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Design and Implementation of Modular Multi-Level Converter Based HVDC System for Grid Connection

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Abstract: *This paper examines Modular Multilevel Converters (MMC) for harnessing power from offshore wind farms. MMCs use many simple Voltage Source Converter (VSC) submodules, enabling high-voltage and high-power applications. They offer faster response times and lower harmonic distortion than traditional two-level VSCs. The paper addresses modelling challenges due to numerous switching devices and discusses the development of Cascaded Two-Level (CTL) converters, which improve output voltage quality. Overall, the study highlights advancements in MMC technology that enhance HVDC transmission capabilities.*

Keywords: Modular Multilevel Converter (MMC), HVDC transmission, Voltage Source Converter (VSC), Converter Control, Mathematical modelling

I. INTRODUCTION

The Modular Multilevel Converter (MMC) has emerged as a pivotal technology in High Voltage Direct Current (HVDC) systems, enhancing the efficiency and reliability of power transmission over long distances. The MMC architecture offers superior control over power flow, making it suitable for various applications, including renewable energy integration and grid interconnections. This paper presents a detailed analysis of the modelling and control strategies employed in MMC-based HVDC systems, focusing on optimizing performance and ensuring stability in dynamic operating conditions. The integration of active and reactive power control mechanisms plays a critical role in achieving desired operational outcomes.

The rapid growth of renewable energy generation, particularly from offshore wind sources, presents significant challenges for existing power transmission systems. Traditional HVDC systems often struggle with issues related to control complexity, voltage stability, and harmonic distortion. The Modular Multilevel Converter (MMC) provides a promising solution but requires robust modelling and control strategies to effectively manage its numerous submodules and maintain system stability. This paper addresses the need for improved modelling techniques and control frameworks to optimize MMC performance in HVDC applications, particularly for grid connections involving renewable energy sources.

- **Enhance Control Mechanisms**: Develop advanced control strategies for the MMC to improve its performance in regulating active and reactive power, thereby ensuring stable operation under varying grid conditions.
- **Modeling Accuracy**: Create accurate mathematical models that reflect the dynamics of the MMC, facilitating better simulation and analysis for optimal design and operation.
- **Integrate Renewable Energy**: Assess the MMC's effectiveness in integrating renewable energy sources, particularly offshore wind, into the existing power grid.
- **Performance Evaluation**: Evaluate the efficiency and reliability of the MMC-based HVDC system through simulations and real-world testing.

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Modular Multilevel Converter (MMC):

- **Scalability**: MMCs can easily be scaled up or down by adding or removing submodules, allowing for flexible system design.
- **Higher Efficiency**: They provide better efficiency in converting DC to AC and vice versa, making them ideal for renewable energy integration.
- **Reduced Harmonics**: MMCs produce lower harmonic distortion, improving power quality.

Line Commutated Converter (LCC):

- **Proven Technology**: LCCs are a mature and widely used technology in HVDC applications.
- **High Power Capability**: They can handle very high-power levels, making them suitable for long-distance transmission.
- **Cost-Effectiveness**: LCCs are generally less expensive to implement for large-scale projects compared to newer technologies.

II. CIRCUIT ARCHITECTURE

The circuit architecture (in fig.1) of the Modular Multilevel Converter (MMC) consists of multiple submodules arranged in series within each phase. Each submodule typically contains a capacitor and switches (S1 and S2) to control voltage levels. The MMC operates by selectively inserting or bypassing these submodules, allowing for various voltage levels in the output waveform. The architecture enables scalability and flexibility, as additional submodules can be added for higher voltage levels, while maintaining control over harmonic distortion and efficiency in power conversion.

