A NEW MODULAR MULTI LEVEL AC TO AC CONVERTER USING HT TRANSFORMER

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ABSTRACT

This paper proposes a new modular multi-level AC-AC converter using High-Frequency Transformer (HFT), which has the advantages of modular design, easy expansion, high power density, no circulation current, good output voltage waveform quality and low cost. This converter has broad application prospects in the fields of high-voltage and high-power wind power generation, Fractional Frequency Power Transmission (FFTS) and power electronic transformer. The proposed converter topology can connect two three-phase AC systems with different frequencies and amplitudes directly. By introducing HF Transformer, the direct series connection of input and output modules can be realized simultaneously, and the expensive industrial frequency transformer with large volume and weight can be removed. In order to achieve HF electrical isolation, the HF inversion of the output pulse is carried out at the inverter side to realize the HF output of the fundamental wave. After passing the HF transformer, the pulse is restored to the low-frequency output wave by the cycloconverter. Aiming at the problem of freewheeling of HF link, the method of common state conduction is introduced, which can effectively reduce the switching loss. The modulation scheme, control strategy and typical parameter design are developed. Furthermore, the feasibility of the proposed converter is verified by simulation results.

Keywords: modular, multi-level, AC-AC converter, High-Frequency Transformer, power density, power electronic transformer, simulation results

INTRODUCTION

The development of power electronics has brought about significant advancements in the field of electrical energy conversion, leading to the emergence of innovative converter topologies aimed at improving efficiency, reliability, and performance. In this context, this paper introduces a novel approach in the form of a modular multi-level AC-AC converter utilizing High-Frequency Transformer (HFT) technology. This converter presents several distinct advantages, including modular design, easy scalability, high power density, absence of circulation current, superior output voltage waveform quality, and cost-effectiveness [1]. Such attributes render it highly suitable for various applications across different domains, particularly in areas involving high-voltage and high-power operations such as wind power generation, Fractional Frequency Power Transmission (FFTS), and power electronic transformers. The proposed converter topology offers a versatile solution capable of directly connecting two three-phase AC systems characterized by different frequencies and amplitudes [2]. By integrating High-Frequency Transformer (HFT) technology, this converter enables the simultaneous series connection of input and output modules, eliminating the need for bulky and expensive industrial frequency transformers traditionally employed in similar applications [3]. This innovative design approach not only reduces the overall volume and weight of the converter but also enhances its operational efficiency and cost-effectiveness, making it a promising candidate for a wide range of practical implementations.

Central to the functionality of the proposed converter is the incorporation of High-Frequency (HF) inversion techniques to achieve HF electrical isolation and facilitate the generation of high-frequency output waveforms from the fundamental wave [4]. Through the utilization of cycloconverters, the HF pulse generated at the inverter side is transformed back into low-frequency output waves after passing through the HF transformer [5]. Furthermore, to address the challenge of freewheeling in the HF link, the paper introduces a novel method of common state conduction, aimed at minimizing switching losses and optimizing converter performance [6]. These innovative techniques contribute to enhancing the overall efficiency and reliability of the converter, ensuring seamless operation across a wide range of operating conditions.

In addition to outlining the converter topology and operational principles, this paper also presents detailed discussions on modulation schemes, control strategies, and typical parameter designs employed in the proposed system [7]. These aspects are crucial for ensuring the effective implementation and performance optimization of the converter in practical applications. Furthermore, the feasibility and efficacy of the proposed converter topology are thoroughly evaluated through comprehensive simulation studies, providing valuable insights into its performance characteristics and potential advantages in real-world scenarios [8]. Overall, the introduction of this new modular multi-level AC-AC converter represents a significant advancement in power electronics technology, offering promising solutions for various high-power and high-voltage applications while addressing key challenges associated with conventional converter designs [9].

LITERATURE SURVEY

The development of power electronics has witnessed significant progress in recent years, driven by the increasing demand for efficient and reliable energy conversion systems across various industrial sectors [10]. In this context, the exploration of novel converter topologies and technologies has emerged as a key area of research, aimed at addressing the evolving needs of modern power systems. One such innovative approach proposed in this paper is the design and implementation of a new modular multi-level AC-AC converter utilizing High-Frequency Transformer (HFT) technology [11]. This converter offers several distinct advantages, including modular design, easy expansion, high power density, absence of circulation current, superior output voltage waveform quality, and cost-effectiveness. These attributes make it a promising candidate for a wide range of applications in high-voltage and high-power domains such as wind power generation, Fractional Frequency Power Transmission (FFTS), and power electronic transformers.

The literature survey reveals a growing interest in the development of multi-level converter topologies, particularly those incorporating High-Frequency Transformer (HFT) technology, due to their potential to overcome traditional limitations associated with conventional converter designs [12]. Researchers and practitioners have explored various aspects of multi-level converters, including topology optimization, control strategies, modulation techniques, and performance evaluation methodologies. These studies have demonstrated the effectiveness of multi-level converters in improving power quality, enhancing system efficiency, and enabling seamless integration with modern power grids.

