Super capacitor/Battery based Hybrid Powered Electric Bicycle

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Abstract — This paper presents a smart power converter to enable an electric bicycle to be powered by a battery/super capacitor hybrid combination. A rear hub motor was retrofitted onto a normal geared bike powered by a lead acid battery pack. A super capacitor module was connected in parallel to the battery pack via a custom made arduino controller-based power converter which arbitrates power between the battery and super capacitor. The control method for the power converter was developed using a practical approach by using various inputs (battery/super capacitor current and voltage) and comparing the robustness of conventional control scheme. Also energy efficient components were used in designing the power converter to ensure maximum power transfer efficiency.

Keywords — Electric Bicycle, Super capacitor, Power Converter, Brushless DC Motor.

1 Introduction

Bicycles have been a transportation mainstay because the work place and housing areas in most of these densely populated cities are within walking or cycling distance. This reliable yet overlooked form of transportation has evolved over the years from simple utility bicycles to powerful geared mountain bikes and now electric assisted bicycles. Environmental concerns in terms of emissions and depleting fuel reserves has revived the electric vehicle industry and research community. Electric assisted bicycles still retain the characteristics of a conventional bicycle with an added advantage of extra power, say when riding up a hill. This enables the elderly or not so physically fit people to still enjoy riding a bicycle up a slope.

Batteries are the weak leak at the moment for any electrically propelled vehicle including the bicycle. The lack of a single reasonably priced energy storage device that can simultaneously provide high power density and high energy density has been the main stumbling block to the acceptance of electric propulsion as the main form of private and public transportation. Presently the only viable solution to this problem is to combine a high energy storage device such as an electrochemical battery or fuel cell with a high power device such as an Electric Double Layer Capacitor (EDLC) or ultra capacitor or more often called a super capacitor.

Usually, some form of power converter executing an energy management control technique is used to interface the battery bank and super capacitor array to the load bus. It is the aim of this research work to design a smart power converter with a heuristic based energy management technique which will optimize the power flow from the battery pack to the load. As the name implies, a super capacitor is a capacitor with capacitance greater than any other, usually in excess of up to 3400 Farad. Super capacitors do not have a traditional dielectric material like ceramic, polymer films or aluminum oxide to separate the electrodes instead a physical barrier made of activated carbon. A double electric field which is generated when charged, acts a dielectric. The surface area of the activated carbon is large thus allowing for the absorption of large amount of ions.

Advantages of Super capacitors

- Cell voltage determined by the circuit application not limited by cell chemistry
- Very high cell voltages possible
- High power density
- Can withstand extreme temperatures
- Simple charging methods
- Very fast charge and discharge
- Overcharging not possible
- Long life cycle
- Low impedance

Disadvantages/Shortcomings

- Linear discharge voltage characteristic prevents use in some applications
- Power only available for very short duration (short bursts of power)
- Low capacity
- Low energy density
- Voltage balancing required when banking
- High self discharge rate

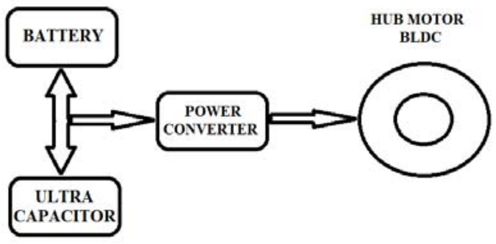

Figure 1 : Schematic diagram hybrid Powered Electric Bicycle

2 Power Converter Design

In order to size the power converter appropriately, the electric bicycle was powered with the 36V 12Ah Lead acid batteries. The track used was a mixture of flat terrain, up hills and down hills. This is shown in the table below.

