

ECE 480 Fall Semester 2008

Design Team 10

Final Proposal

Battery–Supercapacitor Hybrid Energy Storage System

Manager: Marvel Mukongolo

Webmaster: Chi-Fai Lo

Documentation: Michael Kovalcik

Presentation/Lab: Jamal Adams

Facilitator: Dr. Fang Peng

Sponsor: Keld LLC

Executive Summary:

The project undertaken by design team ten is to design and build a “Battery-Supercapacitor Hybrid Energy Storage System” for HEV and renewable power generation. The system will provide optimum energy and power density for HEV and alternative (renewable) power generation. The battery will provide long-term constant power and the supercapacitor will deliver short-term pulse power, to a pulsating load. The hybrid energy storage system will be 48 Volts nominal and able to power a pulsating load with the following characteristics: 48 Volts $\pm$ 20%, one kilowatt peak power for 18 seconds over every two minutes with almost 0 kW for the remaining 102 seconds of every two minute period. Our goal is to create an energy storage system that will be able to provide power for at least ten of these cycles over the course of 20 minutes. Due to time constraints, this project will not involve any power generation or regeneration systems. Team ten will construct a digitally monitored and controlled hybrid lithium ion battery – supercapacitor system, and a variable Ohm, one-kilowatt load for testing purposes.

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Introduction:

The rising cost of energy combined with increasing awareness and acceptance of global warming, has served as kindling for the forge that is now the white-hot “green” technology sector. The field of Electrical Engineering is deeply affected by the push for cleaner energy and transportation. The advent of new, high-energy storage capacitors, and lighter rechargeable batteries, with greater energy density, has allowed new developments in the clean energy sector. The hybrid, in all its fuel saving glory, is flawed. The battery is made of highly reactive substances, is very expensive, heavy, and difficult to replace. Creating and utilizing new technologies is at the forefront of modern engineering and is sure to create many jobs, driving our economy, our careers, and our vehicles for the foreseeable future.

Background:

Demand for hybrid electric vehicles (HEVs) has driven the auto industry to create many different sizes and models. Whether the combustion engine runs on by gasoline, compressed natural gas, propane, ethanol, bio or conventional diesel, they all require some type of battery technology for electrical storage. Batteries are costly, have limited life cycle, high maintenance, environmental hazards, and temperature sensitivity. With all of these drawbacks of a battery, there is considerable research looking for a new energy storage system to augment or replace them. There have been problems in securing an energy source that outperforms the battery in the areas of cost and electrical performance. With new breakthroughs in supercapacitors the wait may not be far away. Using different chemical compounds to produce different types of capacitors is yielding to capacitors having higher energy densities that are comparable to batteries. With this ideology, we will create a power system for a bus. This power system will extend the life span of the battery on the bus.

Objective:

The objective of this project is to develop an energy storage system that is suitable for use in Hybrid Electrical Vehicles (HEV) and can be used for remote or backup energy storage systems in absence of a working power grid. In order to get the highest efficiency from this system, super capacitors will be used in parallel with the battery and a pulsed load. The final product should use active circuit components to influence performance and efficiency in accordance with a varying load. The load will be programmed to simulate a pulsating energy demand. The goal is create an efficient system with an overall reduction in cost, size, and weight.

Tasks:

- (1) Design a battery to provide the average power to the load for at least 20 minutes
- (2) Design a supercapacitor to provide the pulse power to the load
- (3) Design and build a hybrid structure (or circuit configuration) of the battery and supercapacitor to provide needed power to the load
- (4) Design and build a programmable load to simulate the pulsating load
- (5) Test and demonstrate the hybrid energy storage system to prove that the constant power is from the battery and the pulse power of the load is from the supercapacitor
- (6) Provide final report and suggestions to improve/optimize the system

Design Specifications:

For safety reasons the hybrid energy storage system should be 48 volt nominal and able to power a pulsating load with the following characteristics: 48 volt $\pm 20\%$, 1 KW peak power for 18 seconds over every 2 minutes (consider almost 0 kW for the remaining 102 seconds of every 2 minute period). The energy storage system should be able to provide at least 20 minutes of power to the load. The system will be used for vehicle power storage and as an alternative destination for renewable energy output that does not directly connect to the power grid. This design will be on a smaller scale than actual systems used in Hybrid Electric Vehicles and renewable energy storage systems.

