ISSN: 0974-5823 Vol. 7 (Special Issue 5, April 2022)

International Journal of Mechanical Engineering

Simulation of a Hybrid Energy Storage System Source-fed to BLDC Motor

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Abstract – This paper explores the feasibility and capabilities of a hybrid energy storage system (HESS), comprising battery and super-capacitor units, using simulation. Demand for electric vehicles has been gaining traction due to the strategic and environmental challenges posed by the usage of conventional ICE vehicles. In electrified vehicles, the propulsion is fully or partially provided by electric motors, powered by onboard energy storage systems. To make up for the limitations of the existing energy storage devices and contribute to vehicle electrification movement, the choice of HESS topology has been made based on simplicity of power and control circuits, cost, and performance. The design takes into consideration the required power, the converter losses, limitations of energy storage devices, and quality of the current drawn from battery cells. The simulation results validate the performance of the HESS based on the voltage and current characteristics.

Index Terms - Supercapacitor, Battery, Hybrid energy storage system, Brushless DC Motor.

INTRODUCTION

Because the use of fossil fuels pollutes the environment, clean energy sources are becoming increasingly vital across the world. The renewable systems cannot offer constant power to the users. Hybrid power systems can be used with renewable energy systems and batteries for reliable power supply. When renewable energy technologies are unable to provide enough power to meet demand, the battery must cover the shortfall [1]. While the whole power of renewable energy systems cannot be used by the load, the excess energy can be used to charge the battery. Because of the floating nature of renewable energy systems, they are not appropriate for stand-alone applications, generating power network stability difficulties. To address the stability difficulties, energy storage devices were introduced.

Energy storage devices are considered one of the critical technologies for growing markets in the use of additional renewable energy sources, to minimize fossil fuel use and allow suitable integration of clean energy sources in off-grid and on-grid applications. Of all the energy storage technologies, the battery is one of the most utilized [2]. However, employing the battery as the only energy storage device has significant disadvantages.

Unfortunately, most available batteries have rather poor power density. Although there are high power density batteries available, the longevity and price are substantially greater and the thermal management of the battery will be a challenge. Because the load profile varies rapidly according to the road conditions and the driver's behaviour, the energy storage system suffers from random charges (regenerative braking) and discharges (acceleration command), which have a negative effect on the life of the battery [3]. To tackle the challenges described above, hybrid energy storage systems (HESS) have been proposed by numerous researchers.

The main idea of a HESS is to combine ultra-capacitors (UC) with batteries to produce a higher overall performance. This is because, compared to batteries, ultra-capacitors have a high-power density but a low energy density. Hybrid energy storage system of electric cars (EVs) [4] offers great potential to take full benefits of high-power density with super capacitor and high energy density with battery to increase the dynamic performance and energy efficiency of electric vehicles. Hybrid energy systems provide several advantages, such as increased efficiency, greater system performance, and prolonging the battery life. Batteries have a high energy density, and supercapacitors have a high-power density [5,6]. In this paper, a super capacitor relates to the battery in an electric vehicle utilizing a bidirectional DC-DC Converter to increase the dynamic performance of the vehicle system and improving the battery life. Bidirectional DC-DC converters can transmit power between two DC sources in either direction. Non-isolated topology is preferable to isolated topology because it eliminates the need for a transformer and minimizes the cost and bulkiness of the circuit.

Bidirectional DC-DC converters have high gain during buck and boost modes. A supercapacitor assisted battery system is employed in this system. As more than one energy storage system is connected in parallel, the entire system will run without any interruptions. Current mode control is utilized to create gating signals for the power switch in each mode of the bidirectional converter. By adopting a hybrid system, a compact battery with reduced peak power output is only required. So, cost worries and bulkiness issues are handled. In this study, the feasibility and capability of a hybrid energy storage system (HESS), consisting of battery and super-capacitor components, using simulation are studied.

The paper is organized as follows: In the next section a battery-super capacitor hybrid energy storage system is discussed followed by the bidirectional DC-DC converter used for combining both battery and super capacitor. The control strategy for a bidirectional DC-DC converter, the controlling units for the battery and super capacitor and BLDC Motor inverter are discussed in the subsequent sections.

