ECE 445 Project Proposal- Team #11
Active AC-DC Converter for the Power Lab's Wind Turbine
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1 Intorduction

1.1 Objective

As the world races to reduce emissions and satisfy ever-increasing energy demands, one of the problems that continuously persists is the challenge of storing renewable energy for times when the wind ceases to blow and the sun does not shine. Many solutions for storing excess energy on the current electric grid have been proposed and even tested such as compressed air storage, pumped storage dams, and giant batteries; yet, these technologies have failed to be adopted on a large scale[1]. With global energy demand expected to increase by nearly 30% in the next 12 years, many experts are anticipating that much of the world, especially in developing regions, must transition to a microgrid approach where energy is generated and stored in smaller spaces such as individual homes and offices [2] to meet anticipated demand while simultaneously reducing emissions. However, the main barrier to adopting a microgrid can be tied to the costs of implementation. While the price of photovoltaics and wind turbines continues to decrease or remain stable, the costs associated with maximizing power extraction and storage remains to be costly. If the cost barrier can be reduced, the world can accelerate its transition to a more distributed and sustainable electric grid.

In order to help remedy the issue of costly microgrids, our goal will be to produce a cost-effective maximum power point tracker (MPPT) that delivers the maximum amount of power to a DC load such as a battery pack for storage at wattages of 700W-800W. We will create a solution with a footprint suitable for use in a home or office setting where we intend a microgrid wind system to be employed. In addition to maximum power extraction at a lower cost, we will also strive to create a system with a mechanical to electric power efficiency that is comparable to current solutions on the market to reduce any unnecessary energy waste. Overall, our project will offer a comprehensive solution to convert 3-phase AC electricity from small-mid sized turbines into the a maximum power delivery at the load by actively tracking the point of maximum power extraction.

1.2 Background

Many experts agree that the deployment of microgrid systems is a key step towards incorporating more renewable energy generation while also meeting the growing demand for energy in both the industrialized and developing parts of the world. However, the main challenges to overcome are cost of deployment and ensuring reliability when the generating capacity is lower than the demand on the grid[3]. While the cost of photovoltaics and wind power systems has been reduced with increasing global investment in renewable technologies[4], we have still not seen the necessary cost reduction in smaller scale systems. In fact, the charge controller for a 1kW battery bank system often costs over $400, which decreases the incentive for deployment of off-grid or microgrid systems due to the high component costs associated with increasing reliability. Also, individuals may be discouraged from using existing solutions due to the complexity involved in creating an off-grid or small scale wind energy harvesting system.

To make a large impact in this space, our product must aim to reduce the cost of a battery charge controller while also maximizing power extraction so that energy is not wasted and can be made available for times when the wind does not blow. Our MPPT device must also aim to provide an accessible and comprehensive solution to ensure no additional components are need between the generator and energy storage such that cost can be minimized and our product is attractive to use among individuals without a particular knowledge base. Finally, we must deliver an output voltage suitable for charging batteries that are low cost and readily available to a consumer or community in the developing world in the drive to accelerate renewable wind power and microgrid adaptation.

1.3 High-Level Requirements

- Our solution must have a viable market cost of less than \$200 to provide a significant reduction in the current market cost.
- The power electronics must be able to reliably operate at a power rating of 800W and amperage of 40A DC.
- The system must deliver approximately 12V or 24V to the load to charge a low-cost and readily available battery bank.

