BikeBike Revolution: Energy Efficient E-Bike

ECE 445 Design Document

Team 20: Gina Jiang, Shannon Lin, Yee Chan Kim

gjiang20, slin81, yck2

TA: Bonhyun Ku

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1. Introduction

1.1 Problem and Solution Overview

Biking is a longtime hobby and top choice of exercise with a broad audience. Indoor cycling in particular has been a great form of activity that is currently on the rise in popularity [1]. While cycling burns energy for the purpose of staying fit, there are more optimal applications for this mechanical power: to convert it back into electrical energy and use it to power the bike, thus turning the bike into an electrically assisted E-bike. Many advantages can come out of this situation as the energy put into and coming out of the system is largely efficient. Developing a solution to enable the E-bike to double as an indoor and outdoor bike can help users save financially, enjoy the hobby, and exercise in multiple environments - whether stationary or covering real ground.

Our solution is to allow a pedal-assist E-bike to convert into an indoor stationary bike, and to use the energy generated from pedaling indoors to power the E-Bike for use outdoors. The amount of energy generated after pedaling for an hour is about 80 Wh including losses, while the average fully electric E-bike is rated between 300-1000 Wh [2], [3]. The amount of power generated is feasible in an electrically-assisted bike, which can be rated as low as 144 Wh. We plan to implement a multi-input system to allow the battery to adapt to the grid to ensure a reliable energy source if needed. The design includes an indoor stand to support the bike for safe use indoors with the hub motor / generator, battery, and power electronics mounted on the bike frame itself. The power electronics system consists of DC-DC and AC-DC power conversion, as well as a PWM control circuit.

1.2 High-Level Requirements List

1. From full charge, the bike must be able to travel with electric-assisted power with an average of 150W and travel with a rate of at least 10mph.
2. In generator mode at a maximum input, the bike should be able to generate at least 100W of power by the user pedaling the bike. In this mode, the bike must also be able to switch to using power from the grid in order to get charged.
3. The DC-DC Boost converter must be able to exhibit at least 75% efficiency when taking in varying values of voltage output from the generator.

2. Design

2.1 Block Diagram

Our block diagram consists of four interconnected subsystems: the power electronics, hub motor / generator, control module, and sensing module. The major components that drive the system's longevity, effectiveness, and efficiency are within the battery, converters, controls, and the motor. The ratings on these parts are integral to satisfy our requirements of enabling pedal-assist functionality for a certain amount of time, as well as charge the bike at a satisfactory pace in generator mode. The efficiency of power transmission as shown in Figure 1 is not only achieved by these main components but also by direct data transmission between the modules through the digital controls and sensors.

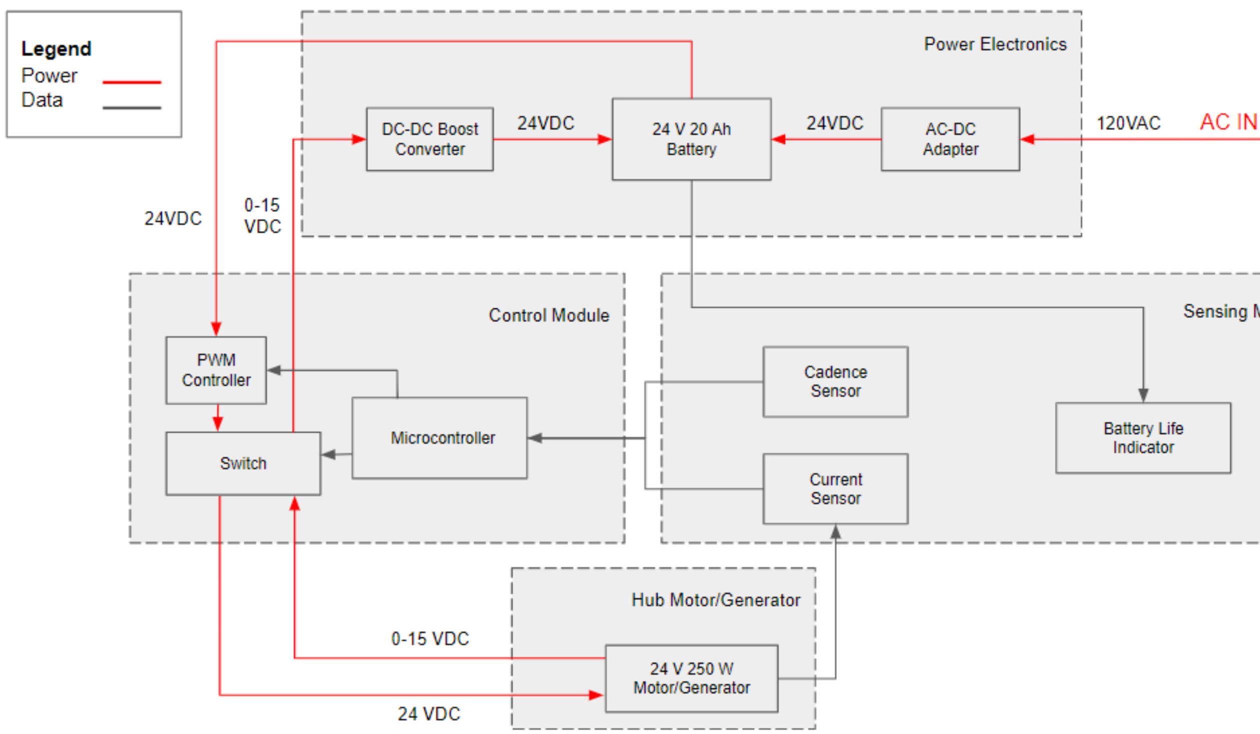

Figure 1. Block Diagram for BikeBike Revolution.

2.2 Physical Design

Our adaptive E-bike will contain almost all of the subsidiary components in our design, including the motor driving on top of the rear wheel secured by a mounting bracket. The power electronics and battery are attached to a plate that is secured on the frame of the bike. An available outlet on the battery will charge the battery using the grid. The cadence sensor will be connected to the chain rings of the pedals. We will be using a Schwinn World Tourist Road Bike, with the frame that is drawn in Figure 2. Two stands will also be designed to support the bike while it is being used indoors as the rear wheel will need to run freely in order for the generator to function. All components will be interfaced with robust wires that connect between the motor, cadence sensor, power electronics, and battery.

