Ultra-Capacitors and the Future of Battery Technology

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Abstract: It is well known that electric vehicles are the future and it is imperative that we study more about electric vehicles and how their performance can be improved so that they can be used by the consumers. Even though the electric vehicle technology has matured a lot, there are a lot of controversial thoughts regarding the battery technology being used in electric vehicles. This is where ultra-capacitors can prove to be a viable option. Ultra-capacitors are high-capacity capacitors that have a capacitance value much higher than other capacitors, but with lower voltage limits. Research conducted on ultra-capacitors have shown that it charges much faster than conventional lithium-ion batteries as well as has a faster discharge rate. Ultra-capacitors also tolerate more battery cycles compared to conventional rechargeable batteries therefore enabling ultra-capacitors to have a longer shelf life. This paper aims at giving a comprehensive overview of what ultra-capacitors are and how they can shape the future of battery technology in the next decade.

Index Terms **- Ultracapacitors, battery, electric vehicles, renewable energy.**

I. INTRODUCTION

Electric power is one of the most essential forms of energy conversion that is required by the human society. As technology progresses, the issues of energy crisis, battery technology and storage of energy becomes more prominent. Electric cars are one of the most studied areas and even as companies such as Tesla pushes electric cars such as the Tesla model S for the consumers to use, the battery technology being employed by these electric cars have always been a question. The currently available battery technology being used in electric cars can give a range of around 300 miles after which they need to be recharged. This is where the issues become much more evident. The charging of these cars from 0-100% take hours, thereby wasting a lot of time. The extensive study of ultra-capacitors has shown that they charge from 0-100% extremely fast and they discharge this acquired charge at a faster rate as well. In order to understand what an ultra-capacitor is, we need to know what a capacitor is and what capacitance means.

A capacitor, also called a condenser, is defined as a passive electronic component with two terminals that stores electrical energy in an electric field and this phenomenon is termed as capacitance. The simplest form of a capacitor consists of two plates separated by a dielectric such as air. Ultra-capacitors, otherwise known as electric double layer capacitors (EDLC's) or supercapacitors, store energy electrostatically by polarizing an electrolytic solution. Since ultra-capacitors fundamentally work on the principle of capacitance, which is an extremely reversible process, the ultra-capacitor can be charged and discharged hundreds of thousands of times. The main differentiating factor between a normal capacitor and a supercapacitor is the material used as the dielectric. Unlike ordinary capacitors, supercapacitors don't use conventional solid dielectrics. They use something called electrostatic double-layer capacitance and electrochemical pseudo capacitance.

- Electrostatic double-layer capacitors: They use carbon electrodes or derivates of carbon electrodes with a high electrostatic double-layer capacitance compared to the electrochemical pseudo capacitance. The separation of charge occurs as a Helmholtz double layer at the interface between the surface of a conductive electrode and an electrolyte. This separation of charge is of the order of a few angstroms, compared to a conventional capacitor where it is larger.
- Electrochemical pseudo capacitors use metal oxide electrodes (or polymer electrodes) which possess a high amount of electrochemical pseudo capacitance in addition to the double-layer capacitance.
- Hybrid capacitors which employ electrodes with different characteristics: one which exhibits electrostatic capacitance while the other exhibits electrochemical capacitance.

This paper will give a general idea about ultra-capacitors, their construction and their application in order to revolutionize battery technology for the upcoming years.

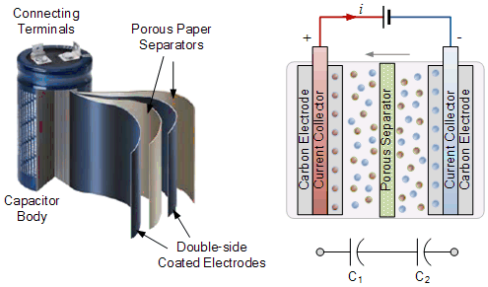

Fig-1: Construction of an ultracapacitor

II. CHARACTERISTICS OF AN ULTRACAPACITOR

Before we can study more about the applications of ultra-capacitors, we need to understand what are the pros and cons of the ultra-capacitor so that we can optimize its performance for our applications.