A BATTERY- SUPER CAPACITOR HYBRID ENERGY STORAGE SYSTEM

A supercapacitor is a large-capacity capacitor that has the power to store 10 to 100 times more energy than regular capacitors. They can sustain a greater number of charge and discharge cycles than batteries. A supercapacitor is made up of two metallic or carbon plates with opposing polarity. They are separated by a very thin dielectric substance. The huge amount of capacitance of a supercapacitor is related to the porosity of the plates of the capacitor storing the charge. A supercapacitor can withstand high power in short intervals. A battery is capable of supplying load at a steady rate for lengthy durations. By adopting a hybrid system [10, 11], only a small battery with reduced peak power output is required. So, cost concerns and bulkiness issues are handled.

Figure 1 depicts the block diagram representation of a HESS comprising a battery and a supercapacitor. There are two input sources: battery and super-capacitor, two bidirectional converters, a DC bus, and a load.

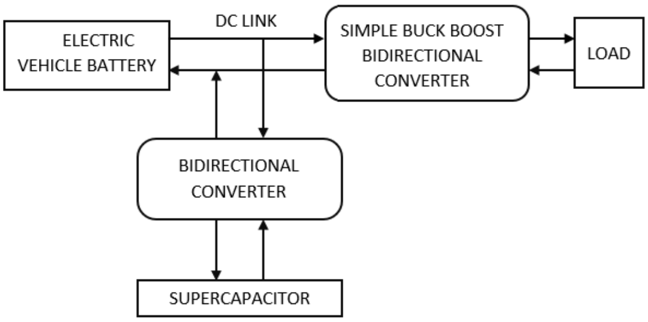

FIGURE 1

BATTERY-SUPER CAPACITOR HYBRID ENERGY STORAGE SYSTEM

BI-DIRECTIONAL DC-DC CONVERTER

Figure 2 shows the circuit diagram of Bidirectional DC-DC converter. It will control the charge or discharge of storage devices by the voltage levels they are adapted to the necessary operational condition. The bidirectional converter has two inductors, two diodes, four switches and a capacitor. The input to the converter is supplied by a supercapacitor. The output of the converter is given to a DC link at the input side of the system. Converter has two modes of operation-Buck and Boost modes [7-9]. In each mode only one switch is responsible for the power flow so control complexity of the circuit is less. This converter is characterized by high gain in both step up and step-down modes. The converter is assumed to be operating in steady state continuous conduction mode. The capacitor value is taken large enough so that voltage across it is taken constant along one switching cycle.

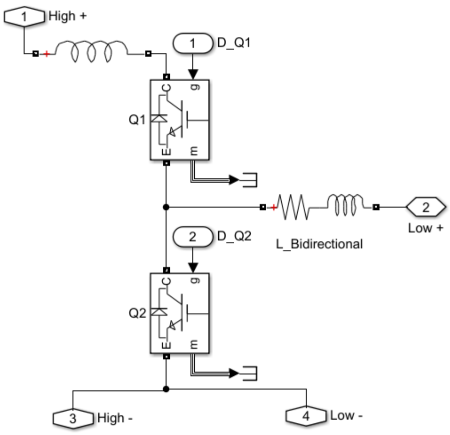

FIGURE 2

BI-DIRECTIONAL DC-DC CONVERTER USED FOR BATTERY AND SUPER CAPACITOR

CONTROL STRATEGY FOR BI-DIRECTIONAL CONVERTER

The bidirectional converters are used to control the battery and super capacitor voltage. BLDC motor connected at DC link through a bi directional DC-DC converter is controlled in constant current/constant voltage (CC/CV). Until the terminal voltage of the EV battery reaches the voltage corresponding to the full charge condition, the EV charges in CC mode. However, after reaching near to the desired terminal voltage in nearly full charge condition, the charging of the EVs is shifted in CV mode. The CC/CV mode of charging is controlled using two PI controllers.

BATTERY AND SUPER CAPACITOR CONTROLLING UNIT

The battery and super-capacitor controlling unit is shown in Figure 3. The DC link voltage is compared with reference voltage and the error in voltage is provided to PI controller. After that the generated reference current is compared with battery current and the error is provided to PI controller.

