ISSN 2277-2685

IJESR/April-June. 2025/ Vol-15/Issue-2/11-18

Dr V. Praveen *et. al.,* / International Journal of Engineering & Science Research

Vehicle-To-Vehicle Energy Transfer In Electric Vehicles Using On-Board Converters

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ABSTRACT

The main aim of this project is electric vehicle to vehicle energy transfer using on-board converters. For EV users, existing V2V methods with an off-board power-sharing interface add extra space and expense. Furthermore, redundant conversion stages cause V2V power transfer using on-board type-2 chargers to be inefficient, as stated in the literature. Through the use of type-2 ac charger input ports and switches, this article suggests a novel approach to V2V power transfer that involves directly connecting the two EV batteries in order to share energy. A small number of switches are utilized as interfaces to link the two EV batteries instead of the active rectifiers of on-board type-2 chargers for rectification during V2V charging. This helps to reduce redundant power conversion and related losses, which significantly raises the overall V2V efficiency. A simulation analysis utilizing MATLAB/Simulink is used to validate the possible V2V charging situations of the proposed V2V strategy.

Key word: *Batteries, Voltage control, Vehicular ad hoc networks, Rectifiers, Electric vehicles, Energy exchange*

1. INTRODUCTION

The world has undergone a challenge in terms of providing electricity and ensuring global energy requirements. The challenge is mainly due to the shortage of primary energy resources from conventional fossil fuels like natural gas, coal and oil [1]. As a result, there is a great tendency to integrate the renewable energy resources and the use of plug-in electric vehicles (PEVs) on the smart grid in order to minimize reliance on conventional energy resources, satisfy the energy demands and consequently decreasing concerns related to global warming effects as well as the ones related to energy crisis [2e5]. The excessive electricity consumption causes intense surges in demand during peak hour which can cause undesirable impacts and harm the stability of the existing network. That's why; some researchers are working on ways to minimize load power variance by using renewable energy sources. In Ref. [6], a stochastic multi objective daily volt/var control based on hydro-turbine, fuel cell, wind turbine, and photovoltaic power plants are investigated. A study in Ref. [7] has developed a new control strategy that involves wind and photovoltaic generation subsystems. Energy storage systems are important components of a micro-grid as they enable the integration of intermittent renewable energy sources. Electric vehicle (EV) batteries can be utilized as effective storage devices in micro-grids when they are plugged-in for charging. Most personal transportation vehicles sit parked for about 22 hours each day, during which time they represent an idle asset. EVs could potentially help in micro-grid energy management by storing energy when there is surplus (Grid-To-Vehicle, G2V) and feeding this energy back to the grid when there is demand for it (Vehicle-To-Grid). V2G applied to the general power grid faces some challenges such as; it is complicated to control, needs large amount of EVs and is hard to realize in short term [1]. In this scenario, it is easy to implement V2G system in a micro-grid. The Society of Automotive Engineers defines three levels of charging for EVs. Level 1 charging uses a plug to connect to the vehicle's on-board charger and a standard household (120 V) outlet.

2. LITERATURE SURVEY

[1] J. Yuan, L. Dorn-Gomba, A. D. Callegaro, J. Reimers, and A. Emadi, "A review of bidirectional on-board chargers for electric vehicles," IEEE Access, vol. 9, pp. 51501–51518, 2021.

This paper presents a comprehensive overview and investigation on the state-of-the-art solutions of bidirectional OBCs. It reviews the current status, including architectures and configurations, smart operation modes, industry standards, major components, and commercially available products. A detailed overview of the promising topologies for bidirectional OBCs, including two-stage and single-stage structures, is provided. Future trends and challenges for topologies, wide bandgap technologies, thermal management, system integration, and wireless charging systems are also discussed in this paper.

[2] M. Y. Metwly, M. S. Abdel-Majeed, A. S. Abdel-Khalik, R. A. Hamdy, M. S. Hamad, and S. Ahmed, "A review of integrated on-board EV battery chargers: Advanced topologies, recent developments and optimal selection of FSCW slot/pole combination," IEEE Access, vol. 8, pp. 85216–85242, 2020.

his paper starts with surveying the main topologies introduced in the recent literature employing either induction or permanent magnet motors to realize fully integrated slow (single-phase) and fast (three-phase) on-board EV battery charging systems, with emphasis on topologies that entail no or minimum hardware reconfiguration. Although, permanent magnet (PM) motors with conventional double-layer distributed winding layouts have been deployed in most commercial EV motors, the non-overlapped fractional slot concentrated winding (FSCW) has been the prevailing choice in the most recent permanent magnet motor designs due to its outstanding operational merits. Hence, a thorough investigation of the impact different FSCW stator winding designs have on machine performance under the charging process is presented in this paper.

