
Converter without load (output upper bound)	24VDC output with 1% tolerance	Apply input voltages ranging from 10.5-14.7V and adjust variable resistor for desired 12VDC output and measure the output voltages
Converter with load	12VDC output with 1% tolerance when LEDs are connected	Apply input voltages ranging from 10.5-14.7V and adjust variable resistor for desired 12VDC output when load is connected and measure the output voltages
LED lights Test	Dual LEDs turn on	Apply input voltages ranging from 10.5-14.7V and check if the LEDs turn on

Table 11. Converter Validation Plan

The validation of the converter began by first measuring the output voltage of the converter without a load connected. The variable resistor of the circuit was adjusted to achieve an output of 12VDC. Then for 15 different input voltages ranging from 10.5 to 14.7V the output voltage was measured. The output voltage was measured over this specific range because the discharge voltage of the battery supplied to the converter has a minimum of 10.5V and maximum of 14.6V. However, no conclusive data was accurately collected for input voltages 10.5V and 13.2 - 14.7V because the output voltage was unstable and caused the LM2577 to overheat.

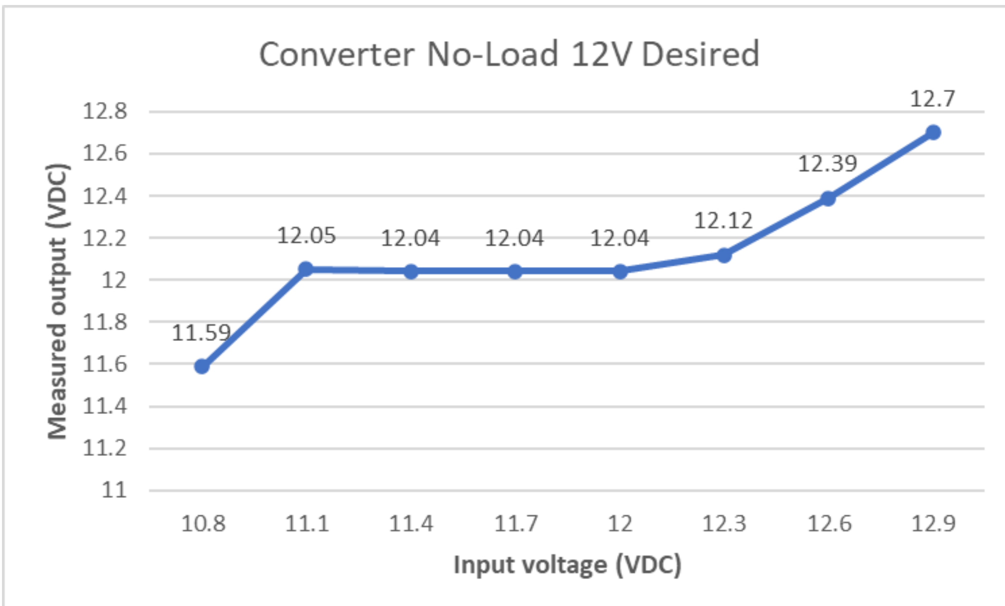


Figure 20. No-load Output Voltages when 12V Desired

Similarly, to the first test, the variable resistor of the circuit was adjusted again to achieve an output of 24VDC. Likewise, the output voltage was measured again for the same input voltages used in the first no-load validation test. The output voltages were within 1% tolerance of the desired 24VDC. These tests validated demonstrate that the converter is capable of operating with no-load with input voltages ranging from 10.5-14.7V to output voltages ranging from 12-25V.

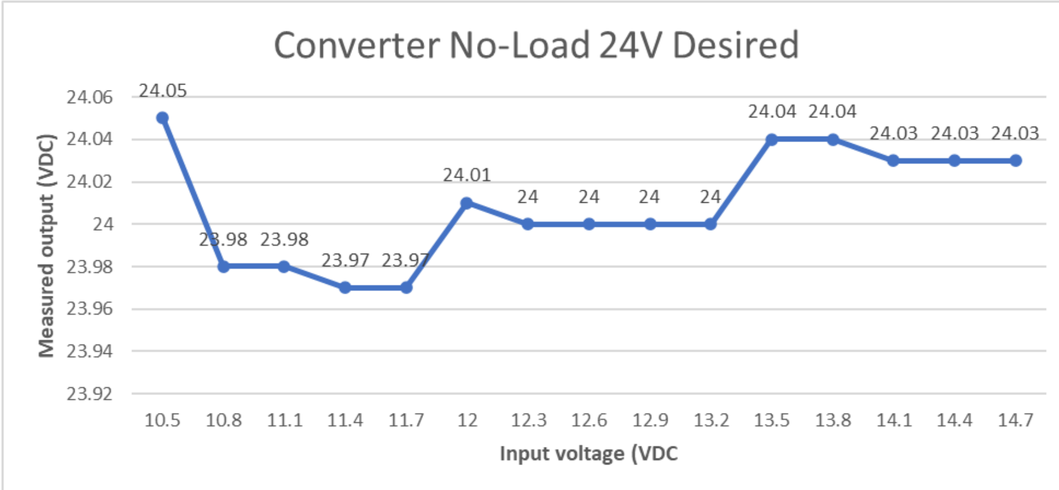


Figure 21. No-load Output Voltages when 24V Desired

To validate the operation of the converter with the LEDs connected, the same input voltages ranging from 10.5 to 14.7V were supplied and the output voltage was measured. During testing the LED switch was turned on. A picture taken during one of the test trials is provided in Figure 22**,** to show that the LEDs produced light when supplied with 12VDC from the converter output. However, for input voltages between 10.5 - 10.8V, the output voltage was unstable and caused the LM2577 to overheat.

