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A Review on Modular Multi-level Converter Based HVDC Systems

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Abstract*:* *Modular Multilevel Converters (MMCs) have emerged as a promising technology for High Voltage Direct Current (HVDC) transmission systems, offering several advantages such as reduced harmonic distortion, high voltage capability and modularity. This paper presents a comprehensive review of MMC-based HVDC systems, focusing on their applications, control strategies and challenges. The paper begins by discussing the basic principles and structure of MMCs, highlighting their modular design and operation. The paper delves into the control strategies employed in MMC-HVDC systems, emphasizing the importance of coordinated control between the AC and DC sides to ensure stable and efficient operation. Furthermore, the paper addresses the challenges associated with MMC-HVDC systems, such as fault ride-through capability, harmonic interactions and grid integration. It highlights recent advancements in control techniques and technologies that are being developed to address these challenges. The paper provides a valuable overview of MMC-based HVDC systems, highlighting their potential benefits and the ongoing research efforts to overcome their challenges. As the demand for renewable energy sources and long-distance power transmission increases, MMC-HVDC systems are poised to play a crucial role in shaping the future of the power grid*

Keywords: Modular Multilevel Converter, Line Commutated Converter, High Voltage Direct Current Systems

I. INTRODUCTION

Modular Multilevel Converters (MMCs) have their modular configuration, which consists of multiple submodules connected in series, offers several advantages over traditional HVDC technologies. MMCs can output a near-ideal sinusoidal voltage, significantly reducing harmonic distortion and eliminating the need for large filters. Additionally, their ability to support high voltage levels makes them well-suited for long-distance power transmission. By minimizing transmission losses and improving system stability, HVDC systems have become an indispensable component of interconnected power grids. However, the traditional line-commutated converter (LCC) technology used in HVDC systems has limitations in terms of reactive power control and harmonic generation. MMCs, with their inherent advantages, offer a viable alternative to LCCs for future HVDC applications. This paper presents a comprehensive review of MMC-based HVDC systems, covering their structure, control strategies, applications and challenges. By understanding the principles and potential benefits of MMC-HVDC, we can explore their role in shaping the future of the power grid. There are various applications of MMC-HVDC systems, including offshore wind power integration, long-distance transmission and grid stability enhancement.

The MMC is composed of numerous individual submodules, each containing a half-bridge and a DC-link capacitor. This modular design facilitates scalability, maintenance and fault tolerance. MMCs can handle high DC voltages and power capacities, making them suitable for long-distance transmission and large-scale power integration. MMCs can transmit power in both directions, enabling flexible grid management and integration of renewable energy sources. MMCs can maintain stable operation during AC faults, ensuring grid reliability and minimizing disturbances. An MMC consists of three arms (positive, negative, and zero) for each phase. Each arm is composed of multiple submodules connected in series. The submodules control the flow of DC current between the DC terminals and the AC grid. To prevent excessive circulating currents within the MMC, a control strategy is employed to balance the capacitor voltages in each arm.

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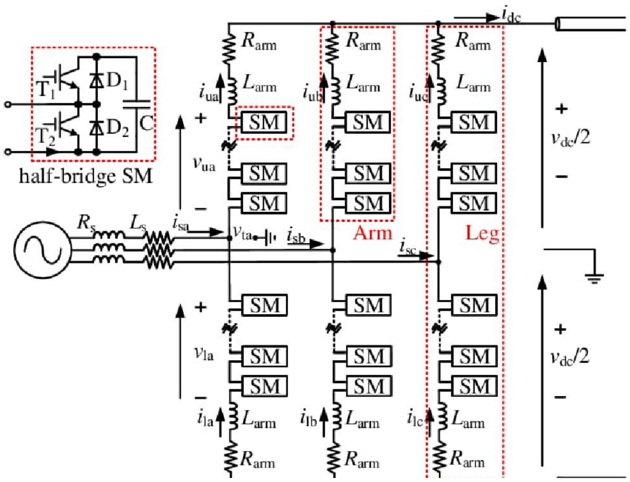

Fig. Modular multilevel converter

MMC-based HVDC systems are used to transmit power over long distances, connecting remote power sources to load centres. MMCs can be used to regulate the voltage of the AC grid, improving system stability and power quality. MMCs can be used to restart the grid after a power outage, providing essential services during emergency situations. Various modulation techniques are employed to control the output voltage of the MMC. Control strategies are implemented to ensure that the capacitor voltages in each arm remain balanced, preventing circulating currents and ensuring efficient operation. Control algorithms are designed to maintain stable operation during AC faults, prevent system collapse and minimize disturbances. While significant advancements have been made in circulating current suppression, further research is needed to optimize control strategies and minimize losses. Capacitor voltage ripple can affect the performance of the MMC. Advanced control techniques and improved capacitor designs are being explored to mitigate this issue. Enhancing the fault ride-through capability of MMCs is an ongoing area of research, with a focus on improving grid stability and resilience. Reducing the cost and improving the efficiency of MMCs are key challenges for their widespread adoption. Advancements in materials, manufacturing processes and control strategies are contributing to progress in this area. The MMC is a promising technology for HVDC transmission, offering a range of benefits such as modularity, high voltage and power capabilities, excellent power quality, bidirectional power flow and fault ride-through capability.