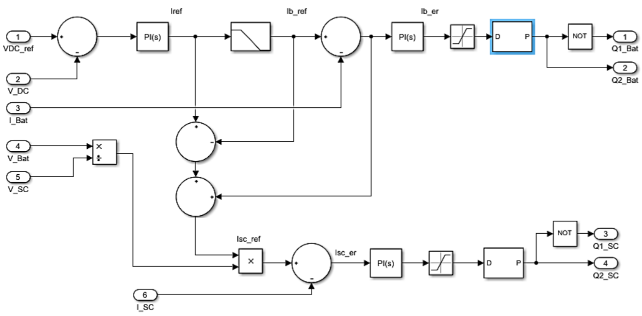

FIGURE 3

BATTERY AND SUPER CAPACITOR CONTROLLING UNIT

The generated reference voltage is provided to PWM generator to provide gate pulses for bidirectional converter at battery. And to give pulses to bidirectional converter at SC the battery voltage is divided with SC voltage and then multiplied with generated reference current.

Voltage source converter:

Single-phase VSIs are used primarily for low power range applications, while three-phase VSIs cover both medium and high-power range applications. Figure 4 shows the circuit schematic for a three-phase VSI.

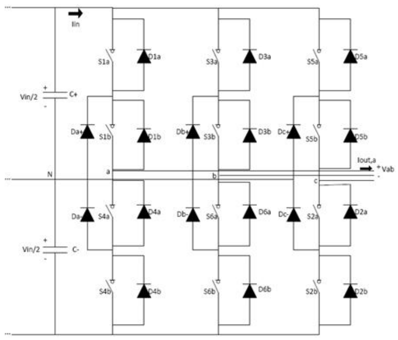

FIGURE 4

THE CIRCUIT DIAGRAM OF A THREE-PHASE VSI

Switches in any of the three legs of the inverter cannot be switched off simultaneously due to this resulting in the voltages being dependent on the respective line current's polarity. States 7 and 8 produce zero AC line voltages, which result in AC line currents freewheeling through either the upper or the lower components. However, the line voltages for states 1 through 6 produce an AC line voltage consisting of the discrete values of V_i, 0 or $-V_i$.

For three-phase SPWM, three modulating signals that are 120 degrees out of phase with one another are used in order to produce out of phase load voltages. In order to preserve the PWM features with a single carrier signal, the normalized carrier frequency, mf, needs to be a multiple of three. This keeps the magnitude of the phase voltages identical, but out of phase with each other by 120 degrees. The maximum achievable phase voltage amplitude in the linear region, ma less than or equal to one, is $V_{phase} = V_i / 2$. The maximum achievable line voltage amplitude is $V_{ab1} = V_{ab} \cdot \sqrt{3} / 2$The only way to control the load voltage is by changing the input DC voltage.

BLDC MOTOR INVERTER CONTROLLING UNIT

The three-phase inverter is controlled through the gates which are controlled by the current controller. This current controller is controlled by the speed controller of the BLDC motor as shown in Figure 5. The rotor speed, electromagnetic torque, stator's back emf and the stator currents are measured.

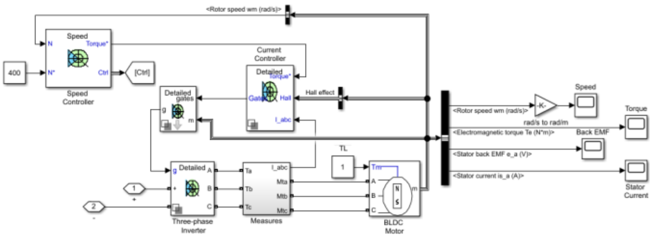

FIGURE 5

SIMULINK BLOCK DIAGRAM REPRESENTING THE SPEED & CURRENT CONTROLLERS FOR A DC MOTOR

SIMULATION RESULTS

The output voltage of the supercapacitor is nearly 31.98V as shown in Figure 6. The battery output voltage at the same instant is 25.8 V. The sum of the voltages is approximately equal to the reference voltage given. Super capacitor starts delivering power when specific power requirement is high.

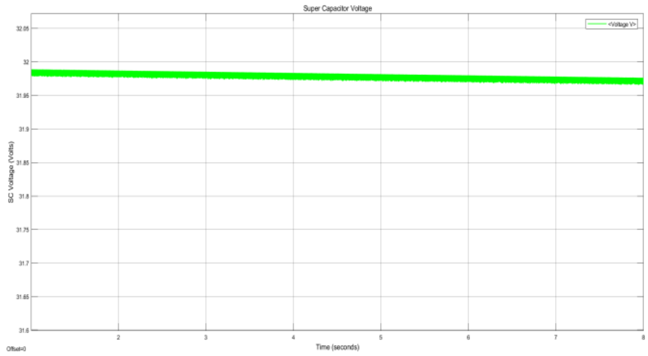

FIGURE 6

THE VOLTAGE CHARACTERISTICS OF A SUPER CAPACITOR

The maximum value of the output current supplied by a supercapacitor is nearly 2A which is shown in Figure 7.