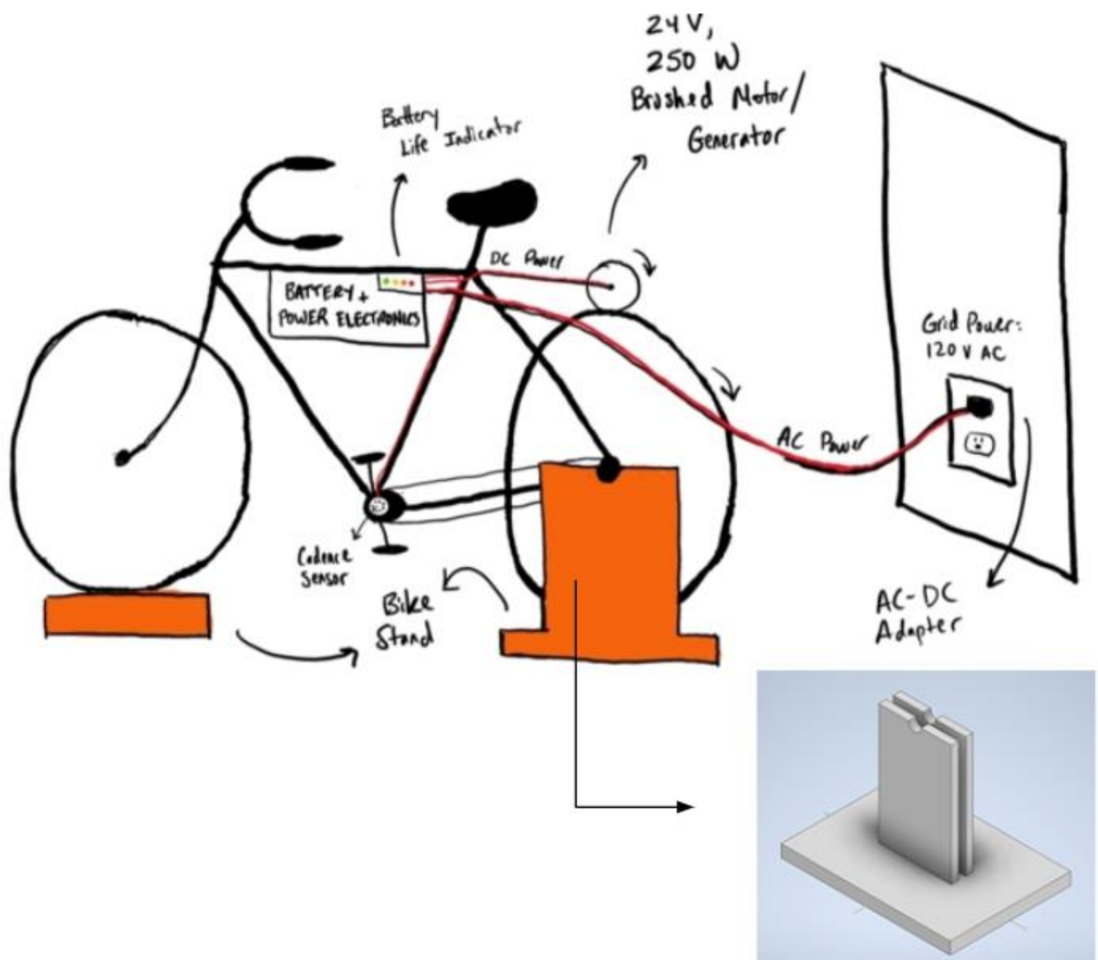

Figure 2. Simple Drawing of Integrated Elements of BikeBike Revolution and Preliminary Indoor Bike Stand CAD Model.

2.3 Power Electronics

2.3.1 Battery: The 24 V, 10 Ah battery is where the power used in the system is stored. The battery will be connected in parallel so that the Ah will double and the rating will be then 24 V 20 Ah to have better longevity. Depending on if it is in generator, motor, or grid power mode, the battery will take charge from the AC-DC adapter, boost converter, or 120 V outlet, respectively.

Requirement	**Verification**
1. From full charge, the battery must be able to power the motor for at least one hour at a range of 50-250 W 2. Has to be able to charge 100% efficiency from the grid through the AC-DC adapter 3. Charge at a 25% efficiency from the generator through the boost converter	1. Directly connect the battery to the motor and let the motor run power until the battery is out of charge to ensure that the motor is able to run for at least an hour 2. Drain the battery to nearly complete discharge and connect the AC-DC adapter to test charging 3. Have the battery at low charge and connect the output of the boost converter to the battery leads to test charging

2.3.2 Grid Power: The 120 V AC power supply coming from the standard American outlet will be also utilized in this system as a way of providing a powerful and reliable energy source to the E-Bike if necessary. This source will be directly charging the DC battery on the bike when in grid power mode.

Requirement	**Verification**
1. Outputs a constant 120 ±0.5 V AC power 2. Effectively connects to AC-DC adapter through the plug	1. Measure output terminals with a multimeter to confirm expected value 2. Ensure good connection by plugging in the cord to the power outlet

2.3.3 AC-DC Adapter: An AC to DC power conversion needs to be made in order to connect the 120 V AC grid power to the 24 V battery. We decided to use a 100-240 V AC to 24 V DC adapter for this step as it is the simplest and has easy accessibility for implementation to the rest of the system. The leads of the adapter will also be connected to alligator clips so that the sealed lead-acid (SLA) batteries can be charged safely.

Requirement	Verification
1. Takes in 120 ±0.5 V AC from the outlet and outputs 24 ±1 V DC through the port 2. Is able to durably connect and deliver 24 ±1 V DC to the battery itself	1. Attach alligator clips from the SLA battery charger and use a multimeter to measure the value at the clips 2. Attach the leads of the SLA battery charger to the leads of the lead acid battery to ensure good connection

2.3.4 DC-DC Boost Converter: DC to DC power conversion will be integral to safely and successfully transfer different voltage ratings between the generator and battery. A boost converter will be used in order to step up the varying input voltage from the generator to the 24 V that is needed for the battery. The converter includes the LM3478 operational amplifiers and the IRF7807 for the switching element and frequency. We chose a converter over a transformer as it is lighter and more cost effective. Since the output voltage of the converter needs to be at a constant 24 ±1 V, the feedback resistors in the converter should be changed in order for the right value to be outputted. The equation used to find this is shown in the equations below, with out design choosing an 18 *Ω* resistor to have a 24 V output. The equations and reference design in Figure 3 are from [4].

Requirement	Verification
1. Converts input voltage from 1-15 ±1 V DC from the generator and outputs 24 ±1 V DC to the battery	1. The boost converter can be tested in the Senior Design lab at varying DC voltages, with the output measured and expected to be 24V ± 1V and input voltages varying from 1-15 V DC.

$$R_f = \frac{1.26R_f}{V_{out} - 1.26}$$

$$R_f = \frac{1.26R_f}{24 - 1.26}$$

$$R_f = 18\ \Omega$$

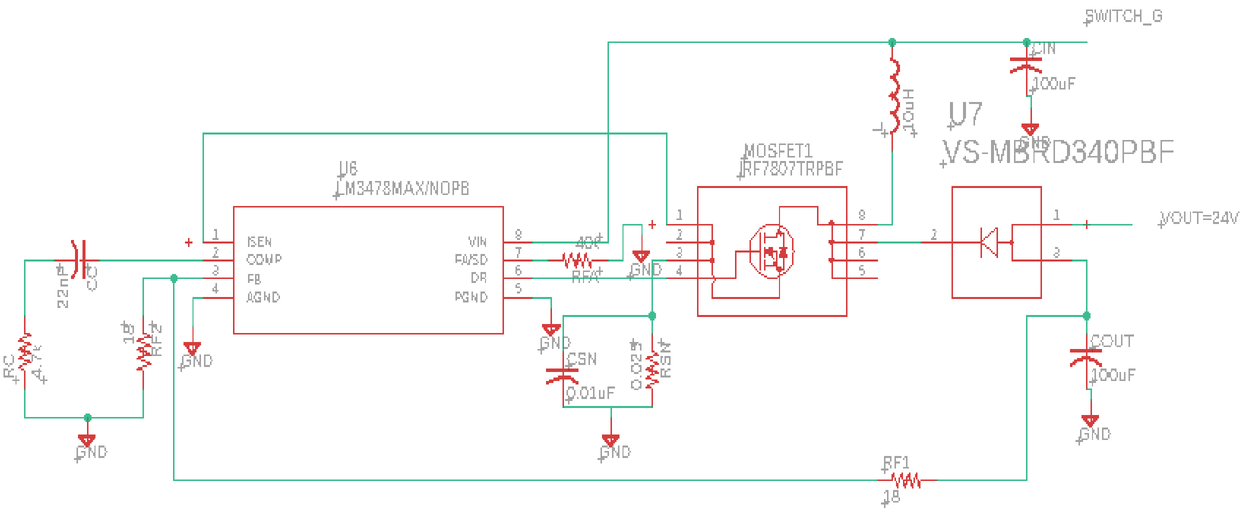

Figure 3. 12 to 24 V DC-DC Boost Circuit Schematic.

2.4 Hub Motor / Generator

2.4.1 Motor / Generator: The motor / generator is a single component determined by the switch to run as a motor or as a generator. We decided to use a 24 V 250 W Brushed DC Electric Motor for this project. In the motor mode, the motor draws power from the battery to drive the rear wheel of the bike. In the generator mode, current is generated as the user pedals and spins the generator. This current is sent out to the DC-DC converter to be stored in the battery.