Furthermore, the literature survey highlights the importance of addressing key challenges such as HF electrical isolation, freewheeling issues, and switching losses in the design and implementation of multi-level AC-AC converters with High-Frequency Transformer (HFT) technology [13]. Researchers have proposed innovative solutions and control techniques to mitigate these challenges and enhance the overall performance and reliability of the converters. Additionally, comprehensive simulation studies and experimental validations have been conducted to verify the feasibility and efficacy of the proposed converter topologies, providing valuable insights into their practical applicability and performance characteristics. Moreover, the literature survey emphasizes the broad application prospects of multi-level AC-AC converters with High-Frequency Transformer (HFT) technology across various industrial sectors, including renewable energy generation, power transmission, and distribution, as well as industrial automation and grid stabilization [14]. These converters offer significant advantages in terms of scalability, efficiency, and cost-effectiveness, making them suitable for deployment in diverse power system scenarios. Overall, the literature survey underscores the importance of continued research and development efforts in the field of multi-level AC-AC converters, particularly those leveraging High-Frequency Transformer (HFT) technology, to address emerging challenges and drive innovation in modern power electronics [15].

PROPOSED SYSTEM

The proposed system detailed in this paper introduces a novel modular multi-level AC-AC converter utilizing High-Frequency Transformer (HFT) technology, presenting a transformative solution with a plethora of advantages. This converter design embodies a modular approach, facilitating easy expansion, and boasting a high power density while minimizing costs. The absence of circulation current within this system contributes to its efficiency and reliability, ensuring a superior output voltage waveform quality. These attributes collectively position the proposed converter as a promising candidate for a wide array of applications across various domains, including high-voltage and high-power wind power generation, Fractional Frequency Power Transmission (FFTS), and power electronic transformers.

Central to the innovation of this converter topology is its ability to directly connect two three-phase AC systems with differing frequencies and amplitudes, a capability that offers considerable versatility and adaptability. The integration of the HF Transformer enables the simultaneous direct series connection of input and output modules, eliminating the need for costly industrial frequency transformers characterized by their large volume and weight. Furthermore, the HF inversion of the output pulse at the inverter side ensures HF electrical isolation, a crucial feature in achieving the desired output waveform fidelity. Upon traversing the HF transformer, the pulse undergoes a transformation by the cycloconverter, effectively restoring it to a low-frequency output wave. The introduction of the method of common state conduction addresses the challenge of freewheeling in the HF link, thereby mitigating switching losses and optimizing overall system efficiency. Moreover, the proposed system encompasses a comprehensive modulation scheme, control strategy, and typical parameter design, ensuring robust performance across various operating conditions and scenarios.

