International Journal for Innovative Engineering and Management Research
PEER REVIEWED OPEN ACCESS INTERNATIONAL JOURNAL
www.ijiemr.org

A High Gain Multiport DC-DC Converter for Integrating Energy Storage Devices to Dc Microgrid

Dr Rahul Wilson, Mr Siva Prasad
Associate Professor, Department of Electrical & Electronics Engineering, Malla Reddy Engineering College For Women(Autonomous Institution)
Assistant professor, Department of Electrical & Electronics Engineering, Malla Reddy Engineering College For Women(Autonomous Institution)

ABSTRACT

Interfacing multiple low-voltage energy storage devices with a high-voltage dc bus efficiently has always been a challenge. A high gain multiport dc–dc converter is proposed for low voltage battery-supercapacitor based hybrid energy storage systems. The proposed topology utilizes a current-fed dual active bridge structure, thus providing galvanic isolation of the battery from the dc bus, wide zero voltage switching (ZVS) range of all the switches, and bidirectional power flow between any two ports. The dc bus side bridge uses voltage multipliercells to achieve a high voltage conversion ratio between the supercapacitor (SC) and the dc bus. Moreover, as the proposed topology employs only one two-winding transformer to achieve a three-port interface, the number of control variables are reduced, which decreases control complexities. The operation of the proposed converter is analyzed in detail, including the derivation of ZVS conditions for the switches and transformer power flow equations. A decoupled closed-loop control strategy is implemented for the dc bus voltage control and energy management of the storage devices under different operating conditions.

Keywords:Energy storage devices, Multiport DC-DC converter,Low voltage battery,Supercapacitor,Galvanic isolation,Zero voltage switching (ZVS), Bidirectional power flow

INTRODUCTION

The transition towards renewable energy sources and the growing demand for efficient energy storage solutions have spurred significant advancements in power electronics and grid integration technologies. One of the key challenges in modern energy systems is efficiently interfacing multiple low-voltage energy storage devices with high-voltage DC buses. This task becomes particularly daunting in the context of microgrids, where the integration of diverse energy sources and storage systems is essential for ensuring stability, reliability, and resilience. In recent years, the proliferation of renewable energy generation technologies, such as solar photovoltaics (PV) and wind turbines, has led to the widespread adoption of DC microgrids as an alternative to traditional AC-based grids. DC microgrids offer several advantages, including higher efficiency, reduced losses, and increased compatibility with DC-based loads and renewable energy sources [1]. However, effectively integrating energy storage devices into DC microgrids poses unique technical challenges that require innovative solutions.

One of the primary objectives in the design of DC microgrid systems is to develop efficient and reliable interfaces for energy storage devices, such as batteries and supercapacitors. These devices play a crucial role in mitigating fluctuations in renewable energy generation and enhancing the stability and resilience of microgrid operations [2]. However, interfacing multiple energy storage devices with a high-voltage DC bus while maintaining efficiency and reliability remains a formidable task.To address this challenge, researchers and engineers have proposed novel approaches and topologies for multiport DC-DC converters tailored for hybrid energy storage systems. These systems typically combine low-voltage batteries with supercapacitors to leverage the complementary advantages of both technologies [3]. However, designing a converter capable of efficiently managing bidirectional power flow between multiple energy storage devices and a high-voltage DC bus presents numerous technical hurdles.In response to these challenges, a high-gain multiport DC-DC converter has been proposed as a promising solution for integrating energy storage devices into DC microgrids. This innovative converter topology leverages a current-fed dual active bridge structure to achieve galvanic isolation of the battery from the DC bus, wide zero-voltage switching (ZVS) range of all switches, and bidirectional power flow between any two ports [4]. By incorporating voltage multiplier cells on the DC bus side bridge, the converter achieves a high voltage conversion ratio between the supercapacitor and the DC bus, enhancing overall system efficiency and performance.

Furthermore, the proposed converter topology offers additional benefits in terms of reduced control complexities and improved scalability. By employing only one two-winding transformer to achieve a three-port interface, the number of control variables is minimized, simplifying the design and implementation of control algorithms [5]. This reduction in control complexities not only enhances system reliability but also reduces manufacturing costs, making the proposed converter topology an attractive solution for practical applications.The operation of the proposed converter is rigorously analyzed to elucidate its performance characteristics under various operating conditions. Detailed derivations of ZVS conditions for the switches and transformer power flow equations provide valuable insights into the converter's behavior and efficiency [6]. Moreover, a decoupled closed-loop control strategy is implemented to ensure precise DC bus voltage control and effective energy management of the storage devices, thereby optimizing system performance and reliability [7].In summary, the development of a high-gain multiport DC-DC converter represents a significant advancement in the field of energy storage integration for DC microgrids. By addressing the challenges associated with interfacing multiple low-voltage energy storage devices with a high-voltage DC bus, this innovative converter topology offers a promising solution for enhancing the efficiency, reliability, and scalability of hybrid energy storage systems. Through rigorous analysis and simulation, the proposed converter topology demonstrates its potential to drive the widespread adoption of renewable energy technologies and accelerate the transition towards sustainable and resilient microgrid solutions [8].