Requirement	Verification
1. The motor must provide torque and run from a speed of 1-2700 ±5 RPM when running under normal conditions 2. The generator must be able to produce at least 100 W of power	1. A. Prop the bike up so that the wheels can freely spin B. Connect the motor to the fully charged battery and run it at rated speed C. Use a speedometer to verify the 2700 ±5 RPM 2. A. Use a multimeter to measure the output of the generator B. Pedal generator at a faster rate until the output power is greater than 100 W

2.5 Control Module

2.5.1 Microcontroller: The microcontroller takes in data from the switch, cadence sensor, PWM controller, and current sensor to determine how much power should be supplied to and from the battery. If the switch is in motor mode, the microcontroller allows the battery to supply power to the motor and depending on the cadence sensor and through the PWM controller, as the microcontroller allows more or less power to be supplied. When the switch is in the generator mode, the microcontroller allows the DC-DC converter to supply power from the generator to the battery. The microcontroller also takes in data from the current sensor as a safety feature to stop the system with a switch if the current goes over the rated current of the motor. [5] was also used to help make the pin layout and schematic build of the microcontroller in Figure 4.

Requirement	**Verification**
1. Be able to take in signals from the cadence sensor and determine the duty cycle and frequency 2. Must generate PWM signal with 0-100% duty cycle to the PWM controller 3. Regulates the current protection by controlling the relay and physical switch and getting the input current signal from the current sensor that cannot be more than the 13.8 A current rating 4. Signals the system to go into grid mode when switch is turned to 'off'	1. Take the cadence sensor and connect it to the microcontroller to see if the input signals are in the range of the expected values 2. Connect the PWM pin of the microcontroller to the PWM controller and probe the signal with an oscilloscope to ensure PWM signal that varies with the duty cycle from the cadence sensor 3. Have the current sensor measure more than 13.8 A from a current supply and make sure the the relay detects the overcurrent and turns off the system 4. Put the switch on off position and observe no current is going to/from the battery using a multimeter

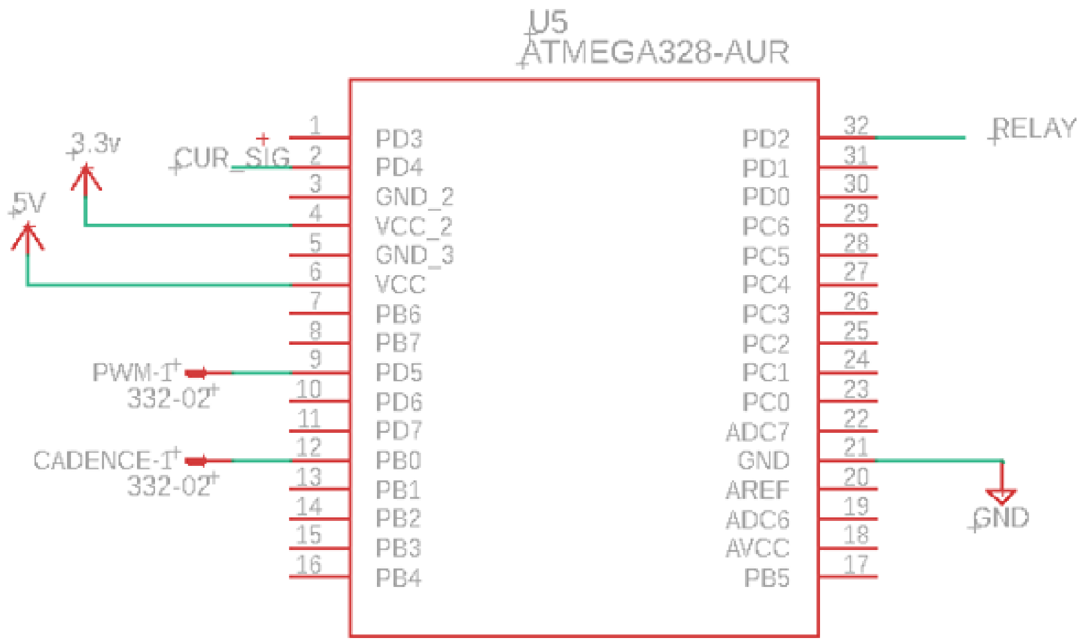

Figure 4. ATMEGA328 Microcontroller Schematic.

2.5.2 Switch: The switch will consist of two relays and the physical switch to control whether the motor-generator should be functioning as a motor, a generator, or in the off position. In the motor mode, the switch connects the battery to the motor through the PWM controller. While in the generator mode, the switch connects the generator to the battery through the DC-DC converter. In the off position, it does not connect anything and the user can charge the battery directly from the grid. The relay's purpose is to direct electrical signals coming from the microcontroller so that it may safely switch off the system in case the current coming from the motor / generator is within the ratings. Figure 5 shows the relay schematic inspired by the reference design in [6].

Requirement	**Verification**
1. Rated current of ≤13.8 A from the motor to the battery has the switch in motor mode 2. Let ≤10.5 A from the generator flow when the switch is in motor mode 3. Signal from microcontroller will tell the switch to turn off	1. A. Set the switch to motor mode B. Measure with an ammeter that ≤13.8 A current is flowing from the battery to the motor 2. A. Set the switch to generator mode and pedal the bike B. Measure with an ammeter

	that ≤10.5 A current is flowing from the generator to the battery 3. A. Output 3.3V from the microcontroller to the relay circuit B. Measure with an ammeter that no current is flowing through the switch

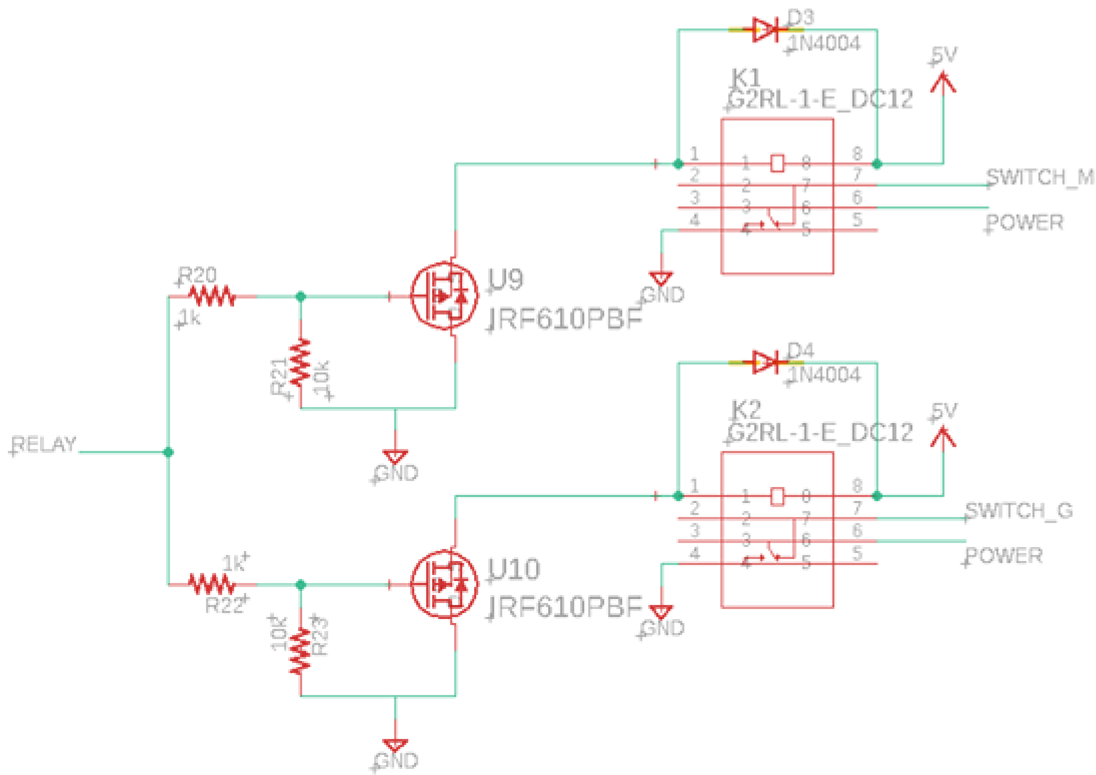

Figure 5. Relay / Switch Circuit Schematic.

2.5.3 PWM Controller: The PWM Controller is used to control the speed of the motor. The microcontroller generates a PWM signal, which is then taken by the Cytron MD10C which uses an H-bridge to drive the motor. It supports motor voltage range from 5V to 30V DC and has maximum current up to 13A continuous and 30A peak (for 10 seconds). A simple flowchart is displayed in Figure 6 and seen in [7].

