

INTELLIGENT RECONFIGURABLE CONVERTER FOR ENHANCED DUAL-BATTERY ELECTRIC VEHICLE PERFORMANCE

KOPPULA RISHITHA¹, MRS.CH.RAJA SRI²

¹Mtech Student, Dept of EEE, Holy Mary Institue of Technology & Science, Keesara, Bogaram, Telangana, India.

²Assistant Professor, Dept of EEE, Holy Mary Institute of Technology & Science, Keesara, Bogaram, Telangana, India. Mailid: rajasri045@gmail.com

ABSTRACT:

As the number of EVs is growing, there is a need for advanced energy storage and power conversion solutions that enhance the performance, driving range, charging flexibility, and reliability of vehicles. This project introduces an Intelligent Reconfigurable Dual-Battery Power Converter for Enhanced Electric Vehicle Charging, Propulsion, and Energy Management employing a new dual-battery concept with reconfigurable power converter. The proposed system allows for battery operating modes, which include independent, series, parallel and battery balancing modes, in order to maximize the use of battery energy as the driving conditions vary and charging conditions change. To enable flexible battery reconfiguration and efficient power transfer, two converter topologies are developed: the Contactor Based Converter (CBC) and Bidirectional Switch Based Converter (BSC). The system also has an Integrated Charger System (ICS), which is capable of charging, propulsion, Vehicle-to-Grid (V2G), Vehicle-to-Load (V2L), and Vehicle-to-Vehicle (V2V). Advanced control strategies are used to control power flow, preserve the stability of the DC-link and to operate the battery in a balanced way. The effectiveness of the proposed architecture is confirmed by the simulation results under various operating conditions, which show better charging capabilities, better utilization of batteries, lower circulating currents and higher system reliability. Overall, the dual-battery converter system is a promising and versatile solution for future EVs, paving the way for more efficient use of electrical power, longer ranges, and sustainable transportation.

Keywords: : Electric Vehicle (EV), Dual-Battery System, Reconfigurable Power Converter, Battery Energy Management, Integrated Charger System, Vehicle-to-Grid (V2G), Vehicle-to-Load (V2L), Vehicle-to-Vehicle (V2V), Bidirectional Converter, Battery Balancing, Energy Storage System, and Smart Transportation.

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I. INTRODUCTION

Electric Vehicles (EVs) are gaining popularity and are a more environmentally friendly alternative to the traditional car with an internal combustion engine. With the increasing awareness of environmental pollution,

greenhouse gas emissions and fossil fuel resources, the development of electric mobility technologies has been moving forward in the last few years. Although EVs have a lot of advantages, some issues are still limiting their mass commercialization like short driving range, long charging time, battery degradation,

and inefficient energy use. The conventional EV systems are based on a single battery pack, which calls for regular charging and discharging, which may impair battery life and/or stress the battery. To address these challenges, new battery architectures and smart power electronic systems that further optimize energy utilization and operational flexibility have been explored. Dual-battery systems have been developed due to the potential for more energy storage, greater reliability and the ability to efficiently share energy between battery packs. Furthermore, the power conversion systems in contemporary EVs are extremely complex and capable of functioning in multiple modes, and must be efficient and dependable. This makes intelligent reconfigurable power converters an essential factor to enhance the performance of EVs and extend their driving range and supply power for future smart transportation systems. This type of technology is expected to be key to developing next-generation electric mobility solutions [1].

Power electronics technology, particularly in recent years, has enabled the design of flexible architectures where different modes of operation of an EV battery can be supported, and can be implemented on the same EV platform. Reconfigurable power converters can dynamically reconfigure battery connections based on driving requirements, charging conditions and energy management objectives. These can be connected to configure battery packs independently, as series and parallel to optimize voltage, current and power delivery characteristics. Moreover, high level converter topologies allow balancing the battery voltage to keep the batteries healthy and ensure that the voltage is even. The ability to power flow bidirectional also further improves system functionality by introducing Vehicle-to-Grid (V2G), Vehicle-to-Load (V2L) and Vehicle-to-Vehicle (V2V) capabilities. Such features allow EVs to be utilized as distributed energy storage systems that can help enable smart grid

applications and integration with renewable energy. Additionally, intelligent charging systems can enable faster charging durations and intelligent battery management via adaptive control algorithms. The conversion of reconfigurable converter technologies has been proven to dramatically improve the efficiency of the system, reduce circulating currents and increase flexibility in system operation. Hence, these technologies are being considered as future EV platforms should be more capable in terms of performance, reliability and energy management [2].