3.MATLAB & SIMULINK

MATLAB® is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. Using the MATLAB product, you can solve technical computing problems faster than with traditional programming languages, such as C, C++, and FORTRAN.

MATLAB is used in wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computational biology. Add-on toolboxes (collections of special-purpose MATLAB functions, available separately) extend the MATLAB environment to solve particular classes of problems in these application areas.

MATLAB provides a number of features for documenting and sharing your work. You can integrate your MATLAB code with other languages and applications, and distribute your MATLAB algorithms and applications.

4. MODELLING OF CASE STUDY

4.1 PROPOSED V2V APPROACH

The proposed V2V configuration is realized by connecting the existing type-2 charging ports of the provider-EV and the receiver-EV. The two EVs are connected by utilizing the threephase active rectifier switches. Turning ON the top switch of one of the phases (phase-a, S1 here) and bottom switch of the other phase (phase-c, S6 here) of the active rectifier-1 and the respective phase switches S'1 and S'6 of the active rectifier-2 directly connects the two EV batteries through the intermediate dc-link of provider and receiver EVs as shown in Fig. 3.1 The four switches S1, S6, S'1, and S'6 are kept ON throughout the V2V power transfer duration. The proposed way of connecting the two EVs realizes a dual bidirectional buck-boost converter that can be controlled to transfer energy between two EVs in either direction regardless of their battery voltage levels. As the active rectifiers of both the type-2 chargers are used as an interface to connect two dc-links instead of their actual purpose of rectification, other switches of both the active rectifiers are kept OFF throughout the V2V operation. Based on the battery voltage of two EVs, the configuration may operate in one of the possible energy transfer modes as discussed below.

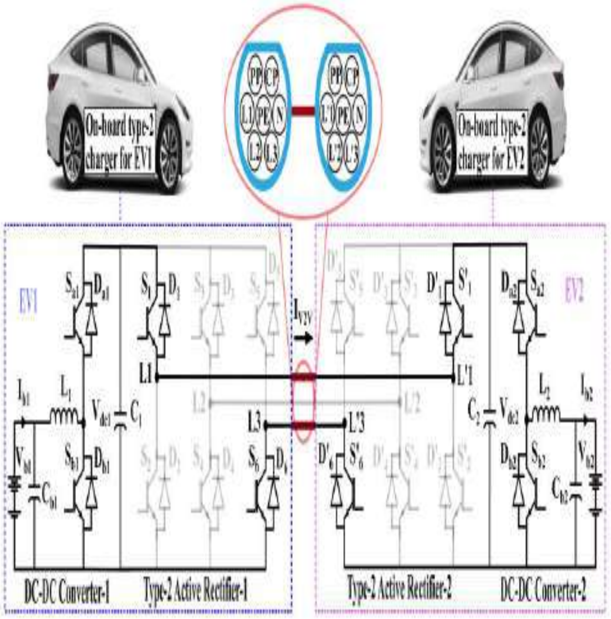


Fig.4.1: Proposed topology for V2V operation.

4.2 CONTROL SCHEME FOR THE PROPOSED V2V APPROACH

The charging rate and the amount of energy transferred during the proposed V2V approach are controlled by controlling the on-board converters. The mode selector flow shown in Fig. 6 decides the V2V mode based on the EV-1 and EV-2 battery values and the provider receiver information. Furthermore, depending on the mode of operation, the on-board charger converters are controlled for achieving the proposed V2V as discussed.

4.2.1 Control of the Active Rectifiers as V2V Interface

Typically, during the normal three-phase ac charging through a type-2 charger, the active rectifier is controlled in d-q control mode to convert the three-phase ac to dc with unity power factor operation at the grid terminals. During the proposed V2V charging, the active rectifier is re-utilized as an interface to access and connect the batteries of the two EVs. After the type-2 charger ports are connected for V2V charging, the gating pulse for the switches S1 and S6 of the active rectifier-1 of the EV-1 and the switches S'1 and S'6 of the active rectifier-2 are kept active high throughout the V2V charging for all the modes.