2 Design

2.1 Block Diagram

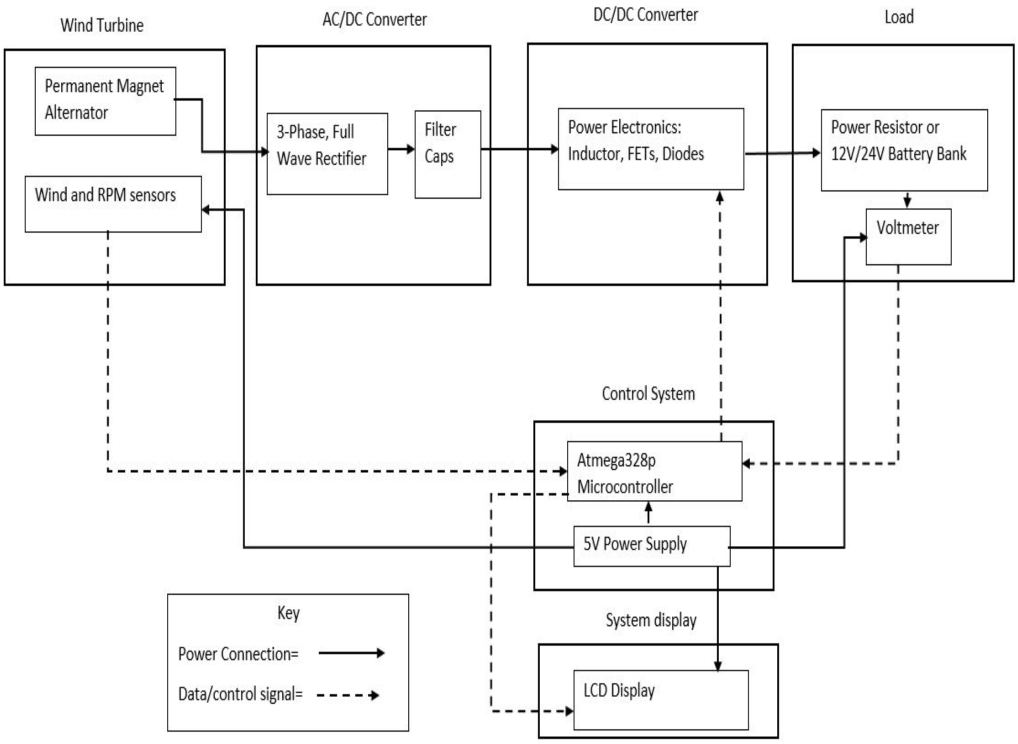

Figure 1: Proposed Sytems Level Block Diagram

2.2 Physical Design

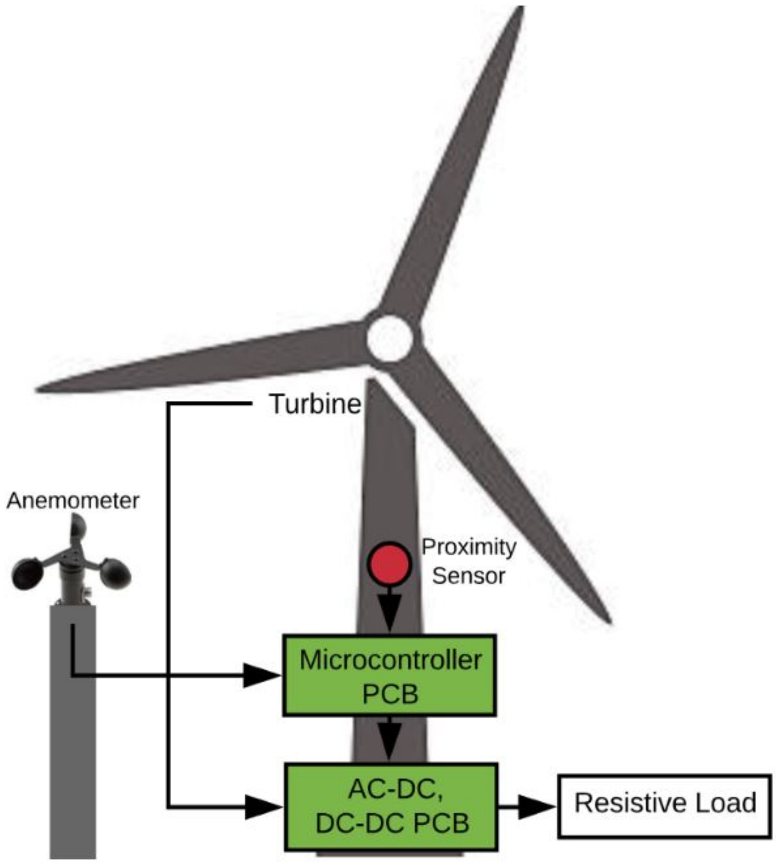

Figure 2: Proposed Physical Diagram

Our design requires us to use both a wind speed sensor, or anemometer, and a proximity sensor. The anemometer can simply be placed close to the turbine, and the proximity sensor will be placed on the turbine's stand so that it can detect when each blade passes by. Both sensors will be connected to the 5V rail that powers the microcontroller PCB and their outputs will be connected to the microcontroller. The turbine's 3-phase output will be connected to the power electronics required to convert the output to DC at the base of the turbine's stand. The AC/DC converter and DC-DC converter can both be placed on the same PCB for simplicity. Their output will then be connected to power resistors capable of dissipating the power output. The microcontroller will be on a separate PCB than the power electronics for added modularity and the fact that the power electronics will require thick power traces that are not needed for the control system's PCB.