To meet these needs, this project puts forth the concept of an Intelligent Reconfigurable Dual-Battery Power Converter for Enhanced Electric Vehicle Charging, Propulsion and Energy Management. The proposed system is based on a dual-battery architecture and is combined with novel reconfigurable converter topologies for operation in various configurations such as independent battery mode, battery series mode, battery parallel mode and battery balancing mode. For flexible control of energy and efficient power transfer two types of converter are built, namely, the Contactor Based Converter (CBC) and Bidirectional Switch Based Converter (BSC). An Integrated Charger System (ICS) is integrated for charging, propulsion and grid interactions like V2G (Vehicle-to-Grid) V2L (Vehicle-to-Load) and V2V (Vehicle-to-Vehicle). Under different operating scenarios, advanced control strategies control power flow, keep the DC-link voltage stable and balance the utilization of batteries. By intelligent battery reconfiguration, the proposed system improves system reliability, battery life, battery flexibility in charging and driving range. A series of simulations is performed to validate the performance of proposed architecture under different operating conditions, and results demonstrate significant improvement in energy efficiency and performance with proposed architecture. The suggested approach can be practically and

scalably adopted into future EVs and sustainable transportation systems [3].

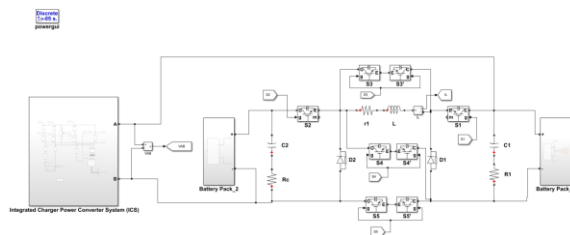


Fig.1. MATLAB/SIMULINK circuit of the system

II SURVEY OF RESEARCH

1. M. Yilmaz and P. T. Krein gave an in-depth overview on the battery charging technology and infrastructure for plug-in electric vehicles and hybrid electric vehicles. This study compared various charger topologies and charging standards and power levels of the charging stations at residential, commercial and public locations. A comparison of the efficiency, implementation and charging performance of conductive and inductive charging systems was made. The authors highlighted a few issues to the widespread use of EVs: problem of charging coordination, electric grid congestion problem, battery degradation problem, and infrastructure problem. Different topologies of the converter have been analysed to verify their suitability for various charging applications. The study also included the topic of Vehicle-to-Grid (V2G) and what potential applications it has to help maintain power system stability with distributed energy storage. Furthermore, renewable energy and smart charging were identified as key solutions to reduce charging costs and optimise energy use. The study also unveiled some critical research and development directions for EV charging systems, such as those involving advanced converter technologies, adaptive control algorithms, and smart communication networks, to support sustainable and efficient transportation electrification.

2. In this work, J. Cao and A. Emadi investigated the dual-battery energy storage systems proposed to improve the performance and flexibility of EVs. To address the above disadvantages of a single battery architecture, the study offered a number of battery packs to surmount the disadvantages of a single battery architecture, which is known as “short range”, “high charging stress”, and “low reliability”. Various battery configurations (serie, parallel and stand-alone) were considered and impact on performance and energy consumption of the vehicle was studied. The authors have shown that the dual-battery systems give superior redundancy, distribution of energy and fault tolerance over conventional batteries. Advanced battery management strategies were formulated to manage the charging and discharging of batteries, and to maintain the safety and health of battery systems. The simulation analysis showed that dual-battery systems can significantly improve the use of energy and battery lifetime. For future EV systems which will need to be more reliable, longer range, and more flexible in charging, the study has uncovered the need for intelligent battery reconfiguration and power management.

