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Control of Ultracapacitor-Battery Combination for Ride-Through Application

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ABSTRACT

In electric vehicles/drives, whenever there is a sudden requirement of high current, battery is under heavy stress and its life degrades. If this period of stress is transferred to another source say ulttracapacitor then battery can be used for longer period. Ultracapacitor act as a power buffer to charging / discharging peak power and to reduce overall energy storage system (ESS) size and extend battery cycle life, battery ultracapacitor hybrid energy storage system (HESS) has been considered. The paper describes the hardware implementation of the bi-directional dc-dc converter with battery and ultracapacitor combination for a dc motor load.

Index Terms: *Batteries , Ultracapacitor (UC), hybrid energy storage system (HESS), Bi-directional DC-DC converter.*

I. INTRODUCTION

In electrical vehicles (EV), batteries are the main energy source components used. The power and energy demand depends on the size of the car. The acceleration and braking situation in the vehicles lead to over sizing of the batteries in order to deliver high power and to avoid unwanted degradation [1]. In electric vehicles energy storage in ultracapacitor or supercapacitor, is one of the modern innovations. The charging and discharging of ultracapacitor can be for several thousands of times compared to batteries. Ultra capacitors are well known for their high lifetime cycles, extremely high power (HP) density and cycling efficiency. The high specific energy batteries with high specific power super capacitors combine to form a hybrid energy storage system (HESS). In the units of wh/kg the energy density of supercapacitor is ten time lower than the energy density of batteries and the unit of w/kg the power density of supercapacitor is ten times higher than the batteries. As the price of supercapacitor is very high, it is important to use supercapacitor in a systematic manner [2]-[3]. In fraction to the increasing application of ride through in commercial and industrial facilities, ride through issue have been more and more highlighted. As the problem have been increased and much research of the ride through system has been performed all over the world, ride through solution are classified as follows

- To existing adjustable speed drives topologies modification.
- Modification to advanced hardware.
- Energy storage technologies.

The various energy storage technologies are used for providing full power ride through, for example: battery backup system, ultracapacitor, fuel cell, flywheel can be used [4]-[5]. Increasing the total efficiency, at light load battery is used to supply large amount of power, whereas acceleration regenerative braking are pleased by using ultracapacitor bank. Such a framework also helps improve onboard battery life time. The amalgamation of ultracapacitor and battery results in decrease size and weight of overall energy storage

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system. The composition of ultracapacitor and battery together meet the storage and peak current characteristics.

This was obtained by connecting two energy sources in a parallel configuration [6]. The power between the sources is passively distributed. The auxiliary source capacity cannot be used completely in the hybrid system. Therefore between the main source and the auxiliary sources dc-dc power converter could be placed [7]. The dc-dc converter output is current controlled and controls the output current of the battery. The remaining power requirement of the load is supplied by ultracapacitor, a two input bidirectional dc-dc converter are also used [8]. In [9], a direct parallel link of two sources has been shown, this system keeps the same voltage above both the sources, thus the power supply from the ultracapacitor is limited between battery and ultracapacitor [10]. It can be seen that the system gives the highest efficiency, reliability and flexibility.

This paper presents the complete design of bidirectional dc-dc converter implementation. Charging and discharging of ultracapacitor through bidirectional dc-dc converter has been carried out. Final test were executed with the vehicle running on lithium ion (Li-ion) battery only and powered by a hybrid configuration of Li-ion battery and ultracapacitor.

The paper is organized as follows: Section II describes the block diagram of compete work. Section III shows the ride-through condition for battery and ultracapacitor. Section IV explanation of system components. Section IV includes the implementation of bi-directional dc-dc converter with ultracapacitor and battery. Finally, the conclusion of this work is provided.

II. BLOCK DIAGRAM

The system is expected to respond in fraction of cycle to a load as a DC motor of 1HP, 180v, 5.3 amps runs. The bidirectional dc-dc converter has been placed in between the battery of 20 AH, 12v as a main source and ultracapacitor of 430F, 16V as an auxiliary source.

