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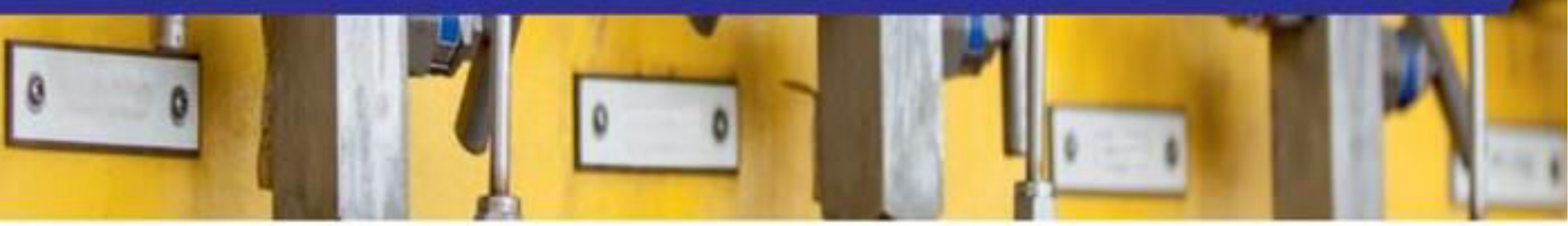

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Enhanced Design of a High Performance PMSM Drive with FOC for EV Propulsion

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ABSTRACT: Because of their excellent dynamic performance, high power density, and high efficiency, permanent magnet synchronous motors (PMSMs) are extensively used in electric vehicle (EV) applications. For precise speed and torque regulation under a range of operating situations, PMSM drives need efficient control. This project uses Space Vector Pulse Width Modulation (SVPWM) to describe, develop, and implement a Field-Oriented Control (FOC) approach for a PMSM drive. The suggested control technique allows the flux and torque components to be independently controlled, improving the system's stability and dynamic reactivity. The PMSM's mathematical model is developed and implemented in MATLAB/Simulink within the d–q reference frame. The suggested control approach is appropriate for high-performance EV traction applications since it performs well in simulations. This work highlights the importance of sophisticated control techniques and offers a strong basis for attaining robust motor performance, high efficiency, and a broad speed range in PMSM-based EV drives.

KEYWORDS: Permanent Magnet Synchronous Motor (PMSM), Field Oriented Control (FOC), Space Vector Pulse Width Modulation (SVPWM), Electric Vehicle (EV), Pulse Width Modulation (PWM)..

I. INTRODUCTION

Electric motor drives play an important role in today's transportation and industrial systems. High-performance motor drives can't use conventional scalar control methods because they don't allow for independent control of flux and torque. To overcome this limitation, Field Oriented Control (FOC) [1] is used. Similar to a DC motor, FOC turns three-phase currents into a rotating reference frame, allowing for precise torque and flux control. The result is an improvement in both efficiency and dynamic response. In order for inverter switching to function properly, Space Vector Pulse Width Modulation (SVPWM) is utilized. SVPWM reduces harmonic distortion and makes better use of the DC bus than conventional PWM techniques. Advanced control strategies like predictive current control have gained popularity in recent years due to their improved control accuracy and rapid dynamic response. This paper focuses on the modeling and simulation of an IPMSM drive using Field Oriented Control and SVPWM. MATLAB/Simulink is used to build the system, which can measure speed, torque, and current performance.Due to its stable operation, quick response time, and high efficiency, the outcomes demonstrate that the proposed control strategy is suitable for contemporary industrial and electric vehicle applications.

