SWITCHING BI-DIRECTIONAL BUCK-BOOST CONVERTER BASED ON ELECTRIC VEHICLE HYBRID ENERGY STORAGE FOR V2G SYSTEM

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ABSTRACT

This paper presents a switching bi-directional buck-boost converter (SBBBC) for vehicles to grid (V2G) system. The topology can provide an energy bi-directional flow path for energy exchange between the Li-battery/supercapacitor (SC) hybrid energy storage system (HESS) of the electric vehicle and the grid. This topology not only has buck-boost capability, but also has the function of energy management. In this paper, the state-space averaging method is used to analyse the stability of the topology in boost and buck modes. The control strategy is given according to the state of charge (SOC) of the energy storage system to ensure that the output voltage and current are stable. And the Li-battery is charged in constant current (CC) and constant voltage (CV) mode. The voltage and current controllers are designed in the frequency domain based on bode plots. Finally, the electrical feasibility of the topology, the suitability of the design controller and control strategy are varied by simulation and experiment.

INTRODUCTION

Electric vehicles have been widely used because of their cleanliness and low impact on the environment [1]. Li-batteries are of critical importance part in energy storage systems of electric vehicle [2]. Although Li-batteries with high energy densities can provide enough energy during steady-state operation, the power densities of Li-batteries are too low to meet the peak power demand [3], [4]. Combining Li-batteries and supercapacitors (SC) to form a hybrid energy storage system (HESS) can solve the problem. The reason is that SC with higher power densities can provide the transient power required by the load [5]–[17]. Since output voltage peak of the voltage source inverter is less than the dc-link side voltage, it is necessary to use the dc-dc converter to raise the Li-battery voltage [18]. Figure 1 shows the block diagram of HESS. The SC is directly connected to the inverter, which can increase the dynamic response of the HESS during transient peak power demand, while the Li-battery is connected to the DC-link by a bi-directional DC/DC converter [19]. The effect of the bi-directional dc-dc converter in the HESS is to transfer the energy and keep the dc bus voltage stability. Moreover, the converter should provide bi-directional power flow because the energy storage system and the grid require energy exchange.

The rapid evolution of electric vehicles (EVs) has paved the way for innovative technologies in the realm of energy storage and management. One such groundbreaking development is the implementation of a Switching Bi-Directional Buck-Boost Converter in the context of an Electric Vehicle Hybrid Energy Storage system for Vehicle-to-Grid (V2G) applications. As the demand for sustainable and efficient energy solutions continues to grow, V2G systems have emerged as a promising avenue for optimizing the use of electric vehicles in conjunction with the power grid. The integration of a Bi-Directional Buck-Boost Converter adds a layer of sophistication to this system, enabling seamless energy flow between the electric vehicle and the grid.

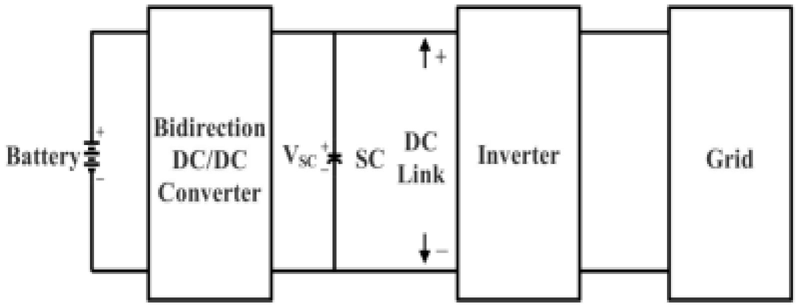

FIGURE 1. The block diagram of HESS.

This research endeavors to explore and elucidate the intricacies of the Switching Bi-Directional Buck-Boost Converter, focusing on its application within the unique context of an EV Hybrid Energy Storage system. By delving into the technical aspects of this converter, such as its switching mechanisms and bidirectional energy transfer capabilities, we aim to uncover its potential benefits and challenges. The utilization of hybrid energy storage, which combines different energy storage technologies, enhances the overall efficiency and performance of the V2G system. This study aims to shed light on the advantages of such an integrated approach and how it contributes to the sustainability and reliability of V2G systems. Through comprehensive analysis and experimentation, this research aspires to provide valuable insights into the Switching Bi-Directional Buck-Boost Converter's performance in real-world scenarios. By doing so, it seeks to contribute to the ongoing discourse on advancing energy storage technologies for electric vehicles and their integration into the larger smart grid infrastructure. The ultimate goal is to foster a deeper understanding of the intricacies involved in harnessing hybrid energy storage within V2G systems, paving the way for a more sustainable and resilient energy future.