2.1 Advantages of an ultra-capacitor:

1. Virtually unlimited cycle life as it can be subjected to millions of charge cycles.
2. Charges extremely fast.
3. Charging mechanism is simple as it draws only what it needs and does not overcharge.
4. Safe to use.
5. Excellent low-temperature charge and discharge performance.
6. Good reversibility.
7. Little degradation over thousands of charge cycles.
8. High specific power.
9. Long shelf-life. Conventional rechargeable batteries will eventually undergo self-discharge and corrosion if left without charging for a long time. Ultra-capacitors hold their capacitance value, thereby they can be charged normally even after not being used for a long time.

2.2 Disadvantages of an ultra-capacitor:

1. Low specific energy, therefore it can hold just a fraction of a regular battery. (An ultra-capacitor stores around 3-5 W.h/Kg compared to 30-40 W.h/Kg for a battery).
2. High cost per watt.
3. High self-discharge compared to most batteries.
4. Linear discharge voltage prevents using the full energy spectrum.
5. Low cell voltage thereby requiring serial connections with voltage balancing.

3.3 Efficiency of an ultra-capacitor:

The biggest factor that works in the favor of an ultra-capacitor is its charging and discharging efficiency. Unlike conventional batteries, the ultra-capacitor has the same efficiency during charging or discharging. This allows the ultra-capacitor to recharge quickly without current limiting as long as the current is within the rated current for the particular device. The primary losses with regards to efficiency in ultra-capacitors are due to the internal resistance of the device. This internal resistance gives rise to IR drop during the cycling of the ultra-capacitor. It is safe to assume that for most uses, the ultra-capacitor has an efficiency of around 98%. Considering the loss due to the internal resistance, under high current and power pulsing, the efficiency does take a hit but the typical efficiency of the ultra-capacitor under high current pulses is still above 90%.

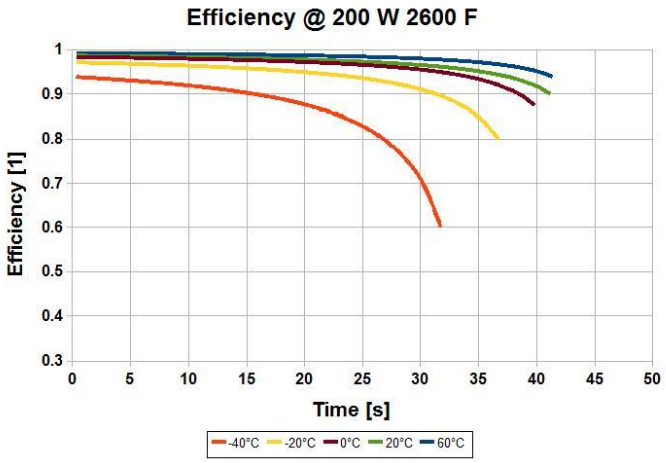

Fig-2: Efficiency of a BCAP2600 at 200W 2600F. Source: Garmanage

III. APPLICATIONS OF ULTRACAPACITORS

The primary reason that the study and research of ultra-capacitors has gained a lot of interest is the replacement of current energy storage systems that are currently available to us. The energy crisis and the need for storage of energy for the near future is something that is of utmost importance and it is therefore imperative that we study more about ultra-capacitors and how to make them a feasible option for energy storage.

3.1 Automobile industry:

One of the main reasons why ultra-capacitors are being studied is for the usage in electric and hybrid electric vehicles. Current electric automobiles run on lead batteries. Ni-Mh batteries, Li-ion batteries and fuel cells. These batteries all have the common advantage of not only having a high energy density but also enabling the electric vehicle to drive for a longer distance. Ultra-capacitors on the other hand have a high-power density coupled with extremely fast charging. Fast charging is an important point to be noted as it can kill two birds with one stone: Reduce the time required for charging the car from a few hours to just a couple of minutes and to charge the car even faster using regenerative braking. The advent and adoption of ultra-capacitor-based technology once it has matured can completely revolutionize the automobile industry.

