Design and Analysis of BLDC Motor Driver for Hybrid Electric Vehicles

Seong-Cheol Kim, Narasimha Sangam, Sravanthi Pagidipala, and Surender Reddy Salkuti

Abstract This chapter presents the design and analysis of brushless DC (BLDC) motor driver for hybrid electric vehicles. Due to the combustion of petroleum, it is going to create a pollution problem. Therefore, it is needed that alternating energy resources for petroleum reserves which are exhaustible in potential are required to be determined. The majority of the automobiles right now are reliant on internal combustion engines (ICEs) for the operation and it the root cause of worry since they are accountable for smog. Therefore, the automobile companies are searching for alternate energy sources which could decrease pollution. As a result of arising pollution issue, the hybrid electric-powered vehicles are important for long term planning. The brushed DC machine works on a setup of wound wire coils and armature which acts as a two-pole electromagnet. The brushless DC machine, by comparison, uses a lasting magnet as it has an outside rotor. Additionally, it runs on 3 phases of coils along with a special sensor that monitors the rotor position. This chapter presents the relative evaluation of the electric vehicle (EV) that is powered by brushless DC (BLDC) motor and the corresponding impact on the state of ripples and charge in the DC voltage at the battery power. This comparison has been carried in the MATLAB application and the outcomes are explained clearly in the results section.

Keywords Brushless DC motor · Hybrid electric vehicles · DC-DC converters · Pulse width modulation · Regenerative energy · Voltage source converter

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S. R. Salkuti and P. Ray (eds.), *Next Generation Smart Grids: Modeling, Control and Optimization*, Lecture Notes in Electrical Engineering 824,
https://doi.org/10.1007/978-981-16-7794-6_12

Nomenclature

BEV	Battery electric vehicle
BLDC	Brushless direct current
CO	Carbon monoxide
CO_2	Carbon dioxide
EVs	Electric vehicles
ICE	Internal combustion engine
HEV	Hybrid electric vehicles
RBS	Regenerative braking system
PID	Proportional integral derivative
FLC	Fuzzy logic control
Li-ion	Lithium-ion
SOC	State of charge
PHEVs	Plug-in hybrid electric vehicles
NiMH	Nickel–Metal Hydride
VSI	Voltage Source Inverter
PWM	Pulse Width Modulation
SPWM	Sinusoidal pulse width modulation
VSC	Voltage Source Converters
IGBTs	Insulated gate bipolar transistors

1 Introduction

The transportation sector is growing rapidly throughout the world and it mostly depends on oils. The fossil fuels utilized in mainstream automobile will release various greenhouse gases such as carbon monoxide (CO), carbon dioxide (CO_2), and methane. The exorbitant of gases causes pollution associated with the environmental surroundings, climate modification, and warming. To reduce these affects, automobile industry is now certainly moving towards the electric vehicle (EV) technology [1, 2]. The electric vehicles (EVs) have reduced fuel price in conformity with fossil-fueled automobiles since they are primarily built with battery pack systems. The battery power coordination in an EV is the large amount of element this is certainly important in determining the distance. The electrical automobiles are trusted for pollution free transportation environment as they operate with an electrical battery [3]. In order to increase the distance travelled by the EVs and to increase the recapturing of the regenerative energy, one must enhance the performance of all components utilized in the EVs such as electric engine, energy converter, and power storage system, i.e., battery power or ultracapacitor.

In recent years, EVs have drawn much attention as compared to conventional internal combustion engine (ICE) vehicles. This contemplation is due to the economic and environmental troubles concerns linked with the utilization of natural gas and petroleum fuels, and these are used as fuel in ICE vehicles. More advancement and researches on vehicles like fuel cell and hybrid cars, pure battery powered EVs, etc. are pursued actively [4]. Owing to the facts that these vehicles are reasoned to serve as an efficient means to deal with global warming caused by the tail pipe-auto emissions. In the case of eco vehicles, the compatibility between safety and running performance has to be ensured especially in the case of EVs where electric devices like batteries, converters and inverters are part of their propulsion force producing system. If such an electric device fails during the motion of the EV, the EVs shall fails to run safely and comfortably. This kind of failure in motion may constitute series traffic accidents like rear end collisions. As an advancement for developing the next generation of EVs, fail safe functions must be interlinked within the propulsion force generating system, there by the EV can persist to run safely even if malfunctions occurs during EV motion [5]. The hybrid electric vehicles (HEV), which mainly contains at a minimum of two sources of power, first one is a primary power source and the other one is named as secondary power source, which have the favors of both the EV and conventional ICE vehicles also had the ability to vanquish their disadvantages.

