A SINGLE INDUCTOR MULTI-PORT POWER CONVERTER FOR ELECTRIC VEHICLE APPLICATIONS

Dr. K. Srinivas, Associate professor and Head of Department of Electrical and Electronics Engineering EEE,JNTUH College of Engineering , Jagityal ,Telangana 505501;cnuiitm05@gmail.com

Gorla Swathi , M.Tech Student, Department of Electrical and Electronics Engineering, Jagityal, Telangana 505501;gorlaswathi053@gmail.com.

ABSTRACT

This research presents a non-isolated multi-port power converter feasible to hybridize energy alternatives in electric vehicles. Due to the hybridization of the various input sources, there are several advantages in load power distribution in the system. Flexible control of discharging as well as the charging process concerning the energy sources can be achieved. The developed converter can able to boost the voltage levels with dual inputs such as a renewable solar PV and the other input as a battery and provides dual outputs with various voltage levels, which can able to suit the converter fed for several loads like motor drive and the low-rated loads like lighting and other auxiliary supplies in electric vehicles. Also, as the various voltages appear at the output, this converter can be interfaced with multilevel inverters fed electric vehicle drivetrain. The utilization of multilevel inverters reduces the total harmonic distortion and torque ripples in motor drives in electric vehicles. The proposed converter consists of less number of components making the circuit simple and cost-effective. With one inductor, two various modes are obtained for charging and discharging states concerning the energy storage units. A state-space analysis is designed for all the converter operating modes along with its control design. The proposed multi-port DC-DC converter is designed in MATLAB/Simulink and tested in a laboratory environment with a hardware setup.

INTRODUCTION

The escalating global population, coupled with the surging demand for energy, has precipitated a shift towards electric vehicles (EVs) as a sustainable alternative to traditional fossil-fuel- driven cars. In this context, the quest for cleaner and renewable energy sources to power EVs has gained momentum. The integration of solar photovoltaic (PV) systems plays a pivotal role in meeting this demand for clean energy. The pressing need for renewable energy integration with power systems is highlighted, particularly emphasizing the importance of solar PV generation for battery charging and grid-tied applications. To intensify the output power of solar PV arrangements, this research introduces a non-isolated multi-port power converter designed for the hybridization of energy alternatives in electric vehicles. The paper addresses the challenges posed by varying energy inputs by developing a converter capable of handling dual inputs from renewable solar PV and batteries. This converter facilitates flexible control over discharging and charging processes, catering to diverse energy demands within the EV system.

In parallel, the paper addresses the critical issue of achieving maximum power point tracking (MPPT) for solar PV systems. An artificial neural network (ANN) based MPPT controller is developed and compared with conventional MPPT methods such as hill climbing, incremental conductance, and fractional open circuit voltage methods. The integration of this MPPT algorithm enhances the efficiency of the solar PV system by continuously tracking the maximum power for any changes in environmental conditions like solar irradiance and temperature. The developed non-isolated multi-port converter exhibits versatility in elevating voltage levels, accommodating various loads within the EV system, including motor drives and low-rated components like lighting. Unlike conventional approaches, this converter prioritizes simplicity and cost-effectiveness, comprising fewer components without compromising performance. The subsequent sections of this paper delve into the intricacies of the proposed converter, detailing its design, operating modes, dynamic modelling, and control architecture. The exploration concludes with a comprehensive analysis of simulation and experimental results, providing a holistic view of the converter's efficacy in real-world applications.

LITERATURE REVIEW

A number of articles were surveyed to know about the present advances in the scientific community in our field of interest. Some of the honorable mentions and there 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 enduser 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].

In the Indian region, solar energy is available almost throughout the year, whereas wind and hydro energies are location-specific, with wind energy being predominantly useful in coastal regions and hydro energy in hilly areas. Although renewable energy-based charging stations are the most feasible solution for electric vehicle (EV) charging, integrating them into the existing charging system introduces an additional power conversion stage, increasing complexity and power loss. Furthermore, each conversion stage requires an individual controller, necessitating integration with the existing control. Therefore, designing an integrated system with multifunctional and multimode operating capabilities is imperative, requiring unified control and coordination among various sources [3].

Several efforts have been made to develop renewable energy-based charging stations. Ugirumurera et al. highlighted the importance of renewable energy for the sustainability of EV charging stations [3]. Mouli et al. utilized solar power for EV charging using a high-power bidirectional charger but did not provide AC charging [4]. Monterio et al. presented a three-port converter for integrating a PV array with an EV charger but did not address current distortions in the grid current created by the charger [5]. Singh et al. proposed a modified z-source converter for a PV array/grid-connected EV charger but did not design it for islanded mode operation [6]. Chaudhari et al. discussed a hybrid optimization model for managing battery storage to minimize charging station running costs and maximize solar PV array utilization [7].