The bidirectional dc-dc converter must be able to transfer energy from the battery to the ultracapacitor and vice versa. The active combination of Li-ion batteries and ultracapacitor has been fabricated for hybrid

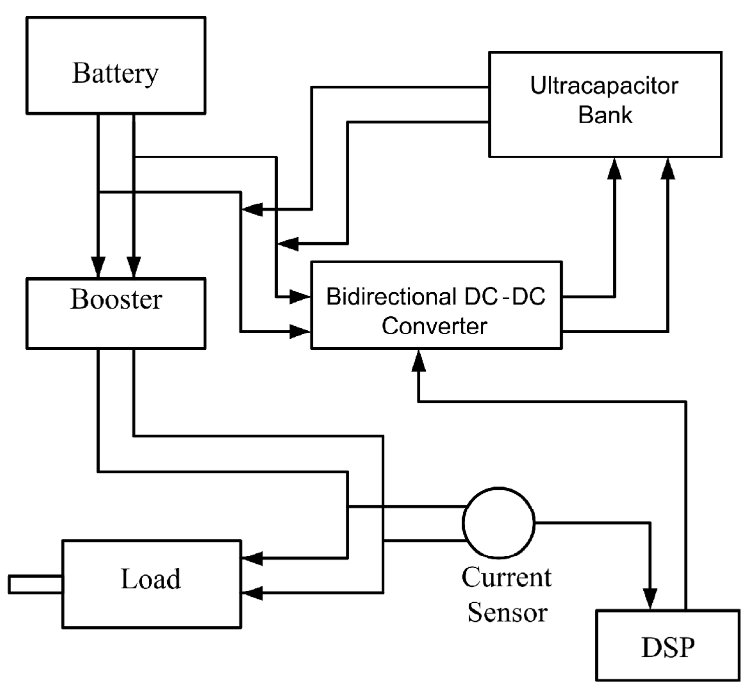

Figure 1: Block Diagram

energy storage system (HESS). Thus Li-ion battery is connected to the booster as per the requirement of the load. In normal condition, the load power is positive. The Main source rated power is greater than the load power, thus the main source from battery is supplies to the load and changes the auxiliary source to the reference voltage. At any condition when load get overloaded, this is the discharging condition in which load power is positive, the main source rated power is less than the load power, thus the auxiliary source ultracapacitor helps the main source battery to feed the load. The current is sensed by the current sensor which transfer signals to the DSP. This control scheme was implemented in a TMS320F2812 DSP from Texas instruments. DSP executes the signals and output of DSP is given to the bidirectional dc-dc converter. Thus ultacapacitor auxiliary source will work as a main source for some time. In recovery condition, the load power is negative. The load gives energy to the system, which results in charging of the auxiliary source.

III. RIDE-THROUGH CONDITION

Energy storage is essential component of ride through system. The technology high power density is chosen for adjustable speed drive (ASD) ride through application but the essential energy density is relatively low in contrast to traditional uninterruptible power supply (UPS) system [5]. Energy storage technologies with the category of advance hardware modification, a new ride-through system for ASDs is proposed. Modification of advance hardware and the use of energy storage technologies are the two schemes whose advantage is taken. In proposed system the voltage rating can be decrease in energy storage device about one third of the rating of the conventional energy storage devices, which reduce the space for the energy storage devices and the cost [7].

IV. SYSTEM COMPONENTS

(A) Lithium-Ion Batteries

In portal electronics and medical devices lithium-ion battery has been proven to have excellent performance. This battery has good high temperature performance, high energy density and is recyclable. The positive electrode is constructing of an corroded cobalt material, and the negative electrode is constructing of an carbon material Li-ion batteries consist of batteries long life of 1000 cycles, high specific energy of 100 wh/kg, high specific power of 300 w/kg [1]. As compare to all batteries like lead-acid, lithium polymer, Ni-MH, zebra batteries etc, Li-ion batteries have high specific power [11]. In relatively narrow operating temperature range batteries must be kept so that they do not bear remarkable degradation in representation [14]. The factor that batteries are popular for their high specific energy levels while the others specific power is low, so the combination of ultracapacitor and Li-ion batteries has been suggested as a energy storage system (ESS) for hybrid electric vehicles [12]-[13].

$$P_{\max} = \frac{\frac{V^2}{4R(1KHz)}}{mass} \quad P_{\max} = \frac{\frac{V^2}{4R(1KHz)}}{mass}$$

$$E_{stored} = \frac{\frac{1}{2}cv^2}{3600} \quad E_{stored} = \frac{\frac{1}{2}cv^2}{3600}$$

(B) Ultracapacitor

Ultracapacitor is a double-layer capacitor integrating an exclusive carbon electrode and an excellent non-aqueous electrolytic solution. It can be charged or discharged for 100,000 times. Ultracapacitor operate like an actual capacitor, their cache energy is proportional to the square of their voltage [2]-[5]. It has an ability to supply a large stable power (10 kw/kg; 1 w. h/kg) [6]. Ultracapacitor for transient power supply and recovery in hybrid vehicles due to high specific power have been considered [8]. The capability of using ultracapacitor arrangement in decreasing the battery current and due to phase shift losses is degraded [9]. Ultracapacitor are only the material which can give an amalgamation of high power density and approximately high energy density. Thus ultracapacitor strength to be easily discharged with long life cycles, grant for actual retainment and reduced cost [14].

