# Regenerative Braking in Electric Bike Conversion Kit

ECE 445 Design Document

Team 38

Chloe Armstrong
Lucas Pruett
Jace Haas

TA: Matthew Qi

March 24, 2023

**Table of Contents**

# 1. Introduction

## 1.1 Problem

Though electric bikes are a greener alternative to gas-powered cars and faster than traditional bikes, electric bikes' limited range can discourage some to make the switch. An average electric bike has a range of 20-40 miles [1]. For some, this range is simply too low to justify purchasing something on the order of $1000 to $2000, especially when that price tag reflects that of an entry-level electric bike [2].

Conventional electric bikes also suffer from the same brake wear as a traditional bike. It is suggested that traditional cyclists replace their brake pads every 500-1000 miles [3]. Since electric bikes use the same braking system as manual bikes, the same advice more or less applies. For those who cycle frequently, brake maintenance may be seen as an undesirable chore. Electric bikes still use traditional brakes which creates an unneeded maintenance item. In addition to this, the thermal energy is wasted.

## 1.2 Solution

To solve these problems, we would like to create a kit that transforms a traditional bike into an electric bike that is capable of regenerative braking. The regenerative braking aspect would both provide a range boost to the user, as well as preserve the manual brakes such that brake maintenance would not need to be conducted as often as with both a traditional bike and more conventional electric bikes.

This kit would contain all of the components of a traditional electric bike, including  motor, battery, and user controls. Completing the assembly would result in a throttle-activated electric bike driven by a friction wheel. The kit would also include the necessary control unit to not only provide the traditional function of supplying power to the motor, but also to supply power to the battery during regenerative braking. The end result is that the user would be able to convert their bike into an electric bike capable of regenerative braking. Riders will be able to use a regenerative braking control that is separate from the manual brake lever, slowing them down. The use of this system will both recharge the battery and reduce manual brake wear. This kit would be especially effective for city riding and maneuvering hilly areas. This is due to the fact that the frequent stop start environment allows for copious amounts of energy to be recuperated.

### 1.3 Visual Aid

The regenerative braking feature will be best utilized when coming to a stop for traffic signs, or when trying to slow down while biking down a hill. It will help recapture kinetic energy that would otherwise be lost to friction due to traditional brakes.

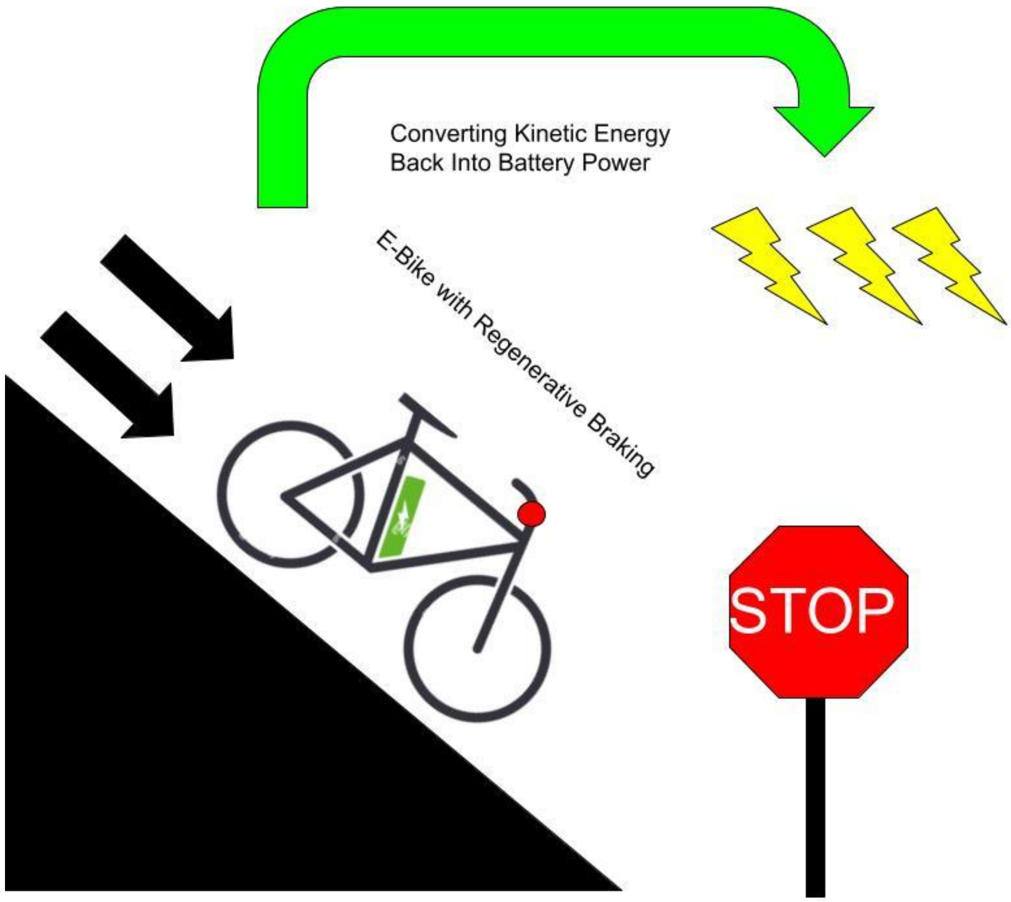


*Figure 1: Example of Regenerative Braking Application*

### 1.4 High-level Requirements List

- Regenerative braking must be utilized to recharge the battery to some extent. Data will be collected to demonstrate this. We are expecting to regain up to 5% battery charge on a chosen route.
- Pressing a button or switch on the bike must initiate regenerative braking. The braking should be strong enough to stop the bike at 15 mph within 150 yards. Regenerative braking should not be relied on for emergency stops.
- There will be an emergency shutoff switch that disconnects everything from the battery.
- The motor will be able to accelerate the bike to at least 10 mph at full throttle.

# 2. Design

## 2.1 Block Diagram

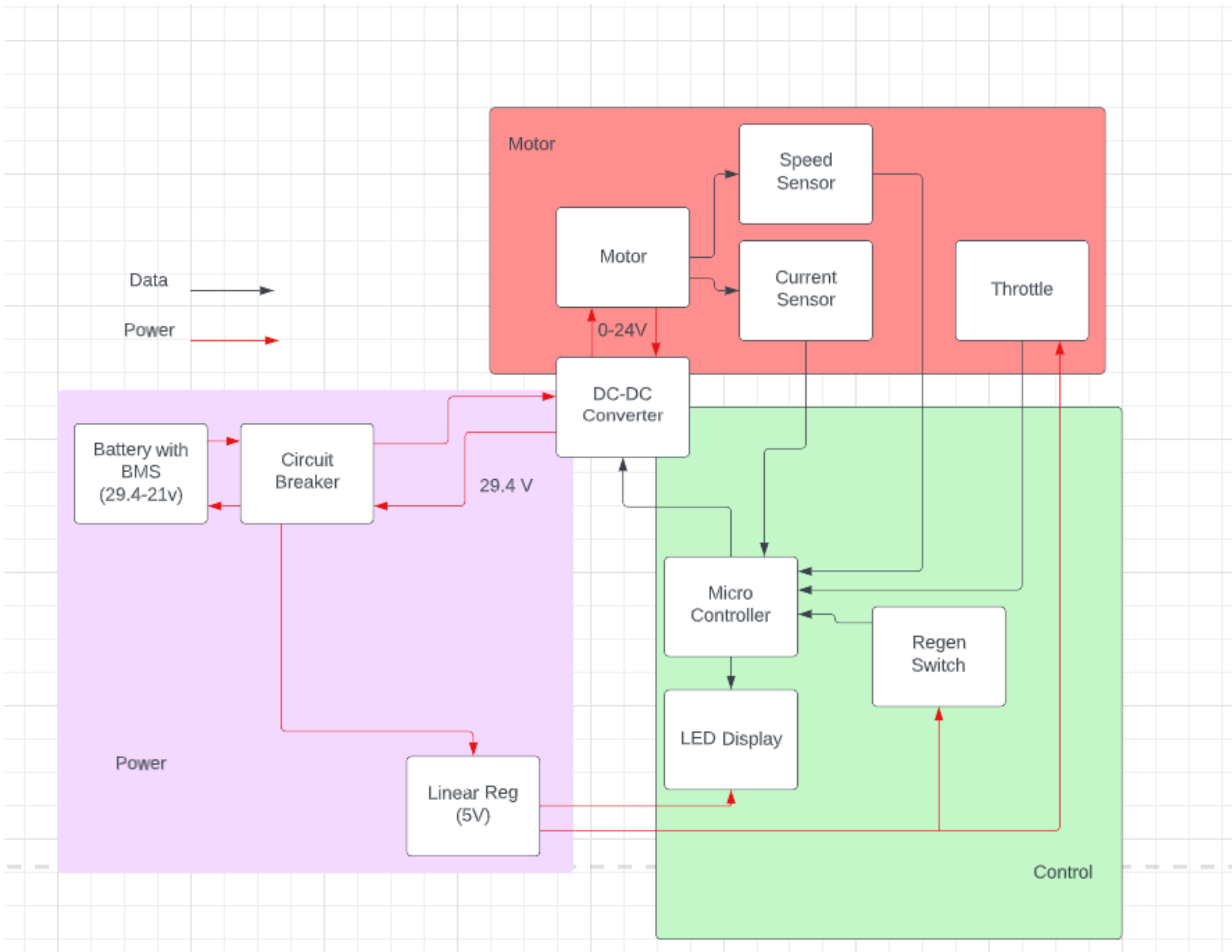


*Figure 2: Block Diagram*

The power subsystem includes the battery and it is responsible for supplying battery power and receiving regenerative braking energy. It also powers the 5V linear voltage regulators needed for user input and output. The motor subsystem includes the motor and motor controller. The throttle input is used by the motor controller (portions of the microcontroller) to determine what the voltage at the motor should be to produce a desired speed. Finally, the control subsystem generates the switching signals necessary to buck the battery voltage to the motor or boost the motor to the battery. The regenerative braking button is used to determine when the direction of power flow should be switched.