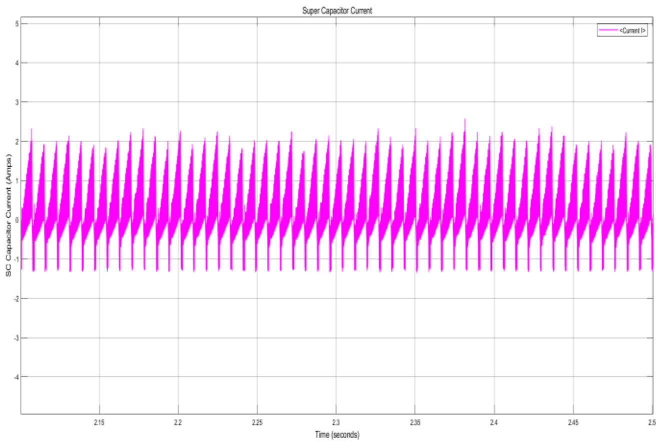

FIGURE 7

THE CURRENT CHARACTERISTICS OF A SUPER CAPACITOR

Initially the battery voltage is high (25.8V) and it falls to 25.15V from 0sec to 0.26 sec. Again, the battery voltage raises to 25.75V and remains constant at 0.55 sec. The simulation is done for 10 secs and is shown in Figure 8.

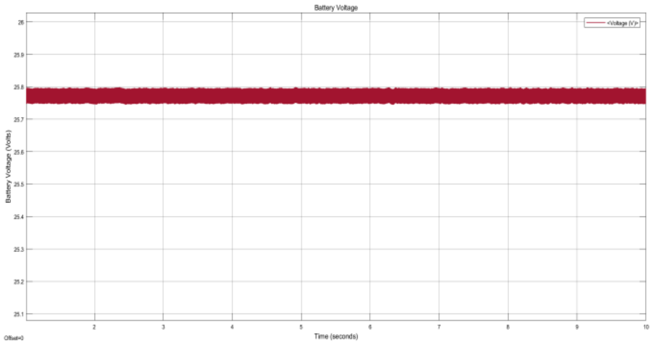

FIGURE 8

THE VOLTAGE CHARACTERISTICS OF A BATTERY

The maximum value of the output current supplied by a battery is nearly 3A which is shown in Figure 9.

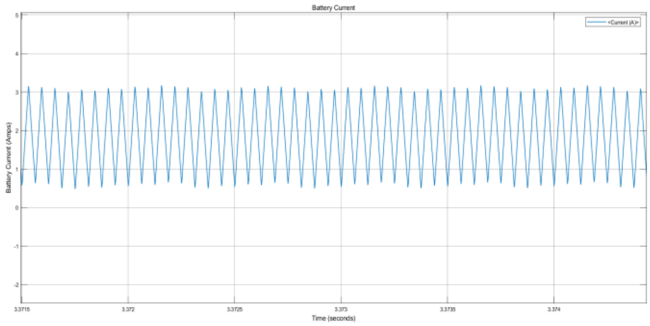

FIGURE 9

THE CURRENT CHARACTERISTICS OF A BATTERY

The DC Link voltage characteristics are shown in Figure 10 below and is 50 Volts.

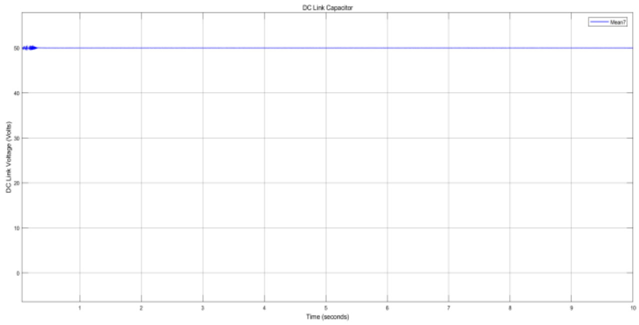

FIGURE 10

THE VOLTAGE CHARACTERISTICS OF A DC LINK

Initially the speed keeps on increasing and stabilizes at 310rpm in 0.32 seconds as shown in Figure 11. The reference speed given in 400 rpm. The number of pairs of poles are 2 and the nominal frequency is 60Hz. The speed is inversely proportional to the load on the motor.