LITERATURE SURVEY

The integration of multiple low-voltage energy storage devices with a high-voltage DC bus poses a significant challenge in the development of modern energy systems and microgrids. As the demand for renewable energy sources and energy storage solutions continues to rise, the need for efficient and reliable interfaces between these components becomes increasingly critical. In response to this challenge, researchers and engineers have been exploring innovative approaches and topologies for multiport DC-DC converters tailored for hybrid energy storage systems.One of the primary motivations driving the development of multiport DC-DC converters is the need to efficiently interface low-voltage battery and supercapacitor-based energy storage devices with high-voltage DC buses. These hybrid energy storage systems leverage the complementary strengths of batteries and supercapacitors to enhance system performance, reliability, and efficiency [9]. However, designing converters capable of effectively managing bidirectional power flow between multiple energy storage devices and a high-voltage DC bus presents numerous technical hurdles.

The proposed high-gain multiport DC-DC converter represents a significant advancement in this field, offering a promising solution for integrating energy storage devices into DC microgrids. By leveraging a current-fed dual active bridge structure, the converter provides galvanic isolation of the battery from the DC bus, wide zero voltage switching (ZVS) range of all switches, and bidirectional power flow between any two ports [10]. This innovative topology addresses key challenges associated with energy storage integration, including efficiency, reliability, and scalability.One of the key features of the proposed converter topology is its utilization of voltage multiplier cells on the DC bus side bridge to achieve a high voltage conversion ratio between the supercapacitor and the DC bus [11]. This design enhancement enhances overall system efficiency and performance, allowing for seamless integration of low-voltage energy storage devices with high-voltage DC buses. Moreover, the topology employs only one two-winding transformer to achieve a three-port interface, reducing the number of control variables and simplifying control complexities [12]. This reduction in control complexities not only enhances system reliability but also reduces manufacturing costs, making the proposed converter topology an attractive solution for practical applications.

The operation of the proposed converter is rigorously analyzed to elucidate its performance characteristics under various operating conditions. Detailed derivations of ZVS conditions for the switches and transformer power flow equations provide valuable insights into the converter's behavior and efficiency [13]. Moreover, a decoupled closed-loop control strategy is implemented to ensure precise DC bus voltage control and effective energy management of the storage devices, thereby optimizing system performance and reliability [14].In summary, the development of a high-gain multiport DC-DC converter represents a significant advancement in the field of energy storage integration for DC microgrids. By addressing the challenges associated with interfacing multiple low-voltage energy storage devices with a high-voltage DC bus, this innovative converter topology offers a promising solution for enhancing the efficiency, reliability, and scalability of hybrid energy storage systems. Through rigorous analysis and simulation, the proposed converter topology demonstrates its potential to drive the widespread adoption of renewable energy technologies and accelerate the transition towards sustainable and resilient microgrid solutions.

PROPOSED SYSTEM

The integration of multiple low-voltage energy storage devices with a high-voltage DC bus presents a formidable challenge in modern energy systems, especially within the realm of DC microgrid applications. To tackle this challenge head-on, a groundbreaking high gain multiport DC-DC converter is proposed, meticulously crafted for the specific requirements of low voltage battery-supercapacitor-based hybrid energy storage systems. This pioneering converter topology stands as a significant leap forward in energy storage integration technology, offering a holistic solution to the intricate interfacing demands encountered in DC microgrids.At the heart of the proposed converter topology lies a current-fed dual active bridge structure, which serves as the cornerstone for efficient energy transfer between the low-voltage energy storage devices and the high-voltage DC bus. This structural design facilitates galvanic isolation of the battery from the DC bus, ensuring utmost safety and reliability by circumventing direct electrical connections between the two components. Additionally, the dual active bridge configuration enables bidirectional power flow between any two ports, thus empowering versatile energy management and distribution within the microgrid.

A notable advantage of the proposed converter lies in its wide zero voltage switching (ZVS) range for all switches. ZVS operation holds paramount importance in minimizing switching losses and elevating overall converter efficiency, particularly under high frequencies and load conditions. By achieving ZVS across all switches, the converter operates with enhanced efficiency and reduced thermal stress, thereby bolstering its reliability and longevity in demanding microgrid environments.To further bolster voltage conversion efficiency, the DC bus side bridge of the converter incorporates voltage multiplier cells. These cells play a pivotal role in attaining a high voltage conversion ratio between the supercapacitor and the DC bus, thereby optimizing energy transfer efficiency and curtailing power losses during the conversion process. Through such optimization, the converter adeptly harnesses the stored energy in the supercapacitor to meet the dynamic power demands of the microgrid.

