Regenerative Braking in Electric Bike Conversion Kit

ECE 445 Design Document

Team 38

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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-assist 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.

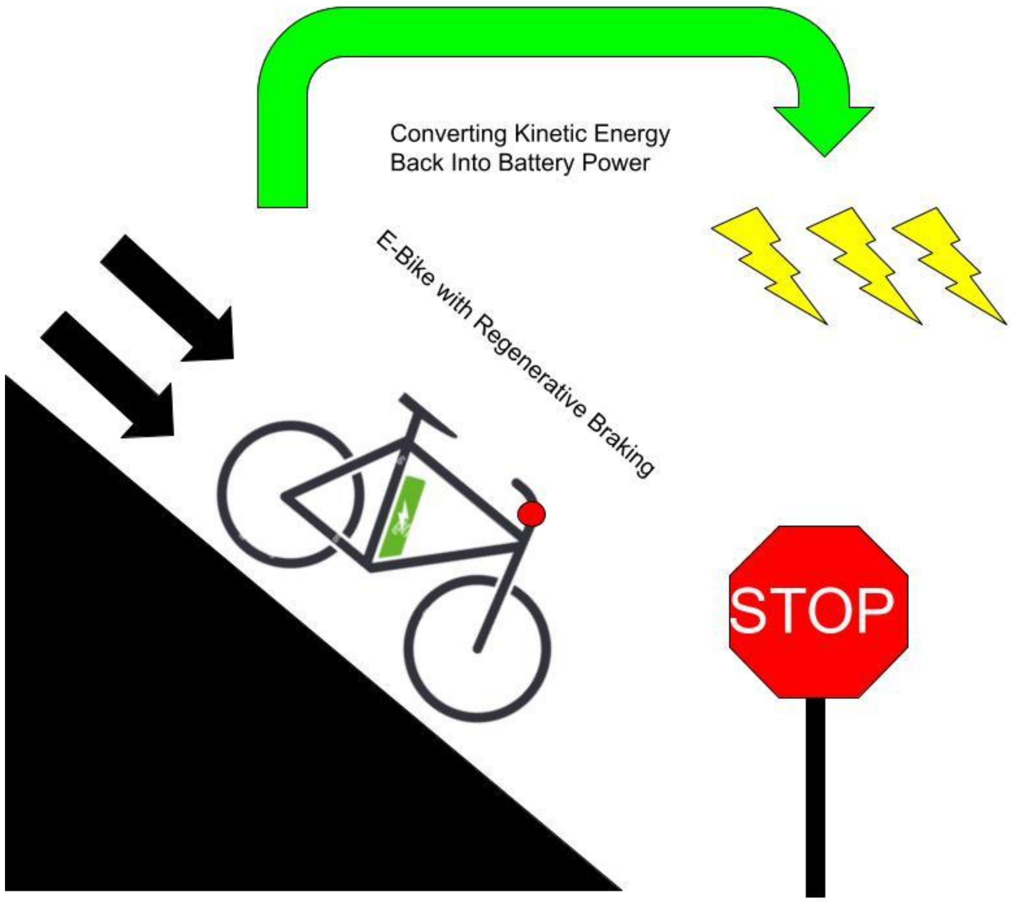

Figure 1: Example of Regenerative Braking Application

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.
- 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 100 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 electric bike will be limited to 20 miles per hour as per Class 2 E-bike definition.

