ENERGY BASED SEVENT LEVEL INVERTER FORMED BY CASCADING FLYING CAPACITOR AND FLOTING CAPACITOR H-BRIDGE

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ABSTRACT

Multilevel inverter for generating 17 voltage levels using a three-level flying capacitor inverter and cascaded H-bridge modules with floating capacitors has been proposed. Various aspects of the proposed inverter like capacitor voltage balancing have been presented in the present paper. Experimental results are presented to study the performance of the proposed converter. The stability of the capacitor balancing algorithm has been verified both during transients and steady-state operation. All the capacitors in this circuit can be balanced instantaneously by using one of the pole voltage combinations. Another advantage of this topology is its ability to generate all the voltages from a single dc-link power supply which enables back-toback operation of converter. Also, the proposed inverter can be operated at all load power factors and modulation indices. Additional advantage is, if one of the H-bridges fail, the inverter can still be operated at full load with reduced number of levels. This configuration has very low dv/dt and common-mode voltage variation.

Keywords: multilevel inverter, voltage levels, flying capacitor, H-bridge modules, capacitor balancing, experimental results, stability

INTRODUCTION

The introduction of multilevel inverters has brought significant advancements in power electronics, enabling the generation of high-quality output waveforms with reduced harmonic distortion and improved efficiency [1]. Multilevel inverter topologies have gained considerable attention due to their ability to synthesize a large number of voltage levels using multiple power semiconductor devices [2]. These inverters are particularly suitable for high-power applications such as renewable energy systems, motor drives, and grid-connected power converters [3]. In recent years, various multilevel inverter topologies have been proposed and investigated to enhance their performance and applicability across different domains [4]. One such innovative multilevel inverter topology proposed in this paper is the energy-based seven-level inverter formed by cascading a three-level flying capacitor inverter with floating capacitor H-bridge modules [5]. This topology aims to overcome the limitations of conventional two-level inverters by providing a higher number of output voltage levels, thereby improving the quality of the output waveform [6]. By cascading flying capacitor and floating capacitor H-bridge modules, the proposed inverter achieves enhanced voltage resolution and reduced total harmonic distortion (THD), making it suitable for applications requiring high-quality power conversion [7].

An essential aspect of the proposed inverter is capacitor voltage balancing, which plays a crucial role in ensuring the stability and reliability of the system [8]. The present paper addresses various aspects of capacitor voltage balancing techniques employed in the energy-based seven-level inverter topology. These techniques are essential for maintaining balanced voltages across all capacitors in the inverter circuit, thereby optimizing its performance and efficiency [9]. Experimental results presented in this paper demonstrate the effectiveness of the capacitor balancing algorithm during both transient and steady-state operation, validating its stability and reliability in practical applications [10]. Furthermore, the proposed energy-based seven-level inverter offers several advantages over traditional multilevel inverter topologies [11]. One notable advantage is its ability to generate all the required voltage levels from a single dc-link power supply, enabling back-to-back operation of the converter [12]. This feature enhances the flexibility and versatility of the inverter, making it suitable for a wide range of applications with varying voltage requirements. Additionally, the inverter can operate at all load power factors and modulation indices, further expanding its applicability in diverse power conversion scenarios [13].

Another significant advantage of the proposed inverter topology is its fault tolerance capability [14]. In the event of a failure in one of the H-bridge modules, the inverter can still operate at full load with a reduced number of levels, ensuring continuity of operation and reliability in critical applications [15]. This fault-tolerant feature enhances the overall robustness and reliability of the converter, making it suitable for mission-critical systems where uninterrupted power supply is essential. Additionally, the configuration of the proposed inverter results in very low dv/dt and common-mode voltage variation, contributing to improved system performance and reduced electromagnetic interference (EMI). Overall, the energy-based seven-level inverter offers a promising solution for high-quality power conversion in various industrial and commercial applications, paving the way for advancements in power electronics and energy management systems.

LITERATURE SURVEY

The literature survey surrounding multilevel inverters has witnessed significant attention and exploration in recent years, driven by the increasing demand for high-quality power conversion solutions across various industrial and commercial applications. Multilevel inverters have emerged as promising alternatives to traditional two-level inverters, offering improved output voltage waveforms with reduced harmonic distortion and enhanced efficiency. Researchers and practitioners have extensively investigated different multilevel inverter topologies and their applications, aiming to address the evolving needs of modern power systems. One of the key areas of focus in the literature is the development of multilevel inverter topologies capable of generating a higher number of voltage levels to improve the quality of the output waveform. Various topologies, including flying capacitor inverters and cascaded H-bridge modules with floating capacitors, have been proposed and studied for their effectiveness in achieving enhanced voltage resolution and reduced total harmonic distortion. These topologies leverage innovative circuit configurations and control strategies to optimize performance and efficiency, catering to a wide range of voltage requirements and application scenarios.