Kineavy et al. suggested using on-site PV-generated power in coordination with an EV charging station for maximum solar PV array utilization with minimal impact on the grid [8]. Zhang et al. studied optimal scheduling of an EV charging station in the workplace with dual charging modes, highlighting the suitability of PV array-powered stations for onsite deployment to provide quality service at a minimum cost while reducing grid impact [9,10]. Kandasamy et al. investigated the battery storage life in a commercial building-based solar PV array system [11]. Wind energy-powered charging stations, available day and night, have been explored in variouspublications [12]-[14].

Electric vehicles are increasingly recognized as distributed energy resources for providing ancillary services due to the substantial energy stored in EV batteries. Singh et al. presented a PV array-based charging station providing vehicle-to-grid reactive/active power, active power filtering, and vehicle-to-home services [15]. Saxena et al. implemented a grid-tied PV array system for EV and residential applications [16]. Razmi et al. proposed a power management strategy with multi-mode control for an integrated residential PV-storage battery system, suitable for both grid-connected and islanded operations [17]. Erdinc et al. and Kikusato et al., as well as Hafiz et al., have explored smart household operations utilizing EVs as storage for providing various services [18-20].

MPPT Algorithm (Perturb and Observe - P&O)

The Perturb and Observe (P&O) algorithm is a widely used maximum power point tracking (MPPT) technique for solar photovoltaic systems. The P&O algorithm works by perturbing the

operating point of the solar panel and observing the resulting change in power output. If the power output increases, the operating point is perturbed in the same direction again. If the power output decreases, the operating point is perturbed in the opposite direction. The P&O algorithm is simple to implement and is effective in tracking the maximum power point of the solar panel

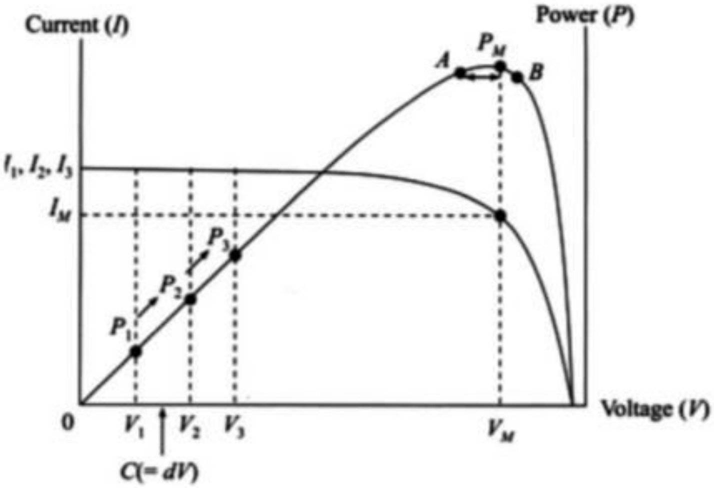


Fig 1 Perturb and Observe (P&O) Technique for MPPT.

ARCHITECTURE OF AN ARTIFICIAL NEURAL NETWORK

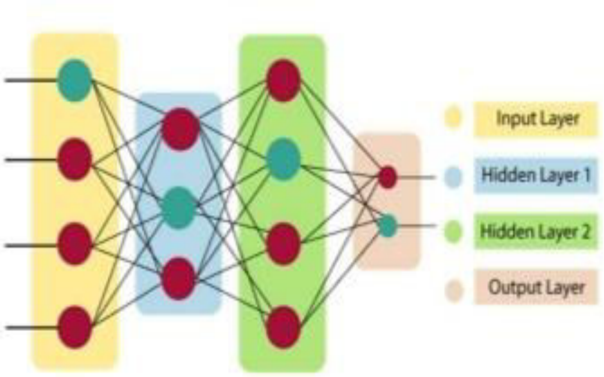
To understand the concept of the architecture of an artificial neural network, we must understand what a neural network consists of. To define a neural network that consists of many artificial neurons, which are termed units arranged in a sequence of layers. Now, various types of layers available in an artificial neural network are as follows.

Artificial Neural Network primarily consists of three layers:

a. Input Layer:

As the name suggests, it accepts inputs in several different formats provided by the programmer.

b. Hidden Layer:



