Reliability Assessment of Ultra Capacitors Under Various Thermal and Stress Shock Conditions

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Abstract:
Ultra capacitors are devices that store charge electrochemically, unlike a battery, which stores energy through chemical reactions. One major hindering factor holding an ultra capacitor from competing with a battery is energy density, the amount of energy capable of being stored in a certain volume. Current research uses carbon nanotubes to improve energy density. Vertically aligning the carbon nanotubes eliminates space for charged particles to shift or bounce" around and in doing so maximizes energy density.

Ultra capacitors were constructed and tested inside the FastCAP laboratory using high tech equipment. Each cell was made by hand and then tested under various conditions various shock conditions on a vibration table. It was concluded that after cycling through various tests only a minor degradation was noticed in each of the cells. It was found that after certain periods of time ultra capacitors ability were hindered and there was minor degradation. Due to time constraints, this data is limited and the cells were not able to be tested until failure. Future research may propose a longer testing period and to test until ultra cap failure.

1. Introduction:

Electric double layer capacitors, ultra-capacitors, or super capacitors all refer to a unique type of energy storage device that creates and stores energy in electric fields (Sharma et. Al '10). Within an ultra-capacitor, there are two sheets of aluminum coated with carbon, each separated by a di-electric composed of fiberglass, paper or polypropylene. Typically, the carbon inside the device is extremely porous to maximize energy density. Charged particles collect on top of the carbon and then are passed through the current collector, also composed of aluminum. Ultra caps can potentially be used in a variety of applications including; vehicular uses and geothermal uses (Tester et. Al '06, Uzunoglu et. Al '07). The one thing preventing these devices from performing in these applications is energy density.

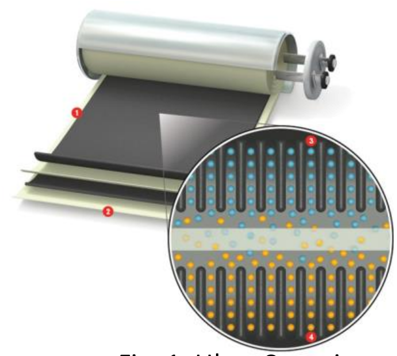


Fig. 1: Ultra Capacitor

2. Comparison- Ultra Capacitor versus Battery:

Many people may wonder why not just use a battery instead of an ultra cap. Here's why, ultra capacitors have many advantages compared to a traditional battery. Ultra caps have an extremely long life cycle, typically spanning the life of the item it's being applied to (Lajnef et. Al '09). The ultra capacitor can completely drain and recharge 500,000 to 1,000,000 times before seeing 10 to 20 percent degradation. A traditional battery can only be cycled 10,000 times before being deposed. (Beard et. Al '11). Charge and discharge time brings about one of the greatest advantages over a battery, ultra capacitors can charge and discharge in a matter of seconds (depending on size), while batteries can take hours to recharge (Beard et. Al ‘11). This specific advantage makes it a key candidate for the use in hybrid vehicles because of rapid acceleration that is used in cars. Temperature exposure plays a crucial role in the how useful a battery can actually be, ultra caps can withstand much more extreme temperatures and conditions because of the materials they are composed of. This feature can potentially be useful in applying ultra capacitors to the field of geothermal energy. Many environmentalists admire the ultra cap as a “green technology”, the content within ultra caps are environmentally friendly, compared to batteries which contain harmful and toxic chemicals such as battery acid (Sharma et. Al). Many concerns are about the current cost of batteries and how much people are buying them because of all the technology available, thus being people are looking for alternatives. Ultra capacitors are significantly cheaper than any traditional battery, specifically $22 per KW cheaper. Many companies including Fastcap Systems are finding methods of production that bring the cost of an ultra cap to about $3 per KW. However, the one factor that is putting a halt to ultra cap’s mass production and being applied worldwide is its energy density. Current ultra capacitors lack energy storage capabilities, or energy density; the carbon pores that are within the device are irregularly shaped causing charged particles to bounce around, thus limiting the energy efficiency (Beard et. Al ’11). Many scientists are research ways to improve upon this flaw; some are turning to the use of carbon nanotubes.