Requirement	Verification
1. 100% duty-cycle must correspond to the max speed of the motor 2. Peak voltage output must be 24 ±1V	1. A. Connect the motor directly to the battery to determine the maximum speed of the motor B. Connect the motor to the PWM controller at 100% duty cycle and compare it to the maximum speed 2. A. Use the 24V battery and measure the output voltage using a multimeter

2.5.3.1 PWM Controller Flowchart:

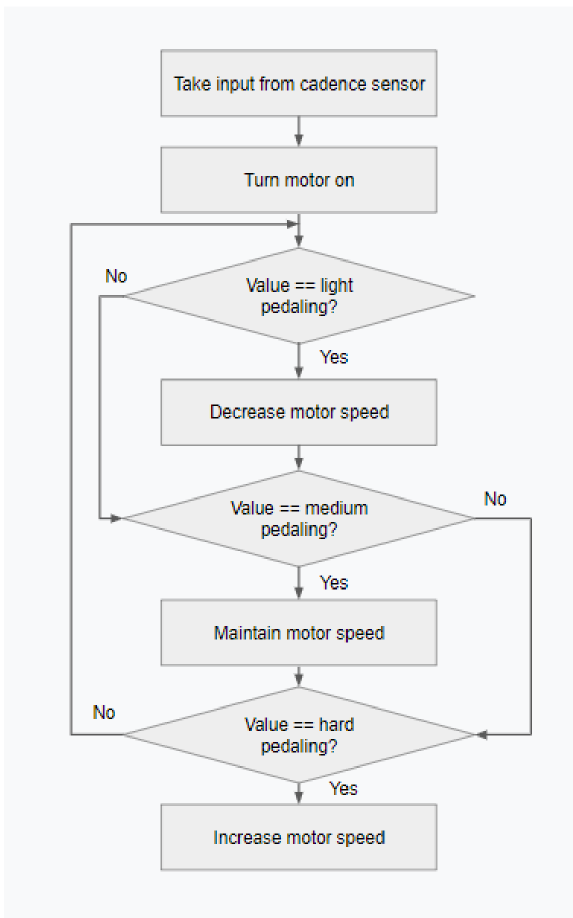

Figure 6. PWM Controller Flowchart

2.6 Sensing Module

2.6.1 Cadence Sensor: The cadence sensor we will be using is to measure how fast the user is pedaling the bike. This sensor will be mounted on the pedals of the bike. The data from the sensor will be input to our microcontroller to direct the motor in pedal-assist mode, specifically to supply more power when pedaling speed decreases and less power when pedaling speed increases.

Requirement	Verification
1. Must vary output current depending on how fast the bike is being pedaled	1. A. Connect the output of the cadence sensor to an ammeter to read current B. Start spinning the cadence sensor slowly, gradually increasing the speed C. Observe that the output current responds to the change in speed

Figure 7. Cadence Sensor Implementation [8].

2.6.2 Current Sensor: The current sensor is used as a safety measure in the system and regulates how much current is going in and out of the battery and the motor to make sure the correct amount is being transferred. If the amount of current is incorrect, the current sensor will notify the microcontroller to turn off the system through the relays and switch. The current sensor uses the ACS725LLCTR-20AB-T current sensor chip rated for at least 20 A for the battery and generator outputs. It also uses a conductive resistor for low power loss and better capability for higher accuracy of measurement from [9]. Figure 8 shows the given schematic provided by the reference design slightly altered to have higher current rating.

Requirement	Verification
1. Regulates the current output of the motor to be 13.8 A and reads from the motor leads 2. Regulates the current output of the generator to be 10.5 A and reads from the leads 3. If current exceeds 13.8, the current sensor will send a signal to the microcontroller that turns off the switches	1. Turn the bike to motor mode and use an ammeter to compare the reading from it to the reading from the current sensor while testing at different input voltages of 1-24 V 2. Turn the bike to generator mode and use an ammeter to compare the reading from it to the reading from the current sensor while testing at ideal voltages of 1-15 V. 3. Have the current sensor measure more than 13.8 A from a current supply and check Arduino Uno if the correct signal was released to turn off the system

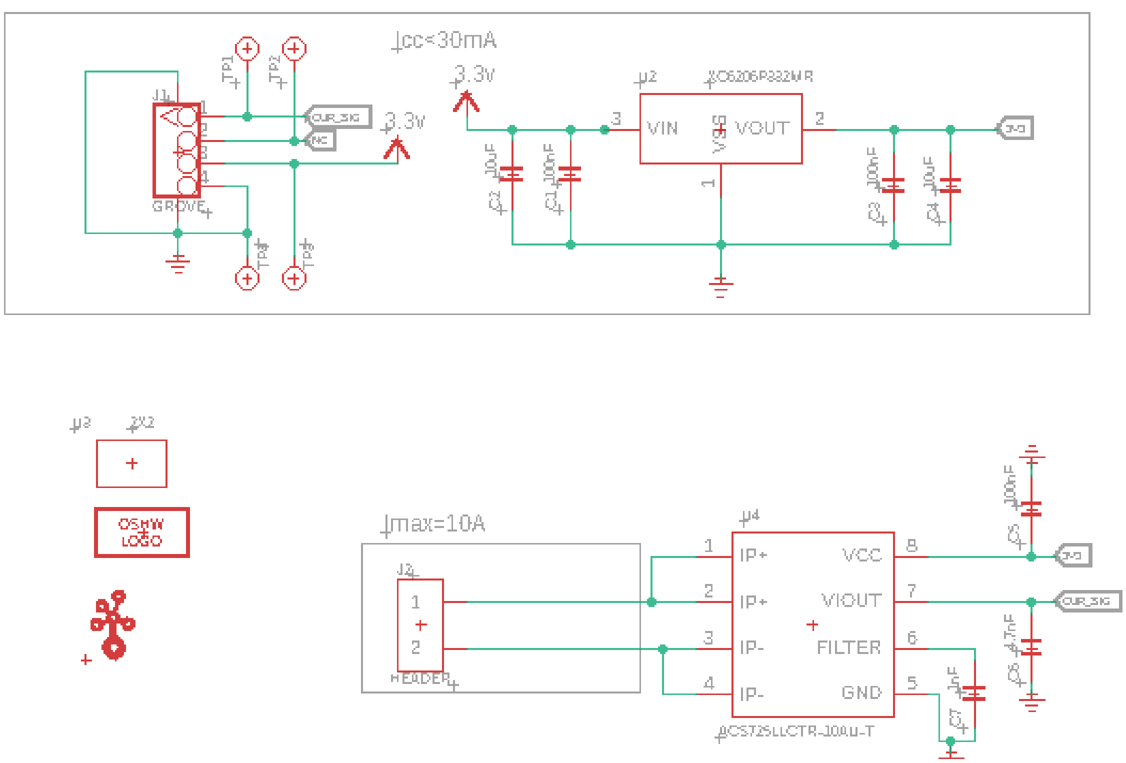

Figure 8. Current Sensor Circuit Schematic.

2.6.3 Battery Life Indicator: This component includes a voltage sensor which checks the voltage of the battery through a voltage divider and uses four LEDs to show how much charge the battery has left. As the battery life decreases, the voltage also decreases following the battery's voltage curve. The number of LEDs lit up is proportional to the voltage detected. One lit LED corresponds to 25% charge, so all four LEDs lit up means the battery is fully charged. Figure 9 depicts the voltage regulator circuit schematic from [10].

