

Wind/Hydro Power Generation Simulator

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Abstract

This project aims to design a wind or hydro power generation simulator. The original scope of this project was to construct a physical simulation apparatus in which wind/water speed data is fed to a microcontroller that adjusts the control voltage of a motor drive. The spinning DC motor would generate power via a coupled generator whose power output would be a scaled down version of wind/hydroelectric generator power output given the same wind/water speed input. Due to Covid-19, the project was altered to be entirely virtual and was made through Simulink in MATLAB. The virtual simulator attempts to mimic physical system behavior by feeding a user input array, over a time span of 30 seconds, representing wind/water speeds, over a time span of 24 hours, into a programmable function block meant to mimic desired microcontroller behavior. The output of this block is fed to a second function block acting as the system's motor drive which drives the pre-defined DC motor module. The connected generator module's output is connected to a DC-DC converter block in order to simulate the system's ability to power appliances with a constant voltage despite the fluctuating generator output.

Chapter 1: Introduction

Due to increased concerns on the use of non-renewable energy sources like coal or gasoline and their harmful effects to the environment, a large market for renewable energy sources has formed within the past decade and continues to grow today. This is evidenced by the fact that in the United States, solar and wind power industries have reportedly created jobs 12 times faster than the rest of the country's economy, and have grown as much as 20% within recent years [1]. Renewable power usage has also become increasingly important for producing power in remote areas throughout the world. The amount of people gaining access to electricity has steadily increased for many years; however, estimates show that 670 million people will have no access to electricity, even by 2030 [2]. Figure 1-1 demonstrates areas, like Africa and Asia, where a large percentage of the population suffers from a lack of electricity [3].

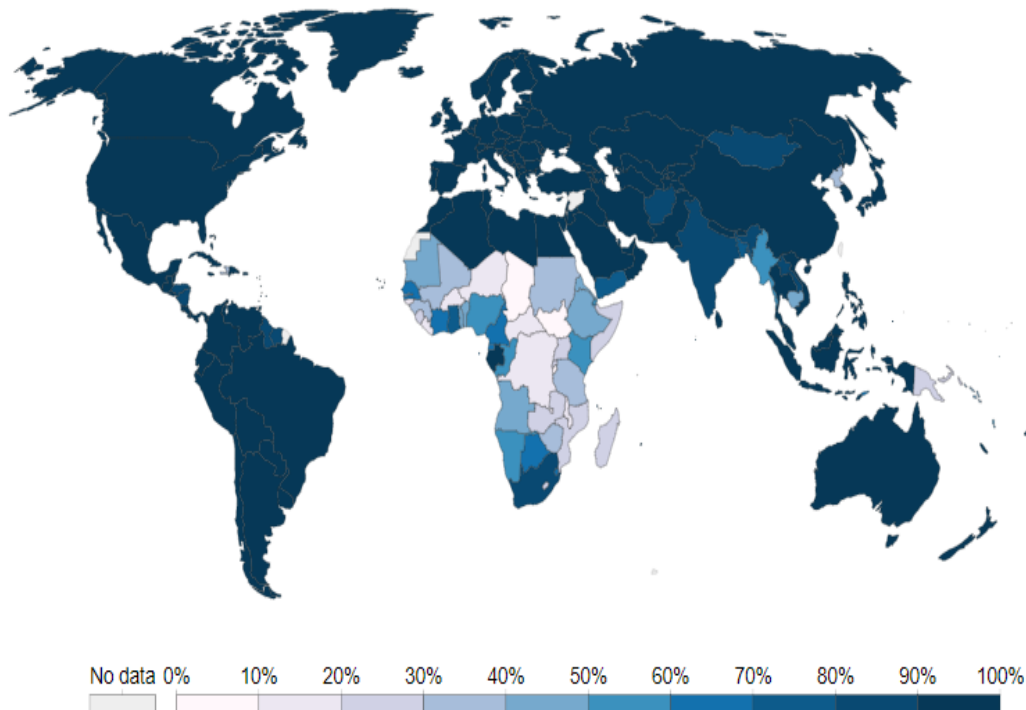


Figure 1-1: Share of Population with Access to Electricity [3].

Providing electricity to everybody is a challenge the world has struggled with, e.g. centralized power plants cannot reach out to every home in the world. It isn't practical or profitable to extend power lines to every rural location far from main cities, especially in countries with underdeveloped public infrastructure. Figure 1-2 shows the exponential curve of how expensive expanding power lines into areas that are sparsely populated [4]. In mid to low density communities developing a small power grid localized to the rural area and unconnected to the national power supply is the most cost effective solution to supply these people with electricity.

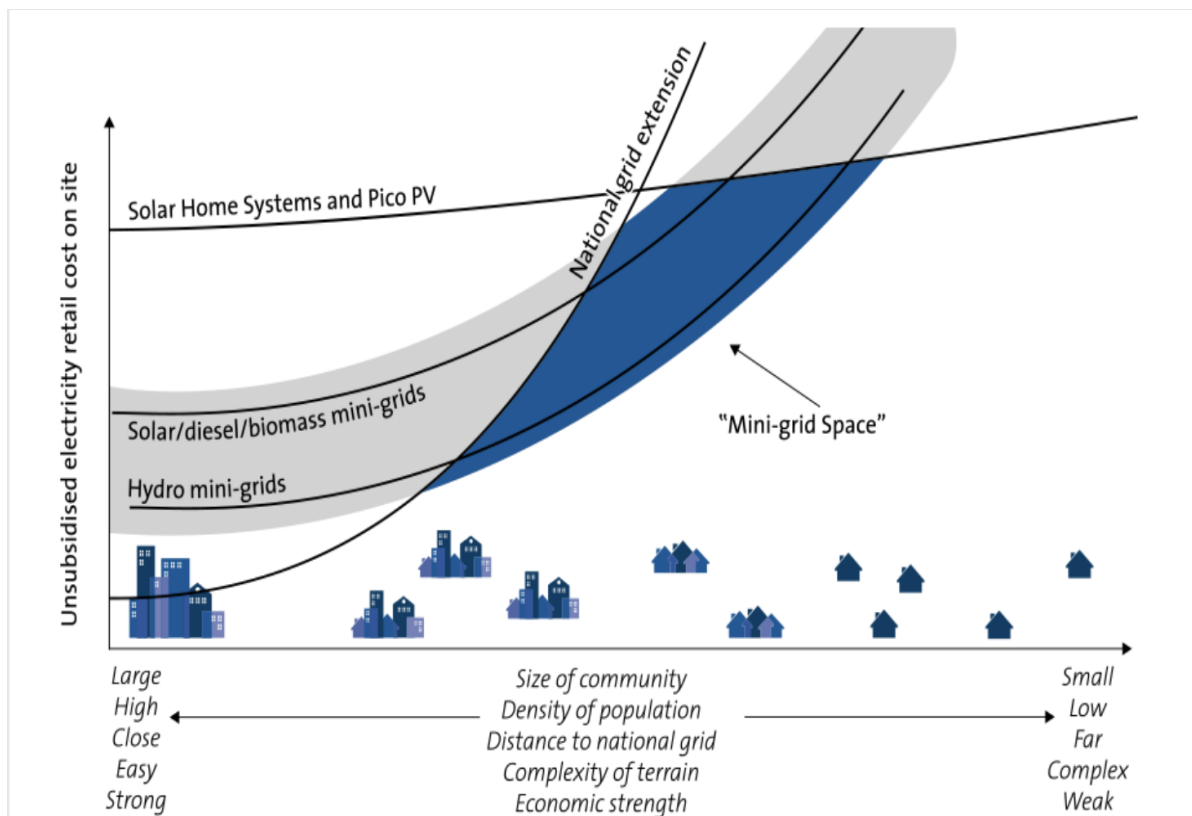


Figure 1-2: Mini Grid Optimization Graph [4].

With the technological advances in solar, wind, and hydro power generation, decentralized power grids that can generate electricity for a small community are becoming

increasingly prevalent. With these advancements in renewable energy, these mini grids can supply power cheaper than ever before through the use of solar panels, wind turbines, and hydro supplies. This helps produce power in rural areas the main grid cannot reach effectively. The more renewable energy is used, the more important accurately predicting the costs and benefits behind building a new renewable power farm become. More accurate data encourages the production of more clean energy in communities throughout the world.

Chapter 2: Background

As previously discussed in Chapter 1, public access to electricity is inadequate in many parts of the world. This lack of available energy causes problems for people living without the necessities power provides; such as A/C, refrigeration, effective lighting, etc. Many rural communities in less developed nations aren't connected to any power grid. One potential solution to this problem is building small scale power grids powered by renewable energy. Renewable energy is gaining traction across the world, so understanding how to efficiently provide the most cost effective solutions becomes more and more important. Products which estimate the energy produced in solar panels at a given location exist, but other forms of renewable energy lack similar software. Different areas benefit more from wind or water powered energy but it is difficult to predict how much power is produced, or how to maximize power efficiency. If a rural community lived near a strong running water stream or a windy plain, it could power their community with little investment. Solar panels can prove their worth, even before production, by estimating the energy produced, and wind and hydro energy must be able to do the same.

Renewable energy sources have demonstrated their practicality in recent years through mini-grids that operate off of solar or wind power. For example, solar mini-grids funded by the state government of Ogun State and the European Union were implemented in the Nigerian city of Gbamu Gbamu in early 2018. Prior to this installation, Nigerian citizens residing in the Ogun State relied on personal generators and could not even run multiple house appliances simultaneously without their power crashing. Now roughly 15,000 people have access to electricity through multiple mini-grids being established [5]. The ability to simulate renewable

power generators facilitates an increase in the amount of renewable energy mini-grids that are installed in areas like Gbamu Gbamu, as it makes cost-benefit analyses more accurate and specific.