2. Design

2.1 Block Diagram

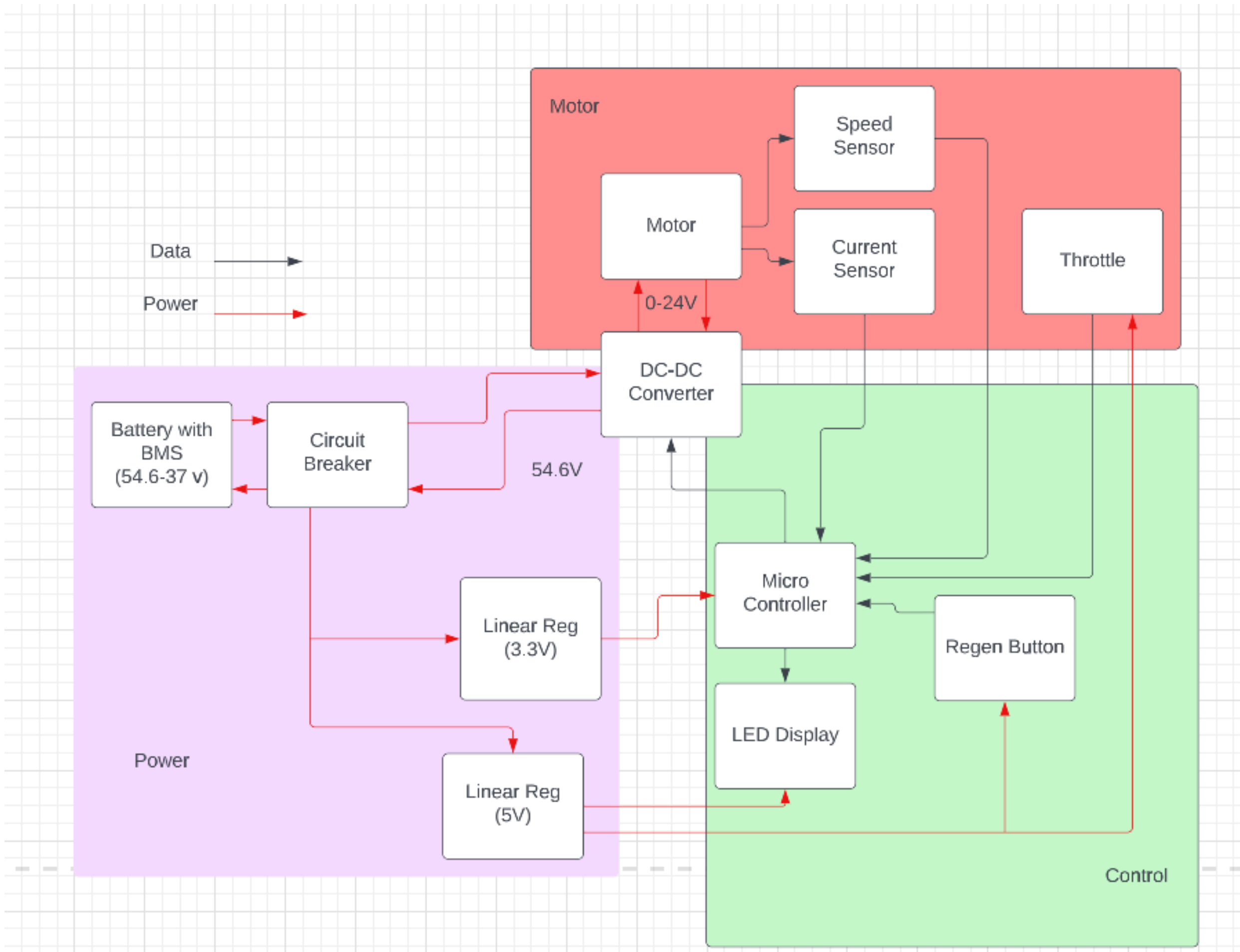

Figure 2: Block Diagram

The power subsystem includes the battery and the bidirectional DC/DC converter. It is responsible for supplying battery power and receiving regenerative braking energy. It also powers the 3.3V and 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

