Micro Urban Electric Vehicle Phase III-Regenerative Braking Subsystem

Final Report

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Abstract

The world has been worrying about high fuel costs and damaging the environment, for a long time there has been a movement to conserve energy. This movement has created a search for alternative energy that is cheap and environmentally friendly. This caused some Bradley students to start a muli-phase project to create a urban electric vehicle. The first group was able to design and build a fully functional urban electric vehicle. The vehicle has a very limited range due to the batteries draining quickly. This is a major obstacle to mainstream integration of the design.

This project is entering the third phase for the 2013 school year. It is focusing on creating a regenerative breaking subsystem to boost the vehicles efficiency. First, models of the power electronics were created using specialized software. Then, the software was used to run several simulations over various configurations and inputs. After sufficient simulations were completed, a prototype circuit was created. This prototype will be tested in various conditions to reaffirm the simulated results. The project is still in its prototype phase, therefore, it does not have any concrete results to report at this time. The implications of a working prototype are very interesting. A correctly implemented regenerative braking system would allow for the MUEV to travel a much farther distance between charges. Range is the one of the major limiting factors afflicting electric vehicles today. With this problem remedied, our reliance on fossil fuels could be nearing an end.

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I. Introduction

There has been a dramatic push for alternative energy sources in the past few years. Fossil fuels are growing increasingly expensive and are damaging the ecosystem. One form of alternative energy is electric vehicles. One of the main technical challenges is increasing net efficiency of alternative energy. Electric vehicles are currently being limited by the range per charge. When a conventional vehicle applies the brakes, the kinetic energy is converted to heat and is effectively wasted. Regenerative braking refers to the process of recovering some of the kinetic energy that otherwise would have been lost. This energy is then boosted to the charging level and is used to recharge the battery. This allows the vehicle to travel further per charge thus increasing the net efficiency of the vehicle.

In the first phase of this project, the team researched and implemented a prototype test platform for a Micro Urban Electric Vehicle (MUEV). To do this, the team researched available batteries, motors, electronics, and vehicle frames. The main goal of this team was to complete the mechanical design and show a proof of concept.

The second phase of this project focused on creating in depth SIMULINK models of each vehicle subsystem to create a comprehensive model of the entire system. Another part of this phase was to perform data acquisition on the MUEV and fine tune the SIMULINK models with the acquired data.

II. System Block Diagram

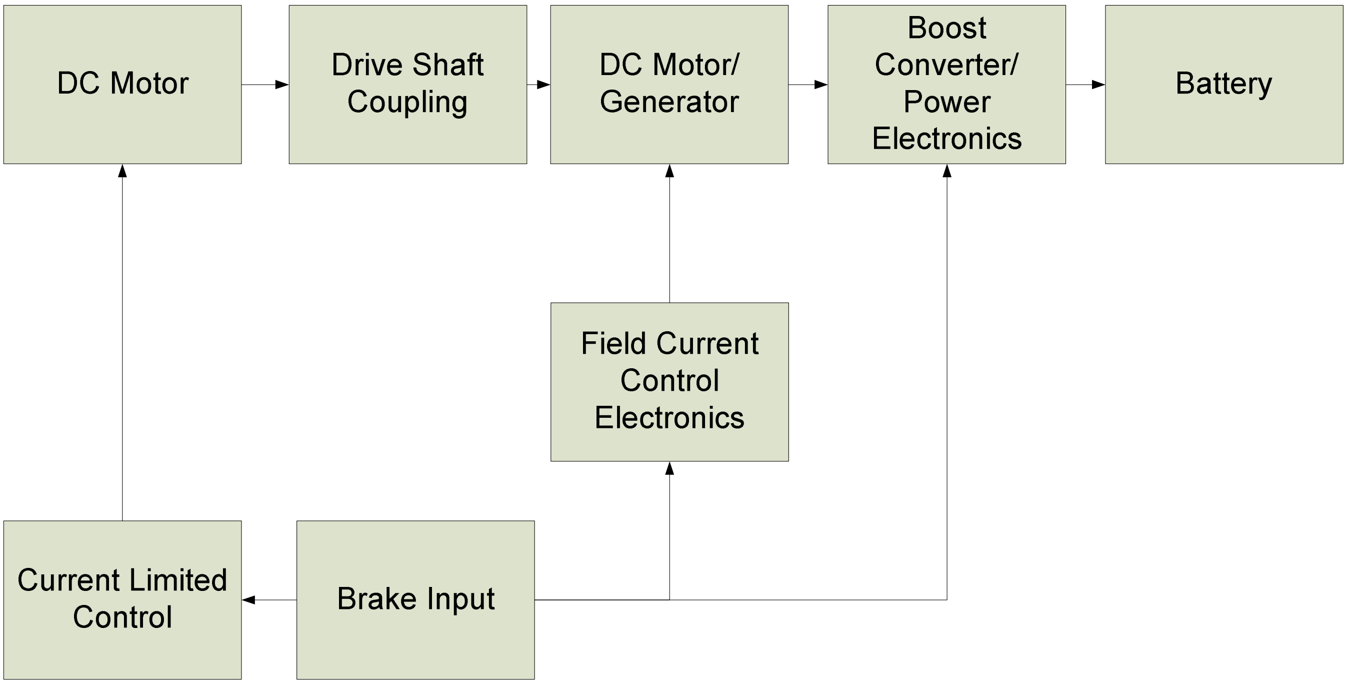

Figure 1 Full system Block Diagram

The driving DC motor is controlled by a current limited control to simulate a braking simulation onto the MUEV motor which acts like a generator. Once the brake is pushed the braking simulation will begin and the field current control electronics will make the MUEV motor act as a generator to produce a back EMF voltage that is the input into the boost converter. The boost converter then increases the voltage to approximately 43 volts which is the charging voltage for the three onboard 12-volt lead acid batteries.

