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A NOVEL HIGH-GAIN DC-DC CONVERTER APPLIED IN FUEL CELL VEHICLES

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Abstract— **Fuel cell cars should have DC-DC converters with high efficiency, low voltage stress, small size, and high gain. Nevertheless, the requirements are not met by traditional two-level, three-level, or cascaded boost converters. In this work, a novel non-isolated DC-DC converter with switched capacitor and switched inducer is proposed. The proposed non-isolated DC-DC converter exhibits a common ground structure, ensuring high gain, a broad input voltage range, and minimal voltage stresses across components. The comprehensive study includes an analysis of component parameters, the elucidation of the working principle, and thorough comparisons with other high-gain converters. To establish a dynamic model, the small-signal modeling approach and state-space averaging method are employed. Experimental and simulation data affirm that the suggested structure performs as intended. The experimental prototype operates within an input voltage range of 25V to 80V, featuring a rated output voltage of 200V and a rated power of 100W. The converter achieves its most efficient state at 93.1%, an aspect that may be underappreciated. Importantly, the recommended converter is deemed suitable for fuel cell vehicles, offering a promising solution to address their unique requirements.**

Keywords— **Fuel cell vehicles, DC-DC converter, switched capacitor and switched- inductor, high-gain, low voltage stress.**

I. INTRODUCTION

The growth of the transportation sector is essential to the country's economy. On the other hand, as the number of fuel-powered vehicles rises, so does the amount of oil used and the pollution it contributes to the environment. As a result, all nations focus on renewable energy sources [1], [2]. The emergence of the new energy vehicle sector offers fresh approaches to these issues. Because of their advantages—zero emissions, zero pollution, and high efficiency—fuel cell vehicles have emerged as one of the new energy vehicle industry's most promising development directions [3], [4]. Meeting the DC bus voltage requirement in front of the inverter is challenging due to the fuel cell's low output voltage. Additionally, the fuel cell exhibits a "soft" output voltage characteristic, meaning that as the output current increases, the output voltage declines too quickly [5, 6]. Designing DC-DC converters for fuel cell vehicles necessitates meeting specific criteria, including a broad input voltage range, compact size, and high gain to maintain DC bus voltage stability and elevate fuel cell voltage. While adjusting the transformer turns ratio is a straightforward method to achieve high gain, challenges arise due to leakage inductance. This phenomenon can lead to issues such as the generation of peak voltages, risking device breakdown, potential electromagnetic interference problems, and reduced converter efficiency. Addressing these challenges requires careful consideration of transformer design, incorporating advanced techniques and optimizations to ensure the reliability and efficiency of the DC-DC converter in the context of fuel cell vehicle applications. Furthermore, the isolated converter's transformer adds to its overall bulk. Fuel cell cars are better suited for the non-isolated DC-DC converter due to its size, affordability, and efficiency. Due to its straightforward construction and limited number of components, the classic boost DC-DC converter is still in use in a wide range of applications. The boost converter's theoretical voltage gain is $1/(1-d)$, where d is the power switch driving voltage duty cycle. Nevertheless, the parasitic characteristics of the actual circuit and its constituent parts limit the voltage gain. Due to the high voltage pressures across the circuit's components, costlier high-voltage components are required, which raises the component's size and cost. Furthermore, in order to achieve high gain, a typical boost converter has an excessive duty cycle that substantially impairs diode reverse recovery and raises losses. Fuel cell vehicles are not a good fit for conventional boost converters because of these drawbacks. The cascaded boost converter, while capable of achieving high gain and a wide input voltage range, comes at the expense of overall power density and efficiency. The voltage stresses across components are notably high, and the circuit structures exhibit complexity. On the other hand, the boost three-level DC-DC converter, while reducing voltage stresses across components, maintains a relatively low voltage gain compared to the conventional boost converter.