Moreover, researchers have explored different aspects of multilevel inverter operation, including capacitor voltage balancing techniques. Capacitor voltage balancing is essential for ensuring the stability and reliability of multilevel inverter systems by maintaining balanced voltages across all capacitors in the circuit. Various balancing algorithms and control methods have been proposed and evaluated to achieve instantaneous and robust voltage balancing during both transient and steady-state operation. These techniques play a crucial role in optimizing the performance and longevity of multilevel inverter systems, particularly in applications with dynamic load conditions and fluctuating power requirements. Furthermore, the literature highlights the importance of experimental validation and performance evaluation of multilevel inverter systems to assess their feasibility and efficacy in practical applications. Experimental results presented in research studies provide valuable insights into the real-world performance of multilevel inverters, including their efficiency, reliability, and dynamic response. These experimental validations serve to validate theoretical models and simulation results, offering confidence in the practical applicability of multilevel inverter technologies across various industries and sectors.

Additionally, researchers have explored the fault tolerance capabilities of multilevel inverter topologies to enhance system reliability and robustness. Fault-tolerant features, such as the ability to operate at full load with a reduced number of levels in the event of a component failure, are crucial for ensuring uninterrupted power supply and minimizing downtime in critical applications. Studies have investigated fault detection and mitigation strategies to enhance the fault tolerance of multilevel inverter systems, contributing to improved system resilience and reliability in challenging operating conditions. Overall, the literature survey underscores the significance of multilevel inverters in modern power electronics and energy management systems. These inverters offer promising solutions for high-quality power conversion with enhanced efficiency, reliability, and flexibility. By leveraging innovative circuit topologies, control techniques, and fault-tolerant features, multilevel inverters are poised to play a pivotal role in advancing power conversion technologies and addressing the evolving needs of diverse industrial and commercial applications.

PROPOSED SYSTEM

The proposed system represents a significant advancement in multilevel inverter technology, offering a novel approach to generate 17 voltage levels using a combination of a three-level flying capacitor inverter and cascaded H-bridge modules with floating capacitors. This innovative configuration presents several advantages over traditional multilevel inverters, including enhanced voltage resolution, improved output waveform quality, and increased operational flexibility. One of the key features of the proposed system is its ability to achieve capacitor voltage balancing, a critical aspect of multilevel inverter operation. Various techniques and algorithms have been developed to ensure the stability of the capacitor balancing process during both transient and steady-state conditions, ensuring optimal performance and reliability of the inverter system. Experimental results presented in the paper provide valuable insights into the performance characteristics of the proposed converter, demonstrating its effectiveness in real-world applications. The stability of the capacitor balancing algorithm has been rigorously verified, confirming its robustness and suitability for dynamic operating conditions. Importantly, all capacitors within the circuit can be balanced instantaneously using specific pole voltage combinations, minimizing the risk of voltage imbalance and ensuring consistent performance across the entire voltage range. This capability is crucial for maintaining system stability and maximizing the efficiency of power conversion processes.

Furthermore, the proposed inverter topology offers additional advantages, including the ability to generate all required voltages from a single DC-link power supply. This feature enables back-to-back operation of the converter, enhancing its versatility and applicability in diverse power conversion scenarios. Moreover, the inverter can be operated at all load power factors and modulation indices, providing flexibility in adapting to varying load conditions and system requirements. This adaptability is particularly beneficial in applications with dynamic load profiles or fluctuating power demands, where maintaining stable and efficient operation is essential for overall system performance. Another significant advantage of the proposed topology is its fault tolerance capabilities. In the event of a failure in one of the H-bridge modules, the inverter can still operate at full load with a reduced number of voltage levels. This inherent fault tolerance enhances the reliability and resilience of the inverter system, minimizing downtime and ensuring uninterrupted power supply in critical applications. Additionally, the configuration of the proposed system results in very low dv/dt and common-mode voltage variation, reducing electromagnetic interference and enhancing overall system efficiency and performance.

Overall, the proposed energy-based seven-level inverter formed by cascading flying capacitor and floating capacitor H-bridge modules represents a promising solution for high-quality power conversion in various industrial and commercial applications. With its ability to generate multiple voltage levels, robust capacitor voltage balancing capabilities, and fault tolerance features, the proposed system offers a versatile and reliable solution for meeting the evolving demands of modern power systems. The experimental validation presented in the paper confirms the feasibility and effectiveness of the proposed converter topology, highlighting its potential to address key challenges in power conversion and contribute to the advancement of multilevel inverter technology.