The range for regenerative braking to be efficient in the MUEV system is from a back EMF voltage from around 5 volts to 35 volts. Anything under 5 volts would not be able to be converted to a high enough voltage to charge the 3 12 volt batteries.

III. **Design Equations and Component Calculations**

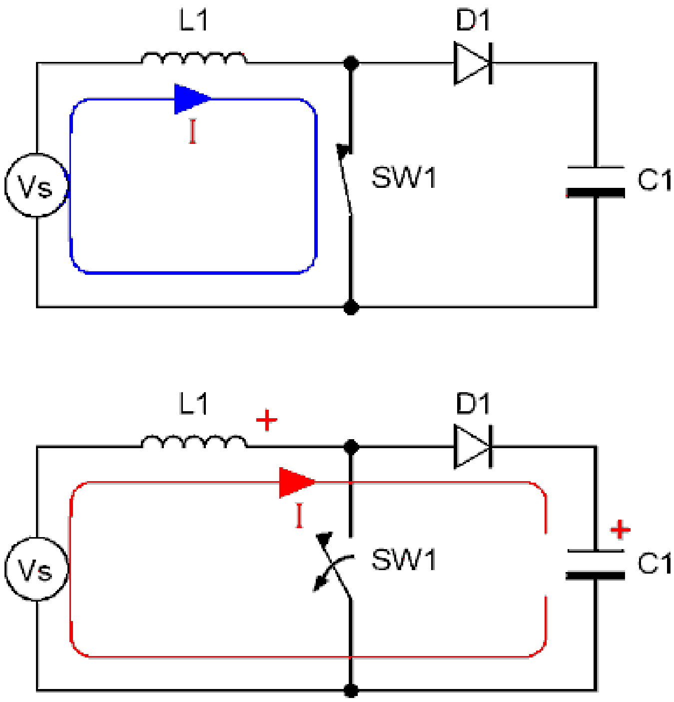

Figure 2: Basic Boost Converter Operation

When the switch is closed the inductors current will begin to increase. Once the switch opens the inductor polarity in reversed. This forces the larger current through the diode across the capacitor and load. The capacitor is necessary to hold the output voltage constant while the switch closes again.

The design equations used

1. $Io = \frac{P_{motor}}{Vo}$ Output Current Equation

2. $\frac{Vo}{Vin} = \frac{1}{(1-D)}$ Duty Cycle Equation

3. $L = \frac{(Ts \cdot Vo)}{2 \cdot Io} \cdot D(1-D)^2$ Inductor Value Equation

4. $C = \frac{Io \cdot D}{fs \cdot \Delta Vo}$ Capacitor Value Equation

The horse power of the MUEV motor is 1/3HP. With 1 HP equal to 746 watts the total power produced from the motor will be 246.66 watts. Using equation (1) the output current will be 5.75 Amps. Using equation (2) the duty cycle of each input voltage can be calculated. Figure 3 shows the list of duty cycles for some input voltage values.

Vin(V)	Duty Cycle (%)	Vout (V)
35	18.98148148	43.2
30	30.55555556	43.2
25	42.12962963	43.2
20	53.7037037	43.2
15	65.27777778	43.2
10	76.85185185	43.2
5	88.42592593	43.2

Figure 3: Table showing duty cycle vs. input voltage

Using equation (3) we find the inductor value for each of the duty cycles in Figure 3.

Vin(V)	Ts (sec)	Vout (V)	Io (A)	Duty Cycle	L (uH)
35	0.00002	43.2	5.75	0.189814815	9.360835272
30	0.00002	43.2	5.75	0.305555556	11.07085346
25	0.00002	43.2	5.75	0.421296296	10.600249
20	0.00002	43.2	5.75	0.537037037	8.647939405
15	0.00002	43.2	5.75	0.652777778	5.91284219
10	0.00002	43.2	5.75	0.768518519	3.093874873
5	0.00002	43.2	5.75	0.884259259	0.889954971

Figure 4: Inductor Calculation Table

The capacitor was designed for the largest duty cycle, which was for a 35 V input. Using 0.1 for the ripple voltage delta V and equation (4) the minimum capacitor size would be Cmin=1mF.

An output power resistor needed to be placed in front of the battery to limit the current into the batteries to 5 Amp. To find this resistor value it’s a simple V=IR equation with V at the output voltage of 43.2 v and with I as the output current of 5.75 A then R=8.63.