## 2.2 Physical Design

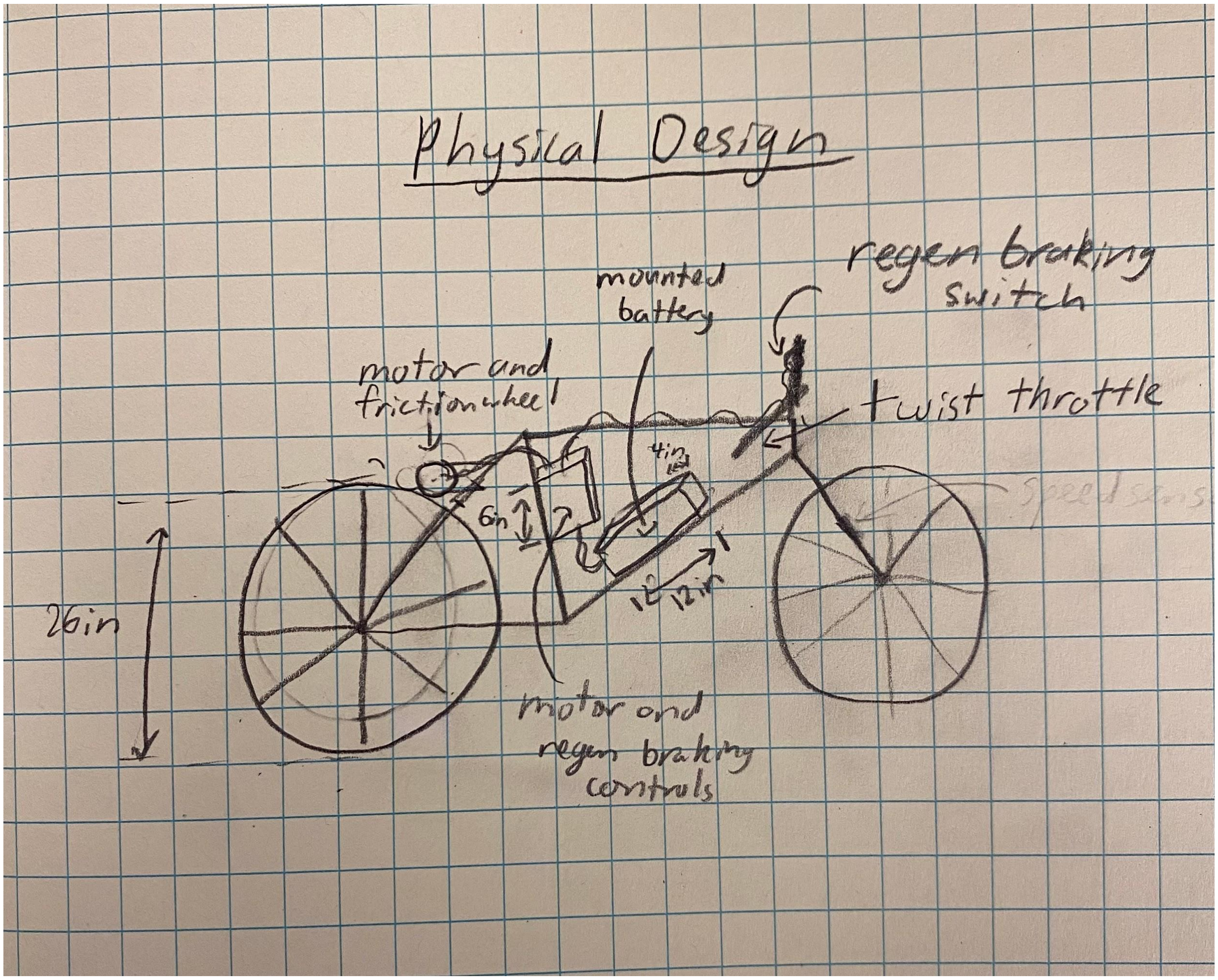


*Figure 3: Representation of Physical Design*

This is a sketch of our bike design. We plan to use a bike with 26 inch wheels. It has a friction wheel drive system, which is mounted on the back of the bike. The friction wheel comes into contact with the back wheel of the bike, which in turn allows the bike to be driven completely by throttle assist. This system has more losses than an integrated rim/motor system, but it was chosen due to the lack of complexity associated with a DC motor. The battery and PCB will be mounted on the frame of the bike, similarly to that pictured in this image. The twist throttle and regenerative braking button will be mounted on the handlebars, and a speed sensor can be mounted to the back wheel.

## 2.3 Subsystems

### 2.3.1 Power Subsystem Overview

The power subsystem is responsible for taking power from the battery and regulating output for all the other subsystems. It will receive the power generated by the motor during regenerative braking, and convert into it to charge the battery. Because we are not using the wall charger designed to work with the BMS, we must also have additional protections in place in order to ensure that the battery is not damaged by charging it. There will be a circuit breaker in between the battery and all other systems in order to allow emergency shutoff and to prevent current spikes.

Power output to the control subsystem will be fairly straightforward. This can be done fairly simply with linear voltage regulators. Battery output to the motor, along with motor output to the battery, is the main challenge in this regenerative braking project.

To do this, we will be using a DC/DC convertor with a built-in error circuit. These functions will be performed using a LM5156HPWP package from texas instruments (TI). We will also be utilizing WEBENCH power designer from TI to assist in the design process to ensure that the error control loop will appropriately compensate for all transient cases. We will utilize MOSFETs to control the flow of current in the appropriate manner to prevent LiPo or motor damage. Two distinct connections will be made between the BMS, the output of the LiPO and the motor to support discharge and regen. Only one circuit will be active at a time with MOSFETs managing the connections. Regen will be triggered by the use of a button that is at the user's disposal.