3. Carbon Nanotubes:

As stated above, the one major setback for an ultra capacitor is its energy density or capability to hold a charge. As of now ultra caps are useful for quick charge and discharge, while batteries are meant for a much longer period of time. One technology that is beginning to appear in the ultra capacitor world is the use of carbon nanotubes. Nanotechnology has a unique capability to design and develop structures on an atomic scale, generally measuring somewhere on the scale of billionths of a meter (Serrano et. Al '09). By combining the sheets of carbon with nanotubes, it creates a unique aligned structure capable of increasing the energy density of an ultra capacitor. The carbon nano-sheets are grown directly on metal current collectors at a high temperature to maximize nanotube growth (Miller et. Al '11). By vertically aligning the carbon nanotubes, it creates a place for charged particles to not to shift or "bounce" around (Mamalis '11). In a study performed by Cheng-Wei Huang, EDLC's grafted with carbon nanotubes were shown to have much higher electron and electrolyte-ion conductivities compared to an EDLC without carbon nanotubes. Carbon nanotubes have tested to be stable in different chemical conditions and a variety of temperatures and vibrations (Huang et. Al '08). The technique of applying carbon nanotubes into ultra capacitor devices exponentially benefits the energy density of the overall EDLC's.

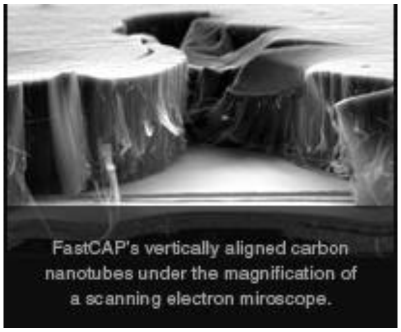


Fig.2: Carbon Nanotubes

4. Ionic Liquid Electrolyte Versus Organic Electrolyte:

Traditionally used in electrochemical devices including ultra-capacitors, organic electrolyte poses a major setback to the technology. The organic electrolyte showed reasonably higher power densities (>7 kW kg^-1) but still relatively low energy densities (≅4 Wh kg^-1). Making the organic electrolyte have a smaller cell voltage and low energy. The one advantage to these electrolytes is their large electrochemical window, or its ability to withstand a wider range of voltages without being oxidized or reduced. While using organic electrolyte in current electrochemical technology, electrolyte depletion occurs causing a number of setbacks to occur; limits energy density, increases cell resistance, which lowers the maximum power. Aside from performance, some organic electrolytes pose a serious health concern including, extreme volatility, flammability and toxicity. These health concerns limit the current use of electrochemical devices because they cannot be exposed to high temperatures. (Lewandowski et. Al).

An alternative to these organic electrolytes is ionic liquid electrolytes (ILs). IL's consist of high ionic conductivity, therefore increasing maximum power and energy. An extremely large liquid phase range (-100-400C) that limits electrolyte depletion. A wide electrochemical window, non-volatility, non-flammability and non-toxicity, all factors that were previously limiting organic electrolyte (Lu et. Al).

5. Applications:

5. 1 Vehicular Application:

Ultra capacitors have the potential to be applied to a variety of applications including the use of ultra caps in vehicular and geothermal fields. These are some of the most recent and up to date applications for ultra capacitors. As stated above the vehicular field is a perfect match for these devices, cars need a fast burst of energy when accelerating which is just what ultra caps can deliver. In a car, the ultra capacitor would work in aid with a traditional battery and a hybrid engine. When the car begins accelerating the ultra cap kicks in and aids in the acceleration process, when the car begins to decelerate or cruise, the regenerative braking energy is regained in the ultra capacitor. Some alternative options for the use of ultra caps in vehicles can also include the combination of a fuel cell and an ultra cap. The combination of these two can significantly increase fuel efficiency within the vehicle by providing an alternative way of creating energy to power a car. This method is especially useful when the car is starting up, accelerating or during sudden changes while the vehicle is in motion (Uzunoglu et. Al '07).

5.2 Geothermal Application:

Geothermal energy is beginning to be recognized as the future of energy here in the United States as well as many other countries. The benefits to utilizing this energy source are endless: the cost benefits, no need to import millions of barrels of oil a year, environmental aspects, benefits over other renewable resources such as minimal emissions. Throughout the United States there is an abundant amount of geothermal energy that is not being utilized. Its hard to estimate just how much potential there is for geothermal energy, however the United Sates has taken the initiative and leads the world in geothermal production at about 30% of total geothermal production (Gallup '09).