Project Deliverables:

- A working unit of a 1 KW hybrid energy storage system
- A working unit of 1 KW programmable load
- A final report of test results and suggestions to improve and optimize the system

FAST Diagram:

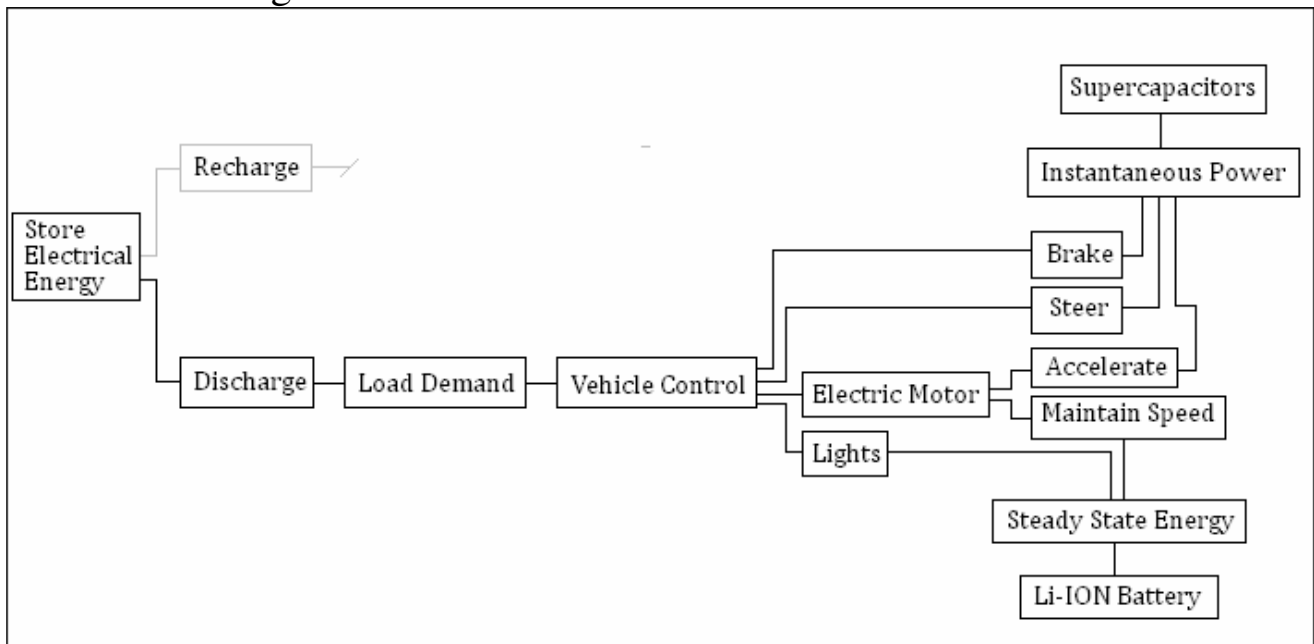


Figure 1. FAST Diagram

Conceptual Design Descriptions:

Design α :

Battery Parallel Comparison System

This system uses no active circuit components. This circuit maximizes efficiency through advanced computer simulation to determine the best capacitance/battery combination. The circuit responds to the load without any active control systems. See Figure 2.

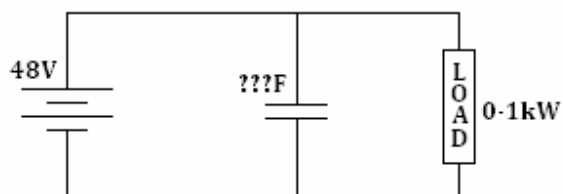


Figure 2.