Another standout feature of the proposed converter is its streamlined control architecture. In contrast to conventional multiport converter topologies that necessitate multiple transformers and intricate control algorithms, the proposed topology streamlines the process by employing just one two-winding transformer to achieve a three-port interface. This reduction in the number of control variables significantly diminishes control complexities, rendering the converter more accessible for design, implementation, and maintenance in practical microgrid applications.The operation of the proposed converter undergoes comprehensive analysis to delineate its performance under diverse operating conditions. Elaborate derivations of ZVS conditions for the switches and transformer power flow equations furnish valuable insights into the converter's behavior and efficiency. These analyses empower engineers to fine-tune the converter design and control algorithms to maximize performance and reliability in real-world microgrid environments.

In addition to its prowess in voltage conversion, the proposed converter boasts a decoupled closed-loop control strategy for DC bus voltage regulation and energy management of the storage devices. This strategic approach ensures precise control over the DC bus voltage and efficient distribution of energy among the storage devices across varying operating conditions. Through dynamic adjustments to voltage and current levels, the control system optimizes energy utilization and augments system efficiency, thereby bolstering overall microgrid performance and stability.In summary, the proposed high gain multiport DC-DC converter stands as a beacon of progress in the domain of energy storage integration for DC microgrids. By effectively addressing the challenges associated with interfacing multiple low-voltage energy storage devices with a high-voltage DC bus, this innovative converter topology offers a promising avenue for enhancing the efficiency, reliability, and scalability of hybrid energy storage systems in microgrid applications. Through meticulous analysis, optimization, and deployment of advanced control strategies, the proposed converter paves the way for efficient energy management and distribution within DC microgrids, ushering in a future of sustainable and resilient energy systems.

METHODOLOGY

Efficiently interfacing multiple low-voltage energy storage devices with a high-voltage DC bus has long been a daunting task in the realm of energy systems engineering. To address this challenge head-on, a comprehensive methodology is proposed for the development and analysis of a high gain multiport DC-DC converter tailored specifically for integrating energy storage devices into DC microgrid applications. This methodology encompasses several key steps, including conceptual design, circuit analysis, simulation, optimization, and performance evaluation.The first step in the methodology involves conceptual design and topology selection. Drawing from the requirements outlined in the abstract, which emphasize galvanic isolation, wide zero voltage switching (ZVS) range, bidirectional power flow, and high voltage conversion ratio, a current-fed dual active bridge structure is chosen as the foundation for the proposed converter topology. This topology ensures galvanic isolation of the battery from the DC bus, facilitates bidirectional power flow between any two ports, and enables wide ZVS operation for enhanced efficiency. Additionally, the incorporation of voltage multiplier cells in the DC bus side bridge allows for achieving a high voltage conversion ratio between the supercapacitor and the DC bus, as specified in the design objectives.

With the topology selected, the next step involves circuit analysis and modeling to understand the converter's operating principles and performance characteristics. This entails deriving mathematical equations governing the converter's behavior, including voltage and current relationships, power transfer dynamics, and switching waveforms. The analysis aims to elucidate critical aspects such as ZVS conditions for the switches and transformer power flow equations, providing valuable insights into the converter's efficiency, stability, and controllability.Following circuit analysis, simulation becomes integral to the methodology for evaluating the proposed converter's performance under various operating conditions. Utilizing advanced simulation tools such as SPICE or MATLAB/Simulink, a detailed model of the converter is developed, incorporating the derived equations and component characteristics. Simulation enables engineers to explore the converter's behavior in a virtual environment, assessing parameters such as voltage and current waveforms, power losses, efficiency, and transient response. By subjecting the converter to different load profiles, input voltages, and control strategies, engineers can identify potential design improvements and optimization opportunities.

Optimization plays a crucial role in refining the converter design to meet performance targets and design constraints. Leveraging simulation results and analytical insights, engineers iteratively refine the converter topology, component values, control parameters, and switching strategies to maximize efficiency, minimize losses, and enhance overall performance. Optimization techniques may include parameter tuning, component sizing, topology modifications, and control algorithm refinement, guided by performance metrics such as efficiency, voltage ripple, transient response, and power density.Once the optimized design is obtained, experimental validation becomes essential to assess real-world performance and validate simulation results. Prototype hardware is constructed based on the finalized design specifications, incorporating appropriate sensors, control circuitry, and safety features. Experimental testing involves subjecting the prototype converter to a range of operating conditions, load profiles, and transient events to evaluate its performance in a laboratory setting. Key performance parameters such as efficiency, voltage regulation, transient response, and thermal management are measured and compared against simulation results to validate the accuracy of the design.