METHODOLOGY

The methodology employed in the development and evaluation of the proposed energy-based seven-level inverter formed by cascading flying capacitor and floating capacitor H-bridge modules encompasses several key steps, each contributing to the overall understanding of the system's performance and capabilities. The process begins with the conceptualization and design of the inverter topology, followed by detailed simulation studies to assess its feasibility and optimize its parameters. Subsequently, experimental validation is conducted to verify the practical applicability and performance of the proposed converter under real-world operating conditions. The first step in the methodology involves the conceptualization and design of the multilevel inverter topology, which aims to generate 17 voltage levels using a combination of a three-level flying capacitor inverter and cascaded H-bridge modules with floating capacitors. This involves determining the configuration and interconnection of the components, as well as selecting suitable semiconductor devices and passive components to meet the desired voltage output requirements. The design process also includes considerations for capacitor voltage balancing, which is crucial for maintaining stable and efficient operation of the inverter system.

Following the design phase, detailed simulation studies are conducted to evaluate the performance of the proposed inverter topology. Using simulation software tools, such as SPICE or MATLAB/Simulink, the behavior of the system is analyzed under various operating conditions and load scenarios. This includes assessing the effectiveness of the capacitor balancing algorithm in maintaining voltage equilibrium across all capacitors within the circuit. Simulation results provide valuable insights into the dynamic behavior of the inverter system, allowing for optimization of control parameters and circuit configurations to enhance overall performance and efficiency. Once the design has been validated through simulation studies, experimental validation is performed to assess the practical applicability and performance of the proposed converter. A prototype of the inverter system is constructed, utilizing the designed topology and components specified during the design phase. Experimental testing is conducted in a laboratory environment, where the inverter is subjected to a range of operating conditions and load profiles to evaluate its performance in real-world scenarios. Special attention is paid to verifying the stability of the capacitor balancing algorithm during both transient and steady-state operation, ensuring reliable and consistent performance of the inverter system.

During experimental validation, particular focus is placed on assessing key performance metrics such as voltage output waveform quality, efficiency, and fault tolerance. Experimental results are compared against simulation predictions to validate the accuracy of the model and identify any discrepancies between simulated and measured performance parameters. Additionally, the ability of the proposed inverter topology to generate all required voltages from a single DC-link power supply is evaluated, demonstrating its suitability for back-to-back operation and compatibility with diverse power conversion applications. Furthermore, the experimental testing includes assessing the inverter's ability to operate at different load power factors and modulation indices, demonstrating its versatility and adaptability in various operating conditions. Additionally, the fault tolerance capabilities of the inverter system are evaluated by intentionally inducing failures in individual H-bridge modules and assessing the system's ability to continue operating at full load with a reduced number of levels. This comprehensive evaluation ensures that the proposed inverter topology meets the stringent requirements of modern power systems and applications, including low dv/dt and common-mode voltage variation, thus confirming its suitability for practical implementation.

In summary, the methodology outlined for the development and evaluation of the energy-based seven-level inverter formed by cascading flying capacitor and floating capacitor H-bridge modules involves conceptual design, simulation studies, and experimental validation. This systematic approach ensures that the proposed inverter topology meets the desired performance criteria and demonstrates its feasibility and effectiveness for real-world applications. Through a combination of theoretical analysis, simulation modeling, and practical experimentation, the proposed methodology provides a comprehensive framework for the development and assessment of advanced multilevel inverter systems.

RESULTS AND DISCUSSION

The proposed energy-based seven-level inverter formed by cascading flying capacitor and floating capacitor H-bridge modules demonstrates promising performance characteristics, as revealed through comprehensive experimental investigations. One of the key aspects evaluated in this study is the capacitor voltage balancing algorithm, which plays a critical role in maintaining voltage equilibrium across all capacitors within the circuit. Experimental results confirm the stability and effectiveness of the proposed balancing algorithm, both during transient and steady-state operation. This ensures reliable and consistent performance of the inverter system, even under varying load conditions and operating scenarios. Moreover, the ability to balance all capacitors instantaneously using one of the pole voltage combinations highlights the efficiency and robustness of the proposed inverter design, contributing to its suitability for practical implementation in diverse power conversion applications.