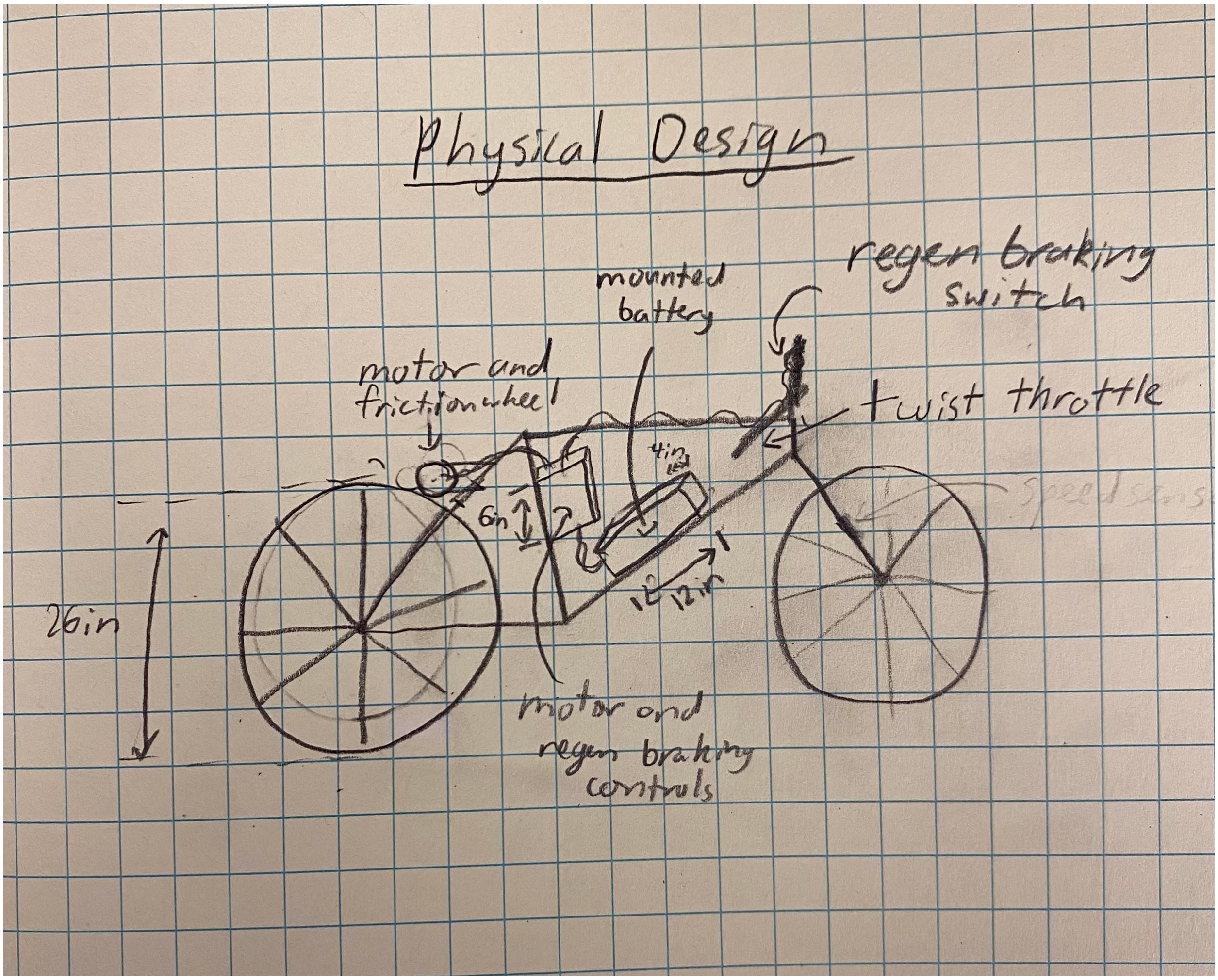

Figure 3: Representation of Physical Design

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 bidirectional DC/DC converter along with an error circuit. These can and will be purchased in a combined package. Switching signals from the control subsystem (discussed in a later section) are used to control the switching action of the MOSFETs in the BDC converter. Depending on the duty cycle of these pulse signals, or lack thereof, to each of the MOSFETs, voltage can be boosted from the motor to the battery, or bucked from the battery to the motor. The BDC converter will allow us to both achieve normal operation, where the battery is powering the motor, and regenerative braking operation, where the motor is recharging the battery.