IV. Design Schematic and Simulation Results

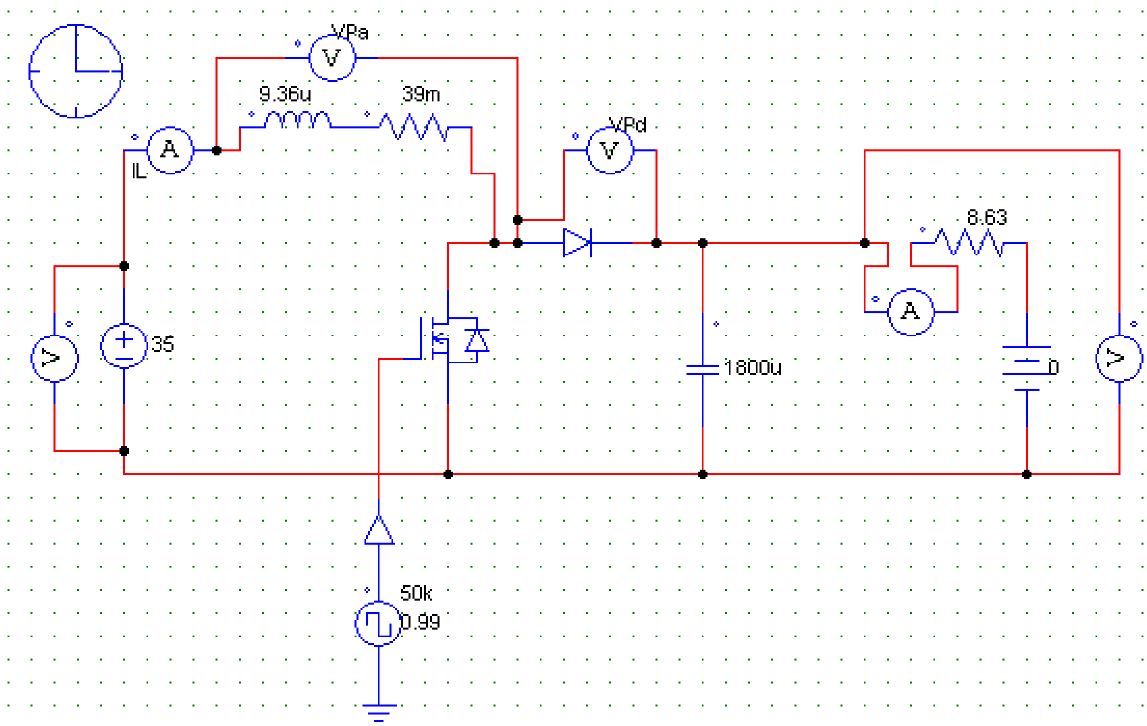

Figure 5: Schematic of boost converter with a 35v input

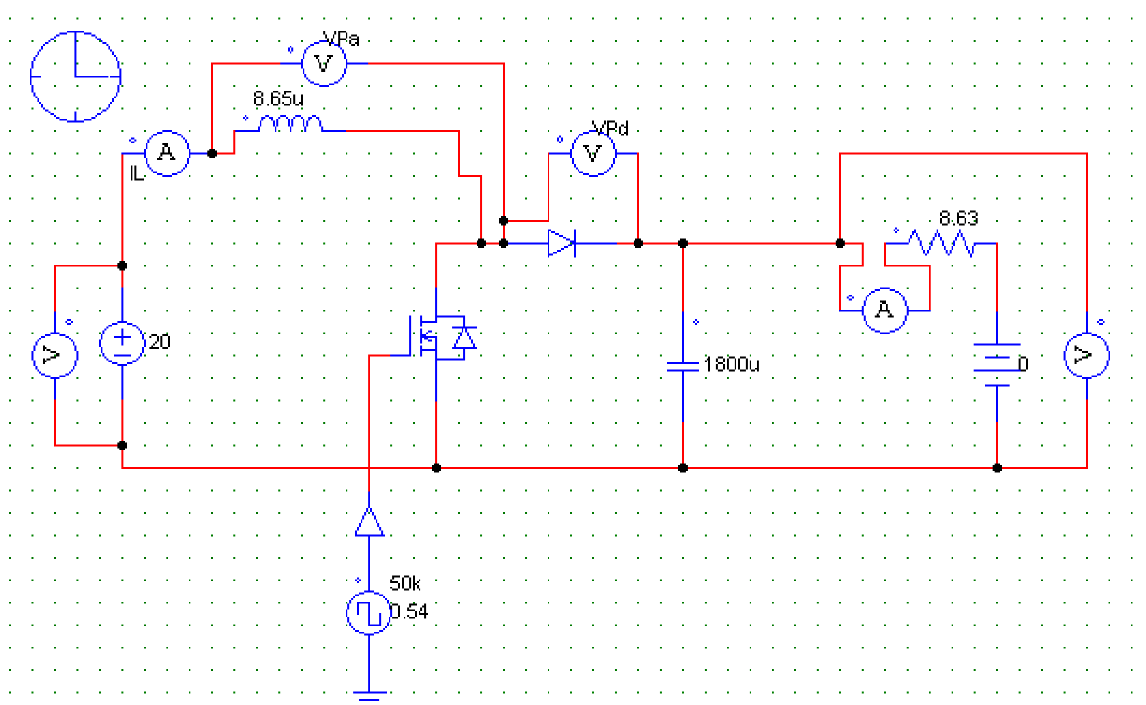

Figure 6: Schematic of boost converter with a 20v input