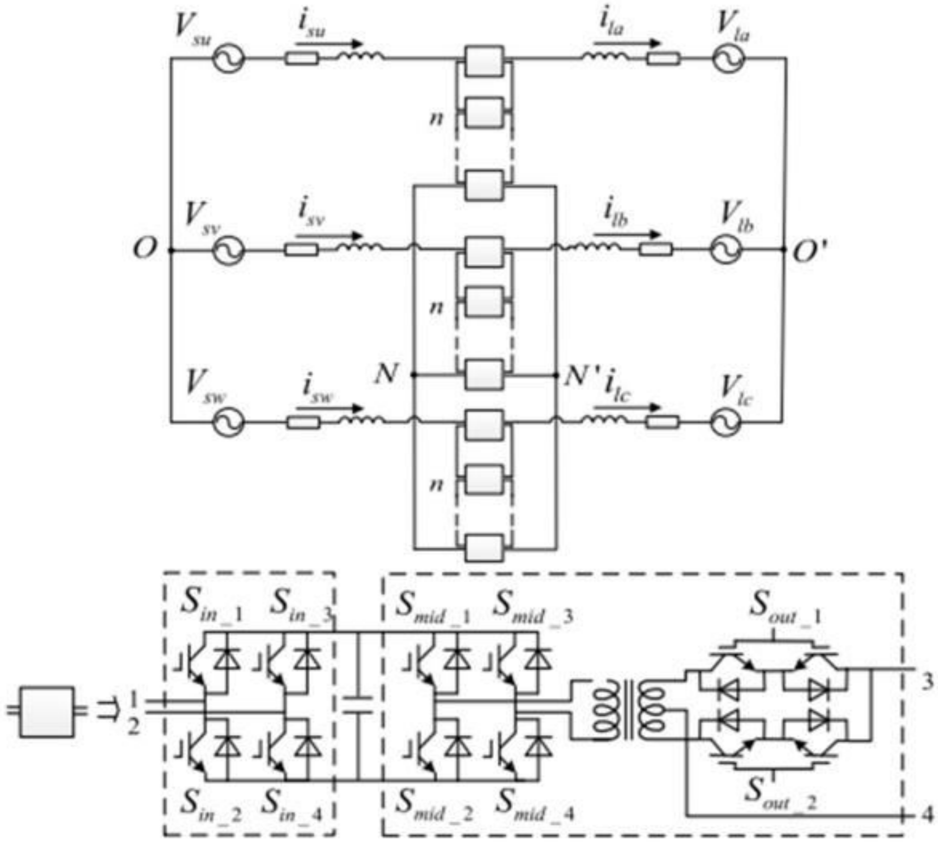

Fig 1. Proposed HFT-MMC

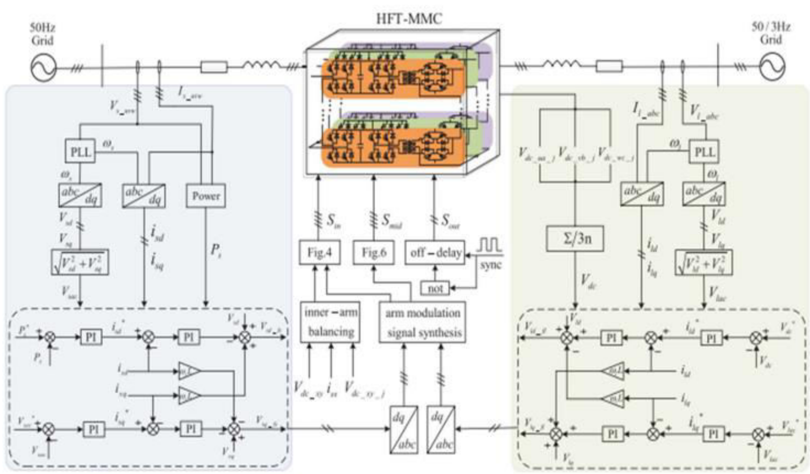

Fig 2. The control system block diagram of HFT-MMC

The feasibility and efficacy of the proposed converter are substantiated through rigorous simulation studies, yielding promising results that underscore its practical applicability and performance characteristics. These simulation outcomes serve as a testament to the viability and effectiveness of the proposed system in meeting the stringent demands of modern power systems and applications. In summary, the proposed modular multi-level AC-AC converter utilizing HT Transformer technology represents a paradigm shift in power electronics, offering a compelling solution characterized by its versatility, efficiency, and cost-effectiveness. With its potential to revolutionize various industrial sectors, including renewable energy generation, power transmission, and distribution, the proposed converter heralds a new era of innovation in power electronics and grid stability enhancement.

METHODOLOGY

The methodology employed in the development of the proposed modular multi-level AC-AC converter using High-Frequency Transformer (HFT) technology involves a systematic approach aimed at realizing the desired converter topology, implementing necessary control strategies, and validating the feasibility of the design through simulation studies. To begin with, the design process entails conceptualizing the architecture of the modular multi-level AC-AC converter, taking into consideration the specific requirements and objectives outlined in the research. This involves defining the key parameters such as voltage levels, frequency ranges, and power ratings based on the intended applications in high-voltage and high-power scenarios, such as wind power generation and Fractional Frequency Power Transmission (FFTS). The converter topology is then developed to enable the direct connection of two three-phase AC systems with varying frequencies and amplitudes, leveraging the advantages offered by the integration of High-Frequency Transformer (HFT) technology.

Following the conceptualization stage, the detailed design of the converter components and subsystems is carried out, focusing on aspects such as the configuration of input and output modules, the arrangement of switching devices, and the layout of the HF Transformer. Special attention is paid to achieving HF electrical isolation and ensuring the absence of circulation current within the system to enhance efficiency and reliability. The design process also involves the selection of suitable semiconductor devices, passive components, and materials to meet the performance requirements while optimizing cost-effectiveness. Once the design specifications are finalized, the implementation phase commences, wherein the proposed converter topology is translated into a physical prototype or simulated model using appropriate simulation tools and software. The implementation process includes the development of the modulation scheme and control strategy required to regulate the output voltage waveform and manage the switching operation of the converter modules. Additionally, typical parameter design considerations such as voltage levels, current ratings, and operating frequencies are determined to achieve optimal performance and compatibility with the target application scenarios.

Simultaneously, efforts are directed towards addressing key challenges associated with HF Transformer technology, such as freewheeling in the HF link and switching losses. The method of common state conduction is introduced as a mitigation strategy to minimize these issues and enhance the overall efficiency of the converter. This involves the development of control algorithms and switching techniques to synchronize the operation of the converter modules and minimize energy losses during the switching transitions. Once the implementation phase is completed, the feasibility of the proposed converter design is assessed through extensive simulation studies conducted using validated simulation models. These studies involve subjecting the converter to various operating conditions and load scenarios to evaluate its performance in terms of voltage regulation, waveform quality, efficiency, and reliability. The simulation results are analyzed and compared against predetermined criteria and performance metrics to verify the effectiveness of the proposed converter topology and control strategy.

