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Electric V2V Energy Transfer Using Bidirectional On-Board Converters Using Fuzzy Logic Controller

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Abstract. Electric Vehicle-to-Vehicle (V2V) energy transfer is an emerging solution for optimizing charging efficiency and extending the operational range of electric vehicles (EVs). This paper explores an intelligent energy-sharing framework utilizing fuzzy logic-based control for onboard converters to enable seamless and adaptive power exchange between EVs. The proposed system dynamically adjusts energy flow based on real-time vehicle parameters such as battery state-of-charge, load demand, and grid availability. By leveraging fuzzy logic optimization, the system enhances energy transfer efficiency, minimizes power losses, and ensures a stable and reliable exchange process. Simulation results demonstrate the effectiveness of the proposed approach in improving energy utilization while maintaining vehicle battery health. This study contributes to the advancement of smart energy management in EV networks, paving the way for more sustainable and decentralized charging solution. The complete system is modelled and simulated using MATLAB/Simulink under various operating modes, including forward boost mode and reverse buck mode. Simulation results such as battery SOC, output voltage, output current, and power transfer characteristics are analyzed to evaluate system performance. The results demonstrate that the proposed V2V energy transfer system achieves efficient bidirectional power flow, reduced overshoot, improved voltage stability, and enhanced charging performance. The proposed approach offers a reliable and efficient solution for future smart electric vehicle energy management systems and sustainable transportation.

Keywords: Electric Vehicles (EVs), Vehicle to Vehicle Energy Transfer, On-Board Converter (OBC), Bidirectional DC-DC Converter, Fuzzy Logic Controller (FLC), State of Charge (SOC), Forward Boost, Reverse Buck, Battery Management System (BMS), Power Flow Control, Energy Management, Smart Charging, Renewable Energy Sources, MATLAB/Simulink.

I. Introduction

With the rapid advancement of electric vehicles (EVs), there has been a growing need for efficient, intelligent, and sustainable energy management systems. Electric vehicles significantly reduce greenhouse gas emissions and dependency on fossil fuels, contributing greatly to environmental sustainability [1][2]. However, despite these benefits, several challenges still impede widespread EV adoption—such as insufficient charging infrastructure, long charging durations, and “range anxiety” among users [3][4]. To mitigate these issues, Vehicle-to-Vehicle (V2V) energy exchange technology has been introduced as an innovative solution.

In a V2V energy transfer system, onboard bidirectional DC-DC converters are utilized to enable controlled and seamless energy sharing between EV batteries. This technology not only facilitates efficient energy utilization and flexible charging but also provides emergency energy assistance in cases where charging stations are unavailable [5]. These onboard converters can operate in both charging and discharging modes, making them ideal for V2V applications.

Recent research has focused on designing high-efficiency bidirectional converters, intelligent control techniques, and advanced battery management systems (BMS) to ensure safe and reliable V2V energy transfer [6][7]. Different converter topologies, such as isolated and non-isolated dual-active bridge converters, are being implemented to minimize switching losses and enhance energy transfer stability. The integration of renewable energy sources and smart grid technology further strengthens the future potential of V2V systems [8][9].

The increasing emphasis on eco-friendly transportation has accelerated global EV adoption. EVs have been widely recognized as effective tools for reducing carbon emissions, mitigating air pollution, and minimizing reliance on non-renewable energy sources [10]. This transition is supported by various governmental policies, industrial initiatives, and advancements in power electronics and control systems [11][12].

Vehicle-to-Vehicle (V2V) energy transfer enables the direct exchange of electrical energy from one EV to another, where one vehicle with sufficient battery capacity assists another with low energy levels. This innovation mitigates range anxiety and allows emergency or on-the-go charging without relying on stationary infrastructure [13]. The success of such systems primarily depends on bidirectional converters, robust battery management, and reliable communication systems to ensure stable voltage balance, high conversion efficiency, and safe operation [14][15].