Design β : Three Supercapacitor Array Pulsating System

This system uses at least three arrays of supercapacitors. While one supercapacitor is powering the load, the other two are being recharged by the battery. Once the supercapacitor powering the load is drained to a predetermined voltage level, it will be replaced by one of the capacitors already being charged by the battery and then begin its own recharge cycle. This process will then repeat by switching to the next supercapacitor. By the time the third supercapacitor is drained, the first will be recharged and ready to continue the cycle. This process is much like a machinegun with a self-replenishing, looped belt of ammunition. Each supercapacitor would fire its charge in sequence like the pistons in an internal combustion engine then recharge and fire again.

The actual number of supercapacitors that would be required to pump out a nearly continuous voltage is dependant on the recharge time of the supercapacitors. Supercapacitors are very quick to charge, and a reasonably small quantity should be needed to create such a system. If it takes one second to discharge a supercapacitor and two seconds to charge it, the system would require a total of three. If it takes one second to discharge a supercapacitor and 50 seconds to recharge one, the system would require 51 supercapacitors. The discharge time can also be manipulated by setting the percentage of voltage drop allowed per capacitor, per cycle lower. For instance, the amount of time it takes for a 10% voltage drop to occur is less than the amount of time it takes for a 30% voltage drop. As a capacitor discharges, its voltage decays to zero exponentially. So the larger the voltage drop allowed, the greater the output voltage ripple will be. The previous process described is the pulse generator. See Figure 3.

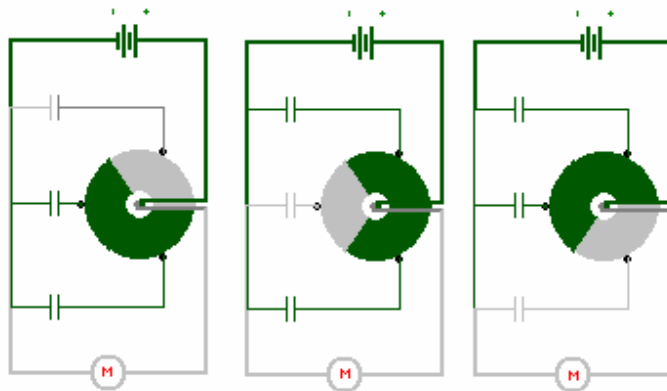


Figure 3. Pulsing Circuit

Design γ :

Li-Ion Battery – Supercapacitor Hybrid System:

The system shown below in Figure 4 will contain a 48.1V Lithium Ion (Li-ION) battery in parallel connection with a 48.6V array of supercapacitors. The connection between the battery and supercapacitor array will be controlled and monitored through active circuit elements and a small microcontroller. A varying load with a maximum resistance of 2.5Ω and a peak dissipation of 1kW will be connected, in parallel, with the battery – supercapacitor system.

Design δ ''

NiMH Battery – Supercapacitor Hybrid System:

This system is similar to design Gamma, but uses a Nickel Metal Hydride battery instead of a Lithium Ion. This also removes the need for a Protection Circuit Module (PCM) reducing circuit complexity and overall system cost.

Conceptual Design Ranking

Feasibility Factors	Design α	Design β	Design γ	Design δ
Microcontroller	No	Yes	Yes	Yes
Li-ION Battery	Yes	Yes	Yes	No
NiMH Battery	Yes	No	No	Yes
Commercially Available Battery	No	No	No	Yes
Commercially Available Supercap Array	Yes	No	Yes	Yes
Single Array of Supercapacitors	Yes	No	Yes	Yes
Time Constraints	Yes	No	Yes	Yes
Computer Model	Yes	No	Yes	Yes
Load Feedback	No	No	Yes	Yes
Feasible	No	No	Yes	Yes

Figure 4. Feasibility Matrix

Desirables	Importance	Design γ		Design δ	
		Rate	R x I	Rate	R x I
Power	5	4	20	4	20
Capacitance	4	5	20	5	20
Modular	2	3	6	3	6
Energy	4	5	20	3	12
Expense	2	3	6	4	8
Safety	3	2	6	3	9
Total			78		75

Figure 5. Desirability Matrix

Proposed Design Solution:

Design γ : Li-Ion Battery – Supercapacitor Hybrid System:

The system shown in Figure 4 will contain a 48.1V Lithium Ion (Li-ION) battery in parallel connection with a 48.6V array of supercapacitors. The connection between the battery and supercapacitor array will be controlled and monitored through active circuit elements and a small microcontroller. A varying load with a maximum resistance of 2.5Ω and a peak dissipation of 1kW will be connected, in parallel, with the battery – supercapacitor system. See Figure 6.

