Team 5: NAU CWC ‘20-21 EE Team

Capstone Project Report
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Introduction

Client Background

Our project client is Venkata Yaramasu. Venkata Yaramasu, PhD, teaches and researches various power electronics technologies such as renewable energy, variable-speed drives, energy storage, smart grid, model predictive control, electric vehicles, and high power converters at NAU. He has granted us use of his AMPERE lab on campus to work on testing and project development for our collegiate competition wind turbine.

Problem Statement

The NAU Collegiate Wind Competition takes teams from US schools to compete in an annual competition for wind turbine development. Our team designed a small turbine that operates at multiple wind speeds up to 13 m/s. This turbine will compete against others at various wind speeds that will determine which turbine produces the most power at each speed. The competition will commence on June 2nd.

Design Process

To start off this project, our design was mainly based off of the constraints and requirements that came straight out of the rules and regulations handbook for the Collegiate Wind Competition. Once our team knew what these rules and regulations consisted of we were able to start our design process that would ultimately help walk us through this project as quickly and effectively as possible. Since our specific capstone has a lot of history, we were able to gain access to lots of resources that we did not expect to have. Resources such as existing designs, PCB gerber files, electrical subsystems and miscellaneous components all became available to us to help further our research. As we had access to all of these resources, we were able to more effectively understand the steps that we were going to have to take in order to complete our first prototype. Before any physical designing took place, various stages of research had to come first. Up until the point of our first prototype being completed, we followed the engineering design process as closely as we could in efforts to eliminate any factors in the design process that could cost us any more money or time that we could not afford to waste as we are on a tight schedule.

Figure 1: Three Phase Generator

Functional decomposition: Three-phase Generator

The three-phase generator acts as the power source for the whole circuit. It experiences a rotational force from the turbine blades as they spin in the wind. The team ordered and tested 4 generators. All were from MAD components, but each generator had a different kv rating. Kv rating is a ratio of rpm per volt:

$$kv = rpm/voltage$$

Prototype findings: Three-phase Generator

The four generators tested by the team were 110 kv, 150 kv, 160 kv, and 200 kv. The 160 kv and 200 kv generators were left over components from a previous year's team. The 200 kv motor had a short circuit and thus did not produce reliable test results. The 110 kv provided results that fit our needs the best. This generator provided the best (highest) output voltage at low rpm values. Table B-2 in Appendix B shows the calculated, or expected, voltage output for each of the tested motors based on their respective kv ratings. Other testing results, including the open circuit voltage of the 110 kv generator as well as the loaded power output of the 110 kv generator are also shown in Appendix B.

Figure 2: Three Phase Rectifier

Functional decomposition: Three-phase Rectifier

The three-phase rectifier serves as an AC/DC converter in this circuit. It is a 6 diode, full bridge rectifier which mounts to a pcb with through holes. The chip is an FUS 45-0045 which has a voltage limitation of 45 V and a current rating of 45 A. These ratings are well above what we expect to be outputting from the generator, so we have a good factor of safety. The diode has a relatively minimal voltage drop across it. The team took measurements of the voltage drop at various input values. These results can be seen in Figure B-5 in Appendix B.

Prototype findings: Three-phase Rectifier

Requires a 3 phase turbine to provide power input to the system. Also uses a capacitor in parallel with the system and an inductor in series with the DC output of the rectifier. For open circuit tests, no load is required, otherwise a programmable DC load is required for monitoring and correcting the situation.

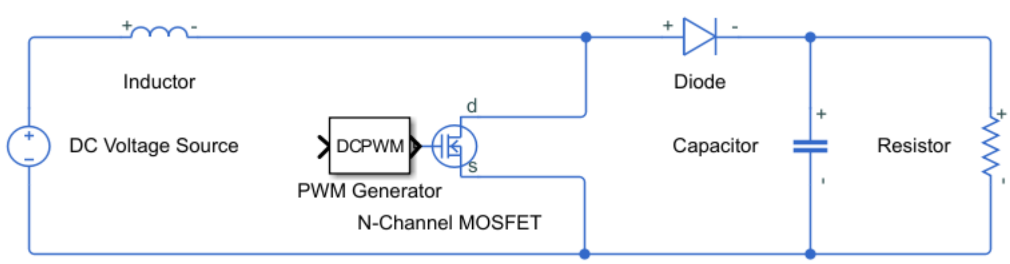


Figure 3: Boost Converter

Functional decomposition: Boost Converter

The initial design of the Boost Converter did not contain a drive circuit, and had a simple arduino PWM generation program.This was made out of parts found around the lab, which used a 100mH inductor, 220µF capacitor, and a 1kΩ load resistor. While this system did work for a simple demo, we of course had to change some components out for a final design.

Prototype findings: Boost Converter

The prototyping phase allowed us to understand the current requirements of our system. This stepped the voltage up around 1.5V (2V accounting for the diode loss) at 50% duty cycle. While we did boost the voltage a small amount, the main takeaway was that our system needs to be able to support high current. This lesson was learned based on trying to run too much current through an Arduino breadboard, which can only handle .5-1A.

Functional decomposition: Arduino Stop Button and boost converter control

The initial design of the arduino controller would be to control the second boost in our system. After some testing we found that we only needed one boost and we could have it controlled by the arduino. This original design was tested using Matlab simulink. A picture of the original system is shown below. We were also planning on the arduino directly controlling the mosfet. After some testing it was found that a driver was needed for the mosfet.

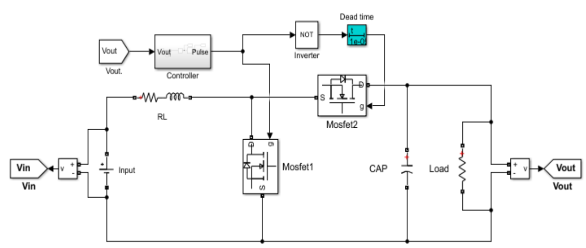


Figure 4: Software Controlled Boost

Prototype findings: Arduino Stop Button and boost converter control

The prototype of the arduino control taught us a few things that we needed to take into consideration when designing the whole system. The Arduino can be programmed using Matlab simulink modeling but there are a few things Matlab can't do like change the clock speed to increase the PWM signal to 30kHz. This is super important to us since our boost will need to run at a fast switching speed. A flow diagram of the various tasks of the simplified arduino can be viewed below. The controls for the turbine braking system and pitch control were implemented later. The prototype was tested using a mosfet connected directly to the arduino. This turned out to be one of our problems since the mosfet deeded to be driven by a driver.