Table 1 Specification of Power Converter

Parameters	Values
Average Voltage	39.0 V
Average Current	8.2 A
Average Power	245.0 W

From the table above, the average voltage is 39.0V. This voltage is actually equivalent to the total batteries voltage at full charge. Even though the datasheet mentions that each battery is only supplied 36V, however there is some tolerance in battery which causes each battery to go up to 39 V. When the motor is running at maximum load (i.e. uphill), the maximum current drawn from the battery is 8.2A whereas when the motor is running at constant load (usually on a flat terrain) the average current is 6.2A. Thus, the super capacitor is required to supply at least 23.18A to ensure that batteries only supplied average current. It can be operated in two modes which are continuous current mode (CCM) and discontinuous current mode (DCM. This converter functions based on pulse width modulation (PWM); PWM is sent from a controller/driver in order to control the MOSFET to switch on or switch off.

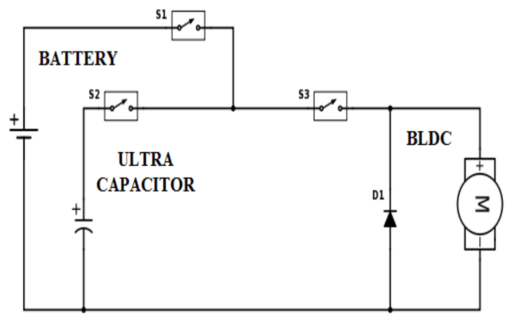

Figure 2: Smart power Converter

The simple control strategy adopted for calculating the duty cycle of the PWM pulse which is required to turn on the MOSFET for the power converter. Inputs from a Hall Effect speed sensor and current sensors are required to turn on the converter. This ensures that the E-bicycle is on and ready for an impending acceleration and also prevents unnecessary usage of the super capacitor’s limited energy. Voltage divider circuits at the input side (super capacitor) and output side (battery/converter out) feed input signals to the controller. By comparing these two signals, the duty cycle can be appropriately adjusted.

3 Simulation Results

The simulink model of the hybrid electric vehicle is shown in Figure 5.The objective of this research work is to design and build a Pulse Width Modulated (PWM) power converter with the following ideal specifications:

- Input Voltage (Ultra Capacitor): 12 - 16.2 VDC
- Input Voltage (Battery): 36 - 39 VDC
- Output Power: 200 – 300 W
- Switching Frequency: 50 kHz

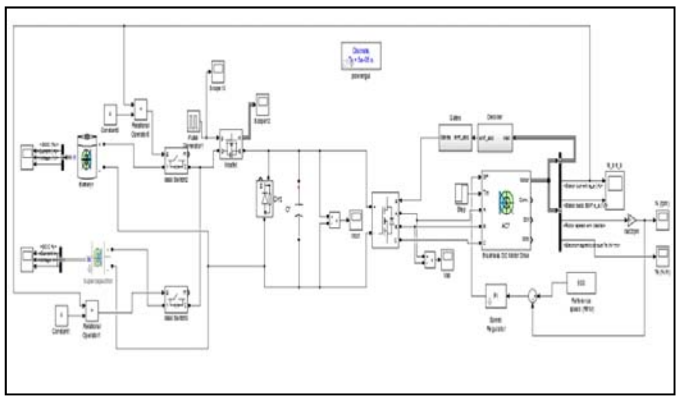

Figure 3 : Simulink model of hybrid Powered Electric Bicycle

4 Battery and Ultra capacitor

The lead-acid battery, although known since long time, are studied in an intensive way because of its application in the automotive and the renewable energy sectors. In this section, the principle of the lead-acid battery is presented. A simple, fast, and effective equivalent circuit model structure for lead-acid battery is implemented [6]. The identification of the parameters of the proposed lead-acid battery model is treated. This battery model is validated by simulation using the Matlab/Simulink.

The main power source consists of a 36V~40V, 12Ah lead acid battery pack with cell balancing circuitry which weighs 7 kg. This can comfortably provide a continuous discharge current of 12A. The super capacitor consists of a 0.25kg 16V, 350F module to be connected in parallel with the battery pack via a power converter which is designed to harvest the maximum energy from it. The propulsion device consists of a state of the art rear hub motor rated at 250W, eliminating the need for transmission and the losses associated with it.