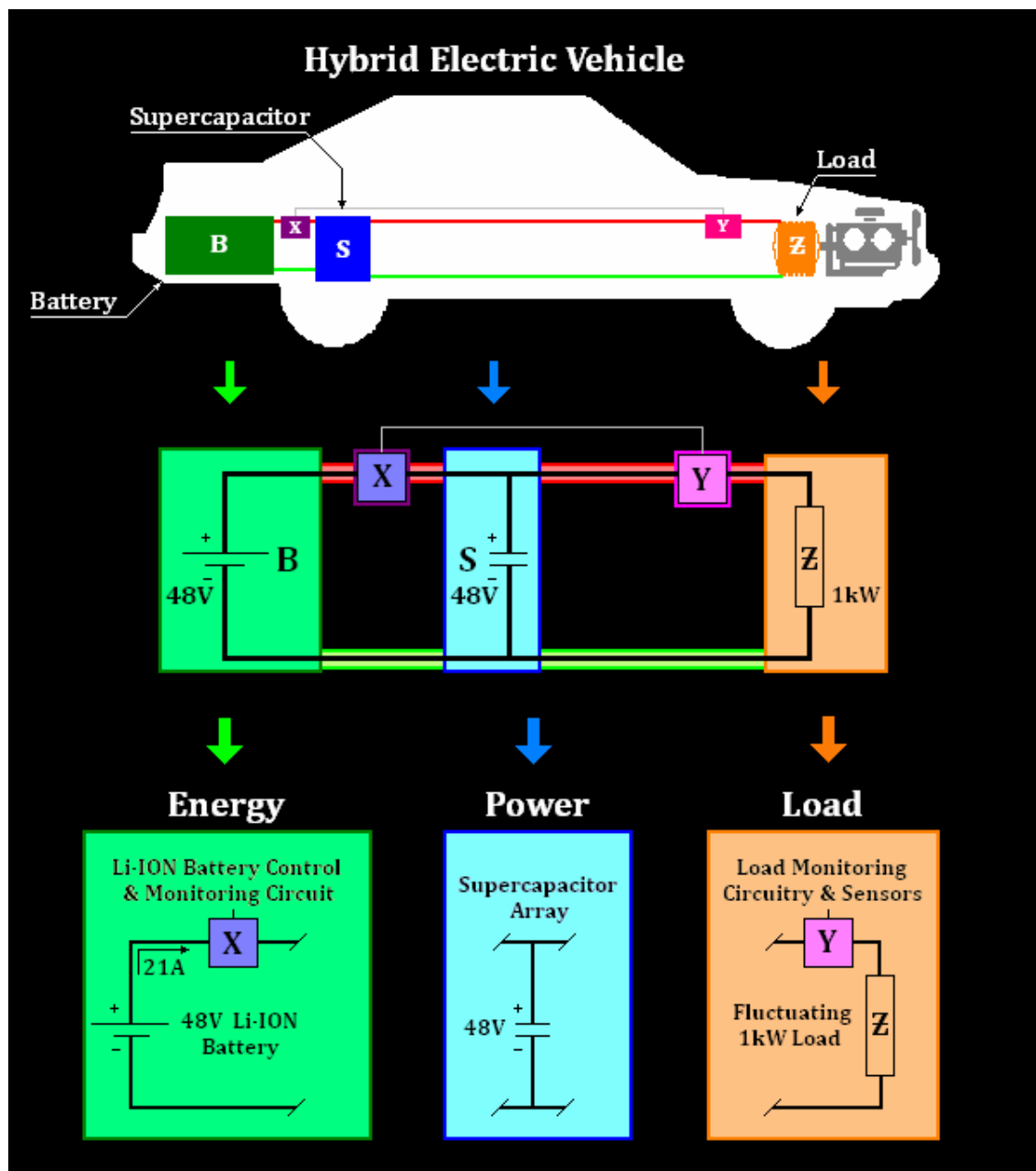


Figure 6. Active circuit components, a microcontroller, and electronic sensors will be included in the hybrid system. The system controller will interface with and receive digital feedback from the Protection Circuit Module (PCM) on the Li-Ion Battery, the internal control circuit of the supercapacitor array, and various sensors monitoring the load demand. This will allow the hybrid system to react to demand from the load, adjusting the voltage between the battery and supercapacitor or temporarily disconnecting the battery from the circuit for instance.