LITERATURE SURVEY

A number of articles were surveyed to know about the present advances in the scientific community in our field of interest. Some of the honourable mentions and their work contribution includes as follows: In [6], the authors consider a few information identified with the PEVs' every day travel. (Dis) charging profiles of a PEV in a parking garage depends on delayed time and minimal loading on the grid. It has considered the parking lot stop amidst every day travel and the likelihood of charging at home for a PEV.

The authors in [7] approach the self-planning issue of a PEV aggregator who offers in the day-ahead market to buy vitality for a PEV fleet. The aggregator must guarantee that the end user limitations of the PEVs under its administration are not disregarded. These individual imperatives are coordinated into a collected "virtual battery". These limitations are parameterized utilizing singular driving examples (arrival and departure times, trip energy consumption) obtained from a transport simulation. This work presents a model of an electric vehicle which can act as a storage system in conjuncture with the power system. A decision-making strategy is built up for the organization of the battery vitality put away, assessing the condition of charge, time of day, power costs and vehicle charging necessities. The development of a battery based energy storage model has been done for the purpose of power system analysis within the IEEE 30-bus test system [8].

In another work, the issue of optimal parallel bidding process of V2G energy and ancillary services for aggregator benefit expansion is detailed. [9]. In paper [10], the authors concentrate on the effect of charging the electric vehicles on network of residential distribution. Diverse EV types and entrance levels, and various charging profiles are

considered. With a specific end goal to limit the effect of charging EVs on a distribution circuit, a demand response strategy is proposed with regards to a keen appropriation arrange.
[11] gives the general conditions utilized as a part of the counts of the value and cost of V2G for direction. Cost and income counts are presented. The authors in [12] propose a decentralized charging method for PEVs and discusses on Plug-in electric vehicles (PEVs) which sees a shift in usage of energy for individual transports from oil to electricity. The results obtained from the proposed scheme shows satisfactory outputs for load valley filling [12].
The authors in [13] propose a technique based on decentralized charging for a substantial populace of PEVs to neutralize the fluctuations in wind power in order to enhance the direction of framework recurrence. Without depending on a focal control element, each self-governing PEV alters its G2V/V2G power because of a collective virtual signal and in view of its own direness level of charging.
A vehicle with V2G abilities can offer various features such as active power regulation, reactive power support, balancing the load, harmonics filtering in the load current [14]. Also, this presents a general overview of a vehicle-to-grid (V2G) technology, in association with different charging/discharging techniques of electric vehicles (EVs), and a detailed analysis of EVs impact on the electricity network. The work in [15] exhibits a theoretical structure to effectively incorporate EVs into electric power frameworks. The proposed system covers two distinct areas the technical operation of the grid and the environment of electricity market. Every one of the players associated with both these procedures, and additionally their exercises, are portrayed in detail. The principal contextual analysis tends to the effects of EVs in a MV arrange, and in addition the advantages for the DSO emerging from the selection of an intelligent charging approach. The second contextual investigation tends to the effects of EVs in the dynamic conduct of a little LV grid and of a bigger MV grid, both worked in islanded way. A large portion of the earlier work has concentrated on controlling the charging of EV [3].
As far as the Indian region is concerned, it is available almost throughout the year. On the contrary to the solar PV array, the wind and hydro energies are location specific. The wind energy is mostly useful in the coastal region, and hydro energy is useful for hilly region. Though, the renewable energy based charging stations are the most feasible solution for the EV charging, however, their integration to the existing charging system introduces the additional power conversion stage, which increases the complexity and power loss in the system. Moreover, each conversion stage needs an individual controller, which needs to be integrated with the existing control. Therefore, it is imperative to design an integrated system with multifunctional and multimode operating capability, for which a unified control and coordination between the various sources are essential. Many efforts have been made to develop the renewable energy based charging station.

PROPOSED SYSTEM CONFIGURATION

In the realm of electric vehicles (EVs) and the associated technologies, the development of efficient and versatile energy storage solutions is of paramount importance. This proposed system delves into the intricacies of a Switching Bi-Directional Buck-Boost Converter, which serves as a crucial component in the context of Vehicle-to-Grid (V2G) systems. The integration of this converter with an Electric Vehicle Hybrid Energy Storage system promises to enhance the overall efficiency and performance of electric vehicles, contributing to the evolution of sustainable transportation. At its core, the Switching Bi-Directional Buck-Boost Converter is designed to efficiently manage the bidirectional flow of energy between the electric vehicle and the grid. This bidirectional capability is particularly relevant in the V2G system, where the vehicle can act not only as a consumer of energy from the grid but also as a potential source of power back to the grid when necessary. The converter, through its dynamic switching mechanism, facilitates seamless transitions between buck and boost modes, allowing for optimal energy transfer in both directions.