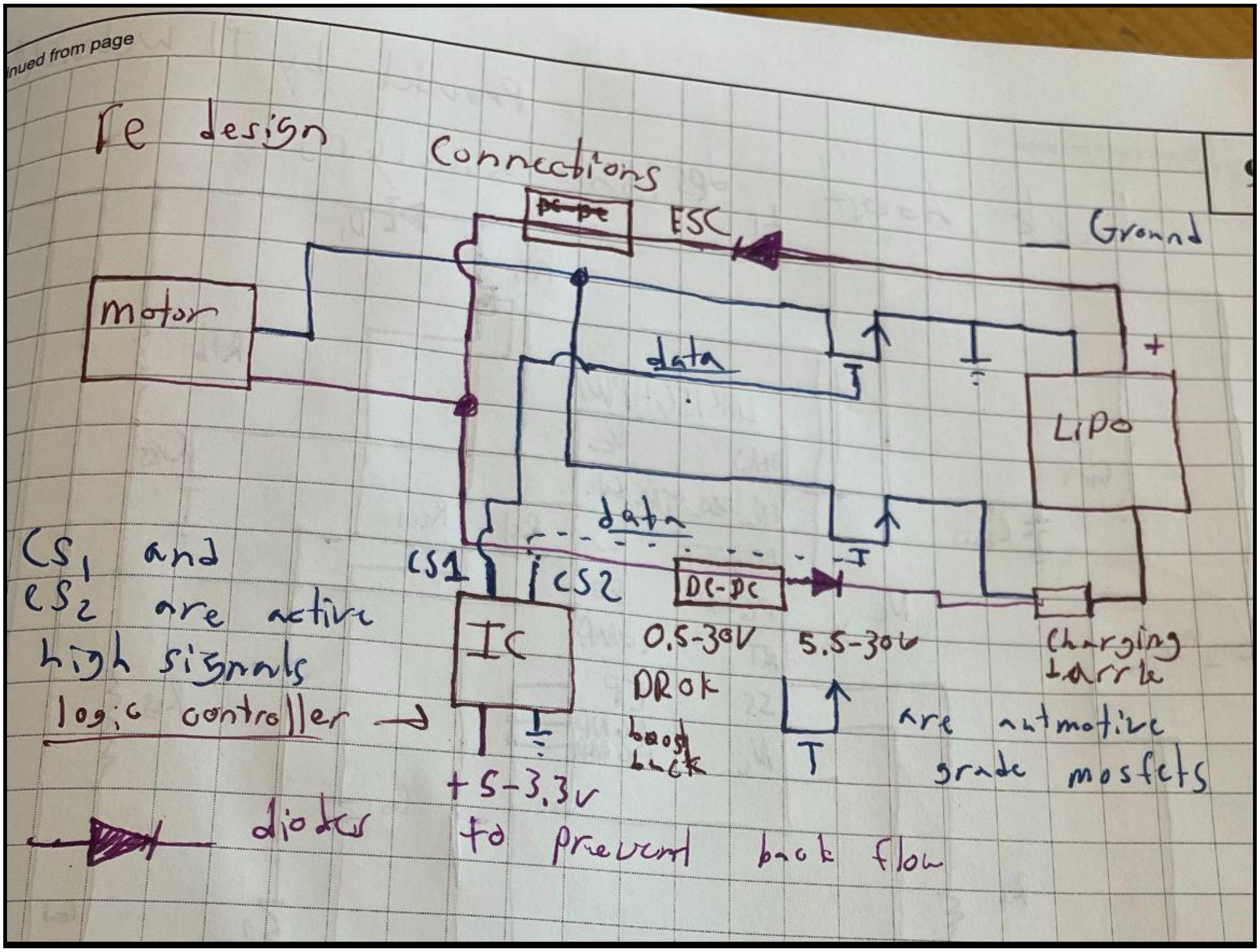


*Figure 4: proposed connections for regen and motor system*

Because the DC/DC converter and the circuitry for voltage ripple correction can be bought as a package, the majority of our design considerations will be focused on which resistors, capacitors, and inductors to use to achieve the desired buck-boost operation. A sample of this can be found in our Tolerance Analysis section.

Figure 5 shows an implementation of the proposed DC/DC package complete with all the appropriate circuitry for compensation and error correction. Here the voltage is being boosted from 10-20V to 29.4V with a proposed tolerance of 1.4%. The values for the boost and compensation circuit were determined by utilizing TI Webench CAD utility. The proposed values are shown in Figure 6. The boost will run at 2A with an ideal voltage of 29.4V because that is the required voltage and amperage to safely charge our lithium ion battery (LiPo). Tolerance analysis will be performed on the charger that came with the LiPo to verify that we are in tolerance with our boost.

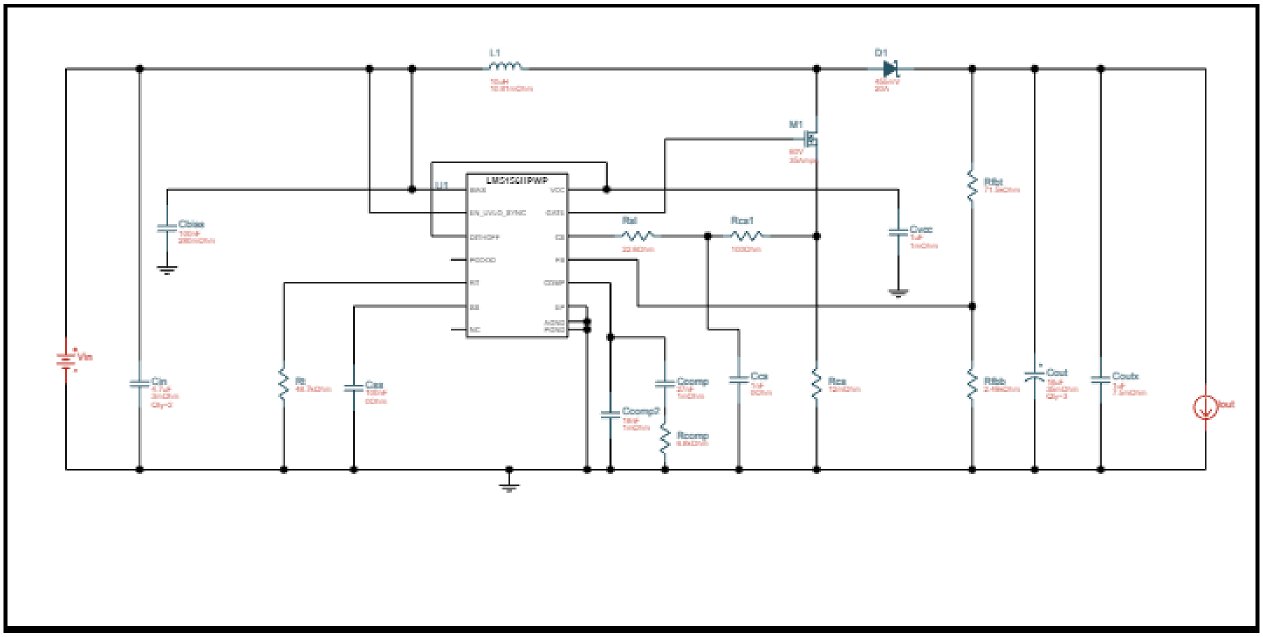


*Figure 5: Webench 10-20V to 29.4V DC/DC boost convertor*

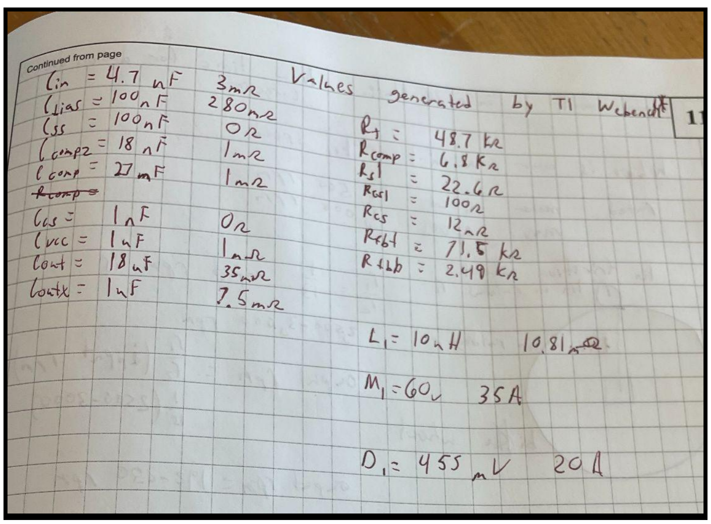


*Figure 6: proposed values for DC/DC convertor (calculated by Webench*

| Requirements | Verification |
| --- | --- |
| • Convert 29.4-21V into 24V ± 2.5V for the motor controller at a load of up to 20A. | • Place an oscilloscope probe at the output of the buck converter.<br>• Measure the output voltage of the voltage divider with an oscilloscope and a varying resistive load. It must stay in the required range for all reasonable battery charge levels. (80%-20% charge) |
| • Convert regenerative power from the motor into 29.4V±0.5V to recharge the motor. | • Spin the motor wheel at various speeds from 5-20 mph and activate regenerative braking.<br>• Measure the output voltage of the buck-boost convertor with an oscilloscope, and ensure it stays in the proper range while using a resistive load comparable to the internal battery resistance.<br>• The value of the internal battery resistance will be measured in the lab prior to conducting this test. |
| • Subsystem must provide 5V ± 0.3V to the twist throttle at the very least during normal operation. | • Place a voltmeter probe on the supply input to the twist throttle<br>• Read the voltage during standstill and normal operation<br>• Verify that the supply voltage is present and within parameters. |
| • Subsystem must provide 5V ± 0.3V to the regenerative braking button in all operation modes. | • Place a voltmeter probe on the supply input to the regenerative braking button.<br>• Read voltage during normal (throttle assist) operation.<br>• Read voltage during manual braking operation.<br>• Read voltage during regenerative braking operation.<br>• Verify that input voltage falls within parameters. |

*Table 1: Power Subsystem R&V Table*

### 2.3.2 Motor Subsystem Overview

The motor subsystem is responsible for the input and output to accelerate the motor. It will also be responsible for taking in torque and converting the kinetic energy into electrical energy to be stored in the battery. The motor controller will take input from the control subsystem and apply power or allow the motor to regen depending on the signal. This will allow the user to safely and easily switch between braking and accelerating without any overlap.

The microcontroller will control signals sent out to the MOSFETs to control when the system is in regen and when it is in motor mode. This will be done by using two distinct control signals in an active high configuration. One MOSFET will complete the regen circuit and the second MOSFET will complete the motor circuit. When the regen button is pressed, the microcontroller will see this digital input and switch the digital outputs to the MOSFETs. As for the motor speed, That will be handled by an analog circuit using a voltage divider that will utilize a potentiometer based throttle.

In short, the potentiometer will vary its resistance based on user input. This will be fed into a voltage divider allowing a variation in the voltage which will let the user control the rpm. The microcontroller will detect a digital input based on a switch. When the switch is flipped, the system will toggle into regen mode. The bike will remain in regen mode until the switch is flipped again.