Recent developments in power electronics, communication, and intelligent control algorithms—such as the Fuzzy Logic Controller (FLC)—have enhanced energy-sharing performance in V2V environments [16]. These advancements collectively enable smarter, decentralized, and more sustainable EV charging systems, contributing to the future of intelligent transportation networks.

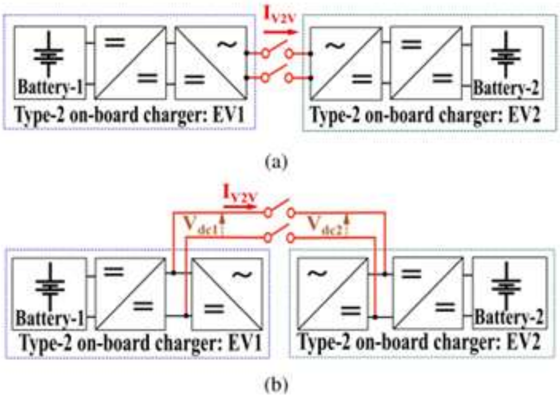

Fig .1 V2V operation (a) ac V2V operation (b) dc V2V operation

II. System Architecture

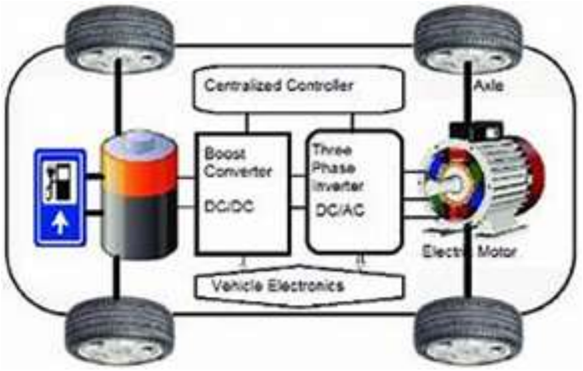

Fig.2 System Architecture

The architecture of the vehicle-to-vehicle (V2V) energy transfer system based on onboard converters is intended to provide for reliable and efficient bidirectional energy transfer between electric vehicles. The basic components that make up the architecture include two electric cars—the donor vehicle and the receiving vehicle, which are linked by means of a power transfer interface. The V2V energy transfer system comprises several components, including the batteries, bidirectional DC-DC converter, on-board charger, control circuitry, switchers, sensors, and battery management system.

The BMS controls safety in relation to the battery's operations by keeping track of SOC,Provision for protection circuits is also present for avoiding over-voltage and over-current situations. The DC-link capacitor helps maintain constant voltage and minimize ripples. The system can work in two-way power flow in case it's necessary. It allows for controlled energy sharing among automobiles.

The Fuzzy Logic Controller (FLC) will be incorporated in the design to allow for adaptive and intelligent control of the DC-DC converters. Standard PI controllers have been known to encounter challenges when controlling nonlinear variations and dynamic conditions encountered in electric vehicle (EV) systems. To address these issues, fuzzy logic control will be employed in the system architecture for effective decision-making and energy transfer. The FLC evaluates input data such as the difference in state of charge (SOC), battery voltage, charging current, and power requirements. With respect to preset fuzzy rules, the FLC makes necessary gating decisions for optimal converter operation.

Another crucial component in the architecture is the communication and supervisory control system. Information concerning the status of the battery, charging needs, availability of the provider, and time required for the charging process will be communicated between the two EVs. The supervisory control then evaluates the information and decides the V2V operation mode. The system also guarantees that there is synchronization between the two cars during the charging process.

III. Bidirectional On-Board Converters Methodology

At first, the SOC, voltage, current, and power of both EVs' batteries will be checked constantly. If the battery voltage of EV1 is more than that of EV2, the converter will operate in forward boost mode, transferring energy from EV1 to EV2. However, if the voltage of EV1 is less, the system operates in reverse buck mode.

A Fuzzy Logic Controller (FLC) has been designed to enhance the operation of the converters. The FLC operates on error and rate of error values and produces appropriate duty cycle pulses for the switching of converters. The objective is to avoid overshoots, minimize errors, and improve the dynamic response.