Components:

48.1V Rechargeable Lithium Ion Battery

Lithium ion batteries have very high energy to weight ratio compared to other rechargeable batteries. They have no memory effect and slow loss of charge when not in use. The battery will provide near constant energy for the system.

Supercapacitor Array (size and capacitance to be determined at a later date)

High power density makes supercapacitors the perfect complement to the high energy density rechargeable Li-ION batteries. Supercapacitors serve as a buffer between the battery and a load and provide pulse power to the load when demand exists.

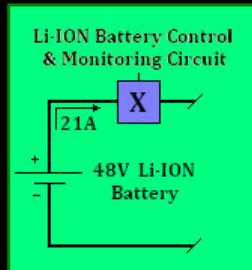
Load

Maximum 2.5 Ohm, pulsating load with 48 volts $\pm 20\%$, and one kilowatt peak power for 18 seconds during a period of 2 minutes (almost zero kilowatts for the remaining 102 seconds of every 2 minute period). This cycle will then be executed nine more times for a total of 10 times over 20 minutes.

Control Circuitry

A DC-DC converter will be used to regulate voltage and to keep the battery safe from large current surges from the capacitor array. A microcontroller will be used to process feedback from the battery - super capacitor system and the load. This feedback will contain system information such as capacitor voltage and charge, battery voltage and remaining power, and load voltage.

Energy



13 Lithium Ion Cells

- 3.7V Each
- Total Series Voltage = 48.1V



Protection Circuit Module (PCM)

- Overcharge/Discharge Protection
- Cell Power Balancing

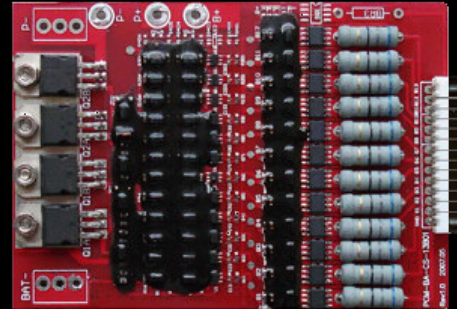
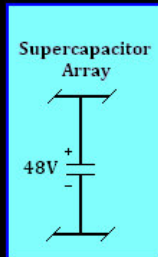


Figure 7. Due to the poor selection of 48.1V Li-ION batteries on the commercial market, we will be constructing our own battery from 13 individual Li-ION cells. This battery will include a Protection Circuit Module (PCM) which will prevent overcharge and discharge and balance the energy in the individual cells.

Power



MC BMOD Power Series 48V Supercapacitor Array

- BOOSTCAP® Ultracapacitor Module
- 48.6V Operating Voltage
- Ultra Low Internal Resistance
- Over 1 Million Duty Cycles
- Individually Balanced Cells
- Voltage & Temperature Sensor Output
- Compact, Fully Enclosed Design



Maxwell Part No.	Capacitance (F)	Ic (mA)	Rth (C/W)	Isc (A)	E _{max} (Wh/kg)	P _{max} (W/kg)	Pd (W/kg)	Mass (kg)
BMOD0083 P048	80	3.0	0.39	3,900	2.48	5,400	2,000	11.0
BMOD0110 P048	110	4.2	0.33	4,300	2.91	6,200	2,400	12.4
BMOD0165 P048	165	5.2	0.25	4,800	3.81	7,900	3,200	14.2

Figure 8. We will be using a Maxwell BMOD0165 165 Farad Supercapacitor array. The Supercapacitors are used to meet instantaneous power demands.

