International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 10 No. 4, 2024
https://theaspd.com/index.php

# Investigation Of Field Oriented Control of PMSM Drive Performance Using Advanced Multilevel Converter Topology

**Mehulsinh G. Jadeja[1], Saurin Shah[2], Dharmesh P. Maheshwari[3], Divyesh J. Vaghela[4]**
[1]Department of Electrical Engineering, Silver Oak University, Gujarat, India
[2]Department of Instrumentation and Control Engineering, Silver Oak University, Gujarat, India
[3]Department of Electrical Engineering, L. D. College of Engineering, Gujarat, India
[4]Department of Electrical Engineering, Vishwakarma Government Engineering College, Gujarat, India

***Abstract:*** *This study investigates the performance characteristics of a Permanent Magnet Synchronous Motor (PMSM) drive system powered by a Modular Multilevel Converter (MMC). MMCs are gaining prominence in motor drive applications due to their ability to deliver high-quality output voltage, scalability, and reduced harmonic distortion. The research focuses on analyzing both transient and steady-state behaviors of the MMC-fed PMSM system. Key indicators such as torque response, speed stability, harmonic content, and overall efficiency are evaluated under varying operating conditions. Simulation-based results highlight the advantages of using MMCs over traditional inverter configurations, particularly in enhancing output waveform quality and control accuracy. This work contributes to a deeper understanding of integrating MMCs with PMSMs for advanced drive applications, especially in high-power environments.*
***Keywords:*** *Advanced Multilevel Converter, Field Oriented Control (FOC), PMSM drive, Sub-Module Capacitor*

## 1. INTRODUCTION

Permanent Magnet Synchronous Motors (PMSMs) have gained prominence in industrial and automotive applications due to their high efficiency, power density, and superior dynamic performance [1]. However, traditional inverter topologies face challenges in handling high power and voltage levels, prompting the development of more advanced converter architectures. Introduced by Lesnicar and Marquardt in 2003, the Modular Multilevel Converter (MMC) offers a scalable and efficient solution with reduced harmonic distortion, improved voltage quality, and modular design benefits [2]. Integrating MMCs with PMSMs enables enhanced performance in medium- to high-voltage drive systems, especially in electric traction and renewable energy applications [3]. This paper investigates the dynamic behaviour, control strategies, and performance benefits of MMC-fed PMSM drives for advanced electric drive applications. In [4], authors proposed discusses the Hybrid Low-Capacitance MMC (HLC-MMC) for medium voltage PMSM drive and its control method. The proposed HLC-MMC aims to reduce SM capacitor voltage fluctuation and energy variations by controlling the transmission of fluctuation currents and achieving their coupling. The document also presents the theoretical basis for the coupling offset of fluctuation currents. In [5], authors present a sensor-less PMSM drive system powered by a five-level inverter using a Modified Model Predictive Torque Control (MPTC) technique combined with a novel Reduced Search Space Algorithm. The proposed method significantly decreases computational complexity while maintaining high dynamic performance and torque accuracy. Eliminating the need for physical sensors improves system reliability and cost-efficiency. a multi-stage hybrid fault diagnosis method to detect open-circuit faults in three-phase Voltage Source Inverter (VSI)-fed Permanent Magnet Synchronous Motor (PMSM) drive systems proposed in [6]. Combining signal-based analysis and model-based techniques, the approach enhances fault detection speed, accuracy, and robustness under varying load and speed conditions. In [7], authors present a control strategy for a Wave shaper Modular Multilevel Converter (MMC) system combined with a thyristor-based front-end converter to drive an open-end winding, variable-speed, medium-voltage induction motor. The proposed approach enables high-quality voltage synthesis, wide speed range operation, and reduced harmonic distortion. The hardware-based comparative study of various multilevel inverter topologies for integrated motor drives, focusing on performance under overload conditions is presented in [8]. It evaluates parameters such as thermal behaviour, efficiency, output quality, and fault tolerance across different inverter types.