Requirement	**Verification**
1. Each LED must light up at its corresponding charge (first LED with 25%, second LED with 50%, third LED with 75%, and all four LEDs at 100%)	1. A. Monitor the battery voltage with a voltmeter B. Starting from full charge, drain the battery C. Observe the corresponding LEDs light up at the correct voltage level

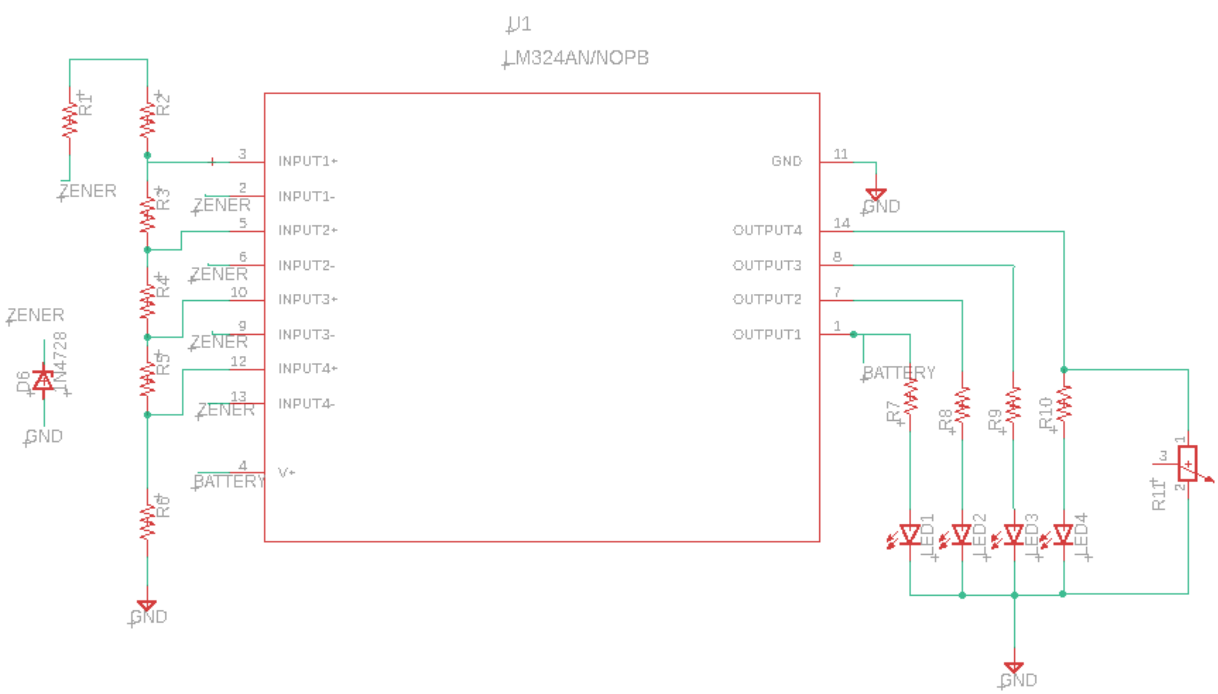

Figure 9. Battery Life LED Indicator Circuit Schematic.

2.7 PCB Layouts

2.7.1 PCB Schematic Layout

All of our components combined in an EagleCAD schematic, including the microcontroller, relay circuit, voltage regulator, boost converter, current sensor, and pins to the battery, generator, and motor.