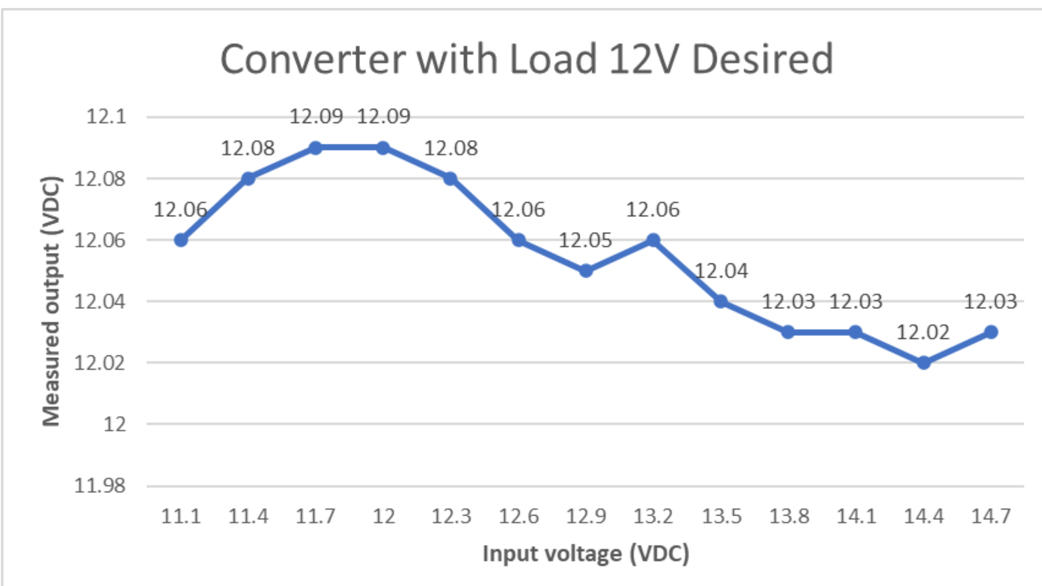


Figure 22. Output Voltages when 12V Desired with Load Connected

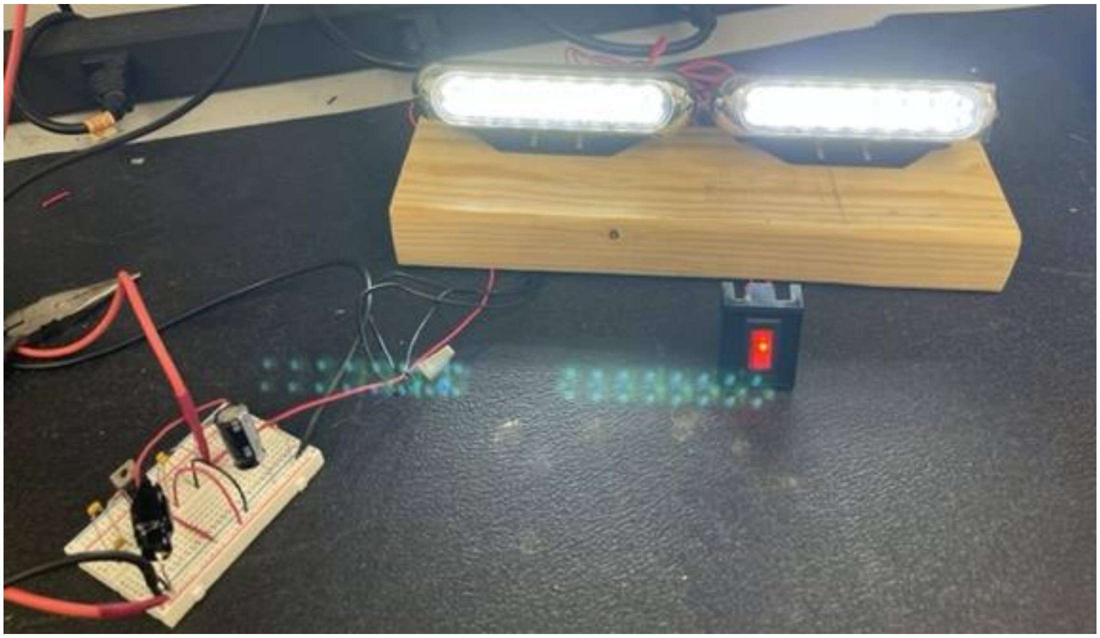


Figure 23. Picture of Converter Powering Dual LEDs successfully

5.3. Subsystem Conclusion

Both the inverter and converter circuits of the subsystem were demonstrated to operate properly, meeting the validation criteria. The inverter was able to receive input voltages of the expected range and supply power to the LED light bulb, displaying its ability to power the building's AC load. Likewise, the converter was able to receive input voltages of the expected range and supply power to the dual LEDs, exhibiting its ability to power the building's DC load. The behavior and results of the circuits differed from what was expected but improvements will be made by completing full simulations and implementing them on perfboards.