1.1 Related Work

Unlike the conventional vehicles, the running capability of battery electric vehicle (BEV) depends completely on the electric motor and battery unit; as there is no involvement of traditional ICEs. In order to recharge the battery to a sufficient amount, it should be plugged with an external electricity source [6, 7]. It can also be recharged by regenerative braking process like all EVs. These vehicles have the merits like no emissions, gases, free from compulsory oil changes, comparatively low cost of running, fast and real smooth acceleration, and also have the capacity to conveniently charge at home. But it also have the demerits like shorter range than gasoline vehicles and moderately expensive than its gasoline equivalent despite the fact that within the span of 2–3 years the gasoline savings will pay off.

Reference [8] reviews the technology and applications of electrical vehicles. It critically appraises the level of state-of-the-art research improvements in this industry developed in the last decade. It also highlights the technical issues of automobile technology. Reference [9] presents which converter or drive is suitable for the electric car. Regenerative stopping can improve power usage efficiency which in turn improves the driving distance of electric automobiles. The importance and characteristics of regenerative braking system (RBS) has been presented in the reference [10]. The RBS is adjusted to DC that is brushless BLDC engine, and it emphasizes in the circulation with this particular force that is powerful in stopping alongside BLDC motor control. In this work, BLDC motor control uses proportional integral derivative (PID) control; consequently, the flow of stopping force uses the fuzzy logic control (FLC). The braking torque could be managed in real-time by PID control because it is certainly slower than PID control.

Reference [11] has designed the effectiveness of DC engine which is highly inexpensive. The controller takes input that is individual manage the rate and drives the engine at that rate regardless of load. This permits fast, smooth motor response. A converter drives the motor by utilizing the power through the battery pack. Reference [12] is targeted at the optimization of core size power inductors in bidirectional DC-DC converters. It describes a characterization that is certainly experimental are large-signal for energy inductors in EV applications and an answer getting an inductance guide value when it comes to ability inductor in DC-DC converters simulation studies. A prototype of one kilowatt inductive wireless power transfer power converters with high frequency supply is modeled in reference [13]. Reference [14] proposes the modeling and evaluation of sizing of battery pack required by using the Simpson in R Studio.

1.2 Motivation and Contributions

This chapter provides the comparative analysis of DC machine powered electric vehicle and BLDC powered electric vehicle, and the corresponding effect on state of charge and ripples in the dc voltage at the battery. This comparison is carried out in the MATLAB software and the comparative results are given individually. The objective of this work is to provide a better percentage of the state of charge (SOC) to make the design much better and efficient. This work discusses the concerns related to the battery storage systems, their types along with their benefits and drawbacks. Also describes the types of converters and primarilyDC-DC converters, their advantages, and just how they are found in this task is certainly proposed. Simulation results and analysis linked to the proposed work are also discussed. In short, the main objectives are to provide better SOC, much better design, improved efficiency, and less maintenance.

Organization of this chapter: In Sect. 2, the description and classification of battery storage system is presented. Section 3 describes the modeling of DC-DC converter. In Sect. 4, simulation results are described. In the last section, the whole chapter is concluded.

2 Battery Storage System

Generally, there are two types of batteries, primary and secondary. Normally, the standards for the secondary/rechargeable batteries rate the capacity over a 4, 8 h, or even longer discharge times. The lithium-ion (Li-ion) battery is used in the design of this hybrid EV due to its low cost and good performance and light weight [15]. It has a nominal voltage of 350 V and an initial state of charge (SOC) of 88%. A power kit is some sort of computer product comprising a genuine degree of electrochemical cells with outside junctions for powering devices which might be electric as flashlights, cellular phones, and automobiles that happen to be electric. These cells are wet electrolytes fluids that are vulnerable to leakage and spillage [16]. Batteries convert chemical power directly to provide power that is electric.