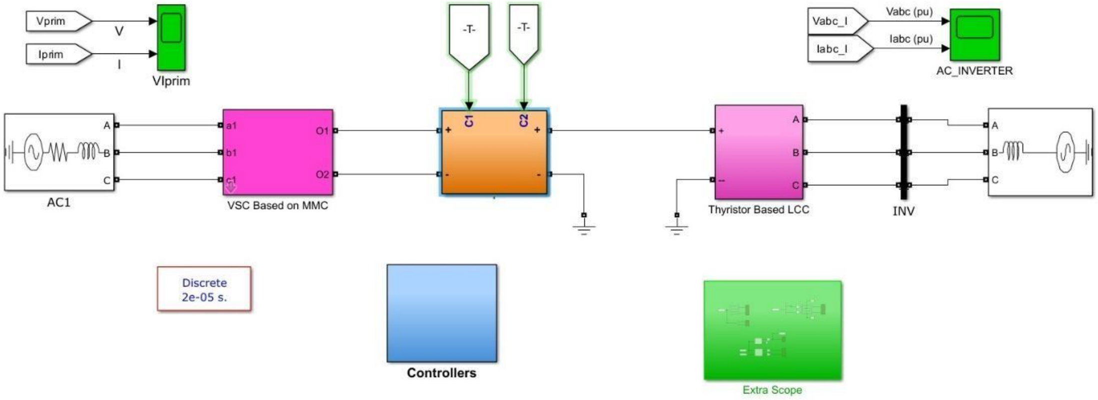

Fig.1: Circuit diagram

III. OPERATING PRINCIPLES

The Modular Multilevel Converter (MMC) generates a staircase-shaped output voltage waveform by inserting or bypassing submodule (SM) capacitors. When switch S1 is active, the capacitor is connected; when S2 is active, it's bypassed. If both switches are off, current flows through the freewheeling diodes. A selector manages the insertion of DC sources based on the MMC's control algorithm, producing a multilevel voltage output. For instance, with five SMs per arm, a six-level voltage waveform is achieved, enhancing performance and reducing harmonic distortion.

- Modular Structure: MMC consists of several identical submodules connected in series, allowing for easy scalability and redundancy.
- Voltage Control: Each submodule can independently switch between charging and discharging states, enabling fine control over output voltage.
- Pulse Width Modulation (PWM): PWM techniques are employed to control the switching of the submodules, shaping the output waveform and reducing harmonic distortion.

- Power Flow Management: The MMC can handle bi-directional power flow, making it suitable for both AC and DC applications, facilitating energy exchange between grids.
- Control Strategy: Advanced control algorithms manage the operation, ensuring stable performance and efficient power conversion.

IV. CONTROLLERS

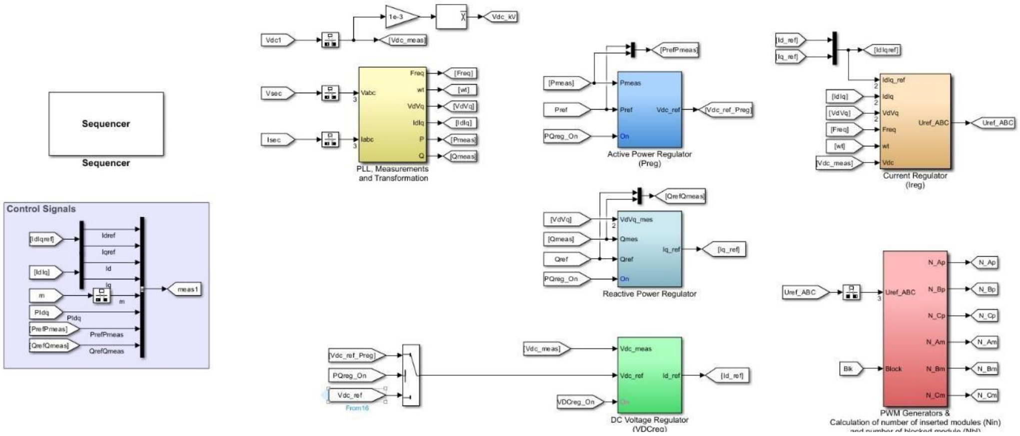

Fig.2: Simulation of project

- **Sequencer**: This component organizes the sequence of operations and control signals, ensuring that different parts of the system work in harmony.
- **Control Signals**: This section manages references for direct current (Id) and quadrature current (Iq), necessary for controlling power flow.
- **PLL (Phase-Locked Loop)**: This component synchronizes the converter's operation with the grid frequency, ensuring stable control under varying conditions.
- **Active Power Regulator (Preg)**: This regulates the active power output by adjusting reference values based on real-time measurements.
- **Reactive Power Regulator (Qreg)**: It manages reactive power, improving voltage stability and power factor in the system.
- **Current Regulator (Ireg)**: This component controls the current flowing through the converter, maintaining it within specified limits.
- **DC Voltage Regulator (VDCreg)**: It stabilizes the DC voltage across the converter, critical for safe and efficient operation.
- **PWM Generators**: These generate the required Pulse Width Modulation signals for the switching devices in the MMC, determining the number of inserted or blocked sub-modules.