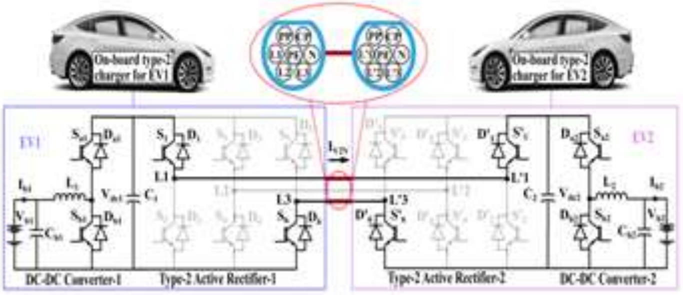

Fig.3 On-board converters topology

Control scheme for proposed V2V approach

The control system includes the main components such as the FLC, voltage and current sensors, BMS, generator, and two-way DC-DC converter. In the case of V2V process, the energy from the provider car is transferred to the receiver car via the charging interface. The various sensor systems monitor critical data like SOC, voltage of the battery, current, temperature, and power transmission. The recorded information is then passed on to the fuzzy logic controller for intelligent decision making.

Control of active rectifiers as V2V interface

In the suggested V2V energy transfer scheme, an active rectifier serves as the connection interface between the provider and receiving EVs, enabling bidirectional energy transmission between them. Conventionally, an active rectifier in electric vehicles acts as an intermediary between the AC grid source and DC battery of the vehicle. In the current suggestion, active rectifiers will act as a medium for direct energy transfer between EV batteries without any other external charger involved.

Control of DC-DC Converters

The control for DC-DC converter manages voltage and energy flow from EV battery packs through the use of PWM control and fuzzy logic control to ensure efficient charge/discharge operations and minimize losses.

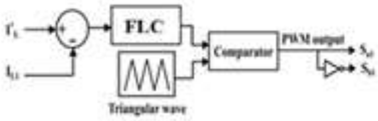

Fig.4 current control scheme with fuzzy logic controller

The control for DC-DC converter manages voltage and energy flow from EV battery packs through the use of PWM control and fuzzy logic control to ensure efficient charge/discharge operations and minimize losses.

$$\frac{\widehat{I_{L1}}(s)}{\widehat{d}(s)} = \frac{(C_1 V_{b1})s + 2(1-D)L_1}{(L_1 C_1)s^2 + \frac{L_1}{R_2}s + (1-D)^2}.$$

The value for I ∗ L is estimated using the following formula, where Ebat1 and Ebat2 represent the rating in kWh for the EV-1 and EV-2 batteries, respectively, while Tc denotes the charging time. Minimum values from the two battery ratings and voltages will be considered when estimating the reference current.

$$I_L^* = \frac{\min(E_{\mathrm{bat1}}, E_{\mathrm{bat2}})}{\min(V_{\mathrm{bat1}}, V_{\mathrm{bat2}}) * T_c}.$$

IV. Direct V2V Controller implementation

The major components of the proposed model include two batteries, two bi-directional DC-to-DC converters, two Type-2 active rectifiers, inductors, capacitors, switches, and the control system. Battery-1 and Battery-2 correspond to lithium-ion battery packs of EV1 and EV2, respectively. The DC-to-DC converters control voltage and energy flow between two EVs. Converter-1 steps up the input voltage of EV1's battery to the appropriate voltage level for energy transfer, whereas Converter-2 manages energy absorption by EV2.

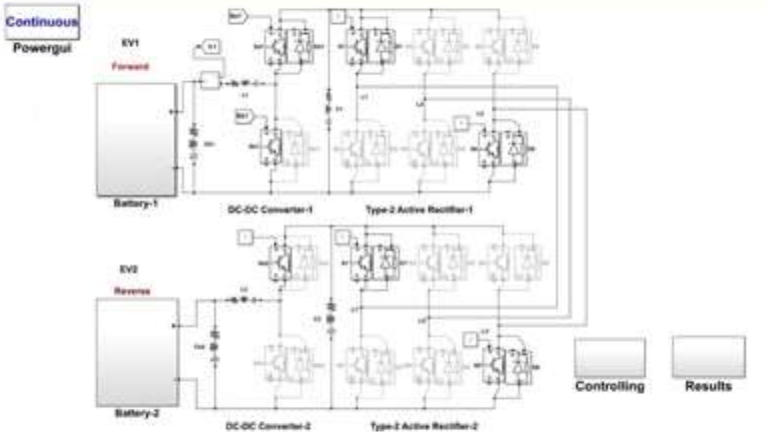

Fig.5 proposed on-board converters for forward boost mode with Vbat1<Vbat2.