It is important that the voltage at the motor can be varied, as this will control the rpm of the motor, and therefore the speed of the bike. Through the motor controller, the twist throttle input can be used to control the overall speed of the bike.

| **Requirements** | **Verification** |
|---|---|
| • Reliably measure the speed of the bike within 1 mph. | • Set up gps-measured speed sensing.<br>• Compare the sensor-measured speed to the gps-measured speed while riding the bike at various speeds.<br>• Measurements could be taken at speeds of 2 mph, 5 mph, and 10 mph to verify that the speed sensor is functioning correctly. |

| | |
|---|---|
| • Measure current output from the motor when regenerating over time. Accuracy must be within ± 5% of a multimeter reading | • The current must be reliably measured over time, and that data will be stored in the microcontroller's permanent storage. This data will be compared to the readings from a multimeter in the lab.<br>• Set up a shunt resistor and run 1A current through it.<br>• Display the current reading, either through the LCD or through an output on the microcontroller.<br>• Compare reading to that taken by an oscilloscope probe. |
| • Motor voltage changes reliably with the throttle input. Motor voltage is within ± 5% of the expected motor voltage based on the duty cycle. | • Test the circuit while not on the bike.<br>• Supply switching signals to the switching converter, note what output should be produced in buck configuration.<br>• Expected and experimental voltage values should be compared.<br>• Calculate the duty cycle associated with expected voltage outputs of 5V, 10V, and 15V.<br>• Measure the actual voltage that the duty cycle produces.<br>• Verify output with a multimeter.<br>• Expected voltage must be within 5%. |
| • Motor does not activate without throttle activation. If twist throttle input is within 0.5V of resting position voltage, the motor should not be on. | • Measure the output voltage from the throttle when it is at 0.5V from rest using an oscilloscope, and ensure that the motor isn't activated.<br>• Measurement will be taken using a multimeter.<br>• Ensuring the motor is not activated translates to motor rpm being 0, or very near 0. |

*Table 2: Motor Subsystem R&V Table*

### 2.3.3 Control Subsystem Overview

The control subsystem will make use of the microcontroller. For our project, we have decided to use an ATmega8A microcontroller with a 125 C temperature rating to ensure that it can continue operation at higher temperatures [12]. This absolute maximum operating temperature should be sufficient for an electric bicycle application. Both operating temperature testing and verification of microcontroller functionality will take place during the assembly and testing phase of our design project.

The control subsystem is responsible for generating the switching signals necessary for both normal operation and regenerative braking operation. The microcontroller generates the gate signals for various MOSFETs in our switching converter. These signals are different depending on which mode of operation the bike is currently in. In terms of regenerative braking, this is the most important function of the control unit. Power flow is directly determined by the MOSFET gate inputs generated in the control unit. A sample of the calculations required for this operation can be found in our Tolerance Analysis section. Essentially, the microcontroller will mainly handle managing the control signals to the MOSFETs to dictate if the bike is in regen or motor mode.

The control subsystem handles the regenerative braking signal. Our regenerative braking function will be controlled by a button (or a switch with the same functionality) mounted on the handlebars of our bike. 5V should be supplied to it from the control unit. When the button is pressed, it will send a regenerative braking signal to the control unit. This signal will be used to override the normal operation switching signals with regenerative braking operation switching signals, allowing the motor to recharge the battery.

Another function of the control subsystem is to perform data collection for both testing and the user experience. Bicycle speed data can be collected from a speed sensor on the wheel. Regenerative braking efficiency can be found from motor data and some quick calculations. The energy at the motor controller can be found by integrating the voltage times the current at the motor controller over the time of braking action [8]. The maximum possible recovered energy from braking can be found by using the kinetic energy equation, or:

$$E = (1/2) * m * (V_0^2 - V_f^2)$$

where V0 is initial velocity and Vf is final velocity. The efficiency can be found by taking the ratio of the motor controller energy to the total available energy and multiplying by 100% to get regenerative braking efficiency [8]. The control subsystem will, as the very least, take the measurements necessary to perform these calculations and save them in memory. At best, the control subsystem will perform these calculations and display the results in real time on the onboard LED display.

Another piece of the data collection will be in monitoring the current drawn into the battery during regenerative braking. This will be done via a current shunt. This data will be stored and used to determine how much energy is being saved over the course of a ride using regenerative braking.

The control subsystem will also provide power to the LED display. This should be a fairly simple operation. The part selected will be compatible with our battery.

Finally, the control system will send relevant data to the LED display. We are most concerned with regenerative braking efficiency data (or parameters relevant to it), but speed and temperature sensing capabilities would be nice to have for testing purposes.

The schematics for the control subsystem and the boost converter this project is utilizing for regenerative braking can be viewed in Figure 7 and Figure 8, respectively.