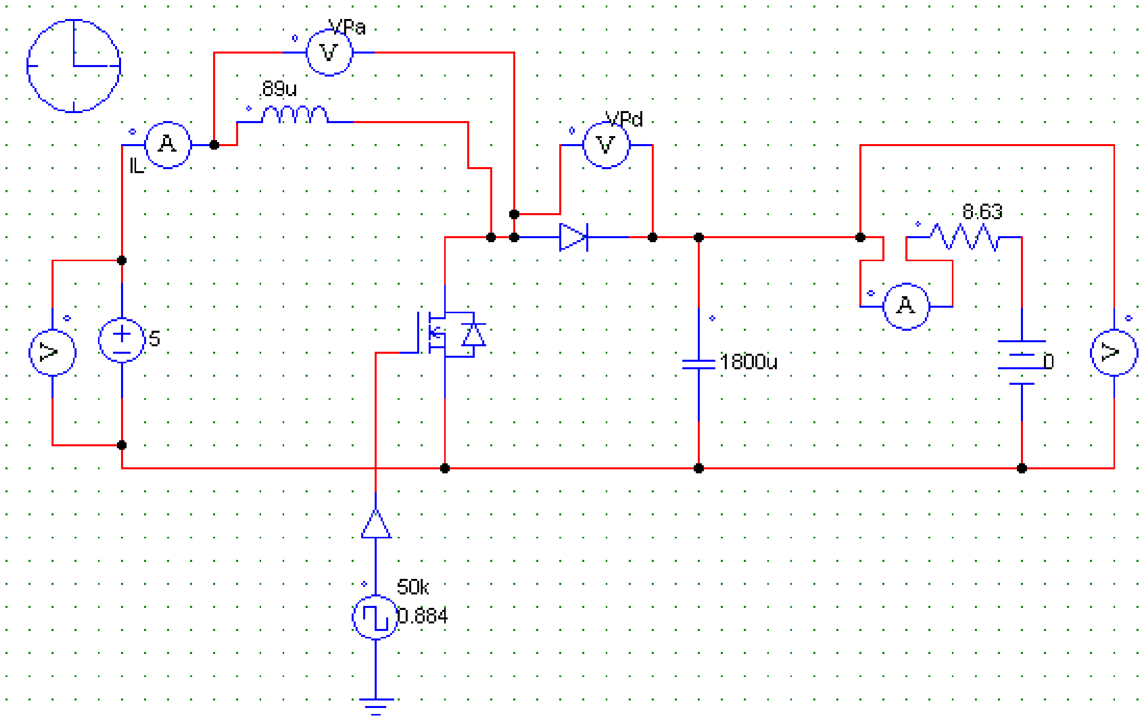

Figure 7: Schematic of boost converter with a 5v input

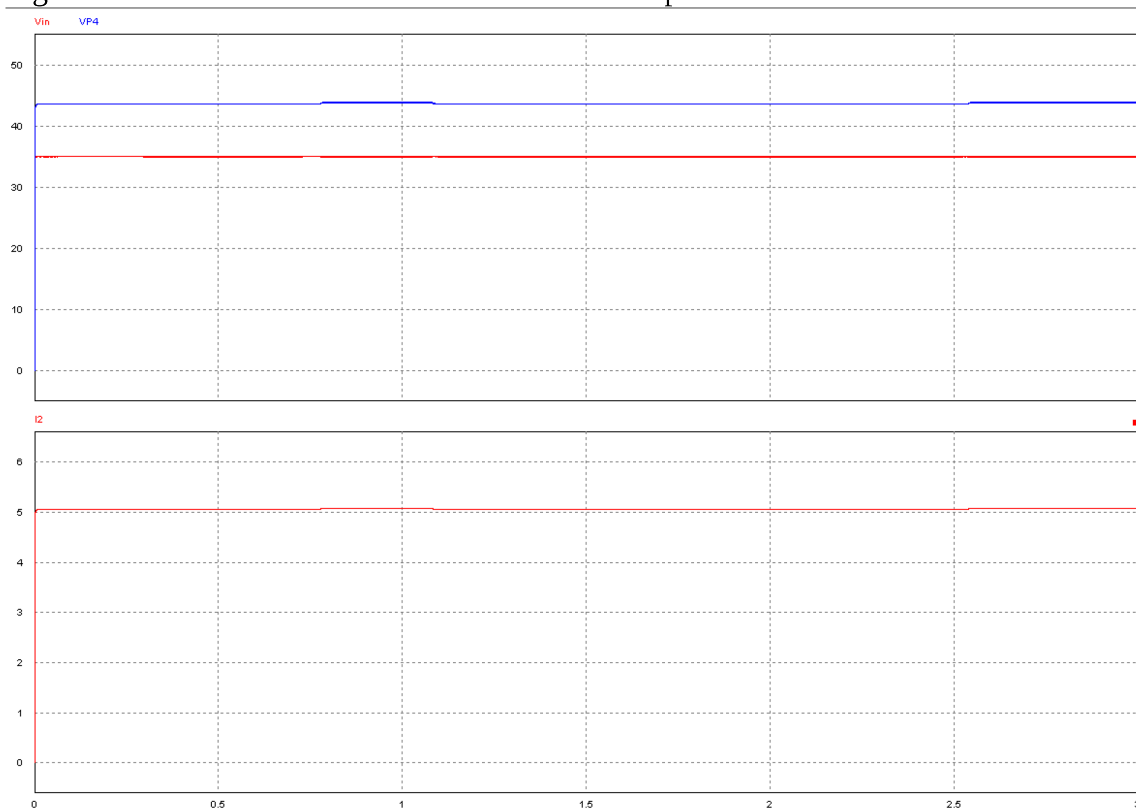

Figure 8: Simulation of a 35 v input with about a 43.2 v output and output current at 5A