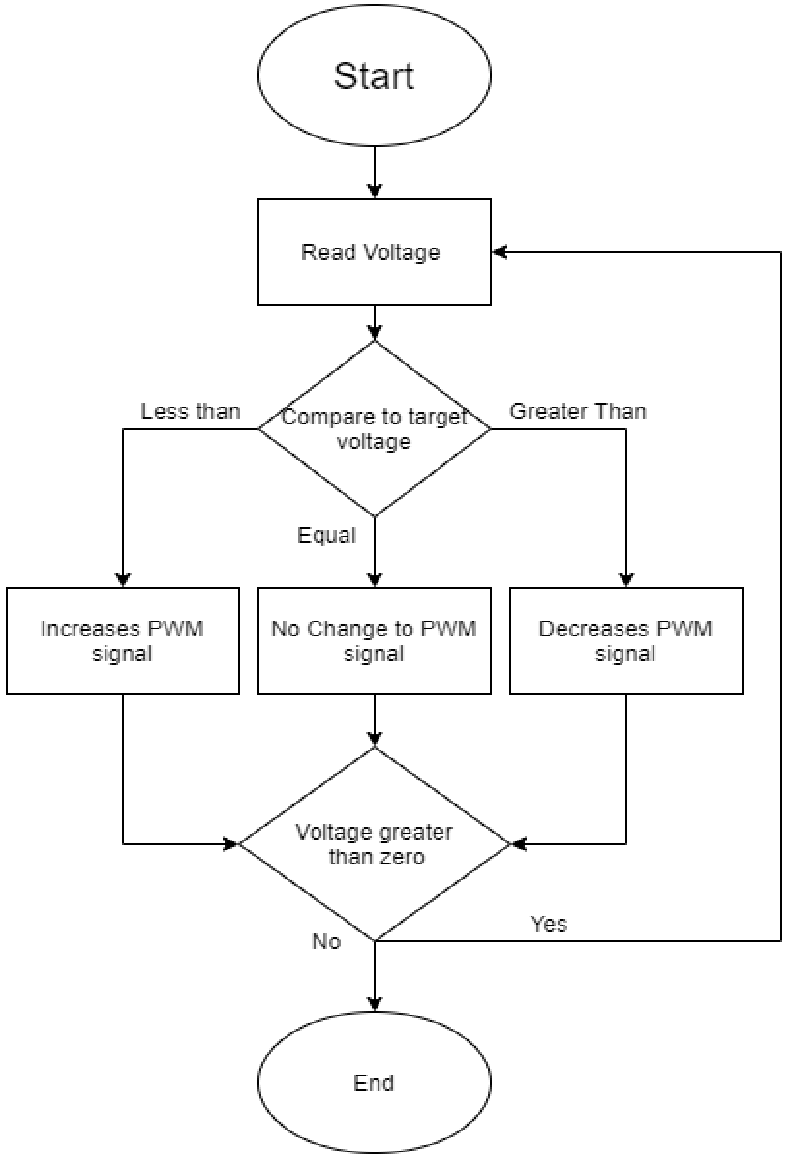


Figure 5: Software Controlled Boost

Final Design

System Architecture

Flowchart

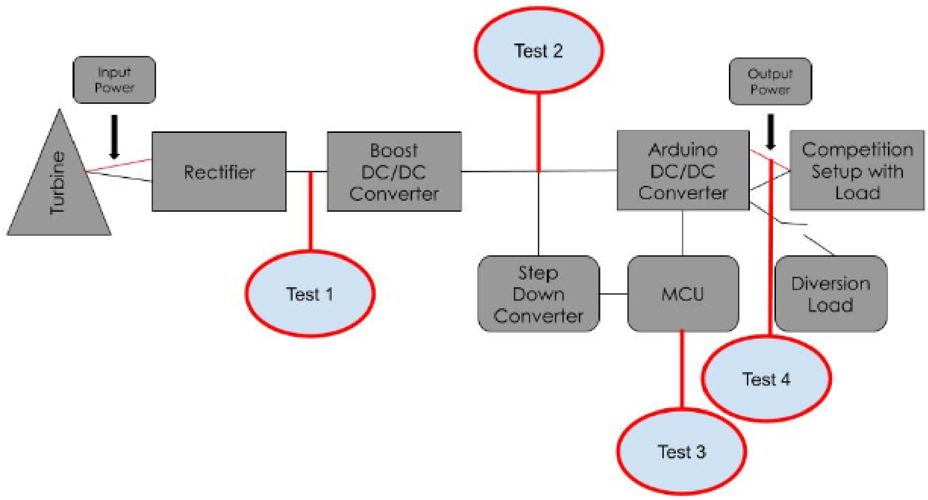


Figure 6: System Architecture

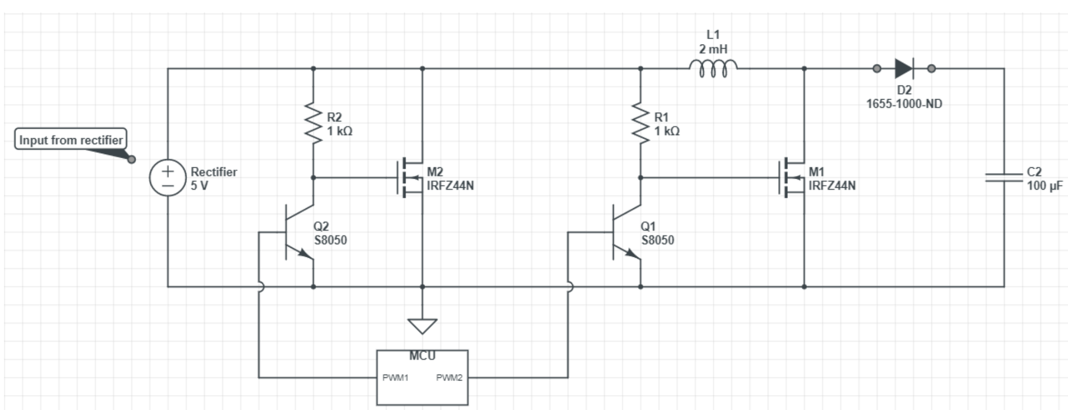


Figure 7: Boost Converter Schematic

The Boost converter is one of the two most complex parts of our system. Barring changes, We are using an S8050 transistor to drive the MOSFET, which is an IRFZ44N. This switches the polarity of the inductor, which is a 2mH inductor. Those three components are the core of our system, as they take advantage of the switching polarity of the inductor, which will in turn charge the capacitor, in this case a 100µF. Because the inductor changes polarity, we need to have a diode to force the capacitor to only discharge into the load. At the time of the composition, the Boost Converter was still in the final design process, and as a result, changes may occur.

Results

The testing workbook includes every major requirement or constraint on the project. This includes the constraints given by the client, the team mentor, and the CWC competition. The team closely followed each requirement and finished the excel sheet shown in figure 2 which describes each requirement in detail. Some requirements changed throughout the course of the project, and these are also noted in the testing workbook.

Type of Test	Status	Req #	Requirement
		1	General Rules:The turbine must be designed, and loads analyzed to withstand continuous winds of up to 22 meters per second (m/s) but no testing will be done beyond 13 m/s.
		1.1	Size Requirements: Within practical limits, there is no size restriction for components located outside the tunnel.
		1.2	Rule Changes: An important change in the rules for the 2020-2021 collegiate wind competition (CWC) is that teams are required to clearly describe what materials and designs they have referenced and used for this year's design
		2	Project Breakdown
		2.1	Auxillary connections
		2.2	Purchasing
		2.3	PCB Design
		2.4	Arduino Code
		2.5	DC/DC Converter
		3	Auxillary Connections
		3.1	I/O
Inspect		3.1.1	All I/O must use anderson power pole connectors
		3.1.2	Output voltage must be <=48V at any given time
		3.1.3	~~Output current must be between 15-45 amps~~
Inspect		3.1.4	All I/O wires should be 10-20 AWG
Matrix	*	3.1.5	Rectifier must output DC with as little drop as possible
Inspect	*	3.1.6	Load with emergency stop button
		3.1.6.1	Verify current cuts to diversion load
		3.1.6.2	Verify brakes get power
Inspect		3.2	Turbine Connection
		3.2.1	All the wires that connect to the turbine should exit at the turbine base.
		3.2.2	All cable pass throughs in enclosures must use cable glands or other similar devices that provide both strain and chafe protection.
		3.2.3	Each cable connection from the turbine to the enclosure should employ a quick-attach connector
		3.2.4	The turbine base plate shall be tied to earth ground. The turbine electrical system ground(s) must be electrically tied to this base plate with a 100 kΩ or lower resistance connection.
		3.2.5	All electrical cables leading from the turbine to the electronic components located outside the tunnel must be in cable form (no individual strands) and have connectors
Inspect		3.3	Point of common coupling(PCC)
		3.3.1	Wires exiting the base of the turbine must be at least 1.5 meters in order to reach the competition testing point of common coupling (PCC).
		3.3.2	The turbine electronics must be in a separate enclosure from the load in order to clearly differentiate load and the control during inspection by judges
		3.3.3	Teams can use the load to power the turbine but the load (a capacitor bank) must not be charged at the beginning of the competition.
		3.3.4	The enclosure should be outside the turbine and the wires should be long enough to reach the electrical enclosure and terminated with a single red and single black anderson power pole connector
Inspect		3.4	Electrical enclosure
		3.4.1	Enclosures are constructed for indoor use to provide a degree of protection for personnel against access to hazardous parts and to provide a degree of protection for the equipment inside the enclosure against ingress of solid foreign obj
		3.4.2	All electrical components must be incorporated into closed enclosures that are fire safe and meet or exceed a National Electrical Manufacturers Association (NEMA) Type 1 rating
		3.4.3	All components must be electrically insulated from the enclosures.
		3.4.4	All electrical components shall be mechanically secured to the enclosure.
Inspect		4	Safety Requirements
		4.1	Teams must follow Occupational Safety and Health Administration rules for safety equipment based on expected activities (see NREL/university subcontract, Appendix B Clause 8: Worker Safety and Health Requirements, for more inform
Inspect		5	PCB Design
		5.1.1	The PCB integration will be designed through the software, Altium
		5.1.2	All components and connections on the PCB layout will be labeled
		5.1.3	In order to define widths of power lines and communication lines, net classes will be made to avoid error within the PCB board
Inspect		6	Arduino Coding
		6.1	Client Constraints
Step by Step	*	6.1.1	Arduino Mega must be used to automatically adjust DC/DC converter
		6.1.2	MATLAB Simulink should be used
		6.1.3	A smaller DC/DC Converter should be used to power MCU
Inspect		7	DC/DC Converter
		7.1	Client requirements
		7.1.1	Team must use previous team's layout
Inspect		7.2	Competition requirements
		7.2.1	Capacitor cannot store >10J
Matrix	*	7.2.2	Max power variance must only vary +/-10% of total power at PCC
		7.2.3	Submit a one page write up of detailed testing with instrumentation used
Integration	*	7.2.4	Whole system test
		7.2.4.1	Perform a time series of power measured at a frequency of at least 200Hz, then compare to section 3.5.2 of competition guidelines

	Passed
	test partially passed
	Failed
	not testable
*	vital to system

Figure 8: Requirements with test progress

The most important requirements of this project were marked with an asterisk in the testing document. These signify tests that simply have to pass to either meet client requirements, or may be vital to the system's overall function. The first of which is 3.1.5: The rectifier must output DC with little to no voltage drop. This is vital to our system because the DC/DC converter of course requires DC input, or else it cannot boost the voltage. Therefore, outside of ME turbine requirements, the rectifier working properly is the start of the whole system, and therefore if it does not function properly, neither will the system. The next is a client required safety feature, 3.1.6: The emergency stop button. This requirement is quite simple, and yet, extremely important. The necessity comes from not only the competition requiring it, but for the safety of our engineers as well as our turbine in the event of a runaway event. The stop button engages the brakes on the turbine, thus slowing them down and allowing for the turbine to remain intact. Should this system not work, the turbine blades may eject in the wind tunnel, as seen in past projects. The next test is 6.1.1: Arduino Mega must be used in the project. This is for the sake of simplicity, as well as the ability to easily convert simulink models into arduino code. Should the arduino not function properly, practically the whole system fails. This is because the arduino logic controls the boost PWM, the diversion load, the emergency stop button, and the brakes. The next requirement marked as important is within the DC/DC converter, 7.2.2: Max power variance within +/- 10% of total power. This is a test of the boost converter's ability to stabilize and properly boost to our predetermined voltage. This is a large section of the competition, and where the whole team gets to see if the system works well, or if there are inefficiencies. Should this not function properly, the rest of the system can still function, but the brakes cannot, which can be very dangerous. The brakes use a buck converter tied to the PCC to get 6V out, and if the boost does not supply exactly what we expect, the buck cannot properly supply the brakes. The final requirement is a whole system test, 7.2.4. This is the sum of the parts, and if everything prior works, this test should work perfectly. There are quite a few pieces within this test, so the importance to the client is of course the system doing what it is supposed to. Should it not work, any of the above consequences may apply.

Major tests:

Rectifier:

The testing for the rectifier was successful, and yielded useful data for the overall circuit and specifically for the design of the boost converter. The rectifier is a critical component in the circuit. This is what converts the AC waveform, generated by the three-phase motor, into a DC signal. The rectifier chip that the team purchased consists of a six-diode full bridge rectifier. The chip has five pins that are threw-hole mounts for a pcb. The first two pins are the DC output pins, positive (+) and negative (-). The other three pins are the input pins for the three-phases. The team performed a loaded test with the rectifier in which the current was held constant at ~1A and the rpm was varied. This provided the data shown in Figure 3. The team also performed an open circuit test with the rectifier. The results of this test are shown in Figure 4. As described in the Testing workbook, the team originally expected the output of the rectifier to be in the range of 10-15 Amps. However, after performing some testing and having difficulty finding inductors with a high enough current rating, the team decided to settle for an output current of approximately 1 Amp. This decreased the expected output power (W) by a factor of ten. The team made this change to the expected values in the testing workbook and the rectifier output values passed for each test. the lowest rpm at which the motor is able to overcome the startup (or cogging) torque is approximately 360 rpm. For the rectifier test, the motor actually started at 300 rpm, which is better than expected. This was probably a result of drawing fewer amps with the DC load.