In an effort to strike a balance between reduced voltage stresses and achieving high gain, a converter design outlined has made strides by significantly decreasing voltage stresses across components. This allows for a theoretical voltage gain of (1+d)/(1−d), slightly surpassing that of the conventional boost converter. Despite these advancements, the achieved voltage gains in [7] fall short of meeting the demands of fuel cell vehicles. Attempts to overcome this challenge have explored the implementation of Z-source and quasi-Z-source networks in the DC-DC converter to achieve high gain. However, despite these innovative approaches, the voltage stresses on components in the converter persistently remain high, presenting an ongoing obstacle in achieving the desired balance of high gain, efficiency, and reduced voltage stresses for fuel cell vehicles. One proposed solution involves arranging three Z-source networks in series to create a converter with low stress, high gain, and a wide input voltage range. However, this configuration results in an excessive number of inductors and power semiconductors, leading to an increase in the converter's size and cost. While the suggested converters demonstrate the capability to achieve low voltage stress and high gain, each faces the challenge of having different ground structures for their input and output ports. During the converter's operation, a high-frequency pulsated voltage exists between the input and output ports, introducing significant challenges related to electromagnetic interference (EMI). The primary issue revolves around voltage feedback in non-common ground structures. To mitigate this, an isolated voltage feedback approach, such as using a linear optocoupler, is recommended. However, it's crucial to acknowledge that this choice may elevate the complexity of the sampling circuit. Considering alternative solutions, multi-level converters, as proposed elsewhere, exhibit the capability to achieve high gain while maintaining low voltage stresses across components. However, drawbacks include an increased count of power semiconductors, leading to higher costs and a larger physical footprint. Moreover, the incorporation of multiple power switches introduces complexity to both the drive circuit and control strategy.The rest of the paper is organized as follows. Proposed embedding and extraction algorithms are explained in section II. Experimental results are presented in section III. Concluding remarks are given in section IV.

II. LITERATURE SURVEY

In recent decades, fuel cells (FCs) have garnered significant attention in the automotive industry for their ease of use, modular structure, and high efficiency. The increasing prominence of fuel cell (FC)-driven electric vehicles (EVs) as a promising alternative to traditional vehicles is widely acknowledged. This paper undertakes a detailed exploration of the topological classification of FC-based hybrid electric vehicles (FCHEVs). Within the realm of FCHEVs, the DC-DC power converter unit emerges as a pivotal component. The integration of FCs with other power sources often demands the incorporation of multiple converter units, introducing complexity into the system. To address this complexity, the paper advocates for the use of a multi-input DC-DC power converter. This converter allows for the connection of more than one energy source, streamlining the system architecture and elevating overall efficiency. The survey meticulously reviews numerous articles, offering a comprehensive assessment of both current and prospective scenarios for FC-based power source topologies and multi-input DC-DC power converter topologies employed in hybrid electric vehicles (HEVs). This survey contributes valuable insights into the evolving landscape of FC-based hybrid electric vehicles, emphasizing the importance of efficient and simplified power converter solutions in advancing the adoption of fuel cell technology in the automotive sector. It serves as a valuable resource for researchers and engineers in this field [1].

A cutting-edge current-fed full bridge high gain isolated DC-DC converter has been innovatively developed for fuel cell applications. This converter incorporates voltage multiplier cells on the secondary side and is specifically designed to generate a DC link voltage for a three-phase grid sourced from a fuel cell. Notably, the current-fed design effectively mitigates input current ripple at the fuel cell input. One key feature is the utilization of energy stored in transformer leakage and parasitic capacitance, allowing the converter to achieve zero-current-switching (ZCS) across a broad operating range. This soft-switching capability facilitates higher switching frequencies, leading to a reduction in the size, weight, and cost of magnetic components, all while enhancing overall converter efficiency. The accompanying paper introduces a unique design method for a half-wave Cockcroft-Walton Voltage Multiplier (H-W C-W VM). This design optimally determines the number of stages required to attain the desired output voltage with minimal total capacitance, contributing to the converter's efficiency and performance. The converter operates at a frequency of 100kHz, and the paper includes a thorough analysis, simulation, and experimental results for the proposed design. The hardware model, operating at an input voltage of 30V and input current of 5 Amps, yields an output of 40V from the inverter and 240V at 0.6 Amps from the three-stage voltage multiplier [2].

Over the past few decades, fuel cells (FCs) have captured significant attention in the automotive sector due to their user-friendly nature, modular design, and superior efficiency. As we look to the future, technological advancements signal a rapid growth in fuel cell (FC)-driven electric vehicles (EVs), positioning them as a compelling alternative to traditional automobiles. This paper delves into a thorough examination of the topological classification of FC-based hybrid electric vehicles (FCHEVs). A critical focal point within these FCHEVs is the DC-DC power converter unit. The integration of FCs with other power sources often necessitates the use of multiple converter units, introducing potential complexity into the system. This survey meticulously examines a wealth of articles and provides an evaluation of the current and future scenarios regarding FC-based power source topologies and multi-input DC-DC power converter topologies used in hybrid electric vehicles (HEVs). It serves as an invaluable resource for researchers and engineers immersed in this field [3].