Because the bidirectional 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 3 shows an implementation of our proposed BDC package. Here, it is being used to boost an input voltage, ranging from 9V to 80V, to an output voltage of 12V. The component values needed for our boost and buck configurations can be determined from information in the ISL81801 Datasheet [11]. This component will allow us to buck the battery voltage and boost the motor voltage. It will be able to change the direction of power flow depending on if the bike is in normal operation or regenerative braking mode.

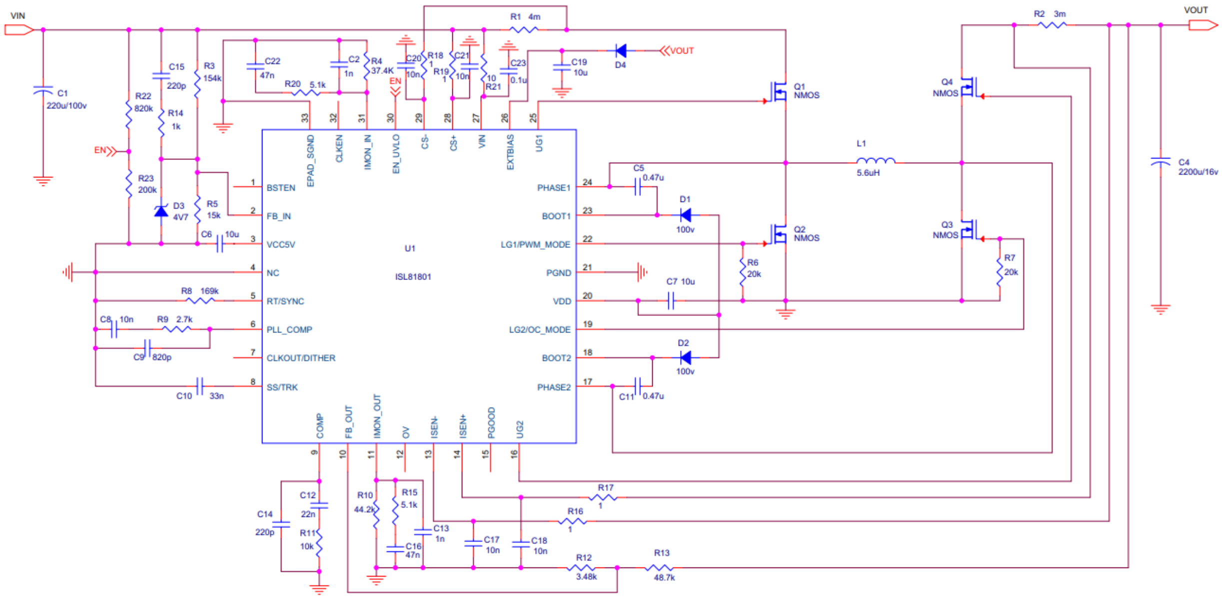

Figure 4: Example Implementation of our BDC Converter

Requirements	**Verification**
• Convert 54.6-37V into 3.3 ± .5V for the microcontroller	• Place a voltmeter probe on the supply input to the microcontroller. • Read voltage during normal (throttle assist) operation. • Read voltage during manual braking operation. • Read voltage during regenerative braking operation. • Verify that input voltage falls within parameters while battery charge is between 95-5%.
• Convert 54.6-37V into 24V ± 2.5V for the motor controller at a load of up to 30A.	• Measure the output voltage of the buck-boost convertor with an oscilloscope and a varying resistive load. It must stay in the required range for all reasonable battery charge levels. (95%-5% charge)
• Convert regenerative power from the motor into 54.6V±2V to recharge the motor.	• Spin the motor wheel at various speeds from 5-20 mph and activate regenerative braking. 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. The value of the internal battery resistance will be measured in the lab.

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 receive the throttle signal from the twist throttle. The magnitude of the twist throttle signal will be used to determine the duty cycle of the switching signals generated in the control unit. Low throttle signal will correspond to low motor voltage, while the max throttle signal will correspond to the full 24V motor voltage. However, if the speed sensor measures a speed of 20mph, the microcontroller will stop sending signals to increase the voltage at the motor.

