Mini Review
Volume 13:04, 2024

International Journal of
Sensor Networks and Data Communications

ISSN: 2090-4886
Open Access

A New Voltage Sensorless Estimation Approach for Modular Multilevel Converters Using Model Predictive Control Strategy

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Abstract

This review explores a novel voltage sensorless estimation method for Modular Multilevel Converters (MMCs) utilizing a Model Predictive Control (MPC) strategy. The approach aims to enhance the efficiency and reliability of MMCs, which are crucial in High-Voltage Direct Current (HVDC) transmission systems and renewable energy applications. By eliminating the need for voltage sensors, the proposed method reduces system complexity and cost while maintaining high performance. This article delves into the principles of MMCs, the challenges associated with voltage sensing, the fundamentals of MPC and the innovative aspects of the sensorless estimation method.

Keywords: Modular multilevel converters • Sensorless estimation method • High-voltage

Introduction

Modular Multilevel Converters (MMCs) have gained significant attention due to their scalability, fault tolerance and high efficiency in high-power applications. MMCs are widely used in HVDC systems, grid integration of renewable energy sources and industrial drives. Traditional MMC control strategies rely heavily on voltage sensors to monitor and control the converter's operation. However, the use of multiple voltage sensors increases system complexity, cost and the likelihood of sensor-related failures. To address these challenges, researchers have developed a voltage sensorless estimation method that leverages Model Predictive Control (MPC). MPC is a robust control strategy that optimizes the control inputs by predicting future system behavior. This review discusses the fundamental principles of MMCs, the drawbacks of conventional voltage sensing methods, the basics of MPC and the innovative sensorless estimation technique [1].

Literature Review

MMCs are composed of Multiple Submodules (SMs) connected in series to form each phase leg. Each SM typically consists of a half-bridge or full-bridge circuit with a capacitor. The modular structure allows for high scalability and redundancy, making MMCs suitable for high-power applications. The main advantages of MMCs include:

Scalability: MMCs can be easily scaled by adding or removing submodules.

Fault tolerance: The modular design allows for the bypassing of faulty submodules, enhancing system reliability.

High efficiency: The reduced switching frequency and low harmonic distortion contribute to high efficiency.

Each SM in an MMC can either insert its capacitor voltage into the circuit or bypass it, depending on the switching states. By appropriately controlling the switching states of the SMs, the converter can generate a staircase output voltage waveform that approximates a sinusoidal waveform. This reduces the need for filtering and improves the power quality. Voltage sensing in MMCs is essential for monitoring capacitor voltages and ensuring proper operation. Model Predictive Control (MPC) is an advanced control strategy that uses a model of the system to predict future behavior and optimize control inputs. MPC has gained popularity in power electronics and drives due to its ability to handle multivariable systems and constraints effectively [2].

The MPC strategy involves the following steps:

Modeling: A mathematical model of the system is developed to predict future behavior.

Prediction: The future states of the system are predicted over a finite prediction horizon using the model.

Optimization: An optimization algorithm is used to determine the control inputs that minimize a cost function, which typically includes terms for tracking performance and control effort.

Implementation: The optimal control inputs are applied to the system and the process is repeated at each control interval.

MPC can explicitly handle system constraints, such as voltage and current limits. MPC can manage multiple inputs and outputs simultaneously, making it suitable for complex systems like MMCs. By predicting future behavior, MPC can proactively address disturbances and uncertainties. The novel voltage sensorless estimation method leverages MPC to estimate the capacitor voltages in MMCs without the need for physical voltage sensors. This section outlines the key components and steps of the proposed method. A detailed mathematical model of the MMC is developed, capturing the dynamics of the submodule capacitors and the overall converter operation. The model includes state variables such as capacitor voltages, arm currents and output voltages. The estimation algorithm uses the system model to predict the future capacitor voltages based on the measured currents and known switching states. The predicted voltages are then used in the MPC optimization process to determine the optimal control inputs. The MPC strategy is employed to optimize the switching states of the SMs. The cost function used in the optimization includes terms for minimizing the deviation of the predicted capacitor voltages from their reference values and minimizing the control effort. The proposed method is implemented in a digital controller and extensive simulations and experimental tests are conducted to validate its performance. The results demonstrate that the sensorless estimation method provides accurate voltage estimates and robust control performance [3,4].

Discussion

The proposed voltage sensorless estimation approach for Modular Multilevel Converters (MMCs) using a Model Predictive Control (MPC) strategy represents a significant advancement in power converter technology. Traditional MMC control strategies often rely heavily on direct voltage

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Received: 01 July, 2024, Manuscript No. sndc-24-144242; **Editor assigned:** 03 July, 2024, PreQC No. P-144242; **Reviewed:** 16 July, 2024, QC No. Q-144242; **Revised:** 22 July, 2024, Manuscript No. R-144242; **Published:** 29 July, 2024, DOI: 10.37421/2090-4886.2024.13.277

measurements for accurate operation, which can introduce complexity and cost, particularly in high-voltage systems. By leveraging MPC, which optimizes control inputs by predicting future system behavior and adjusting control actions accordingly, this approach offers a novel solution. The key advantage of combining sensorless voltage estimation with MPC lies in its ability to provide precise voltage estimates without the need for physical sensors, thereby reducing hardware costs and improving system reliability. The MPC strategy uses a dynamic model of the MMC and predictive algorithms to estimate voltages based on current and voltage measurements from other parts of the system. This method not only simplifies the control architecture but also enhances the converter's performance by incorporating future states into the control decisions. Additionally, this approach can improve fault tolerance and operational flexibility, as it reduces dependency on physical sensors that might fail or drift over time. Overall, the integration of sensorless estimation with MPC in MMCs represents a forward-looking solution that can drive advancements in both the efficiency and practicality of high-power conversion systems [5,6].

Conclusion

The novel voltage sensorless estimation method for Modular Multilevel Converters, combined with a Model Predictive Control strategy, offers a promising solution to the challenges associated with traditional voltage sensing methods. By eliminating the need for physical voltage sensors, the proposed method simplifies the system design, reduces cost and enhances reliability. The use of MPC ensures high-performance operation, even in the presence of disturbances and uncertainties. While challenges remain, the method's potential benefits make it a valuable contribution to the field of power electronics and HVDC systems. Future research efforts focused on improving modeling accuracy, optimization algorithms and experimental validation will further advance the practical implementation and adoption of this innovative approach.

Acknowledgement

None.

Conflict of Interest

None.

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How to cite this article: Xue, Xingkang. “A New Voltage Sensorless Estimation Approach for Modular Multilevel Converters Using Model Predictive Control Strategy.” *Int J Sens Netw Data Commun* 13 (2024): 277.