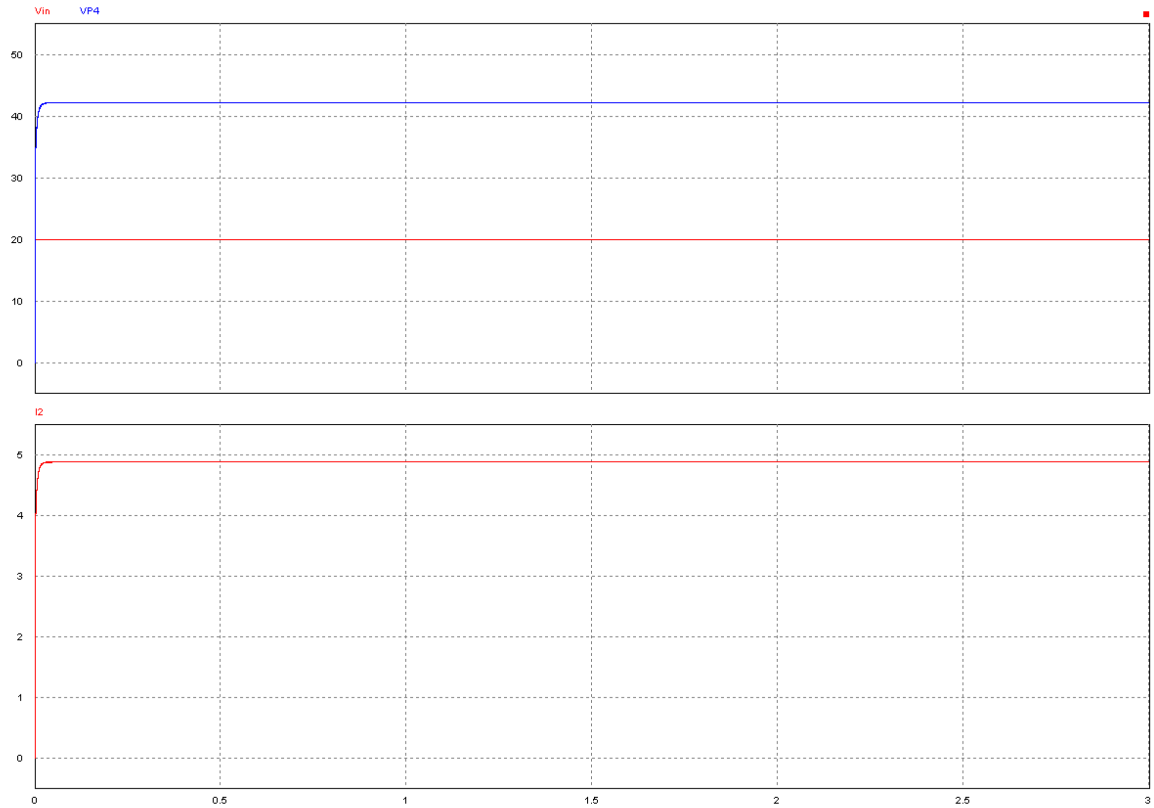

Figure 9: Simulation of a 20 v input with about a 43.2 v output and the output current at 5A

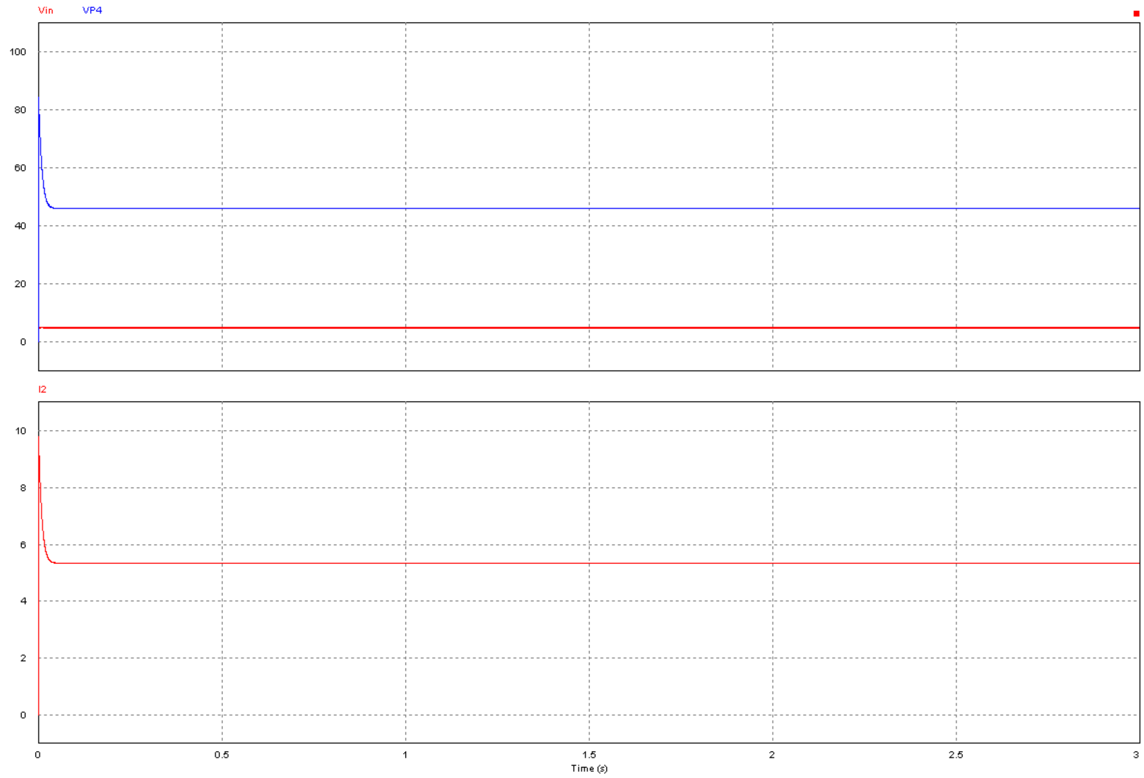

Figure 10: Simulation results of a 5 v input with about a 43.2 v output and the output current at about 5 A

These schematics and simulations show that the equations used were correct and that the design theory was sound. However, these simulations do not take in account the impedance of the inductor. This value is unattainable until a test of an actual inductor with a LRC meter is performed.

V. Extra hardware Implemented

1.) Gate driver circuit: Needed to produce a 15 volt peak to peak square waveform to switch the transistor. An IR2110 was implemented at first but was inefficient since the switching time was too long and created too much power dissipation across the transistor causing it to heat up quickly. A set of complementary MOSFETs were implemented producing a significantly lower rise time.
2.) Safety Reset Circuit: There is a comparator circuit making sure that the output voltage does not exceed 50 volts which can damage the batteries. This circuit shuts down the square waveform input to the transistor shutting down the system.
3.) Heat sinks were used for the transistors and diode to dissipate the heat
4.) Snubber circuit: Dramatically reduced the diodes initial voltage drop.

VI. Design Implementation and Test Results

Issues:

1.) MOSFET reaching dangerously high temperatures when boosting smaller input voltages.
2.) Power supplies being used were current limited so the necessary current needed to boost smaller input voltages was unattainable.
3.) Wire gauges needed to be changed since large currents were being drawn.
4.) Integrated circuitry constantly damaged due to static discharge.
5.) Switching inductor values.

To reduce the MOSFET temperature two MOSFETs were put in parallel to reduce the current across each MOSFET to half the original value. A heat sink and a fan were added to the system to cool the MOSFETs. Even after moving to the power lab, the power supply seemed to be current limiting at 25 A, which is below what is necessary. Every inductor value could not be implemented so the design implements only two different inductor values one for the lower input voltages from 5-20v and the other for 20-35v. The duty cycles however would be different to compensate for the different sized inductors.