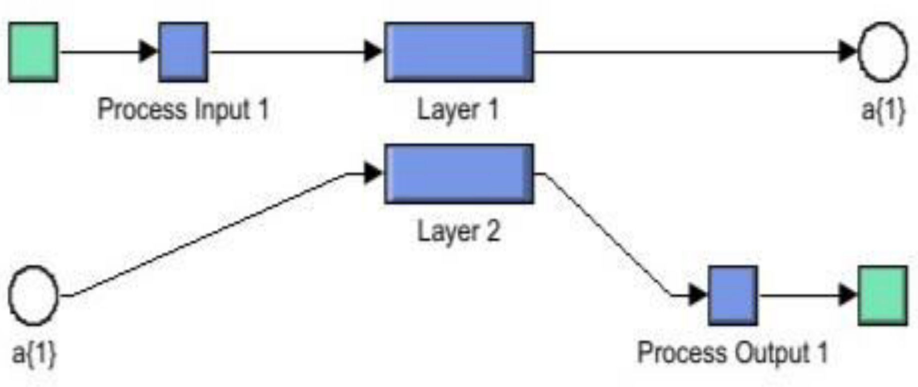
The hidden layer presents in-between input and output layers. It performs all the calculations to find hidden features and patterns.

c. Output Layer:

The input goes through a series of transformations using the hidden layer, which finally results in output that is conveyed using this layer. The artificial neural network takes input and computes the weighted sum of the inputs and includes a bias. This computation is represented in the form of a transfer function.

$$\sum Wi * Xi + b$$

It determines weighted total is passed as an input to an activation function to produce the output. Activation functions choose whether a node should fire or not. Only those who are fired make it to the output layer. There are distinctive activation functions available that can be applied upon the sort of task we are performing



Proposed system configuration

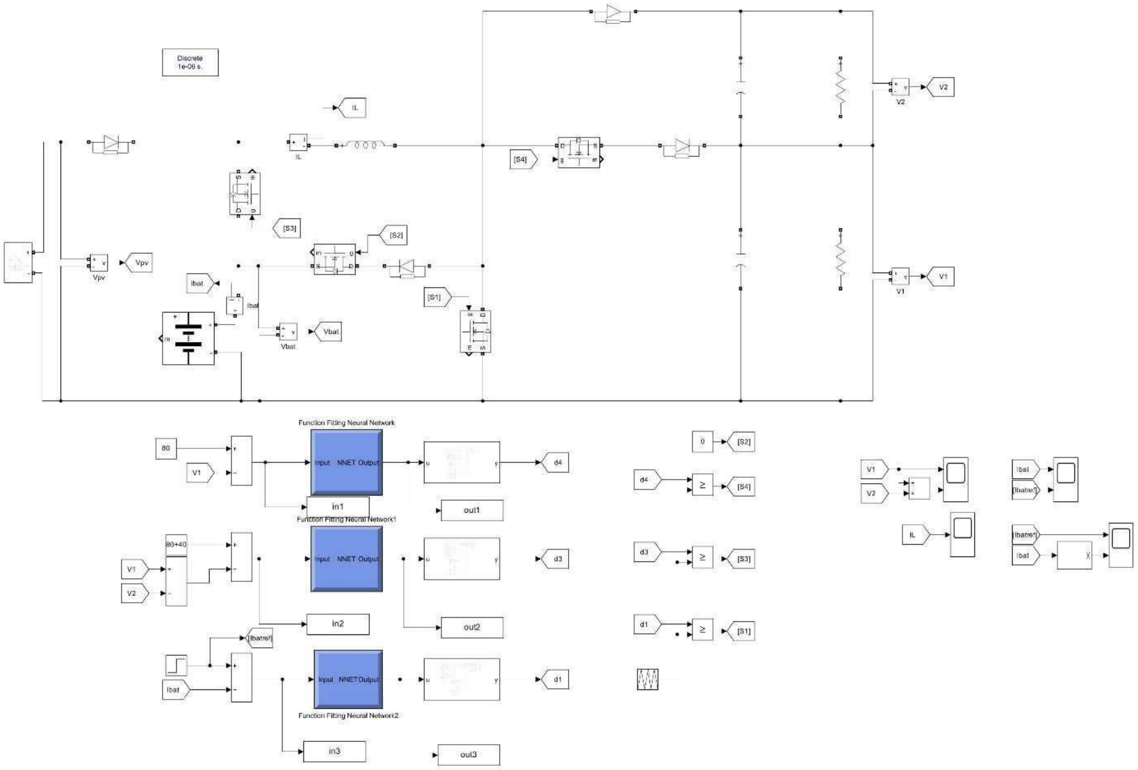


Fig. 2. Simulink model of PV and Battery Storage Based Microgrid Using ANN.

The performance of the developed converter is analyzed and designed using MATLAB software. Vpv = 35V, Vbat = 48V are the input voltage sources. The battery model is utilized as an input source in simulation 2. The converter's output voltages should be regulated at V1ref D 80V and V2ref D 40V. Hence, the total output voltage should be able to regulate at VTref D 120V. In addition, for battery discharge and charging modes, battery current should be regulated at Ibref D 3A and Ibref D 0.9A, respectively. For the battery draining and charging modes R1 = R2 = 35 Ohm and R1 = R2 = 70 Ohm are the load resistances respectively.