3. The Vehicle-to-Grid (V2G) concept was developed by W. Kempton and J. Tomić and its use in the modern electric power system was studied. This study examined the ability of the EV batteries to act as distributed energy storage resources that can provide both supply and demand of electricity to/from the grids, when performing this function. Bidirectional charging has been studied in various applications such as frequency regulation, spinning reserve support, peak load management and emergency power supply. The authors emphasized the economic advantages of V2G operation, such as extra income for EV owners and better utilization of renewable energy resources. Technical issues like battery degradation, charging station needs and communication system implementation were

also covered. The research revealed that V2G coordinated operation can help enhance the grid stability and overall power system reliability. The findings provided the basis for the development of future advanced bidirectional power electronics system which will be able to integrate the smart grid, renewable energy and smart transportation.

4. F. Krismer and J. W. Kolar presented new reconfigurable power electronic architectures for energy management applications in electric vehicles. Converter systems that are able to change the battery system configuration dynamically for optimizing charging rates and vehicle capabilities were analyzed. Various topologies of the converter were considered for efficiency, switching losses, power density and flexibility of operation. The authors proposed the intelligent control method approaches that can achieve smooth switching between the different operating modes, and also guarantee the stable power output. Reconfigurable converters showed better performance than traditional fixed-topology ones with their adaptive voltage and current regulation capabilities. Thermal management, converter reliability and battery balancing issues have also been addressed in the research. The outcomes of the experiments showed significant improvements in energy utilization and efficiency of the converter. According to the study, reconfigurable power electronic systems are a promising approach to future EVs that require an enhanced energy management system, quick charging, and adaptability to varying driving situations.

5. Y. Lee and A. Khaligh explored bidirectional DC-DC converter technologies that are employed in electric vehicle charging and propulsion. This study concentrated on the converter topologies which are capable of charging and discharging process and are capable to produce high efficiency and high power quality. Different control methods were

proposed to control the battery current, stabilize the DC-link voltage and maintain the reliability of the energy transfer between batteries and the traction systems. The authors emphasized the bidirectional converters and the importance of having them in place for enabling Vehicle-to-Grid (V2G), Vehicle-to-Vehicle (V2V), and Vehicle-to-Load (V2L) functionalities. The converter performance was simulated and evaluated under various loads and batteries condition. The impact of the converter design on the battery life and charging time and the system efficiency was also explored. Analysis revealed that bidirectional converter technologies are a key component of the modern EV architecture, facilitating flexibility in energy management and grid interaction. The study offers important insights to design a dual-battery charging system and advanced EV energy management system.

6. H. To improve the performance, safety and reliability of lithium-ion batteries in electric vehicles, he, R. Xiong and J. Fan proposed an intelligent battery management system. The topics studied were as follows: Battery monitoring, State of charge estimation, Battery balancing methods, Thermal management and Fault diagnosis. Validated algorithms have been developed for estimating battery state under various conditions, and for various battery load profiles. The authors demonstrated how intelligent battery management can lead to increased utilization of the battery, charging efficiency, battery life and reduced over charging/draining risks. The energy distribution was evenly adjusted between the battery cells and modules using the battery balancing methods. The experimental results revealed that the proposed management system is beneficial for the safety and stability of the battery operation. The study concluded that intelligent battery management is crucial to ensure the reliability of EVs and combine the advantages of advanced battery technologies. The results are very relevant for dual battery electric vehicle architectures, where efficient energy

management and battery balancing functions are required..