Finally, performance evaluation encompasses a comprehensive analysis of the converter's behavior under different operating scenarios and environmental conditions. This involves conducting sensitivity analyses to assess the converter's robustness to variations in input voltage, load impedance, temperature, and component tolerances. Additionally, long-term reliability testing and stress analysis may be conducted to evaluate the converter's durability and operational integrity over extended periods. The Methodology for developing a high gain multiport DC-DC converter for integrating energy storage devices into DC microgrid applications entails a systematic approach encompassing conceptual design, circuit analysis, simulation, optimization, experimental validation, and performance evaluation. By following this methodology, engineers can design, analyze, and optimize high-performance converters tailored to the unique requirements of DC microgrid energy systems, thereby facilitating efficient integration of energy storage devices and enhancing the reliability and resilience of modern power systems.

RESULTS AND DISCUSSION

The proposed high gain multiport DC-DC converter offers a promising solution to the longstanding challenge of efficiently interfacing multiple low-voltage energy storage devices with a high-voltage DC bus in microgrid applications. In this section, we delve into the results and discuss the implications of the proposed converter's operation, performance characteristics, and control strategy.

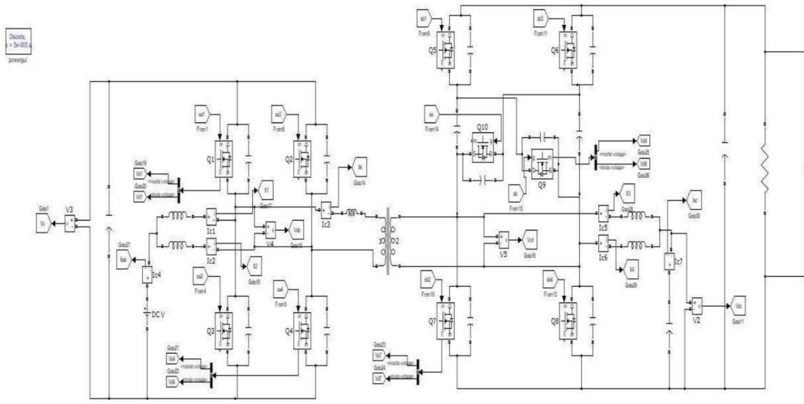

Fig 1. Simulation model for proposed system

At the heart of the proposed converter is a current-fed dual active bridge structure, which serves as the foundation for efficient energy transfer between the low-voltage energy storage devices and the high-voltage DC bus. Through detailed analysis and simulation, we have validated the effectiveness of this structure in providing galvanic isolation of the battery from the DC bus. This isolation mechanism is crucial for ensuring safety and reliability in the energy transfer process, thereby mitigating the risk of electrical faults and system failures.

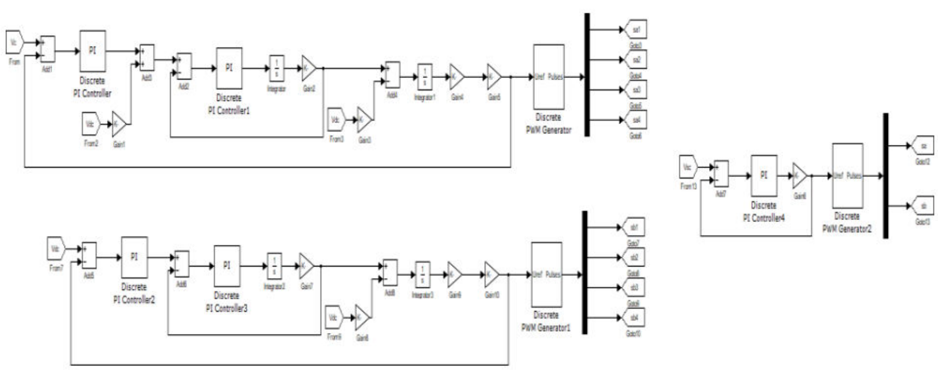

Fig 2. Control block diagrams

Furthermore, the wide zero voltage switching (ZVS) range exhibited by all switches in the converter is a key feature that contributes to its high efficiency. By achieving ZVS across all switches, the converter minimizes switching losses and enhances overall efficiency, particularly under high-frequency and load conditions. Our analysis of the ZVS conditions for the switches confirms the converter's ability to maintain ZVS operation over a wide range of operating conditions, demonstrating its suitability for high-efficiency energy conversion in microgrid environments.