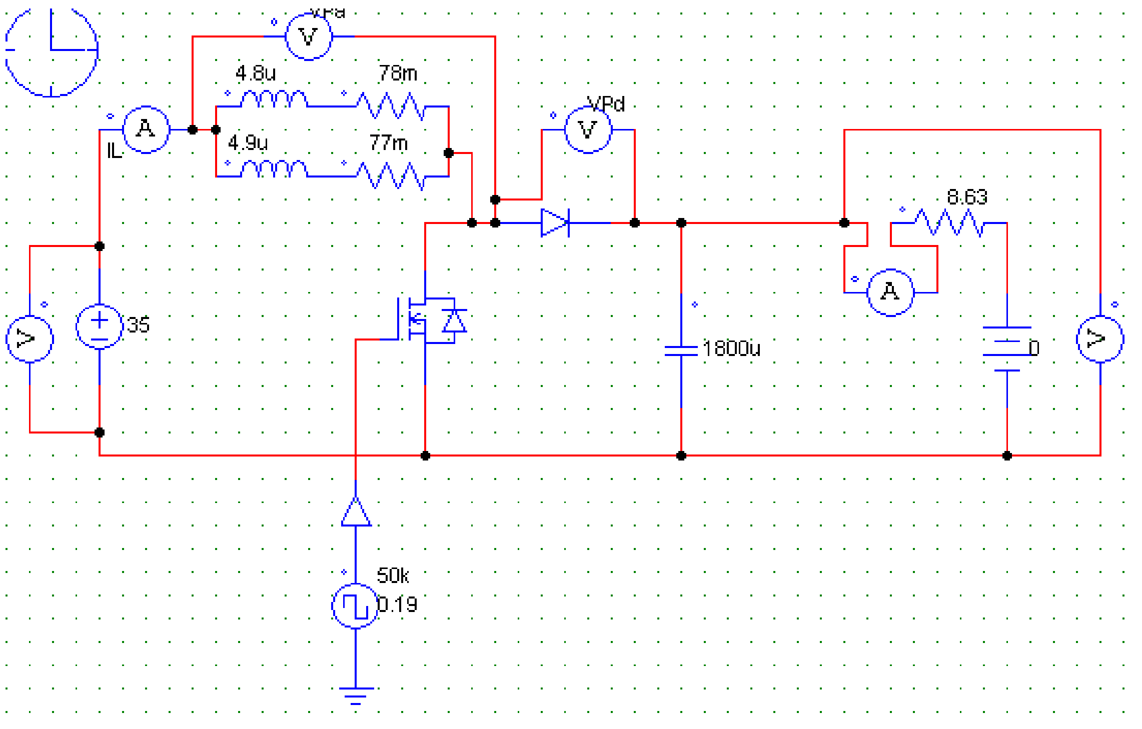

Figure 11: New boost converter schematic with parallel inductors

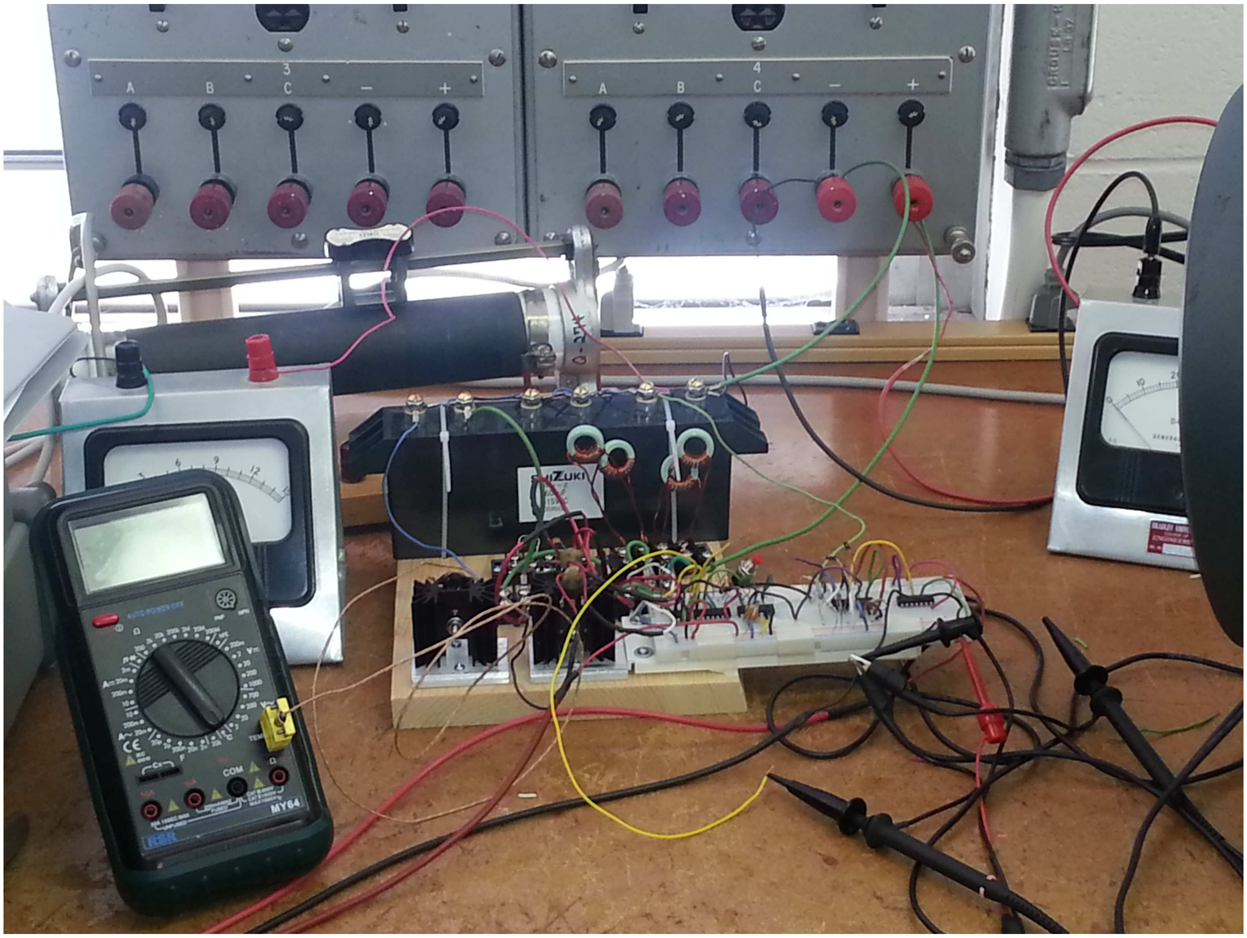

Figure 12: Picture of test set up

The controller needs input voltage vs. duty cycle function so that there can be a constant 43.2 v seen across the output while the input voltage changes. The boost converter was able to operate for 12-35 V input voltages. The lower voltages below 12 V were unattainable