The various energy sources like batteries, ultracapacitors and flywheels of EVs can retrieve and store regenerative energy effectively. Energy management subsystem unit along with vehicle controller unit processes the energy recovery and there by the regeneration process is controlled. In order to monitor the energy source usability and regulate the refueling, the energy refueling unit is utilized. For every EV auxiliaries including climate control and power steering unit, and the sufficient power with various voltage levels are delivered by the auxiliary power supply subsystem.

In plug-in hybrid electric vehicles (PHEVs), batteries reflect as the greatest means of source of energy. To accomplish the “all electric driving range” insistence the powertrains of PHEV’s should carry large number of high rated battery packs with abundant energy and superior power density. Energy supplied from the high rated battery pack should be adequate enough for the impulses to sustain the continuous speed range [17]. Through within the all electric driving range the batteries also need to deliver power to the auxiliaries like air conditioning unit or power steering unit etc. But the use of large quantities of onboard high rated batteries bring up the questions about safety regarding with chances of fire threat, accidents or even the possibilities of short circuit during either operation cannot be avoided. It creates another critical situation; there by the selection of battery technology is highly crucial in consideration with their efficiency, price, and authenticity. The mostly acknowledged batteries in PHEVs are currently Lithium-ion (Li-ion) batteries. They can dispense sufficient-energy density and highly demanded-power density for the batteries of equal weight, and ensures wider all electric drive range with best ever performance of vehicle. One of the other kinds of commercialized battery for PHEVs is Nickel–Metal Hydride (NiMH) batteries.

The EVs are designed to steer with high voltage electrical energy stored batteries. By this way the exhaust emissions can be excluded which further reduces the air pollution since gasoline or other fossil fuels are not required for the propulsion. During the entire driving range, the noises and vibrations from engine is negligibly small in comparison with traditional ICEs. The electric motor employed in EVs is generally higher performance motors [18]. During the downhill or decelerating motion of the said vehicle the restoring of brake energy by regeneration can be employed and will be stored to the high voltage batteries. There by the driving range from single charging will be extended and also reduce the loss during the braking. In case existing charge of battery is not adequate to drive the vehicle, various charging methods like AC or DC charge is applied. The trickle charge can also be applied.

The incorporation of an ICE with electric motor is the most widely used combo for the generation of propulsion force in hybrid EVs. With this integration, energy efficiency will be improved and vehicle emissions will be fall off due to the electric motor and driving range will extended because of the ICE. The stereotypical ICE vehicles show good performances along with large operating range clearly because of the high energy-density yielded by the petroleum products. But these common ICE vehicles have the disadvantage of indigent fuel economy and greater risks of environmental contamination [19]. By far the reasons behind their indigent fuel economy are the contrast between real operation requirements and the vehicles fuel expertise, operating in urban areas, the wastage of kinetic energy during braking, and due to the stop and go driving pattern the productivity of hydraulic transmission in current day automobiles.

The existent EVs powered by battery packs have dominance over typical ICE vehicles by high energy productivity and almost zero environmental contamination. The comparison of these vehicles based on the performance of their driving range per battery charge ICEs hold the upper hand. However, due to the use of two power sources, hybrid electric vehicles can outsmart both traditional ICEs and EVs.

3 DC-DC Converter

The power electronic devices in PHEVs comprises of inverters, converters can be bidirectional or unidirectional, chargers etc. The inverter serves to transfer the battery DC power in to the required AC power for propulsion of electric motor(s). Another important fact is that, with the motor drive power electronic components, the retrieval of regenerative energy and their storage in batteries are possible. Diverse numbers of DC-DC converters are beneficial for applications that require multiple voltage levels [20]. In contemplation of regenerative energy storage in to battery bidirectional power flow has to be ensured regarding with the converter. Apart from these AC to DC converters are essential for battery chargers, as they transfigure the AC power flow of grid to suitable DC power to charge the battery unit. To achieve high efficiency batteries programmable digital controllers having proper voltage and current profiles are needed along with proper power factor correction. Figure 1 depicts the buck-boost converter connected with DC machine. The fuzzy logic control (FLC) finds the duty cycle of S_1 and S_2 to ensure the charge and discharge of battery. Buck-boost converter is a kind of DC-to-DC converter which contains a manufacturing voltage magnitude that is often more than or perhaps much less in comparison with the voltage magnitude of input, and this is equivalent to a flyback converter working with an inductor [21, 22].