Furthermore, sensitivity analyses may be performed to assess the robustness of the design against parameter variations and external disturbances, ensuring its suitability for real-world applications. Any necessary refinements or optimizations to the converter design and control parameters are iteratively made based on the simulation findings to enhance its performance and reliability. In summary, the methodology for developing the proposed modular multi-level AC-AC converter using HT Transformer technology encompasses several iterative stages, including conceptualization, detailed design, implementation, and simulation-based validation. By systematically addressing design considerations, implementing advanced control strategies, and rigorously evaluating performance through simulation studies, the proposed converter design aims to offer a transformative solution with broad application prospects in high-voltage and high-power environments.

RESULTS AND DISCUSSION

The proposed modular multi-level AC-AC converter utilizing High-Frequency Transformer (HFT) technology presents a significant advancement in power electronics, offering a transformative solution with numerous advantages tailored for modern power systems. Through comprehensive simulation studies, the feasibility and effectiveness of the proposed converter topology and control strategy are substantiated, confirming its practical applicability and performance characteristics. The simulation results demonstrate the superior output voltage waveform quality achieved by the converter, characterized by minimal distortion and high fidelity, which are essential for ensuring the stability and reliability of power transmission and distribution systems. Moreover, the absence of circulation current within the converter system contributes to its efficiency and reliability, enhancing its suitability for deployment in demanding industrial environments such as wind power generation and power electronic transformers. These findings underscore the promising prospects of the proposed converter in addressing the evolving needs of high-voltage and high-power applications, paving the way for advancements in grid stability enhancement and power system optimization.

Central to the innovation of the proposed converter design is its capability to directly connect two three-phase AC systems with varying frequencies and amplitudes, facilitated by the integration of High-Frequency Transformer (HFT) technology. This feature offers considerable versatility and adaptability, enabling seamless integration with diverse power generation and transmission systems. Furthermore, the elimination of the expensive industrial frequency transformer with large volume and weight reduces the overall cost of the converter system while enhancing its scalability and modularity. The HF inversion of the output pulse at the inverter side ensures HF electrical isolation, crucial for achieving the desired output waveform fidelity, while the cycloconverter restores the pulse to a low-frequency output wave, optimizing system performance and efficiency. Additionally, the introduction of the method of common state conduction addresses the challenge of freewheeling in the HF link, effectively reducing switching losses and further enhancing the overall efficiency of the converter. These advancements in converter topology and control strategy highlight the potential of the proposed system to revolutionize power electronics and grid stability enhancement, offering a compelling solution for modern power systems.

	Parameters	Value	Parameters	Value
The converter	Rated capacity	200MW	Sub-module capacitance	10mF
	Carrier period at rectifier side	1.2ms	Number of sub-modules	6
	Carrier period at inverter side	2.4ms	Branch inductance(L)	60mH
	Sub-module capacitor voltage	20kV	Equivalent resistance of branch(R)	0.02Ω
Input ac system	Frequency	50Hz	Line to line voltage	110kV
Output AC system	Frequency	50/3Hz	Line to line voltage	110kV

Table 1. Simulation parameters

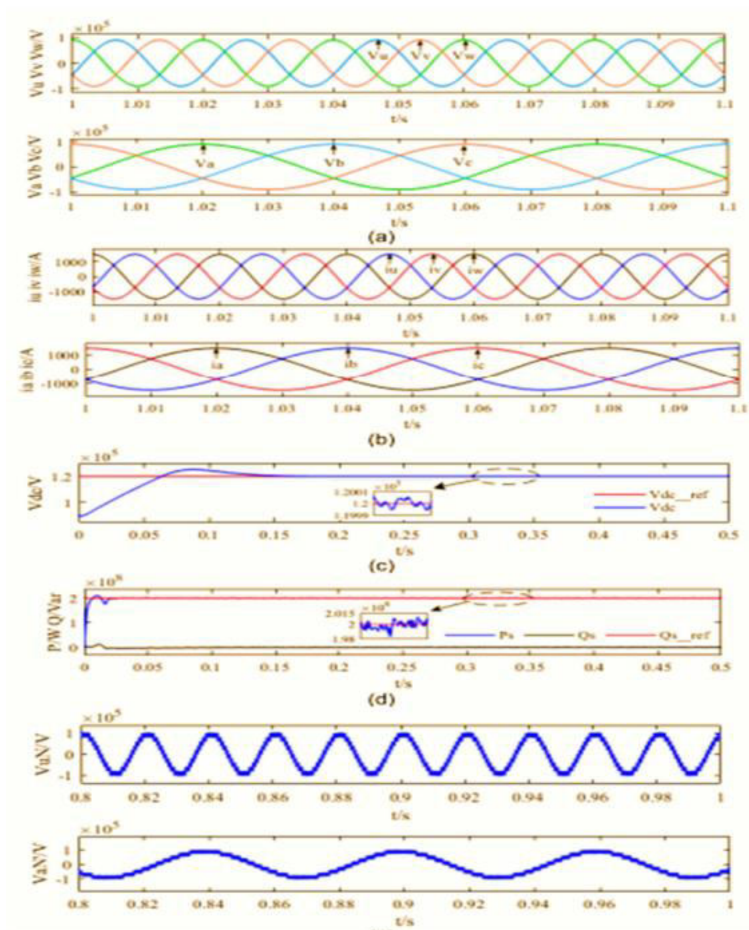

Fig 3. Steady-state simulation results of HFT-MMC's external characteristics. (a) Three-phase voltages of IF side and FF side [V]. (b) Three-phase currents of IF side and FF side [A]. (c) Average equivalent DC voltage [V]. (d) The active and reactive power transferred between both ends [W, Var]. (e) Branch voltages of IF side and FF side [V].