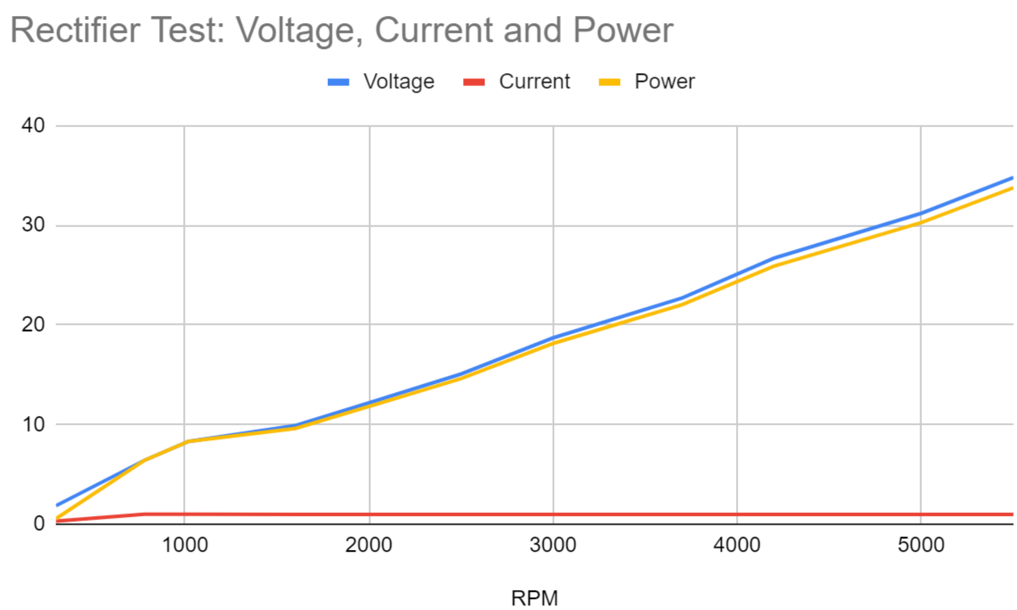


Figure 9: Rectifier CC Test Results

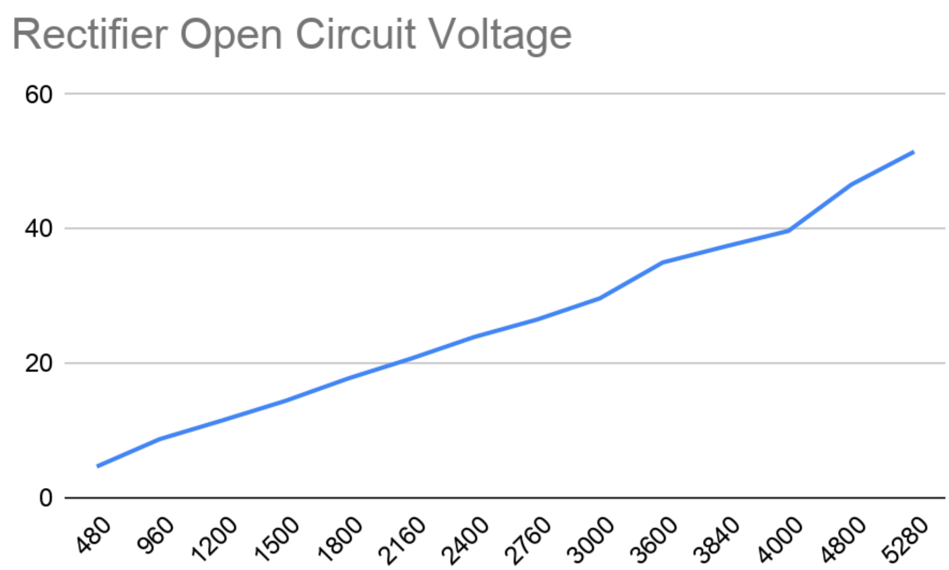


Figure 10: Rectifier Open Circuit Test

<u>MCU:</u>

The Testing of the control system was a success. The Control system is an Arduino Mega with a voltage sensor and emergency stop button. The Sensor and stop button control the amount the boost increases the voltage. To perform the MCU test we used the following items: DC Power supply, Arduino breadboard system, and an oscilloscope. The breadboard setup has power terminals that the power supply connected to. Channel one of the oscilloscope was connected to the PWM pin (Digital pin 45). A picture of the breadboard setup testing can be found in the appendix figure 1. The power supply was set at 4 volts for the start of the test. The DC voltage source was increased by one-volt increments. At each increase the PWM signal was analyzed by the oscilloscope, Duty cycle and frequency was recorded. After the voltage reached the max the power supply outputs (30 volts), We moved on to the Emergency system. The emergency system was tested by pushing the emergency button. The results should be no PWM signal and 6 volt power out of the relay.

Boost Converter:

The boost converter test consists of a representation of the voltage going into the inductor compared to the voltage being discharged by the capacitor. It is a simple Input/Output test, but is one of the most vital to our system. The test begins by hooking up the positive end of the inductor as well as the ground of the circuit to either a DC power supply, or directly to the dynamometer and rectifier set up. A variable DC Load should be connected across the output capacitor, and set to 1A of constant current. From there, any form of DC Voltage measurement is sufficient, but an oscilloscope is preferred. When the circuit is powered, it should also be loaded. From there, the test may begin starting at 1V in, and increasing by 1 volt until we hit 36V. The current should be monitored to only be pulling 1A, and the voltage output should be measured and recorded. A power curve should also be generated using the results of this, as seen below. (Not included as the Boost Testing has not yet been completed.

Analysis of results:

Rectifier:

The conditions for the rectifier are a combined set of results for the rectifier's temperature increase and overall output power from the generator input power. Successfully, the rectifier performed close to the root means square output from the given input, and didn't increase in temperature in high rpms. The rectifier was a white box test, which created expected results from the parameters we choose.

MCU:

The test for the MCU was done and the results received were close to the expected values. We started at 4 VDC and got out a duty cycle of .83. The goal voltage out of the boost converter was set at 32 volts. This value can be changed in the code. The Arduino code prevents the PWM signal from outputting a duty cycle above .83 since the Mosfet doesn't work the best at zero or one duty cycle. The duty cycle decreased when the voltage was increased. The results can be found in the appendix below Figure 2. The values recorded for duty cycle were very close to the expected results. A graph of the expected vs actual duty cycle is found below Figure 5. When the emergency stop button was pressed the relay closed providing 6 volts to the braking system. The PWM signal was also turned off. This is exactly what should happen during an emergency situation.

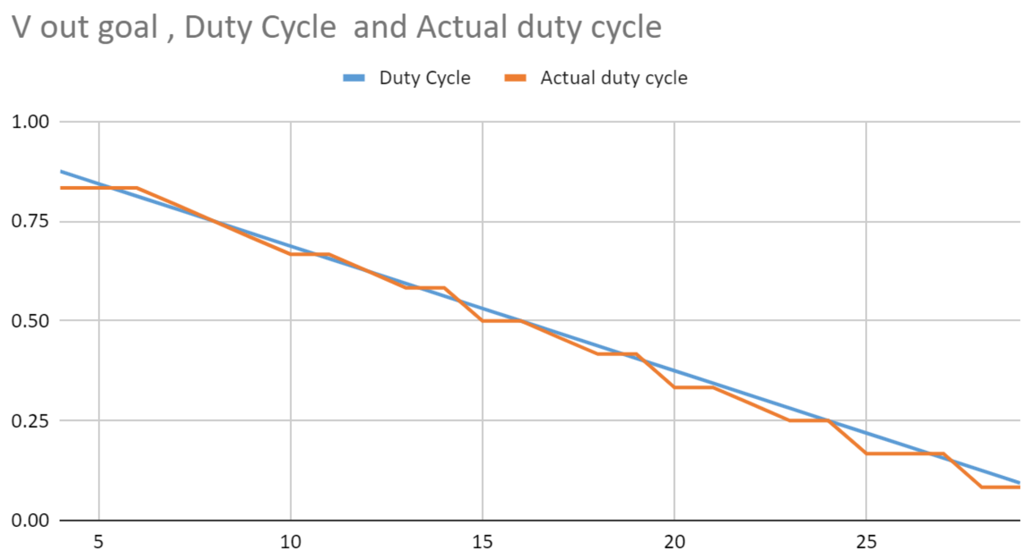


Figure 11: V_out vs expected and actual duty cycle

<u>Boost:</u>

The conditions for the boost are of the combined circuit elements collectively, including the MOSFET, the inductor, capacitor, and MOSFET with dead time. Integration testing between the circuit elements rendered initial testing issues at each node. The biggest issue was concerning powering the MOSFET. The boost was also a white box test, which created expected results from the parameters we choose.

Conclusion of Capstone Report

Most important requirements and their results

Our most important requirements include:

- 3.1.5: Rectifier must output DC voltage with as little drop as possible
- 3.1.6: A load with an emergency stop button must be usable
- 6.1.1: Arduino Mega must be used to automatically adjust converter PWM
- 7.2.2: Maximum power variance must not exceed +/-10%
- 7.2.4: Whole system test must be conducted to verify system integration

Between Wind Competition rules, as well as client requirements, these make up the requirements that simply cannot fail. Results are a mixture between finished, and not tested. The tests that have been passed include tests 3.1.5, 3.1.6 and 6.1.1. We designed a system that converts AC to DC voltage with very little drop which can be seen in Figure __. Both 3.1.6 and 6.1.1 are based on the Arduino, and are simple verification tests, which have easily passed.

The tests that have not yet been conducted both rely on the boost converter being done. Said tests are 7.2.2 and 7.2.4, which are both observed at the load. The issues we faced with the boost have set us back, however, given that the competition is not until the beginning of June, we still have time to troubleshoot.

Lessons Learned

Along the way the team has run into many issues, and have found many solutions. Since we were tasked with also interfacing with two other teams, we have decided to split this into personnel lessons and technical lessons.

Personnel:

Naturally, when three different teams have to come together to interface a small scale project, difficulties may arise. Some issues that came up were of course meeting times and schedule, the each team's respective knowledge on the other team's projects, and as any senior would agree, having other classes. We learned that we are given a whole year for a reason, and we would be wise to use all of it. Hitting the ground running in October proves to quickly work out struggles and allows each member to work out their own schedule and workload, thus making later struggles more manageable. Simply by better time management, all of these problems can be worked out. Members can meet when they can and not be rushed, they can learn what they do not know about the other team's project, and they can front load tasks to mitigate class stress.

Technical:

As expected, the team ran into many technical difficulties, whose origin lays in the hardware. Components not doing what we expected, ideal circuit not performing and lack of knowledge and real world fixes, etc. The team learned that they need to use their resources wisely, and always ask questions, but more importantly, come with a full knowledge of the problem. It is easier for an expert to help if they know all the facts about the problem, but more importantly, they are more willing to help if they do not have to work to even come to the issue. Another problem of a different nature lies in obtaining parts. The team learned that, while we may be on a tight schedule, people we are ordering from are not on the same schedule, and that lead times need to be doubly accounted for.

Outside of these lessons, the team learned how to work with and rely on other members, and how to effectively communicate to integrate certain aspects. Overall, we believe that we have been made better engineers for experiencing a year's worth of working on a team, and will have been better prepared to go into the workforce.

User Manual

Introduction

For Dr. Yaramasu:

The team is honored to have the opportunity to participate in the Collegiate Wind Energy Competition (CWC). Each team member made every effort to make this product satisfactory for the purpose of competing at the CWC despite the competition being changed to a virtual format in which official testing of the product is no longer expected. The team followed all guidance, rules and regulations detailed by the CWC, the client, and other advisors and mentors. As more wind energy was incorporated into the U.S. power generation mix, qualified workers are needed to fill related jobs at all levels. The goal of the CWC was to prepare students from multiple disciplines to enter the wind energy workforce by providing real-world technology experience. This tema has embraced and embodied this goal throughout the project. Our final design provides a Wind Energy Conversion System (WECS) that has been custom-designed to satisfy the rules and requirements of the CWC. Some of the key highlights include:

- An efficient generator providing power to the system
  - The MAD 5010 110 kv motor perfectly fits this application
- A high quality rectifier with a low voltage drop that can withstand up to 45 V and 45 A
  - The FUS 45-0045 chip provides AC/DC power conversion
- The custom designed boost converter provides high voltage output even at low wind speeds
- The microcontroller used to regulate the output voltage of the boost converter
  - An arduino mega perfectly fit our design requirements
- A variable resistive load which is used to control the current output of the system
  - After much experimentation and testing, a rheostat was selected to be the load.