2.3 Functional Overview and Block Requirements

2.3.1 Permanent Magnet Alternator (Provided Turbine)

Windynation Windtura 750, which is rated for a maximum of 800W. The turbine uses a permanent magnet alternator (PMA) attached to 3 35 in. blades to generate power. The tip speed ratio (TSR) is simply the ratio of the linear velocity of the tip of the blade over the wind speed. The optimal tip speed ratio (TSR) is between 5 and 6 for a 3-blade wind turbine, so our goal is control the turbine's speed to achieve that TSR [5]. The advantage of using a permanent magnet alternator is that no excitation circuit is required for the generator and therefore it can run without needing to be connected to a battery. The output voltage is 3-phase AC, with variable voltage and variable frequency. As the wind speed increases, both the amplitude of the output voltage and the frequency of the output voltage will increase. The 3-phase output will be connected to the 3-phase, full-wave rectifier.

Requirement 1: Outputs a 3-phase AC signal of up to 750W

2.3.2 Wind and RPM Sensors

We plan on using two sensors to use as inputs for our maximum power point tracking control algorithm. Both will require a 5V power rail. First, we will have a anemometer to measure the wind speed. This will allow us to calculate the available power at the input to the wind turbine for efficiency calculations. The wind speed from the sensor will be sent to our microcontroller, where the input power from the wind will be calculated. We will also use a proximity sensor that will determine the RPM of the turbine by sensing every time a blade passes by it. The sensor will be connected to the microcontroller, which can then determine the number of blades that pass by the sensor in a given time period, which will allow us to calculate the RPM of the turbine.

Requirement 1: Wind sensor accurate within 10%
Requirement 2: RPM sensor module accurate within 5%
Requirement 3: Both sensors should be waterproof to still work in the rain

2.3.3 Three-Phase Rectifier and Filter

In order to convert the DC signal to an AC signal, we first need to rectify the AC waveform. We are using a full wave rectifier, which will allow us to use smaller capacitors for our filter. This reverses the sign of the negative components of the AC waveform so that the output is all positive. It is important to note that because the input signal is three phase, we will need 6 diodes for our rectifier. The output of the rectifier is now a single-phase signal that needs to be filtered before being fed into our DC-DC converter. Adding filter capacitors will smooth the waveform so that it looks like a pure DC signal.

Requirement 1: Produces a DC output voltage with ripple below 2% of average voltage at 60Hz
Requirement 2: Keep Efficiency >92% by minimizing conduction loss of the diodes

2.3.4 DC/DC Converter

The output voltage of our PMA and Rectifier/Filter will depend on the speed of the turbine. At faster speeds, we will have a higher voltage, requiring our DC/DC converter to step down the voltage. At lower speeds, we will have a lower voltage, requiring our DC/DC converter to step up the voltage. We will not know the exact voltage levels until we evaluate the turbine in the lab, but we will likely need to use a buck-boost topology in order to be able to adjust the voltage up or down. Designing this converter will require selecting a diode and MOSFET with high voltage and current ratings in order to be able to tolerate a system that could output up to 800W. We would also need to take into consideration the conduction of reverse-recovery losses of these components as well to maximize our efficiency. When selecting our capacitor and inductor, we should determine an acceptable level of ripple for our 12V/24V output, and use that with the amount of energy that will need to be stored in the components to size them properly. The duty ratio of the converter will be controlled by the microcontroller.

Requirement 1: Output RMS voltage between 11.5-12.5V or 23-25V
Requirement 2: Output voltage ripple from DC/DC converter ±2% of the output
Requirement 3: Efficiency of just the DC/DC converter >80% at 750W, >90% at 100W

2.3.5 Microcontroller

We are planning on using the ATMEGA328 microcontroller to control the duty ratio sent to the DC/DC converter based on the frequency of the AC waveform coming from the PMA. It is capable of outputting a PWM signal of up to 8MHz, and we likely will not need to go above 100kHz, so it is well within our requirements in this regard. We can use the microcontroller to implement PI control to have the duty cycle adjust to a certain value that will be determined by the turbine's power-frequency curve. The microcontroller will also be able to calculate the input power to the turbine based on the wind speed sensor and the turbine's power calculation.