III.WORKING METHODOLOGY

Developed to enhance the operational flexibility, charging performance and reliability of EVs through the use of two battery packs and advanced power converter architectures, the proposed Intelligent Reconfigurable Dual-Battery Power Converter for Enhanced Electric Vehicle Charging, Propulsion, and Energy Management is created. It is composed of two battery packs, a reconfigurable power converter, an Integrated Charger System (ICS), a traction motor drive and an intelligent control unit. Based on operating needs, the converter adaptively changes the battery packs to operate in independent, series, or parallel mode. In normal vehicle operation, either the Battery Pack-1 or Battery Pack-2 is able to provide power to the traction motor. For higher voltage levels in propulsion, both battery packs are in series to add up the available DC-link voltage. If the current demand is high during the acceleration or rapid charging mode, the batteries can be wired in parallel to boost the batteries' current capacity while keeping the same voltage. This reconfiguration mechanism can achieve flexible reconfiguration, which can extend the driving range, reduce battery stress, improve system reliability and provide operational redundancy. The intelligent controller keeps an eye on the battery voltage, current flow, state-of-charge (SoC), and load demand, and automatically selects the operating mode that works best.

Charging system is based on an Integrated Charger System (ICS) that can operate as a battery charger or traction inverter. The converter works as a Totem-Pole Power Factor Correction (PFC) converter followed by buck converter stage when charging, which enables to regulate charging currents and to improve power quality during charging operation. The charging power to the battery is given by the following equation:

$$[P_{\text{ch}} = V_{\text{bat}} \times I_{\text{bat}}]$$

In the above, (P_{ch}) is charging power, (V_{bat}) is the voltage of the battery, and (I_{bat}) is the charging current. If the batteries are connected in series, the total battery voltage is given as:

$$[V_{\text{series}} = V_{\text{B1}} + V_{\text{B2}}]$$

The voltages of Battery Pack-1 and Battery Pack-2 are (V_{B1}) and (V_{B2}) respectively. When the generators are operated in parallel, the sum of the currents they can supply is:

$$[I_{\text{parallel}} = I_{\text{B1}} + I_{\text{B2}}]$$

I_{B1} and I_{B2} are battery currents of individual Batteries. The converter control system is based on a dual-looping control—outer voltage control loop and inner current control loop. This control structure achieves stable operation of the DC-link voltage, accurate battery charging, high power factor operation, and reduced harmonic distortion, and energy delivered between the utility and battery system is transferred efficiently.

An important feature of the proposed approach is the battery voltage equalization mechanism that is proposed to be implemented for reducing circulating currents between the batteries and also to enhance the battery life in the case of parallel operation

$$[P_{\text{source}} = P_{\text{motor}} + P_{\text{loss}}]$$

The term (P_{source}) represents the battery power, (P_{motor}) is the power of the traction motor and (P_{loss}) is the converter and system losses. The proposed approach extends battery life, increases energy efficiency, increases charging flexibility, and enables future features like Vehicle-to-Grid (V2G),

Vehicle-to-Load (V2L) and Vehicle-to-Vehicle (V2V) energy transfer..

IV RESULTS EXPLANATIONS

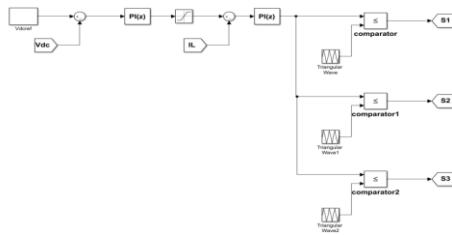
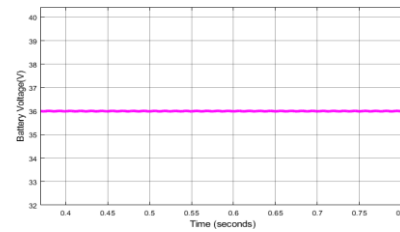