In [9], authors discusses the real-time emulation of a Permanent Magnet Synchronous Motor (PMSM)-loaded Modular Multilevel Converter (MMC) integrated with a Battery Energy Storage System (BESS). The proposed system emulates the dynamic behavior of the motor and converter while optimizing power flow from the BESS. It focuses on the real-time control strategies for managing the interaction between the PMSM and MMC, improving system performance, and ensuring efficient energy storage and

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 10 No. 4, 2024
https://theaspd.com/index.php

conversion. In [10], authors explore the challenges limiting Modular Multilevel Converters (MMCs) in high-performance drive applications, such as control complexity and harmonic distortions. The authors propose novel strategies to address these issues, including advanced modulation and control schemes. Their work extends the practical applicability of MMCs in demanding industrial scenarios. In [11], authors introduce the Active Cross-Connected Modular Multilevel Converter (AC-MMC) for medium-voltage motor drives, aiming to enhance system reliability and efficiency. The proposed topology reduces submodule voltage imbalance and improves fault tolerance. Simulation and experimental results validate the improved performance of the AC-MMC design. In [12], authors investigate the operation of Modular Multilevel Converters (MMCs) at low output frequencies, a critical challenge for industrial drive applications. They highlight issues such as circulating currents and submodule capacitor voltage balancing. The study proposes control strategies to ensure stable and efficient low-frequency performance. In [13], authors have proposed an optimal phase shift angle-based CPS-PWM method for full-bridge MMC systems driving permanent magnet synchronous motors (PMSMs). The method aims to minimize harmonic distortion and improve output waveform quality. In [14]. authors present a control strategy for balanced submodule operation in MMC-based induction motor drives across a wide-speed range. Their approach ensures stable performance and efficient voltage balancing under varying load conditions.

In [15], authors have proposed a hybrid MMC topology combining half-bridge and full-bridge submodules for medium-voltage variable-speed motor drives. The design enhances fault tolerance and reduces system cost while maintaining high performance. In [16], authors have developed a two-degree-of-freedom backstepping observer to suppress DC error in sensorless PMSM drives. The method improves control accuracy and dynamic performance without relying on physical sensors. Based on literature review and problem associated with the PMSM drive, this paper proposed the PMSM drive with advanced power electronic converter topology i.e. MMC which is more reliable and efficient than another converter topology. The details waveform analysis is presented in the paper.

**2. Basic about PMSM and its operation**

The Permanent Magnet Synchronous Motor (PMSM) is a rotating electrical machine where the stator is a classic three phase stator like that of an induction motor and the rotor has surface mounted permanent magnets. In this regard, The Permanent Magnet Synchronous Motor is equivalent to an induction motor where the air gap magnetic field is produced by a permanent magnet. Thus, with the development of permanent materials and control technology the PMSM is mostly used due to high torque/inertia ratio, high power density, high efficiency, reliability and easy for maintenance in different industrial applications. A brushless PMSM has a wound stator, a permanent magnet rotor assembly, and internal or external devices to sense rotor position. The sensing devices provide position feedback for adjusting frequency and amplitude of stator voltage reference properly to maintain rotation of the magnet assembly. The combination of an inner permanent magnet rotor and outer windings offers the advantages of low rotor inertia, efficient heat dissipation, and reduction of the motor size. Moreover, the elimination of brushes reduces noise, EMI generation and suppresses the need of brushes maintenance. Based on the mounting arrangement of magnet on rotor core, Permanent Magnet Synchronous Motor (PMSM) can be categorized into two types: Surface Mounted PMSMs and Buried or interior PMSMs The working principle of permanent magnet synchronous motor is same as that of synchronous motor. When three phase winding of stator is energized from 3 phase supply, rotating magnetic field is set up in the air gap. At synchronous speed, the rotor field poles lock with the rotating magnetic field to produce torque and hence rotor continues to rotate. Figure-1 shows the basic block diagram of MMC fed PMSM drive.