The purpose of this user manual is to help you, the client, successfully use and maintain the 2021 CWC team project going forward. Our aim is to make sure that you and future teams are able to benefit from our product for many years to come!

The goal of the CWC was to prepare students from multiple disciplines to enter the wind energy workforce by providing real-world technology experience. The NAU team consisted of one electrical, and two mechanical engineering subteams. These three teams worked together to design, build and test an effective mechanical, electrical, and aerodynamic wind turbine and load design that is safe and reliable for testing in an on-site wind tunnel. The team was responsible for all electrical components and enclosures from the turbine to the load. This included a three-phase generator, an AC/DC converter, a DC/DC boost converter to raise the voltage, a microcontroller (MCU) circuit to regulate the output voltage, and a resistive load.

In order to effectively complete this project, the client asked the team to divide the project into five subtasks. Each team member would be the lead on a specific subtask and be responsible for the successful completion and integration of that subtask. These five tasks were:

1. Auxiliary input/output connections
2. AC/DC converter
3. DC/DC Boost converter

4. Microcontroller (MCU)
5. PCB design

A comprehensive system architecture, detailing how the subsystems of the project interconnect is shown in Appendix C, specifically in Figure C-1.

The generator could be selected either by the CWC mechanical engineering team working on the project or by the electrical engineering team. The three-phase generator acts as the power source for the entire system. The AC/DC converter is a 6 diode full bridge rectifier. The team could choose whether to design and build their own rectification circuit or purchase a pre built one online. Based on the team's research and due to a multitude of delays due to COVID-19, the team elected to utilize the same pre-made rectifier that was selected by the previous year's team, the FUS45-0045. This component can handle up to 45 V and 45 A and convert a three-phase AC signal into a DC signal. This DC output must be boosted using a DC/DC boost converter and the output of the boost converter must be regulated by a MCU. This is then fed into a resistive DC load which is used to control the amperage of the circuit. The whole circuit, once designed, is printed onto a PCB using an outside manufacturer. The maximum voltage that the system can output is 49 V according to the competition requirements. The current in the system is limited by the components and their individual current ratings.

There is a significant amount of communication and cooperation required for this project because it involves an electrical engineering subteam as well as two different mechanical subteams. These teams must work together to integrate their respective systems in order to make the whole system work. The mechanical engineering team is responsible for all the physical design and construction of components and parts for the wind turbine. The electrical engineering subteam is responsible for taking the variable three-phase generator output and converting it into a steady, or semi-steady, DC signal. The CWC requires that an emergency stop condition be accounted for in the system design. The competition also requires that the teams be able to deal with a loss of power situation in which the load is disconnected from the circuit. These were two obstacles that the electrical engineering team had to accommodate.

Installation

Installing the electrical system for the wind turbine will be thoroughly described in this section. The electrical subsystem of the wind turbine consists of 5 parts that will be crucial to the completion of the device. All of the parts that are included will be the Auxiliary input/output connections, AC/DC converter, DC/DC boost converter, Microcontroller. Each of these subsystems will be printed on to a circuit board in order to be conveniently placed in a housing unit so no wires will be exposed, as per the rules and regulations handbook. Through the use of Anderson Power Pole connectors a three phase input will be plugged into the header on the PCB labeled "AC/IN & AC/IN 2". These inputs go straight to the full bridge rectifier and come straight from the generator. Another pair of headers labeled "Load Out" will be the output of the electrical system that will be connected to another set of Anderson powerpole connectors for reading output values. As all of the electrical subsystems of the main electrical system are integrated onto a printed circuit board, the only connections left to make will be the point of common coupling which will only be used at competition. This is the point from where they will read all of the values that are being outputted, most importantly the power output.

Configuration and Use

Once the electrical system is connected to the turbine, signal wires, and the load then the unit is ready for operation. The control unit will automatically turn on when the voltage supplied from the turbine reaches the minimum amount of voltage (2.5 Vdc) which is approximately 3.5 meter per second. Once this happens the system should be operating and boosting the voltage supplied from the generator mounted on the turbine. The output voltage should be boosted to the predetermined output voltage goal. This output voltage goal can be changed by updating the arduino code. During the test of the turbine with the electrical system the load can be adjusted by turning the knob to increase or decrease the resistance of the load. This will cause the current of the system to change. This is key in keeping the various components from burning due to current values above the rated value. The component with the lowest amount of max amps is the inductor. The inductors max amps is 10 amps.

At some point in the test the emergency stop button will be activated and a few things will occur. The stop button is connected to the arduino and will enter emergency mode. When the stop button is pressed the arduino will cause the brakes to be activated. This will cause the turbine to slow down and stop spinning. The boost will also stop increasing the voltage. This can be seen on the voltmeter connected to the load. The stop button will need to be reset once the emergency is over. This is done by rotating the knob clockwise until it clicks and is raised. Once the stop button is reset the system will start back up and be in normal operation.

As a safety precaution the arduino is also looking for any major changes in the load. When the load is disconnected the arduino will enter emergency mode. In this mode the arduino will apply the brakes and stop the boost from increasing the voltage. Once the arduino recognizes the load being connected, the mode will be changed to normal operation mode.

Maintenance

The Electrical system has very few components that need regular maintenance. There are three major components with moving parts: the mosfet, generator, and transistors. These components might need to be replaced if they fail.

The Mosfet is basically a fast switch that opens and closes really fast. Since it is a switch that moves it might wear out. The mosfet can be replaced by unsoldering the original mosfet and soldering on the new mosfet. The mosfet can be purised on digikey or mouser. There is a chance the mosfet might be replaced with a new mosfet. If this is the case the available mosfets datasheet can be compared against the original mosfet datasheet.

The Arduino code can be adjusted or tuned for better performance. The Arduino mega controls the boost and emergency stop system. The code can be adjusted for a faster response of the PWM signal to the boosts. The code references a few libraries that were provided with the components used to read the voltage. The voltage sensor and turbine sensors use libraries that can be found on the adafruit website (www.adafruit.com).

The transistors also have moving parts so it also might wear out. The transistors can be replaced by unsoldering the original mosfet and soldering on the new mosfet. The transistors were purchased on digikey but can also be purchased on mouser. There is a chance the transistor might be obsolete. If this is the case a different transistors can be selected based on comparing the datasheet to the original.

Troubleshooting Operation

This section describes the subsystems that are most likely to fail, as well as how to fix them. The best way to perform troubleshooting is to remove the system from the actual turbine, and use one of the dynamometers. Using this will allow the team to avoid car testing, or testing from a wind tunnel, as well as manually controlling RPM. For use and troubleshooting of the dynamometer, refer to David Willy of the ME team.

Starting off in order of the system is the generator. Generators are often selected by the team and purchased from an online source, so fixing them is generally easiest by simply purchasing a new one. Before you do that, verify that the bearing it sits on is not stripped, and that the 3 phase output is connected and stable. This is likely to be a system that you will have to work closely with the mechanical team, as it is installed in the turbine hub. As the only actual moving part of the system, they will likely be able to assist in many ways.

The next section is the full bridge rectifier. It is quite simple, and can work independently of the rest of the system if it is simply hooked up to the generator, so troubleshooting will be made easy. Of course you will want to verify connections are still as they should be, and that the correct 3 phase, input and output DC pins are connected. The circuit should be the rectifier connected in parallel with a capacitor, which will stabilize output. From there, use an oscilloscope or digital multimeter on the DC I/O to verify proper output from the rectifier. A table of the ideal DC voltage output can be found in Appendix B (MAD 5010 110KV), or if there was a change in generator, refer to the ME team for a proper conversion. If the voltage is not meeting expectations, and the generator has already been verified, the rectifier is likely to have gone bad. In a pinch, a full bridge is simply 6 diodes, and can easily be soldered while waiting for a new one.

After this is the DC/DC converter, or Boost, which is the most likely to fail. This can be any number of things, so it is best to isolate it if possible. This can be done by bypassing the rectifier and attaching a DC power supply to the positive lead of the inductor, and the emitter of the drive circuit. This works in conjunction with the MCU, verifying proper PWM output from it is best to be done first. This can be seen in the next section. Assuming proper PWM, while the system is on, verify that the bridge of the transistor (driver) is receiving specified bridge voltage with a DMM, and do the same for the gate of the MOSFET. Refer to respective data sheets for specified value. Once this has been done, hook up an oscilloscope to the bridge and ground to verify the transistor is switching, and the same with the gate and ground for the MOSFET. A good signal will be a square wave with a high state equal to specified duty cycle. If we know the MOSFET is switching, some simple tasks using the DMM are next. Of course we want to verify no open circuits or shorts are present, so verify that the capacitor is discharging. This will be a matter of holding a steady voltage on the output, and is usually a matter of properly hooking up the load. Next verify that the current is reaching the Diode, and finally verify that current is passing through the inductor. This can be done using a DMM on voltage mode.

Last is the MCU. The 2020-2021 team is using an Arduino MEGA, which is used to control several systems. The code can be found in Appendix A. First, you will want to verify PWM output equal to what the duty cycle has been set to. Attach an o-scope to the PWM output pin, and verify that the duty cycle you set is being presented on the o-scope. Next, you will want to verify that the buck that the Arduino is connected to is outputting the necessary voltage. At the time this document was written, it should output 6V. This controls the brakes, pitching mechanism, and hall sensor on the turbine, and is simply powering a rail. Last system you will want to verify is the emergency stop. Hitting this will engage the brakes, and is simply a matter of using the code generated by the ME team to engage the braking mechanism. The easiest way to verify all the ME subsystems is using LED’s connected to the outputs.

If all else fails, go back to the basics. Know what the system should be doing, and go component by component to make sure each individual part is working. Sometimes components simply do not work. Do not be afraid to break out a breadboard and recreate each system; it could be a flaw in original design that an update has caused.

Conclusion

The team would like to offer a special thanks and gratitude to the client, Dr. Venkata Yaramasu, for his assistance and the generous use of his lab throughout the project. The hope is that this document serves as a guide and a tool to future capstone teams as they work toward designing and building a wind turbine for future years of the Collegiate Wind Energy Competition. Since, the competition was transitioned to a virtual format this year, we wish even more for next year’s CWC team to use our work and build on it in order to compete and succeed at the competition. While we will each be graduating in the coming weeks or months, the team members will continue to add work to the existing project and take our work to the virtual CWC competition which will be held at the beginning of June. If the client or any subsequent CWC teams would like further information on our project, the team would be happy to provide whatever assistance possible.