The specification of the ultracapacitor used has been shown in table 1

Table 1
Ultracapacitor Features

	Technology	*Specifications*
1.	Model	BMOD0430 E016
2.	Capacitance	430 F
3.	Rated Voltage	16 V
4.	Mass	5.50Kg
5.	Voltage across individual cell	2.7 V
6.	Operating temperature range	-40ºc to +65ºc
7.	Number of cells	6
8.	ESR,1KHz (mohm)	2.8mohm
9.	ESR,DC (mohm)	3.5mohm

V. BI-DIRECTIONAL DC-DC CONVERTER

The power between the sources is passively distributed. The auxiliary source capacity cannot be used completely in hybrid systems therefore between the main source and the auxiliary source dc-dc converter is located. Figure 2 shows the bi-directional dc-dc converter which consists of a two switching circuit.

Single switching circuit consists of two relays. All switching circuit connected to a logical unit reads the signal as per the condition and operation executed. Relay consist of a five terminals NO (not connected to load), NC (connected to load), common and two coils. The common terminal connected to the battery

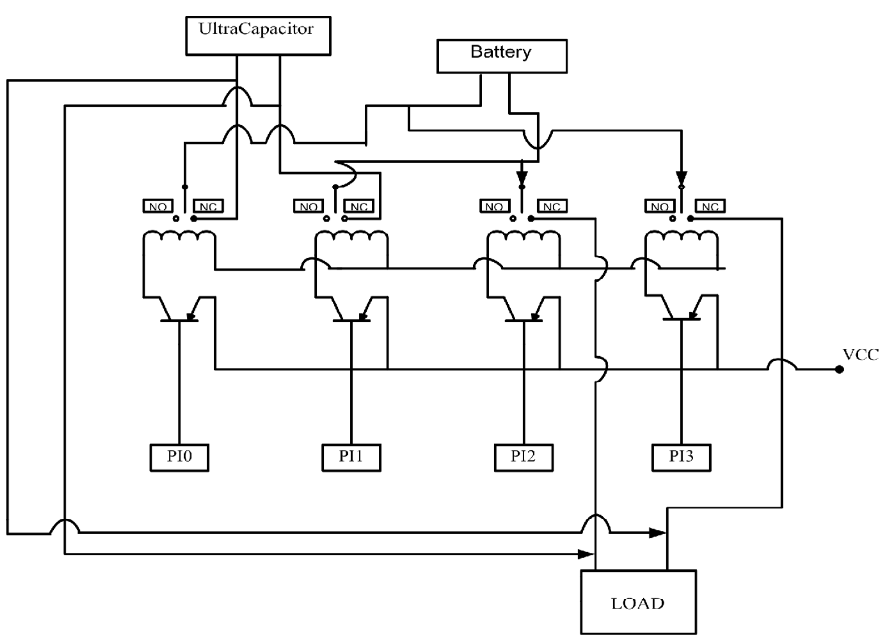

Figure 3: Bidirectional dc-dc converter

input and connected to NO thus, Battery directly connected to the load via ultracapacitor. The NC terminal connected directly to charge the ultracapacitor but this switching circuit connected with IO pins of the controller. The switching circuit has been activated via battery monitoring circuit connected to controller which send signal to the controller pins, perform the logical instructions and switch the relay NO condition to NC condition thus, ultracapacitor disconnect to main battery source.

The second switching circuit connected directly to the output of ultracapacitor and to the common terminal of the switching circuit. Ultracapacitor connected directly to the load for NC terminal but normal condition of the relay is NO (not connected to the load). Input signal leads to controller for the IO pins. Switching circuit becomes active as per the load increases, sense the signals for the logical unit and switches act to perform in switching circuit which is connected to NC for the common terminal and connected to the load. This condition will perform loop to loop operation which connect and disconnect ultracapacitor directly to load as per battery monitoring circuit required.

(A) Charging of Ulttracapacitor

The charging of ultracapacitor has been done by battery through bi-directional dc-dc converter and the results obtained were shown in table 2. The graphical results and experimental setup has been shown in Fig. 4 and Fig. 5 respectively.

