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DESIGN AND SIMULATION OF PARTIALLY-DECOUPLED CONVERTER TOPOLOGY FOR BLDC MOTOR OPERATED ELECTRIC VEHICLE

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Abstract

A hybrid energy storage system of lithium-ion battery and super capacitor are proposed for BLDC motor operated electric vehicle. This paper focus on the reduction of reliance on vehicle batteries using super capacitor and partially-decoupled converter. Brushless DC Motors are one of promised motors for EV applications. In this work, a battery-operated vehicle is driven by 48V BLDC Motor. Control the energy flow between the super capacitor and battery to power the BLDC motor a DC-DC bidirectional SEPIC converter is also proposed in this paper.The proposed system of electric vehicle is analysed through simulation for three modes of operation such as starting, running and loading for flexible flow of energy for control of driving and hybrid control of charging. All modelling and simulations works are done on MATLAB/ Simulink software. The effectiveness of the partially decoupled converter topology is proved by the simulation results. Combination of battery and super capacitor energy sources are good solution for better performance operation of electric vehicle

Keyword *Battery, BLDC motor, Electric vehicle, SEPIC bidirectional converter, Supercapacito*

1. INTRODUCTION

Consequence of global warming and environmental change, auto mobile industries are moving towards electrification of automobiles to fully electric vehicles (EV). Electric vehicle has the advantages of more efficiency and low emissions of carbon monoxide, higher starting torque and easy control of driving force.

The on-board energy storage system (ESS) helps to enhance the performance and electric range of electric vehicle .Now a days, Lithium-ion rechargeable batteries are widely used in electric vehicle applications because of its high energy density and design flexibility. Electrochemical properties of lithium-ion batteries are also supporting electric vehicle applications. But the main drawback of on-board energy storage rises doubles when its electric range is raised by 15%. This is because of the rise in the incremental cost of onboard storage. Effective operation of wheel electric vehicle is highly depending on ESS. So ESS should have feature of high energy and high-power densities. But it cannot be satisfied by a single energy source. Generally, batteries are available with higher energy density. But the problem is its low specific power and life cycle. In addition to that battery efficiency may reduce, when the load draws very high current. This situation is found at peak demands. Another serious problem of battery is when its state of charge (SOC) is low, it may undergo thermal stress. Therefore, a super capacitor along with a battery is proposed in this paper. Super capacitor includes the advantages of higher power density, lifecycles, efficiency and quick response on charge/discharge cycles.

Both energy storage device complement each other in terms of energy density, life cycle and power density. Batteries with higher capacity can be used for higher power densities but it is not a commercially viable solution. Size and weight should not be constraint for an automotive application.[5] Therefore, in a HESS, super capacitor is used to supply higher current for acceleration and also absorb power during braking and the battery is utilized for

vehicle operations involving lesser power. In this paper load is a Brushless DC (BLDC) motor.[7]
The requirements of power flow between the energy storage units are as follows. The Super capacitor discharges very quickly and need to be charged frequently. At the same time and the voltage level of the Super capacitor should not go beyond a certain level in this project it is 48V, as it will damage the motor. Therefore, the power has to be controlled by a bidirectional DC-DC converter.

A bidirectional SEPIC DC-DC converter is proposed in this paper because it has lower device stress, lower losses, reduce ripple and lesser number of components. [10]
The partially decoupled topology is designed and it sis analysed in simulation for three modes of operation. Design of bidirectional DC-DC SEPIC converter is done based on the ratings of the both energy sources. In addition to that, converter must be capable to allow both directions of the power flow and increase or decrease the voltage in each power flow direction. Chapters 2, 3 and 4 presented the design methodology which is done in MATLAB simulation .Simulation results are followed by conclusion in chapter 5

2.PARTIALLY DECOUPLED TOPOLOGY FOR ELECTRIC VEHICLE APPLICATION

Battery and super capacitor fed electric vehicle with Brushless DC motor drive by interfacing bidirectional converter specifications are given in Table 1.