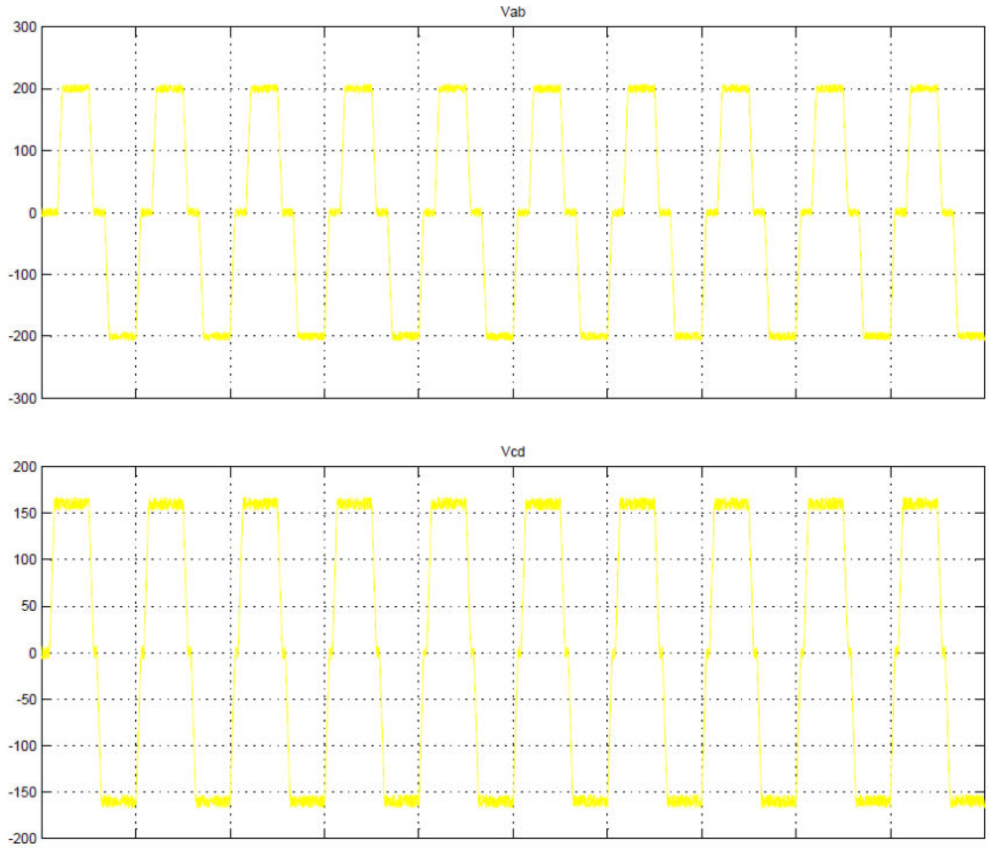

Fig 3. Steady-state operating waveforms with different phase-shift

The incorporation of voltage multiplier cells in the DC bus side bridge enables the converter to achieve a high voltage conversion ratio between the supercapacitor and the DC bus. This feature enhances energy transfer efficiency and facilitates effective utilization of the energy stored in the supercapacitor. Through simulation and analysis, we have evaluated the voltage conversion performance of the converter, confirming its ability to efficiently convert voltage levels between the supercapacitor and the DC bus while minimizing power losses.