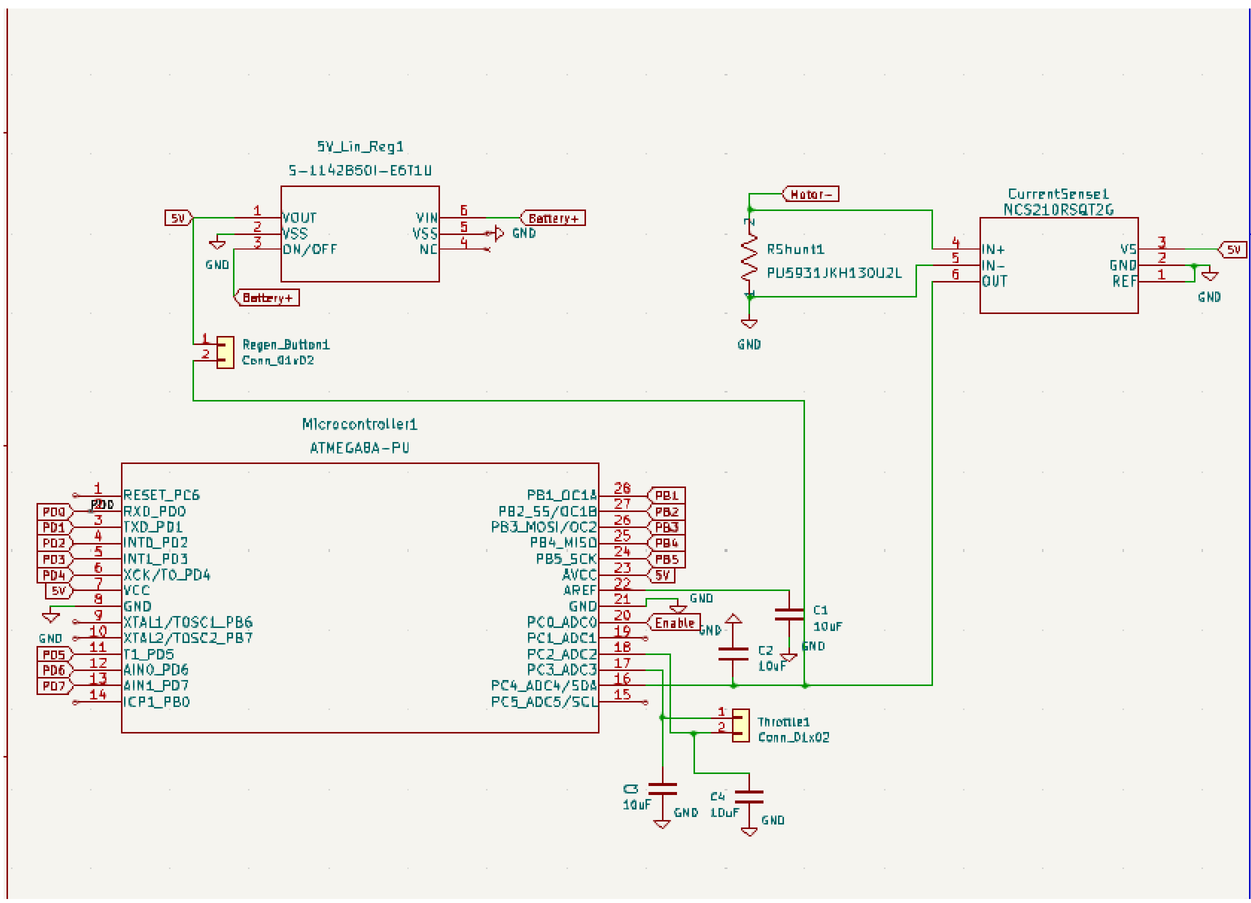


*Figure 7: Control Subsystem Schematic*

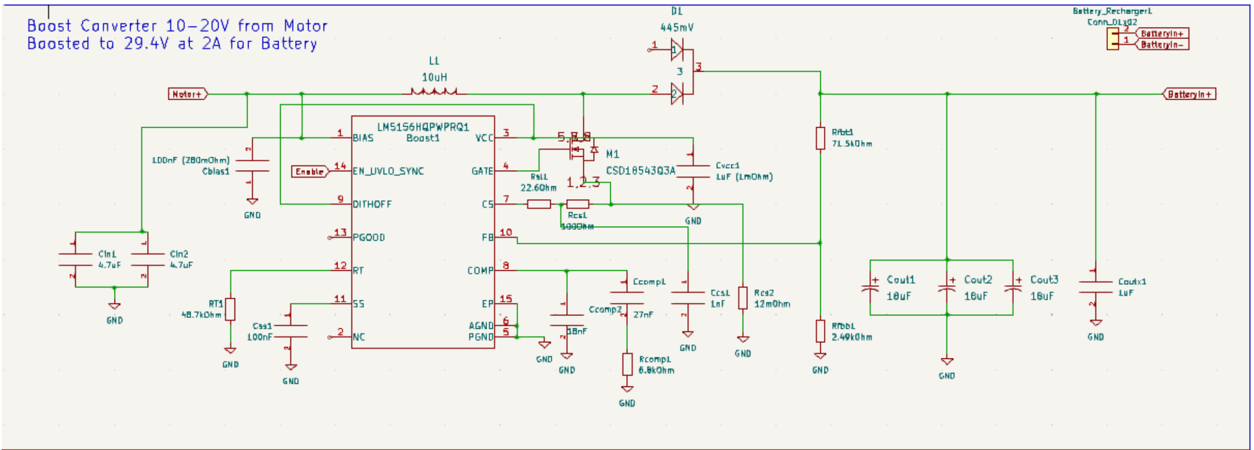


*Figure 8: Boost Converter Schematic*

| Requirements | Verification |
| --- | --- |
| • Microcontroller must recognize the regenerative braking “ON” signal and change from normal switching mode to regenerative braking switching mode within 1s. | • Off-bike testing: Supply regenerative braking signal to microcontroller.<br>• Read switching signals on oscilloscope.<br>• If they change to the correct switching signals within 1s, the microcontroller passes this step of verification.<br>• On-bike testing: Press and hold the regenerative braking button once the bike has reached a speed of 10mph<br>• Project passes the test if the user can feel the slowing down of the bike within 1s. |
| • Microcontroller must recognize the regenerative braking “OFF” signal and change from regenerative braking switching mode to normal switching mode within 1s. | • Off-bike testing: Supply regenerative braking signal to microcontroller, then switch off.<br>• Read switching signals on an oscilloscope.<br>• If they change to the correct switching signals within 1s, the microcontroller passes this step of verification.<br>• After pressing and holding the regenerative braking button, apply a steady throttle input.<br>• Passes if the bike begins to accelerate within 1s. |
| • Subsystem must be consistently below 125C throughout the duration of operation for microcontroller function. | • Monitor temperature periodically during the assembly phase.<br>• Must stay below 125C to progress to on-bike testing<br>• Monitor temperature using LED display during test rides.<br>• Temperature must stay below 125C for final verification. |

*Table 3: Control System R&V Table*

### 2.4 Tolerance Analysis

One aspect of our design that poses the risk to the successful completion of this project is our bidirectional DC/DC converter. If this component does not function reliably or successfully, then the motor cannot receive voltage from the battery and the battery cannot be recharged by the motor. The converter's operation is crucial to the success of this project.

For our Tolerance Analysis section, we decided to model a simple bidirectional DC/DC converter in boost mode. More details on the model can be found by seeing reference [9]. We firstly wanted to see if it was possible to boost a motor voltage of 24V up to the required 29.4V. To accomplish this, the bidirectional DC/DC converter was drawn in LTSpice. Because we are still waiting to test the parts, a few reasonable assumptions about the battery internal resistance and the load resistance and inductance of the motor were made. These will be modified as more tests are run. The battery was modeled as a DC voltage source with an internal resistance of 0.7R. The motor was modeled as a DC voltage source with series resistance and inductance. See Figure 9 for more details.

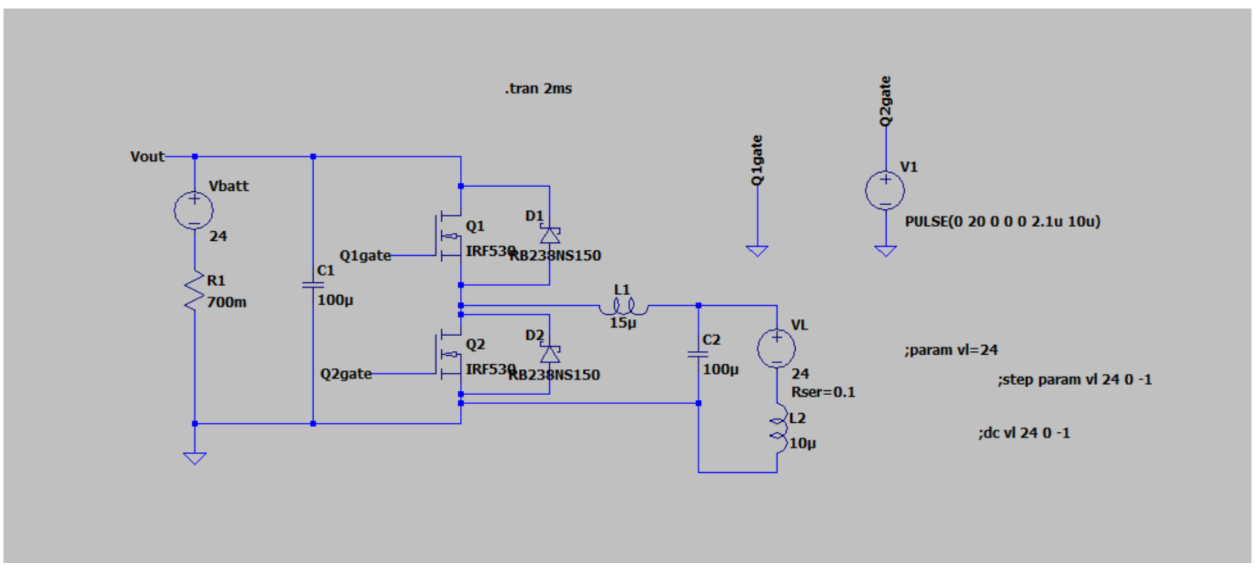


*Figure 9: Bidirectional DC/DC Converter Schematic in Boost Mode*

The next steps for implementing this converter were to decide on the duty cycle and values for the inductors and capacitors seen in Figure 9. The duty cycle calculation can be seen in Figure 10. It typically contains an efficiency term, but this was set to 1 due to this being an ideal model.

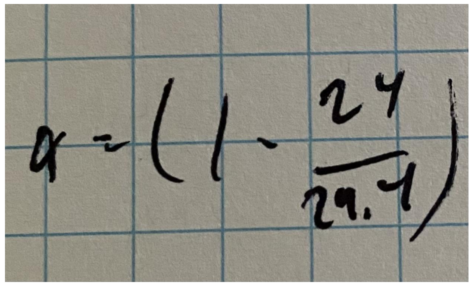

*Figure 10: Duty Cycle Calculation for 24V Motor Voltage*

The inductor and capacitor calculations are done separately for buck and boost modes. These equations can be found in the figures below.

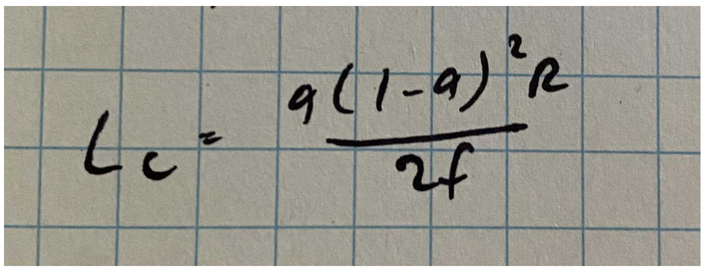

*Figure 11: Minimum Inductance Calculation for Boost Mode*

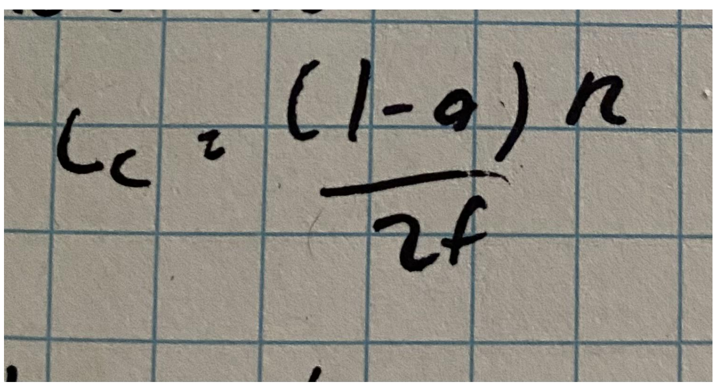

*Figure 12: Minimum Inductance Calculation for Buck Mode*

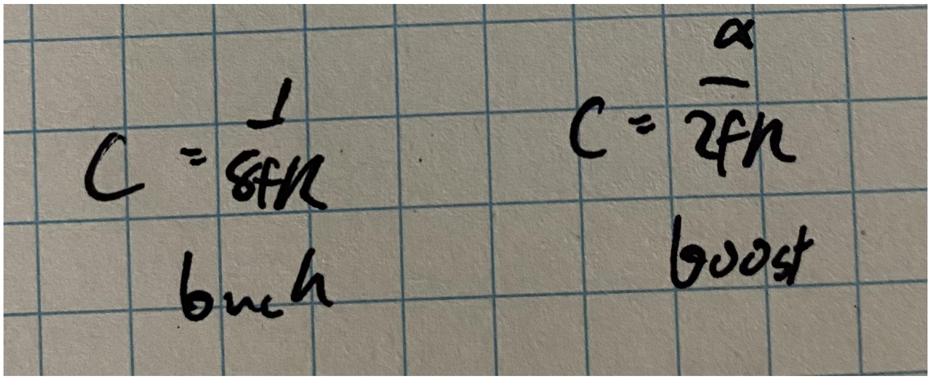


*Figure 13: Minimum Capacitance Calculations for Buck and Boost Mode*

In the boost mode equations, R represents the internal resistance of the battery. In the buck mode equations, it represents the motor resistance. F in all equations represents the switching frequency. For this test, it was set to 100 kHz. There are different tradeoffs when considering switching frequency. At some point speed is sacrificed for efficiency. As a result, switching frequency will likely change to meet the demands of our bidirectional DC/DC converter. This frequency was chosen because it fit within the parameters of some of our considered bidirectional DC/DC converter components.