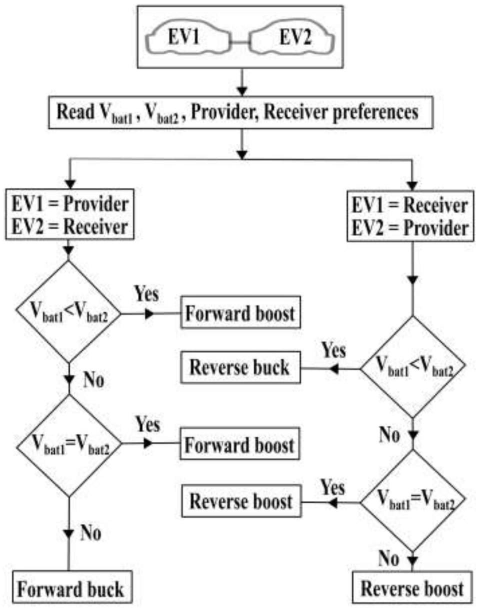


Fig. 4.2:Proposed V2V power transfer control flow.

4.2.2 Control of DC–DC Converters

For the proposed V2V charging approach using the on-board chargers, the dc–dc converters of the type-2 chargers are closed-loop current-controlled. For forward boost and reverse buck mode control (Vbat1 < Vbat2): In these modes, the dc–dc converter-1's inductor current IL1 in forward or reverse direction is controlled in closed-loop by feeding the error between the reference current I∗L and the actual inductor current IL1 to a PI controller to generate duty ratio for switch Sa1, and Sb1 is complimentarily switched to Sa1 as shown in Fig. 3.3

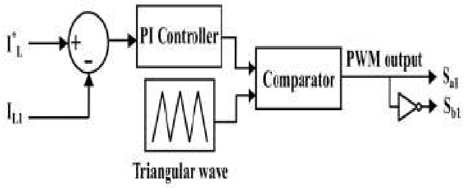


Fig.4.3: Current control structure in forward boost and reverse buck modes (Vbat1 < Vbat2).

Gating signal to the switch Sa2 is kept active high throughout this mode. The current to control transfer function to the dc–dc converter-1 used to tune the PI controller is given in the following equation, where D is the duty ratio and R2 is the load resistance equivalent to charging current of the EV-2 battery [20]

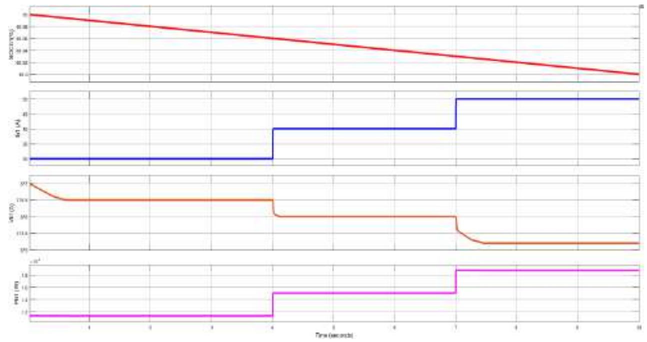
$$\frac{\widehat{I_{L1}}(s)}{\widehat{d}(s)} = \frac{(C_1 V_{b1})s + 2(1-D)L_1}{(L_1 C_1)s^2 + \frac{L_1}{R_2}s + (1-D)^2}. \tag{3.1}$$

Reference current I ∗ L is calculated based on the following equation, where Ebat1 and Ebat2 are kWh ratings of the EV-1 and EV-2 batteries, respectively, and Tc is the desired charging time. The minimum values among the two battery ratings and voltage levels are selected to calculate the reference current