Appendix A: Software

This appendix contains the software of the project listed in less than four pages. The software for this project was implemented to regulate the output voltage of the boost converter by using an arduino mega to control the duty cycle and frequency of the circuit. The arduino mega was coded using arduino ide. The code during the test is found below in Figure A-1.

```
#include <Adafruit_INA260.h>
    Adafruit_INA260 ina260 = Adafruit_INA260();
    int middleVoltage=21
    float Rvoltage,Duty;
    int Ogoal=32;
    int Bpwm=45;
      int  buttonState;
      const int buttonPin = 2;
    const int relayOne=5;
    const int stopLight=9;

void setup() {
  //Set up timer 5 PWM boost
    TCCR5A = B00100011;    // Fast PWM
    TCCR5B = B11001;         // Prescaler = 1
    OCR5A = 1599;                // TOP
    pinMode(Bpwm, OUTPUT);
// Pin Setup
    pinMode(relayOne, OUTPUT);
    pinMode(stopLight, OUTPUT);
    pinMode(buttonPin, INPUT);
 // Status lights
    digitalWrite(stopLight,LOW);
}
void loop() {
     buttonState = digitalRead(buttonPin);
     Rvoltage=(ina260.readBusVoltage()/1000);
     Duty=((1-(Rvoltage/Ogoal))*1599);
   if (Duty >= 1299){
    Duty=1279.2;
   }
if((buttonState == LOW) ){
  digitalWrite(stopLight, LOW);
        if ((Rvoltage <= middleVoltage)) {
        digitalWrite(relayOne, LOW);
            analogWrite(Bpwm,Duty);
        }
      else {
        digitalWrite(relayOne, HIGH);
        analogWrite(Bpwm,0);
      }}
 else {
   digitalWrite(stopLight, HIGH);
 analogWrite(Bpwm,0);
}
}
```

Figure A-1: Arduino Code

Appendix B: Figures, Tables, and Schematics

This appendix contains figures and tables referred to in the report. It also shows detailed schematics of each subsystem that involves a circuit design. The PCB schematic is the most notable of these circuits.

Setup of control unit and sensors during test. DC voltage source powers the red and black cable. The oscilloscope is the gray cable on the bottom of the picture.

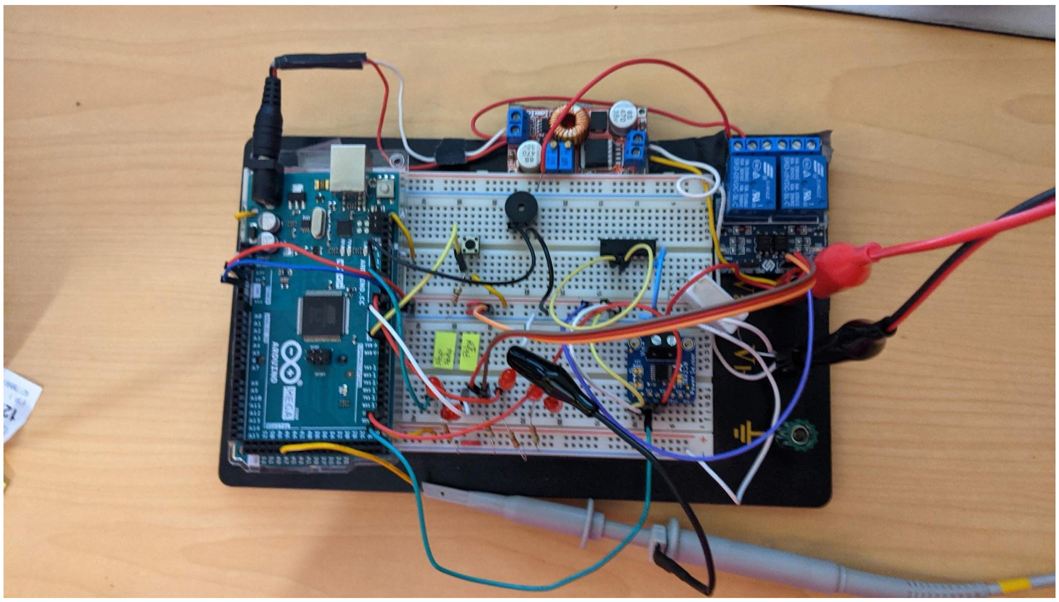


Figure B-1: Breadboard setup of MCU Circuit

This graph shows the duty cycle output versus the actual measured output.

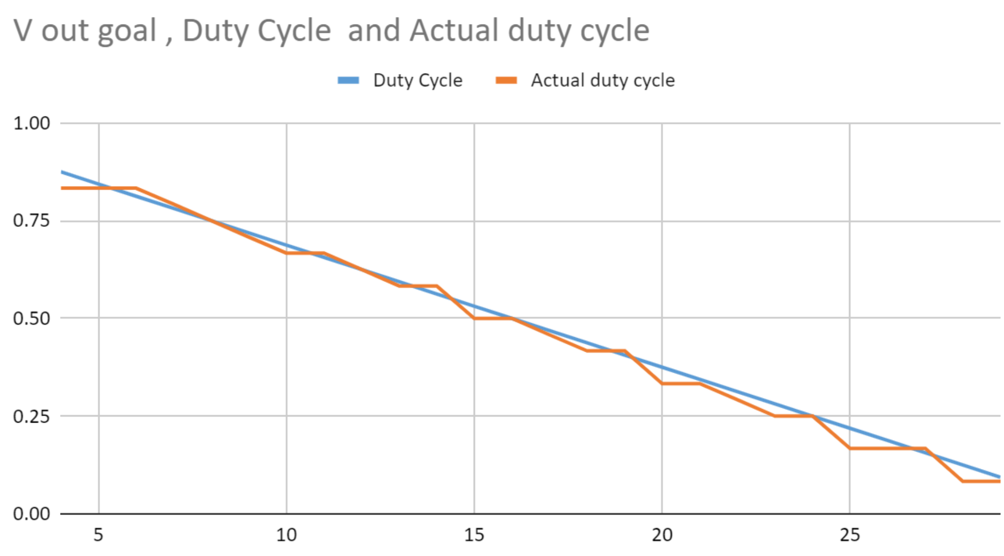


Figure B-2: V_out vs expected and actual duty cycle

This schematic shows the current edition of the teams PCB board. It was done using Altium.

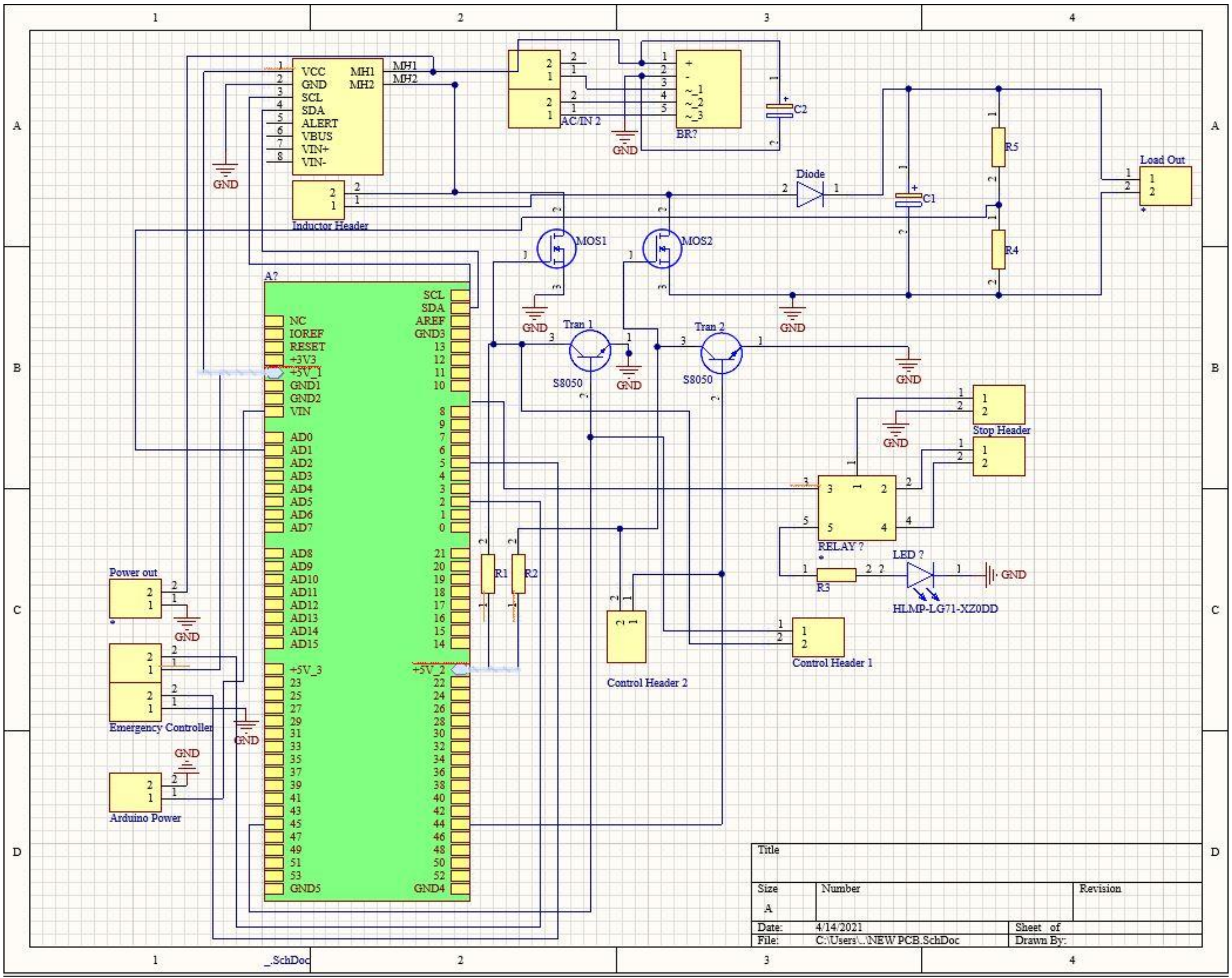


Figure B-3: PCB Schematic

This figure shows B-3 converted into the actual PCB layout, along with the actual trace paths. It will be the most accurate version of the current PCB.