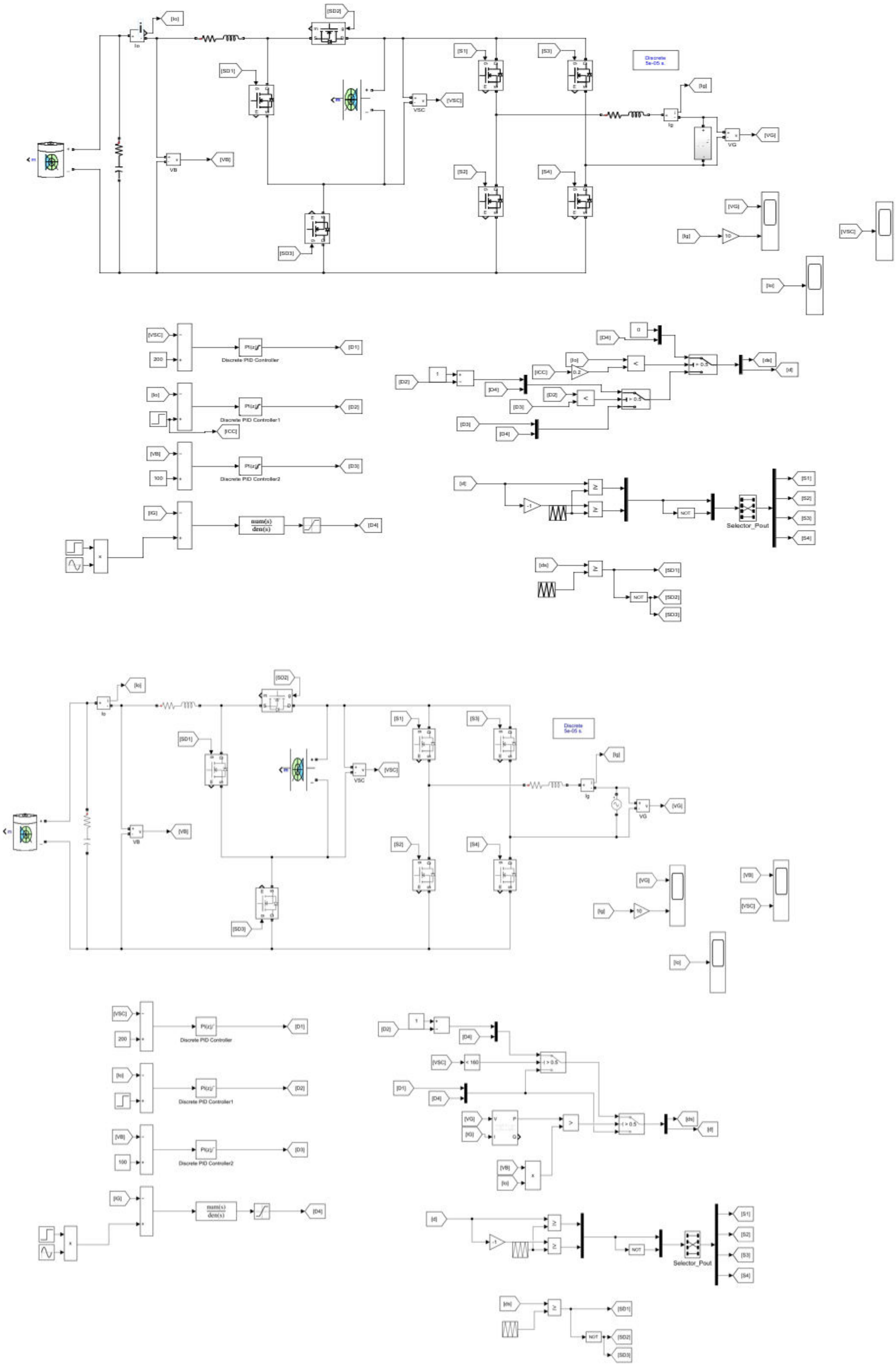

Fig 2 Simulation Model For Buck / Boost Mode

The incorporation of an Electric Vehicle Hybrid Energy Storage system further elevates the system's functionality. This hybrid storage solution combines the advantages of different energy storage technologies, such as lithium-ion batteries and ultracapacitors, to create a synergistic approach. Lithium-ion batteries, with their high energy density, provide the necessary capacity for sustained driving range, while ultracapacitors offer rapid charge and discharge capabilities, enhancing the converter's responsiveness during V2G interactions. One of the key features of the proposed system is its adaptability to various driving conditions and grid demands. The Switching Bi-Directional Buck-Boost Converter intelligently adjusts its operation based on the vehicle's power requirements and the grid's needs. During acceleration and high power demand phases, the converter efficiently boosts the voltage to meet the demands of the electric motor. Conversely, during braking or periods of excess energy, the converter steps down the voltage, facilitating energy recovery and storage.

SIMULATION RESULTS FOR BOOST MODE

The seamless transition between buck and boost modes is made possible by the implementation of advanced control algorithms. These algorithms leverage real-time data from sensors monitoring the vehicle's energy state, grid conditions, and other relevant parameters. The converter's control system uses this information to optimize the power flow, ensuring that energy transfer is efficient, and losses are minimized. The bidirectional nature of the converter allows for a high degree of flexibility, enabling the electric vehicle to actively participate in grid stabilization and demand response initiatives.

