Ultracapacitor based Hybrid Energy Storage System for Hybrid and Electric Vehicles

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Abstract **-A new ultracapacitor/battery based hybrid energy storage system (HESS) is proposed for hybrid and electric vehicles by using both renewable and non-renewable resources, Compared to the conventional HESS design, which uses a larger dc/dc converter to interface between the ultracapacitor and the battery/dc link to satisfy the real-time high power density demands during high speed operation, the proposed design uses a much smaller dc/dc converter working as a controlled energy pump to maintain the voltage of the supercapacitor at a value higher than the battery voltage for the most city driving conditions.**

Key Words: Ultracapacitor(UC), battery, hybrid energy storage system(HESSs), hybrid electric vehicles (HEVs), regenerative braking system, power electronics.

1.INTRODUCTION

The basic idea of Ultracapacitor based Hybrid Energy Storage System for Hybrid and Electric Vehicles is to combine UCs and batteries to achieve a better overall performance. UCs having quick charging and quick discharging capacity will act as a Buffer or an assistant energy source between battery and the DC link . There are several conventional HESS configurations proposed, while Most of these combinations share one common feature batteries are most widely used energy storage devices, it cannot be used for high rate charge discharge operations, which causes unbalance of voltages between individual cells eventually the total capacity decreases.

1.1 ULTRACAPACITOR CONCEPTS

A ultracapacitor, often referred to as an electrochemical capacitor, is an electrical energy storage device that is constructed much like a battery in that it has two electrodes immersed in an electrolyte with a separator between the electrodes. The electrodes are fabricated from a high surface area, porous material having pore diameters in the nanometer (nm) range. The surface area of the electrode materials used in an ultracapacitor is much greater than that used in battery electrodes being 500-2000 m^2/gm. Charge is stored in the micropores or near the interface between the solid electrode material and the electrolyte. The energy stored in the capacitor is given by ½ CV^2, where C is the capacitance of the capacitor in Farads and V is the voltage between the terminals. The rated voltage of the capacitor is dependent on the electrolyte used in the device. The charge Q (coulombs) of the capacitor is given by CV. The charge and energy stored in the ultracapacitor are calculated using the same expressions as for a simple dielectric capacitor. However, calculation of the capacitance of the electrochemical capacitor is much more difficult because depends on complex phenomena occurring in the micropores of the electrodes. For an ideal double-layer capacitor, the charge is transferred into the double-layer and there are no reactions between the solid material, ions, and the electrolyte. In that case, the capacitance (dQ/dV) is a constant and dependent on voltage. For devices that utilize pseudo-capacitance, most of the charge is transferred at the surface of the solid electrode material. Ultracapacitors can be fabricated with one electrode being of a double-layer (carbon) material and the other electrode being of a battery-like material. Such devices are referred to as hybrid capacitors. Most of the hybrid capacitors developed to date use metal oxides (for example, lead or nickel oxide) as the battery-like material in the positive electrode or lithiated graphite in the negative. The energy density of these hybrid capacitors is significantly higher than for carbon/carbon double-layer capacitors.

Table-1: TYPICAL CHARACTERISTIC OF ULTRACAPACITOR CELLS

Nominal cell voltage(volts)	2.5/2.7
Energy density(Wh/kg)	2-30
Power density(kW/kg)	4-10

1.2 TEST RESULTS FOR ADVANCED ULTRACAPACITORS

A number of new ultracapacitor devices has been tested in the laboratory at the University of California-Davis. These devices include carbon/carbon devices from Estonia (Skeleton Technologies) and Ukraine (Yunasko) and hybrid devices from Ukraine (Yunasko) and Japan (JSR Micro).The carbon/carbon device from Skeleton Technologies (Figure 1) has high power capability with no sacrifice in power density. In fact, the Skeleton Technology device has the highest power density (9 Wh/kg) of any carbon/carbon device tested at UC Davis. This is due to higher capacitance and increase in the rated voltage from 2.7V to 3.4V resulting from the use of an improved organic electrolyte.

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Fig-1 Photograph of the 3200F Skeleton Technologies device

The JSR Micro devices (Figure 2) uses a graphitic carbon in the negative and an activated carbon in the positive. Such devices are called as lithium capacitors (LiC). Lithium ions are stored into the negative and stored in the double-layer at the positive electrode. The voltage of the LiC varies between 3.8V and 2.2V. When ultracapacitors are packaged in a laminated pouch, the energy densities of the devices are about 10 Wh/kg and 19 Wh/L. When ultracapacitors are packaged in rigid, plastic case as shown in Figure 1 for the 2300F device, the energy densities are 7.5 Wh/kg and 13 Wh/L. Both values are high values, especially for hybrid ultracapacitors.

