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Implementation for Modeling of Super Capacitors during Charge and Discharge for Electric Vehicles

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Abstract

On increasing demand of electric vehicle, efficiency and performance plays a very vital role and it depends upon the energy storage system of EV. In this paper, a new battery super capacitor hybrid energy storage system is proposed to meet the requirement. For automotive applications, the batteries are sized to ensure many constraints like start up, acceleration, braking and energy recovery. All these constraints give us a very heavy battery with very high energy compared to that required for these applications. To reduce the weight of the storage system, the battery can be associated with high power component like super capacitor. It is one of the crucial tasks to improve both efficiency and performance of the electric vehicle regarding electric power density and energy capacity. Super capacitor integrates system by means of static power converter. These systems can be completely electric or by using Fuel cell. The MATLAB simulation is performed to evaluate its performance and investigate the mitigation of battery stresses. Simulation model of hybrid energy source is presented and used to investigate the design optimization of electric vehicle on board of energy source in terms of energy efficiency and storage mass. Introduction of super capacitor reduces electric stresses, increases efficiency and enhances the overall performance.

Keywords: *Electric Vehicles, Super Capacitors, Charging and Discharging.*

Introduction

In short, super capacitors are high-capacity capacitors. They have higher capacitance and lower voltage limits than other types of capacitors, and functionally, they lie somewhere in between electrolytic capacitors and rechargeable batteries. What this means in practice is that they:

1. Charge much faster than batteries
2. Can store much more energy than electrolytic capacitors
3. Have a lifespan (measured in charge/discharge cycles) somewhere between the two (more than rechargeable batteries and less than electrolytic capacitors)

For a lifespan comparison, consider that while electrolytic capacitors have an unlimited number of charge cycles, lithium-ion batteries average between 500 and 10,000 cycles. Super capacitors, however, have a lifespan ranging from 100,000 to a million cycles.

Unlike conventional capacitors, a super capacitor has two solid electrodes (in contact with a terminal plate) each with a liquid electrolyte. The area between the solid electrode material and its electrolyte solution, as shown in Fig. 1, forms the ‘double layer’.

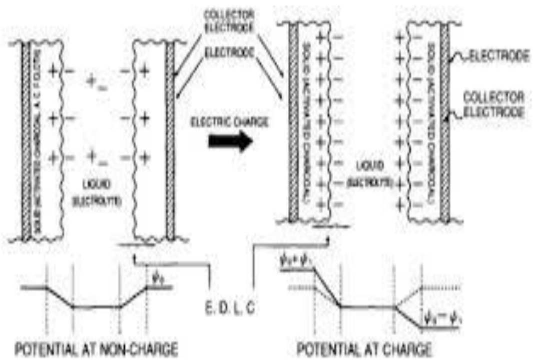

Figure 1: Super capacitor structure with positive and negative ions

When the super capacitor is charged, the electrons at the cathode attract positive ions and on the anode the vacancies of electrons attract negative ions in order to locally obtain a charged balance. This attraction of ions leads to a capacitance being formed between the ions and the surface of the electrode. The name dual layer comes from the two layers of ions at each electrode. The layer closest to the electrode acts as a dielectric and the layer outside the first layer hold the charges. This occurs at both electrodes in the super capacitor and the total capacitance consists of these two capacitances connected in series. When charges attract ions, they are gathered at the electrode surface (this is shown in Fig. 1 which is an ideal case). In the picture that describes the charged state, all the ions are at the respective electrodes. In reality the diffusion causes some ions to be located at varying distances around the electrodes. The intensity of the electric field determines the concentration of ions at the electrodes, which means that an increased voltage results in an increased capacitance. A major application of super capacitor is in hybrid electric vehicles (HEV). The super capacitor has energy storage system for a Metro-vehicle where the kinetic energy of the vehicle is conserved during breaking. Regenerative breaking is then used to store the energy into a super capacitor for later use. This method helps in saving energy voltage.

Experimental Methodology

An experimental system was developed which allowed the super capacitor to be normalized and subjected to controlled-current tests which then enable the equivalent circuit parameters to be calculated.