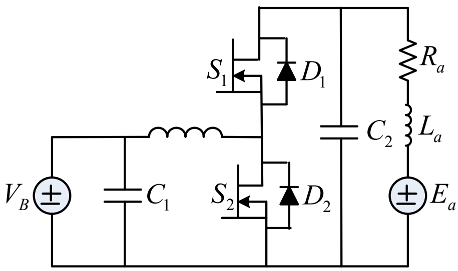


Fig. 1 Buck-boost converter connected with DC machine

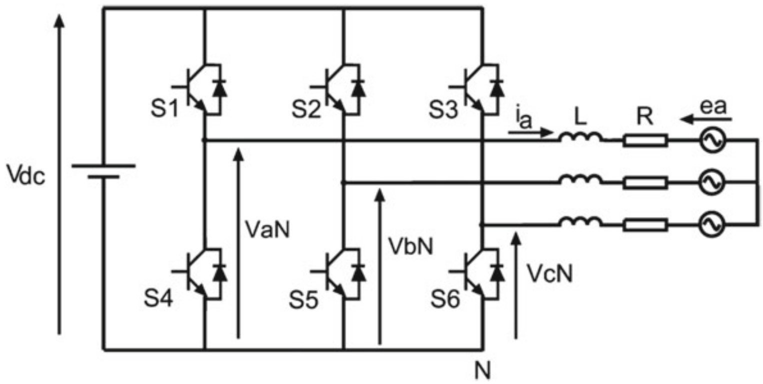


Fig. 2 The schematic diagram of VSI

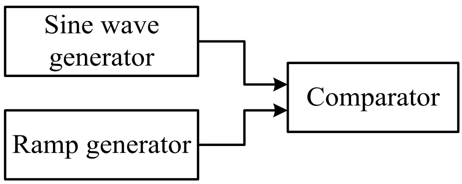
3.1 Voltage Source Inverter (VSI)

The main purpose of VSI is to convert a constant DC voltage into an AC voltage with variable magnitude and frequency. The VSI maintains a fixed polarity of DC voltage, and the reversal of power can be obtained without reversing the direction of the current. The schematic view of VSI is depicted in Fig. 2.

3.2 Pulse Width Modulation (PWM)

It is a modulation technique which is used to encode a pulsating signal. The switching frequency of PWM is much higher than what would affect the load. By doing that the resultant waveform is as smooth as possible [23, 24]. The main advantages of using PWM are cheap to create, consumes less energy, use of high frequencies (around 40 to 100 kHz), extremely efficient in energy-smart while dimming the radiant light or perhaps in voltage conversions, high control ability of power and high efficiency, i.e., around 90%. A modulation strategy is helpful to encode a communication as an illustration that is pulsing. This modulation strategy assists to encode information for transmission, and it allows the control related to the power supplied which could be electrical products and services. Figures 3 and 4 depict the block diagram and