The electric vehicle (EV) industry faces several challenges, and one of them is sourcing sufficient power from alternative energy systems. Fuel cells offer high-performance energy sources, but they provide relatively low output voltage, which is inadequate for driving EV motors. In addressing the critical challenge of increasing the voltage output of fuel cell systems and aligning them with the demands of the entire electric vehicle (EV) system, DC-DC converters play a pivotal role. A single-input three-output (SITO) DC-DC unidirectional converter emerges as a promising solution, offering the potential to significantly decrease losses and system costs while concurrently enhancing overall efficiency. This paper introduces an innovative single power-switch-based SITO converter topology designed explicitly to improve voltage gain and conversion efficiency. This converter assumes the role of the front-end DC-DC converter for the DC-AC inverter, supplying power to auxiliary DC loads and charging the auxiliary battery in the EV. A distinctive feature of this converter is the incorporation of a single-stage voltage multiplier cell with a voltage clamp circuit. This design choice aims to elevate voltage gain and achieve soft-switching, thereby reducing losses and optimizing overall efficiency. [4].

In recent years, fuel cells have garnered increasing interest as a clean and sustainable energy source. Fuel cells, which generate electricity directly from hydrogen and oxygen, offer a promising alternative for a range of applications, including fuel cell vehicles. However, a significant challenge in these applications is the disparity between the relatively low output voltage of fuel cell sources and the higher voltage required by the vehicle's DC bus, especially when faced with varying loads. This report introduces a modified DC-DC converter tailored for fuel cell vehicles, with a primary focus on achieving a high voltage gain capability. Unlike conventional topologies, the proposed configuration boasts a unique ability to provide increased voltage gain with minimal duty ratio, reducing voltage stress on power switches and capacitors while minimizing electromagnetic interference. This innovation enables the selection of semiconductor switches with lower ON-state resistance and voltage ratings, enhancing equipment reliability, efficiency, and cost-effectiveness. The report also provides a step-by-step design procedure for each passive element (capacitors and inductors), simplifies the circuit's complexity with only two operational modes, and employs state-space averaging and small-signal modeling to derive the converter's dynamic model. Extensive validation of the proposed DC-DC converter's operational performance and detailed stability margins is conducted through MATLAB®/Simulink TM simulations and frequency response analysis. The results demonstrate the superior capabilities of the proposed converter, particularly in terms of high voltage capacity and a reduced number of components and passive elements when compared to benchmark DC-DC converter topologies [5].

Fuel cells have emerged as a highly promising green power source for microgrid systems, attracting significant attention in recent years. However, the quality of a fuel cell's voltage output is significantly influenced by operating conditions and integrated components, necessitating energy management techniques to regulate power in microgrid applications. Uncontrolled fuel cell energy injection, especially in high-power and medium-voltage systems, can result in problems like excessive energy demand, overloading, and power losses. While fuel cells offer many advantages, they often fall short in producing high voltages independently to meet microgrid demands. As a result, including a DC-DC converter becomes crucial. This study presents a new high-voltage gain converter for microgrid power management that is integrated with a 1.26 kW fuel cell and has the capacity to increase the fuel cell's voltage by up to 20 times. This substantial voltage gain also leads to a significant reduction in voltage and current ripple from the fuel cell. The analysis demonstrates that the proposed converter outperforms other converters, primarily due to its high voltage gain and remarkably low voltage ripple. As a result, the microgrid's current exhibits a reduced total harmonic distortion (THD) of 3.22% and minimal voltage ripple of 4V. To validate the converter's performance, a hardware prototype is built alongside extensive simulations. Voltage regulation of the fuel cell is achieved using a simplified proportional-integral controller. The research not only outlines the operating principles of the converter-integrated fuel cell but also showcases its application in microgrid power management. A comparative analysis demonstrates the significant performance improvements offered by the proposed converter when compared to other available options [6].

III . TECHNOLOGY USED

- Switched-Capacitor and Switched-Inductor Design: The core technology used in this converter is the switched-capacitor and switched-inductor topology. This approach involves the use of capacitors and inductors that are switched on and off in specific configurations to achieve the desired voltage conversion.
- Non-Isolated Design: Without a transformer to separate the input and output electrically, the converter is non-isolated. For automotive applications, non-isolated converters typically have an advantage in terms of size and weight.

IV. METHODOLOGY USED

- Operating Principle: The paper would describe in detail how the switched-capacitor and switched-inductor design operates. This likely involves the configuration of these components to achieve voltage multiplication and regulation.
- Component Parameters Design: The methodology would involve the design and selection of specific components such as capacitors and inductors, taking into consideration

their values, switching frequencies, and other electrical parameters.