V. SIMULATION RESULTS

This file is automatically executed in the MATLAB workspace when the example is open. Run the model and observe the following events:

- At 0.1s to 1s,Breaker 1 closes at 0.1s, allowing Converter 1 to energize through a resistor, and the capacitors are charged. By 1s, Breaker 2 is closed, bypassing the start-up resistor. During this period, the voltage likely ramps up as the system stabilizes. This section shows a decaying oscillatory waveform. The large oscillations represent the system's response to the initial energization and charging of the capacitors. As the system charges, the amplitude of oscillations gradually diminishes.
- At 1.5s,Converter 1 is deblocked, and the voltage regulator is enabled. The waveforms may show smoother dynamics or increased stability starting from this point. The waveform narrows significantly after the voltage regulator is enabled and Converter 1 is deblocked.

- At 1.7sPQ regulators are enabled, affecting power flow. Active power ramps up to 1pu (1000 MW). You might observe a significant change in the signal's behaviour. The active power and reactive power regulators are engaged, and their setpoints are ramped.

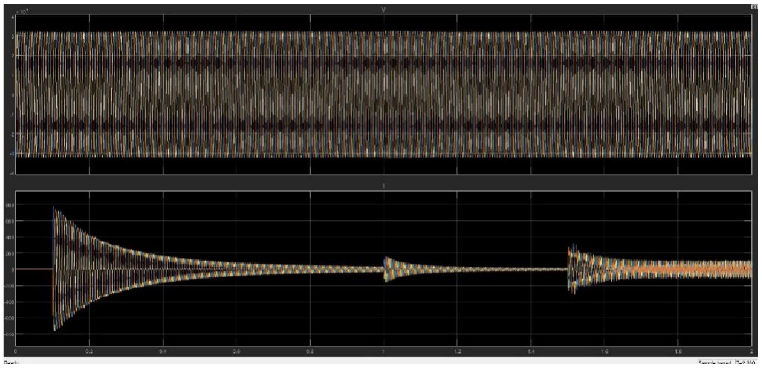

Fig.3: Voltage and Current of Transformer (AC System1)

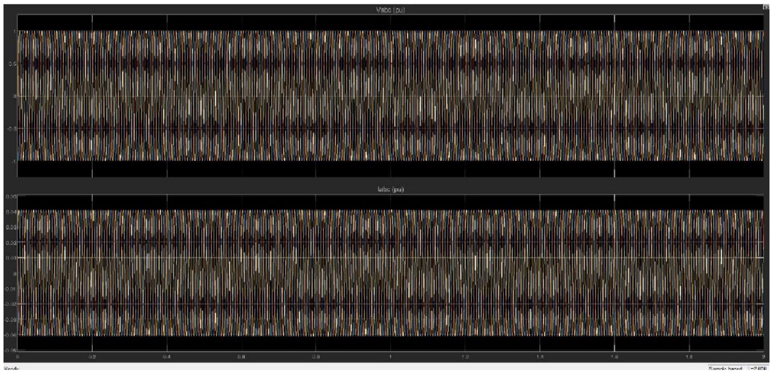

Fig.4: Voltage and Current of Inverter in PU (AC System 2)