Fig. 3 SPWM block diagram



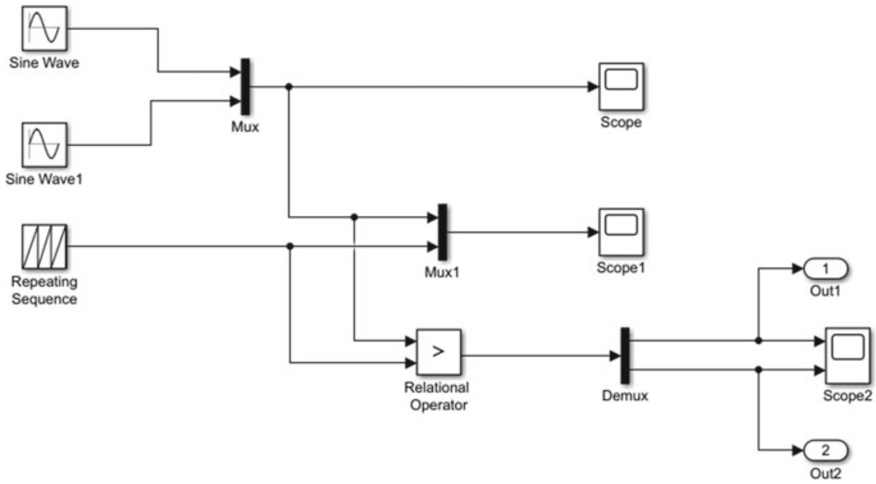


Fig. 4 SPWM simulation diagram

simulation diagram of sinusoidal pulse width modulation (SPWM). The (ON and OFF time frames) period of pulse is continuous. The (ON time and OFF period) about the pulse is called period with this pulse, and the ratio attached with the time that is full punctually that is from the period is named as duty cycle.

3.3 Voltage Source Converters (VSC)

The polarity of a DC voltage is typically fixed and it is smoothed by using a capacitance [14, 25]. Because of this, an HVDC converter utilizing insulated gate bipolar transistors (IGBTs) is often known as a voltage source converter (VSC). The controllability introduces several benefits; particularly the ability to change the ON/OFF status of IGBT's a couple of times per duration to have the ability to enhance harmonic performance. A two-level converter can function as the type that is most basic of three-phase VSC and will undoubtedly be seen as a six pulse bridge [26, 27]. Figure 5 depicts the two-level VSC for HVDC.

Some HVDC methods were constructed with three-level converters to improve the negative performance are harmonic the converter is unquestionably two-level. The three-level converters can synthesize 3 (instead of just two) discrete voltage quantities while in the AC terminal of the phase [28]: $+\frac{1}{2}U_d$, zero, $-\frac{1}{2}U_d$. Here, a common type of the converter is used [29], i.e., diode clamped converter with 4 IGBT valves in each phase.

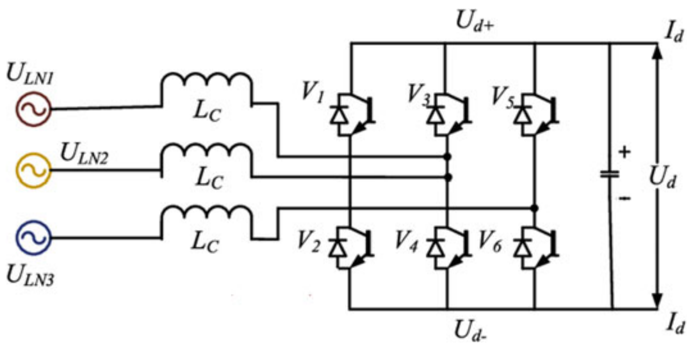


Fig. 5 Two-level VSC for HVDC

4 Results and Discussion

Batteries of PHEVs are charged with the assistance of EV supply equipment (EVSE), i.e., charging stations. The charging stations communicate along with vehicles to guarantee that electricity flows in to the system will be shielded and pertinent. The classifications of EVSE in plug-in vehicles are elicited from the rate at which batteries will charge. The two major kinds of EVSE are 'AC level 1' and 'AC level 2', which will be able to supply the vehicle with alternating current. The vehicle is equipped with an on board electrical equipment/charger which transfer AC to DC for charging the vehicle battery [30, 31]. DC fast charging might also appropriate for direct DC supply to automobile, simply named as DC level 2.

Converter circuit configuration of hybrid electric vehicle (HEV) using DC machine has been depicted in Fig. 6. The duty ratio is produced by fuzzy logic control (FLC) with ramp revolution of changing and hence the pulse created for

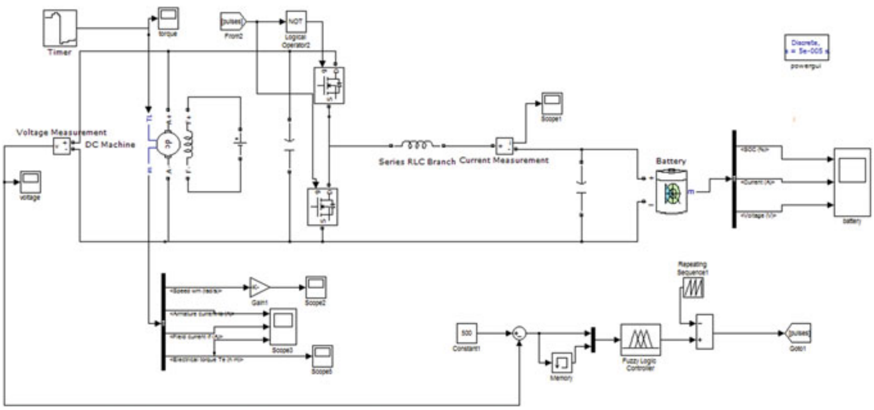


Fig. 6 Converter circuit configuration of hybrid electric vehicle using DC machine