The super capacitor under test was subjected to controlled current charge and discharge. It has been developed to deliver a range of voltages and currents and hence is capable of characterizing the range of super capacitors. It is able to charge or discharge at up to 300mA in 2mA increments and current values are stable within 3ms. Simulations were run on a charge and discharge using the proposed model and the ideal which were then compared against the behavior of the BMOD0165 Super capacitor. The ideal model is obtained using MATLAB-Simulink while the proposed model is obtained from experiments carried out. Firstly, to remove any residual charge from the super capacitor, the super capacitor was normalized for 24 hours and then rapidly charged at 100mA.
This charging current allowed the verification of both the 'fast' and 'slow' effects of the super capacitor behavior to be verified, and is consistent with the charging rate of the super capacitor. After charging, the super capacitor was rested for one minute before entering a pulsed discharge test for one hour.

The device was subjected to a pulsed discharge of 70mA with a 2% duty cycle (70mA discharge current for 1s). There is a good correlation between the real (solid black line) and proposed (solid gray line) model performance, indicating that the generated model and parameters are correct.

Simulation Results

As the super capacitor is charged from almost empty to full charge, measurement points are taken at several places during the test cycle. The voltage drop occur ring over the series resistance is constant during charging and so does not affect the voltage difference measurement. Since the capacitance varies with the voltage, this relation is included into the model than to simply have a constant C value all the time a lookup table is added, so the correct capacitance value can be used in the simulations. The capacitance curve that is the result of the input voltage to the lookup table is shown in Fig. 2.

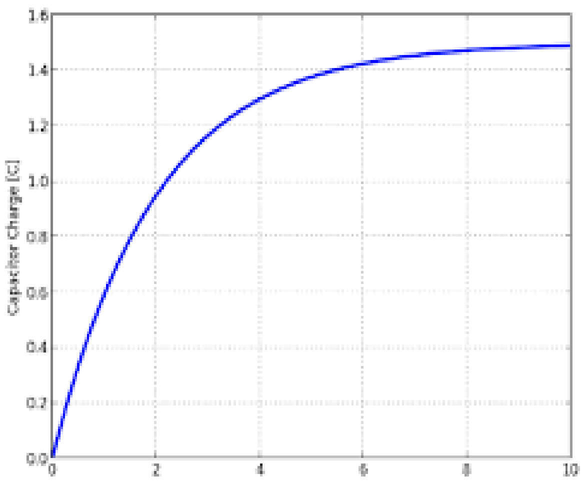

Figure 2: Capacitance Lookup

Fig. 3 shows the charge profile of the super capacitor at supply current of 20 Amperes where dashed and solid curve are represented as simulation and experimental results respectively.

Fig. 4 shows the discharge profile of the super capacitor at load currents of 20A, 40A and 60A where dotted and solid curves are simulation and experimental results respectively which shows a good correlation between simulation and

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experimental results However, the minor difference observed can be attributed to the effect of the approximated electrical model. Although the derived equivalent model is not a perfect model, it gives a good approximation of the super capacitor characteristics when compared to a real device in slow discharge applications. Using this model, it can be estimated by how much time the super capacitor can be fully charge at high levels of supply current.