Fig-2 Photographs of the JSR Micro 1100F and 2300F devices

The Yunasko 5000F hybrid device (Figure 3) utilizes carbon and a metal oxide in both electrodes. Different metal oxides are used in the two electrodes and the percentages of the metal oxides are relatively small. The voltage range of the Yunasko is 2.7 - 1.35V. The energy density of Yunasko is 30 Wh/kg for constant power discharges up to 4 kW/kg. The device has a low resistance but it has high power capability of 3.1 kW/kg, 6.1 kW/L for 95% efficient pulses.

Fig-3 Photograph of the 5000F Yunasko hybrid ultracapacitor device

1.3 VEHICLE APPLICATION OF ULTRACAPACITORS

Vehicle applications of ultracapacitors (electrochemical capacitors) have been discussed in the literature for many years beginning in the late 1980s. These applications have been quite slow in materializing. However, at the present time there are a few of applications are now commercialized. These include hybrid-electric transit buses in the United States and China, electric braking systems in passenger cars, and recently in stop-go hybrid vehicles. This latter application is the first one that is potentially a mass market application in the world-wide auto industry. There are several potential future applications which could be large scale, mass market opportunities for ultracapacitors. These future applications include plug-in hybrids, battery electric vehicles using advanced high energy density batteries, ultracapacitors and hybridized fuel cell vehicles.

2. PROPOSED SYSTEM

Conventional HESS connects the ultracapacitors and batteries via a dc/dc converter to satisfy the real-time peak power demands of the powertrain controller. This will require the dc/dc converter to have the same power capability as the ultracapacitor bank or at least higher than the maximum possible demand value. The proposed HESS achieves this in a different way, and also using ultracapacitor to achieve high speed operations.

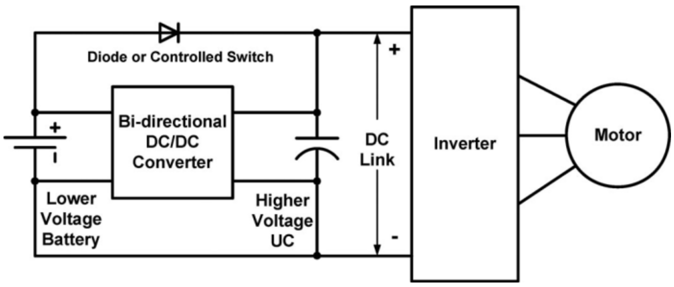

Fig-4 Proposed HESS configuration.

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3 .REGENERATIVE BRAKING SYSTEM

Regenerative braking is a brake strategy to utilize mechanical vitality from the engine and change over motor vitality to electrical vitality and offer back to the battery. In the regenerative braking mode, the engine moderates downhill the auto. When we apply power to pedal of brake, at that point auto gets back off and engine works backward bearing. When running in nullify course engine goes about as the generator and consequently charge the battery. In this way, the auto which is running in typical condition where engine goes ahead and takes vitality from the battery.

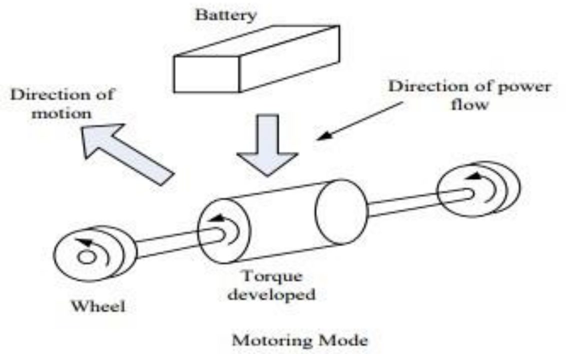

Fig-5 Regular driving Mode

When utilizing regenerative braking in electric vehicles, it decreases the cost of fuel, expanding the fuel money related framework and emanation will be brought down. The regenerative slowing mechanism gives the braking power amid the speed of vehicles is low, and henceforth the activity unpredictable in this way deceleration required is less in electric vehicles.

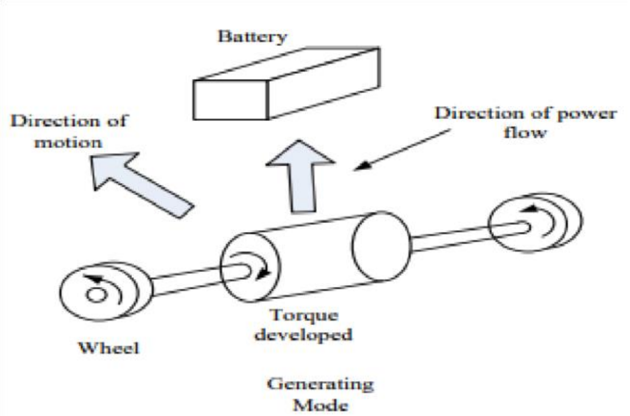

Fig-6 Regenerative action through braking

4. CASE STUDY AND SIMULATION RESULTS

A case study of the proposed HESS design has been carried out and the designed system is simulated using the MATLAB software in order to prove the concept of the HESS.