Currently, no products are able to simulate wind or hydro generators based on a set of data for wind or hydro currents at a given location. Multiple senior projects have utilized a similar system, and this project attempts to build on their work. The primary project referenced is another senior project, “Wind and Hydroelectric Power Simulation for the DC House Project” by Randy Lormand and Christopher Goloskie [6]. The group developed a working system that was more reliant on a potentiometer instead of a set of wind/hydro speeds running through a microcontroller, enabling a voltage range much larger than 0 V to the maximum output voltage of the microcontroller. Another senior project, “Wind/Hydro Generator Simulator” by Michael Djaja and Christopher Rotsios [7] aimed to solve the same problem as ours; however, was unable to complete it due to the unreliability of their parts. Their system is similar to the system that we will be implementing; however, this project focuses on improving the system characteristics by choosing appropriate components that will be able to handle the speeds of the system. This project aims to improve the accuracy of simulation by having a larger range of outputs available.

To summarize, this design project aims to accurately simulate the power generation of both wind and hydroelectric generators. By inputting a set of wind or water speeds for a given amount of time, this will simulate a scaled down energy output to a generator that will then be converted to a 12V power supply for use. This project will represent an accurate representation of the amount of power that would be generated by a renewable power generator and demonstrate how a real system would benefit a community.

Chapter 3: Design Requirements

Block Diagrams

The overall requirement of this system is to power a DC motor using a set of wind/hydro flow speeds in a data file created in Excel or Matlab. The motor spins a generator to form usable power that follows the Wind/Hydro speed data. The level 0 diagram is shown in Figure 3-1.

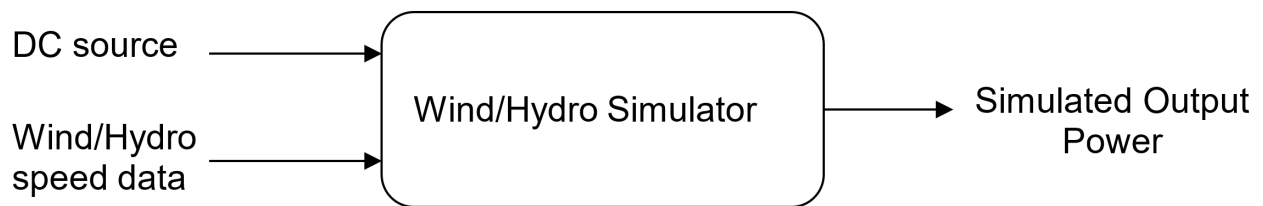


Figure 3-1: Level 0 Block Diagram

Table 3-1: Functional Requirements Level 0

Module	Wind/Hydro Simulator
Inputs	- Input Power - Wind/Hydro Speed Data
Outputs	Simulated Output Power following Wind/Hydro speed data
Functionality	The device should have user defined inputs for specific wind and hydro parameters. With the wind and hydro current data, the system calculates the energy produced in a simulation. It then demonstrates a scaled down power output via physical emulation with a 100W maximum output.

The level 1 block diagram shown in Figure 3-2 demonstrates the different modules within the scope of the project. The simulator will utilize a computer to program the microcontroller with the wind/hydro flow speed data via a Matlab or Excel file. The microcontroller will communicate this information to the adjustable speed drive to adjust the input voltage to the motor based on the data provided. The motor will turn at different speeds to simulate the actual

wind/hydro currents spinning a turbine in whatever location is being analyzed, and it will charge a generator. That generator output connects to a DC-DC converter to regulate the voltage into a constant value required by the load.

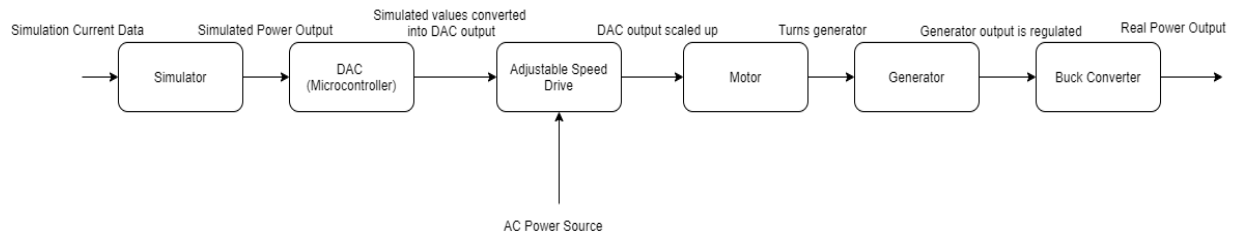


Figure 3-2: Level 1 Block Diagram

Table 3-2: Functional Requirements Level 1

Module	Simulator
Inputs	Simulation Current Data
Outputs	Simulated power output
Functionality	The simulator determines which power output the generator should target in response to the wind and hydro current data input into the system.
Module	Microcontroller
Inputs	Simulated power output
Outputs	Controlled motor speed reading
Functionality	The microcontroller translates the simulated power output signal into a voltage signal which charges the generator until the real output power matches the simulated output power
Module	Adjustable Speed Drive
Inputs	- Control signal (Output of DAC) - AC Power Source
Outputs	DC motor voltage supply
Functionality	Sends an appropriate amount of voltage to the motor to control the speed that the motor turns. It can change the speed of the motor by changing the input voltage based on different readings.

Module	Motor
Inputs	DC motor voltage supply
Outputs	Generator power
Functionality	The motor receives the voltage signal from the microcontroller and turns the generator in response.
Module	Generator
Inputs	Generator power (turns generator)
Outputs	Real Power Output
Functionality	The generator models the simulation results on a small scale, representing the effectiveness of a turbine's placement via live demonstration.
Module	Buck Converter
Inputs	DC power from the generator
Outputs	Constant DC power supply
Functionality	Takes the variable voltage from the generator and converts it to a constant voltage that can be used to power an appliance

Technical Design Requirements

A set of data representing wind currents at a hypothetical wind farm location and hydro currents at a hypothetical dam or offshore generator is run through a microcontroller that controls the input voltage with a speed drive. The microcontroller can be easily programmed with the user's data to communicate how high the input voltage of the motor should be to the speed drive. This should follow the scaled down speed profile with a $\pm 5\%$ error rating. The speed drive is powered by 120 V_{AC} and is converted to DC voltage to power the motor. The motor is rated for 187W and the generator is rated for 300W, so the input power for the motor should be no higher than 150W in order to preserve the motor. To create usable output power the input voltage to the motor should be between 20V to 100V. This range of input voltage will create an output voltage

between 5V and 30V from the generator. This is to make sure that the Buck converter doesn't overload with current or voltage with our load. This creates a maximum power output of 50W to the Buck converter. All of these components must fit inside a 18" x 8" x 8" enclosed box for protection and to be able to easily move the system. The box must have wires protruding from it that allow a user to connect a laptop to the microcontroller and to connect an appliance via USB to the system output voltage. Table 3-3 summarizes the marketing requirements along with their corresponding engineering specification and justification.

Table 3-3: Requirements and Specifications

Marketing Requirements	Engineering Specifications	Justification
1 & 5	The output of the generator must be between 5V and 30V.	To protect the buck converter from breaking the output voltage must be kept in an acceptable range
2 & 4	System must use a microcontroller to interface between the simulator and the motor.	A microcontroller allows the computer simulation to produce the correct amount of power for the motor.
1 & 5	Generator must have a maximum operating speed of 1000 RPM.	To balance between low cost and functionality, the motor must have a high rpm rating.
3	All components must fit within an enclosed 18" x 8" x 8". It must also have access points to power the system and input user data.	A box of this size ensures that components do not become damaged and can move easily between labs. This also protects the user by isolating the electrical components from the user.
4 & 2	System must have +/- 5% error when changing the speed of the motor based on the data input.	The power charts measured from the generator must have the same shape within a 5% deviation range as the simulation data input
5	The motor charges the generator up to a maximum of 50 W.	The generator should not output extremely high power to the load.

1 & 5	Buck converter regulates generator output to useable power.	The buck converter must convert the changing output voltage of the generator to a constant voltage that can be used to power an appliance.
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Marketing Requirements

1. The component parameters balance functionality and cost of materials.
2. A customizable input voltage signal must control the speed of the motor.
3. The components fit safely in a mid-sized box.
4. The system must accurately represent the energy production information simulated in real world conditions of wind and hydro generators.
5. The motor output power to the generator does not require an excess amount of energy and models real life turbines effectively.

Chapter 4: Design

Due to COVID-19, the scope of our project has changed from building a system that physically simulates the power output of wind and hydroelectric generators at different speeds to simulating that system with the Simulink tools in Matlab. We are unable to use the lab equipment to build our prototype, so we are re-creating a system that mimics the initial design from Chapter 3. Within Matlab’s Simulink tools, a library known as “Simscape” allowed us to incorporate many different electrical components into our design. We used the Simscape components whenever possible, and when it wasn’t possible we designed our own. Each block of the system was re-created with the hope that this simulation can be a useful reference when building a physical prototype. The following level 2 block diagram represents the simulated blocks that were built inside Simulink.

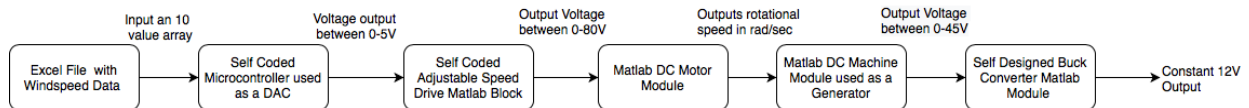


Figure 4-1: Level 2 Block Diagram

Because many of the system components were simulated and not purchased, much of the information in a bill of materials is incomplete at this time, but it was still constructed in an attempt to catalogue all of the components that are relevant in this system’s design.