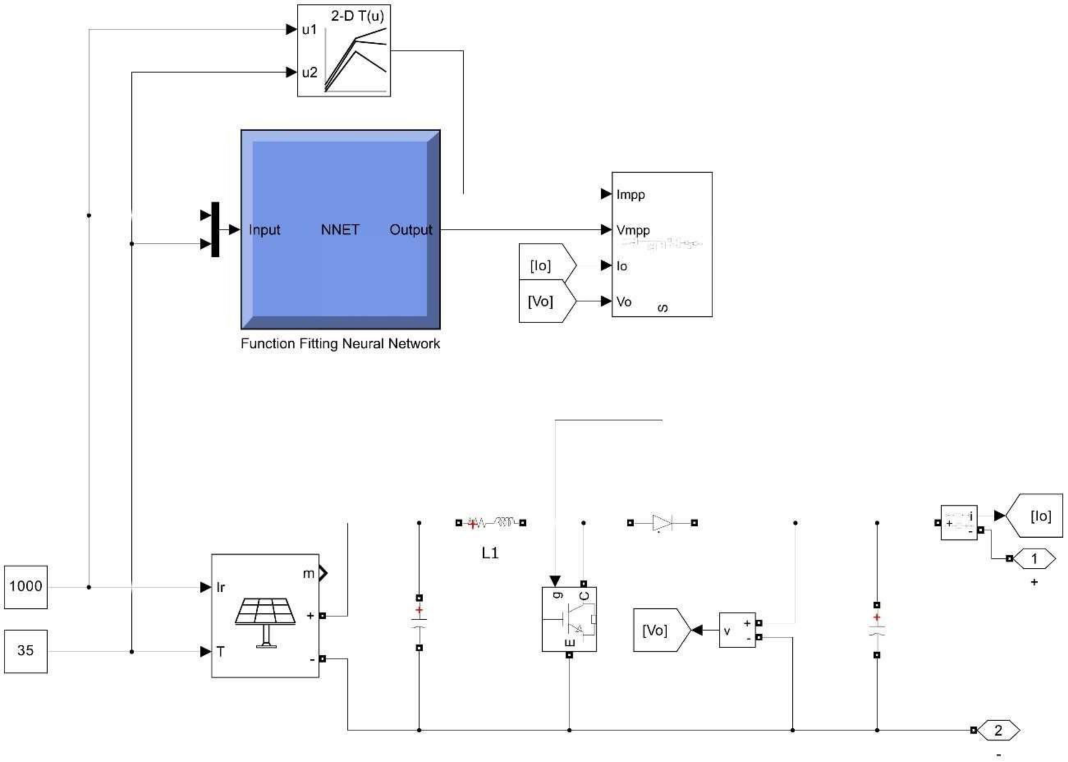


Fig.3 Simulink model of subsystem-I, three phase voltage source inverter.

Initially, the converter is in the discharging battery mode, with the switches S1, S3, and S4 active, as shown in previous sections. Each switch is controlled by a compensator, which is built in FIGURE 34 depicts the output voltages V1 and VT. Regulating the output voltage represented yields the required values. FIGURE 36 depicts the battery current. The battery current is compared to the reference value. FIGURE 34 illustrates the inductor current. At a specific time (t D 0.01s), the battery source's reference current is abruptly increased from 3A to 4A. At a specific time (tD0.07s), the load power is abruptly increased.

Load resistances are modified to R1 = R2 = 17.5 Ohm at that moment. The respective change in the battery current is represented in FIGURE 36. As can be seen, controllers did an excellent job of regulating the battery current and the output voltages in response to load variations. In reality, the load power can be fed among the input sources by managing the battery current. In the charging mode of the battery, source 1 supplies power to source 2 in addition to the loads (battery). Switches S1, S2 and S4 are active in this mode. In this mode, the required output voltages are V1ref D 80V, V2ref D 40V and the current reference of battery charging is Ibref D 0.9A, similar to the battery discharge mode.