COMPONENT	SPECIFICATION
BLDC Motor	Power :440W
	Speed :500rpm
	Torque:1.4nm
LITHIUM-ION Battery	V:48v
	I: 30Ah
Super Capacitor	V:100v
	C: 2.8F

TABLE.1 partially decoupled topology components specification

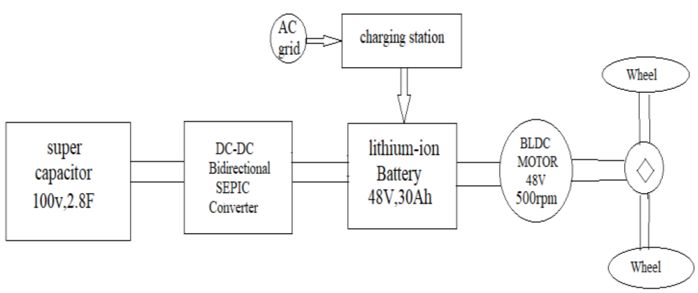

Fig.1 Block diagram partially-decoupled converter topology

In partially-decoupled configurations, either lithium-ion battery or super capacitor is decoupled from the DC bus using a DC-DC converter. In this topology, the battery is directly connected to the DC bus while the super capacitor is interfaced to the bus via the DC-DC converter. The DC bus does not undergo significant voltage fluctuations as it is clamped to the Batteryterminals. Using the DC-DC converter, the super capacitor can operate over a wide voltage range which improves the functionality of super capacitor. Being installed directly on the DC bus, the Battery is exposed to high charge/discharge current fluctuations. This can result in reducing the life time of Battery. The DC-DC converter is rated according to the power rating of UC which is supposed to take care of sharp and large power demand variations.

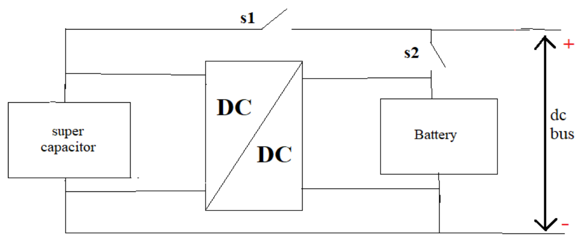

Fig.2 Partially-decoupled converter topology

In this configuration both the supercapacitor and battery are connected to the DC bus through N-channel MOSFETs. If the battery has to power the motor switch S_2 has to be triggered, and if super capacitor has to power the motor switch S_1 has to be triggered. Also, the body diode in S_1 is such that power can flow from motor to super capacitor in case of regenerative braking if required. A bidirectional DC-DC converter is placed between super capacitor and the battery. The low voltage side of bidirectional converter is connected to battery and the high voltage side is connected to super capacitor. The above topology needs to operate under three cases.

Case 1

Starting the motor with super capacitor and later switching to battery as the super capacitor can provide a high starting current, and the rise of the motor speed is low compared to when started by the battery. Up to 2 seconds super capacitor drives the motor, later switched to battery. Power flow diagram from HESS to motor terminals is shown below in Fig.3.

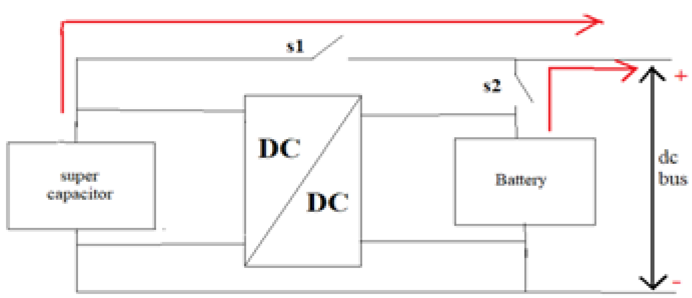

Fig. 3 Power flow from partially decoupled system to motor/ DC bus terminals under starting period.

A. Case 2

During running period, the supercapacitor discharges within seconds, so it has to be charged either by the battery or by regenerative braking. If the battery has to run the motor, it has to charge the supercapacitor frequently. So again, motor started with supercapacitor for certain seconds and then switched to battery. Simultaneously the switch Q2 of the DC-DC converter has to be triggered to run the bidirectional DC-DC converter in boost mode so as to charge the supercapacitor. In all these cases the motor speed was maintained constant at the rated speed of 500 rpm with the help of a PI controller in MATLAB/Simulink.

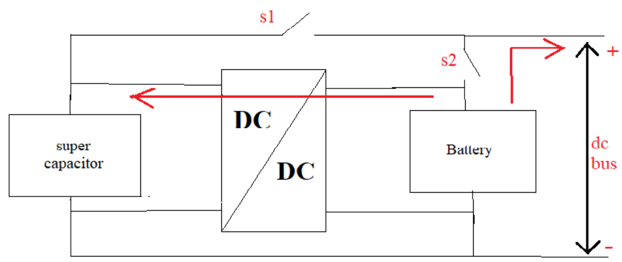

Fig. 4 Power flow from partially decoupled system to motor/ DC bus terminals under running period.