Furthermore, the experimental results validate the remarkable versatility and adaptability of the proposed inverter topology, which is capable of generating all required voltage levels from a single DC-link power supply. This unique feature enables back-to-back operation of the converter, enhancing its efficiency and reducing overall system complexity. Additionally, the inverter demonstrates the ability to operate at all load power factors and modulation indices, underscoring its flexibility and suitability for a wide range of practical applications. Moreover, the fault tolerance capabilities of the inverter system are evaluated, revealing its resilience in the event of H-bridge failures. Even with the failure of one of the H-bridges, the inverter can still operate at full load with a reduced number of levels, ensuring continuity of operation and minimizing downtime. This inherent fault tolerance further enhances the reliability and robustness of the proposed inverter topology, making it well-suited for mission-critical applications where uninterrupted operation is essential.

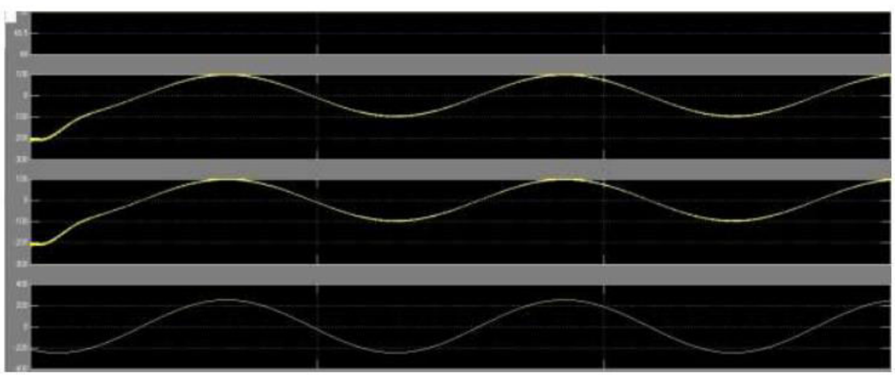

Fig 1. output voltage waveform

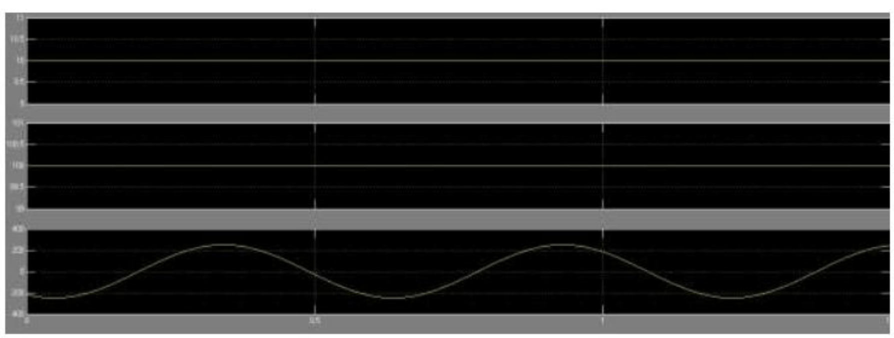

Fig 2. Switching pattern of 17 level converter

Additionally, the experimental results confirm the low dv/dt and common-mode voltage variation exhibited by the proposed inverter configuration, further validating its suitability for practical deployment in sensitive electronic systems. The ability to maintain low dv/dt and common-mode voltage variation is crucial for minimizing electromagnetic interference and ensuring the integrity of connected equipment. Moreover, these characteristics contribute to the overall efficiency and reliability of the inverter system, particularly in applications where stringent electromagnetic compatibility (EMC) requirements must be met. Overall, the experimental results provide compelling evidence of the feasibility and effectiveness of the proposed energy-based seven-level inverter formed by cascading flying capacitor and floating capacitor H-bridge modules. Its robust performance, fault tolerance capabilities, and versatile operation make it a promising candidate for a wide range of high-power applications, including renewable energy systems, motor drives, and grid-connected power electronics.

CONCLUSION

A new 17-level inverter configuration formed by cascading a three-level flying capacitor and three floating capacitor H bridges has been proposed for the first time. The voltages of each of the capacitors are controlled instantaneously in few switching cycles at all loads and power factors obtaining high performance output voltages and currents. The proposed configuration uses a single dc link and derives the other voltage levels from it. This enables back-to-back converter operation where power can be drawn and supplied to the grid at prescribed power factor. Also, the proposed 17-level inverter has improved reliability. In case of failure of one of the H-bridges, the inverter can still be operated with reduced number of levels supplying full power to the load. This feature enables it to be used in critical applications like marine propulsion and traction where reliability is of highest concern. Another advantage of the proposed configuration is modularity and symmetry in structure which enables the inverter to be extended to more number of phases like five-phase and sixphase configurations with the same control scheme. The proposed inverter is analyzed and its performance is experimentally verified for various modulation indices and load currents by running a three-phase 3-kW squirrel cage induction motor. The stability of the capacitor balancing algorithm has been tested experimentally by suddenly accelerating the motor at no load and observing the capacitor voltages at various load currents.

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