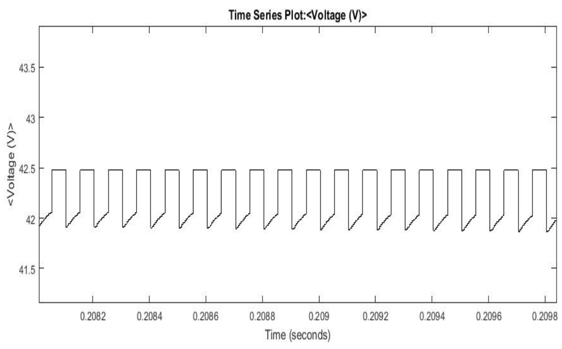

Figure 4: Battery voltage characteristics

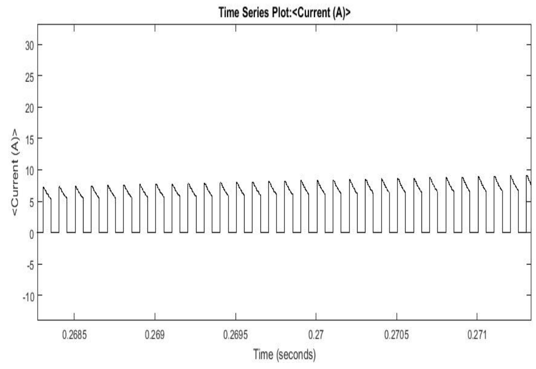

Figure 5 : Battery current characteristics

Figure 4 & 5 shows that charging voltage of battery is about 42.5 V. The charging current of battery is about 7.5 A. State of charge of battery is about 80%.It is the present capacity of the battery. It is the amount of capacity that remains after discharge from a top-of-charge condition. Depth of charge is the percentage of battery capacity to which a battery is discharged. The battery maximum temperature is about 28 C.

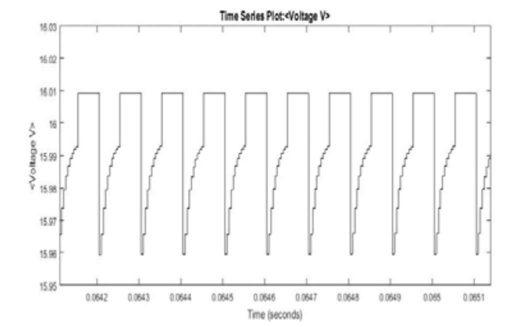

Figure 6 : Ultra capacitor voltage characteristics

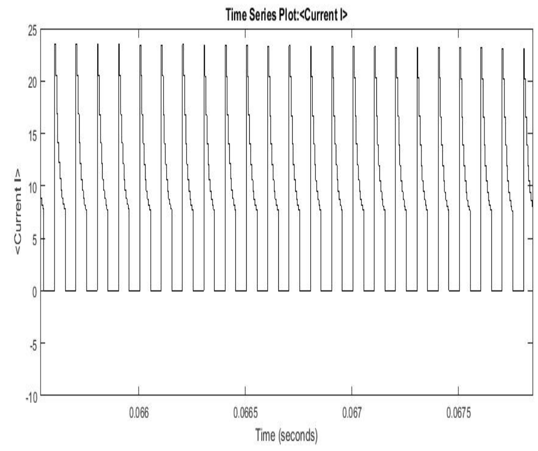

Figure 7 : Ultra capacitor current characteristics

Figure 6 & 7 shows that charging voltage of ultra capacitor is about 16.0 V. The charging current of ultra capacitor is about 23.5 A.

The simulated results (rotor speed, electromagnetic torque, stator current and back EMF) of BLDC motor are shown in Figures [8-11] respectively.