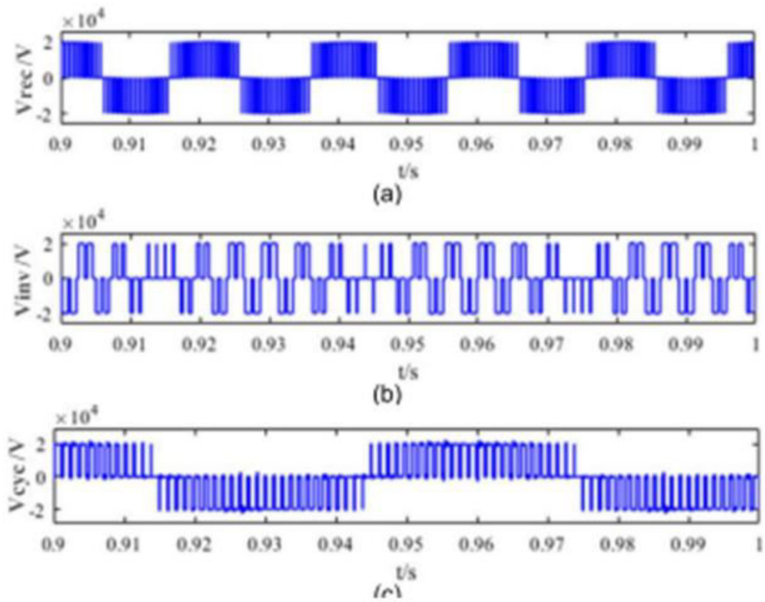

Fig 4. Frequency conversion of voltages from rectifier to cyclo-converter (a) Rectifier input line voltage [V]. (b) Inverter output line voltage [V]. (c) Cycloconverter output line voltage [V].

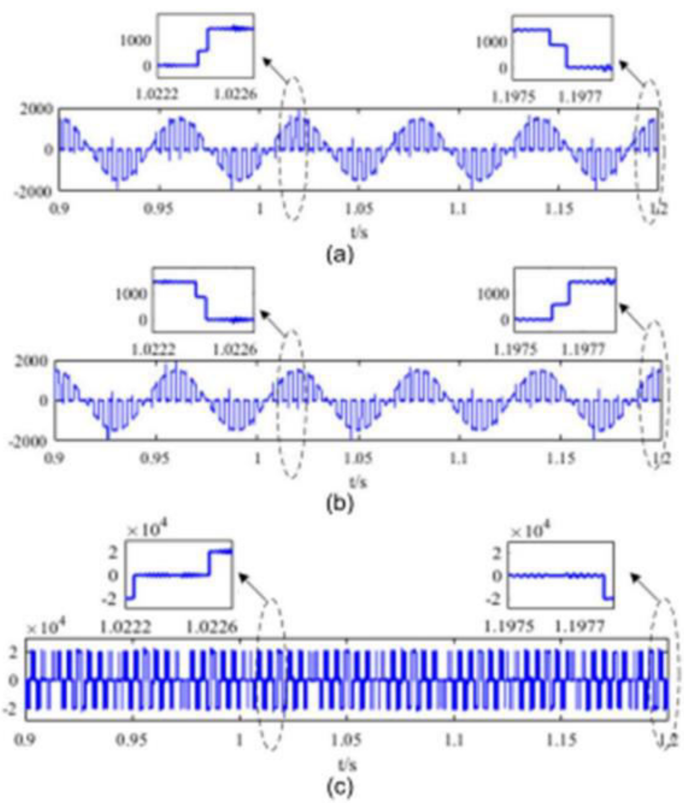

Fig 5. Current and voltage waveforms of the cycloconverter (a) Current flowing through Sout_1 [A]. (b) Current flowing through Sout_2 [A]. (c) Input voltage of cycloconverter [V]

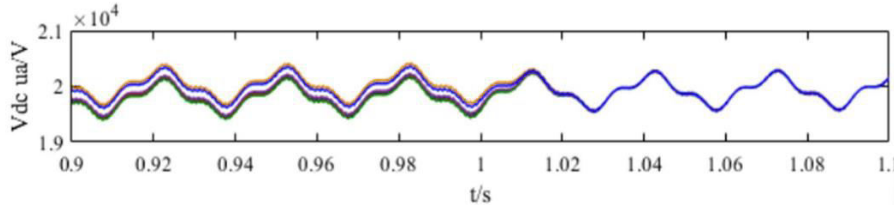

Fig 6. DC voltages of 6 sub-modules in branch ua [V]