Table 4-1: Bill of Materials

Qty	Value	Description	Size	Part Number	Manufacturer	Per Unit Cost (\$)
1	N/A	Microcontroller	N/A	MSP432	TI	\$23.00

1	90V, 1.4HP	DC Motor	N/A	AP7402	Baldor	\$499.99
1	12/24V	DC Magnetic Generator	N/A	2325121 61551	TTech	\$55.95
1	90/180V, ½ HP	DC Drive	N/A	GSD4- 240-5C	Automation Direct	\$71.00
1	6V - 40V	DC-DC Converter	N/A	LM2596	Wmyconggong	\$7.95
Total						\$657.89

MSP432 Microcontroller

The desired functionality of the MSP432 microcontroller was simulated by using a MATLAB function to build an array of input values that represent wind speeds, in kilometers per hour, throughout a 24-hour period. This period was condensed into a simulation duration of 60 seconds to allow for faster testing. The input of wind speeds is 0 - 50 km/h to represent realistic wind speeds. The user input array is indexed sequentially via a selector module whose index input is connected to a feedback system that delays the indexing process in order to achieve desired system timing. The microcontroller will read 0 until the cut in speed of 13 km/h, where it will start outputting values between 0 and 5. The wind input from the array is inputted into the equation $Output = (wind\ speed) * (5/37) - (65/37)$ to linearly relate the wind speed to the microcontroller output starting at 13 km/h. Figure 4-2 displays the microcontroller model with a 1-D array of the following values: [15, 20, 30, 45, 10, 15, 22, 50, 38, 3].

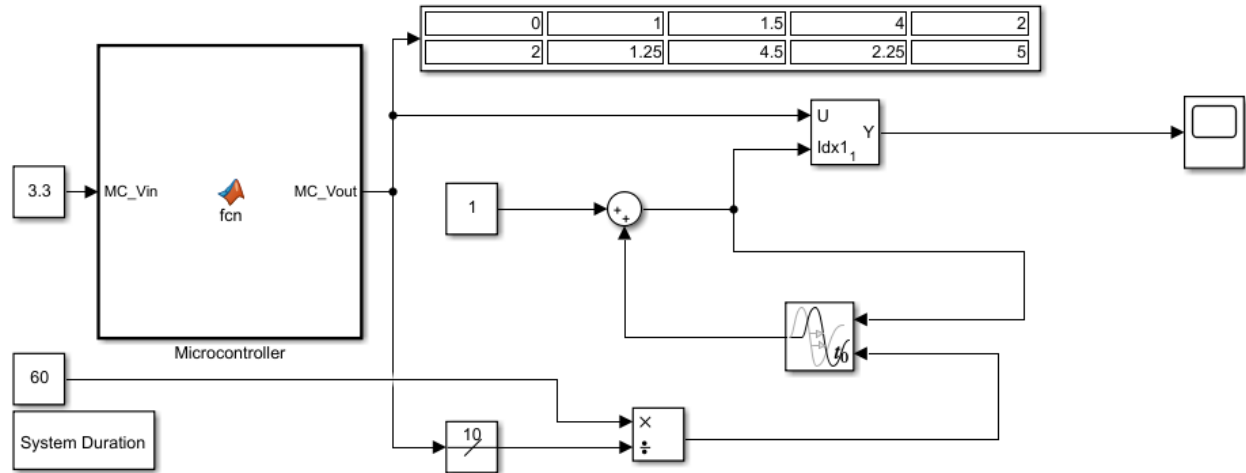


Figure 4-2: Microcontroller Model

The following was the MATLAB code used to program the microcontroller function block:

```
% Define function output and input
function MC_Vout = fcn(MC_Vin)

% Define user-input array (0 - 50 km/h)
InputArray = [15 20 30 45 10 15 22 50 38 3];
Array_Size = length(InputArray); % Number of array elements
m = (5/37); % Slope of Wind/Power Curve
b = -(5/37)*13; % Wind/Power Curve Adjustment

% Initialize Conv Array
ConversionArray = zeros(1,Array_Size,'double')
% Initialize output array
MC_Vout = zeros(1,Array_Size,'double')

% Convert wind speed input data into speed drive control voltage
for index1 = 1:Array_Size
    if InputArray(index1) > 13
        ConversionArray(index1) = InputArray(index1)*m + b;
    else
        ConversionArray(index1) = 0;
    end
end

if MC_Vin == 3.3 % 3.3V Source is connected to MSP432
    for index2 = 1:Array_Size % Index through the array
        MC_Vout(index2) = ConversionArray(index2);
    end
else % 3.3V Source is not connected
```

```

    for index2 = 1:Array_Size % Set output array elements to 0
        MC_Vout(index2) = 0;
    end
end
end

```

Self-Coded Adjustable Speed Drive

The adjustable speed drive was programmed to receive a voltage signal within a specific range from the microcontroller model and output a range of values that are mathematically scaled via a linear equation defined in the user-defined MATLAB module. The output of this module was converted to a Simscape electrical DC signal so that it can be used as an input to the DC motor module. Figure 4-3 displays the adjustable speed drive model. Note that the input and output range was set to 0V - 5V and 0V - 100V, respectively. This can be changed by the user in the code used to program the function block. The output of the speed drive gets converted to an electrical DC signal using the same array from the microcontroller section where the two component models are connected.

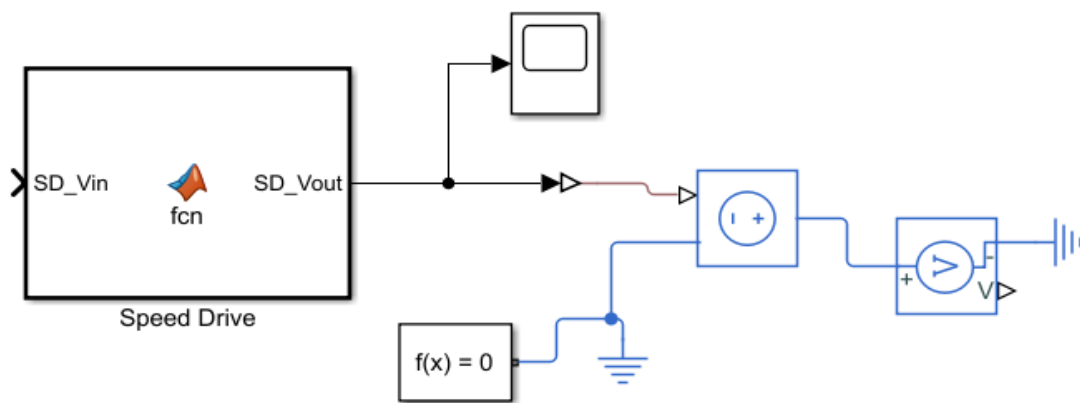


Figure 4-3: Adjustable Speed Drive Model

The following was the MATLAB code used to program the adjustable speed drive function block:

```
% Define function output and input
function SD_Vout = fcn(SD_Vin)

Vin_Max = 5; % Define maximum Vin to 5V
Vout_Min = 0; % Define minimum Vout to 20V
Vout_Max = 100; % Define maximum Vout to 80V
% Minimum Vin is assumed to be 0V

if SD_Vin >= 0 % If input is not negative
    SD_Vout = ((Vout_Max-Vout_Min)/Vin_Max)*SD_Vin+Vout_Min;
    % Linearly scale input to output
else % If input is negative
    SD_Vout = Vout_Min; % Set output to minimum Vout
end
```

DC Motor Module

The DC Motor Model used was taken directly out of the Simscape Library in Matlab as illustrated in Figure 4-4. It is driven by a constant DC voltage source and it produces the rotational speed needed to input into a generator. To utilize the rotational speed of the motor, the Ideal Rotational Motion Sensor model depicted in Figure 4-5 is used to produce the final output of the motor: the rotational speed. To simulate the range of voltages that would be inputted into the Baldor DC Motor, which is the original motor that was going to be used in the hardware implementation, the speed drive produces a range of outputs between 0 – 100V. The motor model was a predefined Simscape Module in Simulink and was chosen for the ease of implementation and that it can handle a wide variety of voltages.

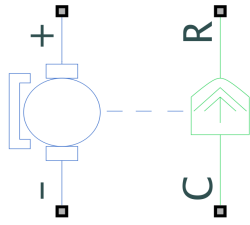


Figure 4-4: DC Motor Model

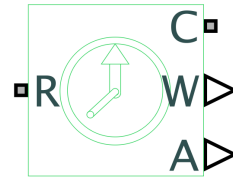


Figure 4-5: Ideal Rotational Motion Sensor

DC Machine used as a Generator

The generator was designed using the Simulink model DC Machine because of its ability to input rotational speed and convert it into a constant voltage and it is configurable. Figure 4-6 shows the machine model. Since the motor can output a range of rotational speeds (ω), the DC Machine mechanical input was set to take ω , instead of torque. The voltage source between the positive and negative field voltage terminals characterized the voltage output, compared to the rotational speed input. To replicate voltage values that can work for an available DC-DC converter a voltage value of 0.05V was chosen. This creates an equation of $V_o = V_i * 0.5375$ between the input of the motor and the output of the generator.