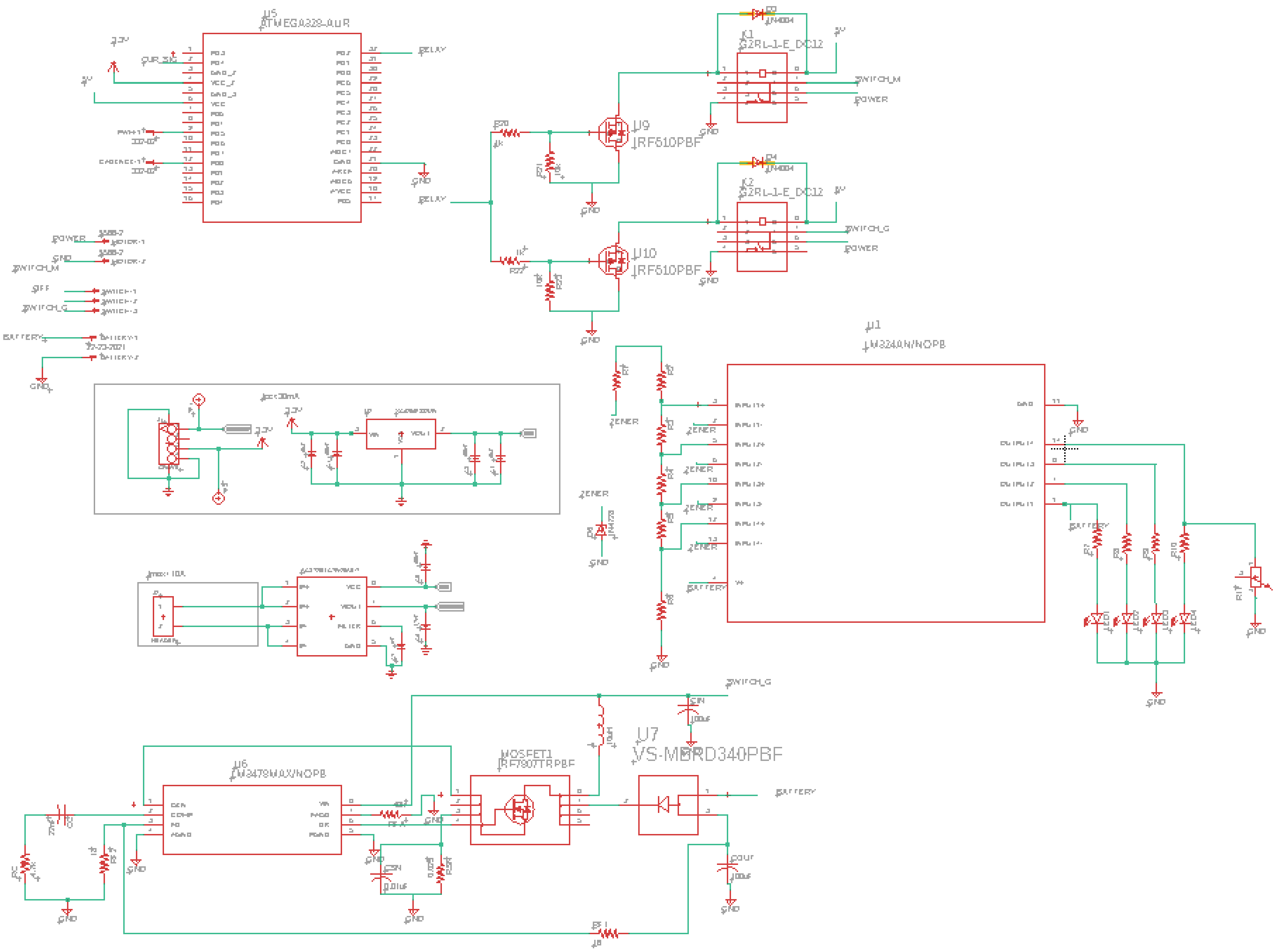

Figure 10. PCB Schematic Design of the Components

2.7.2 PCB Board Layout

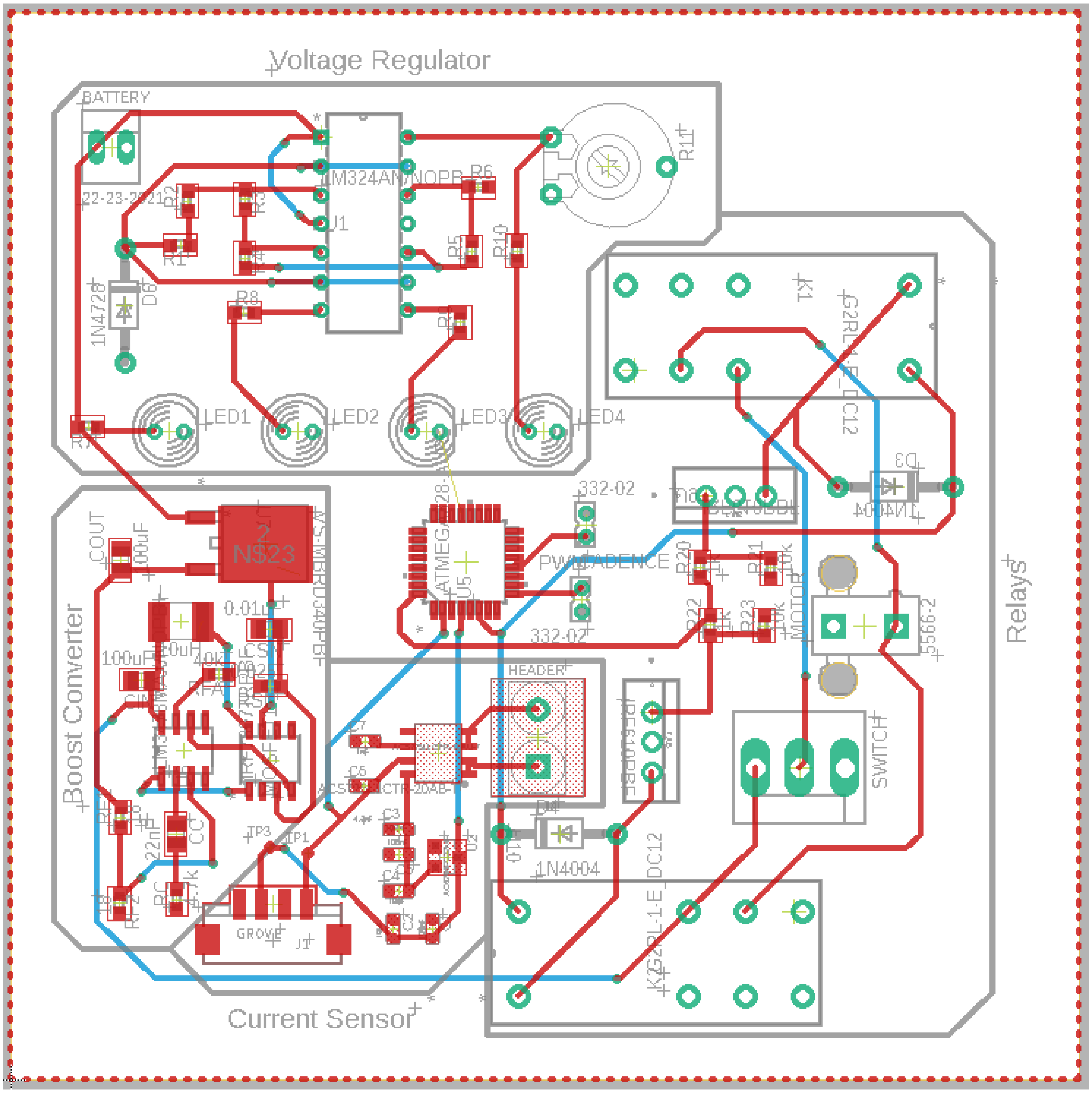

Figure 11. PCB Design of the Components

2.8 Tolerance Analysis

The most critical component of our project is the motor / generator. Since we are using the same component for a motor and a generator, we want to make sure that it can be used effectively. The DC motor we are using is rated at 24V with 250W of power and 2750 rpm. As shown in Figure 10, we used the 'DC Machine' block to simulate a separately excited DC motor with our known values. This simple simulation showed characteristics of our motor. Torque input to the motor is estimated 0.868 Nm at full load. The maximum motor output speed is around 500 rpm and increases as load decreases as shown in Figure 11. The electrical torque is around 4.5 Nm and decreases as load decreases as shown in Figure 12.

$$T = \frac{P}{\omega} = \frac{250\text{W}}{2750\text{rpm} * \frac{2\pi}{60}} = 0.868\text{Nm}$$

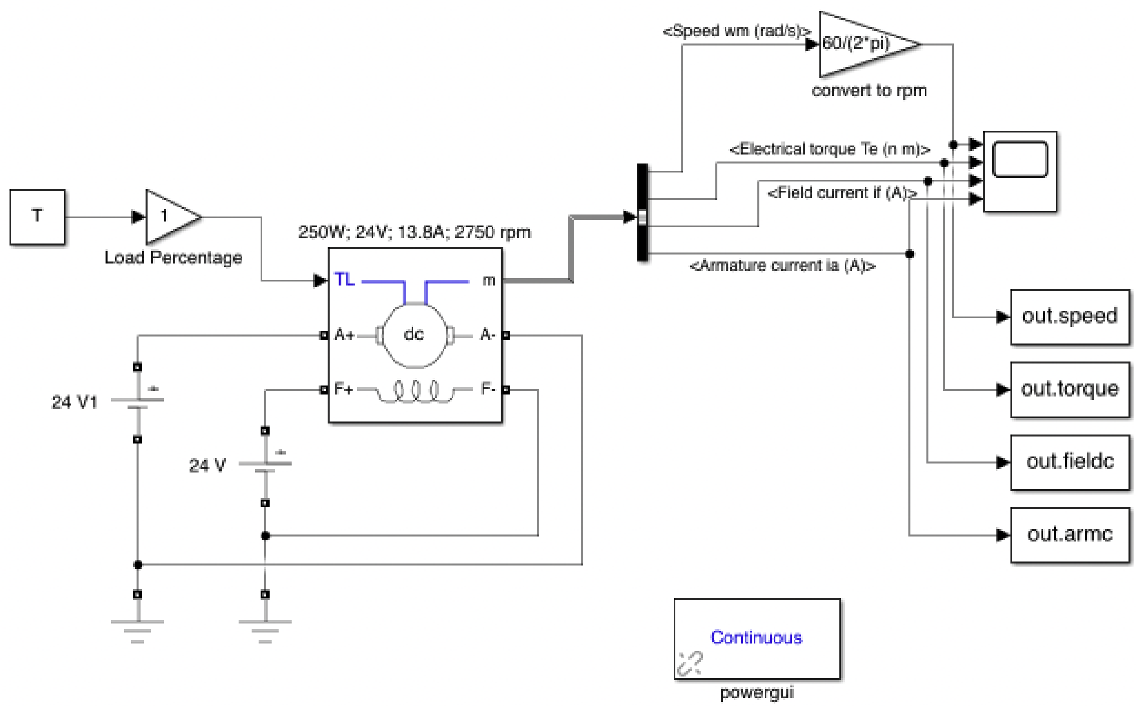

Figure 12. Simulation Model of Separately Excited DC Motor in MATLAB/Simscape.

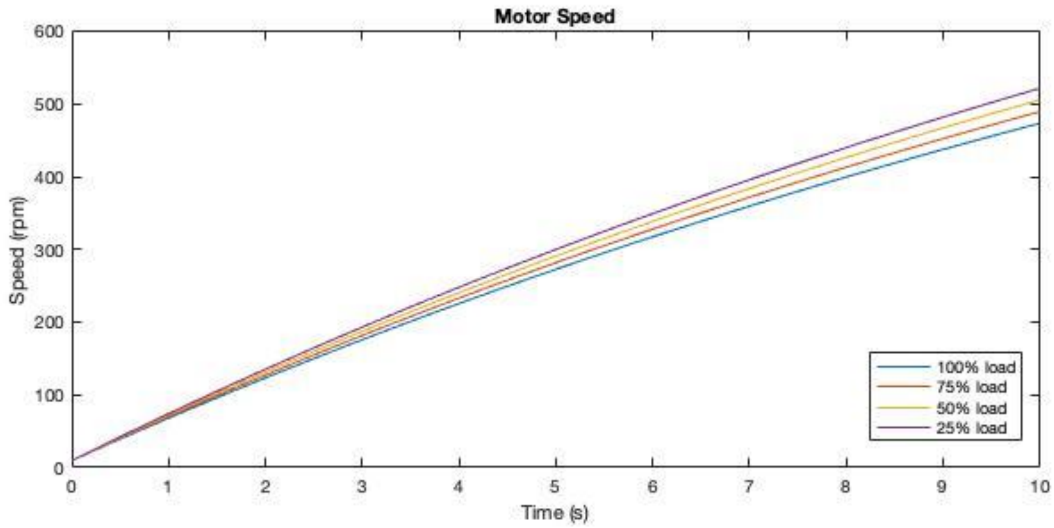

Figure 13. Speed Performance of Motor.