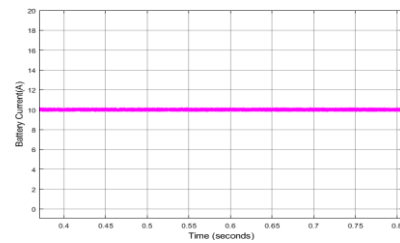
Fig.2 Control system with PI controller

The control system for regulating the operation of the dual-battery reconfigurable converter is shown in Fig. 2, which is a proportional-integral (PI) controller based control system. The controller will continuously monitor the difference between the reference voltage and the actual output voltage and will produce an error signal that can be manipulated by the PI controller to give the desired control action. The proportional part will react quickly to very sharp changes and the integral part will compensate for steady state error as well as ensure the system accuracy. The control structure comprises of an outer voltage control loop and an inner current control loop, which are coordinated to maintain the stability of the DC-link voltage, control charging current, and achieve efficient power supply between the grid and battery packs. The voltage from the PI controller is fed to a PWM generator which generates switching pulses for the converter switches. This control method not only helps to regulate the voltage, but also minimizes overshoot, voltage ripple, boosts charging efficiency and assists in the battery balancing process. Thus, the PI controller

maintains stable operation of the converter, maintains reliable charging of the battery and ensures the proper functioning of the electric vehicle system in different operating modes.



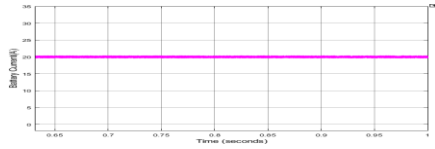
(a)



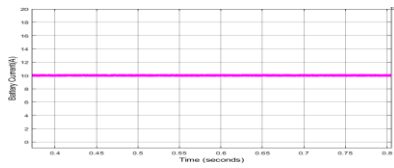
(b)

The results of the simulations in figure 3(a) and 3(b) illustrates the charging of a single battery pack at 70V(RMS) from the mains power supply using the Grid-to-Vehicle (G2V) mode of operation. In these situations, the Inverter-Charger System (ICS) is under a dual-loop voltage management control, which is realized by implementing a Totem-Pole Power Factor Correction (PFC) converter. In the meantime, during battery charging, the current is controlled by means of a buck converter stage using a reference current of 10 A. The proposed converter topologies (Contactor Based Converter (CBC) and Bidirectional Switch Based Converter (BSC) shown in Figure 3(a) and Figure 3(b), respectively (or equivalent switching topologies in Table I) are designed in the single battery operating mode. Figures 3(a)

and 3(b), respectively, present the results that prove the good regulation of the DC-link voltage ($V_{\text{DC-link}}$) and the battery charging current (I_{AB}) to their set points.

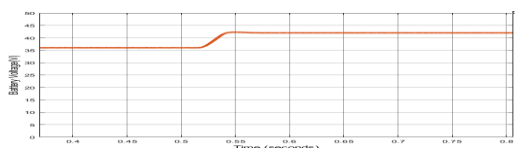


(c)

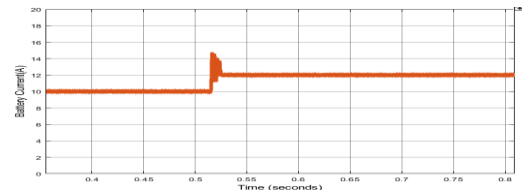


(d)

The outcomes of the simulations performed in the case of dual battery charging system in G2V mode are presented in Fig. 6(c, d). As can be seen in Figure 3(c), the terminal voltage remains the same for parallel battery charging ($V_{\text{AB}}=36\text{V}$) and in Figure 3(d) a series battery charging setup is shown with a terminal voltage ($V_{\text{AB}}=72\text{V}$). Conditions and settings for the grid, as well as the controller, remain the same as in the previous one, with the exception of the battery charging current as 20A when used in parallel and 10A when used in series. Based on the results of the simulations the proposed converter topologies can charge the batteries either in series or in parallel.



(e)



(f)

The simulation results are given as follows: (a) Waveforms of grid voltage, grid current, DC-link voltage and battery terminal voltage; (b) When one battery is charged; (c) When two batteries are charged in parallel; (d) When two batteries are charged in series; (e) Response to the reference voltage variation and current controllers; and (f) Response to the reference current variation.