B. Case 3

Now the motor has to be loaded, and for this condition the battery and supercapacitor performance has to be monitored. The torque on the BLDC motor has to be above the rated torque of 1.4 Nm. So, a torque of 3 Nm was applied and driven first by the battery and then the supercapacitor as highlighted in Fig.5.

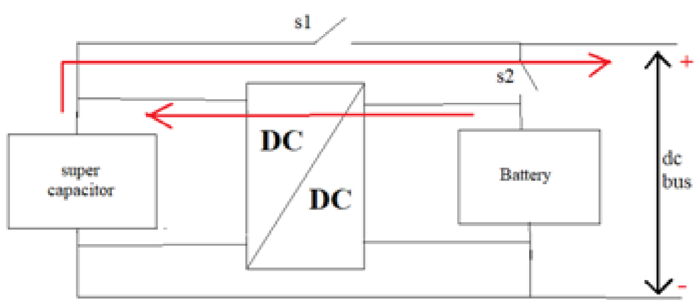

Fig. 5 Power flow from partially decoupled system to motor/ DC bus terminals under loading period.

3.BIDIRECTIONAL DC-DC CONVERTER FOR PARTIALLY DECOUPLED SYSTEM

Supercapacitor discharges quickly if it is being used for longer durations, so it needs to be charged regularly using the battery. Terminal voltage remains almost constant for a Lithium-ion battery as the voltage drop is very less. Also,the supercapacitor voltage should not increase beyond a limit, so the voltage of the supercapacitor should be maintained between two limits. If the power flows to the battery, there would not be any significant change in state of charge (SOC) of the battery as the energy storage capacity of supercapacitor is very less compared to that of battery. Power flow between the battery and the supercapacitor is done using the control switches of the bidirectional DC-DC converter. The circuit is shown in Fig.6.

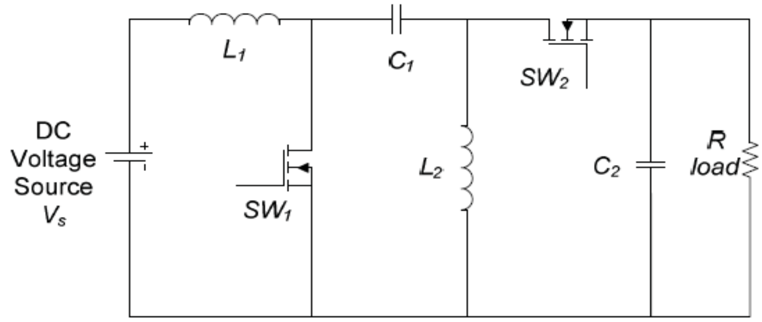

Fig. 6 Bidirectional DC-DC SEPIC converter

The topology of SEPIC converter generally includes power switch (MOSFETs), a diode, two inductors (L_1, L_2) and two capacitors (C_1, C_2) which is comes under unidirectional converter, this unidirectional SEPIC converter can be convert in to a bidirectional SEPIC converter by replacing unidirectional switch (Diode) with a bidirectional switch (MOSFET) which is shown in Fig.6. Assuming continuous conduction mode (CCM), the converter acts as buck converter during mode-1 and boost converter during mode-2.[10]

A. Mode 1 (Boost mode)

During this mode SEPIC converter behave like a buck converter and voltage step down action takes place. SW_1 will change to ON state and SW_2 changes to OFF state . The input current starts flowing through inductors and capacitor, inductors L_1& L_2 charged by source V_s and V_{c1} respectively.

B. Mode 2 (Buck mode)

Boost mode define the backward power flow operation of this converter. During this period SW_1 change ON state to OFF state and SW_2 change its state OFF to ON. The capacitor C_1& C_2 start discharging through inductor and load.[10]