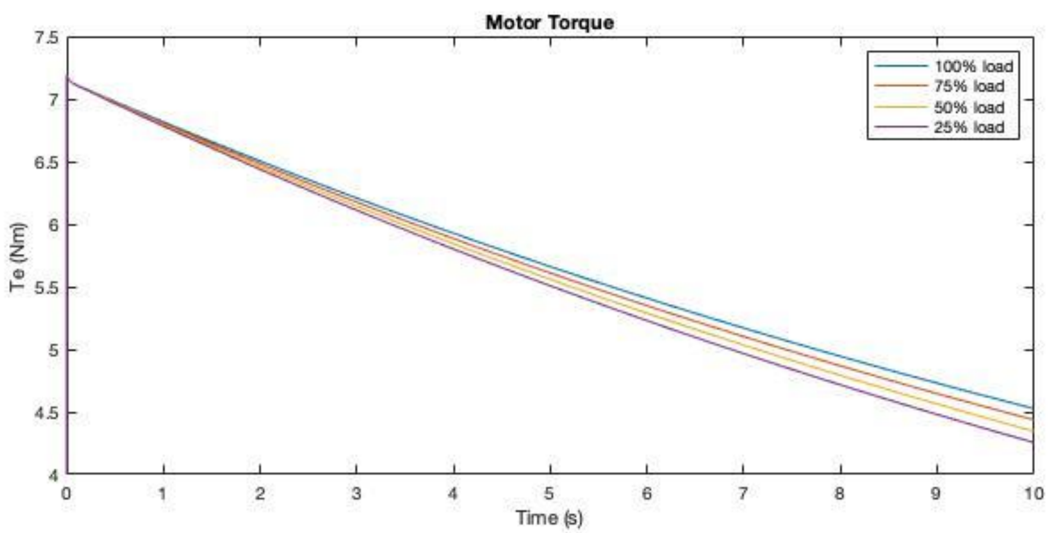

Figure 14. Electrical Torque Performance of Motor.

As one of our high-level requirements states, the bike should be able to generate at least 100W of power from the user pedaling the bike in generator mode. We know that our motor is rated at 2750 rpm, so we are interested to see the power output when the machine speed is varied. Since we are turning the generator shaft based on the speed the user is pedaling at, the machine speed won't be at its maximum speed all the time. In Figure 13, we start with maximum speed input to the generator and convert it from rpm to rad/s.

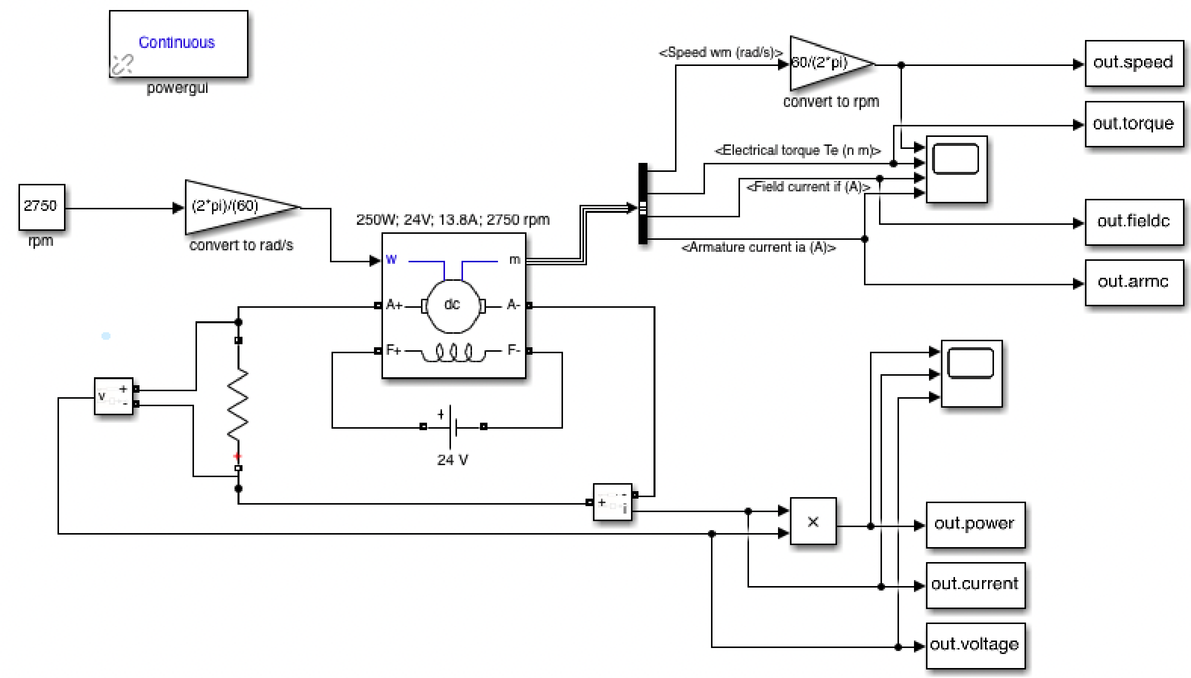

Figure 15. Simulation Model of Separately Excited DC Generator in MATLAB/Simscape.

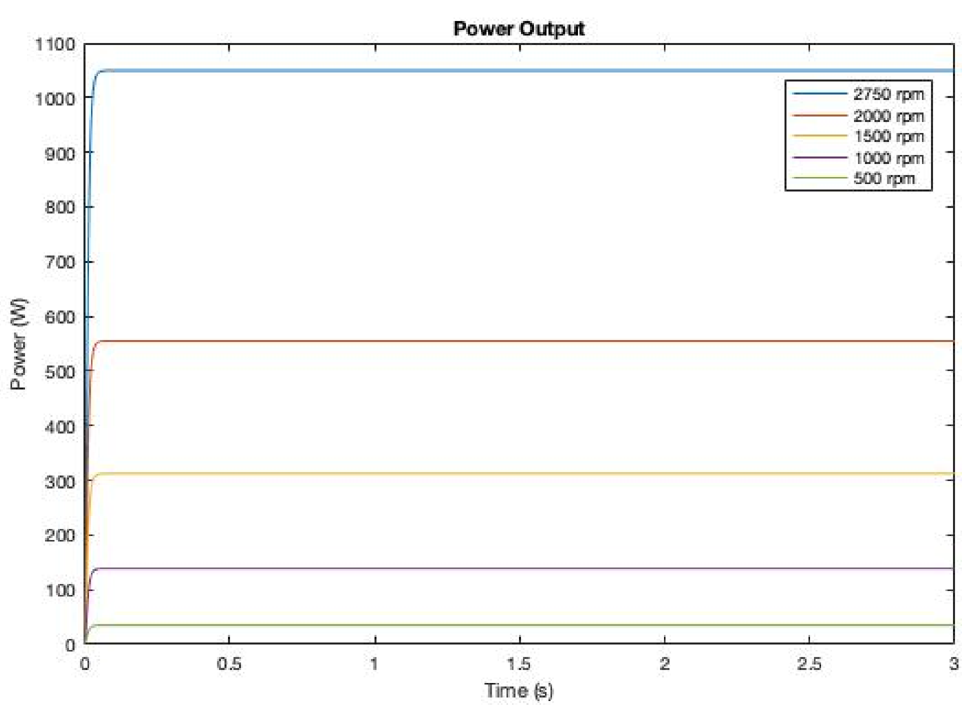

Figure 16. Power Output from Generator.

As long as the machine speed is 1000 rpm or higher, our requirement for the generator output should be met. At maximum speed, the generator is outputting above 10x the amount of power we named as our requirement. Since the user pedaling will ultimately determine how quickly the generator is spinning, this is a reasonable conclusion to draw since we have a range of 1750 rpm from 1000-2750 rpm to still meet our high-level requirement.

It's important to note that these simulations do not account for losses that will occur in the real world. However, it gives us a better understanding of how the system works and what to expect. Additionally, since we were not provided a datasheet and are still waiting for our motor to be delivered, we do not know all the specifications of the motor. Therefore, some values we used for this simulation are estimates from similarly rated motors found online. Once we receive and are able to run tests on the motor we ordered, we will be able to determine its performance and give a more accurate assessment.