To test the outer voltage control loop which controls the outer voltage control loop when charging in Constant Voltage (CV) mode dynamically, the reference voltage at the battery terminals was changed from 36 V to 42 V. The equivalent response is shown in Figure 3(e) and it is easily observed that the voltage controller is able to control the terminal voltage to the reference voltage required within an acceptable settling time and overshoot. This current reference ($I_{\text{AB-ref}}$) was then changed from 10A to 13A under constant current (CC) mode and the transient response of the current control loop was found to be good and steady as shown in Figure 3(f) of the Controller response. The same parameters as shown in Table IV were used for additional simulations to verify the ability of the proposed converter topologies to balance the voltage. The two battery packs were deliberately charged to 90% and 30% State of Charge (SoC), respectively,

having 41 V and 38 V terminal voltages, respectively, which meant that 2C rate of charge was assumed to provide a balance verification in a shorter simulation time with reduced battery capacity ratings of 3 Ah. Thus, Equation (7) and the current regulation approach outlined in Section III were used to set the inductor current reference to 6 A. Due to the fact that BP-1 had a larger terminal voltage than BP-2, the voltage balancing unit of the converter was set to function in buck mode. This enabled energy to be transferred from BP-1 to BP-2. The simulation results show that the balancing operation is achieved and the voltage difference between battery packs is minimized, proving that the proposed design can effectively ensure energy balance between the two energy storage systems.

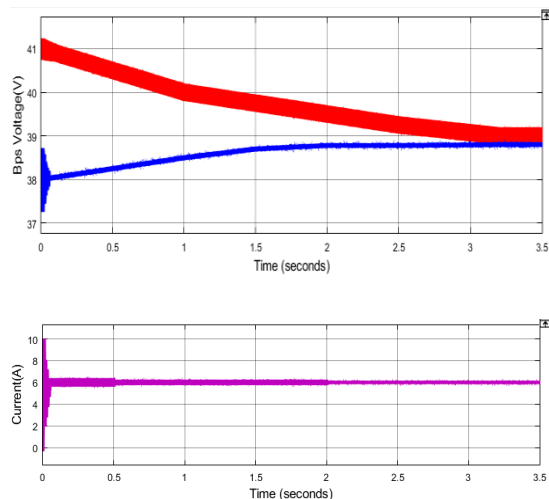


Fig. 4. Simulation Result for Voltage Balancing Facility with BP's of different SoC.

V.CONCLUSION

This study proposed and analyzed in detail two novel reconfigurable power converter topologies, the Contactor Based Converter (CBC) and the Bidirectional Switch Based Converter (BSC) for application in Electric

Vehicles with two batteries. The suggested dual-battery design's charging capabilities were tested by including a non-isolated Inverter-Charger System (ICS) into the system architecture. Comprehensive MATLAB simulations and experimental hardware implementation were used to test the reconfiguration features of the converters that were suggested. They are single battery operation, battery series, battery parallel in charging and traction operation. The results obtained show that the converter topologies proposed in this study would improve the utilization of the batteries and provide higher flexibility in operations because of the battery load sharing among the battery packs. The capacity to choose link either battery pack to the output terminals is a major strength of the suggested system that improves system dependability, fault tolerance, and battery design adaptability. Apart from this, the recommended converters prior to parallel operation also offer voltage balancing function, which can also balance the battery voltages at the battery pack terminals. This extends the life of the batteries and increases the reliability of the operation as it decreases the flow of current between the packs of batteries, thus reducing the stress on the batteries. Simulation studies and hardware testing have been carried out, and the proposed converter designs are effective, fault tolerant and can be used in various operating condition. One of the biggest challenges that lie in the path of EVs is their limited range, lack of dependability, and operating flexibility. The integration technique proposed for dual batteries is feasible and effective in the solution. Other advantages of the reconfigurable topology are improved functional safety, better system resilience, longer battery life and uninterrupted operation even if a part of the battery fails. The proposed architecture has less up-front hardware cost but is an attractive and low-cost solution for future EV applications due to its high reliability, low maintenance, and enhanced battery performance and continuity.

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