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Different Control Strategies of Multi-Level Inverter for Grid Connected Wind Power Systems

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Abstract
Multi-level inverters have attracted high-performance and medium voltage energy control in many institutional work and industry. Further, the multi-level concept is used to reduce the harmonic distortion on the output wave form without reducing the inverter power output. The multi-level concept is used for reducing harmonic distortion in the output waveform. We have many control strategies in multi-level inverters which have been gaining high popularity in research teams and in the development of high and medium voltage applications for industrial applications. The proposed strategies include the use of pulse width modulation (PWM) schemes, artificial intelligence-based controllers to enhance the performance of multilevel inverters. These advanced control strategies effectively improve the power quality and overall efficiency of renewable energy systems. This paper explores the different control techniques for multi-level inverters, making their implementations versatile in many industrial areas in some power applications and Control methods for a new class of converter, the multilevel modular converter (MMC).
Keywords: *MMC (Multi Modular Converter), PWM (Pulse Width Modulation).*

1. Introduction
Offshore wind power plants with multi-level converters, require sophisticated control strategies to ensure efficient operation, stability, and reliability. Here's an overview of various controllers used in these systems:

1.1. Voltage Source Converter (VSC) Controllers
- **Direct Current (DC) Voltage Control:** Regulates the DC link voltage to maintain a stable grid connection. This control ensures that the converter operates within its voltage limits and can be either open-loop or closed-loop.
- **AC Voltage Control:** Maintains the AC voltage at the point of connection to the grid. It can include both reactive power compensation and active power control to manage voltage levels and support grid stability converter maintains the desired current

1.2. Current Control Strategies
- **Current Loop Control:** Ensures that the converter maintains the desired current in both the AC and DC sides. This control is essential for managing power flow and preventing overcurrent.
- **Vector Control (Field-Oriented Control):** Separates the control of torque and flux in the converter, allowing for precise control of power output and improved dynamic performance.

1.3. Power Control Strategies
- **Active Power Control:** Adjusts the active power output to match the wind turbine's power generation capabilities and grid demand. This can involve power setpoint adjustments based on wind speed and power generation forecasts.
- **Reactive Power Control:** Manages the reactive power to support voltage regulation

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and improve the power factor. It helps in compensating for reactive power losses in the system.

1.4. Advanced Control Technique

- **Model Predictive Control (MPC):** Utilizes a model of the converter and system dynamics to predict future behaviour and optimize control actions accordingly. This approach can handle complex constraints and multi-variable interactions.
- **Adaptive Control:** Adjusts control parameters in real-time based on changing operating conditions, such as wind speed fluctuations or grid disturbances.

1.5. Grid Synchronization Controllers

- **Phase-Locked Loop (PLL):** Synchronizes the converter's output with the grid frequency and phase. It's crucial for maintaining grid stability and preventing phase mismatches.
- **Frequency and Phase Control:** Ensures that the converter's output frequency and phase match the grid requirements, which is essential for stable grid integration.

1.6. Fault Ride-Through (FRT) Control

- **Ride-Through Capability:** Ensures that the converter can handle and recover from grid faults or disturbances without disconnecting. This includes voltage dip ride-through and frequency deviations.

1.7. Protection and Safety Controls

- **Overvoltage and Overcurrent Protection:** Safeguards the converter and associated equipment from damaging conditions.
- **Temperature and Insulation Monitoring:** Monitors the temperature of the converter and its components to prevent overheating and ensure operational safety.

1.8. Communication and Coordination

SCADA Systems: Supervisory Control and Data Acquisition (SCADA) systems are used for real-time monitoring, control, and data analysis of the wind power plant and its converters.

Grid Management and Coordination: Ensures proper coordination between multiple converters and wind turbines to optimize overall plant performance and integrate with the wider grid.

These control strategies help manage the complexities of offshore wind power plants, ensuring they operate efficiently, safely, and in harmony with the electrical grid. The choice of controllers often depends on the specific requirements of the wind power plant and the characteristics of the grid to which it is connected.