Requirement 1: Capable of receiving data from the anemometer, proximity sensor, and output voltage sensor
Requirement 2: Can calculate the efficiency of the overall system using the output power of the power electronics and the power from the wind going into the turbine
Requirement 3: Uses a PI control algorithm to determine the optimal duty ratio for the DC/DC converter to achieve the optimal TSR

2.3.6 5V Power Supply

To power the microcontroller, wind sensor, proximity sensor, voltmeter, and LCD display we will use a 5V, 1A power supply with electricity available from a wall outlet or 9V battery with a 5V linear regulator. In a practical implementation of this system in a permanent fixture, the power could be supply from the battery bank using a 12V-5V buck converter, so this design choice reflects the developmental nature of our project

Requirement 1: Output voltage between 4.8V and 5.2V
Requirement 2: Can provide output current to power the sensors and microcontroller

2.3.7 LCD Display

In order to display the efficiency of our system in real time, we plan on incorporating a simple, low cost LCD display, which will allow the user to view the output voltage and system efficiency in real time. The display will receive data from the microcontroller to indicate the output voltage using the voltmeter in the load module along with the system efficiency by calculating power at the load and dividing by the mechanical power available at the turbine. This element in our design will enable the user to verify the correct voltage at the load and serve a an indicator of our system's efficiency.

Requirement 1: Low Cost LCD display capable of displaying relevant data that is processed by the microcontroller, which includes efficiency and output voltage

2.3.8 Load

The load for our system will simply be a power resistor capable of absorbing up to 800W. We can use the power resistors from the power lab to act as our load because they have ratings of 1kW, which provides us a margin for safety. We will also have a voltage sensor to measure the power delivered to the load. The data from the voltage sensor will be fed back to the microcontroller so we can calculate the output power, and therefore the efficiency of the overall system. The resistor is simulating another DC load, such as a DC battery, which would allow the user to store energy from the turbine for days that are not windy enough or too windy to operate the turbine.

Requirement 1: Resistors with power rating of at least 1kW
Requirement 2: Voltmeter capable of measuring the voltage level within 3%

2.4 Risk Analysis

The biggest risk to our design working is the interface between the DC/DC converter and the turbine's speed works correctly. It is necessary for our design that when the PWM signal's duty ratio adjusts and the DC/DC converter's input current changes, that the speed of the turbine is adjusted quickly in response to maintain the optimal TSR. If the control loop takes too long to adjust the PWM signal to the changes in wind speed or it it takes too long for the change to propagate from power electronics to the the alternator in the wind turbine, then our control loop wouldn't be able to maintain the proper TSR properly. Additionally, if the control loop converges at a duty ratio that is too high or low, then the current drawn by the power electronics might be too high, and the efficiency of the DC/DC converter could take a nosedive.

3 Ethics and Safety

Since the wind turbine does have spinning blades, safety precautions must be put in place to ensure that no one is injured while testing the turbine, in accordance with IEEE Code of Ethics, #9 [6]. While the turbine is active, it is pertinent that no one is within reach of the blades. Where we test the turbine also matters, as we need access to instruments but a way to spin to the blades, so if we are using a lab, then we need to alert others to the fact that we will be testing the wind turbine so they are safe and their work is not disturbed. We will also have to give adequate time for the blades to come to a rest after testing before normal activities can resume to be certain that no one is ever harmed by the wind turbine.

Due to the high amperage and large transfer of energy, our components must be carefully selected so that they are rated for the conditions in which they will be used and that the integrity of the system is not affected by using subpar components. Attentiveness when picking parts for the power electronics and the load is key.

The projects fits the spirit of IEEE Code of Ethics, #5, as we are striving to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies. [6] If successful, our project can accelerate the growth of microgrid systems and promote the use of green energy. Making microgrid solutions more accessible can drastically change the lives of people around the world, as more than 1 billion people still live without electricity [7]. We hope that our project's success causes not only improvements in microgrid technology, but also the lives of people worldwide.

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