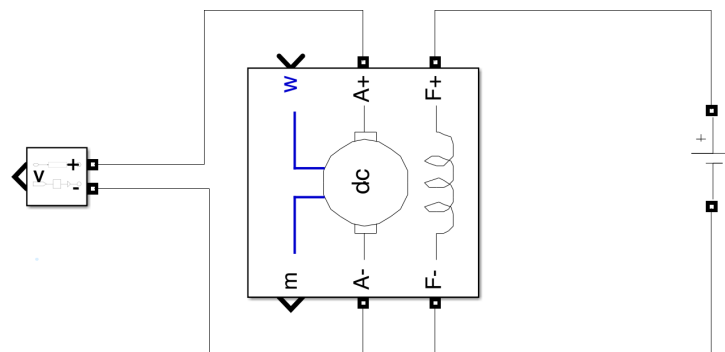


Figure 4-6: DC Machine used as a Generator

Self-Designed Buck-Boost Converter

The DC-DC converter needs to regulate the large input range into a more predictable, fixed output voltage. Since most appliances are charged at 12V, this was the voltage we targeted. The generator produces voltage above and below 12V, requiring a buck-boost implementation to handle the wide voltage range as shown in Figure 4-7. 55 V is the upper limit of what our system can output, but that is a dangerous threshold to operate under for most common appliances. To control this, the DC-DC converter uses a subcomponent shown in Figure 4-8 designed by Diamond Matlab Tutorials that helps our converter to always reference the correct voltage. The other components were characterized to work with the range of possible voltages. In order to give the components time to charge and discharge properly, a maximum duty cycle of 80% was set. By analyzing different signals in the simulation program $V_{INMAX}=55\text{ V}$, $\Delta V_O=0.28\text{ V}$, $I_{OMIN}=600\text{ }\mu\text{A}$, $I_{OMAX}=780\text{ }\mu\text{A}$, and $T_S=100\text{ }\mu\text{s}$ were all determined. With these parameters set, the remaining characteristics of the converter could be calculated. When duty cycle D is set to the maximum value, the minimum value of input voltage V_{IN} can be calculated with the following steady-state buck-boost equation in continuous conduction mode.

$$V_o = V_{In} * \frac{-D}{1 - D}$$

Using the above equation, V_{IN} is found to be 3 V; thus, providing an input range of 3 V to 55 V. By using the same equation, the minimum duty cycle can be found by using the maximum input voltage. The result yields minimum duty cycle D_{MIN} of 36.4%. The switching frequency can be calculated simply from the period:

$$f = \frac{1}{T_s}$$

This yields switching frequency of 10 kHz. Using these system parameters, the minimum values of the capacitors and inductor can be calculated with the following formula.

$$L_c = \frac{(1 - D)^2 * V_O}{2 * f * I_{O_{MIN}}}$$

$$C_O = \frac{I_{O_{MAX}} * D}{\Delta V_O * f}$$

$$C_{IN} = \frac{I_{O_{MAX}} * D}{\Delta V_{IN} * f}$$

The smallest or critical inductance or capacitance values are needed to ensure that the components will function properly in all operational conditions. Using the above equations, the minimum inductance is 40 mH, minimum output capacitance is 101.4 nF, and minimum input capacitance is 676 pF. Input capacitance is unnecessary in simulation where ideal voltage sources are possible but it is an important consideration in the actual hardware design. Readers should note that because these values represent theoretical minimums, component sizes will need to be increased and finely tuned to properly function in simulations with nonideal conditions and especially in hardware.

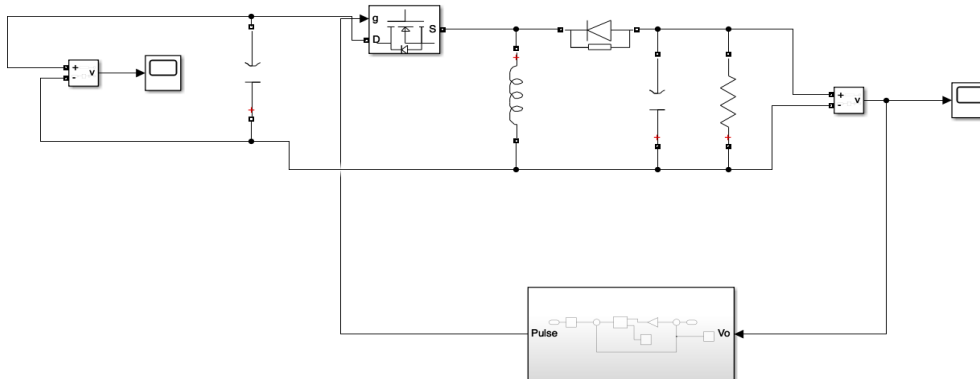


Figure 4-7: Buck-Boost Converter

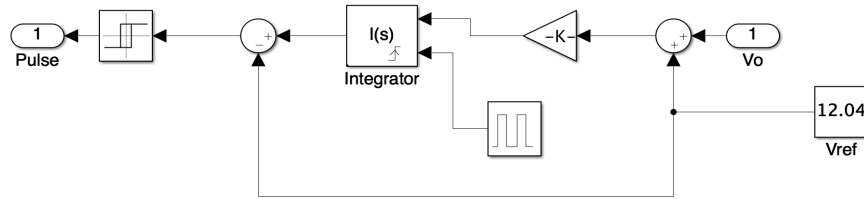


Figure 4-8: Buck-Boost Converter Subsystem

Finally, all components previously described were combined as depicted in Figure 4-9 to make the complete model of the full system. Note that a capacitor was added between the generator and the DC-DC converter to help with feedback voltage.

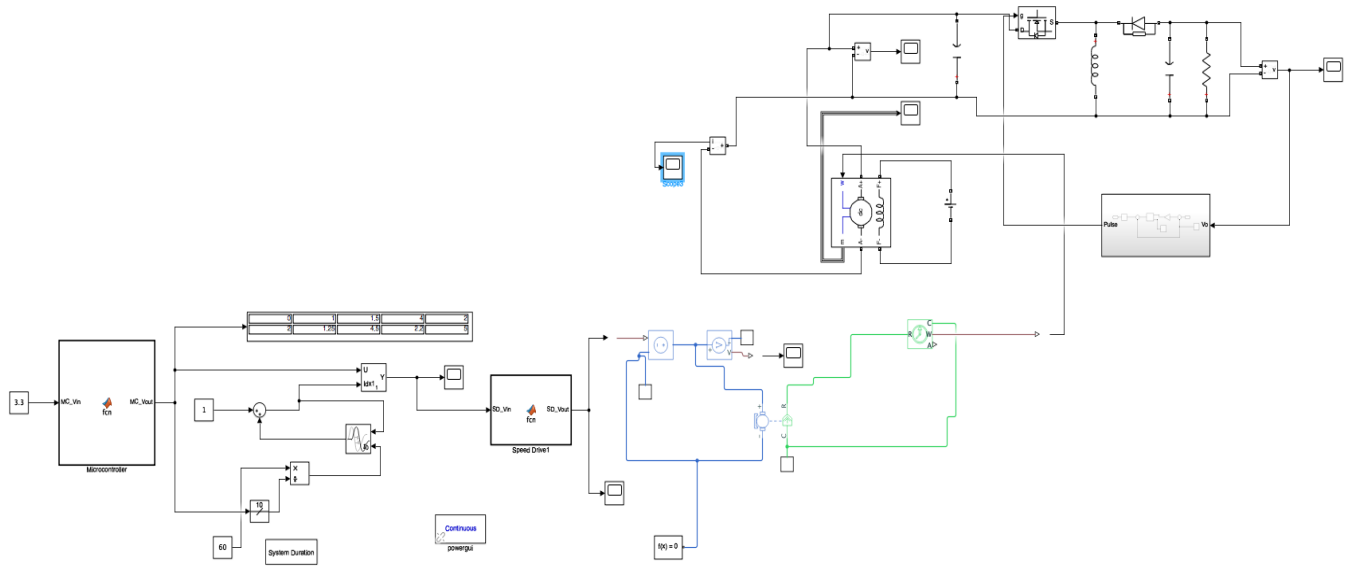


Figure 4-9: The Complete Simulink Model of the Wind/Hydro Simulator

Chapter 5: Simulation Results

The simulation tool that was used for this project was Simulink in Matlab. This is a graphical programming environment for modeling, simulating, and analyzing multi-domain dynamic systems [8]. This program was chosen because Simulink works very well when simulating complex circuitry, and it can also include Matlab programs into the simulation. Within Simulink there is a library called Simscape, a folder that allows for the simulations of electrical systems like capacitors, resistors, and even the motor. This is the only simulation tool that has physical systems already programmed into the simulation tool.

At various stages in the project different voltage and current ranges are required in order to ensure that the system accurately translates an array of wind speed data into a corresponding generator output. The system was probed at each stage to test that every component was operating under expected conditions. Finally, the generator output was compared to the wind speed array to ensure that it was incrementing and decrementing proportional to the changes within that array.

The user inputs an array of 10 values that represent wind speed in kilometers per hour. This value is converted into a corresponding speed drive control voltage with a range from 0 to 5 volts via the microcontroller module. The scaling for this was based upon the wind power curve for a 1 MW wind turbine shown in Figure 5-1 by linearly relating the control voltage range to the wind speed once the cut-in speed is reached. The user array input utilized for testing purposes and its corresponding speed drive control voltage array is shown in Table 5-1.