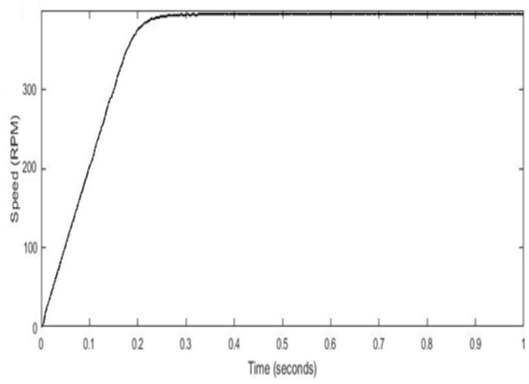

Figure 8 : BLDC motor speed characteristics

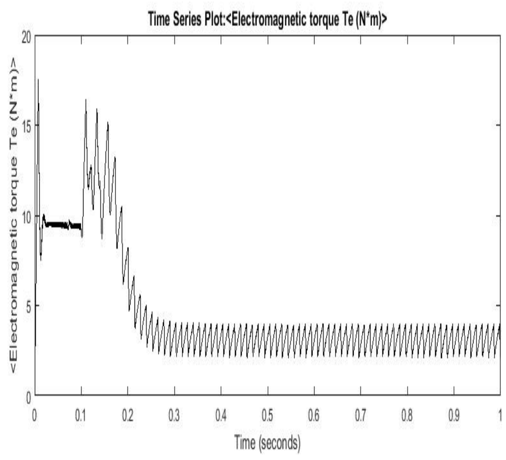

Figure 9 : BLDC motor torque characteristics

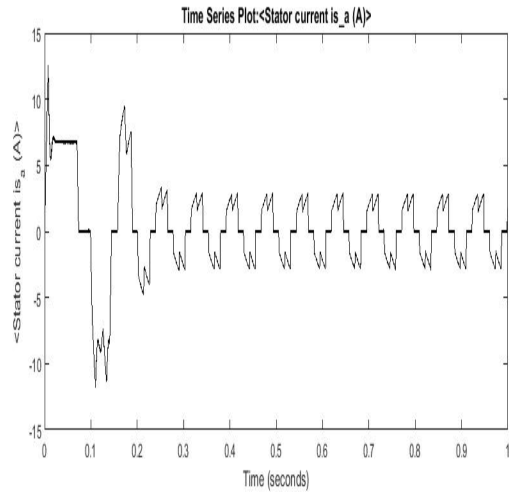

Figure 10 : BLDC motor stator current characteristics

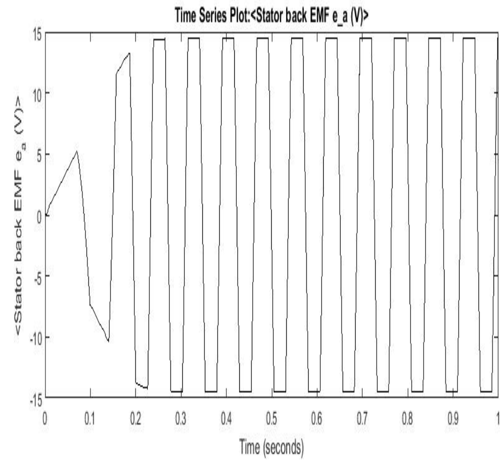

Figure 11 : BLDC motor back EMF characteristics

Figures 8 & 9 show that the BLDC motor speed is settled 350 rpm and torque is about 4 Nm. Figures 10 & 11 show that the BLDC motor stator current and back emf voltage.

6 Hardware implementation of E bicycle:

The hardware prototype of the proposed smart power converter is developed using MOSFETs as the power device, along with driver circuit. The gating pulses were obtained from a arduino controller. The hardware set-up for smart power converter with arduino board is shown in Figures 12.Figure 13 shows that battery and ultra capacitor charging setup.