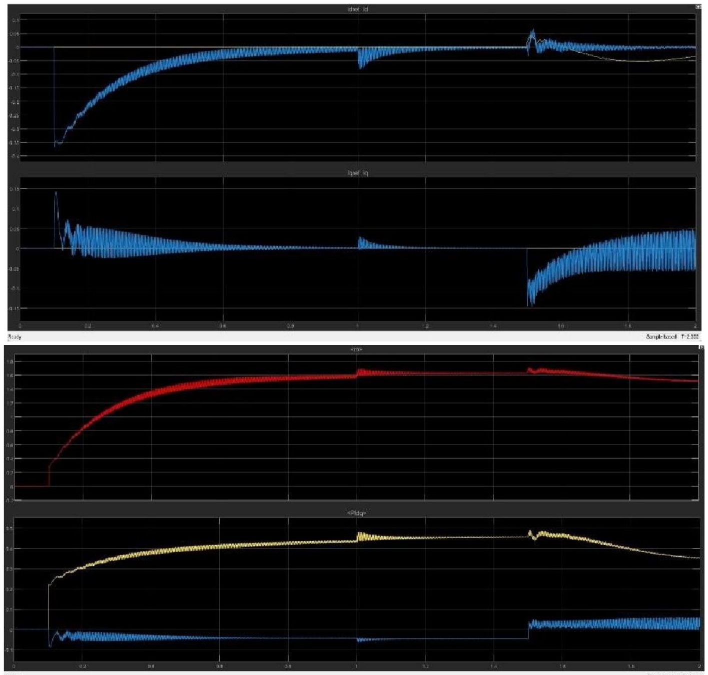

Fig.5: Simulation Results showing the Modular multilevel converter Performance for HVDC Transmission

- The waveform is dense with periodic oscillations, suggesting that it represents the DC voltage across the system.
- The voltage appears stable with minimal variation after initial transients. This is indicative of a well-regulated DC voltage, consistent with steady-state operation at a setpoint. The bottom plot shows a similarly dense waveform, likely representing the DC current flowing through the system.
- The waveform also appears stable with consistent oscillations, which might be due to normal converter switching and power regulation behaviour.
- This graph shows the dynamic response of a power system, with both plots representing current (likely active and reactive components). However, the system recovers quickly, regaining stability after a brief period of fluctuations.
- The Y-axis appears to be the signal strength, starting near zero and gradually increasing.
- The X-axis likely represents time or another continuous parameter.
- The red line shows a curve that starts quickly increasing and then levels off, indicating a behaviour that could be associated with an exponential rise or a charging process (e.g., a capacitor charging). There is a minor disturbance or anomaly toward the end of the curve, which might represent some instability or noise in the signal.
- The Y-axis may also represent a similar type of measurement, though there are two colours (yellow and blue) that likely represent two different signals or aspects of the same system.
- The yellow curve shows a steep rise initially, then stabilizes before a slight dip and flattening out. This could indicate a system reaching some equilibrium or steady-state after an initial surge.
- The blue line appears at the bottom part of the graph, displaying oscillatory behaviour that starts off less prominent but grows in amplitude toward the right side. This could indicate damping oscillations or vibrations after an initial event (such as a step response or other system disturbance).

Parameter Table:

Table 1: AC System-1

Sr. No.	System Parameters	Value
1.	Transformer primary line- line voltage (Vprim)	396000V
2.	Transformer secondary line- line voltage (Vsec)	333000V

Table 2: Converter parameter

Sr. No.	System Parameters	Value
1.	Model Type	Aggregate Model
2.	Number of Power module	36
3.	Submodule capacitor (C)	0.001758 F
4.	Capacitor initial voltage (V)	0

Table 3: AC System-2

Sr. No.	System Parameters	Value
1.	Inverter (Thyristor based Lcc) voltage (pu)(Vabc)	1
2.	Inverter (Thyristor based Lcc) current (pu)(Iabc)	0.04

VI. CONCLUSION

In conclusion, the Modular Multilevel Converter (MMC) offers significant advantages for high-voltage direct current (HVDC) systems, such as modularity, scalability, and superior power quality. Its control strategies enhance voltage balancing, current control, and adaptability to varying grid conditions, ensuring stable and efficient operation. The comparison with Line Commutated Converters (LCC) highlights MMC's flexibility and robustness in modern power

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systems. Overall, the MMC is a promising solution for integrating renewable energy sources and enhancing grid stability, aligning with future energy demands.