For this particular test, we calculated an ideal duty cycle of 0.1837. The inductance was chosen to be 15uH to fall outside of possible minimums, and capacitances of 100uF were chosen to help mitigate the ripple seen in the output voltage. The duty cycle was adjusted slightly to 0.21 for the simulation. The end result can be seen in Figure 14.

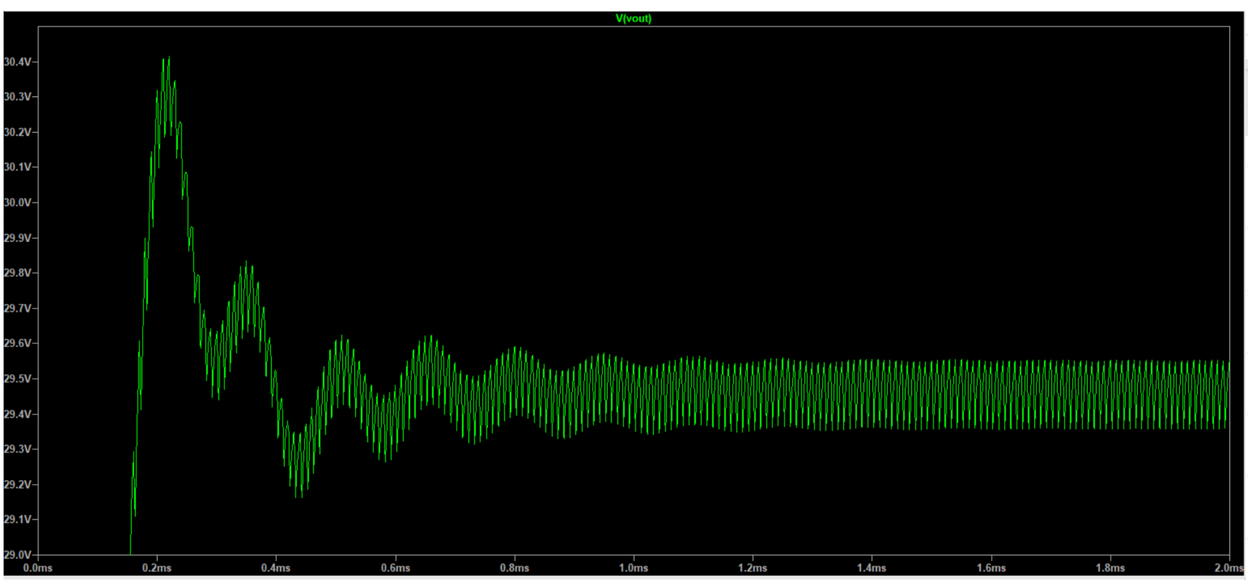


*Figure 14: Initial Simulation Results*

Though the initial peak and voltage ripple will have to be mitigated somehow, one can see that our bidirectional DC/DC converter is perfectly capable of supplying 29.4V ± 1.5V to the battery. Though this design will need to be tweaked as more testing is done, it shows promise as it is. The issues that we can see with it now will need to be mitigated by an error circuit to prevent systemwide ripples. This will be another consideration we must make with our design.

The next step in this analysis was attempting to decide approximately at what motor voltage regeneration becomes unsustainable. We wanted to know approximately how low the motor voltage could drop while still producing a voltage output that could charge the battery. The motor voltage was dropped to 18V. The duty cycle was recalculated to be 0.387, then adjusted to 0.415. The inductor and capacitor values were left unchanged, as a varying duty cycle was accounted for in the initial calculations. The results of this new simulation can be seen in Figure 15.

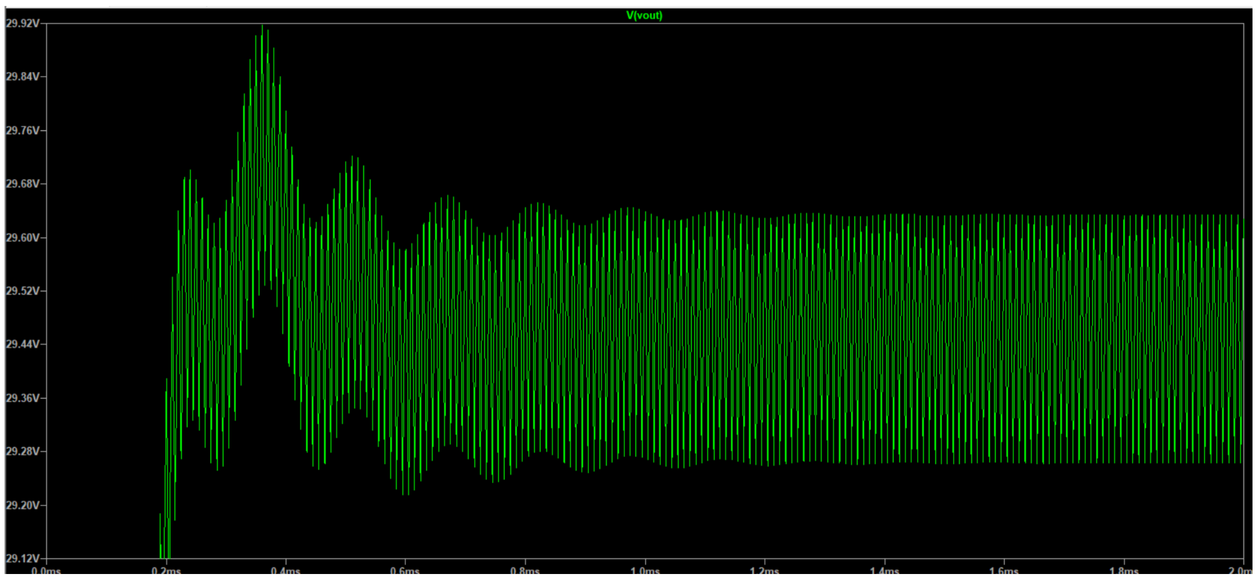


*Figure 15: Boosted Battery Voltage when Motor Voltage is 18V*

Figure 16 shows the results obtained at 14V. The calculated duty cycle was 0.5238, but was adjusted to 0.595. 29.4V was also obtainable here.

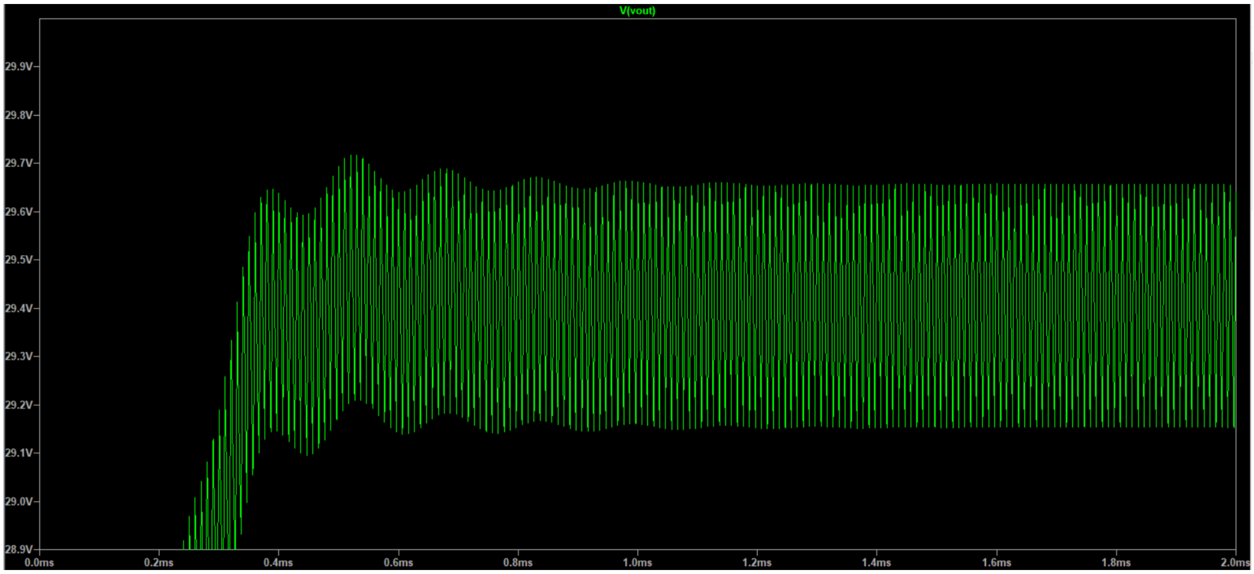


*Figure 16: Boosted Battery Voltage when Motor Voltage is 14V*

Favorable results could also be obtained with 13V. The duty cycle was calculated to be 0.5578, but was adjusted to 0.68. This is noted to be a large adjustment, much larger than the other adjustments. The results of this simulation can be seen in Figure 17.