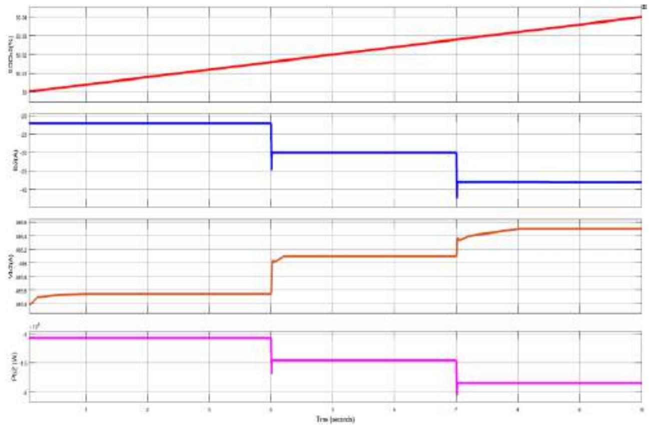
$$I_L^* = \frac{\min(E_{\mathrm{bat1}}, E_{\mathrm{bat2}})}{\min(V_{\mathrm{bat1}}, V_{\mathrm{bat2}}) * T_c}.$$

The maximum value of I ∗ L depends on current rating Is1r of the on-board active rectifier IGBTs (S1, S6, S’1, and S’6), if I∗L computed from (3.2) exceeds Is1r, the current reference will be caped to Is1r. Similarly, for the forward buck and reverse boost mode with (Vbat1 > Vbat2), the same control structure is used to control the IL2 in the forward or reverse direction by generating the duty ratio for the switch Sb2 and switch Sa2 is complimentarily switched to Sb2. The gating signal to switch Sa1 is made active high throughout this mode. Furthermore, in the forward boost mode with (Vbat1 = Vbat2), both the dc–dc converters are operated in current control mode to control IL1 and IL2 in the forward direction. As both the battery voltages are equal in this case, the current reference I ∗ L should be equal for both the dc–dc converters to maintain power balance at the two EV batteries. This mode can be controlled alternatively by regulating the dc-link at a higher voltage by operating one of the dc–dc converter-1 in voltage-controlled boost mode and the dc–dc converter-2 in currentcontrolled buck mode. The higher efficiency, lower losses, and convenience of connecting two EVs through the existing on-board type-2 charger ports make the proposed V2V approach more practically adaptable among EV users. In general, for the practical implementation of any V2V approach, access to the on-board instrumentation sensors and BMS controllers of the provider and receiver EVs are required to establish a communication between two EVs and to fetch the required parameters for V2V. These aspects of V2V are already discussed in [10]–[12], with details of game theory-based algorithms to match the receiver and the provider EVs with an assumption that the bidirectional power converter interface for V2V is available. Practical implementation of the proposed V2V approach for commercial EVs assumes that communication between EVs and access to controllers and instrumentation sensors is readily available as detailed in [10]–[12] and proposes to provide a powerful interface for the actual V2V power transfer through the on-board type-2 charger’s hardware components. The provider EV and the receiver EV are connected directly through the existing on-board type-2 charging ports for V2V energy sharing. Depending on the battery voltage levels, provider, and receiver preferences, fetched using the on-board instrumentation sensors and EV user inputs, the V2V mode is decided, as shown in Fig. 3.2 Based on the mode of operation selected (e.g., forward boost), the power flow direction and the required amount of energy transfer are commanded through the on-board DSP controllers. Active rectifiers of both the on-board chargers are controlled to act as an interface by turning on the top and bottom switches of any two legs. Once the dc-links of both the on-board chargers are connected, depending on the selected V2V mode the battery side dc–dc converter of the on-board chargers is current-controlled, to deliver the required charge to the receiver EV as discussed in the initial parts of this section.

5. SIMULATION RESULTS

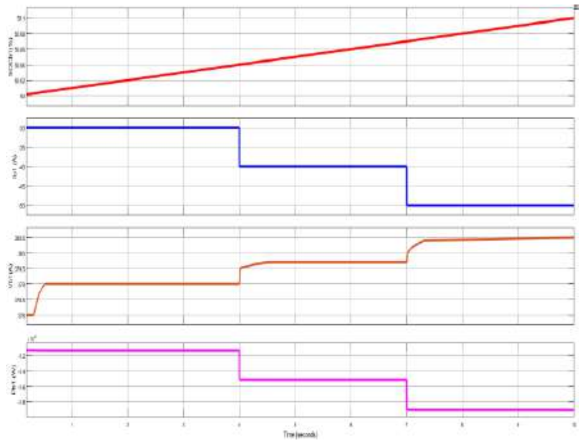


(a)