In short, the motor controller receives a throttle signal and uses that information to determine the duty cycle of the switching signals generated by the control unit. The duty cycle of these signals determine the voltage at the motor when the BDC is in buck mode. Thus, the voltage at the motor can be varied depending on the duty cycle of the switching signals.

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 0.5 mph.	• We will test gps-measured speed against sensor measured speed while riding the bike at various speeds.
• 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.
• 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. • Supply switching signals to BDC, note what output should be produced in buck configuration. • 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.

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 a TI F280xx microcontroller with automotive specification (Q at the end of part number, see Cost Analysis section) to ensure that it can continue operation at higher temperatures. The maximum operating temperature of this device is 125 C, which should be sufficient for an electric bicycle application [7]. Both operating temperature testing and verification of microcontroller functionality will take place during the assembly and testing phase of our design project.

The first function of the control subsystem is to route the twist throttle signal directly to the motor controller. The twist throttle will give an analog output between 0V and 5V, which can be directly used by the motor controller to regulate bike speed. The control subsystem must also provide the power supply to the twist throttle.

The control subsystem is also 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 duty cycle of a pulse signal generated by the control subsystem, and to which MOSFETs that signal goes to, determines if the BDC is in buck or boost mode and to what voltage the BDC will buck or boost to.

Similarly to the twist throttle, the control subsystem also 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.

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.

Requirements	Verification
• 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 • Read the voltage during standstill and normal operation • 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. • Read voltage during normal (throttle assist) operation. • Read voltage during manual braking operation. • Read voltage during regenerative braking operation. • Verify that input voltage falls within parameters.
• 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. • Read switching signals on oscilloscope. • If they change to the correct switching signals within 1s, the microcontroller passes this step of verification. • On-bike testing: Press and hold the regenerative braking button once the bike has reached a speed of 10mph • 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. • Read switching signals on an oscilloscope. • If they change to the correct switching signals within 1s, the microcontroller passes this step of verification. • After pressing and holding the regenerative braking button, apply a steady throttle input.

	● 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. ● Must stay below 125C to progress to on-bike testing ● Monitor temperature using LED display during test rides. ● Temperature must stay below 125C for final verification.

Table 3: Control System R&V Table

2.4 Tolerance Analysis

One important aspect of our current design is our switching converter. This component will very likely be bought (see cost analysis section), but it is important that we can show that it can properly do its job considering the motor voltage and battery voltage. For our tolerance analysis, we have simulated a bidirectional DC/DC converter in regenerative braking mode. That is, it is boosting the 24V motor voltage to the 54.6V ± 2V necessary for battery recharge. This is a fairly simple model, but we will show that we can meet our voltage tolerance requirements with this simple circuit. Shown below is the model for a bidirectional DC/DC converter.