2. Voltage Sourced Converter (VSC)

Voltage sourced converter (VSC) based HVDC systems exhibit many attractive features over the conventional line commutated converter (LCC) based systems in high voltage high power applications [1]. These unique features such as independent control of active and reactive power [2], operation in weak ac systems [3], black start capability [4], and multi terminal connection [5] have led to their increased adoption in modern schemes. Till recently, two-level or three-level VSC topologies were used for HVDC transmission applications, with pulse-width modulation (PWM) control to reduce the lower harmonic content. The ratings were typically limited to below 400 MW because of the higher switching losses inherent in such topologies. Numerous multilevel topologies and modulation strategies have been introduced for machine drive applications [6]-[8]. Diode clamped multilevel converters [6] [7] synthesize a stepped ac waveform resembling a sine wave, by stacking fixed magnitude voltage steps on top of each other. This topology typically has lower losses than two level PWM converters. However, the number of levels has been limited to 3 (in HVDC applications) due to the circuit complexity. Also, capacitor voltage balancing is a critical and challenging issue. The recently initiated modular multilevel converter (MMC) is a major step forward in VSC converter technology for HVDC transmission [9]. This topology is designed to make lower switching frequency, avoid connecting the devices in series. The modular structure easily scales to higher voltage and power levels, with the addition of more modules. A power rating of 1 GW and above now becomes possible. Although the MMC topology has been presented in earlier literature [9], [10], the discussion on control methods is sparse. This paper discusses control approaches and investigates their performance using electromagnetic transients (EMT)

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simulation. The paper also investigates the control and performance of a HVDC transmission scheme feeding to a weak ac system.

3. Circuit Structure of Modular Multilevel Converter

The basic building block of the MMC converter is the sub-module shown in Fig. 1, which consists of two IGBT switches T1 and T2 and a capacitor C. In normal operation, exactly one switch (T1 or T2) is ON at any instant, giving a sub-module output voltage of Vc or 0 (1): (Figure 1,2)

$$V_{OUT}(t) = \begin{cases} V_C & T_1\text{-ON, } T_2\text{-OFF} \\ 0 & T_1\text{-OFF, } T_2\text{-ON} \end{cases} \quad (1)$$

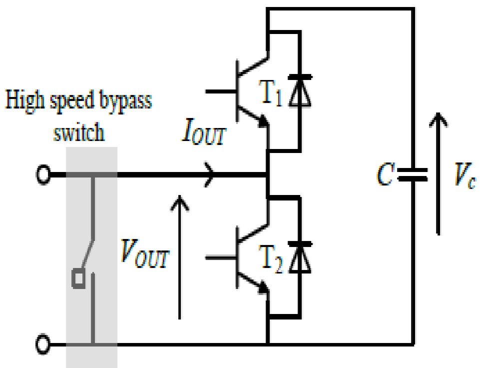

Figure 1 Sub-Module of MMC Converter

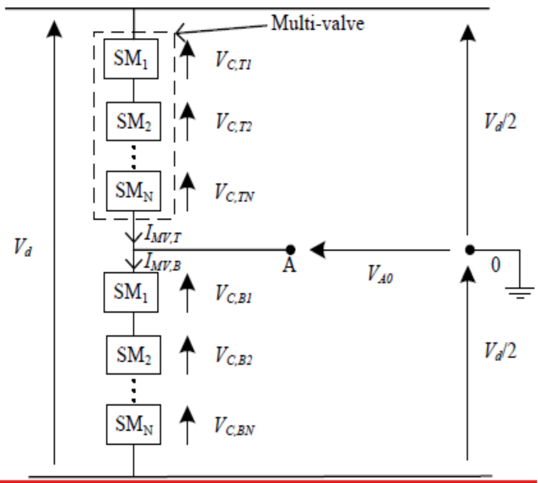

Figure 2 Phase Module of an MMC Scheme for an N-Level Arrangement

Thus, this modular structure can be scaled for different voltage and power levels [9]. By controlling the ON/OFF state of the sub-modules, the output voltage waveform, VA0, can be synthesized to track a given sinusoidal voltage reference Vref as shown in (Figure 3)

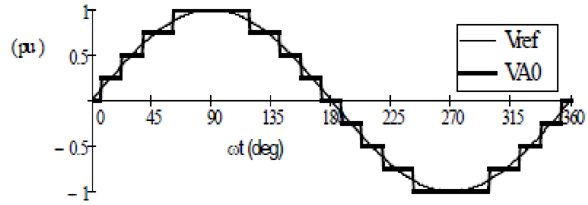

Figure 3 Reference and Output Waveforms for MMC with 8 Sub-Modules Per Multi-Valve