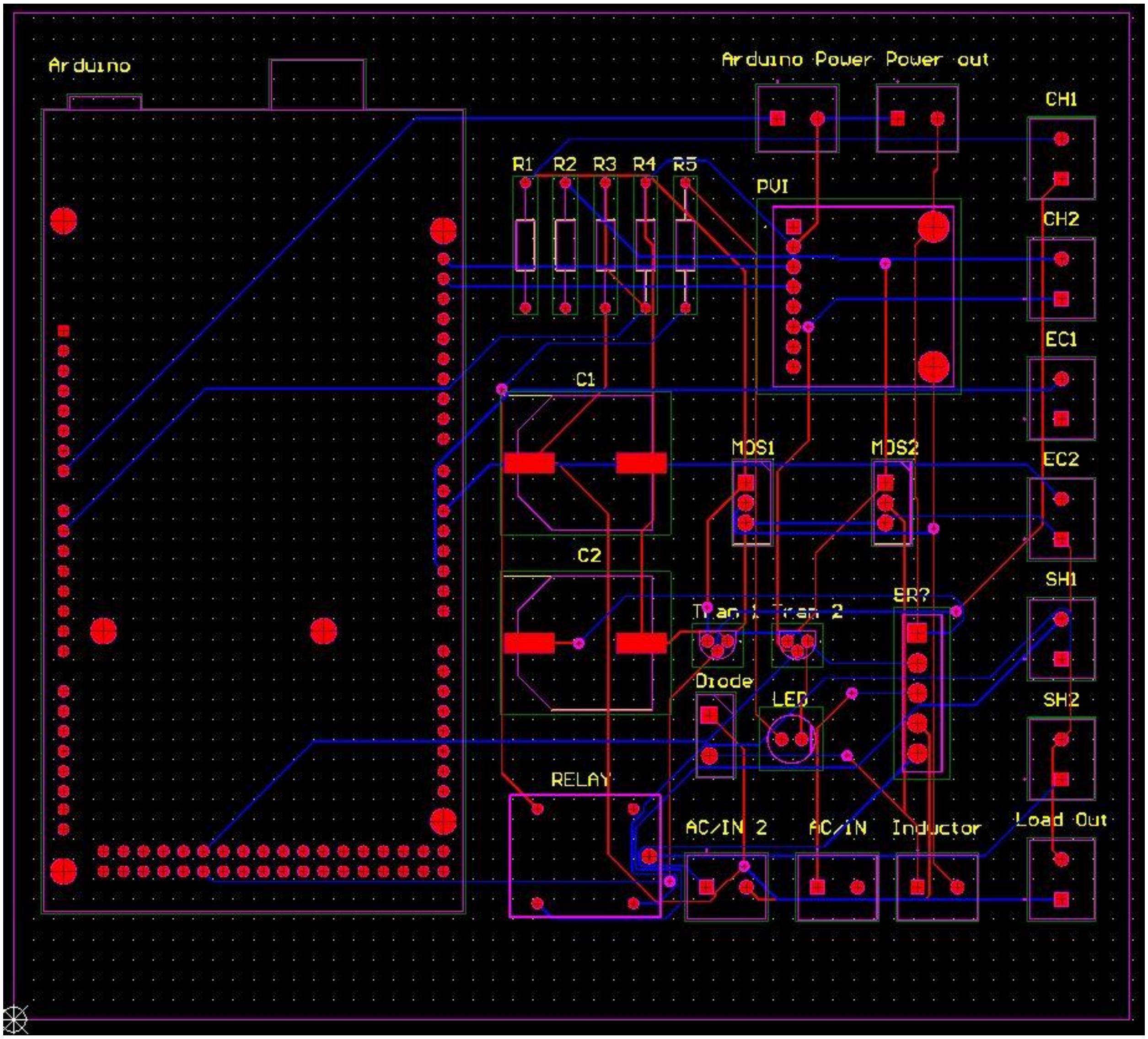


Figure B-4: PCB Layout and Wire Trace

Table B-1: Wind speed to rpm Conversion

This is a helpful table, mainly for the use of understanding what is expected of the rectifier. Included for use in the troubleshooting of the user manual.

F	G	H	I	J	K	L	M
Cp max	0.5398		U	Power	Omega	RPM	Torque of Blades (N*m)
Lamda	6		0	0	0	0	#DIV/0!
Radius of Disk	0.04		1	0.064919	24	229.176	0.000283269
Mew	0.9		2	0.519348	48	458.352	0.001133078
Moment of Inertia	0.00019576		3	1.752801	72	687.528	0.002549425
Mass of Disk	0.2447		4	4.154788	96	916.704	0.004532311
Area	0.196349541		5	8.11482	120	1145.88	0.007081736
Max density of Air	1.225		6	14.02241	144	1375.056	0.0101977
Radius of Blades	0.25		7	22.26707	168	1604.232	0.013880203
			8	33.2383	192	1833.408	0.018129244
			9	47.32563	216	2062.584	0.022944825
			10	64.91856	240	2291.76	0.028326944
			11	86.4066	264	2520.936	0.034275603
			12	112.1793	288	2750.112	0.0407908
			13	142.6261	312	2979.288	0.047872536
			14	178.1365	336	3208.464	0.055520811
			15	219.1001	360	3437.64	0.063735625
			16	265.9064	384	3666.816	0.072516977
			17	318.9449	408	3895.992	0.081864869
			18	378.605	432	4125.168	0.091779299
			19	445.2764	456	4354.344	0.102260269
			20	519.3485	480	4583.52	0.113307777
			21	601.2108	504	4812.696	0.124921824
			22	691.2528	528	5041.872	0.13710241

Table B-2: Generator Expected Output Voltage

Another table included for understanding of the rectifier.

rpm	100 kv	V	150 kv	V	160 kv	V	180 kv	V
300	110	2.727273	150	2	160	1.875	180	1.666667
500	110	4.545455	150	3.333333	160	3.125	180	2.777778
1000	110	9.090909	150	6.666667	160	6.25	180	5.555556
1500	110	13.63636	150	10	160	9.375	180	8.333333
2000	110	18.18182	150	13.33333	160	12.5	180	11.11111
2500	110	22.72727	150	16.66667	160	15.625	180	13.88889
3000	110	27.27273	150	20	160	18.75	180	16.66667
3500	110	31.81818	150	23.33333	160	21.875	180	19.44444
4000	110	36.36364	150	26.66667	160	25	180	22.22222
4500	110	40.90909	150	30	160	28.125	180	25
5000	110	45.45455	150	33.33333	160	31.25	180	27.77778

This graph shows the voltage drop across the rectifier, and shows how efficient it is.

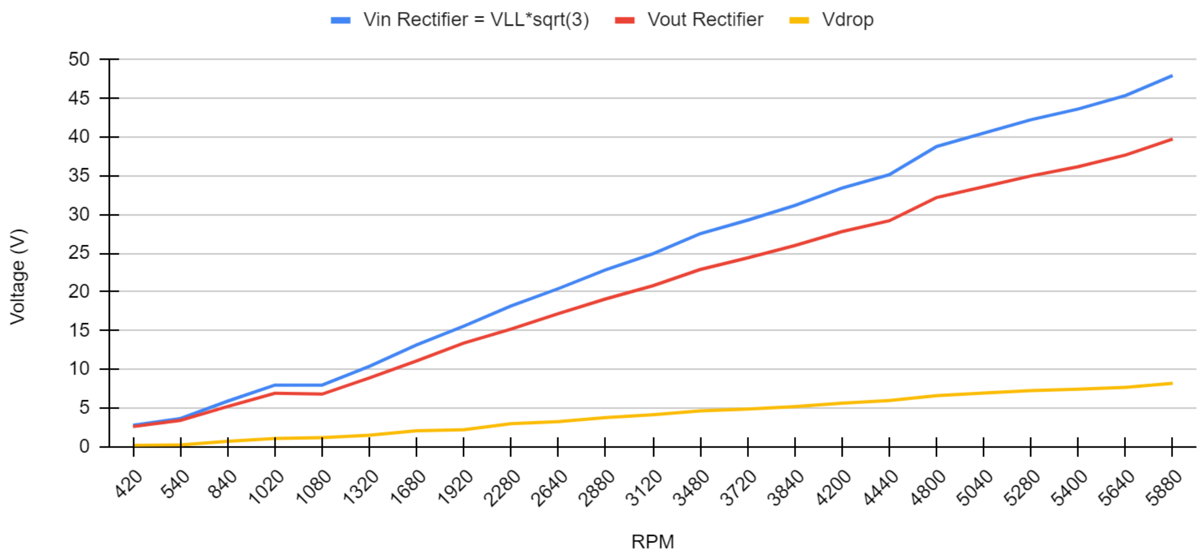


Figure B-5: Rectifier Voltage Drop Test Results

This graph shows the 160KV motor test data. It shows the effective power output of the system.

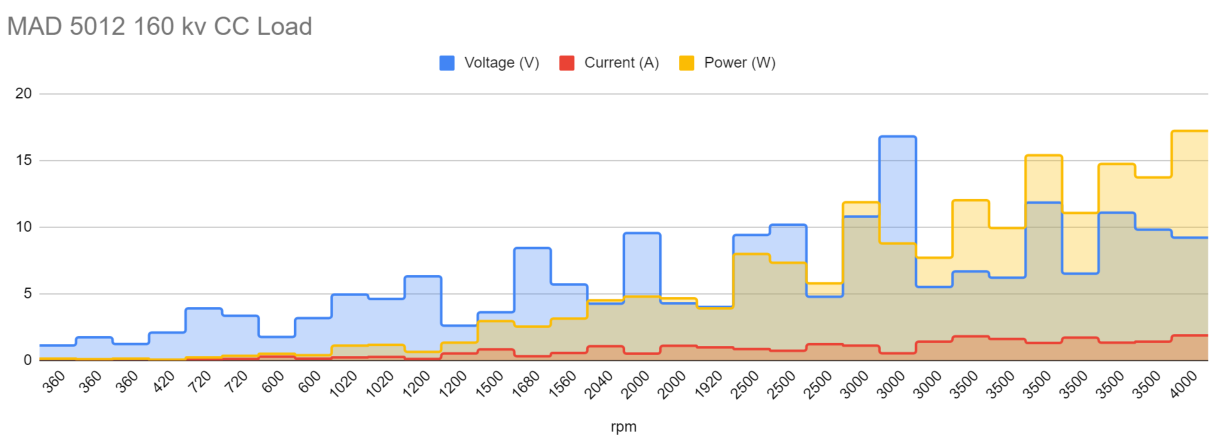


Figure B-6: MAD 5012 160 kv Power Output (with DC load)

This graph shows the 150KV motor test data. It shows the effective power output of the system.