since the duty cycle on the waveform generator used only went from 20-80%. Limiting the duty cycle to 80% did not allow lower voltages to achieve a 43.2 V output.

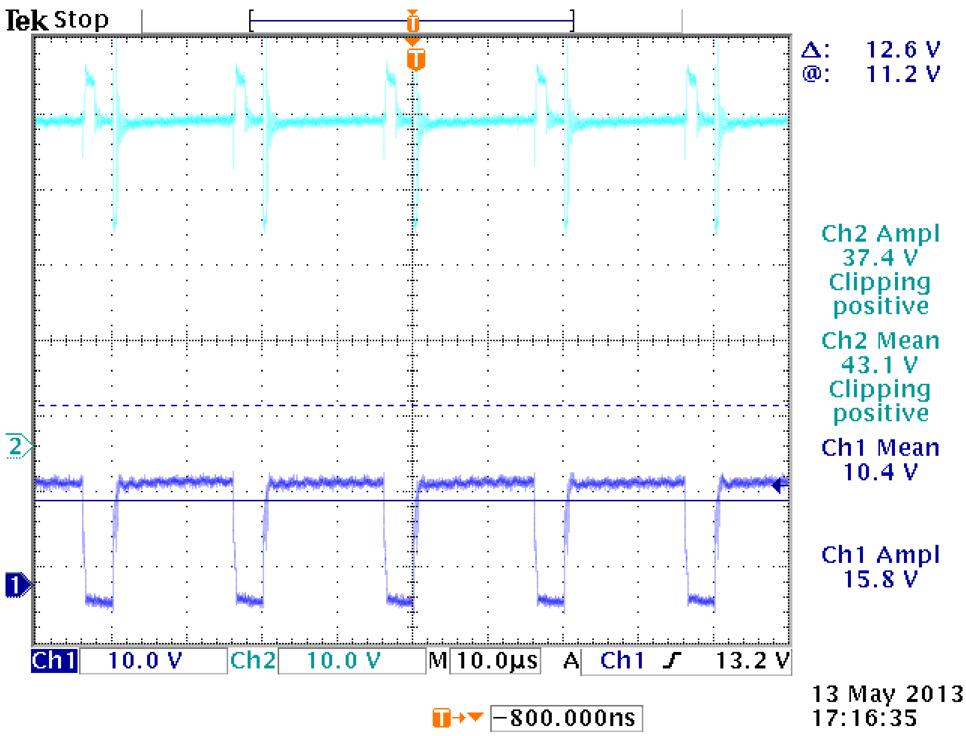

Figure 13: Oscilloscope results of a 12v input voltage showing a 43.1v output voltage.

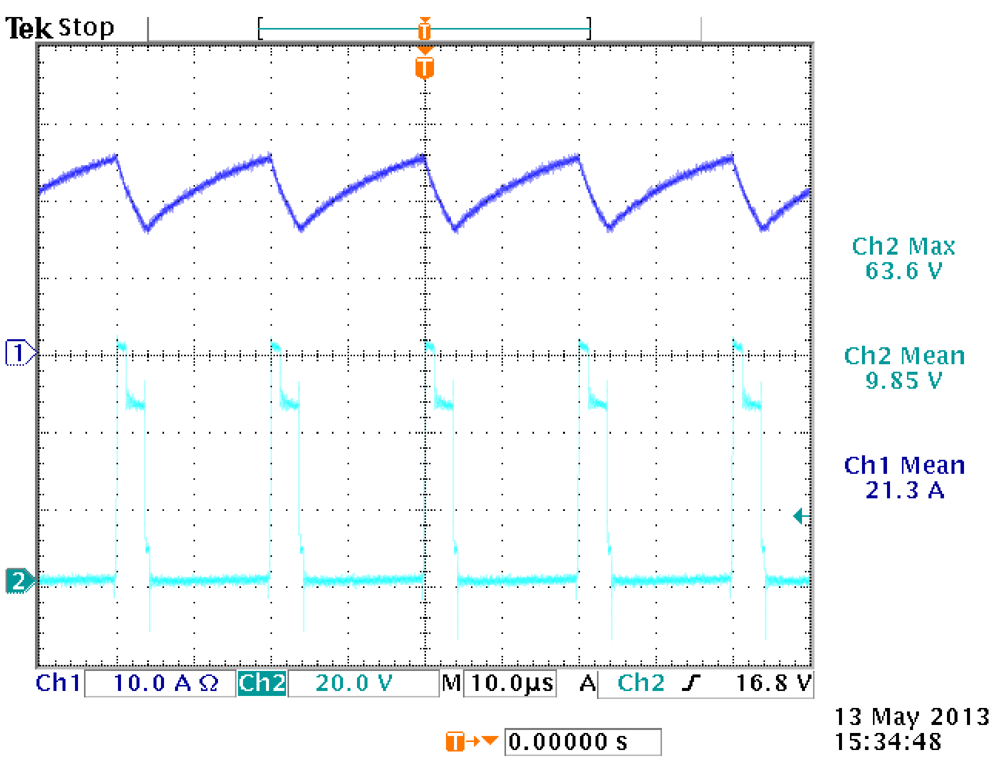

Figure 14: Oscilloscope results of a 12v input voltage showing the output current and the MOSFET switching waveform.