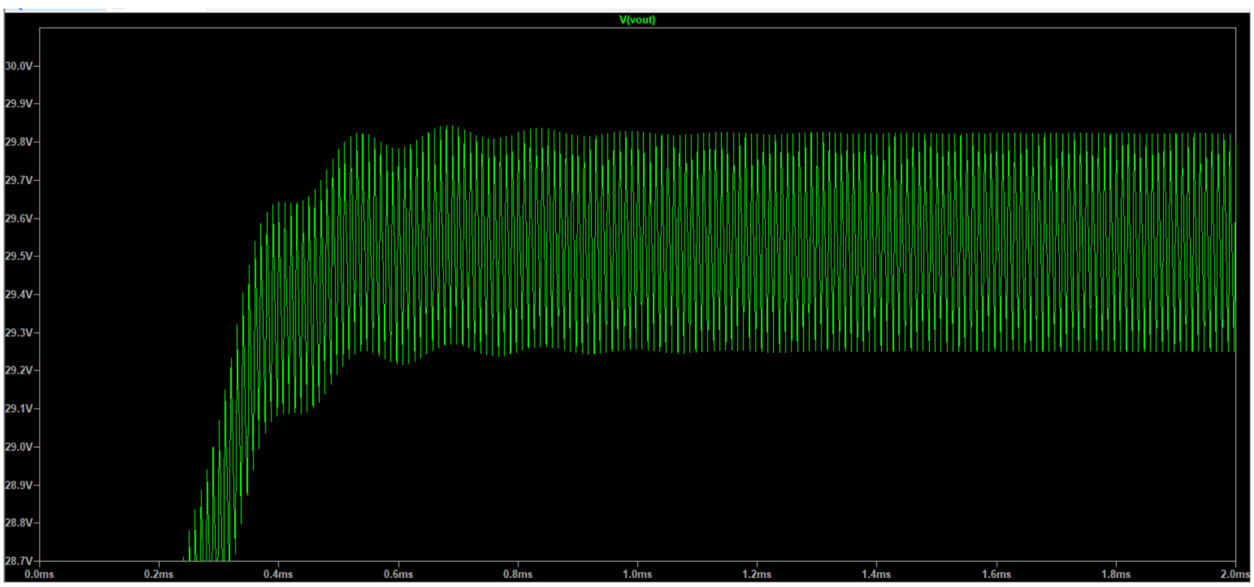


*Figure 17: Boosted Battery Voltage when Motor Voltage is 13V*

Unfortunately, the 12V motor voltage simulation did not work out quite as well as expected. The best results obtained were at a duty cycle of 0.77 at an average voltage of 29.1V. The results can be seen in Figure 18.

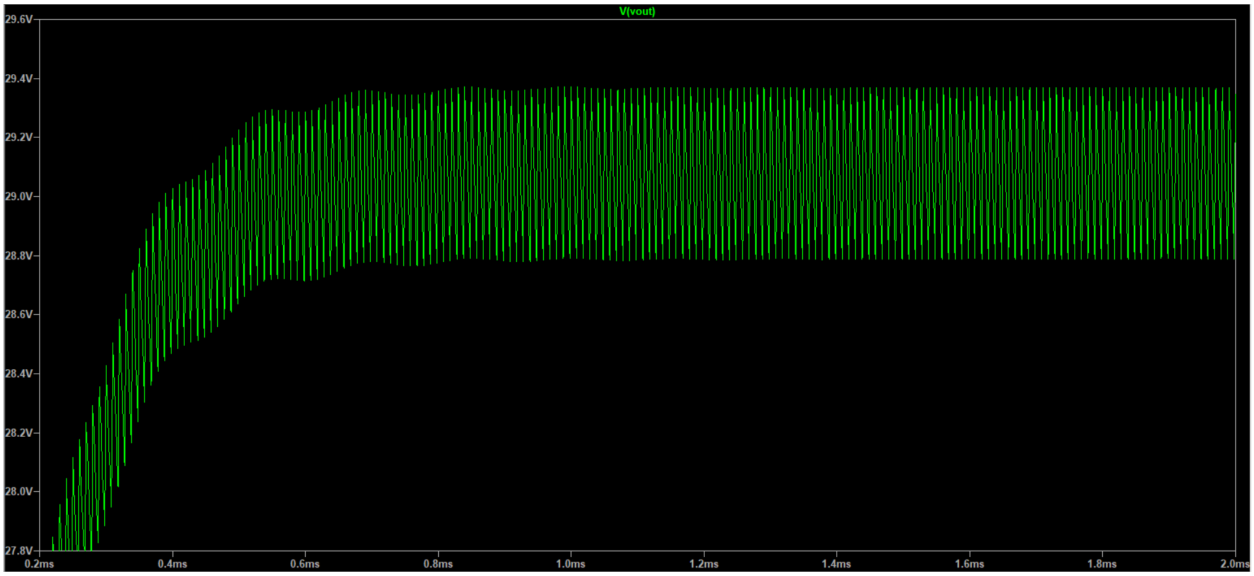


*Figure 18: Boosted Battery Voltage when Motor Voltage is 12V*

We stop reliably seeing 29.4V at the output when the motor voltage hits 12V. This is not to say that the battery will not recharge at 29.1V, or that this cannot be improved upon as the design of the bidirectional DC/DC converter improves. Adjusting internal resistances can also produce different results. This will be something to consider when the physical motor and battery are tested.

This tolerance analysis was conducted to give us a baseline for when regeneration no longer becomes possible. As of now, we have shown that half of the motor voltage range can produce the 29.4V required at the battery. A 12V motor voltage comes close, but falls short at 29.1V. Improvements should be made upon the circuit to increase the range of input voltages it can reliably operate under. Despite this, regeneration is certainly possible with our motor and battery combination.

Another important factor to consider is the heat generated in our linear regulator. We are using a significantly higher battery voltage (24V) than the output of our linear regulator (5V). This could result in significant heat dissipation if our load current is high, so we should ensure that heat won't be an issue in this part of the design. In order to ensure this, we pulled the following values from the datasheet of our 5V linear regulator. The maximum junction temperature is 125℃. We should keep well below this value for stable output. The voltage drop across the CMOS in the linear regulator at 200mA of load current is 0.5V. We should be around that range of load, as our maximum current draw from the microcontroller, the LCD display, and the regen button is around 205mA. For the sake of safety, we will largely inflate these values to 300mA and 1V of dropout voltage, in case of small differences in manufacturing, and in case the button draws more power than assumed. In this case, the power dissipated by the linear regulator will be 300mW. Using the thermal resistance value from the data sheet of 53℃/W, and assuming an ambient temperature during the maximum summer heat of 38℃, we can calculate the maximum junction temperature for our use case.

$$T_{junction} = T_{ambient} + P_{diss} \times R_{thermal} = 38℃ + 0.3W \times 53℃/W = 54℃$$

*Figure 19: Junction Temperature Calculation for 5V Linear Regulator*

This value is much below the maximum rating, so a heat sink won't be necessary.

# 3 Cost and Schedule

## 3.1 Cost Analysis

### 3.1.1 Parts

| Component | Manufacturer | Part Number | Quantity | Cost | Link |
|---|---|---|---|---|---|
| Battery (battery charger included) | WOGQX | B0B7DYN236 | 1 | $103 | Link |
| Motor | Hi-Gear | MY1020 | 1 | $72 | Link |
| Speed Controller with Throttle | Vbestlife | 4xcw9dgto1-01 | 1 | $27.58 | Link |
| Microcontroller | Microchip Technology | ATMEGA8A-PU | 1 | $3.36 | Link |
| Shunt Resistor | YAGEO | PU5931JKH130U2L | 1 | $1.43 | Link |
| 5V LDO | ABLIC | S-1142B50I-E6T1U | 1 | $1.60 | Link |
| LCD display | Focus LCDs | C162A-BW-LW65 | 1 | $6.27 | Link |
| Boost Converter | Texas Instruments | LM51561H | 1 | $2.27 | Link |
| Regenerative Braking Button | VGEBY | VGEBY2wngre41ph | 1 | $6.74 | Link |
| Power MOSFET | Texas Instruments | CSD17559Q5T | 2 | $6.36 | Link |
| XT60 Connectors | Elechawk | XT60FM55 | 1 | $8.99 | Link |
| XT60 Y Connectors | Fly RC | 43234-1912 | 1 | $8.99 | Link |
| 12 AWG Wire Roll | BNTECHGO | SW12G68008F10C2 | 1 | $12.98 | Link |
| Bike+Parts | - | - | 1 | $30 | - |
| Miscellaneous (resistors, capacitors, inductors, wires, connectors, and any other necessary but less costly components) | - | - | - | $60 | - |
| **Total** | - | - | - | $351.57 | - |

*Table 4: Cost of Parts*

### 3.1.2 Labor

We will estimate our hourly wage to be \$30/hr, and we will work 15 hours a week each for the main 12 weeks of this course.