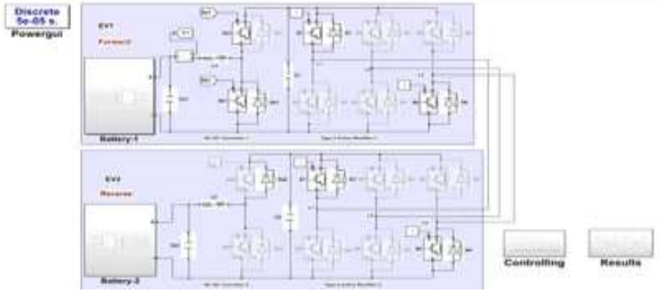

Fig.5.1 Reverse buck mode with Vbat1<Vbat2

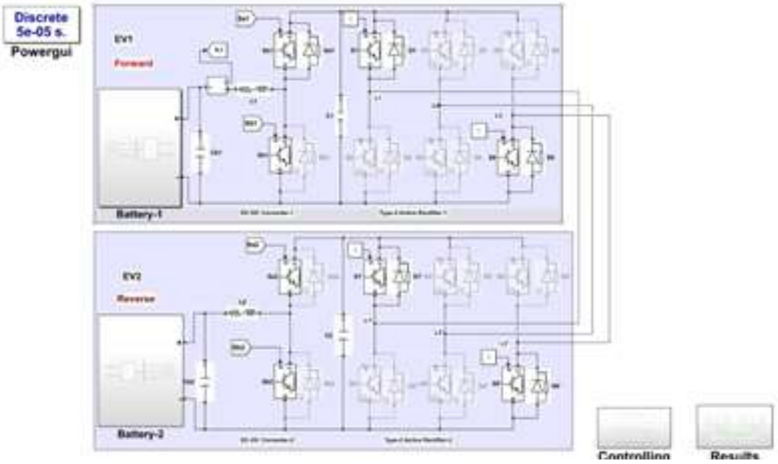

Fig.5.2 Forward boost mode with Vbat1=Vbat2

Simulation Results

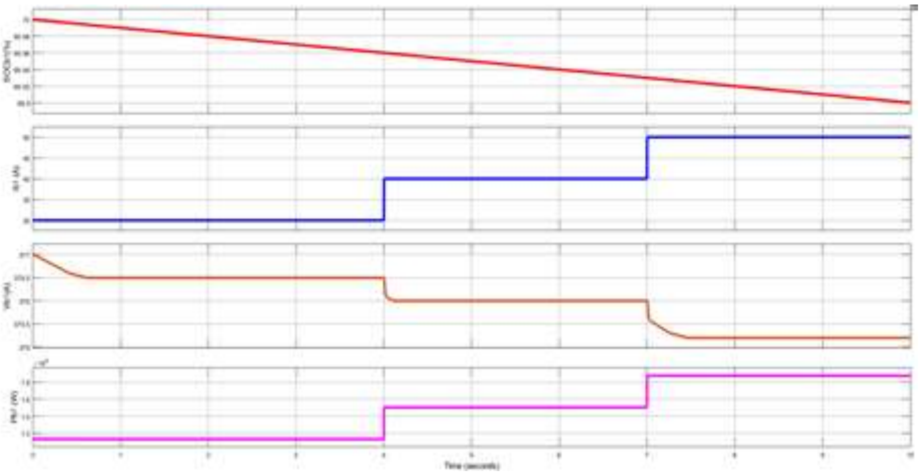

Fig .5.3forward boost mode of EV1 with Vbat1<Vbat2

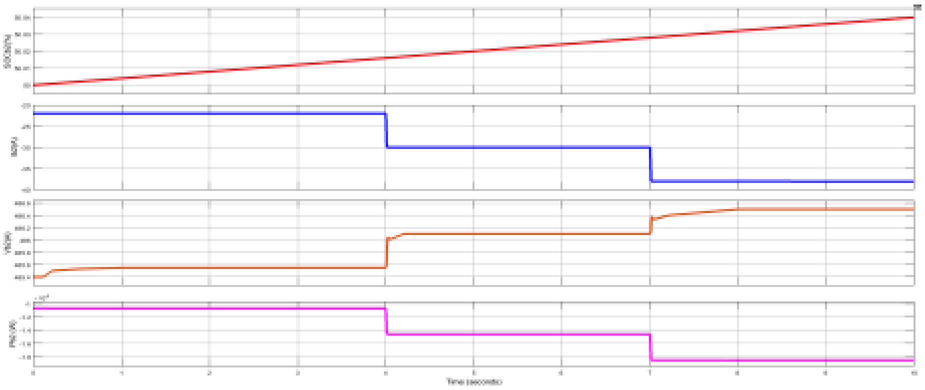

Fig.5.4 forward boost mode of EV2 with Vbat1<Vbat2

Simulation outcomes for the suggested V2V procedure under reverse buck mode with Vbat1 < Vbat2. (a) Waveforms of state of charge, voltage, current, and power for the