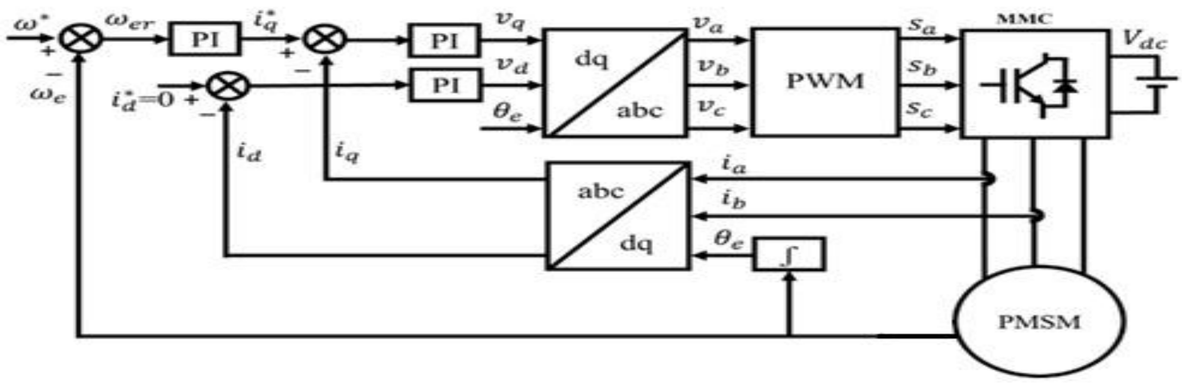



Figure-1 Block diagram of MMC fed PMSM drive

## 3. Field Oriented Control of MMC fed PMSM drive

Modular Multilevel Converters (MMCs) are advanced power electronic converters well-suited for high- and medium-voltage applications due to their scalability, modularity, and superior output waveform quality. When used to drive Permanent Magnet Synchronous Motors (PMSMs), MMCs offer enhanced efficiency, reduced harmonic distortion, and improved dynamic performance.

Field-Oriented Control (FOC) is a popular control strategy for PMSM drives that allows independent control of torque and flux by transforming the stator currents into a rotating reference frame. Combining MMC with FOC enables precise and efficient control of PMSM operation across a wide speed range.

The FOC block diagram typically consists of the following components:

- **Current Controller (PI):** Two PI controllers are used to regulate the d- and q-axis currents (id, iq). The controller compares the actual current values with reference currents (id∗, iq∗) and adjusts the voltage commands vd,vq accordingly.
- **Clarke & Park Transformations:** This block converts the three-phase stator currents ( ia,ib,ic) into two-axis (d-q) rotating reference frame components using the rotor position angle (θ). This simplifies control, allowing independent regulation of flux and torque.
- **Speed Controller (PI):** The actual rotor speed (ω) is subtracted from the reference speed (ω*) to calculate the speed error. This error is processed by a Proportional-Integral (PI) controller, which generates the reference q-axis current iq∗, responsible for producing the required torque.
- **Inverse Park & Clarke Transformations:** This transforms the control voltages vd,vq back into three-phase AC voltages va,vb,vc required by the MMC to drive the PMSM. These voltages are then modulated and applied through the converter.
- **PWM Generation for MMC:** The reference voltages are fed into a Carrier Phase-Shifted PWM (CPS-PWM) or another advanced modulation technique suitable for MMCs. This block generates switching signals for each MMC submodule, ensuring smooth output voltage with low harmonic content.

Figure-2 shows transformation of 3 phase quantity to 2 phase quantity using clark and park transformation.