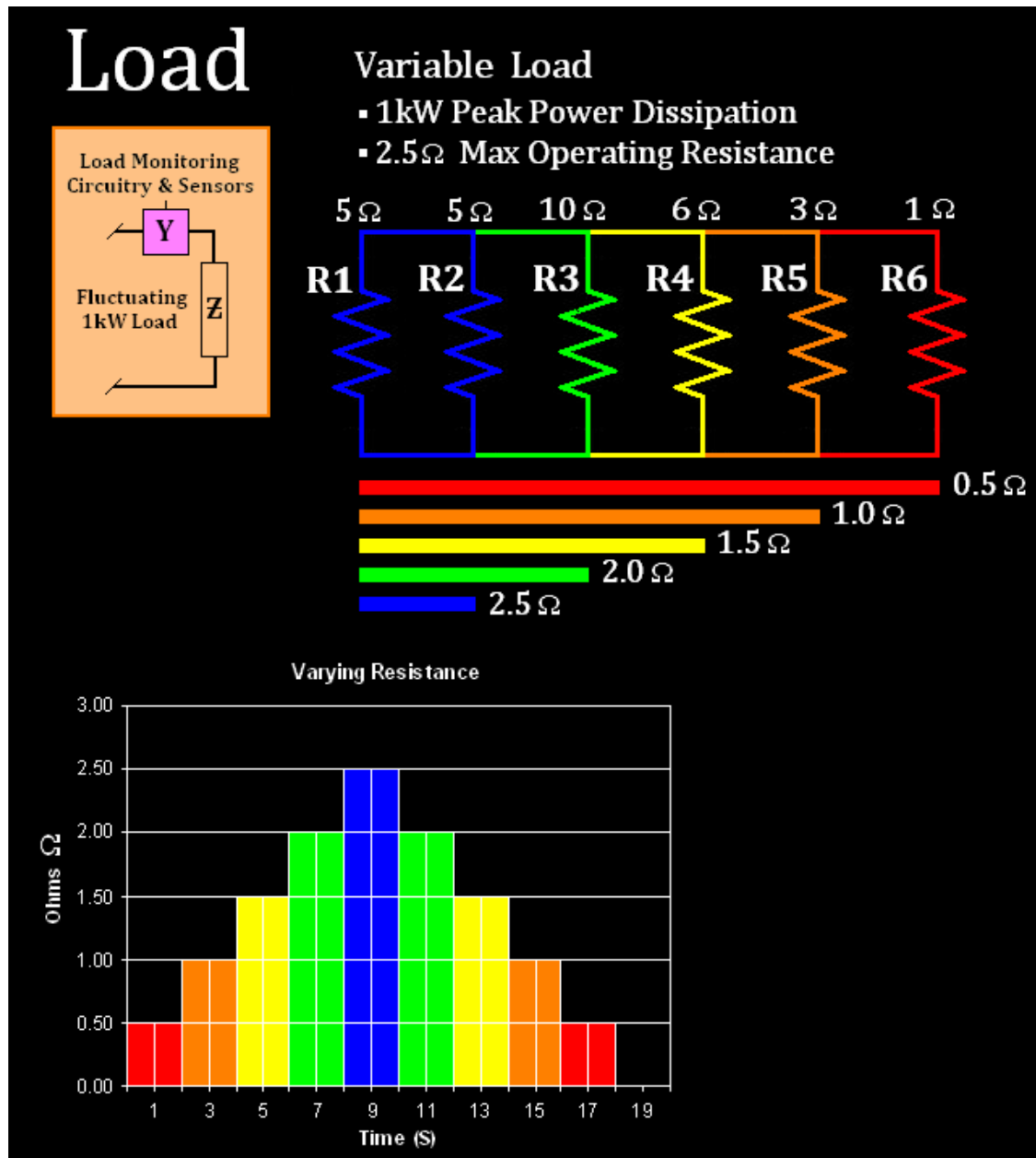


Figure 9. The programmable load will have a maximum resistance of 2.5 Ohms and 1 kilowatt peak power dissipation. The load will be fluctuating from 0.5 to 2.5 Ohms for 18 seconds, and then be near zero for 102 seconds, for a total cycle time is two minutes. System specifications require this process to repeat 10 times over the course of 20 minutes. There will be no on-board generation system in this design; we will assume that the battery has been fully charged.