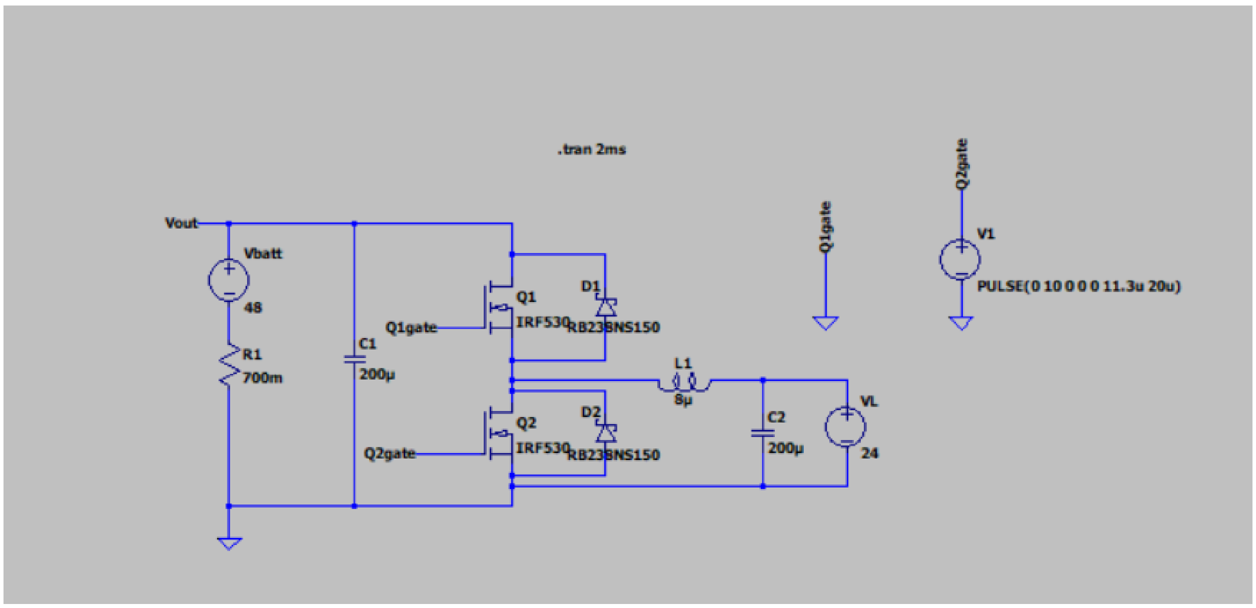

Figure 5: Simulated Boost Configuration on Bidirectional DC/DC Converter

In boost mode, the Q1 MOSFET is not active. Current can only pass through the D1 diode. Q2 is active and is receiving a pulse modulated width signal. For this specific instance, the duty cycle was calculated to be 0.56. This calculation can be done using the duty cycle equations found in Sharma et. al [10].

$$\alpha = \frac{1}{\eta}\left(1 - \frac{V_S}{V_O}\right) \text{ in boost mode}$$

Here, Vs is our source voltage, 24V, and Vo is our output voltage, 54.6V. Efficiency was estimated at 100% for the initial calculation. For a switching frequency of 50kHz, this results in an on time of 11.2us. This was then adjusted to 11.3us based on simulation results. These are shown below. Here, V(vout) is the output (battery) voltage, and I(R1) is the current into the battery.