II. LITERATURE SURVEY

China has a lot of offshore wind power, but using it well is a big challenge. Connecting offshore wind power to the grid using MMC-HVDC is the best way. However, there are still problems with controlling offshore wind power connected to the grid using MMC-HVDC. We need to study this in detail. This paper looks at how it works, how to start it up quickly, how to handle problems and how it affects the AC grid. These ideas help use offshore wind power safely and efficiently. This paper focuses on the challenges and solutions for connecting offshore wind power to the electrical grid using a technology called MMC-HVDC. It highlights the importance of efficient offshore wind energy utilization in China. The paper analyse the operating characteristics, proposes strategies for fast start-up and fault handling and discusses how offshore wind power interacts with the existing grid. These strategies aim to ensure the safe and effective use of offshore wind resources**[1]**.

When there are large disturbance in the power grid, it can cause the electricity's frequency to change. This can affect wind farms and even make them stop working. To help keep the frequency stable, wind turbines can be controlled. However, most studies only focus on one type of wind turbine control. This paper compares different ways to control wind turbines and how they can help the grid's frequency. This paper focuses on how wind turbines can help stabilize the electrical grid during disturbances. It compares different control strategies for wind turbines and their effectiveness in supporting grid frequency. The paper finds that combining wind turbines with a special type of converter (MMC-HVDC) that provides inertia support which provides the best results for maintaining grid stability**[2]**.

The paper provides a thorough analysis of how the Zero Sequence Circulating Current controller impacts system stability. However, it could be beneficial to explore a wider range of operating conditions and fault scenarios to assess the controller's robustness. The paper provides a valuable contribution to the understanding of Zero Sequence Circulating Current controller influence on Modular Multilevel Converter-High Voltage DC Current grid-connected offshore wind power systems. By addressing the key challenges and proposing effective strategies, it can support the safe and efficient operation of these systems**[3]**.

The paper highlights the risk of submodule voltage damage during fault ride-through due to delayed unloading circuit activation. Accurate modelling of the system's dynamic behaviour during faults is crucial for effective protection strategies. The proposed control strategy aims to address this issue by modifying the unloading circuit activation logic. However, further analysis and validation are needed to ensure its effectiveness under various fault scenarios. The semi-physical simulation model of the pseudo-bipolar flexible HVDC transmission system provides a valuable platform for testing and validating the proposed control strategy. However, it's essential to ensure that the model accurately represents the system's dynamic behaviour. The simulation model can be extended to represent larger and more complex systems, which would further enhance its applicability**[4]**.

The paper provides a clear understanding of how MMC-HVDC systems can improve Multi infeed interaction factor and Multi infeed effective short circuit ratio in multi-infeed DC systems. However, further analysis of the impact on other system parameters, such as power flow distribution and voltage stability would be beneficial. The derivation of the calculation formula based on the nodal impedance matrix is a valuable contribution. However, validating the formula against real-world data or detailed simulations would strengthen its credibility. The paper provides guidelines for selecting the optimal operation mode and connection location of the MMC station. However, additional case studies with varying system parameters and grid conditions would strengthen the conclusions**[5]**.

This paper focuses on a type of power transmission system called Back-to-Back HVDCthat uses MMC technology. Back-to-Back systems can connect two power grids that have different frequencies or phases. However, there are problems with how faults can spread between the two grids.The paper first explains how the system works and how it is usually controlled. Then, it looks at what happens when there is a problem in one of the grids. Finally, the paper proposes new ways to control the system to make it better able to handle these problems. The new methods are tested using a computer simulation**[6]**.

The paper provides analysis of the challenges associated with AC fault ride-through in MMC-HVDC systems with short lines.The proposed control strategy addresses the specific challenges posed by short lines and aims to ensure both DC grid stability and AC grid voltage recovery.The paper should emphasize the robustness of the proposed control strategy in maintaining DC grid stability under various fault conditions and operating scenarios.The paper should quantify the effectiveness of the proposed control strategy in aiding AC grid voltage recovery during sags**[7]**.

This paper focuses on a type of power converter called Modular Multilevel Converter (MMC) that can be used for high voltage direct current (HVDC) transmission. MMCs are a promising technology for future smart grids because they can produce a very smooth, almost perfect sinewave which helps reduce noise in the power system. This means you don't need to use big filters, which can save money. Additionally, MMCs can handle very high voltages, making them ideal for HVDC transmission.The paper studies how an MMC-HVDC system works by simulating it with its control system. This helps us understand its performance and potential benefits for future power grids**[8]**.

The paper emphasizes the importance of accurate modelling for analysing MMC-HVDC systems. Validating the models against real-world data and comparing the simulation results with actual system performance would strengthen the credibility of the study. The complexity of the models should be balanced with computational efficiency, especially for large-scale simulations.The paper highlights the system's good dynamic performance under various fault conditions. However, it would be beneficial to explore a wider range of fault scenarios to assess the system's robustness.The use of RTDS for simulation provides valuable real-time capabilities for testing and validation. However, the computational requirements and scalability of RTDS simulations should be considered for large-scale systems**[9]**.

III. CONCLUSION

MMC-based HVDC systems offer a promising solution for the challenges faced by traditional HVDC technologies. Their modular configuration, high voltage capability and reduced harmonic distortion make them well-suited for various applications, including offshore wind power integration and long-distance transmission. While MMC-HVDC systems have demonstrated significant advantages, further research and development are necessary to address the challenges associated with their implementation. These challenges include fault ride-through capability, grid integration, and economic feasibility. By overcoming these challenges, MMC-HVDC systems can play a crucial role in enhancing the efficiency, reliability, and sustainability of future power grids. As the demand for renewable energy sources and long-distance power transmission continues to grow, MMC-HVDC systems are poised to become an integral part of the global energy landscape. By leveraging their unique capabilities and addressing the associated challenges, we can harness the full potential of this innovative technology to create a more sustainable and resilient power grid.

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