Table 2
Charging of ultracapacitor through bidirectional dc-dc converter

Time	*Ultracapacitor Voltage*
10 sec	7.00v
40 sec	7.78v
1min 10sec	8.4v
1mins 40sec	8.86v
2mins 10sec	9.20v
2mins 40sec	9.4v
3mins 10sec	9.5v
3mins 40sec	9.7v
4mins	10.00v

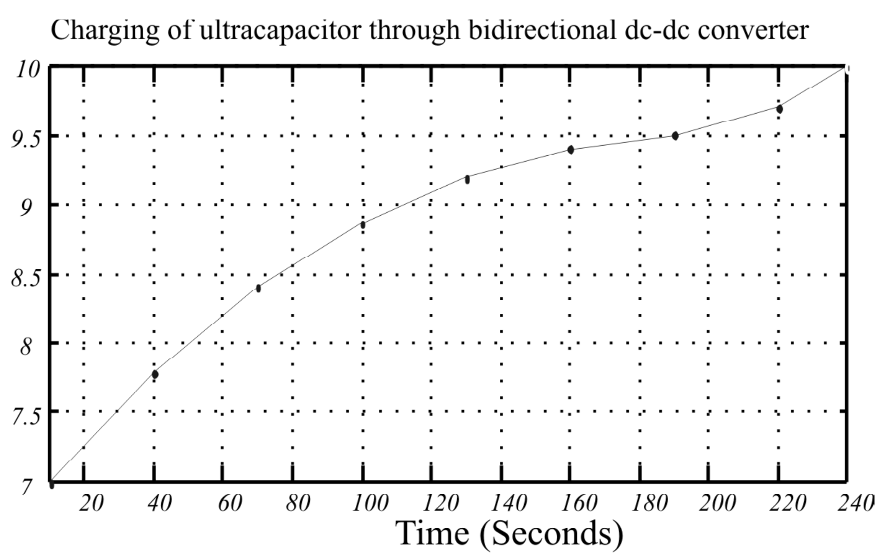

Figure 4: Ultracapacitor Voltage

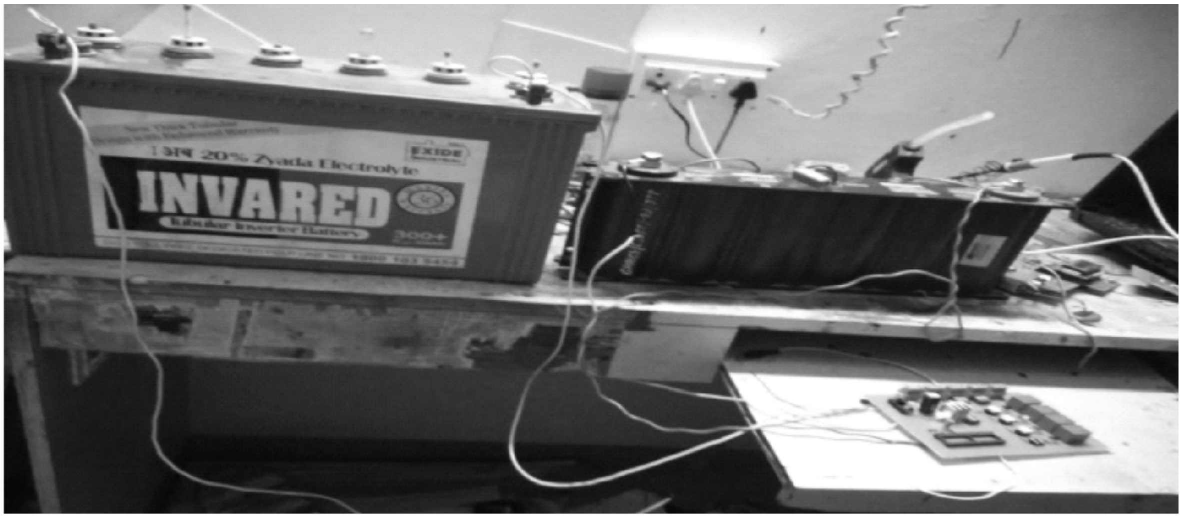

Figure 5: Experimental Setup of ultracapacitor charging

(B) Discharging of Ultracapacitor

Table 3

Time (minutes)	*Ultracapacitor Voltage (Volts)*
1m	9.83V
2m	9.67V
3m	9.50V
4m	9.40V
5m	9.24V
6m	9.09V
7m	8.93V
8m	8.77V
9m	8.58V
10m	8.43V

The discharging of the ultracapacitor has been done through load of 12V, 200 rpm. Bi-directional dc-dc converter is connected between the ultracapacitor and the load. The result of capacitor discharging is shown in table 3. The graphical results and experimental setup has been shown in Fig. 6 and Fig. 7 respectively.