Vin (V)	Duty Cycle	Vo (V)	Io (A)
35	20%	45.5	4.2
32.5	21%	43.2	5.2
30	29%	43.5	5.2
27.5	35%	43.3	5.2
25	42%	43.3	5.2
22.4	50%	43.3	5.2
20	62%	43.6	5.2
17.5	70%	43.5	5.2
12	80%	43.1	5.2

Figure 15: Results attained when testing the boost converters when finding the duty cycle needed for each input voltage.

VII. Conclusion

In summary, the Phase III team has successfully designed and simulated the boost converter portion of a regenerative braking system. The team also created a proof of concept boost converter with additional circuitry for gate drivers and over voltage protection. After the power electronics were assembled, extensive testing was performed to insure the initial voltage range that was designed for could be achieved. Due to some extra losses not accounted for the power electronics are able to boost over the range of 35 volts to 12 volts. Although this is not the entire range that was designed for, it is adequate for a proof of concept design. With additional time the full range could be implemented. Due to time constraints the duty cycle controller was not able to be completed. This is a key part of the regenerative braking system and would need to be completed in future work.

VIII. Recommendations for Future Work on Regenerative Braking

Future teams of the MUEV project should begin by completing the duty cycle controller on a microcontroller. This will allow the system to adjust the duty cycle in real time by comparing the input and output voltages. A second item to work on is attach the regenerative braking system to a DC motor/generator. This will allow for more thorough testing of the system as well as verify its regeneration range. Next a braking profile needs to be developed for the DC motor which would slow the motor down at a defined pace allowing for more data acquisition and testing. Another recommendation would be to create a SIMULINK model of the regenerative braking system and add it to the Phase II teams models. This is important because having the most accurate model possible will be beneficial to later groups. A final recommendation is to attach the regenerative braking system to the MUEV and perform data acquisition to measure the increase in net efficiency.

IX. Recommendations for Future Work for MUEV project

Future teams of the MUEV project should begin with creating an accurate battery model that is tested and verified with the current batteries. Also, the Data Acquisition System (DAQ), which is referenced in appendix A, must be mounted on the vehicle platform in order to verify the vehicle dynamics and complete system model. In order to mount the DAQ, a portable voltage source must be used, as well as a new current sensor that can operate with a uni-polar voltage source. The DAQ will also need to be integrated with the digital tachometer on the tire to measure wheel RPM, which will be converted to speed. The armature and field voltages will need to be converted to a digital input so the sampling frequency can be increased, which will allow for a more accurate duty cycle reading. Also, the throttle position sensor must be integrated into the DAQ. It would also be helpful to more accurately measure the mass of the vehicle, as well as the load force coefficients.

As a more in-depth look at the model is required, it will be necessary to model the auxiliary loads such as heat, air conditioning, lighting and radio. Finally, the components of the vehicle should be optimized. For example, the current batteries have a very limited capacity. With the current vehicle model, a model of a lithium ion battery can be substituted into the battery model and the driving length of the vehicle can be calculated. The last stage of the project would be to design a zero carbon emissions charging station that will use photovoltaic cells to power the MUEV while at the owner's home.

X. Standards

Society of Automotive Engineers:

Standard for Hybrid Electric Vehicle (HEV) & Electric Vehicle (EV) Terminology, SAE J1715_200802

This SAE Information Report contains definitions for electric vehicle terminology. It is intended that this document be a resource for those writing other electric vehicle documents, specifications, standards, or recommended practices. Hybrid electric vehicle terminology will be covered in future revisions of this document or as a separate document.

Vibration Testing of Electric Vehicle Batteries, SAE J2380_200903

This SAE Recommended Practice describes the vibration durability testing of a single battery (test unit) consisting of either an electric vehicle battery module or an electric vehicle battery pack. For statistical purposes, multiple samples would normally be subjected to such testing. Additionally, some test units may be subjected to life cycle testing (either after or during vibration testing) to determine the effects of vibration on battery life. Such life testing is not described in this procedure; SAE J2288 may be used for this purpose as applicable.

Recommended Practice for Performance Rating of Electric Vehicle Battery Modules, SAE J1798_200807

This SAE Recommended Practice provides for common test and verification methods to determine Electric Vehicle battery module performance. The document creates the necessary performance standards to determine (a) what the basic performance of EV battery modules is; and (b) whether battery modules meet minimum performance specification established by vehicle manufacturers or other purchasers. Specific values for these minimum performance specifications are not a part of this document.

XII. References

[1]. Dieter, Kyle, Spencer Leeds, and Nate Mills. Micro Urban Electric Vehicle & Test Platform. Senior Project. Electrical and Computer Engineering Department, Bradley University. May 2009. http://ee1.bradley.edu/projects/proj2009/move/index.html

[2]. Komperda, Steven, Brian Kuhn, Matthew Leuschke. Micro Urban Electric Vehicle Phase II – Modeling. Senior Project. Electrical and Computer Engineering Department, Bradley University. May 2010. http://ee1.bradley.edu/projects/proj2010/muev/index.html

[3] A Review of Regenerative Braking Systems by: Dr. S J Clegg, White Rose University http://eprints.whiterose.ac.uk/2118/1/ITS105_WP471_uploadable.pdf