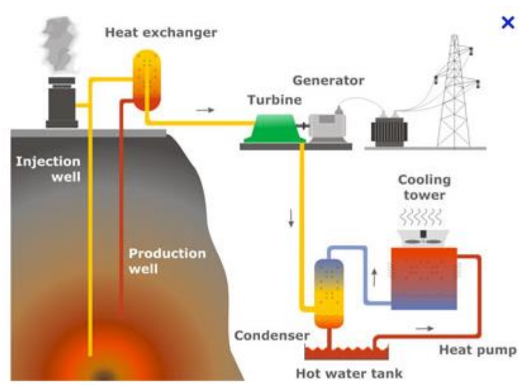


Fig. 3: A standard geothermal drilling well

Because of ultra capacitors capability to withstand extreme heat, making them a perfect candidate for geothermal applications. As of now, it is hard to get accurate measurements about the geothermal energy (how much there is and where it is). Ultra capacitors would be capable of withstanding those extreme temperatures of thousands of degrees Fahrenheit and the extreme vibrations deep below the surface of the earth. This would increase the efficiency of geothermal energy, save time and money while preserving and protecting out environment (Tester et. Al '06).

6. Research Objectives:

Research objective consisted of:

- Characterizing the durability of cells across various shock stress conditions

7. Methods:

Ultra capacitors were constructed and tested inside the FastCAP laboratory using high tech equipment. Each cell was made by hand and then tested under various conditions. Ultra caps were to be tested under various shock conditions on a vibration table. Each of the five cells was tested as follows:

Chart 1: Represents how each cell was tested, under what stress and for how long.

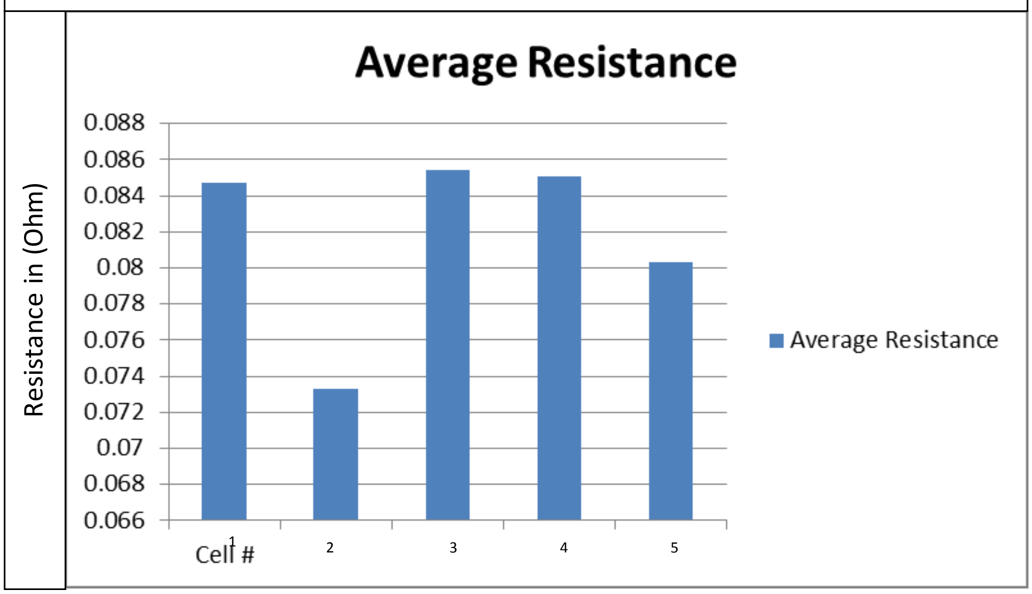
Cell 1 Organized Data			
Cell	Test	Resistance (Ohm)	Discharge Capacity (Ah)
1	Post Fill no vibration	0.1207	0.0142
1	10G 1 hr	0.0827	0.0154
1	5G 65 hr	0.0871	0.0147
1	50G 1 hr	0.0733	0.0164
1	50G 1 hr 2	0.0751	0.0161
1	50G 1 hr 3	0.0781	0.0164
1	50G 1 hr 4	0.0921	0.0151
1	50G 1 hr 5	0.0739	0.0167
1	50G 1 hr 6	0.0761	0.0159
1	50G 1 hr 7	0.0871	0.0149
1	50G 1 hr 8	0.0777	0.0153
1	50G 1 hr 9	0.0839	0.0152
1	50G 1 hr 10	0.0897	0.0151
1	50G 1 hr 11	0.0928	0.1031
1	50G 1 hr 12	0.0804	0.0158

For one, we had to determine and standardize the definition of ultrcap failure, at what point is the ultra capacitor unable to perform at ability level. Along with standard testing, we used Highly Accelerated Life Testing (HALT) to aid the process for time purposes. In addition we had to extrapolate life expectancy to expected environmental conditions. Evaluate the mean and standard deviation of the time to failure for each cell tested. Equipment for testing consisted of the use of the vibration table, set to various strengths and pulses.