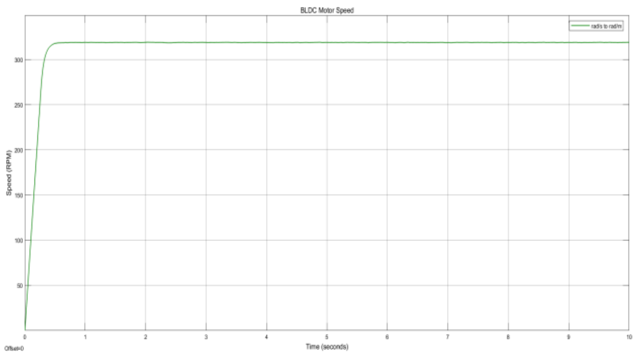

FIGURE 11

THE SPEED CHARACTERISTICS OF A BLDC MOTOR

The torque characteristics of the BLDC motor with speed and current controller using battery and super capacitor are shown in Figure 12. The starting torques obtained is 12 N-m and the running torque is evidently reduced to 1 N-m in less than 0.5 seconds. The back emf and the stator current characteristics are presented in Figures 13 and 14 respectively.

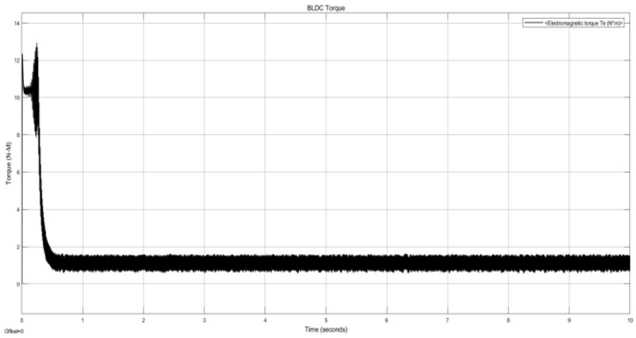

FIGURE 12

THE TORQUE CHARACTERISTICS OF A BLDC MOTOR

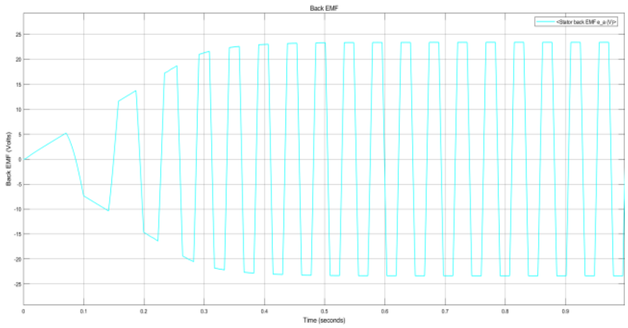

FIGURE 13

THE BACK EMF CHARACTERISTICS OF A BLDC MOTOR

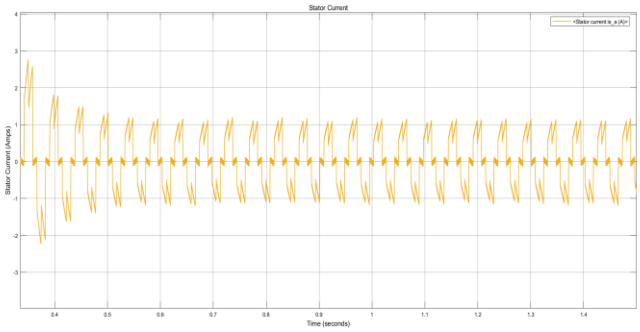

FIGURE 14

THE STATOR CURRENT CHARACTERISTICS OF A BLDC MOTOR

CONCLUSION

The characteristics of hybrid energy storage system comprising battery and super-capacitor units are explored in this paper under Simulink environment. The voltage and current characteristic of the battery and super capacitor are achieved in the permissible ranges. The torque, back emf, stator current characteristics are also obtained. Hence, the choice of HESS topology in this paper that has been made based on simplicity of power and control circuits, cost, and performance sufficiently validates the chosen hybrid energy storage system. The design takes into consideration the required power, the converter losses, limitations of energy storage devices, and quality of the current drawn from battery cells. The simulation results validated the performance of the HESS based on the voltage and current characteristics.

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