



Design and Computer Modeling of Ultracapacitor Regenerative Braking System

Adam Klefstad, Dr. Kim Pierson
Department of Physics & Astronomy UW-Eau Claire

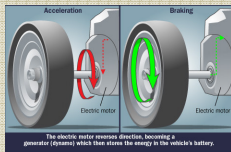


Project Purpose

Our primary research objective was to create a computer model of an ultracapacitor regenerative braking system and compare its performance with a real circuit on a real electric scooter. The computer model was refined until its performance matched the real system performance. Once we had a reliable computer model of our simple circuit, a number of enhancements were added to the circuit design. Electronic sensors were installed to acquire real-time data of the state of charge (voltage) on the ultracapacitor, the amount of current going to and coming from the ultracapacitor, the voltage produced by the motor/generator on the scooter, and the speed of the scooter. A computer control program was used to monitor the sensors, analyze the data, and control the regenerative braking process. This data was used to assess the validity of our computer model and enhance the performance of the control program.

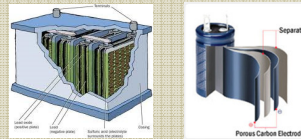
Regenerative Braking with Ultracapacitors

Reclaiming Energy by Braking



Regenerative braking does not create new energy, but reclaims energy that is typically lost through heat dissipation during regular frictional braking. The torque produced by the wheels turns the shaft of an electric motor to generate electricity.

Energy Storage Components

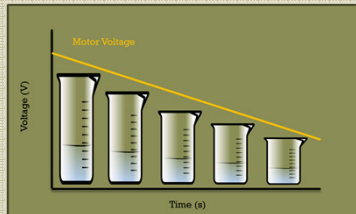
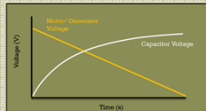


Batteries store energy in a chemical reaction, but have a limit to how fast and how often they can be charged. Since regenerative braking produces a lot of current in a short amount of time, batteries have a hard time capturing all of the energy during a braking scenario. Ultracapacitors are able to capture large amounts of current in a short amount of time and can be charged and recharged thousands of times.

Choosing Capacitors

Maximum braking occurs when the capacitor draws the most current. As a capacitor is filled, its ability to draw current decreases and so does its braking power. Switching capacitors while braking provides maximum braking force every time a new capacitor is added. Furthermore, using different sized capacitors during a given braking scenario will ensure that each capacitor is completely charged.

V (mph)	KE (J)	C (F)
5.0	238	76
10.0	952	304
15.0	2142	685



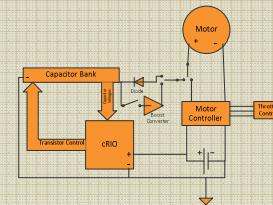
National Instruments/LabVIEW technology was used to create a control algorithm that chooses the correct sized capacitor based on the kinetic energy of the scooter and rider. Furthermore, the algorithm sequentially chooses the next logical capacitor size based on the remaining kinetic energy. This is important because the electronic circuit that takes the energy stored in the capacitors and recycles it requires a high input voltage in order to output the correct voltage to run the motor.



Speed (mph)	Voltage (V)	Current (A)
2.0	5.0	5.5
1.5	3.0	7.0
2.5	5.0	10.0

When fully charged, the capacitors hold 2.7 volts. Experimentation revealed that at least 5 volts and 10 amps of current are required to operate the scooter motor. Thus after a regenerative braking event a "boost converter" circuit must be engaged to raise the voltage of the capacitors up to greater than 5 volts.

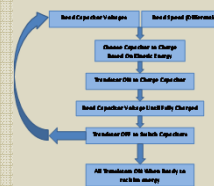
Scooter Regenerative Braking Control Circuit



A diagram of the entire system shows how three major subsystems work together. While two switches control the operation of the regenerative braking process, the cRIO data acquisition system chooses which capacitors to charge by controlling the transistors and gathers voltages used to determine when to switch capacitors. The boost converter circuitry is designed to boost the voltage from the capacitor bank to power the motor.

LabVIEW Program Flowchart

Braking Scenario

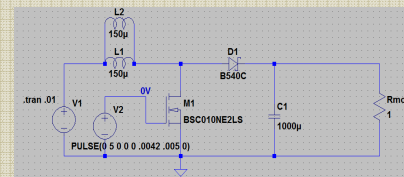


An NI LabVIEW program was used to monitor, analyze, and control the energy throughout the system. The cRIO was used to get data via wireless communication and allows the data acquisition system to be easily altered. The cRIO has a very fast processing speed which is used to monitor the current through the inductor of the boost converter circuit and control its transistor.

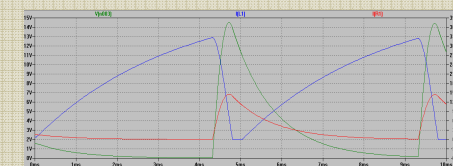
Reclaiming Stored Energy



Boost Converter Circuit Simulation



The graph displays the output voltage (green), the inductor current (blue), and the output current (red) of the boost converter. With an input voltage of 2.0 volts and a duty cycle of 84% for the transistor, the output peaks around 14.5 volts and 15 amps. The drain source resistance and gate charge are the two characteristics of the transistor that affect the output voltage. The lower these values, the higher the output voltage.



A boost converter needed to be implemented because the voltage of the capacitor bank was too small to run the motor. Experimentation determined the voltage and current needed to power the scooter with a rider. Using the circuit simulation software LT Spice, we ran various simulations to find a boost converter circuit that produced the most current and voltage. It was discovered that the duty cycle for the transistor and the type of transistor greatly affects the output voltage and current produced. Likewise, the paralleled inductor provides less resistance in the circuit and increases performance.

Conclusion and Future Research

At this concluding point in our research, we have built a regenerative braking system on an electric scooter using ultracapacitors to store the reclaimed energy. The system is monitored, analyzed, and controlled wirelessly by NI LabVIEW's cRIO which allows the scooter to communicate with a laptop as the scooter is in operation. After a few preliminary trials, it was clear that the system would need a boost converter to make use of the reclaimed energy. A simulation of the most efficient boost converter was designed using LT Spice and the real circuit is ready to be installed in the scooter. Once installed, the live performance of the scooter will be compared to computer simulated results.

Future research projects may emerge from the completion of this project. NI LabVIEW has the capabilities to control the boost converter circuit through the cRIO on the scooter. Developing an appropriate algorithm will allow for the boost converter to operate most efficiently for a range of speeds. Another future contribution to this project is to make the system more compact by engineering a printed circuit board. Using a program called ExpressPCB, a student will be able to design and test the most efficient layout of the circuit before sending out the design to be printed.

Acknowledgements:

- Differential Tuition, UWEC ORSP Research Grant
- Dr. Kim Pierson, Professor at UW-Eau Claire
- UW-Eau Claire Physics and Astronomy Department