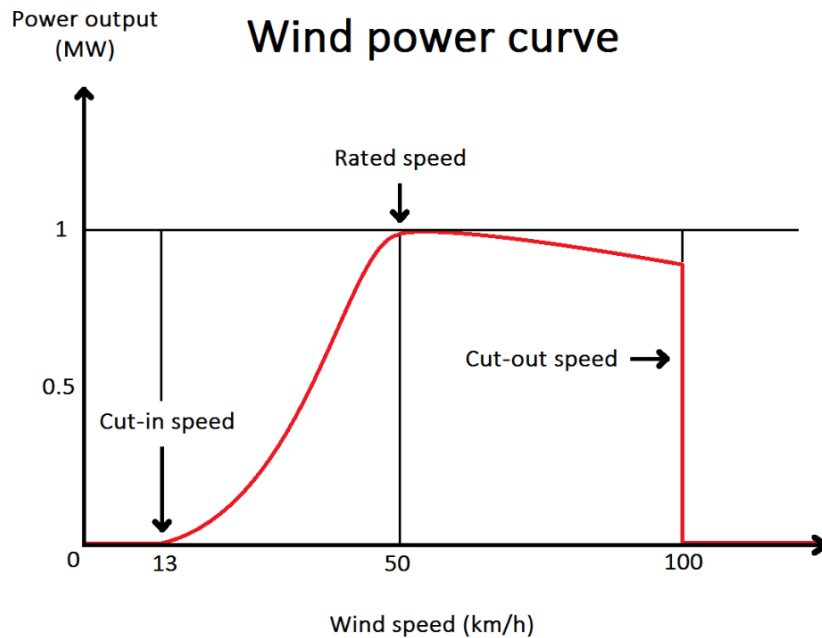


Figure 5-1: Wind Power Curve - Power Output (MW) vs. Wind Speed (km/h) [9]

Table 5-1: Wind Speed Array and Control Voltage Array Test Data

Wind Speed Array (km/h)	5	20	25	40	50	40	35	10	15	20
Control Voltage Array (V)	0	0.9459	1.622	3.649	5.000	3.649	2.973	0	0.2703	0.9459

The adjustable speed drive is used to transfer the small voltage signal output by the microcontroller from Table 5-1 into a large voltage signal that powers the motor. This allows for the proportional scaling of the wind speed data into a power signal that will power a generator.

Figure 5-2 shows the adjustable speed drive input, and as expected the motor input voltage

represented by Figure 5-3 is an identical graph with one exception, the voltage range is expanded from 0-5 V up to 0-100 V. This was chosen to represent the predicted input range of the Baldor DC Motor that was originally going to be used, as we tried to replicate the parts that were going to be built so that implementation will be easier in the future. There were complications born from system integration; the voltage signal rapidly oscillates between held values within the speed drive. This oscillation was not present during the testing of each individual system; however, it does not affect the output of the total system. What is causing this error is unknown, and while the implementation of a capacitor could potentially damp it, adding one properly in Simulink proved difficult.

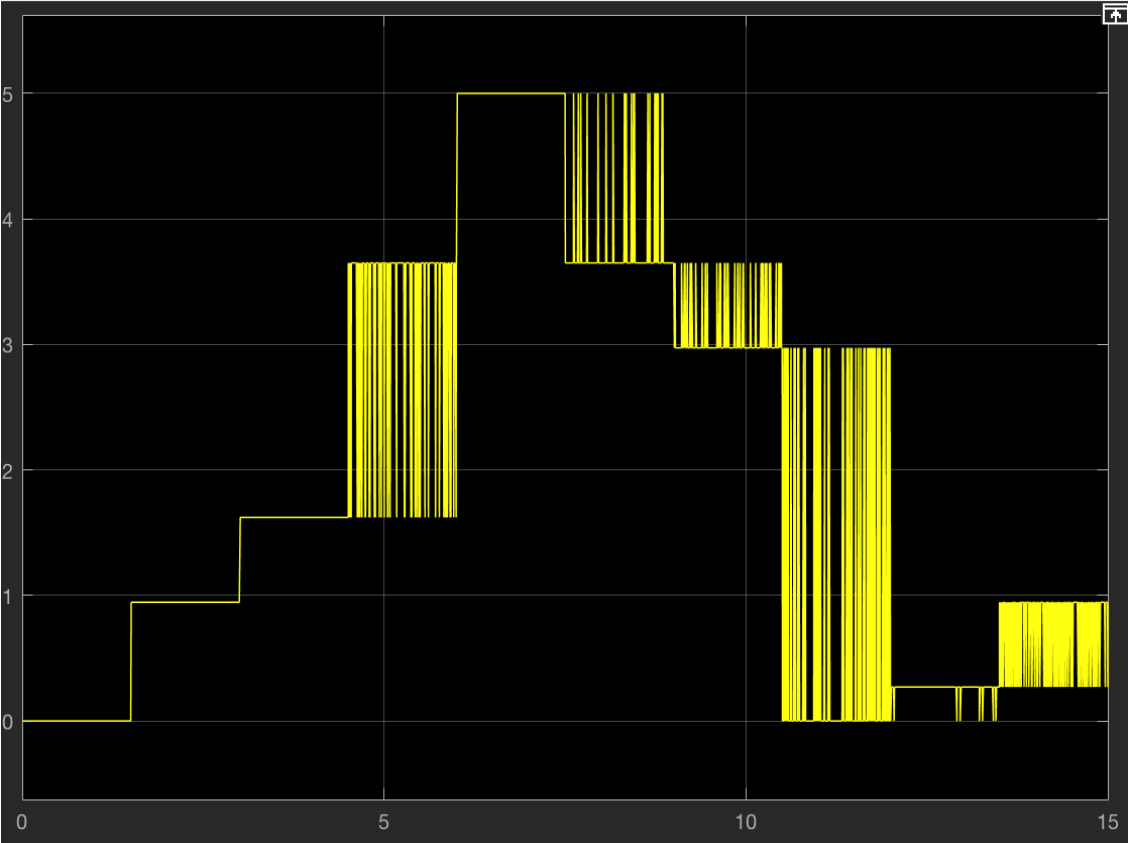


Figure 5-2: Speed drive input

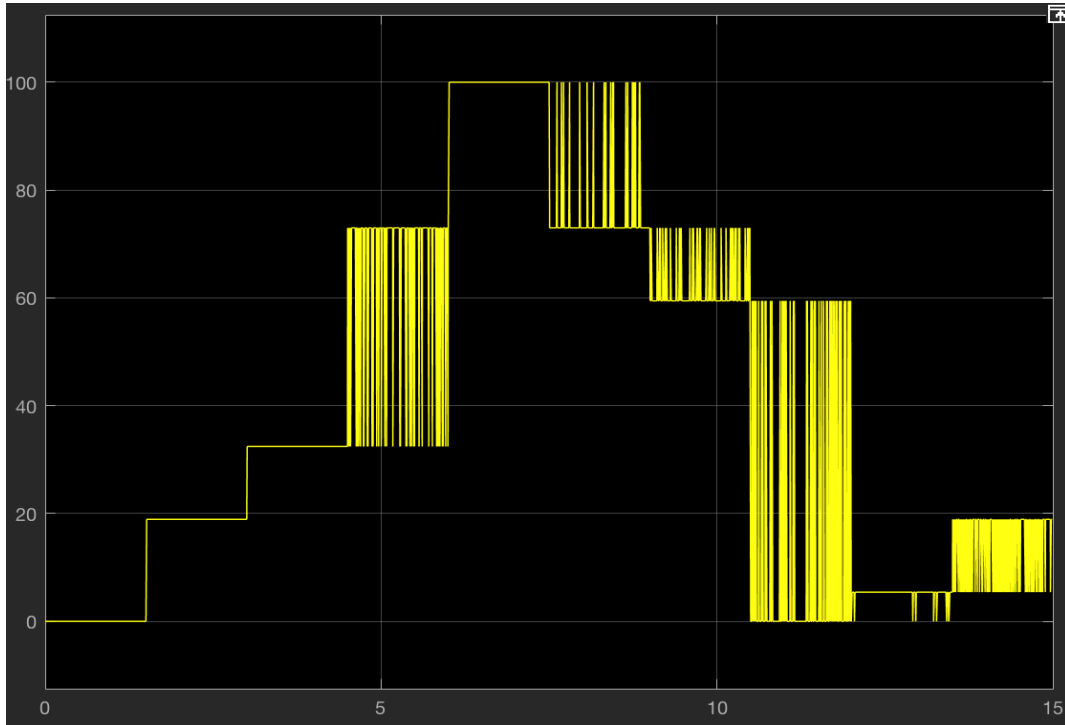


Figure 5-3: Output of Speed Drive

The output voltage of the generator represents the changing power output of the wind/hydro generators for different speeds and as shown in Figure 5-4. When this is compared to the wind speed array that is the system input, clear evidence can be observed of the voltage output increasing and decreasing proportionally to the changes within the array. There are changing voltages related to wind speed, as well as a 0 V output if the minimum cut in speed is not reached. The accompanying current plot in Figure 5-5 demonstrates large spikes in current occurring every time the array proceeds to its next value. This current spike is related to the change in voltage from the previous state and does not relate well to the output power for the given wind speed. Using the output voltages at different wind speeds, and the output powers given in Figure 5-1 related to the same speeds, an equation was developed to predict the estimated output power of the wind turbine at that same speed.

$$\text{Turbine Power} = 0.009 * (\text{Output Voltage})^2 + 0.0478 * (\text{Output Voltage}) - 0.0904$$

and is calculated using the related values shown in Table 5-2. Note that this equation solves for power in MW and uses a logarithmic trendline to calculate power.