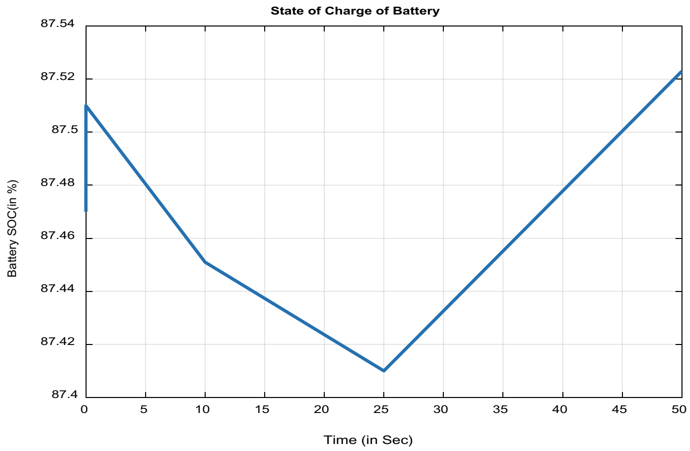


Fig. 7 Battery SOC (in %)

semiconductor switch to the group of zero and 25 moments. DC unit voltage is elevated on the worthiness that is needed.

The battery energy state of charge (SOC) is improved based on the simulation outcome. In the EV, the regenerative braking has happened in this state. The charge and also the discharge states of this particular battery energy are required for determining the distance of travel. Figure 7 depicts the plot of battery SOC (in percentage) versus time for the converter system with DC machine. The output waveforms of battery voltage and current are depicted in Fig. 8.

The proposed converter system with BLDC motor is simulated and it is shown in Fig. 9. Figure 10 depicts the plot of battery SOC (in percentage) versus time for the converter system with BLDC motor. The output waveforms of battery voltage and current are depicted in Fig. 11. The voltage waveform of BLDC motor has been depicted in Fig. 12.

The DC machines operate in generating mode in the case of battery is charged and also the bi-directional DC-DC converter operates in the buck mode. In the EV, regenerative braking has occurred in this state. In the BLDC machine, when the battery is charged, the machine is operated in generator mode. The battery SOC has been increased from 87.6 to 87.8%. Results being exemplary analysis are acquired straight into the MATLAB and all the simulation results are analyzed for different conditions alongside the SOC, the voltage quantities are also improved.

5 Conclusions

The charging and discharging states of battery plays an important role in determining the distance to travel the electric vehicle. This chapter has presented the design and