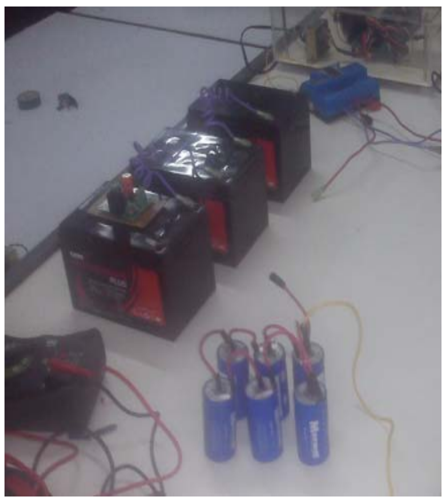

Figure.12.Hardware set-up Battery/Ultracapacitor

Figure 13 Battery and ultra capacitor set up for E-bicycle

Table 2 Specification of Battery set up

Voltage	36 V (no of series = 3, 12 V)
Current	12 Ah
Type	Lead acid
No of cells	6 cells with a voltage of 12 V

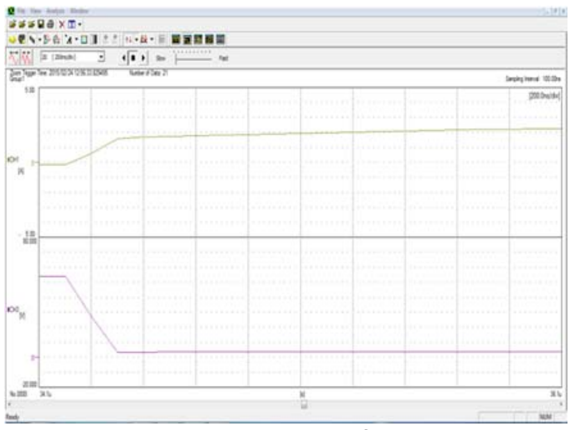

Figure 14 Experimental results for Battery charging characteristics

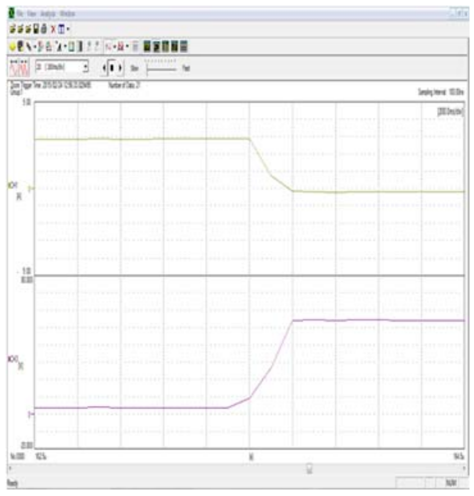

Figure 15 Experimental results for Battery discharging characteristics

The dynamic charging and discharging characteristics of battery is measured using scope corder and it is shown in Figures.14 & 15

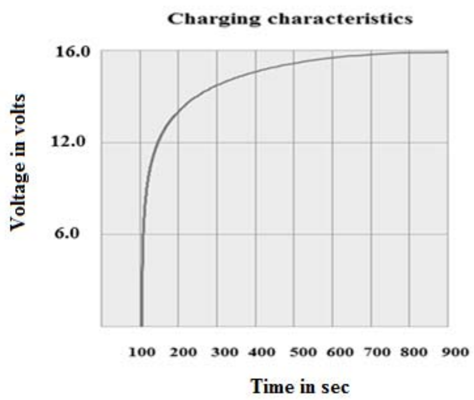

Figure 16 Experimental results for Ultra capacitor charging characteristics

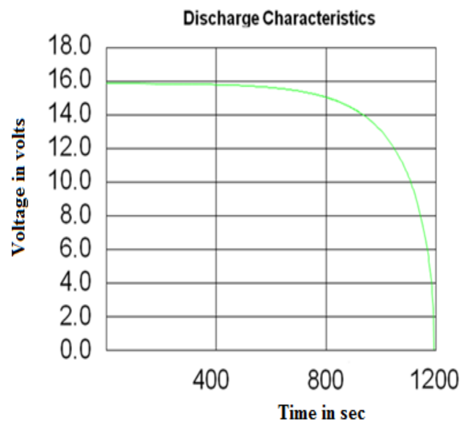

Figure 17 Experimental results for Ultra capacitor discharging characteristics

The dynamic charging and discharging characteristics of super capacitor is measured and it is shown in Figures.16 & 17.