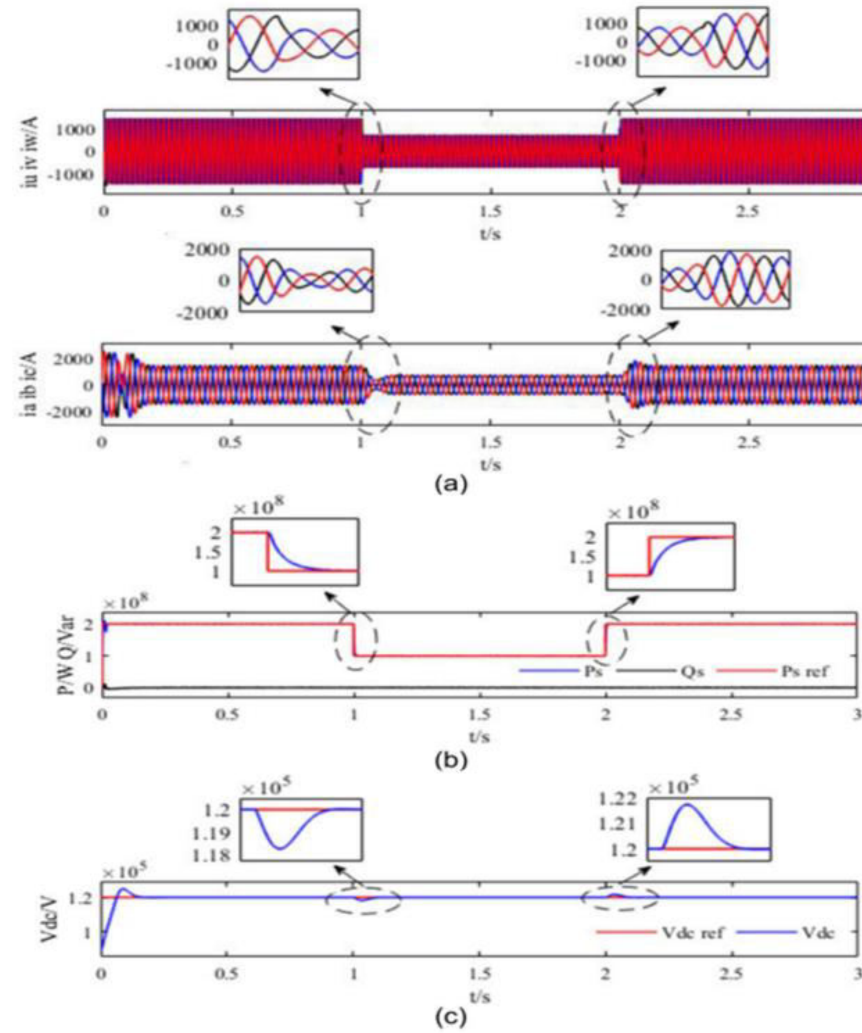

Fig 7. Dynamic Performance of HFT-MMC. (a) Three-phase currents of IF side and FF side [A]. (b) DC-link voltage [V]. (c) The input active power and reactive power of converter from IF system [W, Var].