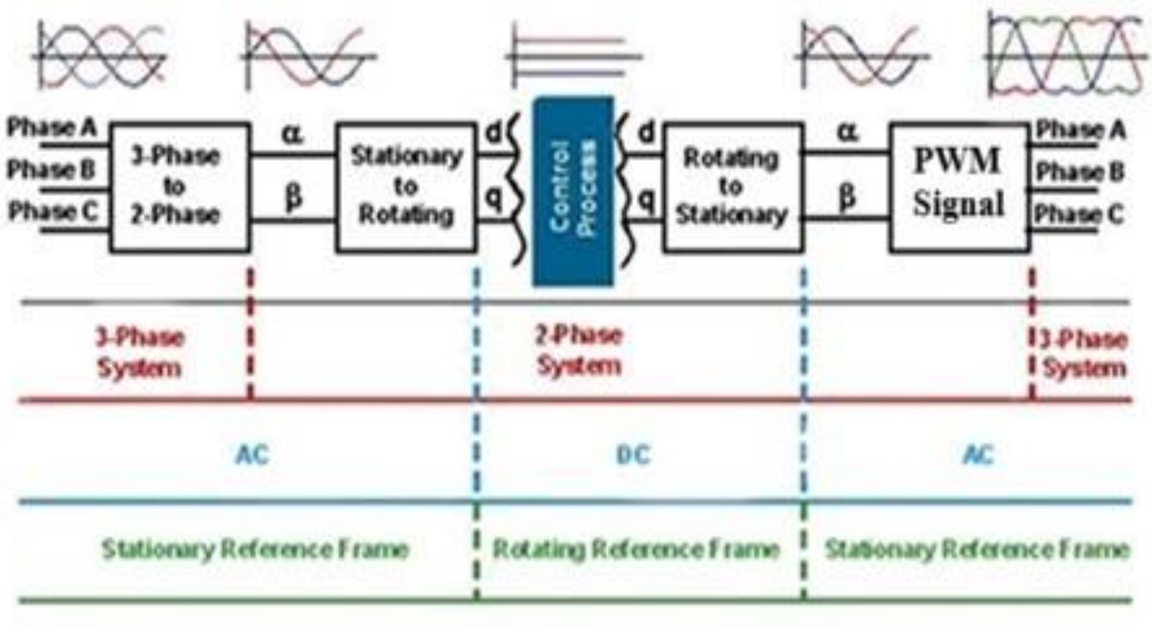



Figure-2 Transformation of current and voltage (Clark and Park's Transformation)

## 4. Experimental Results and Discussion

To check the performance of MMC fed PMSM drive under no load and full load application, small laboratory prototype is prepared. The details circuit diagram of MMC fed PMSM drive is shown in figure-3. Figure-3 shows the three phase MMC converter with half bridge sub-module topology. To control the speed of induction motor, Field Oriented Control (FOC) technique is employed in closed loop. Phase Shifted Multi Carrier PWM (PSC-PWM) used to control the MMC parameters. Model based Simulation is used to generate the code for real time controller. For each arm, 4 SM is used, and central arm inductor is employed which is used to limit the circulating current.