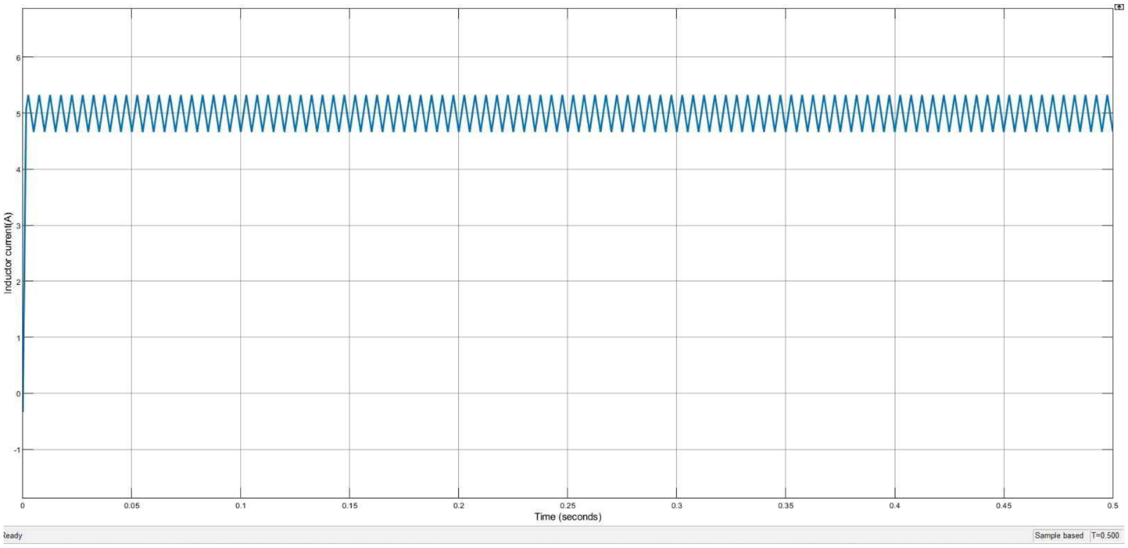


Fig. 4. Simulation results of discharging mode inductor current of the system.

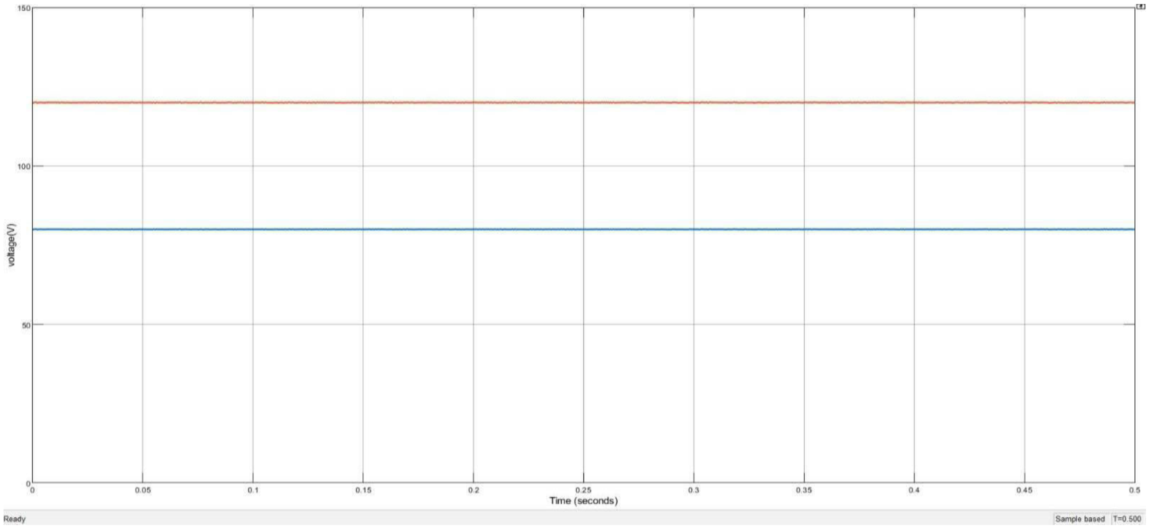


Fig. 5. Simulation results of output voltage in discharging mode of the system.

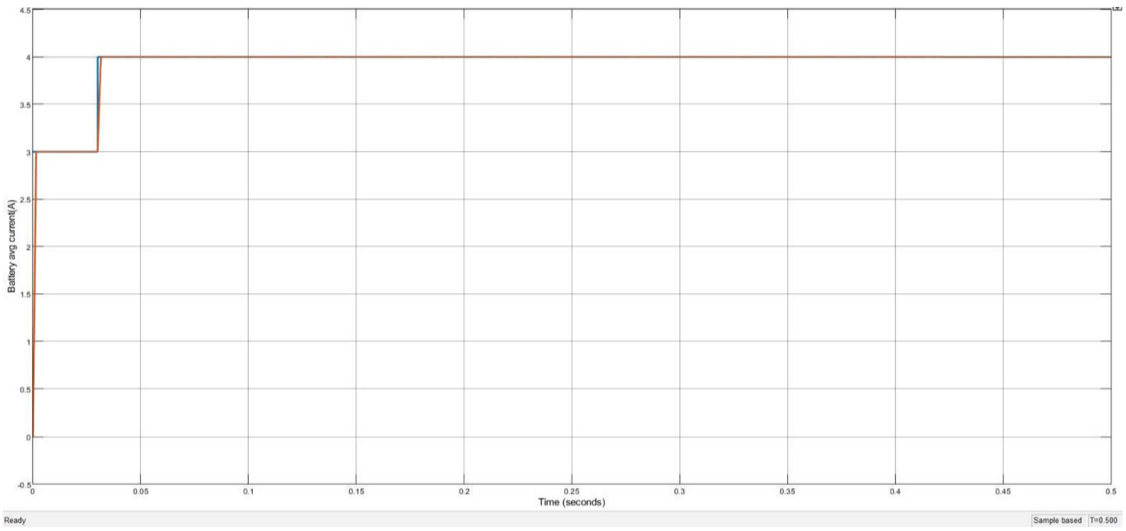


Fig. 6. Simulation results of change of Battery reference current in discharging mode of the system.