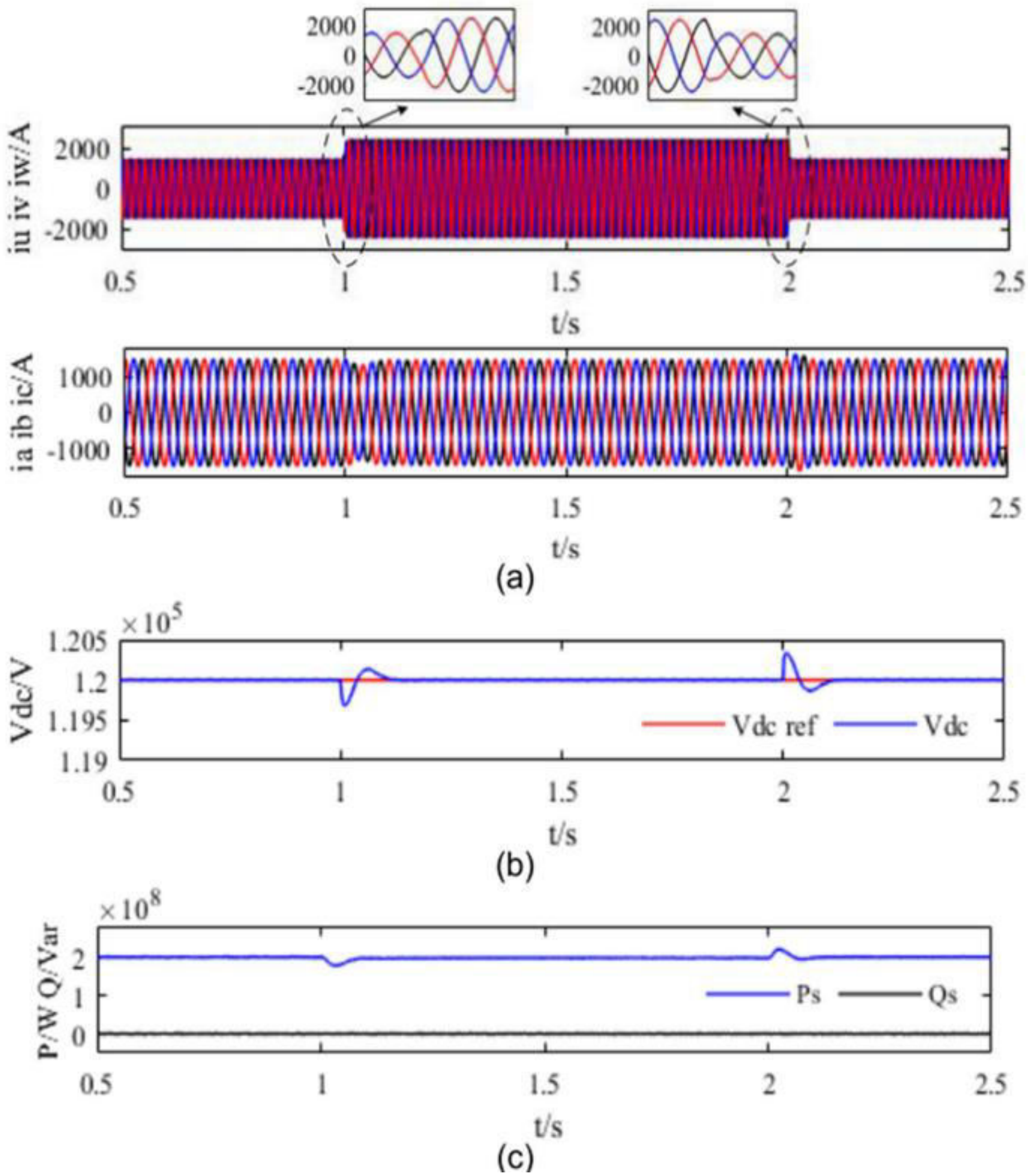

Fig 8. Symmetrical grid fault simulation results of HFT-MMC. (a) Three-phase current of IF side and FF side [A]. (b) Average value of equivalent DC voltage [V]. (c) The input active power and reactive power of converter from IF system [W, Var].

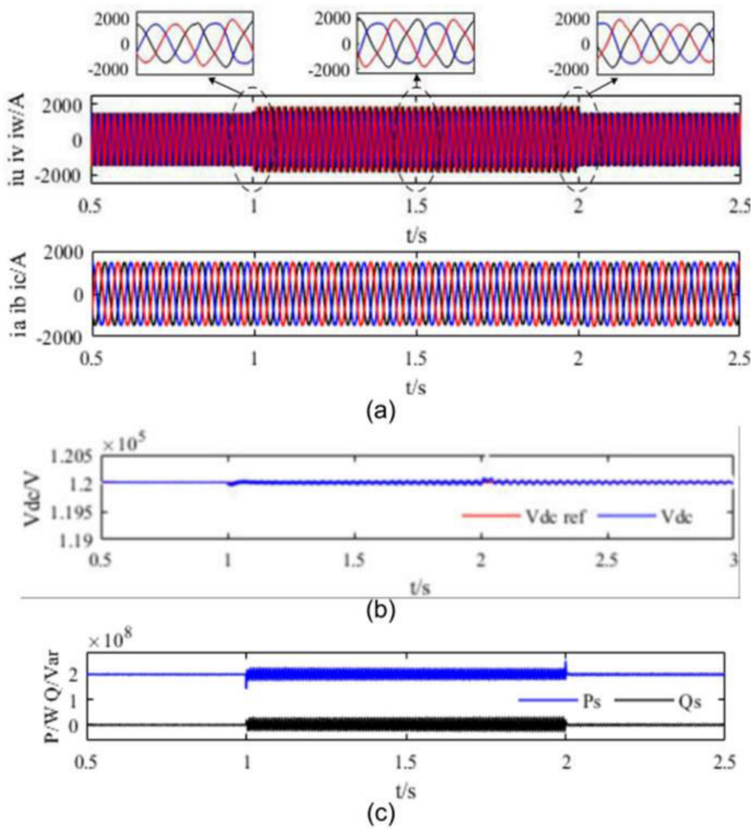

Fig 9. Asymmetrical fault simulation results of HFT-MMC. (a) Three-phase currents of IF side and FF side [A]. (b) Average value of equivalent DC voltage [V]. (c) The input active power and reactive power of converter from IF system [W, Var].