The bidirectional SEPIC DC-DC converter is designed based on the ratings of the battery and the supercapacitor. The design includes the calculation of the inductance based on the maximum discharge current of the battery and the supercapacitor. The load used is a Brushless DC motor of rating 440W 500rpm 48V and the battery used is 48 V 30Ah Lithium-ion battery. The voltage required for the supercapacitor to attain the rated speed of the motor is found to be 100V and the capacity found to be 2.8F. The battery will be on the low voltage side of the converter, and supercapacitor will be on the high voltage side. The voltage variations in both the energy sources have to be defined for the design of the converter. It is assumed that battery state of charge (SOC) has to be between 100% and 50%. The nominal voltages of the battery for these SOC conditions are found to be 55V and 40V respectively. Now for the supercapacitor the voltage variations are to be from 100V to 43V. As the rated voltage of the motor is 48 V, it requires a supply voltage above 43 V below which the motor stops running. When battery is discharging, the converter will operate in boost mode and the supercapacitor voltage increases. The inductor is designed based on these voltage limits and the maximum discharge current of the battery of 13A. The ripple in inductor current is required in calculating the inductor current which is taken to be 20% of maximum inductorcurrent. The ripple in capacitor current is required in calculating the current which is taken to be 2%ripple.

Δi_L=20% of 13A=2.6A ΔVo=2% ; where Δi_L ,ΔVo is ripple in capacitor & inductor current. In boost mode the voltage of the high voltage side is obtained as $V_H=V_L/(1-D)$ where D is the duty ratio and V_L is the voltage of the low voltage side in the bidirectional DC-DC converter. For the inductor design maximum change in voltage variations has to be considered for maximum value of inductance. Here the lowest voltage of low voltage side (V_L) has to be taken and maximum voltage of high voltage side (V_H)has to be considered,i.e.40Vto100V.Forthesevalues of voltages the duty ratio is found as 0.6. To find the inductance in boost mode. equations

$$L = \frac{Vs*D}{\Delta IL*fsw} \quad (1)$$

$$C = \frac{D}{R(\frac{\Delta Vo}{Vo})*fsw} \quad (2)$$

Where; $f_{sw,}$ is the switching frequency and it is taken as 20kHz. From the above relation the inductance is found as L_1 is 1.307mH and L_2 is 0.623mH & C1&C2 is 2.197*10^-4.

Table 2 bidirectional converter designing parameters

COMPONENTS	PARAMETERS
Inductor(L1)	1.307mH
Inductor(L2)	0.623mH
Capacitor(C1),(C2)	2.197*10^-4
Switching Frequency(fsw)	20khz
Duty ratio	60%
Average inductor current	20%
Average ripple voltage	2%

4.SIMULATION STUDIES OF PARTIALLY DECOUPLED TOPOLOGY SYSTEM FOR BLDC MOTOR

BLDC motor needs trapezoidal 3 phase voltage to run the motor which is based on the commutation table of the motor. For the above motor the optimum battery rating is set as 48V 30 Ah Li ion battery, and the supercapacitor voltage should be high enough for reaching the rated speed of the motor, so set to be 100V 2.8F based on simulation studies. The BLDC motor being used in the simulation of hybrid energy storage system is of 48V 440W and 500 rpm. The motor is modeled in MATLAB/Simulink environment with a permanent magnet synchronous machine which generates trapezoidal back EMF. The bidirectional converter circuit was designed for the voltage ranges.