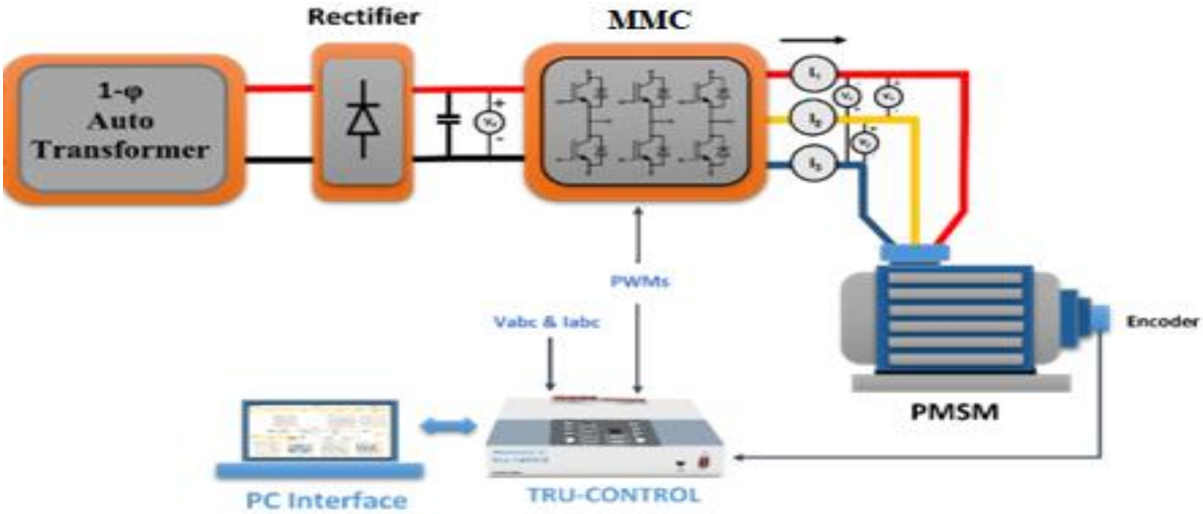
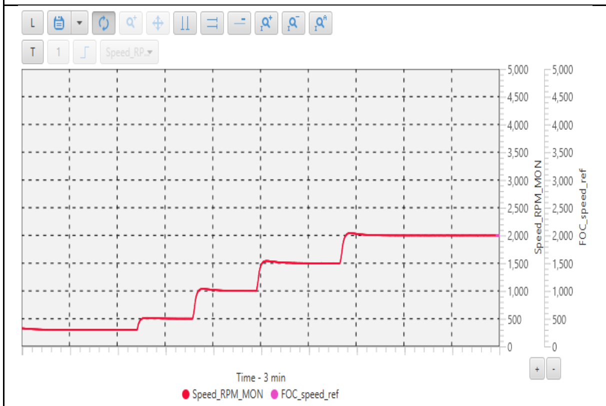
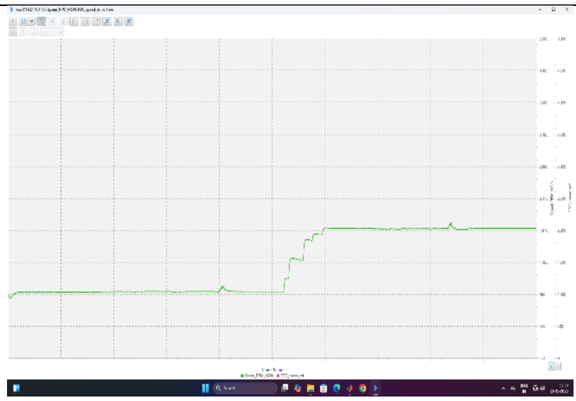
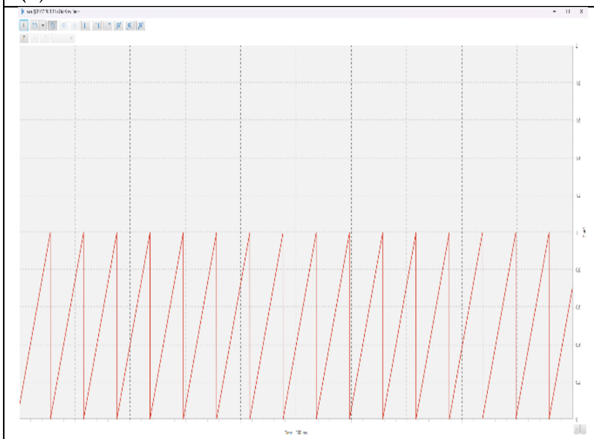
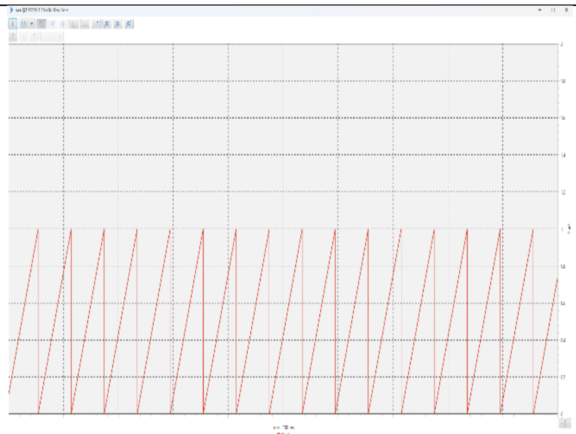
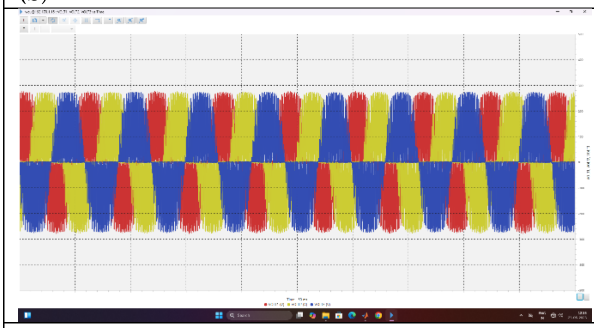
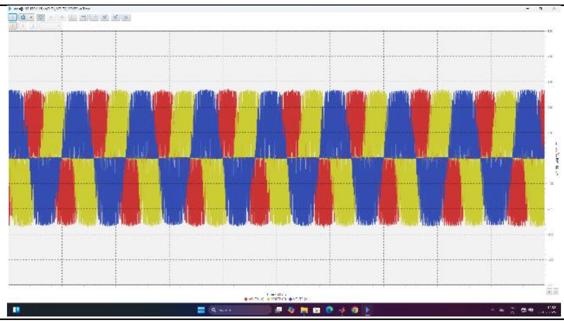
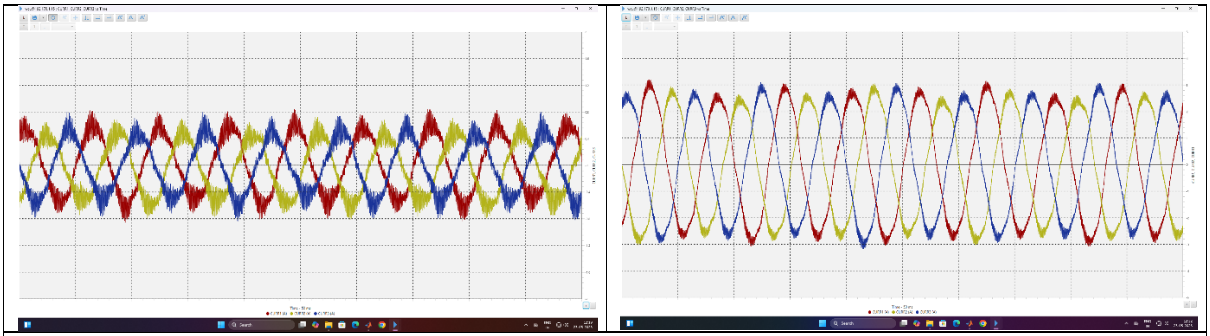
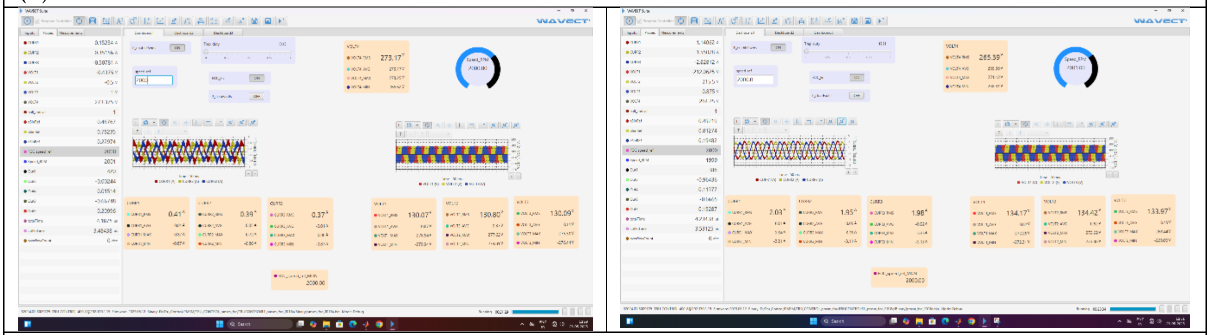