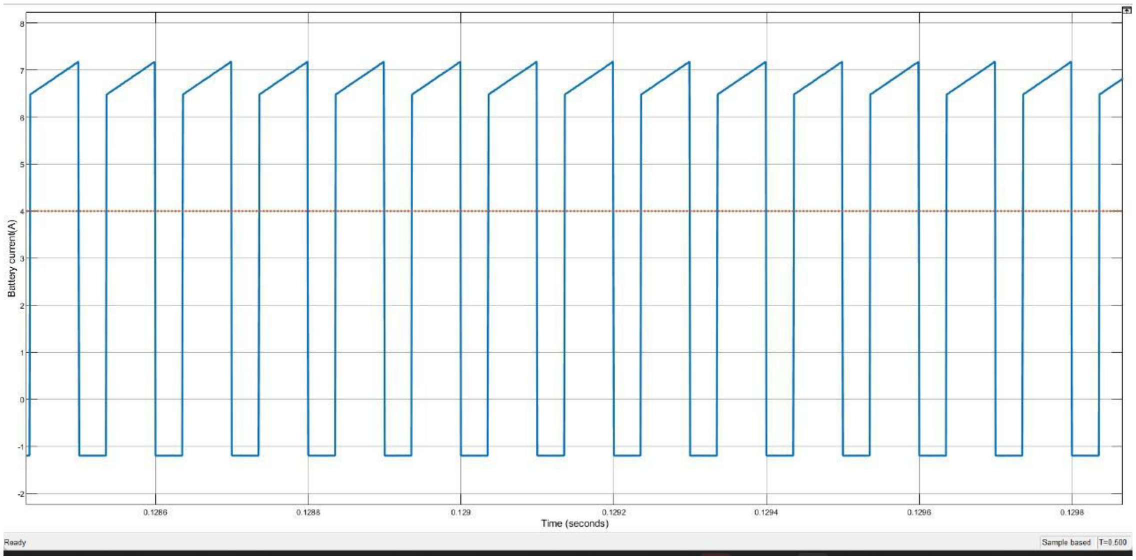


Fig. 7. Simulation results of output current in discharging mode of the system.

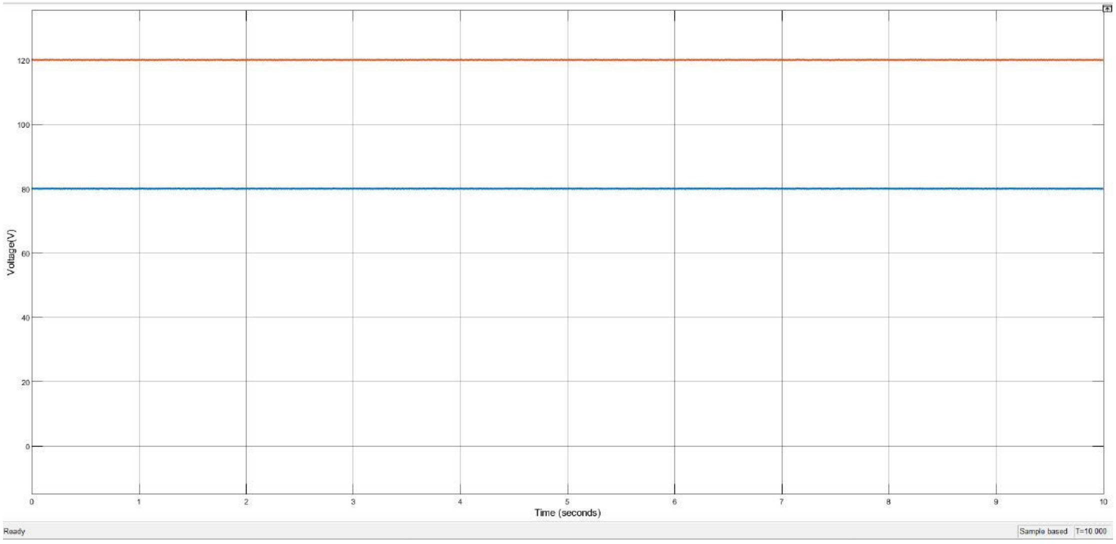


Fig. 8. Simulation results of output voltage in battery charging mode of the system.