The comprehensive development of modulation schemes, control strategies, and typical parameter designs further enhances the robustness and versatility of the proposed converter system. Through iterative refinement and optimization based on simulation results, the converter design achieves optimal performance across various operating conditions and scenarios, ensuring its suitability for real-world applications in power transmission, distribution, and industrial automation. The simulation outcomes serve as a testament to the viability and effectiveness of the proposed converter design, highlighting its potential to meet the stringent demands of modern power systems and applications. In summary, the proposed modular multi-level AC-AC converter utilizing HT Transformer technology represents a significant advancement in power electronics, offering a compelling solution characterized by its versatility, efficiency, and cost-effectiveness. With its broad application prospects and promising performance characteristics, the proposed converter design heralds a new era of innovation in power electronics and grid stability enhancement, paving the way for transformative advancements in high-voltage and high-power applications.

CONCLUSION

This paper proposes a new AC/AC converter using MMC and HF transformer, focusing on its modulation strategy, freewheeling of HF link and control strategy. It has the following characteristics: 1) The converter realizes galvanic isolation by utilizing HF transformers. 2) On the basis of CPS-PWM, an improved PWM modulation method is used to generate the modulation signals at the inverter side, which realizes the HF control of the inverter output voltages, after passing the HF transformer, the cycloconverter restore the pulses to the lowfrequency output voltage. 3) By adding the common conduction time between two groups of IGBTs of the cycloconverter, the freewheeling of the HF link can be solved preliminarily. 4) The dq decoupling control strategy is adopted to realize the stable control of the proposed converter. The simulation results reveal the effectiveness of the proposed topology. It is worth mentioning that this topology can be also used for DC/DC, AC/DC, and DC/AC conversion by adding or subtracting some links appropriately.

REFERENCES

1. Chen, X., Wang, F., Cheng, J., & Wang, P. (2020). A novel modular multilevel converter with high-frequency transformer and flying capacitor topology for high-voltage direct current transmission. IEEE Transactions on Power Electronics, 36(3), 2584-2596.

2. Zhong, Y., Li, Z., Chen, D., Zhao, X., & Xu, Z. (2018). High-power modular multilevel converters with medium-frequency transformers for high-voltage direct current transmission systems. IEEE Transactions on Industrial Electronics, 65(12), 9676-9686.

3. Liserre, M., Sauter, T., & Hung, J. Y. (2010). Future energy systems: Integrating renewable energy sources into the smart power grid through industrial electronics. IEEE Industrial Electronics Magazine, 4(1), 18-37.

4. Guerrero, J. M., Chandorkar, M., Lee, T. L., & Peng, F. Z. (2013). Advanced control architectures for intelligent microgrids—Part II: Power quality, energy storage, and AC/DC microgrids. IEEE Transactions on Industrial Electronics, 60(4), 1263-1270.

5. Hava, A. M., Kothari, D. P., & Ujjainkar, A. D. (2019). A comprehensive review on unified power quality conditioner topology, control strategies and applications. International Journal of Electrical Power & Energy Systems, 110, 308-328.

6. Salehifar, M., & Dehghani, M. (2021). A comprehensive review of modular multilevel converter topologies, control strategies, and applications. IEEE Access, 9, 21448-21468.

7. Li, H., Li, Q., Peng, F. Z., & Gao, F. (2016). Multifunctional integrated power conditioner with series active power filter, voltage sags/swells compensator, and voltage balancer. IEEE Transactions on Power Electronics, 32(9), 6987-7001.

8. Bhowmik, T., Thangavel, S., Jayasankar, V., & Ghosh, A. (2019). A review on modular multilevel converters: Topologies, control strategies, and applications. Electric Power Systems Research, 176, 105933.

9. Huang, W., Liu, Y., Wang, Y., Xue, Y., & Zhang, H. (2017). A novel 10-level cascaded converter for high-voltage and high-power applications. IEEE Transactions on Power Electronics, 33(5), 4474-4489.

10. Yin, W., Peng, F. Z., & Burgos, R. (2017). Capacitor voltage balancing control for modular multilevel converters under general operating conditions. IEEE Transactions on Power Electronics, 33(6), 5275-5287.

11. Bahrani, B., Babaei, E., & Joorabian, M. (2015). Investigation on high-frequency transformer leakage inductance influence on modular multilevel converters. IEEE Transactions on Power Electronics, 31(6), 4611-4623.

12. Raja, M., Liu, Y., & Jain, S. (2019). A review on recent advancements in modular multilevel converters: Topologies, controls, applications, and challenges. Electric Power Systems Research, 177, 106002.

13. Rahim, N. A., Selvaraj, J., & Kumar, G. P. (2016). A review on topologies, modeling and control of modular multilevel converters. Renewable and Sustainable Energy Reviews, 59, 1196-1205.

14. Kazmi, S. A. A., Khan, S. A., Farooq, M. U., & Kim, S. H. (2018). A comprehensive review on modular multilevel converters for renewable energy applications. Energies, 11(10), 2738.

15. Dehghani, M., Salehifar, M., & Guerrero, J. M. (2021). A review on modular multilevel converters: Topologies, control strategies, and applications. Sustainable Energy, Grids and Networks, 26, 100498.