Another way we can try to use ultra-capacitors are in public transport, mainly buses and urban rail systems. Buses can be electrically powered using an ultra-capacitor and can be charged every other stop that it makes at the bus stop. Since the charging is extremely fast, the bus can be fully charged by the time the passengers even get on or off the bus, therefore making the experience extremely seamless. The fast charging capability of the ultra-capacitor also means that the regenerative braking will charge the system faster compared to a normal battery system. The energy produced by braking can be equivalent to 30% of the pulling energy. A similar system can be implemented for urban railway systems. Once the train starts up, all the energy that has been transferred back due to the regenerative braking can be used to power the train forward. The MITRA C Energy Saver, that

has been developed by the Bombardier Company can be considered as a typical application of an ultra-capacitor in urban rail traffic. The system that has been implement by MITRAC Energy Saver is seen to possess the following advantages:

- Significant decrease in the need for maximum power from the catenary.
- Under the condition of the catenary systems being disconnected, the train could still run for hundreds of meters.
- The stored energy in the ultra-capacitor can enable the urban rail system to travel in the heart of the city without the need of a catenary system to supply the necessary power.

Fig-2: MITRAC energy saver by the Bombardier Company

3.2 Industries:

Ultra-capacitors can supply a high short-time power for forklifts and cranes, thereby solving the problem of power limitation as well as reduce the carbon emission. Ultra-capacitors can also be used in data centers which need a constant supply. Systems such as a communication center, data center and network server, the UPS is an essential device that can be used for eliminating the grid faults, such as power outage, surge voltages, and frequency oscillations. The primary issue that can occur in a UPS is that when the electric source faults, the battery discharges immediately. Thus, the output power is limited to a lower level. The use of ultra-capacitors in the UPS system can improve the power output, lifetime as well as reduce the overall cost required for maintenance of the UPS.

Fig-3: Riello SuperCaps UPS uses supercapacitors to accumulate energy

3.3 Renewable energy:

Ultra-capacitors can be used in the control of the pitch angle in the harnessing of the wind power. This system can thereby change the pitch, regulate rotational speed as well as the power output by just adjusting the blade incidence of the device. Under normal conditions, the electrical energy produced by the wind turbine will charge the energy storage device (based on the ultra-capacitor) until the nominal voltage level is reached. The energy storage device will output electricity power in order to change the pitch of the wind turbine as and when required. This holds true even for high wind scenarios where the ultra-capacitor-based energy storage device ensures that the output power of the wind turbine does not exceed the rated power.

Another field where the ultra-capacitor technology can be applied is in solar energy. Photo-voltaic cells (PV cells) convert the energy coming in from the sun into electrical energy. Since these types of cells depend on the sunlight, these cells are adversely affected by weather conditions. Ultra-capacitor-based systems can help in the scenario by:

- Storing the electrical energy during the day and producing the output to satisfy the loads during the night.
- Performing Maximum Power Point Tracking (MPPT)
- Smoothening out the power delivery in combination with the PV cells.

IV. CONCLUSION

It is understood that electric vehicles are deemed to be the future and a lot of study and research needs to be done on them in order to fully adopt them all around the world and to make them extremely feasible for the OEM's to manufacture them as well as the consumers to purchase them. One of the main points of debate regarding electric vehicles is the battery technology that is being employed right now in electric vehicles. The batteries right now do have the advantage of having a high energy density as well as extending the range of the vehicle. But in order to charge the battery, it takes a few hours which can prove to be a hassle for many in this fast-paced world. This is one of the primary reasons why the interest in ultra-capacitors has peaked. Ultra-capacitors are seen to have a high power density as well as an extremely fast charging capability. Another issue that has plagued people is the energy crisis and the possibility of a future arising where there is not enough energy available to be spent. The need for long-term energy storage is essential and ultra-capacitors seem to be a viable option for that as well. There are a lot of advantages and disadvantages of ultra-capacitors and it is important to carry out extensive research as they have the potential to revolutionize the future of the entire earth. The important areas of research with respect to ultra-capacitors needs to happen in the fabrication, modelling and in the

reduction of the huge disadvantages faced by ultra-capacitors as compared to the already matured currently available battery technologies such as Li-ion.

Ultra-capacitors have a chance to shape the future of our nations in the coming decade all thanks to their characteristics and only extensive study and research can provide us with a significant break-through.

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