Risk Analysis:

Lithium-Ion batteries are commonly used cell phones and laptops. In comparison with Nickel Metal Hydride batteries, a Lithium-Ion battery is smaller and lighter. A Li-ION battery also has a higher energy density, almost four times greater than that of Nickel Metal Hydride batteries. Because Li-ION batteries are inherently more powerful, they are also more dangerous and can be overheated if not charged under specifically monitored conditions. There may also be risk to the battery its self, if it is operated for an extended period of time and/or discharged below a certain level. The array of supercapacitors is especially dangerous because of their high capacitance. Extra care should be expended when working with any supercapacitors.

The battery has many chemicals capable of causing injury. The chart below highlights some potential risks and warnings, and what corrective action to take.

	Risk			
1	Battery might be overheated(by external sources)	Do not store next to a heat source		
2	Battery might be overheated(by short circuited)	Stop the operation immediately		
3	Cell Leakage(skin/eye contact with electrolyte)	Rinse with plenty of water immediately and seek medical attention		
4	Cell Leakage(having reaction with metals such as zinc)	Evacuate building and notify fire department		
5	The capacitor might not be completely charged or discharged	Do not short circuit terminals		

Project Management Plan:

Marvell Mukongolo

Project manager: The project manager is in-charge of the organization of the team. Tasks include scheduling meetings with team members, sponsor and facilitator. While also making sure all homework, projects and deadlines are met.

Technical Role: Pulse load simulation and implementation.

Chi-Fai Lo

Webmaster: The webmaster is in-charge of maintaining the teams webpage.

Technical Role: Nickel-Metal Hydride battery research, simulation and implementation.

Michael Kovalcik

Documentation: The documentation manager is in-charge of all paper work done by the team. They are required to polish all paper work before the final product is handed in.

Technical Role: Lithium ion battery research, simulation and implementation.

Jamal Adams

Presentation and Lab coordinator: The lab coordinator is responsible of part orders, parts tracking and maintaining equipment. The presentation coordinator is responsible for final editing of all power points and poster board presentations.

Technical Role: Ultra capacitor research, simulation and implementation.

Gantt Chart:

See Appendix: A

Budget:

Team ten has a budget of \$10,000 provided by our sponsor KELD LLC.

	Equipment	Quantity	Manufacturer	Part No	Price
	13 cells Lithium ion battery	13 cells	OEM from Japan	LC-18650-JP-2200	\$3.65 x13 =\$47.45
	Microcontroller (load & battery)	2	N/A	MEKAVR128-KIT	\$79.95
	Protection Circuit Module (PCM)	2	N/A	N/A	\$100
	DC-DC converter	1	MeanWell	VSD-50C Series	\$70
	Array of Super capacitors		N/A	N/A	500-3000
	Charger for Lithium ion cells	2	YUNTONG Power Co Ltd	YT-55240P	\$100
	Load Resistors(1KW power rating)	1	N/A	N/A	\$2000
Total					1097.40 to 3597.40

***Since we had difficulty finding a lithium ion battery with exactly 48.1 volts, we will be building our own battery pack.**

References

How Capacitors Woks

<http://electronics.howstuffworks.com/capacitor.htm>

How Batteries Work

<http://electronics.howstuffworks.com/battery.htm>

How Electric Car Batteries Work

<http://auto.howstuffworks.com/electric-car-battery2.htm>

How Lithium Ion Power Batteries Work

<http://auto.howstuffworks.com/lithium-ion-battery-car1.htm>

Electric Double Layer Capacitors

<http://en.wikipedia.org/wiki/Supercapacitor>

Ultracapacitors for Use in Power Quality and Distributed Resource Applications

<http://ieeexplore.ieee.org.proxy2.cl.msu.edu:2047/iel5/8076/22348/01043241.pdf?tp=&isnumber=22348&arnumber=1043241&punumber=8076>

Ultracapacitor/ Battery Hybrid for Solar Energy Storage

<http://ieeexplore.ieee.org.proxy2.cl.msu.edu:2047/iel5/4468832/4468909/04469050.pdf?tp=&isnumber=4468909&arnumber=4469050&punumber=4468832>