Table 5-2: Final Output Voltages related to Output Power of a Wind Turbine

Wind Speed (km/h)	Generator Output Voltage (V)	Power (MW)
13	0	0
15	2.95	0.05
20	10.3	0.08
25	17.7	0.216
30	25	0.34
35	32.4	0.552
40	39.8	0.744
45	47.15	0.912
50	54.5	1

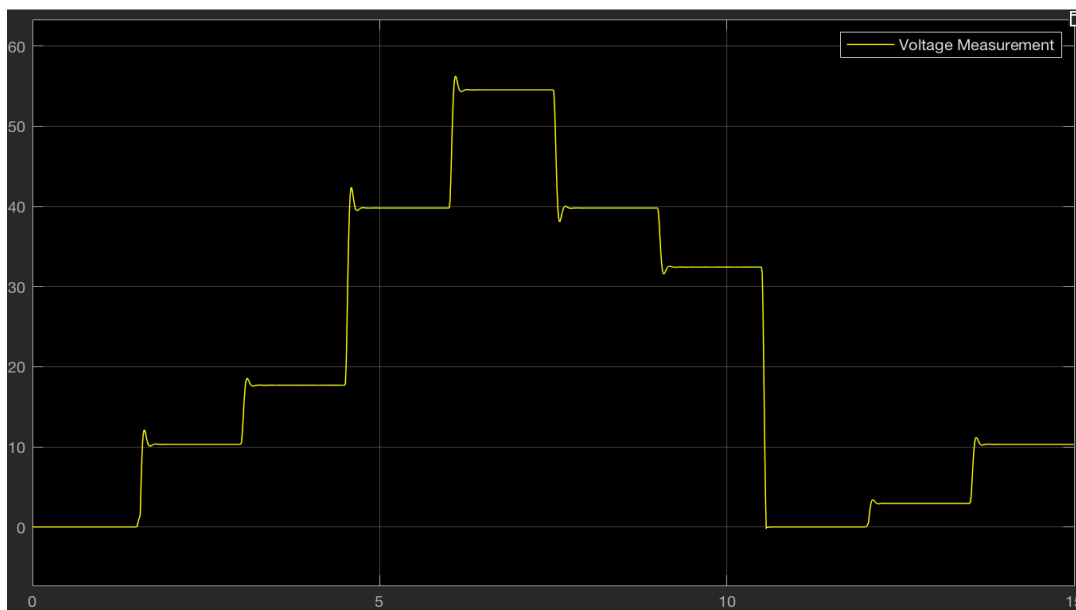


Figure 5-4: Final voltage output

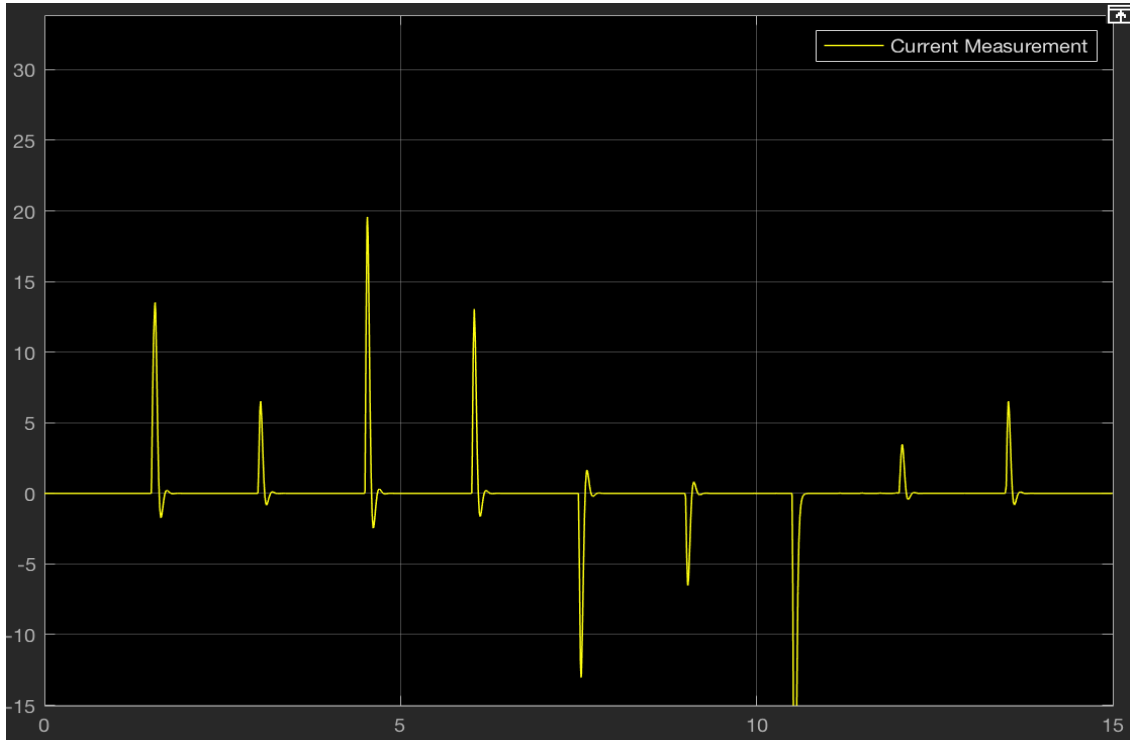


Figure 5-5: Final Current Output

The DC-DC converter output shown in Figure 5-6 should regulate the generator output into a safe and predictable 12 V, and in general this behavior is followed. This is to make the output voltage usable for the common device during implementation. Since a Buck-Boost design was used, any output voltage is going to be able to generate 12 V. This is useful in implementation so output power is not wasted, and it is easy to see when the cutout speed is not reached. As you can see in Figure 5-6, the only time it does not reach 12 V is when the input voltage is 0 V. This is when it slowly starts to climb back to 0 V output voltage, until wind speed increases and it is again held at 12 V. It is important to note that in real implementation, the DC-DC converter will have a voltage limit below the voltages used here. This will decrease the voltage range in between change in wind speed.

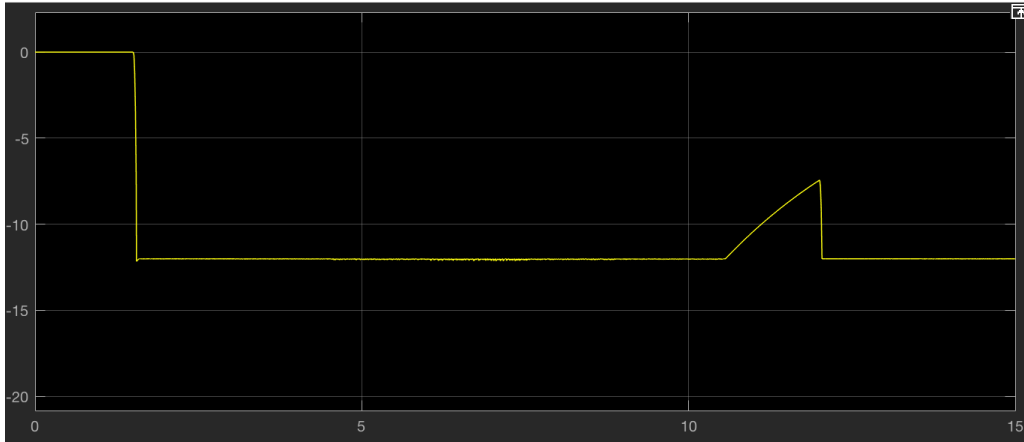


Figure 5-6: DC-DC Converter Output

Chapter 6: Conclusion

The goal of this project is to develop a Wind/Hydro Simulator that can simulate the power generation of wind and hydroelectric turbines created by various wind and water speeds. As demonstrated in Chapter 5, Matlab/Simulink implementation of the proposed design demonstrated that the goal was accomplished and a relationship between the generator output and wind/water speed input parameter was determined. The proposed design was able to follow a general pattern of wind speeds consistently and an equation was developed to model the voltage output of the system to a hypothetical power output for a 1 MW wind turbine. However, this system was designed to be physically implemented and was developed to mimic the system of components that we had available to us in the lab.

Due to the nature of the project being remodeled into a virtual simulation as a result of COVID-19, certain system functionality had to be artificially generated in Matlab such as the microcontroller and motor drive. Since the preliminary Matlab/Simulink model for the proposed may not include every single non-ideality in the system, the simulation results had an error in voltage reading between these components. This resulted in rapid oscillation in the voltage readings for these components; however, this does not affect much on the final result, at least as far as simulation is concerned. Other parts of the system such as the motor coupled to a DC generator needed to be simulated through Simulink components found within the Simscape library of the program. The input of the motor was between 0 - 100V which would replicate the hypothetical input for the Baldor DC motor. The output of this generator is between 0 - 54.5 V, which gives us a large range to develop an equation for the change in wind speeds. Commercially available DC-DC converters typically do not have a range this large so the voltage

jumps when wind speed changes would be smaller. This might make it difficult to record a variety of data points in implementation. We advise a possible change in the implementation for this part of the project. After developing a simulation and reading the results of the previous senior project group [7], it seems like this is the crippling part of the project. It is hard to have a wide variety of motor outputs in such a specific range. A custom made wide-range input DC-DC converter, or a possible change in design, could help the building of this project to work better.

Furthermore, mechanical limitations that would be present in a wind/hydroelectric turbine had to be accounted for as well in the form of maximum power generation at a specific wind/water velocity before beginning to fail. We implemented a 13 km/h cut-in speed and a maximum power speed at 50 km/h. The next step to improve this project would be to develop a better relationship between wind speeds and power generation of wind and water turbines. This system can separate wind speeds into distinct voltages, and if a better relationship were developed between wind speeds and power generation, a more accurate equation could be developed. Continuously, each Simulink block can be made more accurately; components could be created like a motor drive that has proper output behavior while still accounting for small power losses. In addition, the system integration could have gone more smoothly, and through further testing and debugging more stable characteristic plots may be generated. The end goal of this is developing an actual prototype that can follow and improve upon the characteristics of the simulation.