Figure-3 Experimental set-up block diagram

| No Load Condition | Full Load Condition |
|---|---|
|   |  |
| (a) | |
|  |  |
| (b) | |
|  |  |
| (c) | |



(d)



(e)

Figure-4 Real time simulator waveform analysis and comparison (a) Speed at no load and full load, (b) theta angle at no load and full load, (c) Line voltages at no load and full load, (d) Load current at no load and full load, (e) Real time simulator waveform analyser window showing at no load and full load condition.

Figure-4 shows waveform analysis of MMC fed closed loop control of induction motor drive using TRUE Controller (Real Time Hardware Simulator). The comparison between no load and full load condition of MMC fed induction motor drive is evaluated. Figure-4 (a) shows the reference speed and actual speed of motor with and without loading arrangements. It is observed that due to robust control algorithm, actual speed of motor follows the reference speed. Figure-4 (b) shows theta angle with respect to motor speed. Based on reference speed command signal, theta angle will very and track the motor speed according to reference speed. Line voltages at the motor terminal is shown in figure-4 (c). It is observed that at no load and full load condition, the magnitude of line voltages remain same due to robust control structure. Figure-4 (d) shows load current waveform. It is observed that at no load condition, motor draws very minimal value of current to supply the motor losses. Complete dashboard view of real time hardware simulator is shown in figure-4 (e).

From the above experimental set-up and results analysis, it is observed that field orientated control of MMC fed PMSM drive is more reliable and accurate compared to conventional 2- level converter fed PMSM drive.

## 5. CONCLUSION

This paper presented the new converter topology for PMSM drive. Conventional 2-level converter fed PMSM drive is not reliable due its construction limitation as well as it is not suitable to operate the motor under entire speed range. The modular multilevel converter has a flexibility in increasing the any level of output voltage without adding any extra complex hardware circuitry as well as modularity in structure make more suitable for field-oriented control of PMSM drive. It is observed from the experimental set-up and waveform analysis, the performance of PMSM drive under entire speed range is satisfactorily. The steady state and transient response of motor is observed under varying motor speed and torque condition.