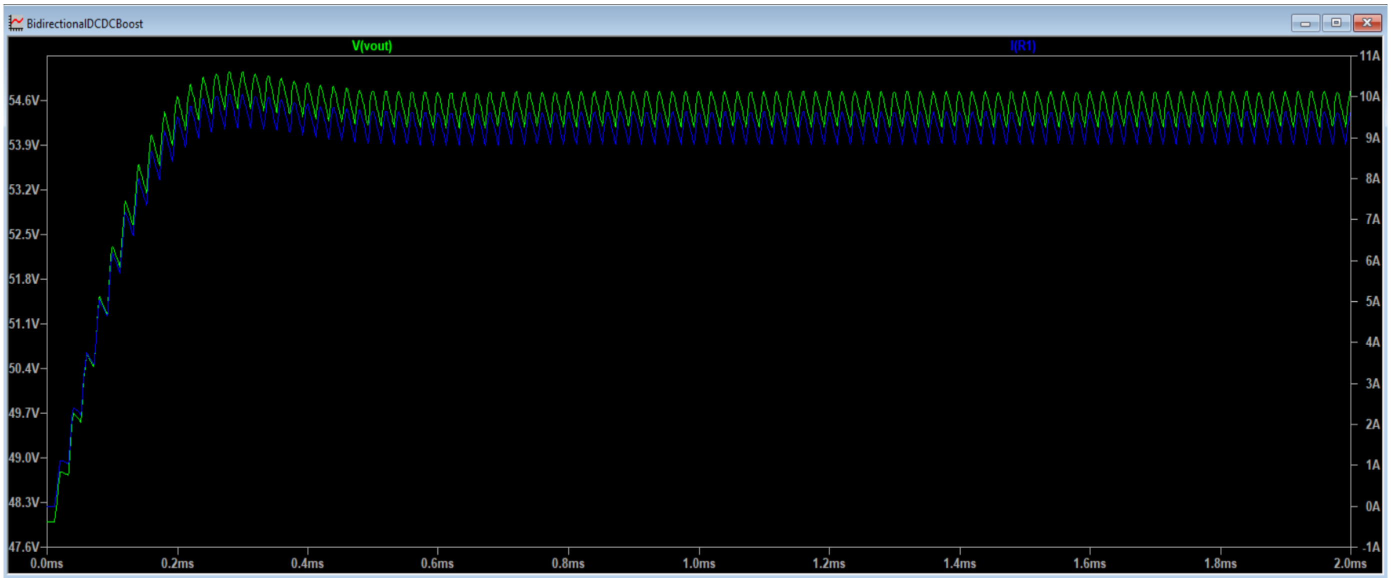

Figure 6: Battery Output Results from Tolerance Analysis Simulation

In this plot, voltage at the battery is averaging around 54.5V, which is very close to the desired 54.6V. There is also a peak-to-peak ripple of around 0.5V to 0.6V. The ripple seen here is expected of bidirectional DC/DC converters, and will be mitigated with a PID controller. As a side note, ripple can also be reduced by increasing the capacitance of both capacitors. In either case, the PID controller is not simulated here, meaning the ripple is not a concern. What we have shown with this simulation is that, even with the overshoot present starting at the 0.2ms mark, we are still within the 54.6V ± 2V voltage tolerance for battery recharging.

Battery current is also shown on this plot. We were able to keep the average current below the battery's 20A limit, meaning that the battery current is also within tolerance.

Though our current design goal is to use a bidirectional DC/DC converter package with an included PID controller, this simulation was conducted to show that we are able to meet battery current and voltage tolerance requirements. Based on the plot above, it is very possible to meet tolerances with a bidirectional DC/DC converter.

For our final project implementation, the main tolerance issues surrounding our BDC will be in the capacitor, inductor, and resistance values we choose in accordance with the part that we buy. These can affect the switching frequency and peak-to-peak ripple observed at the output. The peak-to-peak ripple will be for the most part mitigated by the error circuit included in our BDC package, but it is still something to consider during testing.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Parts

Component	Manufacturer	Part Number	Quantity	Cost	Link
Battery (battery charger included)	H Hailong	3608	1	$195	Link
Motor	Hi-Gear	MY1020	1	$72	Link
Twist Throttle	NB Power	NBP-KT-PAS	1	$14.98	Link
Brake Lever	BQPOLING	B0B37QZT6V	1	$12.99	Link
Microcontroller	Texas Instruments	TMS320F28035PAGQ	1	$14.78	Link
3.3V LDO	Maxim Integrated	MAX5024TASA+	1	$4.64	Link
5V LDO	ABLIC	S-1142B50I-E6T1U	1	$1.60	Link
LED display	CSC	KT-LCD3	1	$27.64	Link
Bidirectional DC/DC Converter	Renesas	ISL81801FRTZ-T7A	1	$13.78	Link
Regenerative Braking Button	Wuxing	DX-02	1	$1.21	Link
Speed Sensor	Micro Traders	SP|470	1	$18.39	Link
Circuit Breaker	Schurter	TA45-ABKTFC00C0-ND	1	$20.55	Link
Bike+Parts	-	-	1	$30	-
Miscellaneous (resistors, capacitors, inductors, wires, any other necessary but less costly components)	-	-	-	$50.00	-
Total	-	-	-	$477.56	-

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 $40977.56.

3.2 Schedule

Week	Important Deadlines	Jace	Lucas	Chloe
2/20	Design Document Team Contract 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 Design Review 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 Teamwork Evaluation I 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. Start testing design components. Work on microcontroller programming.
3/27	Second Round PCBway Orders Individual Progress Reports	Order PCBs Submit progress reports.	Order PCB. Submit a progress report.	Order PCB. Continue testing circuit design. Work on

				microcontroller programming Submit the progress report.
4/3	-	Testing and assembly. Test and debug power circuit.	Testing, assembly, debugging.	Testing and assembly. Test and debug microcontroller programming
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 Final Paper 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].

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].