EV-1 battery. (b) Waveforms of state of charge, voltage, current, and power form the EV-2 battery

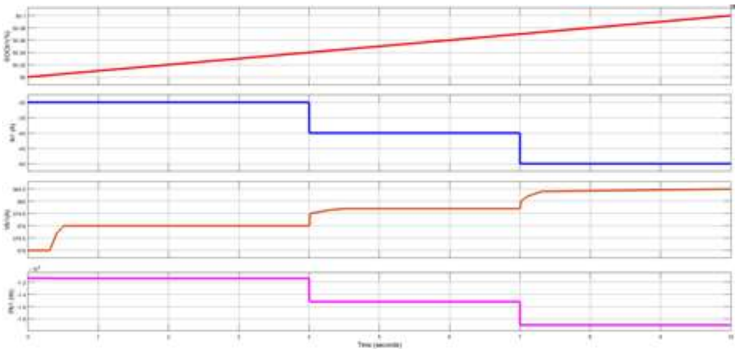

Fig.5.5 Reverse buck mode of EV1 with Vbat1<Vbat2

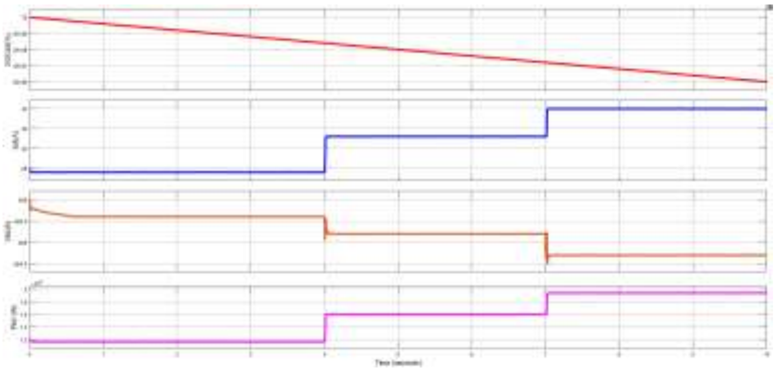

Fig.5.6 Reverse buck mode of EV2 with Vbat1<Vbat2

Simulation results for the V2V control strategy in reverse buck configuration under conditions where Vbat1 < Vbat2. (a) Waveforms of SOC, voltage, current, and power for the EV-1 battery. (b) Waveforms of SOC, voltage, current, and power for the EV-2 battery