REFERENCES

[1]. B. Finn, “Origin of Electrical Power”, National Museum of American History, Accessed: Feb. 1,2013.
[2]. O. Peake, “The History of High Voltage Direct Current Transmission,” presented at the Australasian Engineering Heritage Conference, 2009.
[3]. ABB “Tesla vs. Edison: the war of currents”, Accessed: Feb. 1, 2013.
[4]. A. Lesnicar, R. Marquardt, "An innovative modular multilevel converter topology suitable for a wide power range," Proceedings of Power Tech Conference, 2003 IEEE Bologna, vol.3, pp. 23-26, June 2003.
[5]. N. Ahmed, A. Haider, D. Van Hertem, Lidong Zhang, and H.-P. Nee, “Prospects and challenges of future HVDC SuperGrids with modular multilevel converters”, Proceedings of the 2011-14th European Conference on Power Electronics and Applications, 2011, pp. 1–10.
[6]. P. Fairley, "Germany jump-starts the supergrid," Spectrum, IEEE, vol.50, no.5, May 2013.
[7]. J. Arrillaga, Y.H. Liu, and N.R. Watson Flexible Power Transmission, The HVDC Options, West Sussex: John Wiley & Sons 2007.
[8]. R. Adapa, "High-Wire Act: HVdc Technology: The State of the Art," Power and Energy Magazine, IEEE, vol. 10, no. 6, pp. 18-29, Nov. 2012.
[9]. K. Meah, S. Ula, "Comparative Evaluation of HVDC and HVAC Transmission Systems," Power Engineering Society General Meeting, 2007. IEEE, pp. 1-5, 2007.
[10]. R. Rudervall, J. Charpentier, and R. Sharma, “High voltage direct current (HVDC) transmission systems technology review paper,” Energy week, pp. 7-8, 2000.
[11]. M.P. Bahrman, B.K. Johnson, "The ABCs of HVDC transmission technologies," Power and Energy Magazine, IEEE, vol. 5, no. 2, pp. 32-44, 2007.
[12]. O. Peake, “The History of High Voltage Direct Current Transmission,” presented at the Australasian Engineering Heritage Conference, 2009.
[13]. A. M. Abbas, P.W. Lehn, "PWM based VSC-HVDC systems — A review," Power & Energy Society General Meeting, PES '09. IEEE, pp. 1-9, 2009.
[14]. S. Kouro, M. Malinowski, K. Gopakumar, J. Pou, L. G. Franquelo, Bin Wu, J. Rodriguez, M. A. Pérez, and J. I. Leon, "Recent Advances and Industrial Applications of Multilevel Converters," IEEE Transactions on Industrial Electronics, vol. 57, no. 8, pp. 2553-2580, Aug. 2010.
[15]. Alstom “Alstom Grid will provide Tres Amigas LLC in the USA with first-of-its-kind Smart Grid “SuperStation” Accessed: Jun.2,2013.
[16]. R. Marquardt, "Modular Multilevel Converter: A universal concept for HVDC-Networks and extended DC-Bus-applications," Proceedings of Power Electronics Conference (IPEC), 2010 International, pp. 502-507, 2010.
[17]. E. Abildgaard, “Exploring the Properties of a Modular Multilevel Converter Based HVDC Link. With
[18]. Focus on Voltage Capability, Power System Relations, and Control System,” M.S. Thesis, Dept. Electric Power Eng., Norwegian Univ. of Sci. and Tech., Norway. 2012.
[19]. M. Vasiladiotis, “Analysis, Implementation and Experimental Evaluation of Control Systems for a Modular Multilevel Converter,” M.S. Thesis, Dept. Elect. Eng., Roy. Tech. Inst., Stockholm, Sweden 2009.
[20]. Y. Zhang, G. P. Adam, T. C. Lim, S. J. Finney, and B. W. Williams, “Analysis and experiment validation of a three-level modular multilevel converters,” Proceedings of IEEE 8th International Conference on Power Electronics and ECCE Asia (ICPE & ECCE), pp. 983, 990. 2011.
[21]. Y. Zhang, G. P. Adam, T. C Lim, S. J. Finney, and B. W. Williams, “Mathematical Analysis and Experimet Validation of Modular Multilevel Converters,” Journal of Power Electronics, vol. 12, no. 1, pp. 33, 39, 2012.
[22]. R.K. Behera, S.P. Das, "Space vector modulation for a three-level NPC ac-dc converter system: An experimental investigation," Proceedings of International Conference on Power, Control and Embedded Systems (ICPCES), pp. 1-5, Nov. - Dec. 1 2010.