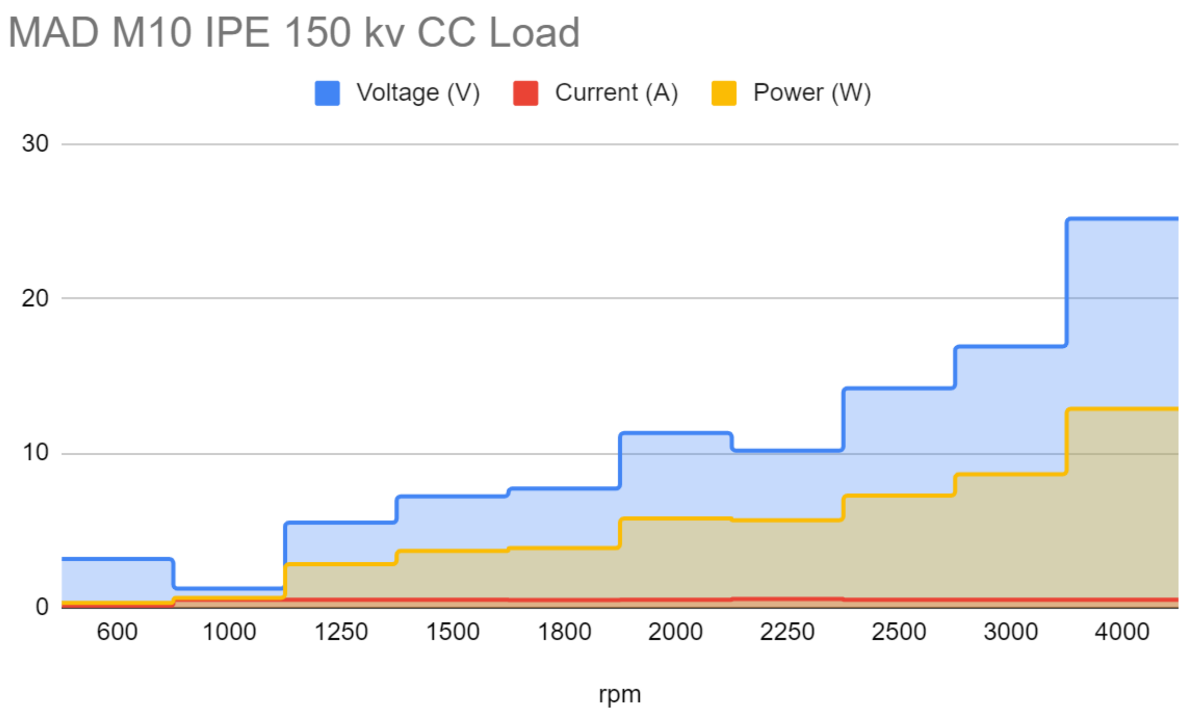


Figure B-7: MAD M10 IPE 150 kv Power Output (with DC Load)

This graph shows the 110KV motor test data. It shows the effective power output of the system.

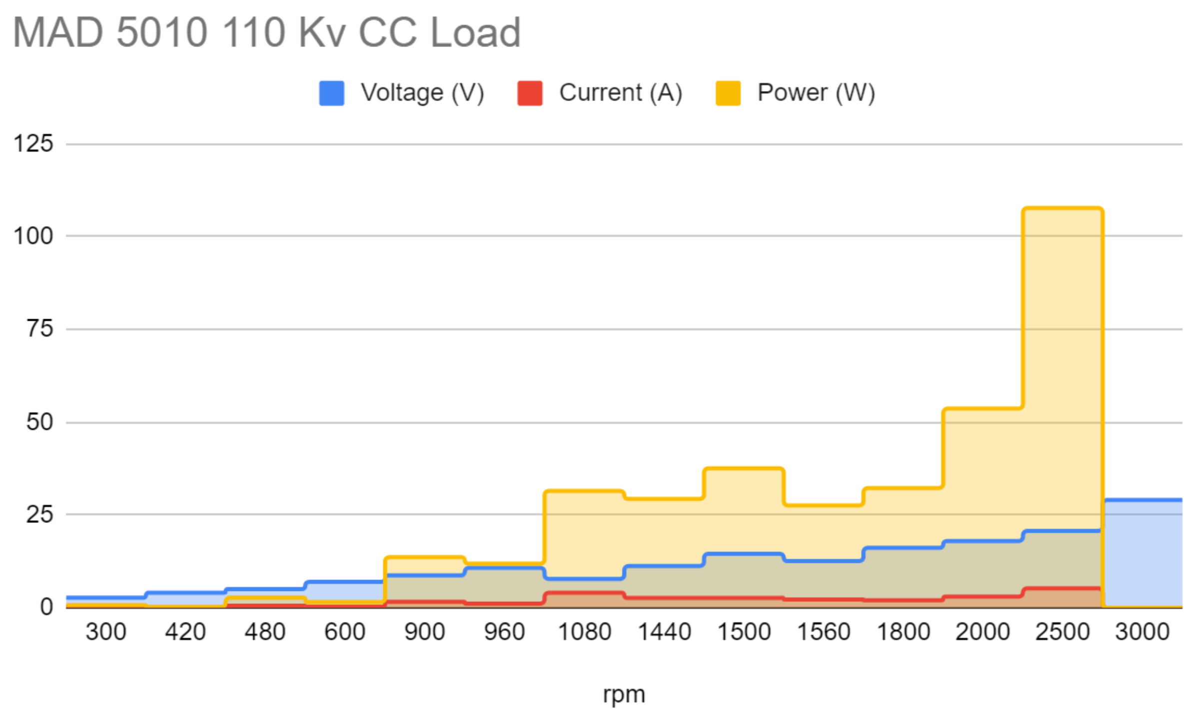
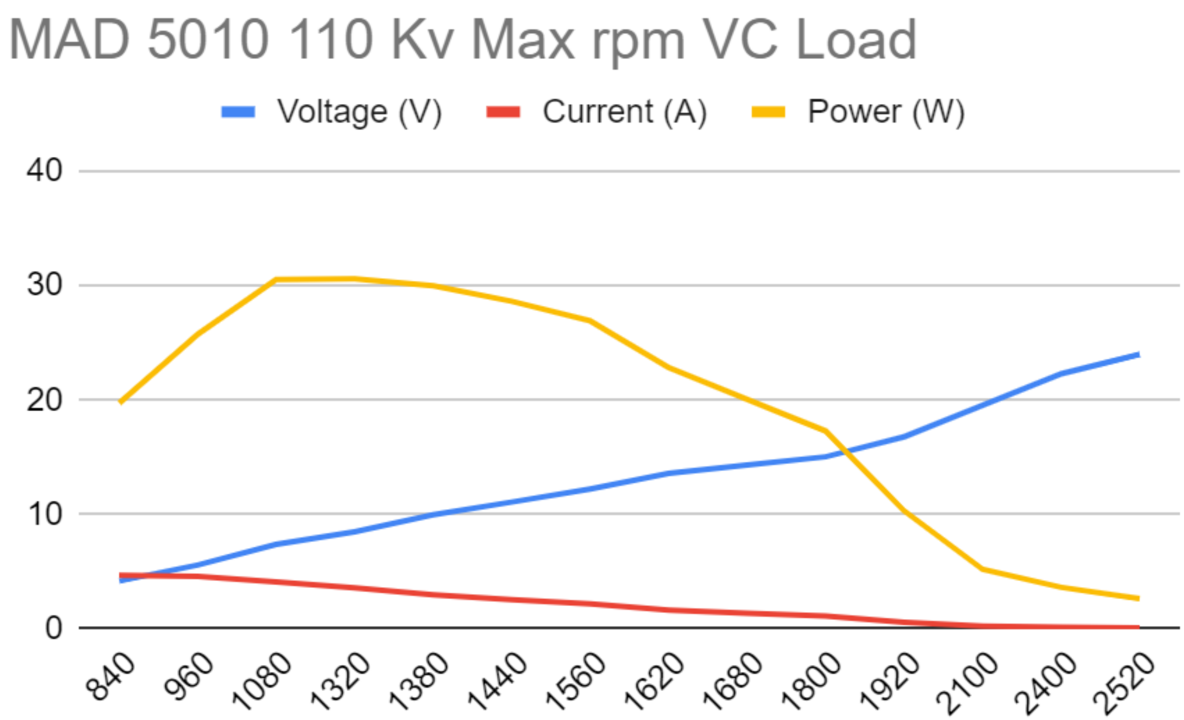


Figure B-8: MAD 5010 110 kv Power Output (with DC load)

This shows our selected generator's power curve. This was necessary for the competition deliverable.



d)

Figure B-9: MAD 5010 110 kv Power Curve (Voltage Control load)

This shows an open circuit test with no load of the RPM vs voltage out of the 110 KV.

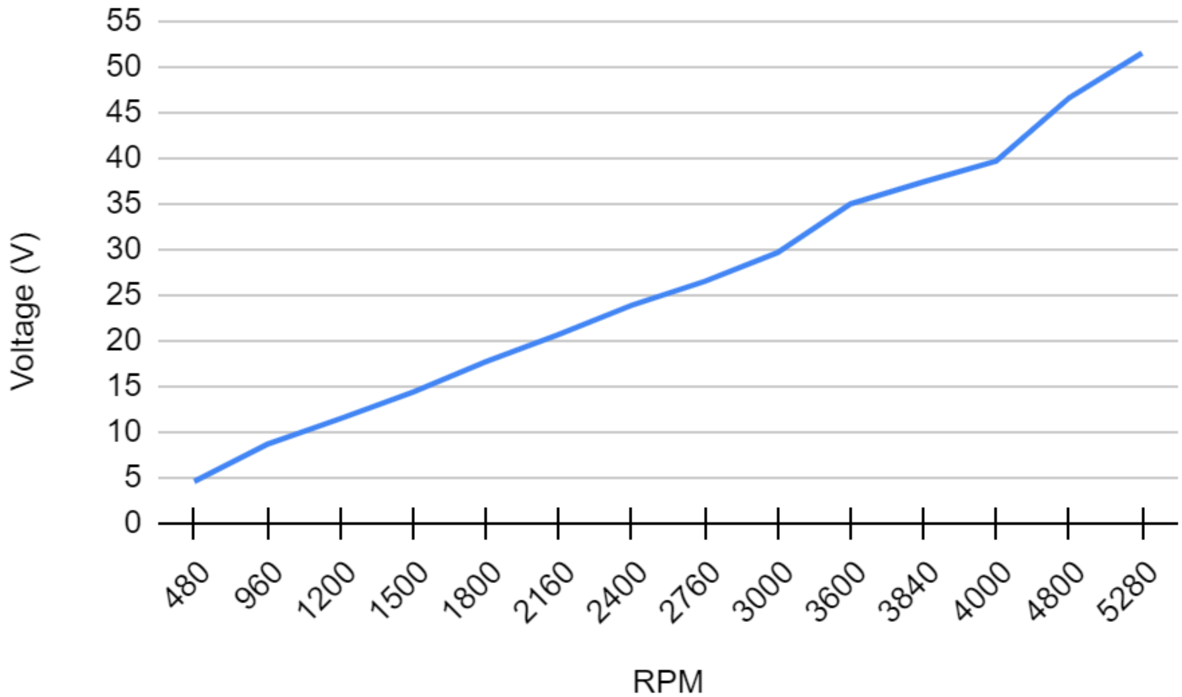


Figure B-11: MAD 5010 110 kv Open Circuit Voltage Test Results

Appendix C: System Architecture

This appendix includes both the level 1 and level 2 system architecture for the project. It also contains the testing system architecture which notes each place that testing was done in the system. The results of these tests are in the testing workbook. The level 2 system architecture shown in Figures C-3 through Figure C-6 go into more detail on each of the critical components in the system architecture.