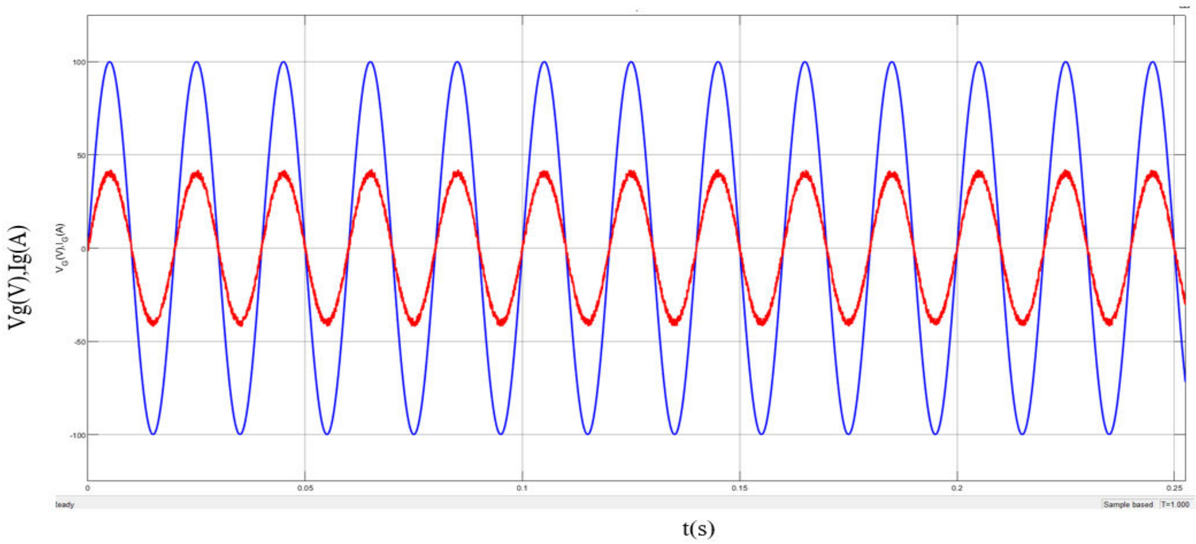

Fig 3 Grid voltage and current vs time for Boost mode

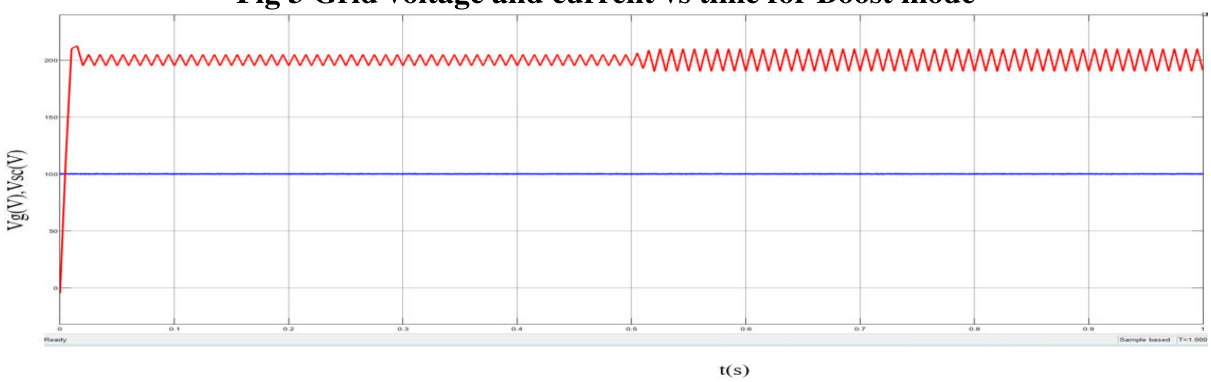

Fig 4 RMS Grid voltage and current vs time for Boost mode

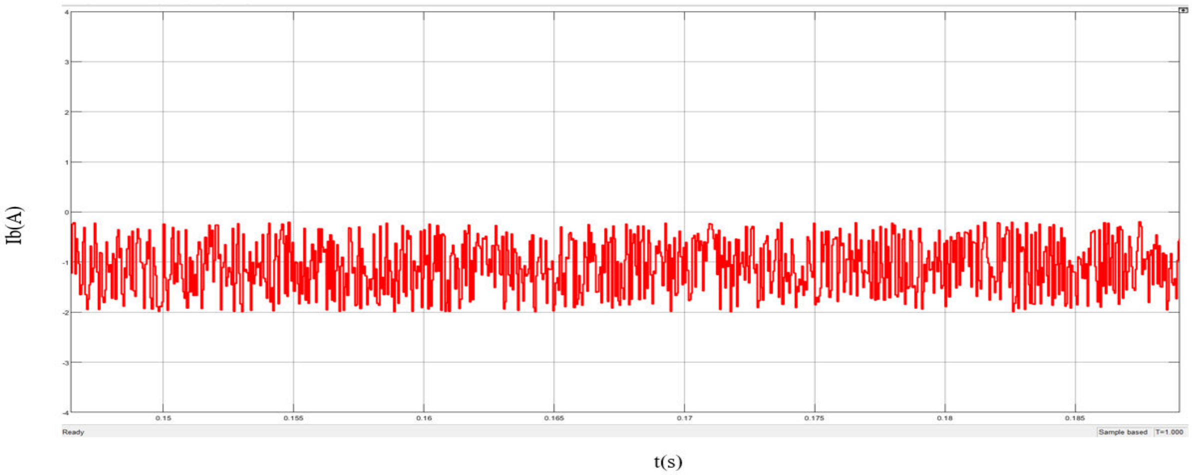

Fig 5 Battery current vs time for Boost mode

SIMULATION RESULTS FOR BUCK MODE

The significance of such a system extends beyond individual vehicle operation. In a V2G context, a fleet of electric vehicles equipped with these converters and hybrid energy storage systems can collectively contribute to grid stability and reliability. The bidirectional flow of energy allows for a distributed approach to energy management, where the collective capabilities of numerous vehicles can be harnessed to address peak demand periods, provide ancillary services, and enhance overall grid resilience.

Moreover, the proposed system aligns with the broader goals of sustainability and environmental conservation. By enabling electric vehicles to actively participate in grid services, the dependency on traditional power plants during peak demand can be reduced. This, in turn, contributes to a decrease in greenhouse gas emissions and promotes the integration of renewable energy sources into the grid. The converter's bidirectional functionality enables a seamless interface between the electric vehicle and the grid, fostering a symbiotic relationship that benefits both the user and the larger energy ecosystem.