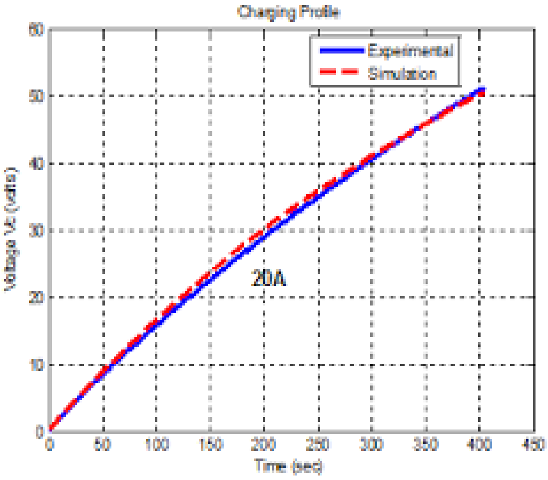

Figure 3: Charging profile of BMOD0165 Super capacitor

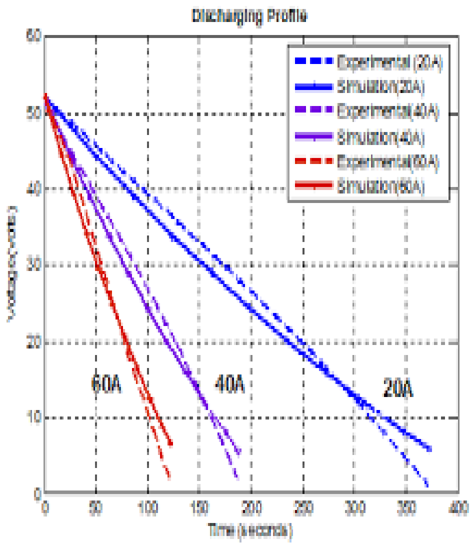

Figure 4: Discharging profile of Super capacitor

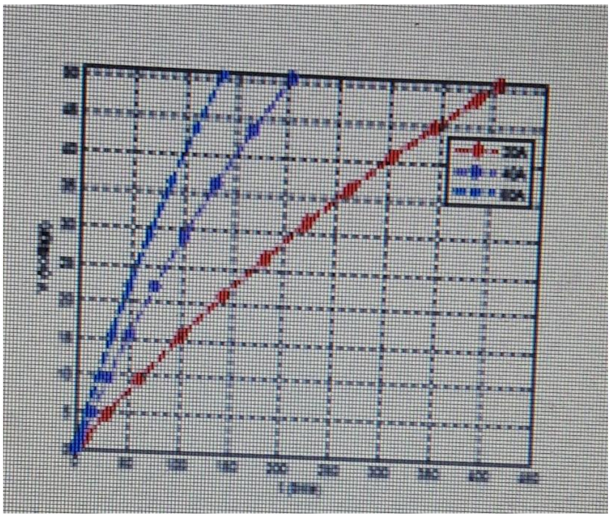

Figure 5: Simulated charge profile of the Super capacitor at 20, 40 & 60 Amperes

Graphical representation of experiment

This new electro-mathematical model is post-processed at different conditions of voltage, current, power and energy levels to analyze its performance and verify its accuracy. Fig 6 and Fig 7 summarizes the results of test set-ups devised through the charge and discharge profiles of the two reference super capacitors under test. Fig 6 provides the effects for different load consumption discharge profiles on the behavior of the same and different super capacitor at the same temperature. Fig 7 presents how changing the temperature affects the super capacitor's storage capacity having the same load consumption discharge profile and shows which super capacitor value goes into critical working level.

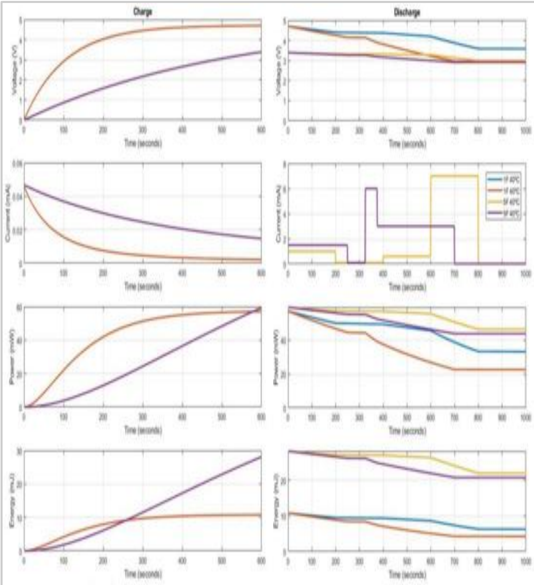

Figure 6: Mathematical model results with 1 F and 5 F super capacitors, 600 s charge with 5 V at 40 °C temperature and different profiles of discharge. Yellow discharge profile has five steps all with 200 s of duration; First 1 mA, second self-discharge, third 0.5 mA, fourth 7 mA and fifth self-discharge. Purple discharge profile has also 5 steps; First 1.5 mA for 250 s, second self-discharge for 75 s, third 6 mA for 50 s, fourth 3.5 mA for 325 s and fifth self-discharge for 300 s.