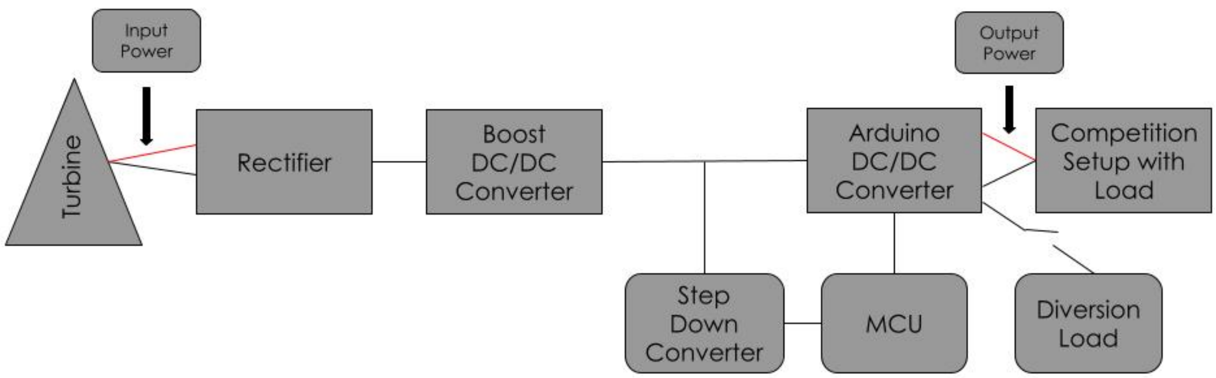


Figure C-1: Level 1 System Architecture

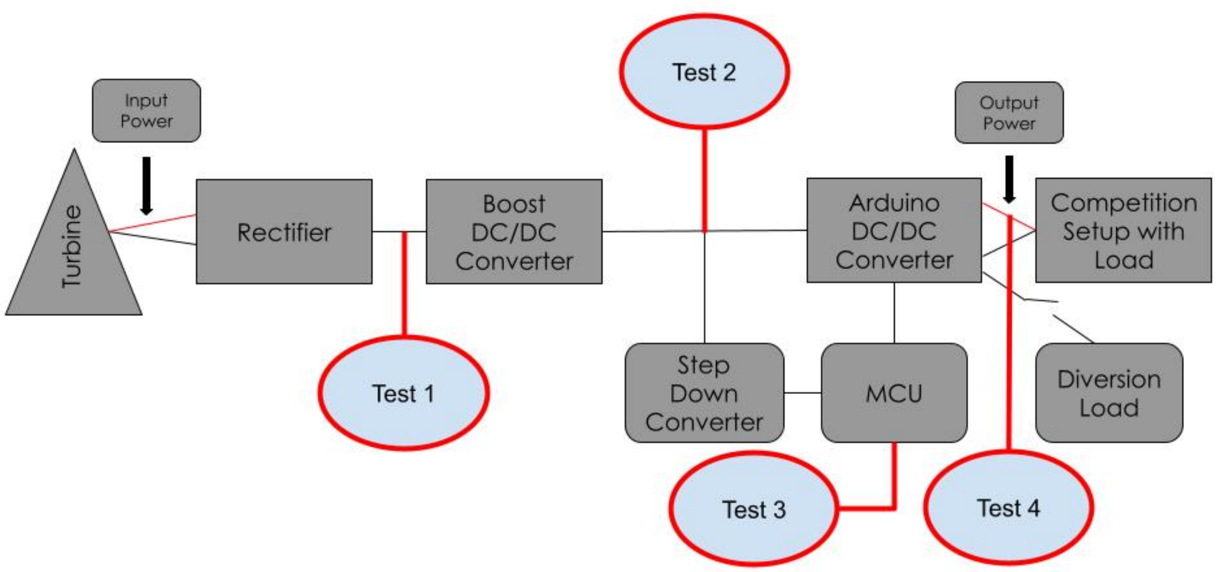


Figure C-2: Testing System Architecture

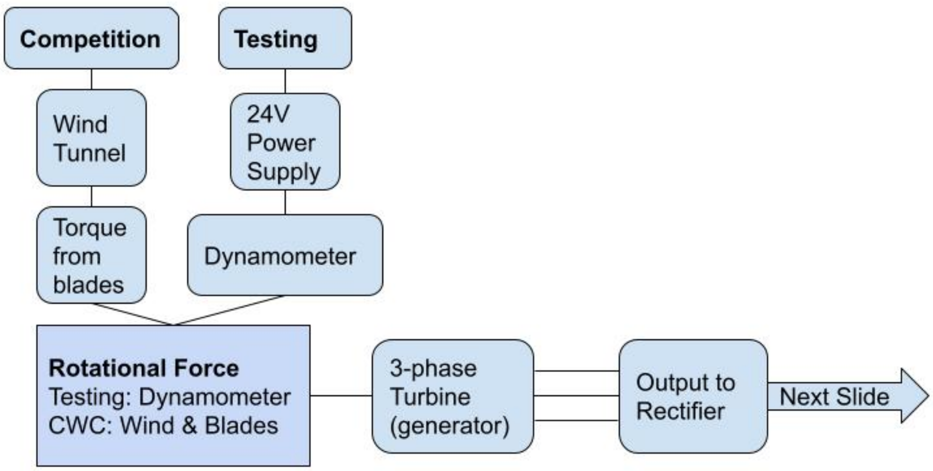


Figure C-3: Level 2 Generator System Architecture

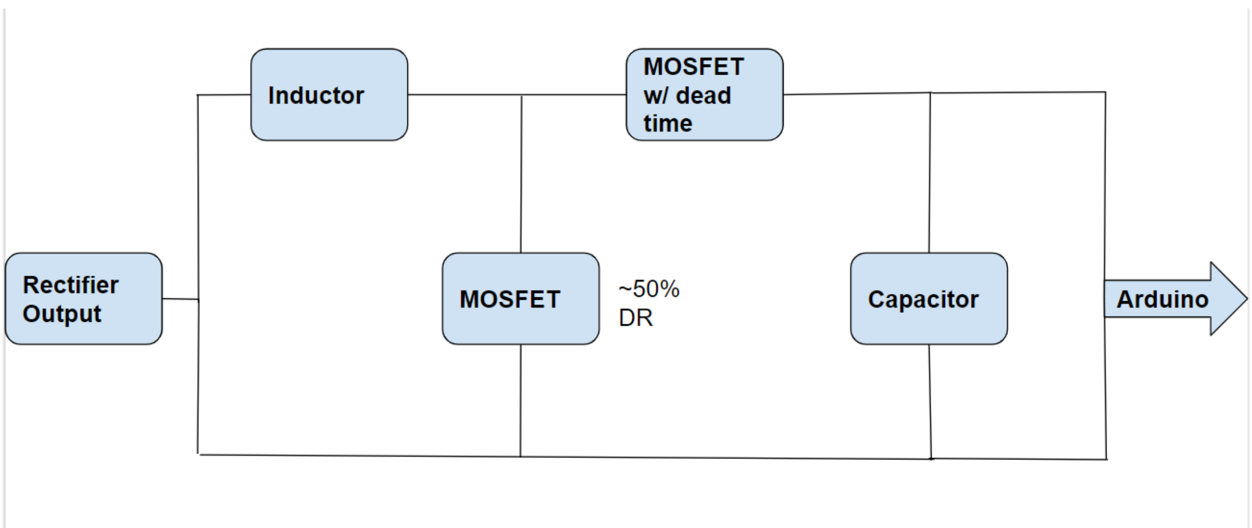


Figure C-4: Level 2 Boost Converter System Architecture

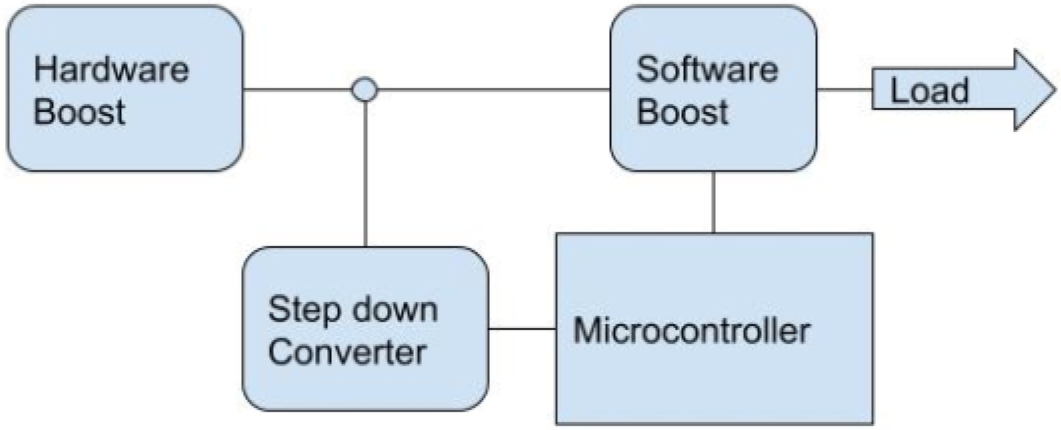


Figure C-5: Level 2 MCU System Architecture

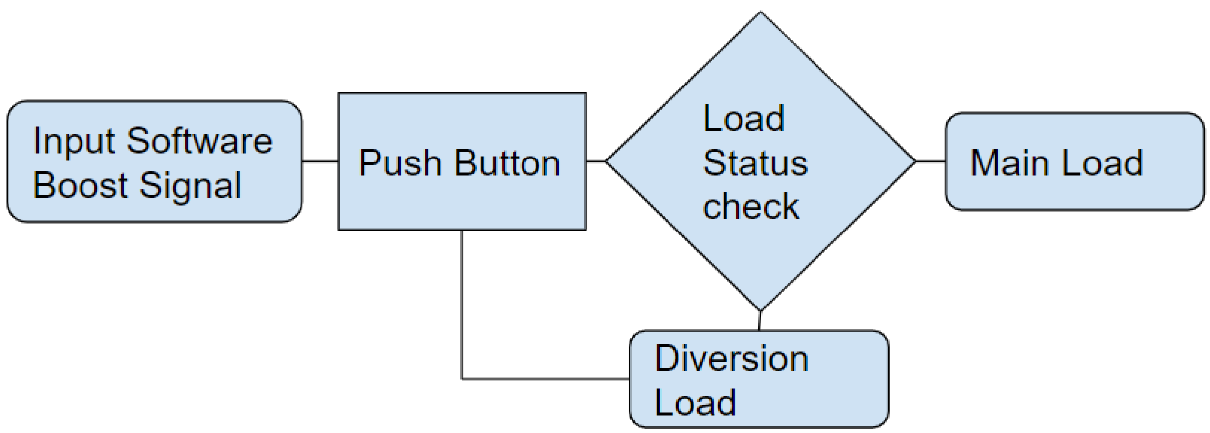


Figure C-6: Level 2 Load System Architecture