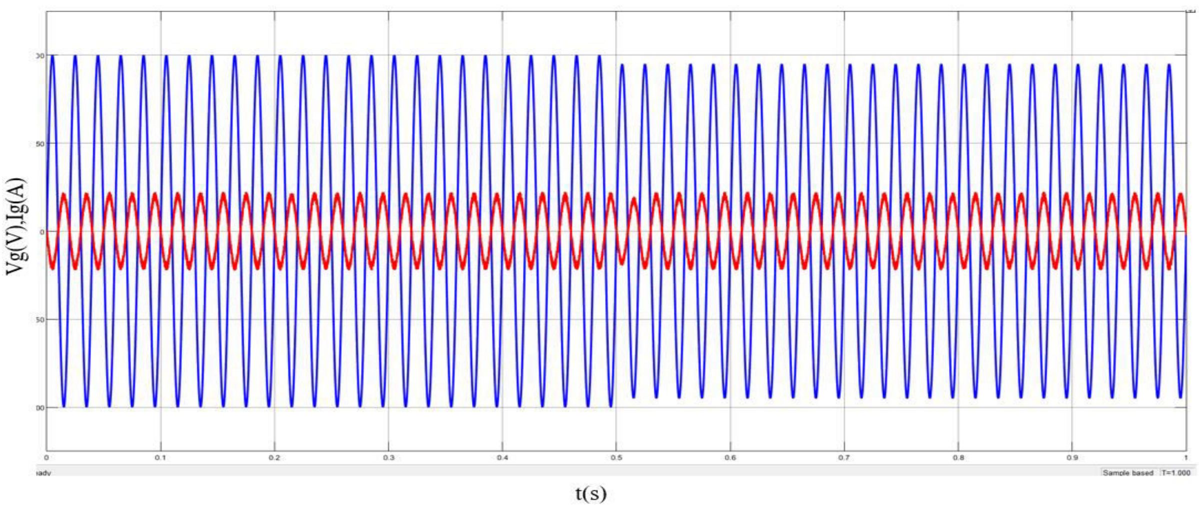

Fig 6 Grid voltage and current vs time for Buck mode

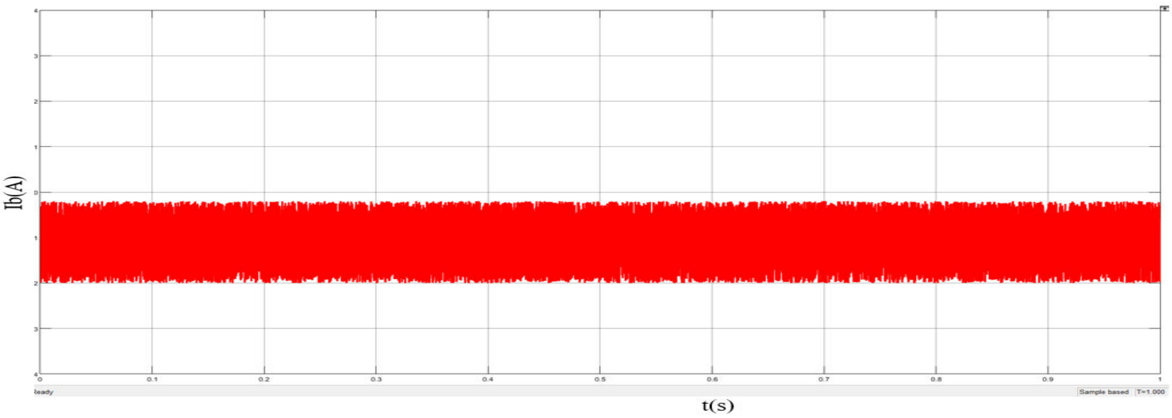

Fig 7 Battery current vs time for Buck mode

The practical implementation of the proposed system involves the integration of the Switching Bi-Directional Buck-Boost Converter and the Electric Vehicle Hybrid Energy Storage system into the existing electric vehicle architecture. This may require modifications to the vehicle's power electronics and energy storage components. The control algorithms would be embedded in the vehicle's electronic control unit (ECU), ensuring real-time adaptability and responsiveness to changing conditions.

In conclusion, the proposed system represents a significant step forward in the evolution of electric vehicles and their role in the broader energy landscape. The Switching Bi-Directional Buck-Boost Converter, coupled with the Electric Vehicle Hybrid Energy Storage system, forms a sophisticated and adaptable solution that addresses the challenges of bidirectional energy flow in V2G systems. This integration not only enhances the operational efficiency of individual electric vehicles but also contributes to the development of a more resilient and sustainable energy infrastructure. As the automotive industry continues its transition towards electrification, innovations like the one proposed here pave the way for a future where electric vehicles play a pivotal role in shaping a cleaner and more efficient energy ecosystem.

CONCLUSION

This paper presents a SBBBC for V2G system. The proposed converter not only has high voltage gain and immunity to electromagnetic interference, but also provides a bidirectional energy flow path. In this paper, different working modes of the SBBBC are discussed in detail and the small signal model of the converter is established. The zero-pole diagram of the system was drawn, the dynamic characteristics of the system were analyzed and its stability was proved. This paper proposes control strategies for V2G and G2V modes, which implement energy management of the HESS. The controller is designed in the frequency domain, so that the controller has good dynamic performance. Finally, the correctness of the theory and the feasibility of the control strategy have been verified through simulations and experiments on laboratory prototypes.

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