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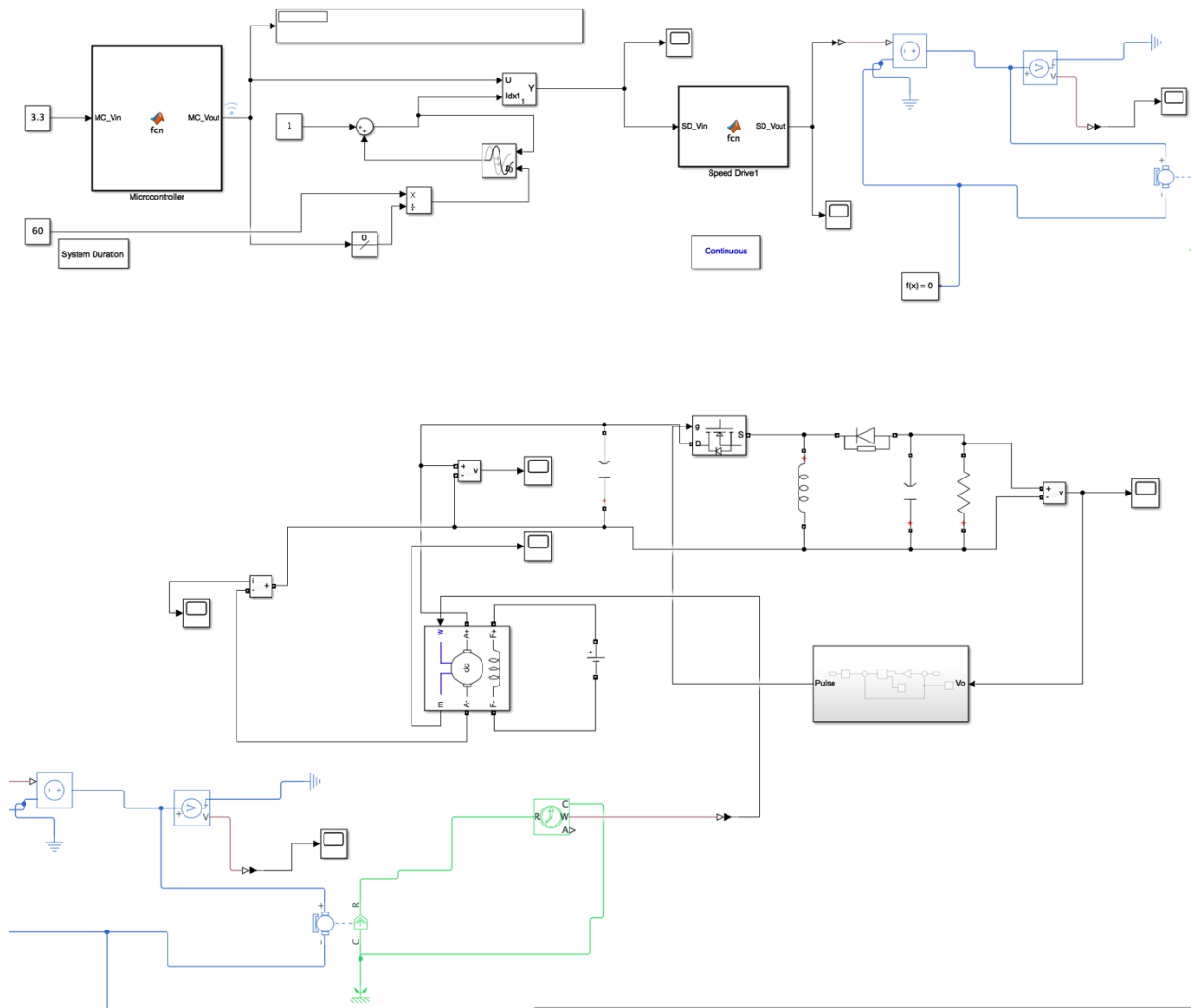
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Appendix

APPENDIX A — FINAL SCHEMATIC



APPENDIX B — MICROCONTROLLER AND DC DRIVE CODE

Speed Drive:

```
% Define function output and input
function SD_Vout = fcn(SD_Vin)

Vin_Max = 5; % Define maximum Vin to 5V
Vout_Min = 0; % Define minimum Vout to 0V
Vout_Max = 100; % Define maximum Vout to 100V

if SD_Vin >= 0 % If input is not negative
    SD_Vout = ((Vout_Max-Vout_Min)/Vin_Max)*SD_Vin+Vout_Min;
    % Linearly scale input to output
else % If input is negative
    SD_Vout = Vout_Min; % Set output to minimum Vout
end
```

Microcontroller:

```
% Define function output and input
function MC_Vout = fcn(MC_Vin)

% Define user-input array (0 - 50 km/h)
InputArray = [15 20 30 45 10 15 22 50 38 3];
Array_Size = length(InputArray); % Number of array elements
m = (5/37); % Slope of Wind/Power Curve
b = -(5/37)*13; % Wind/Power Curve Adjustment

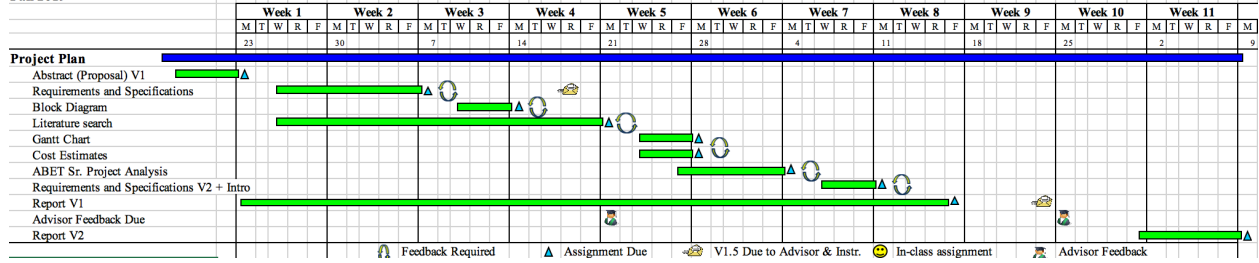
% Initialize Conv Array
ConversionArray = zeros(1,Array_Size,'double')
% Initialize output array
MC_Vout = zeros(1,Array_Size,'double')

% Convert wind speed input data into speed drive control voltage
for index1 = 1:Array_Size
    if InputArray(index1) > 13
        ConversionArray(index1) = InputArray(index1)*m + b;
    else
        ConversionArray(index1) = 0;
    end
end

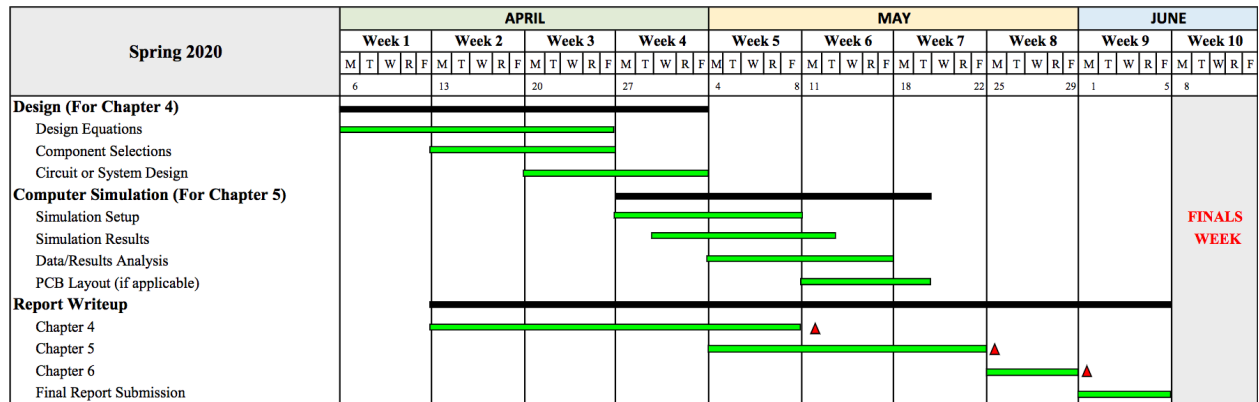
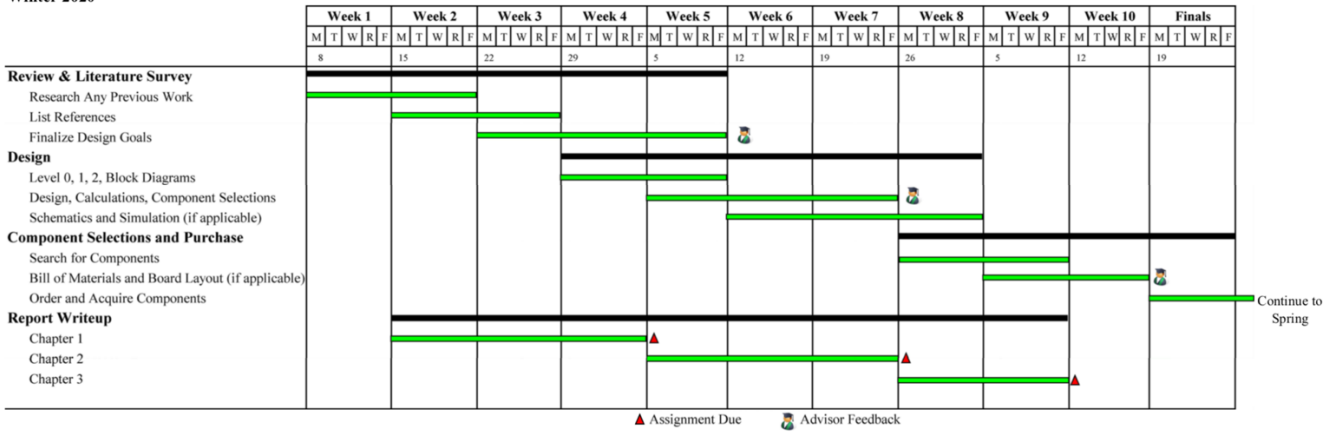
if MC_Vin == 3.3 % 3.3V Source is connected to MSP432
    for index2 = 1:Array_Size % Index through the array
        MC_Vout(index2) = ConversionArray(index2);
    end
else % 3.3V Source is not connected
    for index2 = 1:Array_Size % Set output array elements to 0
        MC_Vout(index2) = 0;
    end
end
```

APPENDIX C — PROJECT TIMELINE

**EE 460 Gantt Chart
Fall 2019**



Winter 2020



APPENDIX D — ANALYSIS OF SENIOR PROJECT DESIGN

Project Title: Wind/Hydro Power Generation Simulator

Student's Name: Patrick Murphy, Justin Otus, Nick Steele

Advisor's Name: Taufik

1. Summary of Functional Requirements

The project aims to create an accurate simulator that can model the behaviors of power generation based on wind and hydro current speeds. It simulates the rotational speed generated by a wind or hydro turbine based on an input of speeds and translates that into a voltage that can be converted into power generation. It then converts that voltage into a 12 V voltage source to simulate a usable power output.