3. Cost and Schedule

3.1 Cost Analysis

The cost of labor for three electrical engineering graduates is estimated to be $40/hour, 10 hours/week for 12 weeks. The total labor cost would then be $36,000.

$$3 \text{ graduates} \times \frac{\$40}{\text{hr}} \times \frac{10 \text{ hr}}{\text{week}} \times 12 \text{ weeks} \times 2.5 = \$36,000$$

3.2 Parts

We already have a bike to modify, but we still need to buy the components to assemble the E-bike. The total cost of parts for our prototype is $199.20. Adding this to the labor cost yields $36,199.20 for the total development cost.

Part	**Cost**	**Quantity**	**Total**
Electric Motor 24V DC Scooter Motor Brushed Chain Motor (250W 2750RPM)	35.89	1	35.89
24 V, 10 Ah DC Battery	69.99	1	69.99
Cadence Sensor (Amazon, ZOOMPOWER)	18.50	1	18.50
100-240 V AC-24 V DC Power Adapter (Amazon, Shnitpwr)	11.99	1	11.99
Microcontroller - ATMEGA328-AUR (Digikey)	2.40	1	2.40
G2RL-1A-E-HA DC5 Relay (Digikey)	6.80	1	6.80
SWITCH TOGGLE SPDT 15A 125V (Digikey)	7.36	1	7.36
ACS725LLCTR-20AB-T Current Sensor (Digikey)	4.89	1	4.89
LM324 Amplifier (Digikey)	0.55	1	1.10
XC6206P332MR-G Linear Voltage Regulator IC (Digikey)	0.33	1	0.33
IRF7807ZTRPBF N-Channel MOSFET (Digikey)	0.69	1	0.69
MBRD340G Schottky for Boost Converter (Digikey)	0.82	1	0.82

Cytron 13A DC Motor Driver MD10C (Amazon)	11.50	1	11.50
Misc. RCL components (Digikey)	5.00	1	5.00
PCB (PCBWay)	20.00	1	20.00
Total Amount		15	$199.20

3.3 Schedule

Week	**Gina**	**Shannon**	**Yee Chan**
2/28/21	Continue testing Simulink and Simscape motor system	Order motor, cadence sensor, batteries	Finalize PCB designs and order parts
3/7/21	Work on microcontroller programming for PWM and controls	Check in with ece machine shop on motor, stand, and cadence sensor implementation	Order remaining components needed including passives, transistors, op amps, etc.
3/14/21	Start assembling and soldering PCB components	Start assembling and soldering PCB components	Start assembling and soldering PCB components
3/21/21	Debugging control circuit / microcontroller	Bench test DC-DC power converter	Bench test voltage regulator and current sensor
3/28/21	Debugging power circuit and motor system	Debugging power circuit and motor system	Debugging power circuit and motor system
4/4/21	Implement PCB, cadence sensor, motor, LEDs, and battery	Implement PCB, cadence sensor, motor, LEDs, and battery	Implement PCB, cadence sensor, motor, LEDs, and battery
4/11/21	Test complete system	Test complete system	Test complete system
4/18/21	Plan final report and presentation	Plan final report and presentation	Plan final report and presentation
4/25/21	Prepare Final Presentation	Prepare Final Presentation	Prepare Final Presentation
5/2/21	Prepare Final Report	Prepare Final Report	Prepare Final Report

4. Ethics and Safety

4.1 Ethics

When designing this project, many factors went into the safety precautions that would be needed in order to finalize a secure product. Elements such as speed and power from the pedal-assist mode and even hazards that could be formed when using the bike in the generation mode can pose as harmful and dangerous to the user when not operated correctly. Electrical and physical malfunctions and overheating are potential risks exposed to the user, while there are also possibilities of exposing harm to the general public while using this product. The following sections identify the different hazards that our project may have and discuss the actions that we will take to adhere to IEEE ethical standards [12].

4.2 Public Safety Hazards

We must ensure that the safety of the public is protected and users of our E-bike are aware of any potential dangers associated with it. This is acknowledged in the IEEE Code of Ethics, #1: "to hold paramount the safety, health, and welfare of the public… and to disclose promptly factors that might endanger the public or the environment" [12].

The main concern regarding public safety is misuse of the E-bike, which could result in accidents or violation of traffic laws. Following the Illinois Vehicle Code under Sections 1-140.10, 1-140.15, and 11-1516, our E-bike would fall under the "low-speed electric bicycle" category, meaning that the motor must be less than 750W [13]. Additional restrictions on using the E-bike include that the bike cannot be used on a sidewalk, may not be operated at a speed greater than 20 mph, and can only be used by people aged 16 years or older [13]. We are using a motor that is less than 750W, meeting the requirement set by Illinois law. Informing users on how to properly use the bike and the limitations of the components can help mitigate actions that could endanger the user and others. However, we would not be responsible for users explicitly deciding to violate traffic laws.

4.3 Overheating Hazards

Some potential safety issues that could arise with our project include the components of our E-bike breaking or overheating, specifically our battery and motor-generator. If excessive voltage is supplied to the motor, this could cause overheating and motor failure. We will avoid this situation by controlling the amount of voltage supplied to the motor through a battery management IC that can be implemented as a safety feature for this hazard.

4.4 Electrical Safety Hazards

We are operating with a high voltage battery and motor, and if both components are not used properly, then a risk can occur with electric shock in the case of exposed wires or improper insulation and connection. Additionally, since our E-bike is meant for use outdoors, harsh weather conditions could damage the electronics, wiring, sensors, and motor if they are not properly protected against inclement weather. Our end product will ensure that all necessary components are covered with the appropriate material to combat against these kinds of scenarios.

References

[1] C. Woodford. “Electric Bicycles.” Explainthatstuff.com. https://www.explainthatstuff.com/electricbikes.html (accessed Feb. 13, 2021).

[2] A. Frank. “Could You Power Your Home With A Bike?” NPR.org. https://www.npr.org/sections/13.7/2016/12/08/504790589/could-you-power-your-home-with-a-bike (accessed Feb. 15, 2021).

[3] S. Anderson. “Understanding E-Bike Power, Range, And Energy.” Cyclevolta.com. https://www.cyclevolta.com/understanding-e-bike-power-range-and-energy/ (accessed Feb. 15, 2021).

[4] Texas Instruments, “LM3478 High-Efficiency Low-Side N-Channel Controller for Switching Regulator,” LM3478 datasheet, July 2000 [Revised Dec. 2017].

[5] “Atmega328 Pinout.” Learningaboutelectronics.com. http://www.learningaboutelectronics.com/Articles/Atmega328-pinout.php (accessed Mar. 3).

[6] “Relay Switch Circuit.” Electronics-tutorials.ws https://www.electronics-tutorials.ws/blog/relay-switch-circuit.html (accessed Mar. 3).

[7] “Control Large DC Gearmotors with PWM & Arduino.” Dronebotworkshop.com. https://dronebotworkshop.com/dc-gearmotors-pwm/ (accessed Mar. 3).

[8] “ZOOMPOWER pas Pedal Assist Sensor kt-d12l kt d12 d12l 12 Magnet Easy to Install.” Amazon.com. https://www.amazon.com/ZOOMPOWER-Assist-Sensor-kt-d12l-Install/dp/B079ZRRHSR/ (accessed Mar. 3).

[9] “Grove - 10A DC Current Sensor (ACS725).” Seeedstudio.com https://www.seeedstudio.com/Grove-10A-DC-Current-Sensor-ACS725-p-2927.htm (accessed Mar. 3).

[10] “How to Make a Car Battery Voltage Monitor Circuit.” Makingcircuits.com. https://makingcircuits.com/blog/how-to-make-a-car-battery-voltage-monitor-circuit/ (accessed Mar. 3).

[11] A. Boldt. “The Average Exercise Bike Pedaling Speed.” Livestrong.com. https://www.livestrong.com/article/396118-average-speed-human-pedaling-exercise-cycle/ (accessed Mar. 3).

[12] "IEEE IEEE Code of Ethics." IEEE.org. http://www.ieee.org/about/corporate/governance/p7-8.html (accessed Feb. 14, 2021).

[13] U.S. Senate. 111th Congress, 1st session. (2009, Aug. 4). *Public Act 096-0125.* [Online]. Available: https://ilga.gov/legislation/publicacts/96/PDF/096-0125.pdf