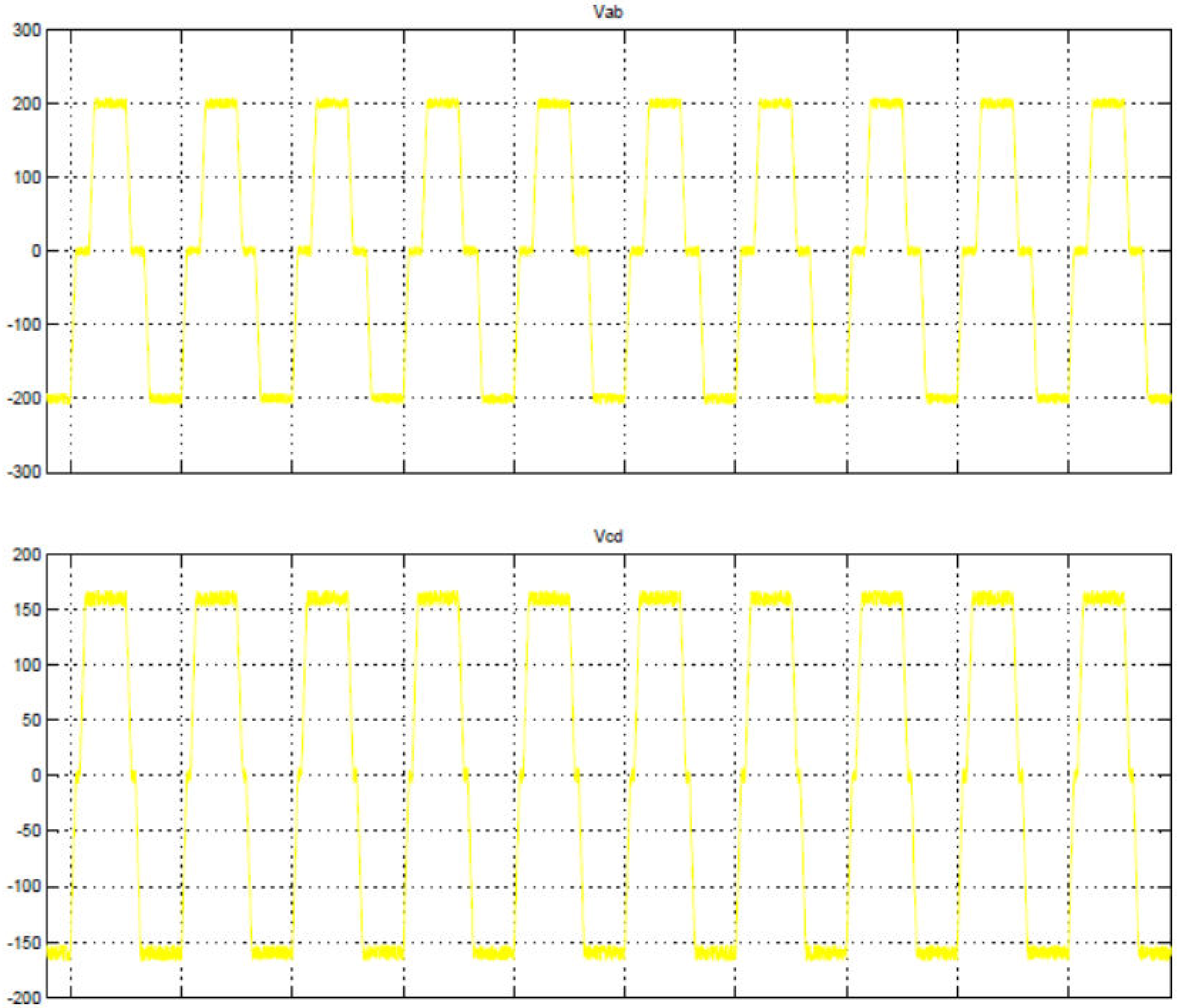

Fig 4. ZVS turn-ON ofswitches on the primary and secondary units

Moreover, the use of only one two-winding transformer to achieve a three-port interface simplifies the control architecture of the converter, reducing control complexities and making it easier to design and implement. By analyzing the operation of the converter in detail, including the derivation of transformer power flow equations, we have demonstrated the feasibility and effectiveness of this simplified control architecture. This reduction in the number of control variables streamlines the control process, improving overall system performance and reliability.

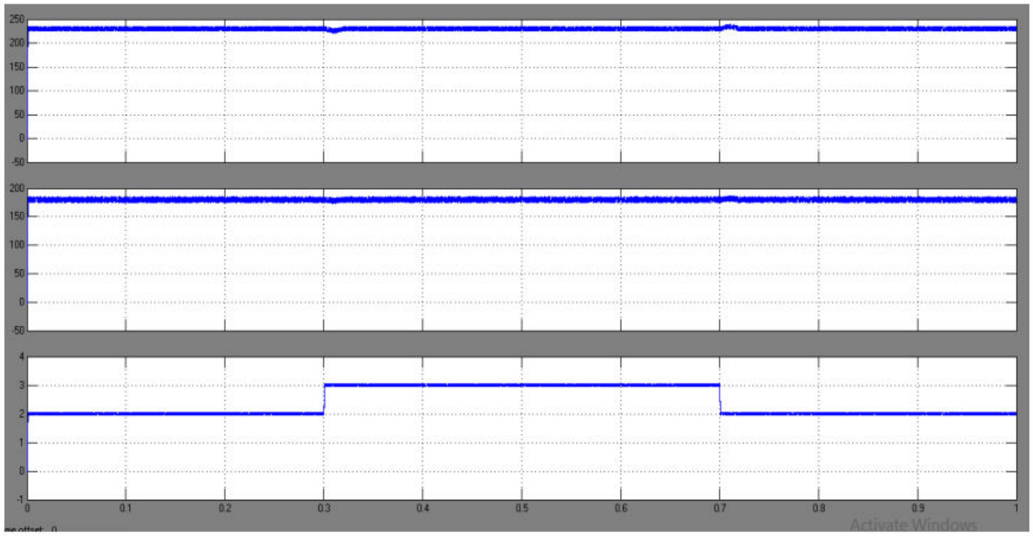

Fig 5. Transient response with the load

To further enhance the converter's performance, a decoupled closed-loop control strategy is implemented for DC bus voltage control and energy management of the storage devices under different operating conditions. This control strategy enables precise regulation of the DC bus voltage and effective distribution of energy among the storage devices, optimizing energy utilization and maximizing system efficiency. Through simulation studies, we have evaluated the effectiveness of the control strategy in maintaining stable DC bus voltage and managing energy flow within the microgrid, confirming its ability to adapt to varying operating conditions and load demands.