8. Results:

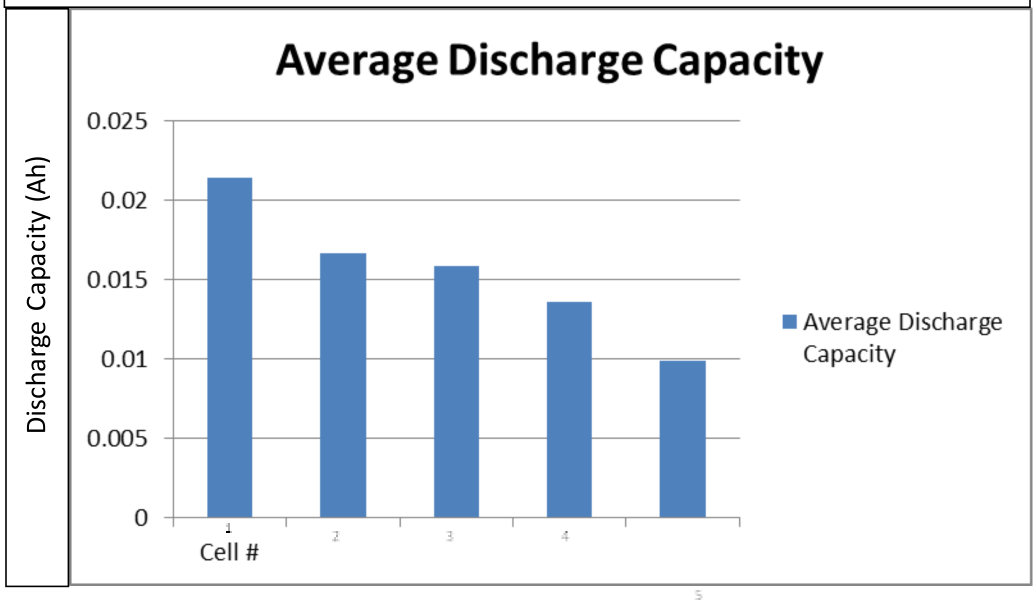
Results were calculated using a few different methods: average resistance and average discharge capacity were calculated, along with resistance measured in cells one and three to show the downward trend.

Graph 1: Average Resistance



Graph (1) shows the average resistance of all five cells across all tests performed on the cells. Resistance was measured in Ohms and varied at a minimum of .073 Ohms for cell two and a maximum of .085 Ohms for cell three.