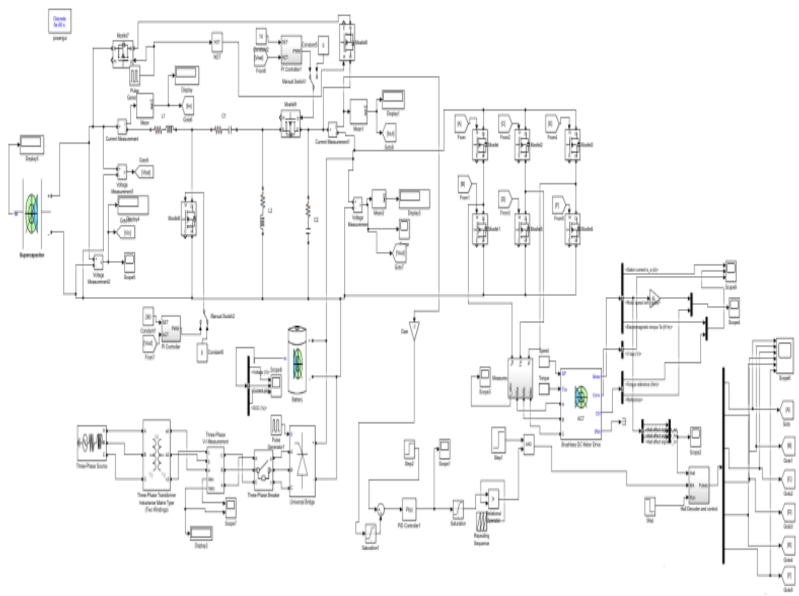

Fig.7 MATLAB/Simulink model of partially-decoupled system

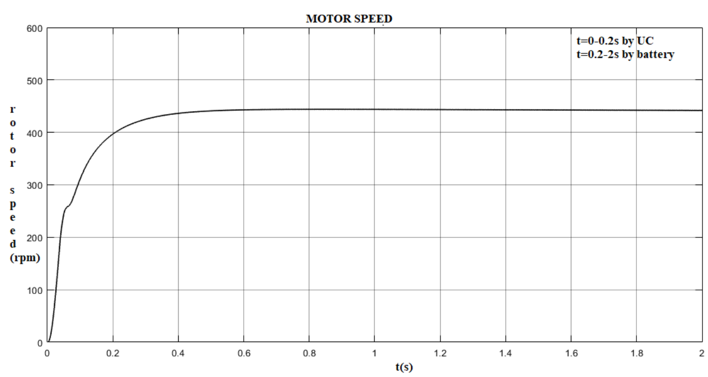

Fig.8 Simulation result of starting with capacitor(case a)

The above simulation result shows that 0.2 seconds capacitor first start the motor then after battery take over the motor speed rating, output waveforms with respect to time during running condition.

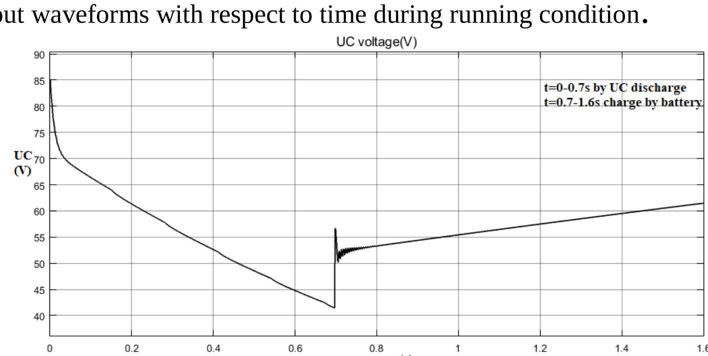

Fig.9 Simulation result of super capacitor voltage (case b)

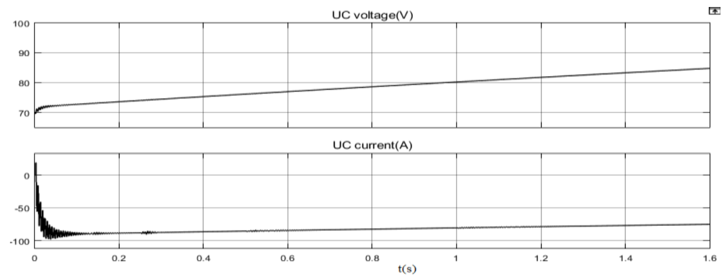

Fig.10 Simulation result of super capacitor voltage charge by battery (case b)

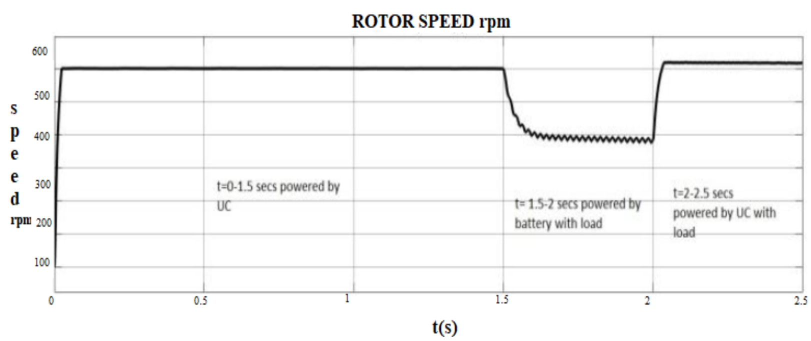

Fig. 11 Simulation result of rotor speed under loading period(case c)

The above simulation results shows that output waveform with respect to time during loading period of bldc motor

5.CONCLUSION

In this paper partially decoupled topology System with a combination of battery and Supercapacitor powering the BLDC motor in electric vehicle is Implemented. The Supercapacitor powering the motor initially speeds up the motor in few seconds when compared to battery with the same voltage. For powering the motor for longer duration, the capacity of super capacitor has to be still higher. Therefore, a support with battery will provide high power density and super capacitor with high energy density is the hybrid energy storage system for electric vehicle is proposed in MATLAB/Simulink software.

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