2. Primary Constraints

The greatest challenge in this project was designing the system to try to simulate actual component parts. Since this project was not able to be built, the Simulink modules try to replicate possible values that could be seen based on the components recommended in the report. The DC-DC converter input will be hard in implementation because of how sensitive they are to voltages and currents. This directed how we characterized our modules and what our inputs and outputs should be.

The integration between different modules was the most difficult part of the project. Since we were using multiple kinds of libraries (Matlab code, Simulink, Simscape), connecting the different components limited the tools we could use and the amount of extra components we could attach. This caused oscillation with our voltage readings because we were unable to add components to help solve the problem.

3. Economic

This project relates to natural capital, because it focuses on increasing the renewable energy produced by accurately determining the location with the best value to install wind/hydro turbines in specific

geographical areas. With increased construction of renewable energy turbines, jobs in manufacturing and construction enable more wind and hydro farms. Although the project focuses on software, the results promote the construction of real turbines.

The cost of this project would mostly be in the development stage of the project lifecycle. Since this project is now completely simulation, no cost would be needed for manufacturing or selling, instead the designers would be the bulk of the cost. There will be a little cost in maintaining and improving the system, but again that would be to the designers. The benefits presented by the project happen after the project lifecycle and interest those involved with the design of turbines, as it is much cheaper to test a turbine in a simulator than to spend the time and money to build a product that may have suboptimal performance. This will help them improve their project by being used in the testing phase of their project lifecycle.

The project only requires a computer with Matlab installed. The user can input data into the predesigned Matlab program and run it through a simulation. The product costs \$50 because it serves a niche market and presents great value to a few individuals, but has no manufacturing cost. Our potential customers are renewable energy companies and people who are interested in the development of off grid communities. This would help them understand the estimated power generation they should receive and maximize their power output.

Original estimated cost of component parts (as of the start of your project).

DC Motor: \$ 77.00

Microcontroller: \$ 19.99

Generator: \$ 65.00

DC-DC Converter: \$ 7.98

Total Estimated Cost of Components: \$ 169.97

The actual cost and bill of materials was \$0. Since this project got limited to only a simulation, none of the original parts were purchased. The only piece of equipment needed is a laptop with a functioning Matlab license. Since Matlab is provided by Cal Poly, no costs were accrued during this project. If Matlab did need to be purchased, it would cost \$149 to get a personal license.

The only inputs required for this project is Matlab, however, students can acquire the license for free, making the cost negligible during the prototyping phase. This means that the project would cost nothing except for the designers time. This project earns money through consumers and is targeted for a price of 75\$. Since there is no cost to the project except the designers time, virtually all the revenue would be profits. The profits go to the entrepreneurs who built the simulator, but the customer also benefits by gaining more profitable generators, and the environment benefits by increasing consumption of clean energy.

Because the product is based in software, maintenance and operation costs stay low and product durability stays high. The only cost would be updating the simulation code periodically to produce more accurate results. This product can emerge at any time because renewable energy is so relevant today. Expanding the amount of clean energy and providing energy to everyone is a continuous goal. This product, with proper maintenance, can last forever. Since it is a simulation, it will never break down and can be continuously updated.

The project Gantt charts that describe the time estimates of each section of the project are presented in appendix C, however, after the project ends continuous updates are needed. Since there is no manufacturing, after the project improving the system is the only thing that needs to be worried about.

4. If manufactured on a commercial basis:

Since our product appeals to a specific industry, it markets to companies who specialize in the renewable energy industry and people who are aiming to develop mini-grids. Few companies exist in these fields, so the expected amount of units sold is 250.

Since there is no manufacturing process, there would be no cost associated with it.

The estimated price point per device rests at \$75. We have to cover the costs of time during development and make it a worthwhile project. Since it is a niche market and the cost of manufacturing is \$0, the price is tried to be kept low to encourage more customers.

Calculating these numbers would result in a \$18,750 profit.

$$250 * 75 - 0 = \$ 18,750 \text{ profit}$$

The only time needed to execute the program involves the time needed to input data. The consumption of the data would take the most time, if specific conditions weren't already documented. The simulation would require approximately 5min to execute and would determine a specific geographical location for the time that the data captures. The data samples over a 60 second time interval and estimates those specific conditions for any set of wind data.

5. Environmental

This project promotes environmental sustainability, because it directly relates to the production of more renewable energy, decreasing the environmental impact of power generation. The manufacturing of devices and construction of wind and hydro generators would use natural resources such as metals or polymers that might be harmful to mine or synthesize, however the benefits in renewable power generation outweigh the costs of the materials and their manufacturing processes.

The project does not directly use any natural resources or ecosystems because it leans heavily on programmed simulations. Indirectly, it promotes the construction of wind or hydro turbines that use powerful wind or water currents from the ecosystem. The environmental costs are very low, as they're limited to indirectly promoting subsequent construction projects.

The project would serve to improve the natural energy we produce which would decrease the energy causing harm to the environment. A potential problem exists in the disruption of animal ecosystems. For example, a birds ecosystem gets heavily disrupted if a wind turbine gets installed in their flight paths, and

the potential deaths of birds becomes a risk in this scenario. In the long term this could cause migration patterns to shift, doing permanent ecological damage.

This project could have a negative impact on specific ecosystems, if more wind or hydro generators get installed. But it also has the potential to produce a cleaner environment, benefiting many different species by replacing dirty forms of electricity generation such as coal or oil burning and cutting down on pollution. Less pollution means higher air and water quality, two essential parts of any ecosystem.

6. Manufacturability

The only subsystem of the project needing manufacturing are the motor and generator, and the challenges associated with manufacturing the motor include the difficulty of finding a component rated for both high power and low rpm. This could cause an increase in price for components; however the assembly should go smoothly due to the limited parts. Once the units are manufactured, shipping would likely cost a lot due to the size and weight of the device. This product sells to specific companies, and would have individually ship to each business. Therefore, our device does not get cheaper when scale increases. The simulation aspect of the project can distribute easily through download and works on any computer with a Matlab license. This aspect would scale very easily, and cost no additional money.

However, because COVID19 forced an abrupt shift in the direction of the project, there are no real manufacturing costs. While the analysis above is still applicable to anybody crafting a prototype, this project was completed entirely within the Simulink program in Matlab. As a result, the only thing needed to replicate the project would be a Matlab license.

7. Sustainability

The sustainability challenges associated with the maintenance of the device don't relate to the project itself, the device exists on a small scale and has no substantial impact on the environment. Nevertheless, the simulator functioning properly has an extraordinary influence on sustainability, as it encourages more power generation through sustainable sources.

This project impacts sustainable resources by contributing more renewable power sources into the world. Improving the operation of sustainable power sources increases the world's sustainability. Further understanding energy calculations or predicting wind and hydro patterns is a challenging part of improving the design. Since the project focuses on software, updating and renewing the code to maintain relevance becomes important. The challenge in getting more accurate simulations involves accurately simulating data entered into the simulation.

There are few issues or challenges with maintaining the completed device. Upgrading and distributing the simulation software carries no sustainability challenges on its own, as releasing an update via the Internet doesn't involve using natural resources or interacting with ecosystems.

8. Ethical

Use of this project and, more broadly, any device utilizing or genuinely addressing renewable energy is ethical within a utilitarian moral framework because doing so combats the effects of climate change on the planet while only costing those who work in dirty industries, like coal, in the short term. Far more people are helped by the project than those harmed.

In terms of the IEEE code of ethics, the design process of this project coincides with sustainable developmental practices as it furthers the development of renewable energy sources. Furthermore, information presented when reporting project results is delivered with integrity, not misrepresenting findings or accepting bribes to allow for mistakes or cut corners. If results were to be presented dishonestly, this project would violate the IEEE code of ethics.

Misuse of the project could take the form of misrepresentation of renewable power generation via exploitation of potential software limitations by companies that would want to present renewable energy as a wasted effort.

9. Health and Safety

Due to the virtual nature of the project, there are no safety precautions that need to be taken in order to use the simulation system.

10. Social and Political

Because the project addresses renewable energy, this inevitably associates it with the political debate within the United States concerning climate change. Because of this, it would impact companies that invest in renewable power systems that utilize wind and hydroelectric energy as well as companies that compete with such companies.

Examples of companies that could benefit from the project include Avangrid Renewables and NextEra Energy Resources. Companies that could potentially be negatively affected include Peabody Energy, ConocoPhillips, and Enterprise Products.

Companies that could benefit the most from this project would not be particularly large or powerful. Larger companies have likely developed renewable power simulation software more accurate than the scope of this project can reach and more accurate than what smaller companies have access to. Therefore, this project would benefit smaller companies that generate wind and hydroelectric power to a greater degree. Those negatively affected by the project have much more power than the companies that benefit from it. Companies that harvest a large percentage of resources such as oil and coal have great political power within the United States, thus allowing for congressional manipulation via lobbying. Such companies would be negatively affected by smaller renewable energy companies infringing on their market share.

11. Development

Due to the virtualization of this project as a result of COVID-19, the original system design was simulated in Matlab via Simulink, utilizing Simscape as a tool to represent electrical signals. We learned how to properly implement Simscape electrical blocks such as the built-in DC motor as well as program Simulink user-defined function blocks in order to mimic specific component functionality that was not found in Matlab's base libraries such as the motor drive.