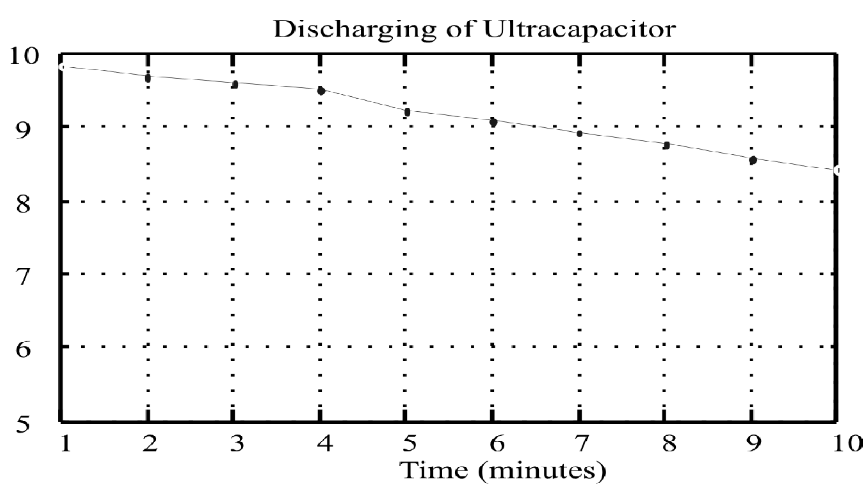

Figure 6: Discharging of ultracapacitor

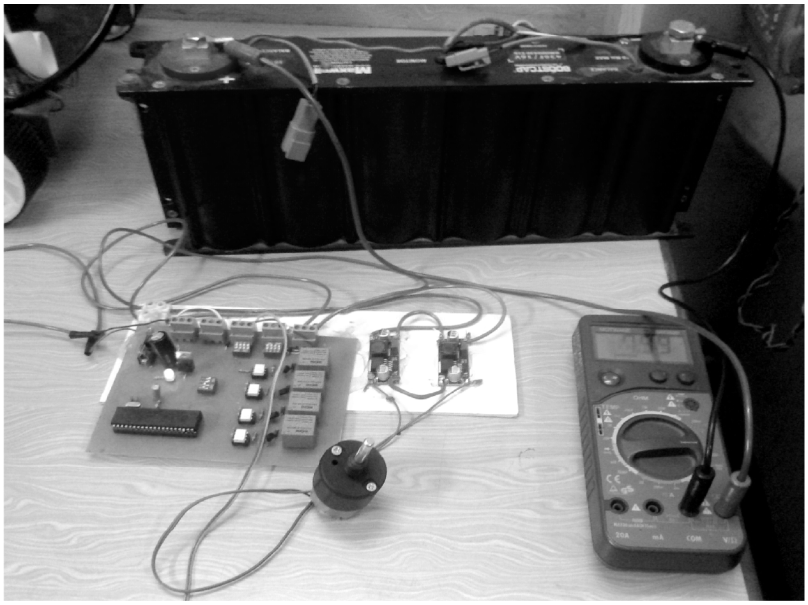

Figure 7: Experimental Setup of ultracapacitor discharging

In experiment 12V dc motor was run through bi-directional dc-dc converter and booster which increase the output voltage to 41V and contant voltage is maintained. Table 4 given below shows the input and output current of the dc motor.

Table 4

Dc motor	*Input current*	*Output current*
Motor at no load	0.9 amp	0.5 amp
Motor at loaded condition 1	1.1 amp	0.48 amp
Motor at loaded condition 2	2.0 amps	0.45 amp

CONCLUSION

In modern electric vehicles/drives, a combination of ultracapacitor and batteries can provide better efficiency and improved battery life. In this paper battery ultracapacitor is proposed to serve as a ride through for battery, thus improving battery life and providing uninterrupted power to the load. The bi-directional dc-dc converter has been designed and further used in the experimental setup of charging and discharging of ultracapacitor. It is found that without battery only with ultracapacitor it takes 7 minutes to discharge 1V.

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