4. Pulse Width Modulation (PWM)

PWM is a fundamental control strategy used in MLCs to generate the desired output voltage waveform by modulating the switching of semiconductor devices. In PWM control, the duty cycle of the switching signals is adjusted to regulate the output voltage magnitude and frequency. Different PWM techniques, such as carrier-based PWM, space vector PWM, and selective harmonic elimination PWM, are employed to achieve specific performance objectives, including reduced harmonic distortion and improved efficiency. The PWM techniques available in literature are shown in (Figure 4)

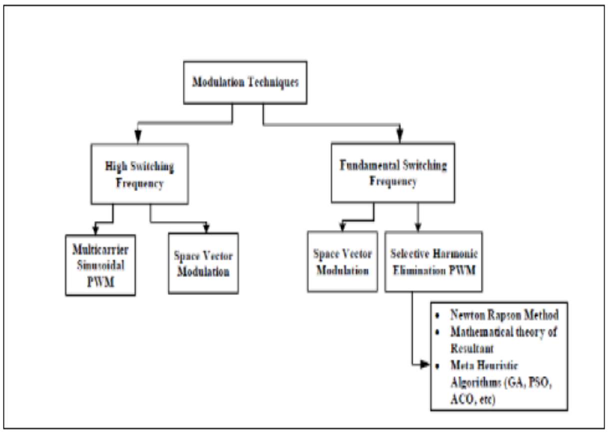

Figure 4 PWM Techniques for the Control of MLCs.

5. Voltage Balancing Control

Voltage balancing control is vital for MLCs to maintain uniform voltage distribution across cells or

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submodules. It addresses voltage imbalances stemming from component disparities or load variations, ensuring system reliability. Various strategies, such as voltage feedback, capacitor balancing, and phase-shift control, are employed to achieve balance. Implemented through digital control algorithms, voltage balancing adjusts submodule switching patterns based on voltage feedback, enhancing system efficiency and power quality. Challenges like computational complexity persist, but effective voltage balancing improves MLC performance, reducing stress on components and enabling their use in high-voltage applications. By ensuring consistent operation and mitigating voltage disparities, voltage balancing control enhances system longevity and reliability, making MLCs viable for diverse power electronic applications. As MLCs continue to advance, further research into voltage balancing strategies promises even greater efficiency and reliability, driving the adoption of multilevel converters in modern power systems.

6. Current Control

Current control is a pivotal aspect of multilevel converters (MLCs), ensuring precise regulation of output currents in various power electronic applications, including Voltage Source Converter (VSC)-based High Voltage Direct Current (HVDC) systems. The primary objective of current control is to accurately track reference currents, facilitating stable operation, optimal power delivery, and adherence to performance requirements. Common control strategies for current regulation in MLCs encompass Proportional-Integral (PI) control, Predictive Control, and Hysteresis Control. PI controllers adjust switching signals based on the difference between actual and reference currents, minimizing steady-state errors for stable operation. Predictive control techniques utilize system models and predictive algorithms to anticipate future system behavior, offering faster response and improved dynamic performance. Hysteresis controllers impose upper and lower bounds on output currents, triggering switching events to maintain currents within these bounds, although this approach may increase switching frequency and losses. Implementation of current control algorithms typically involves digital signal processors (DSPs), microcontrollers, or field-programmable gate arrays (FPGAs). These controllers receive feedback signals from current sensors or measurement circuits, computing control signals to regulate the converter's operation accurately. In HVDC systems, precise current control is paramount for regulating power flow, ensuring grid stability, and maintaining reliable operation over extended distances. Current control in MLCs is indispensable for HVDC transmission, where accurate current regulation enables efficient power transfer and mitigates grid disturbances. Current control in MLCs plays a vital role in achieving stable operation, optimal power delivery, and adherence to performance requirements in various power electronic applications, particularly in HVDC systems. Ongoing advancements in control algorithms and hardware technologies continue to enhance the efficiency, reliability, and versatility of current control strategies in MLCs.

Conclusion

The multi-level modular converter is an attractive topology for HVDC operation. The paper presented the basic control approach for use of this device in HVDC transmission applications. Through calculation and EMT simulation, it was shown that the MMC can provide an essentially sinusoidal waveform that meets accepted guidelines of harmonic content. This paper explores the different control techniques for multi-level inverters, making their implementations versatile in many industrial areas in some power applications and Control methods for a new class of converter, the multilevel modular converter (MMC). Maximum efficiency, reduced harmonic distortion, and enhanced voltage regulation capabilities of MLCs compared to conventional converters. Control strategy enhancements, semiconductor device innovations, and integration with energy storage systems have further advanced the performance and functionality of MLC-based converters.

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