- State-Space Averaging Method: Using this technique, a mathematical model of the converter's average behavior is produced. It simplifies the analysis of the converter's operation.
- Small-Signal Modeling Method: This technique is used to develop a linearized model that characterizes the converter's small-signal response, which is crucial for control design and stability analysis.

V. ALGORITHM

- While the paper doesn't explicitly mention a specific algorithm, the development of the DC-DC converter would likely involve the following steps:
- Topology Design: The design of the converter topology, including the arrangement of switched capacitors and inductors, and the control strategy.
- Component Selection: Determining the values and characteristics of the capacitors and inductors to meet the converter's requirements.
- Control Algorithm: Developing the control algorithm that governs the switching of these components. This algorithm ensures that the converter operates efficiently and effectively.
- State-Space Averaging: This technique is used to create a model that roughly represents the behavior of the converter in various operating scenarios.
- Small-Signal Model: To assess the dynamic behavior of the converter and develop control strategies, a linearized small-signal model must be created.
- Simulation and Experimental Validation: Testing the converter through simulation and experimentation to verify its performance and efficiency.

VI.CONCLUSION

We've talked about the development of fuel cell technology and its many benefits, such as high efficiency, low emissions, and adaptability. Since they provide a clean and effective replacement for internal combustion engines, fuel cells have grown in popularity as a solution for the automotive sector, which is ready to see a transportation revolution. Furthermore, in the context of microgrid systems, fuel cells are emerging as a promising power source, contributing to enhanced power quality and reliability. This evaluation has addressed a number of issues, including the requirement for DC-DC converters in order to adjust fuel cell output voltage to suit various application requirements. The proposed converter topologies discussed in these papers have shown remarkable improvements in voltage gain, efficiency, and reduction of electromagnetic interference, making fuel cells even more viable for integration into microgrids and electric vehicles. The developments presented in these papers indicate that fuel cells are not only a clean and sustainable power source but are also becoming increasingly practical and versatile in real-world applications. The ongoing research in this field promises a more sustainable and eco-friendly future, and it will be fascinating to witness how these advances continue to evolve and shape our world.

REFERENCE

[1] Shahid Beheshti University, Karaj Islamic Azad University, "An Innovative Step-up DC-DC Converter for Fuel Cell-based Power Source to Decrease Current Ripple and Increase Voltage Gain with Low Stress and Switch Counts", https://doi.org/10.21203/rs.3.rs-336166/v1.

[2] Siddhartha Nigam, D. Elangovan, R. Saravanakumar, "DESIGN AND IMPLEMENTATION OF SOFT SWITCHED HIGH GAIN CURRENT FED FULL BRIDGE DC-DC CONVERTER FOR FUEL CELL APPLICATIONS", Academic research paper on "Electrical engineering, electronic engineering, information engineering".

[3] Pawan Kumar Pathak, Anil Kumar Yadav, Sanjeevikumar Padmanaban, P. A. Alvi, Innocent Kamwa, "Fuel cell-based topologies and multi-input DC–DC power converters for hybrid electric vehicles: A comprehensive review", 04 March 2022 https://doi.org/10.1049/gtd2.12439.

[4] P. Ravi Kumar & C. Gowri Shankar, "High-performance single-input three-output DC–DC high gain converter for fuel cell-based electric vehicles", Electr Eng 102, 1715–1737 (2020). https://doi.org/10.1007/s00202-020-00990-z.

[5] Ch. Sai Krishna Reddy, Dr. M. GopiChand Naik, "Modelling and Simulation of Novel High Gain DCDC Converter Applied For Fuel cell Vehicles" © 2022 JETIR September 2022, Volume 9, Issue 9 www.jetir.org (ISSN-2349-5162).

[6] Farhan Mumtaz 1ORCID,Nor Zaihar Yahaya 1,Sheikh Tanzim Meraj 1ORCID,Narinderjit Singh Sawaran Singh, "A High Voltage Gain Interleaved DC-DC Converter Integrated Fuel Cell for Power Quality Enhancement of Microgrid", Sustainability 2023, 15(9), 7157; https://doi.org/10.3390/su15097157.

[7] Jayachandran Divya Navamani , Sathik Jagabar , Padhi Tanmay , Kumari Aditi, "A Comprehensive Review of the Quadratic High Gain DC-DC Converter for Fuel Cell Application" International Journal of Electronics and Telecommunications DOI 10.24425/ijet.2022.139882 2022, Vol. 68, No. 2 page No.299—306.