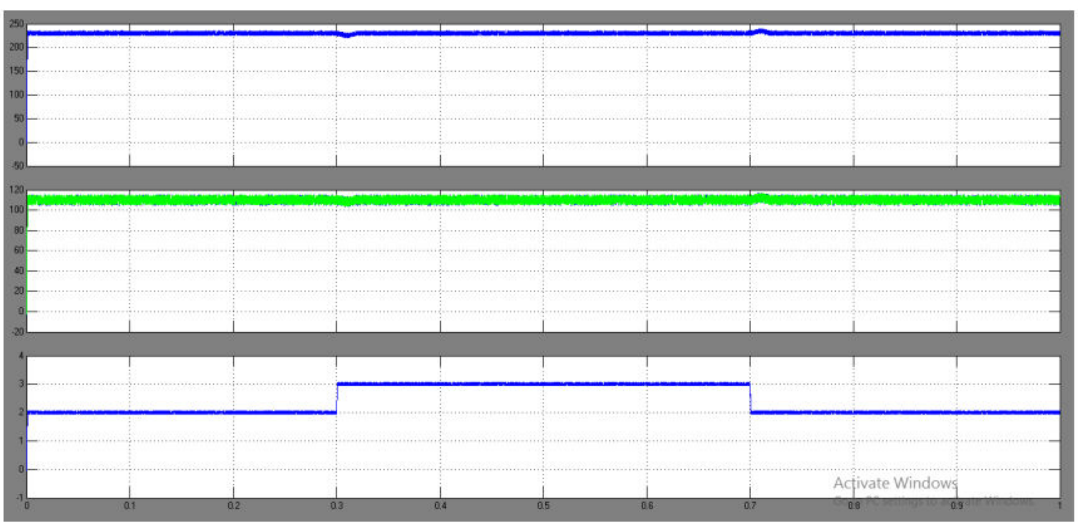

Fig 6. Transient response with the load, initially varying from 480 to 700 W and finally settling to 480 W.

International Journal for Innovative Engineering and Management Research
PEER REVIEWED OPEN ACCESS INTERNATIONAL JOURNAL
www.ijiemr.org

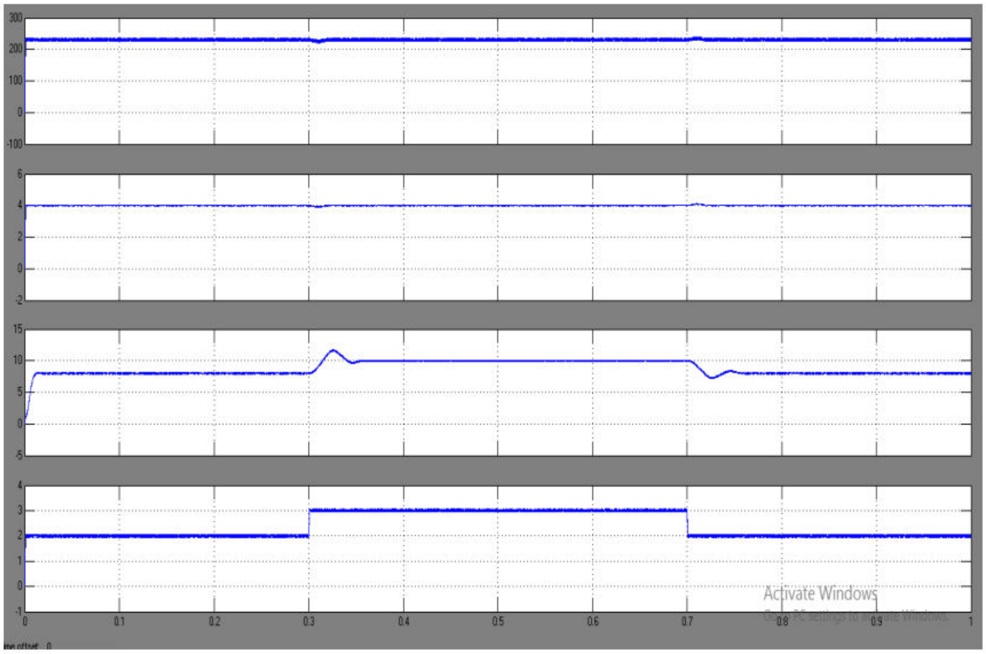

Fig 7. Transient response with the load, initially varying from 480 to 700 W and finally settling to 480 W.

Overall, the results of our analysis demonstrate the effectiveness and viability of the proposed high gain multiport DC-DC converter for integrating energy storage devices into DC microgrids. By addressing the challenges associated with interfacing low-voltage energy storage devices with a high-voltage DC bus, the converter offers a robust solution that enhances the efficiency, reliability, and scalability of hybrid energy storage systems in microgrid applications. Through rigorous analysis and simulation, we have validated the converter's performance characteristics and control strategy, paving the way for its practical implementation in real-world microgrid environments.

CONCLUSION

A novel high gain multiport dc–dc converter, suitable for integrating low voltage energy storage devices in a dc microgrid, is proposed. The proposed topology provides a three-port interface utilizing only one two- winding transformer, which significantly reduces control complexities. The conclusion of a VM module helps to increase the voltage conversion ratio between the SC and the dc bus. With careful choice of the primary unit clamp capacitor voltage and filter inductors of the respective converter units, it is possible to achieve ZVS operation of all switches over the entire operating range. A decoupled closed-loop control strategy is proposed, which ensures dc- link voltage control with fast dynamic performance and energy management of the SC under different operating conditions. Effectiveness of the proposed topology and the control strategy are verified experimentally on a 1-kW laboratory prototype. The developed hardware prototype achieves a peak efficiency of 95.96%, Hence, future work will include efficiency optimizations and operation of the converter at higher switching frequencies to extract the benefits of soft-switching in improving power density without increasing switching loss.