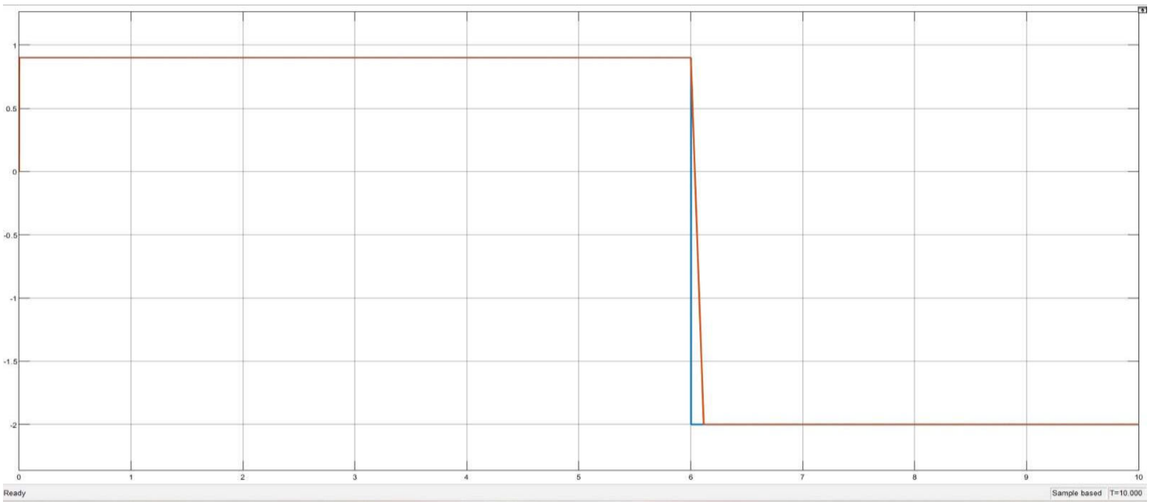


Fig. 9. Simulation results of change of Battery reference current charging mode of the system.

CONCLUSION

In conclusion, the development and implementation of a Single Inductor Multi-Port Power Converter represent a significant advancement in the realm of electric vehicle (EV) applications. This innovative converter design addresses key challenges in the electrification of vehicles by efficiently managing power distribution among multiple ports. The single inductor architecture streamlines the converter, reducing complexity and enhancing overall reliability. One of the notable strengths of this converter lies in its ability to simultaneously handle multiple energy sources and loads within the EV system. By seamlessly integrating power from various sources, such as batteries, solar panels, and regenerative braking, the converter optimizes energy utilization and contributes to increased overall efficiency. This is particularly crucial in the context of electric vehicles, where the effective management of power resources directly impacts driving range and performance. Furthermore, the compact and simplified design of the Single Inductor Multi-Port Power Converter aligns with the imperative for lightweight and space-efficient components in electric vehicles. The reduction in the number of inductors not only minimizes the physical footprint of the converter but also translates into potential cost savings and improved manufacturability. As the automotive industry continues to transition towards sustainable and electric mobility solutions, the proposed power converter emerges as a promising technology that enhances the effectiveness and versatility of electric vehicle power systems. Its multi-port capability and efficiency improvements contribute to the ongoing efforts to make electric vehicles more practical, economical, and environmentally friendly. In essence, the Single Inductor Multi-Port Power Converter serves as a pivotal building block for the future of electric vehicle applications, addressing the intricacies of power distribution with a holistic and innovative approach.

REFERENCES

[1] S. R. Khasim and C. Dhanamjayulu, ``Selection parameters and syn- thesis of multi- input converters for electric vehicles: An overview,'' Renew. Sustain. Energy Rev., vol. 141, May 2021, Art. no. 110804, doi: 10.1016/j.rser.2021.110804.

[2] P.-J. Liu, Y.-K. Lo, H.-J. Chiu, and Y.-J. Emery Chen, ``Dual-current pump module for transient improvement of step-down DCDC converters,'' IEEE Trans. Power Electron., vol. 24, no. 4, pp. 985990, Apr. 2009, doi: 10.1109/TPEL.2008.2010322.

[3] J. Macaulay and Z. Zhou, ``A fuzzy logical-based variable step size P&O MPPT algorithm for photovoltaic system,'' Energies, vol. 11, no. 6, p. 1340, May 2018, doi: 10.3390/en11061340.

[4] M. Dhananjaya, D. Ponuru, T. S. Babu, B. Aljafari, and H. H. Alhelou, ``A new multi- output DCDC converter for electric vehicle application,'' IEEE Access, vol. 10, pp. 1907219082, 2022.