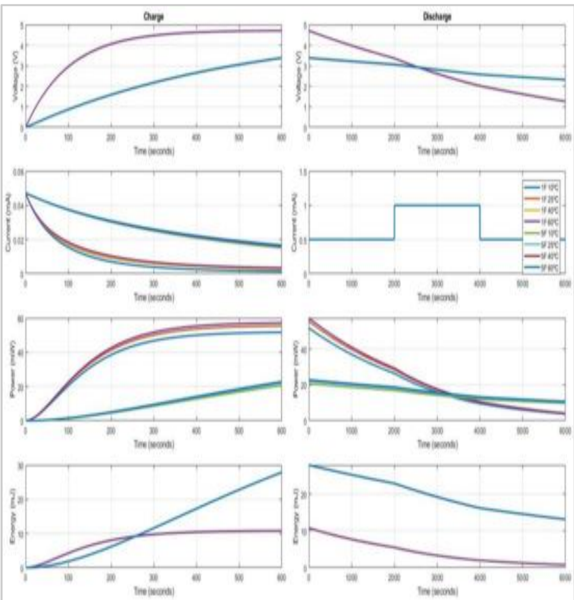

Fig. **7** Charge and discharge results obtained with the mathematical model for 1 F and 5 F super capacitor values at different temperatures (10, 25, 40 and 60 °C), 600 s charge with 5 V and same outer profile consumption composed by three steps; First step 0.5 mA for 2000 s, second step 1 mA during also 2000 s and third step as first one.

Fig. 8. It must be mentioned that these examples have a 50% value of ambient moisture. Fig. 2.14(a) represents a charge through 10 min with 5 Volt of input at 40 °C in a 1 Farad super capacitor. Then, a unique consumption profile of 1 mA is applied for discharge. As is shown in this example, the discharge curve descends quickly because of reproduced constant consumption of a low power system. Fig. 2.14(b) represents a 2.5 V of charge for 10 min at 25 °C in a 5 Farad super capacitor.

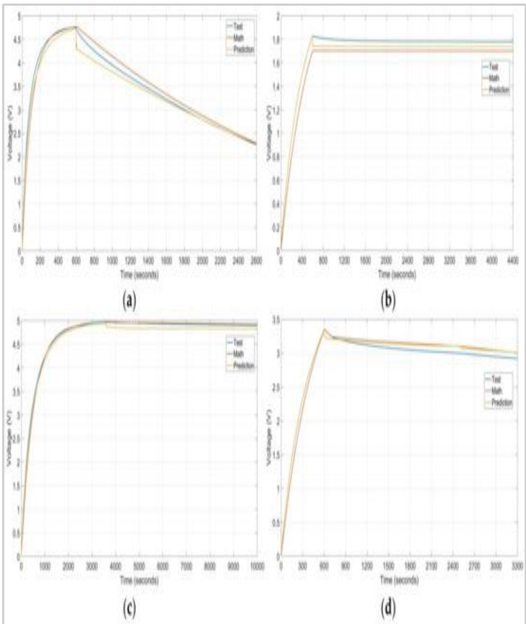

Figure 8 Graphic results and comparisons of described four different tests. (**a**) 1 Farad super capacitor charged through 10 min with 5 V at 40 °C and 1 mA consumption discharge, (**b**) 5 Farad super capacitor charged for 10 min with 2.5 V at 25 °C and self-discharge procedure, (**c**) 1 Farad super capacitor charge during 1 h with 5 Volt at 10 °C and self-discharge procedure, (**d**) 5-Farad super capacitor charge through 10 min with 5 V at 40 °C temperature and three discharge steps: 0.3 mA consumption through 3 min, 0.1 mA consumption through 10 min and self-discharge.

After charge time, the represented profile belongs to the self-discharge curve. Then, Fig. 8(c) represents a 10 °C temperature, 1 Farad super capacitor charge during 1 h with 5 Volt of input. In this case, the discharge procedure is also based on self-discharge technique. In the last displayed test, Fig. 8(d) represents a 5-Farad super capacitor charge with 5 V at 40 °C temperature for 10 min. Discharge has three different steps. The first one has 0.3 mA consumption profile through 3 min, the second one has 0.1 mA consumption profile through 10 min and represents the self-discharge process to the end.

Conclusions

Batteries and super capacitors have long been compared and contrasted by performance criteria. Batteries offer a superior energy density and possess a higher breakdown voltage, while super capacitors are lighter, have more robust operating limits, possess a longer life expectancy, and have an unparalleled power density.

The introduction of nano materials is revolutionizing super capacitors allowing for greater storage capacity and more diverse applications. It has now gained the semblance of a competing technology to rechargeable batteries in the field of energy storage devices in extreme environments. While it is yet to be seen how much of market penetration advanced supercapacitors will have, rechargeable batteries will continue to be the go-to device when higher voltage limits and greater energy density are needed and extreme environments aren't a limiting factor.

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