(b)

Fig.5.1 : Simulation results of the proposed V2V operation in forward boost mode with Vbat1 < Vbat2. (a) SOC, voltage, current, and power waveforms of EV-1 battery. (b) SOC, voltage, current, and power waveforms of EV-2 battery



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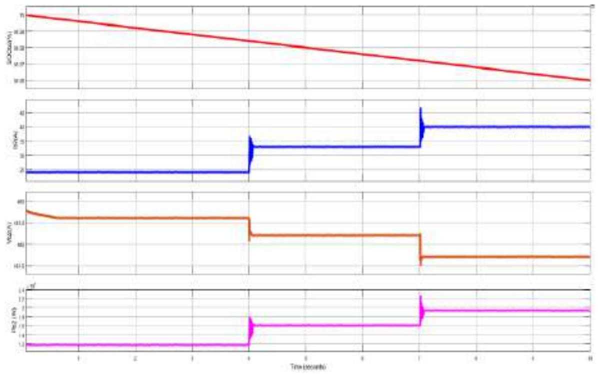
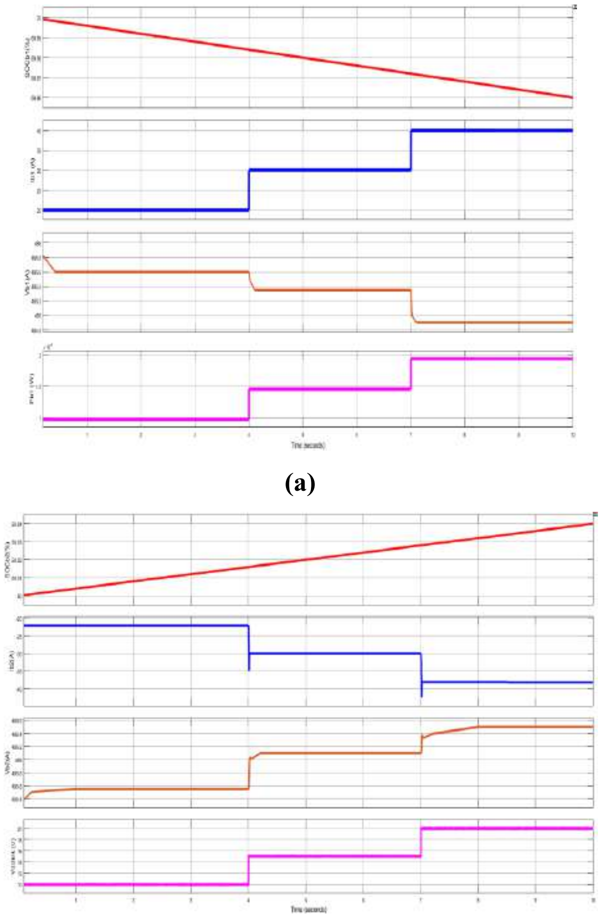


(b)

Fig.5.2: Simulation results of the proposed V2V operation in the reverse buck mode with Vbat1 < Vbat2. (a) SOC, voltage, current, and power waveforms of the EV-1 battery. (b) SOC, voltage, current, and power waveforms of the EV-2 battery



(a)

(b)

Fig.5.3: Simulation results of the proposed V2V operation in the forward boost mode with Vbat1 = Vbat2. (a) SOC, voltage, current, and power waveforms of EV-1 battery. (b) SOC, voltage, current of EV-2 battery, and dc-link voltage.

6. CONCLUSION AND FUTURE SCOPE

This project proposes a direct V2V charging approach for power transfer between two EVs without the need for external hardware or additional charging ports. It is an emergency rescue charging solution in the case of non-availability of ac grid and dc fast-charging stations. Connecting two EV batteries directly through the on-board charger ports leads to significant hardware infrastructure savings. The redundant power conversion stages were avoided, which improved the overall efficiency of the proposed V2V approach which is evident in the performance analysis. The proposed V2V approach mitigates range anxiety and cooperatively shares energy between EV users with minimum infrastructure and cost. In the future, this system will be further integrated with Neural network technology to increase the efficiency of the system and also the proposed system will be implemented in real time

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