[5] L. Wang, E. G. Collins, and H. Li, ``Optimal design and real- time control for energy management in electric vehicles,'' IEEE Trans. Veh. Technol., vol. 60, no. 4, pp. 14191429, May 2011, doi: 10.1109/TVT.2011.2122272.

[6] M. Zandi, A. Payman, J. P. Martin, S. Pierfederici, B. Davat, and F. Meibody-Tabar, ``Energy management of a fuel cell/supercapacitor/ battery power source for electric vehicular applications,'' IEEE Trans. Veh. Technol., vol. 60, no. 2, pp. 433443, Nov. 2011, doi: 10.1109/TVT.2010.2091433.

[7] K. Suresh, C. Bharatiraja, N. Chellammal, M. Tariq, R. K. Chakrabortty, M. J. Ryan, and B. Alamri, ``Amultifunctional non-isolated dual input-dual output converter for electricvehicle applications,'' IEEE Access, vol. 9, pp. 6444564460, 2021.

[8] S. R. Khasim and C. Dhanamjayulu, ``Design and implementation of asymmetrical multilevel inverter with reduced components and low voltage stress,'' IEEE Access, vol. 10, pp. 34953511, 2022, doi: 10.1109/ACCESS.2022.3140354.

[9] A. Ajami, H. Ardi, and A. Farakhor, ``A novel high step-up DC/DC converter based on integrating coupled inductor and switched- capacitor techniques for renewable energy applications,'' IEEE Trans. Power Electron., vol. 30, no. 8, pp. 42554263, Aug. 2015, doi: 10.1109/TPEL.2014.2360495.

[10] M. R. Banaei, H. Ardi, R. Alizadeh, and A. Farakhor, ``Non-isolated multi- input-

single- output DC/DC converter for photovoltaic power generation systems," IET Power Electron., vol. 7, no. 11, pp. 28062816, Nov. 2014, doi: 10.1049/iet-pel.2013.0977.

[11] O. Hegazy, R. Barrero, J. Van Mierlo, P. Lataire, N. Omar, and T. Coosemans, ``An advanced power electronics interface for electric vehicles applications," IEEE Trans. Power Electron., vol. 28, no. 12, pp. 55085521, Dec. 2013, doi: 10.1109/TPEL.2013.2256469.

[12] C. Dhanamjayulu, S. Padmanaban, V. K. Ramachandaramurthy, J. B. Holm-Nielsen, and

F. Blaabjerg, ``Design and implementation of multilevel inverters for electric vehicles," IEEE Access, vol. 9, pp. 317338, 2021.

[13] Y. Cao and J. A. Abu Qahouq, ``Evaluation of bi-directional single-inductor multi-input battery system with state-of-charge balancing control," IET Power Electron., vol. 11,no. 13, pp. 21402150, Nov. 2018.

[14] S. R. Khasim, D. C, S. Padmanaban, J. B. Holm-Nielsen, and M. Mitolo, ``A novel asymmetrical 21-level inverter for solar PV energy system with reduced switch count," IEEE Access, vol. 9, pp. 1176111775, 2021, doi: 10.1109/ACCESS.2021.3051039.

[15] R. Ahmadi and M. Ferdowsi, ``Double-input converters based on H-bridge cells: Derivation, small-signal modeling, and power sharing analysis," IEEE Trans. Circuits Syst. I, Reg. Papers, vol. 59, no. 4, pp. 875888, Apr. 2012, doi: 10.1109/TCSI.2011.2169910.

[16] L. Solero, A. Lidozzi, and J. A. Pomilio, ``Design of multiple-input power converter for hybrid vehicles," IEEE Trans. Power Electron., vol. 20, no. 5, pp. 10071016, Sep. 2005, doi: 10.1109/TPEL.2005.854020.

[17] B. Faridpak, M. Farrokhifar, M. Nasiri, A. Alahyari, and N. Sadoogi, ``Developing a super-lift luo-converter with integration of buck converters for electric vehicle applications," CSEE J. Power Energy Syst., vol. 7, no. 4, pp. 811820, 2020.

[18] S. R. Khasim and D. C, ``Design of multiple input DCDC converters for interfacing solar/fuel cell/battery electric vehicles," in Proc. Innov. Power Adv. Comput. Technol. (i-PACT), Nov. 2021, pp. 17.

[19] C. Dhanamjayulu, S. R. Khasim, S. Padmanaban, G. Arunkumar, J. B. Holm-Nielsen, and

F. Blaabjerg, ``Design and implementation of multilevel inverters for fuel cell energy conversion system," IEEE Access, vol. 8, pp. 183690183707, 2020, doi: 10.1109/access.2020.3029153.

[20] K. Suresh, N. Chellammal, C. Bharatiraja, P. Sanjeevikumar, F. Blaabjerg, and J. B. H. Nielsen, ``Cost-efcient nonisolated three-port DCDC con- verter for EV/HEV applications with energy storage,"