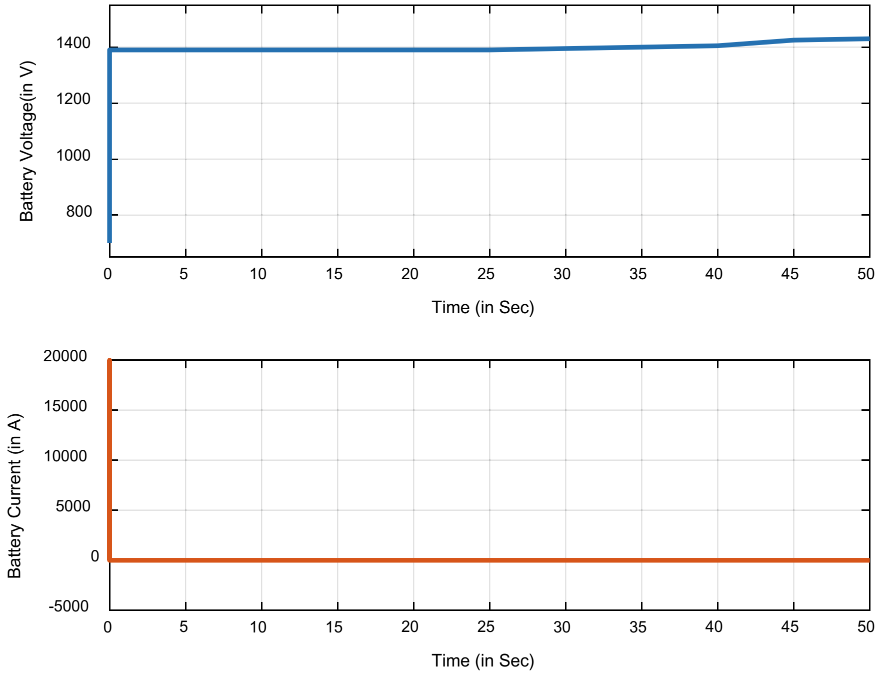


Fig. 8 Battery voltage and current versus time

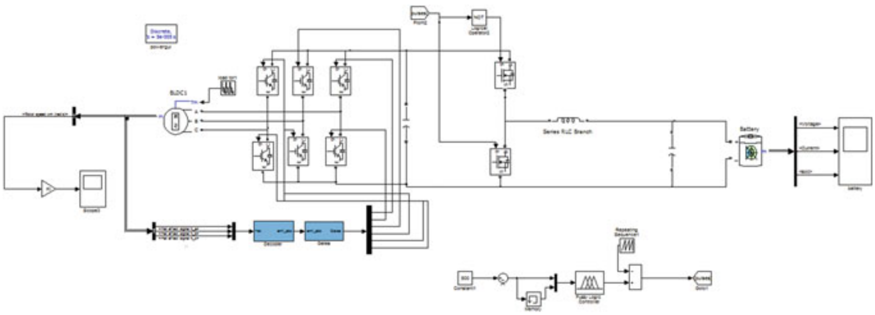


Fig. 9 Proposed converter system with BLDC motor

analysis of brushless DC (BLDC) motor driver for the hybrid electric vehicles. The relative evaluation of the electric vehicle (EV) that is powered by BLDC motor and the corresponding impact on the state of ripples and charge in the DC voltage at the battery power are also presented. This comparison has been carried in the MATLAB application and the outcomes are explained clearly in the results section. Battery pack energy has been enhanced from 87.47 to 87.55% according to the simulation effect. In the all-electric automobile, regenerative braking has occurred. The charge

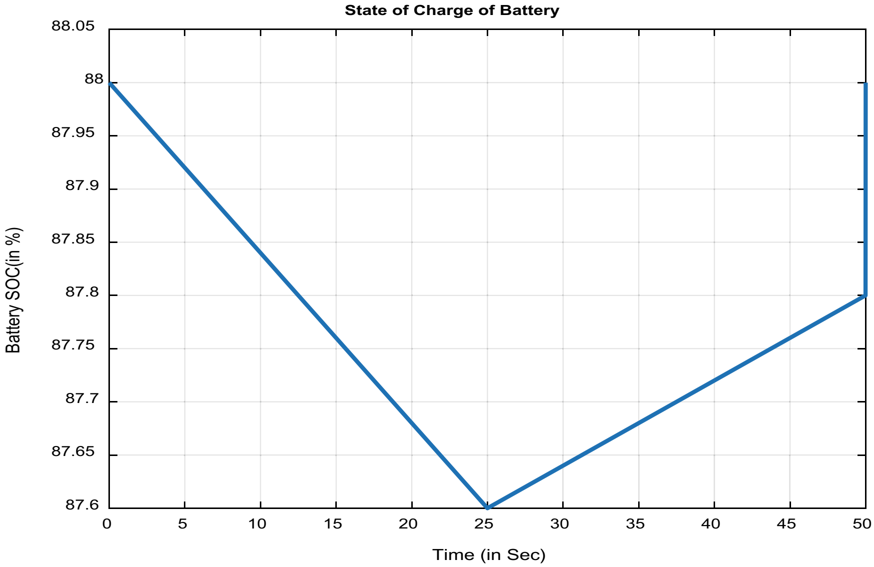


Fig. 10 SOC of battery (in %)