$\$30/hr \times 2.5 \times 15\, hrs \times 12\, weeks \times 3\, workers = \$40500$

### 3.1.3 Sum of Costs

The sum of costs include the total cost of parts and the total cost of labor over the course of the semester. Summing the parts cost and the labor cost, our project will have a total cost of \$40851.57.

### 3.2 Schedule

| Week | Important Deadlines | Jace | Lucas | Chloe |
|---|---|---|---|---|
| 2/20 | Design Document<br>Team Contract<br>Proposal Revision | Finish Power Subsystem DD and help with cost analysis and block diagram. | Finish Motor Subsystem DD, help with formatting and block diagram. | Finish Control Subsystem DD, help with tolerance analysis and discussion of ethics and safety. |
| 2/27 | Proposal Revision<br>Design Review<br>PCB Board Review | Update Power system, cost analysis and help finish DD update. | Update Motor subsystem for DD update. | Update Control system for DD update. Order remaining parts. Work on BDC circuit and switching signals. |
| 3/6 | First Round PCBway Orders<br>Teamwork Evaluation I<br>Deadline for Machine Shop Revisions | Send machine shop size information for friction wheel Do evals. Start working on building schematic/ design for power subsystem. Start ordering components. | Do evals. Design motor subsystem. Start ordering components. | Do evals. Design control subsystem. Work on simulating functional BDC. Start ordering components. Modify switching signals. |
| 3/13 | (spring break) | Nothing planned, work as needed. | Nothing planned, work as needed. | Nothing planned, work as needed. |
| 3/20 | - | Test design in the lab with off the shelf components. | Test motor and adjust design as needed. | Work on PCB.<br>Start testing design components.<br>Work on microcontroller programming. |
| 3/27 | Second Round PCBway Orders<br>Individual Progress Reports | Order PCBs Submit progress reports. Order | Order PCB.<br>Submit a progress report. Order parts as needed. | Order PCB.<br>Continue testing circuit design.<br>Work on |

| | | | | |
|---|---|---|---|---|
| | | parts as needed. | | microcontroller programming Submit the progress report. Order parts as needed. |
| 4/3 | - | Testing and assembly. Test and debug power circuit. Order parts as needed. | Testing, assembly, debugging. Order parts as needed. | Testing and assembly. Test and debug microcontroller programming. Order parts as needed. |
| 4/10 | Team Contract Fulfillment | Work on PCB assembly. Team contract Fulfillment. | Work on PCB assembly. Team contract Fulfillment. | Work on PCB assembly. Team Contract Fulfillment. |
| 4/17 | Mock demo | Continue working on testing and improving design. | Work on finalizing the project. | Work on final testing, demo, final assignments. |
| 4/24 | Final Demo | Work on Final Demo | Work on Final Demo | Work on Final Demo |
| 5/1 | Final Presentation<br>Final Paper<br>Lab Notebook | Finalize everything and pass the class. | Finalize everything. | Finalize presentation, paper, and lab notebook. |

*Table 5: Weekly Project Schedule*

# 4 Discussion of Ethics and Safety

Due to the potential risks associated with the battery being used for this project, we as a team must take care to minimize those risks, as stated in Section I.1 of the IEEE Code of Ethics [4]. We will take care to ensure that the batteries do not receive more charge than they can hold. We will also make protections against any unsafe battery conditions, such as overcurrent, overvoltage, short circuiting. During assembly, we must also take care not to drop or damage the battery in any way, as this can be unsafe to users. Charging at cold temperatures and ensuring that the battery does not operate above its rated temperature will also be important considerations. Charging below 0C will also be a consideration for the end user, as this may render our finished project unsafe [5].

The team also plans on undertaking high voltage training for lab testing. This is less necessary now that the battery voltage has been decreased from 48V to 24V, but it is still important that the team understands the risks and procedures involved with testing this project. Safety guidelines for lithium ion batteries will be similarly read and considered during lab testing.

There will also be an easily accessible emergency shutoff switch to prevent any unsafe conditions with the battery from progressing further. This will be especially important during the testing phase, but it will be included in the finished product design should the user ever need it. Though we will take great care to ensure that the battery is protected in our design, and we have discussed what external conditions are unsafe for the battery, we understand that fail safe measures are incredibly important for this type of project.

Another important consideration for our project is that our regenerative braking system must function to a satisfactory degree. The user must be able to slow the bike to a stop during typical use using our braking system. Design considerations will be made to have the bike slow to a stop in a reasonable distance. A manual braking system will also be included in the final design to ensure that the user can stop the bike at all times, especially during emergency situations.

Finally, our project will have top speed limitations. Though this is in part to rules and regulations surrounding electric vehicles, it is also to ensure that the rider maintains a certain level of safety at all times. Electric bikes can be dangerous to ride without proper precautions at 20mph, which is the speed cap for electric bikes in Illinois [6]. They would be more so at 30mph.

We are not responsible for the user riding the finished project in any way that is not in accordance with the traffic laws in their area. Safe riding practices must be determined and followed by the user. Helmets and protective eyewear are recommended while riding an electric bike.

# 5 References


[1] "Over 450 electric bikes compared! What does an ebike cost?," *eBikesHQ.com*, 25-Oct-2022. [Online]. Available: https://ebikeshq.com/cost-of-an-ebike/. [Accessed: 08-Feb-2023].

[2] M. Toll, "The truth: How far can an electric bicycle really go on a single charge?," *Electrek*, 19-Mar-2022. [Online]. Available: https://electrek.co/2020/06/12/how-far-can-an-electric-bicycle-really-go-on-a-charge/. [Accessed: 08-Feb-2023].

[3] "Do bike brake pads get old?," *Cycling Vitality*, 07-Aug-2022. [Online]. Available: https://cyclingvitality.com/do-bike-brake-pads-get-old. [Accessed: 08-Feb-2023].

[4] "IEEE code of Ethics," *IEEE*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 08-Feb-2023].

[5] "Preventing fire and/or explosion injury from small and wearable lithium battery powered devices," 20-Jun-2019. [Online]. Available: https://www.osha.gov/sites/default/files/publications/shib011819.pdf. [Accessed: 09-Feb-2023].

[6] "Illinois State Electric Bike Laws," *EVELO*, 30-Aug-2022. [Online]. Available: https://evelo.com/blogs/ebike-laws/illinois#:~:text=Class%201%3A%20eBikes%20equipped%20with,the%20speed%20of%2020%20mph. [Accessed: 21-Feb-2023].

[7] "TMS320F28035PAGQ active," *TMS320F28035-Q1 | Buy TI Parts | TI.com*. [Online]. Available: https://www.ti.com/product/TMS320F28035-Q1/part-details/TMS320F28035PAGQ?utm_source=google&utm_medium=cpc&utm_campaign=ocb-tistore-promo-epd_opn_en-cpc-storeic-google-wwe&utm_content=Device&ds_k=TMS320F28035PAGQ&DCM=yes&gclid=CjwKCAiA9NGfBhBvEiwAq5vSy-mpGC0CSzPUqzT8iId2IAa3t4vTAQYJSXHOQhM31TPLRp3YH1JwIRoCqKcQAvD_BwE&gclsrc=aw.ds. [Accessed: 21-Feb-2023].

[8] "Universidad politécnica salesiana sede cuenca - ups," Jun-2021. [Online]. Available: https://dspace.ups.edu.ec/bitstream/123456789/20506/1/UPS-CT009183.pdf. [Accessed: 22-Feb-2023].

[9] D. Torres and P. Heath, "Regenerative braking of BLDC Motors - Microchip Technology." [Online]. Available: https://ww1.microchip.com/downloads/en/devicedoc/regenerative%20braking%20of%20bldc%20motors.pdf. [Accessed: 22-Feb-2023].

[10] A. Sharma, R. Mishra, A. K. Yadav, and A. Phukan, “Bidirectional DC-DC converter for incorporating regenerative braking in e-bikes,” *2018 International Conference on Electrical, Electronics, Communication, Computer, and Optimization Techniques (ICEECCOT)*, 2018.

[11] “ISL81801 Datasheet,” *Renesas Electronics Corporation*. [Online]. Available: https://www.renesas.com/us/en/document/dst/isl81801-datasheet. [Accessed: 24-Feb-2023].

[12] “Atmega8a Data sheet summary - microchip technology.” [Online]. Available: https://ww1.microchip.com/downloads/en/DeviceDoc/Microchip%208bit%20mcu%20AVR%20ATmega8A%20data%20sheet%20summary%2040001991A.pdf. [Accessed: 24-Mar-2023].