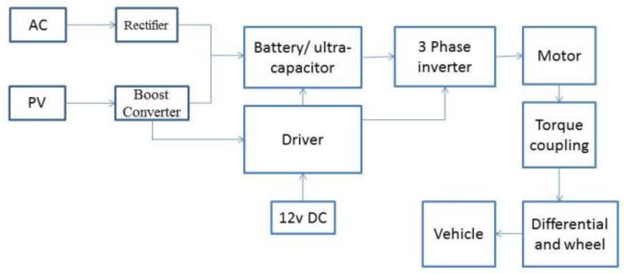

Fig-7 Simulated drivetrain configuration in MATLAB .

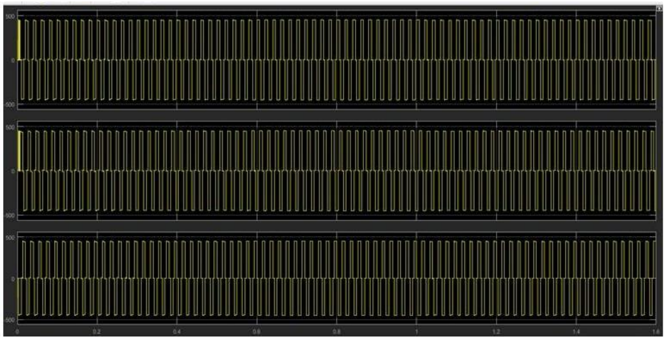

Fig-8 Three phase voltage from inverter

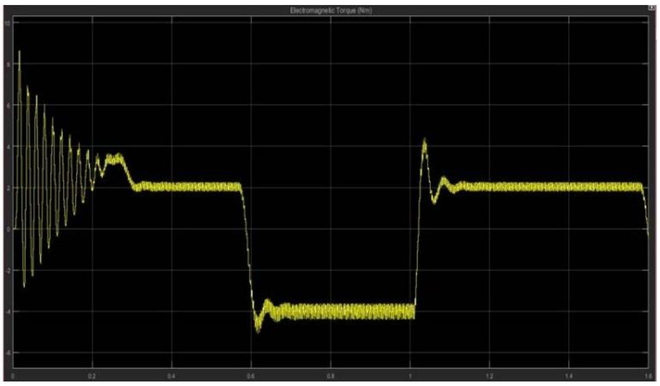

Fig-9 Torque of BLDC motor

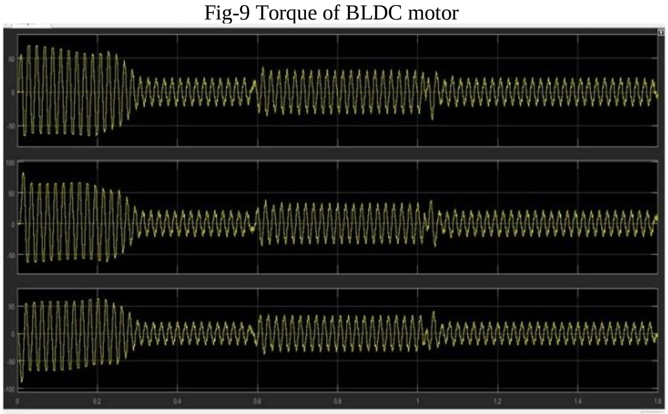

Fig-10 Three phase current from inverter

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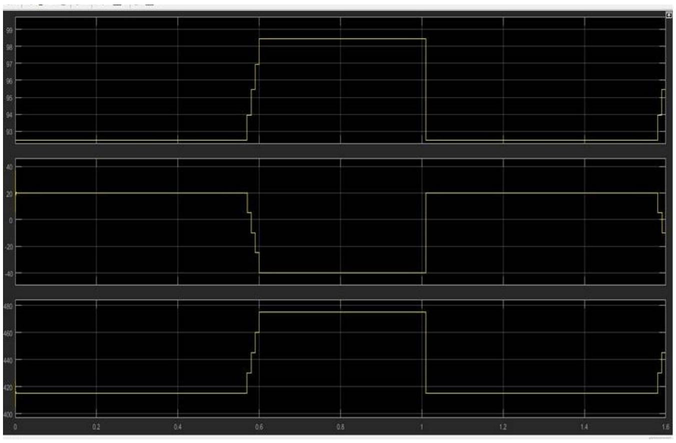

Fig-11 Voltage of ultracapacitor

5. CONCLUSIONS

In this paper, a new hybrid energy storage system(HESSs) design has been proposed. Compared to the conventional HESS, the new design is able to fully utilize the power capability of the ultracapacitor. Much smoother load profile is created for the battery pack. Future work related to this design will focus on the analysis of the system efficiency in the high-voltage conditions.

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