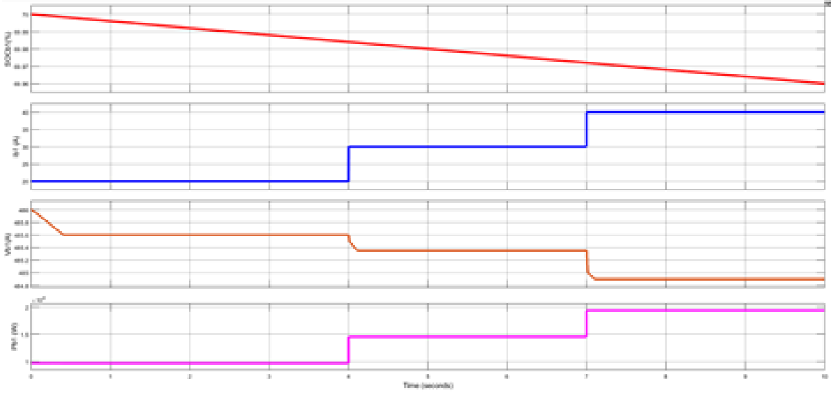

Fig.5.7 forward boost mode of EV1 with Vbat1=Vbat2

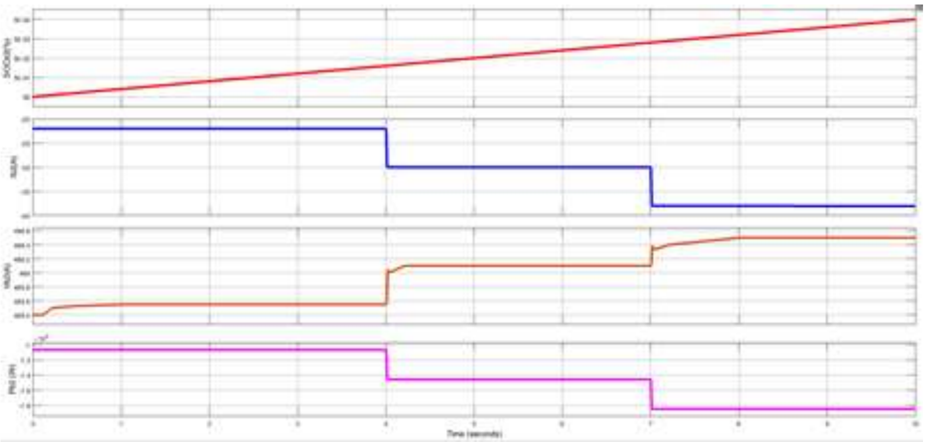

Fig.5.8 forward boost mode of EV2with Vbat1=Vbat2

V. Discussion

Simulation results for the proposed V2V system in forward boost with Vbat1 = Vbat2. (a) SOC, Voltage, Current, and Power waveforms for the battery of EV-1. (b) SOC, Voltage, Current for EV-2 Battery, and DC Link voltage.The simulation findings achieved using the V2V energy transfer system reveal that the bidirectional onboard converter operates effectively in both forward boost and reverse buck modes. The system developed is able to achieve successful energy transfer from one electric vehicle to another while retaining constant voltages, currents, and power levels. The application of the Fuzzy Logic Controller greatly enhances the dynamics of the converter as compared to the traditional PI controller.

VI. Conclusion

In this paper, a FLC strategy for effective V2V energy exchange through on-board converters in electric vehicles (EVs) has been suggested. "The proposed controller offers rapid dynamic response, accurate current tracking, and robustness against system uncertainty. As a result, it is highly applicable for use in real-time energy sharing situations due to the ability to keep the current in the hysteresis range, thereby reducing the voltage fluctuation and ensuring the stability of the energy exchange process. The effectiveness of the suggested approach was confirmed by simulation results, which demonstrated high energy exchange efficiency, low switching losses, and high stability of the system". In comparison with traditional approaches, the FLC strategy allows achieving higher transient characteristics and flexibility in adaptation to changing requirements. The outcomes of this study can be utilized in the development of smart and distributed solutions for EV charging. Further research will be aimed at developing predictive controllers

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