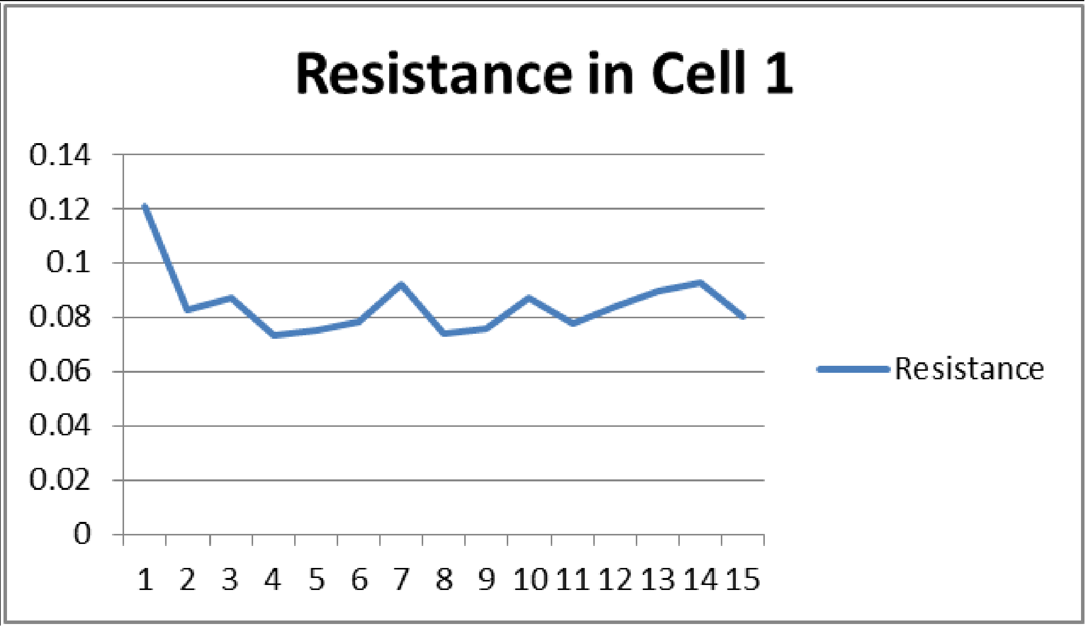
Graph 2: Average Discharge Capacity



Graph (2) shows the average discharge capacity of all five cells under all testing conditions. The cells discharge capacities varied from .09 Ah for cell five to a maximum of .022 Ah for cell one. Average resistance was then found across all cells by averaging the averages of the five cells. This number came out to be .0818 Ohm's. The same was done for discharge capacity. The average discharge capacity across all five cells came out to be .0155 Ah.

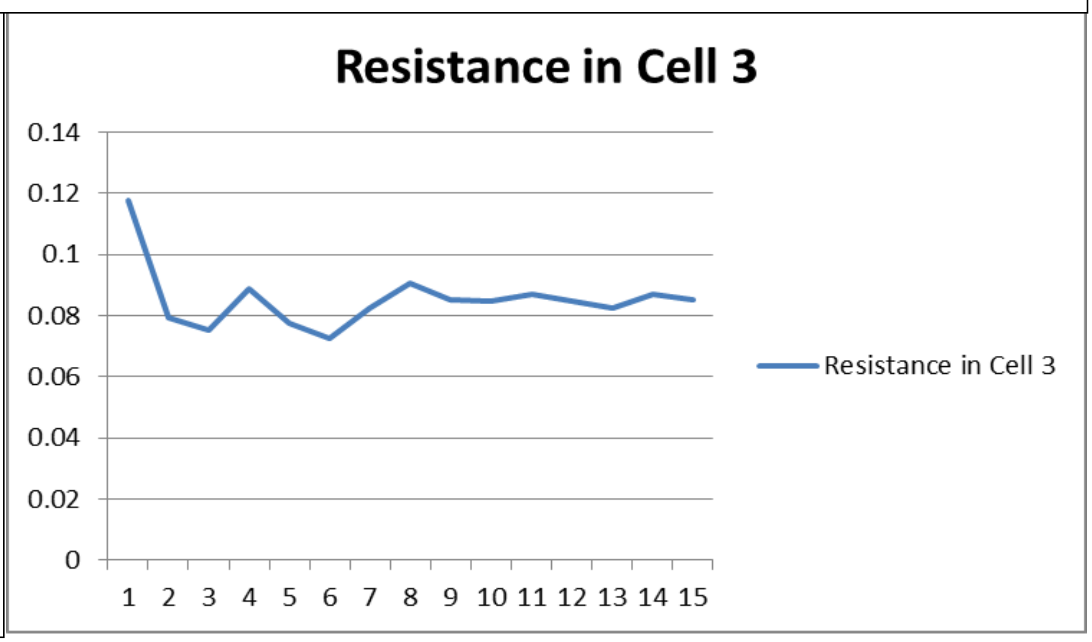
Graph 3: Resistance Across Cell 1

Resistance (Ah)



Graph 4: Resistance Across Cell 3

Resistance (Ah)



In graph (3) and (4) a downward trend is noted as cell one and cell three goes through consecutive testing at various vibrations.

9. Limitations/ Future Research:

One of the major limitations for this study was time constraints. Ultra capacitors are meant to withstand hours and hours in extreme conditions. Due to time constraints we used HALT testing to aid in the testing process. As for future research, it must be determined which method of constructing these ultra capacitors is most effective. For this research, metal-metal seals were used to close the ultra caps. In addition to construction, how can researchers improve energy density within ultra capacitors to compete with traditional batteries.

10. Conclusion:

Electric Double-Layer Capacitors have the potential to thrive in the field of energy storage devices, surpassing batteries for numerous reasons. As stated above ultra capacitors do have their setbacks including their limit on energy density, a key component to an energy storage device. It was also proven that using ionic electrolyte would be proven more effective for the use in electrochemical devices because of high ionic conductivity, large liquid phase range, large electrochemical window, its non-volatile, non-flammable and non-toxic, creating an ideal electrolyte for these devices. This paper focused on the analysis of five ultra capacitors under various stress shock conditions. It was found that after certain periods of time ultra capacitors ability were hindered and there was minor degradation.

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