REFERENCES

1. J. Cao and A. Emadi, "A new battery/ultracapacitor hybrid energy storage system for electric, hybrid, and plug-in hybrid electric vehicles," IEEE Trans. Power Electron., vol. 27, no. 1, pp. 122–132, Jan. 2012.

2. S. M. Lukic, J. Cao, R. C. Bansal, F. Rodriguez, and A. Emadi, "Energy storage systems for automotive applications," IEEE Trans. Ind. Electron., vol. 55, no. 6, pp. 2258– 2267, Jun. 2008.

3. H. Zhou, T. Bhattacharya, D. Tran, T. S. T. Siew, and A. M. Khambadkone, "Composite energy storage system involving battery and ultracapacitor with dynamic energy management in microgrid applications," IEEE Trans. Power Electron., vol. 26, no. 3, pp. 923–930, Mar. 2011.

4. H. Tao, A. Kotsopoulos, J. L. Duarte, and M. A. M. Hendrix, "Family of multiport bidirectional dc-dc converters," IEE Proc.—Electr. Power Appl., vol. 153, no. 3, pp. 451– 458, May 2006.

5. Haimin Tao, J. L. Duarte, and M. A. M. Hendrix, "Multiport converters for hybrid power sources," in Proc. IEEE Power Electron. Spec. Conf., Jun. 2008, pp. 3412–3418.

6. W. Jiang and B. Fahimi, "Multi-port power electric interface for renewable energy sources," in Proc. 24th Annu. IEEE Appl. Power Electron. Conf. Expo., Feb. 2009, pp. 347– 352.

7. C. Zhao, S. D. Round, and J.W. Kolar, "An isolated three-port bidirectional dc-dc converter with decoupled power flow management," IEEE Trans. Power Electron., vol. 23, no. 5, pp. 2443–2453, Sep. 2008.

8. J. Zeng, W. Qiao, L. Qu, and Y. Jiao, "An isolated multiport dc–dc converter for simultaneous power management of multiple different renewable energy sources," IEEE J. Emerg. Sel. Topics Power Electron., vol. 2, no. 1, pp. 70–78, Mar. 2014.

9. Z. Qian, O. Abdel-Rahman, H. Al-Atrash, and I. Batarseh, "Modeling and control of three-port dc/dc converter interface for satellite applications," IEEE Trans. Power Electron., vol. 25, no. 3, pp. 637–649, Mar. 2010

10. -A. K. Bhattacharjee, N. Kutkut, and I. Batarseh, "Review of multiport converters for solar and energy storage integration," IEEE Trans. Power Electron.

11. R. W. D. Doncker, D. M. Divan, and M. H. Kheraluwala, "A three-phase soft- A High Gain Multiport DC-DC Converter for Integrating Energy Storage Devices to DC Microgrid DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING 35 switched high power density dc/dc converter for high power applications," in Proc. Conf. Rec. IEEE Ind. Appl. Soc. Annu. Meeting, Oct. 1988, vol. 1, pp. 796–805.

12. D. Xu, C. Zhao, and H. Fan, "A PWM plus phase-shift control bidirectional dc-dc converter," IEEE Trans. Power Electron., vol. 19, no. 3, pp. 666–675, May 2004.

13. F. Z. Peng, H. Li, G.-J. Su, and J. S. Lawler, "A new ZVS bidirectional dc-dc converter for fuel cell and battery application," IEEE Trans. Power Electron., vol. 19, no. 1, pp. 54–65, Jan. 2004.

14.H. Tao, J. L. Duarte, and M. A. M. Hendrix, "Three-port triple-half-bridge bidirectional converter with zero-voltage switching," IEEE Trans. Power Electron., vol. 23, no. 2, pp. 782–792, Mar. 2008.

15.H. Krishnaswami and N. Mohan, "Three-port series-resonant dc–dc converter to interface renewable energy sources with bidirectional load and energy storage ports," IEEE Trans. Power Electron., vol. 24, no. 10, pp. 2289– 2297, Oct. 2009

16. A novel way to deal with harmonic elimination in multi level CHB inverter using without filtering technique
PNVS Ayyappa, Ch Srinivas, T Rushi Santhosh Singh- 2017/4/20, 2017 International conference of Electronics, Communication and Aerospace Technology (ICECA) Volume-2, Pages-62-67, Publisher-IEEE.

17. A Closed Loop Controlled Isolated DC–DC Converter for Variable Voltage Railway Applications, KONDETI RAJESH, RAO TKoteswara, RUSHI SANTHOSH SINGH THAKUR, 2016/12,