Laptop Batteries Are Linked to Fire Risk

<http://query.nytimes.com/gst/fullpage.html?res=9403E1DA1F3AF936A25750C0A9679C8B63>

Safety Data Safety Data Sheet Secondary Nickel-Metal Hydride Sealed Cells

<http://www.inficon.com/download/en/930-4061-G1%20NiMH%20BATTERY.pdf>

Hybrid electric vehicle

http://en.wikipedia.org/wiki/Hybrid_electric

Nickel-metal hydride battery

http://en.wikipedia.org/wiki/Nickel-metal_hydride_battery

Lithium-ion battery

http://en.wikipedia.org/wiki/Lithium_ion_battery

Regenerative brake

http://en.wikipedia.org/wiki/Regenerative_braking

UltraBattery Combines Battery and Supercapacitor Power

<http://www.greencar.com/features/ultrabattery/>

Appendix: A

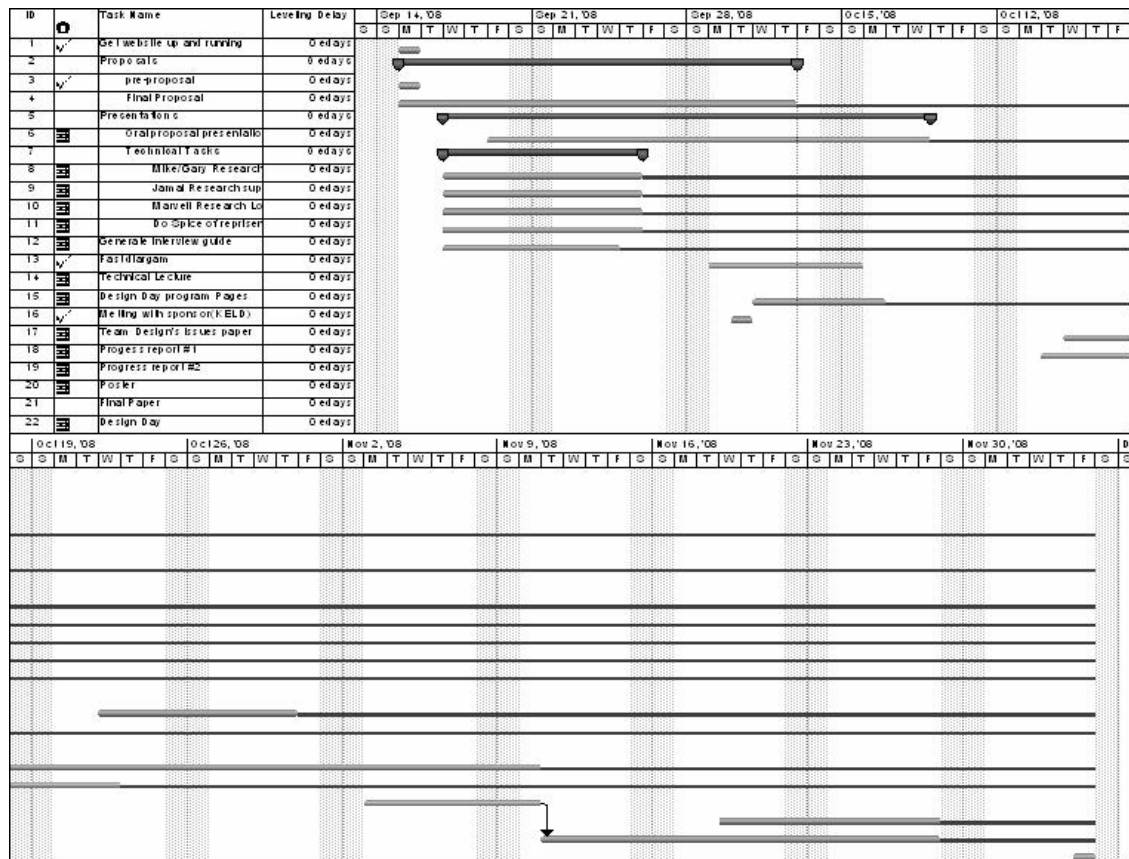


Chart 1. Gantt Chart