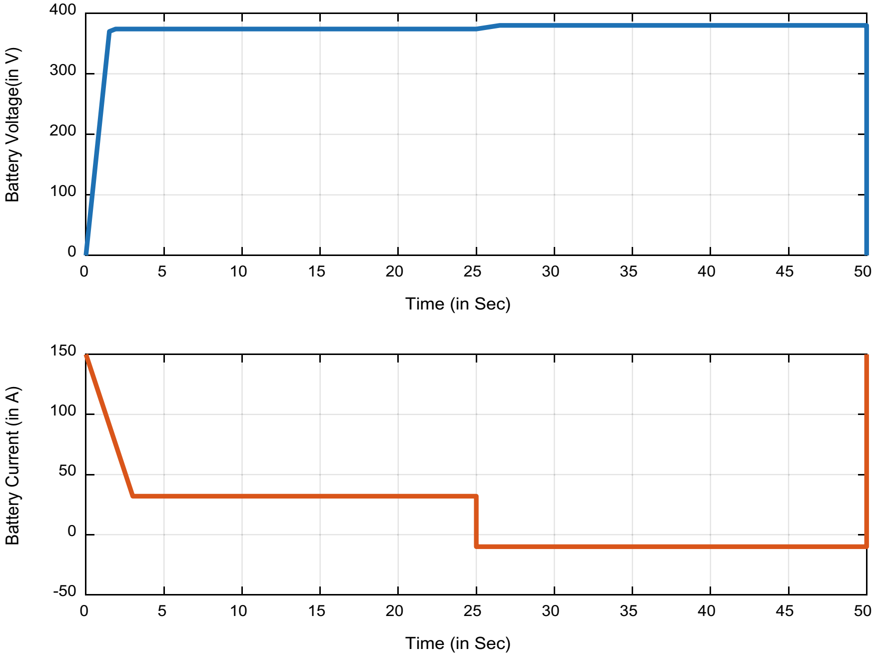


Fig. 11 Battery voltage and current of converter system with BLDC motor

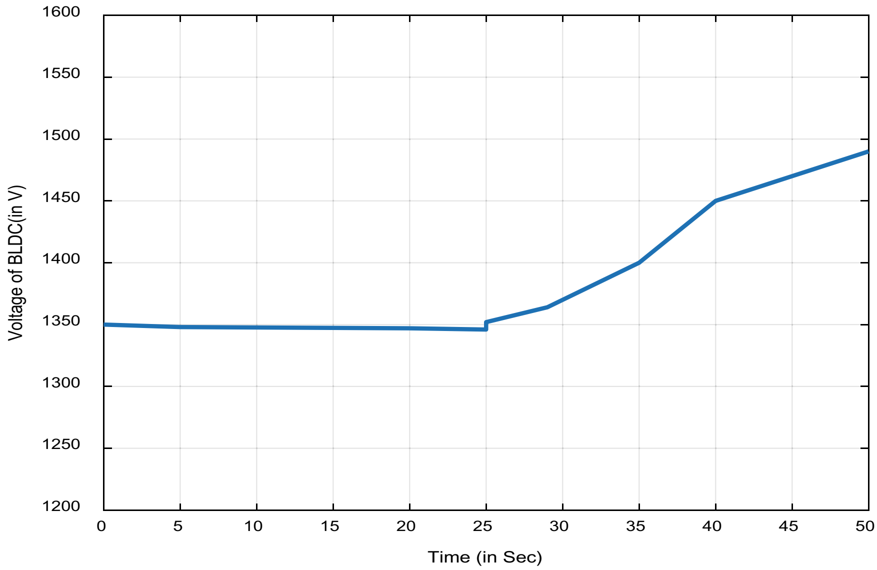


Fig. 12 Voltage of converter system with BLDC machine

and also discharge states of the electric battery may be many needed for distance to determining. If the battery pack is charged, the unit which is dc operated turbine setting and the bi-directional DC-DC converter will be operated in the buck mode. Adjustable torque which is unfavorable is placed about the BLDC device as well as influence the battery pack. Based upon the simulation results, the battery state of charge (SOC) has been improved from 87.6 to 87.8%.

Acknowledgements This research work was funded by "Woosong University's Academic Research Funding-2021".

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