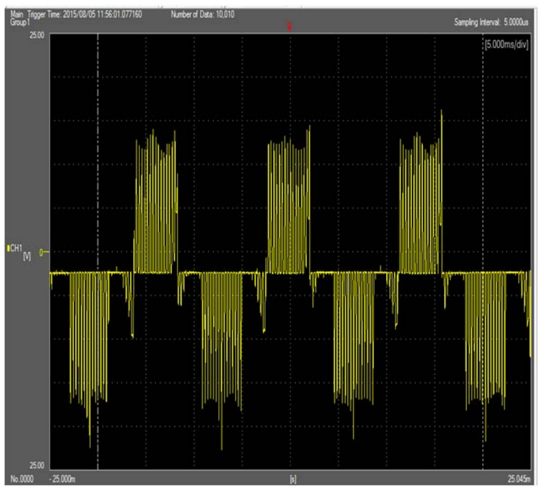

Figure.18. Output voltage of BLDC drive

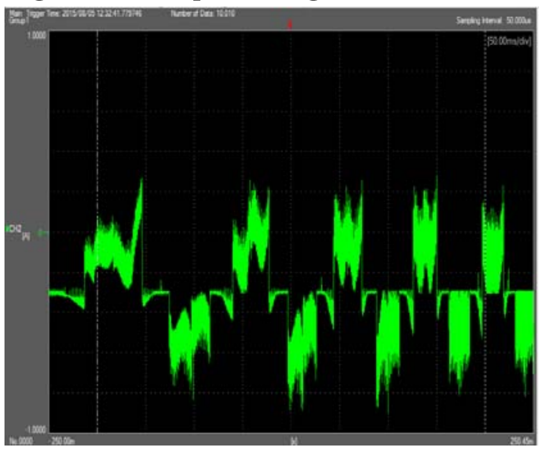

Figure.19.Stator current of BLDC drive

Figure.20.Motor speed in BLDC hub motor

Figures 18-19 show the phase voltage and stator current of hub BLDC drive with the following testing conditions: starting voltage: 30 V, minimum speed: 50 rpm, maximum voltage: 36 V,300 rpm, high frequency - 10 KHz and low frequency-50 Hz. Figure 20 shows that with the e bicycle developed motor shaft speed measured was 354 rpm which is verified experimentally. Figure 21 shows that Battery with Ultra capacitor set up and Final working model E-bicycle.

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Figure.21.Final working model E-bicycle

A Simulation and experimental results discussed that the battery voltage, battery current, super capacitor voltage and super capacitor current. This was used to evaluate the performance of the electric assisted bicycle in terms of motor voltage, stator current and motor speed. The parallel hybrid power source has no significant effect on the maximum speed achievable over a drive cycle except that the rider felt an improvement in uphill acceleration as compared to battery alone.

4. Conclusion

This research work has successfully implemented a battery/super capacitor hybrid power source for an electric assisted bicycle using state of the art hub motor technology. A power converter was designed and implemented based on the energy requirements of the system. Based on the implemented system experimental results show an improvement in the up-hill acceleration of the bicycle as a direct result of the power converter being responsive enough to harvest the extra current from the high power complementary super capacitor module avoiding deep discharges from the battery. This enhanced battery life. The maximum speed remained unchanged. The main battery pack was shielded from high discharge currents which would eventually enhance its life cycle.

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