**REFERENCE:**

[1] Krishnan, R., 2010, Permanent Magnet Synchronous and Brushless DC Motor Drives, CRC Press.

[2] Lesnicar, A., and Marquardt, R., 2003, “An Innovative Modular Multilevel Converter Topology Suitable for a Wide Power Range,” Proc. IEEE Power Tech Conf., Bologna, Italy.

[3] Akagi, H., 2017, “Medium-Voltage Motor Drives Based on Modular Multilevel Converters,” IEEE Trans. Ind. Electron., 64(3), pp. 2253–2261.

[4] Zhang, Y., Li, S., Zhang, X., Liu, C., Liu, Z., and Luo, B., 2023, "A Hybrid Low Capacitance Modular Multilevel Converter for Medium Voltage PMSM Drive and Its Control Method," IEEE Access, 11, pp. 92796–92806. doi:10.1109/ACCESS.2023.3308950.
[5] Kumar, P. D., Ramesh, T., Ramakrishna, P., and Tangirala, I., 2023, "Five-Level Inverter Fed Sensorless PMSM Drive Using Modified MPTC With Novel Reduced Search Space Algorithm," IEEE Trans. Ind. Appl., 59(6), pp. 6826–6838. doi:10.1109/TIA.2023.3309609.
[6] Mohammadi, F., and Saif, M., 2023, "A Multi-Stage Hybrid Open-Circuit Fault Diagnosis Approach for Three-Phase VSI-Fed PMSM Drive Systems," IEEE Access, 11, pp. 137328–137341. doi:10.1109/ACCESS.2023.3339549.
[7] Chakraborty, S., and Maiti, S., 2022, "Control of a Waveshaper-MMC With Thyristor-Based Front-End Converter for Open-End Winding Variable Speed Medium-Voltage Induction Motor Drive," IEEE Trans. Ind. Appl., 58(5), pp. 6203–6214. doi:10.1109/TIA.2022.3180041.
[8] Rohner, G., et al., 2023, "Hardware-Based Comparative Analysis of Multilevel Inverter Topologies for Integrated Motor Drives Considering Overload Operation," IEEE Open J. Power Electron., 4, pp. 934–944.
[9] Omar, A., Wood, A., Laird, H., and Gaynor, P., 2023, "Real-Time Emulation of a PMSM-Loaded MMC With BESS," IEEE Access, 11, pp. 55035–55045.
[10] Breda, R., Breda, S., Calligaro, S., and Others, 2023, "Extending the Application Range of MMCs in High-Performance Drives: Limiting Issues and New Proposals," Elektrotech. Inftech., 140, pp. 21–33.
[11] Du, S., Wu, B., Tian, K., et al., 2016, "An Active Cross-Connected Modular Multilevel Converter (AC-MMC) for a Medium-Voltage Motor Drive," IEEE Trans. Ind. Electron., 63(8), pp. 4707–4717.
[12] Korn, A. J., Winkelnkemper, M., and Steimer, P., 2010, "Low Output Frequency Operation of the Modular Multi-Level Converter," Proc. IEEE Energy Convers. Congr. Expo., pp. 3993–3997.
[13] Hu, C., Xu, W., Geng, W., Ma, Y., and Liu, B., 2022, "An Optimal Phase Shift Angle Based CPS-PWM Method for Full-Bridge MMC-PMSM System," Proc. IEEE Int. Power Electron. Appl. Conf. Expo. (PEAC), Guangzhou, China, pp. 1546–1551.
[14] Kumar, Y. S., and Poddar, G., 2020, "Balanced Submodule Operation of Modular Multilevel Converter-Based Induction Motor Drive for Wide-Speed Range," IEEE Trans. Power Electron., 35(4), pp. 3918–3927.
[15] Li, B., Zhou, S., Xu, D., Finney, S. J., and Williams, B. W., 2017, "A Hybrid Modular Multilevel Converter for Medium-Voltage Variable-Speed Motor Drives," IEEE Trans. Power Electron., 32(6), pp. 4619–4630.
[16] Shao, Y., Yu, Y., Chai, F., and Chen, T., 2022, "A Two-Degree-of-Freedom Structure-Based Backstepping Observer for DC Error Suppression in Sensorless PMSM Drives," IEEE Trans. Ind. Electron., 69(11), pp. 10846–10858.