II. PMSM DRIVE

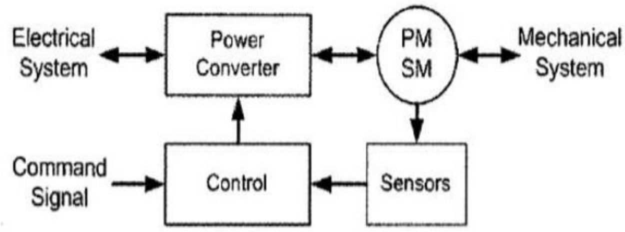

Fig1. PMSM Drive

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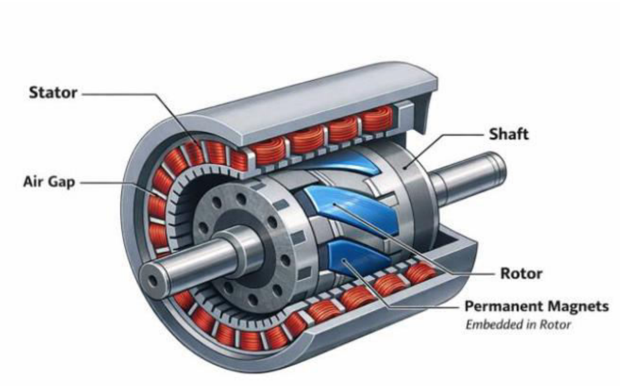

Fig2. Structure of IPMSM

III. METHODOLOGY

The present work is divided into two main sections. MATLAB/Simulink is used to simulate the Field Oriented Control (FOC) method in the first section, while hardware implementation of the control strategy is covered in the second. Field Oriented Control is a well-established and widely used method for controlling electric motors, especially in electric vehicle (EV) applications. It enables smooth and precise control of motor torque and speed, resulting in quiet and efficient operation.

The adoption of FOC in electric vehicles has increased significantly due to its ability to provide high efficiency, fast dynamic response, and reduced acoustic noise. These characteristics are essential for modern EV systems, where smooth performance and energy efficiency are critical requirements. Furthermore, the use of FOC contributes to improved driving comfort and enhanced motor reliability.

From a societal perspective, the implementation of FOC in electric vehicles plays an important role in reducing air pollution and noise pollution. FOC-based motor control contributes to the global shift toward environmentally friendly and sustainable transportation systems by enhancing the effectiveness and performance of electric drives.

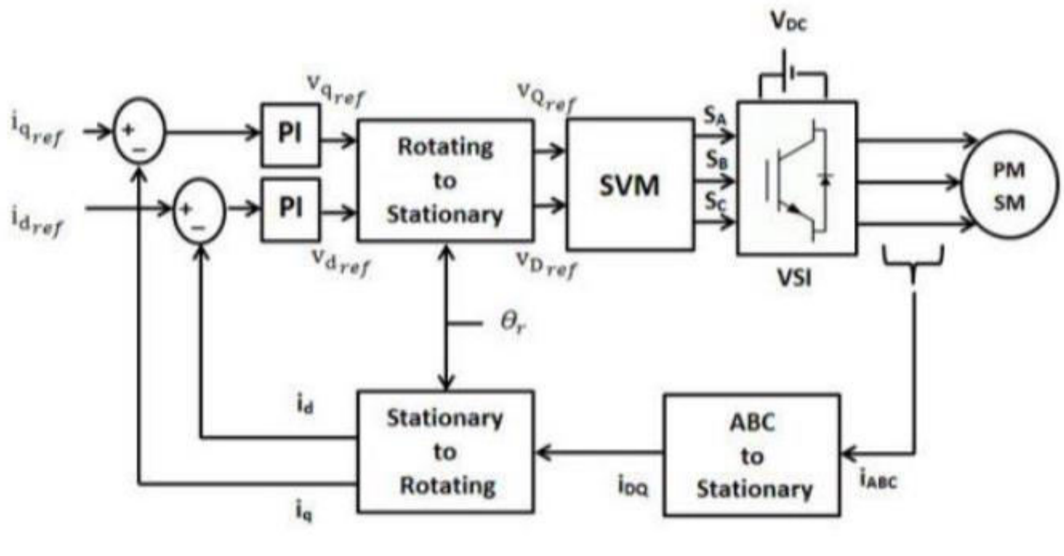

FIG 3.FOC Block diagram

The machine's actual speed is compared to a reference value, and the error is sent to the PI controller as input so that it can be changed to be sent to the next stage as input. As a result, the reference speed and the actual speed are contrasted, and the error is adjusted with the help of the PI controller. This information is then passed on to the subsequent stage as

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quadrature axis current, which is then used to calculate the reference quadrature current. The park transformation block, where the line currents Ia,Ib,Ic are measured and converted into d-q axis currents, is where the actual quadrature current is derived.

IV. OVERALL SIMULINK SYSTEM DESCRIPTION

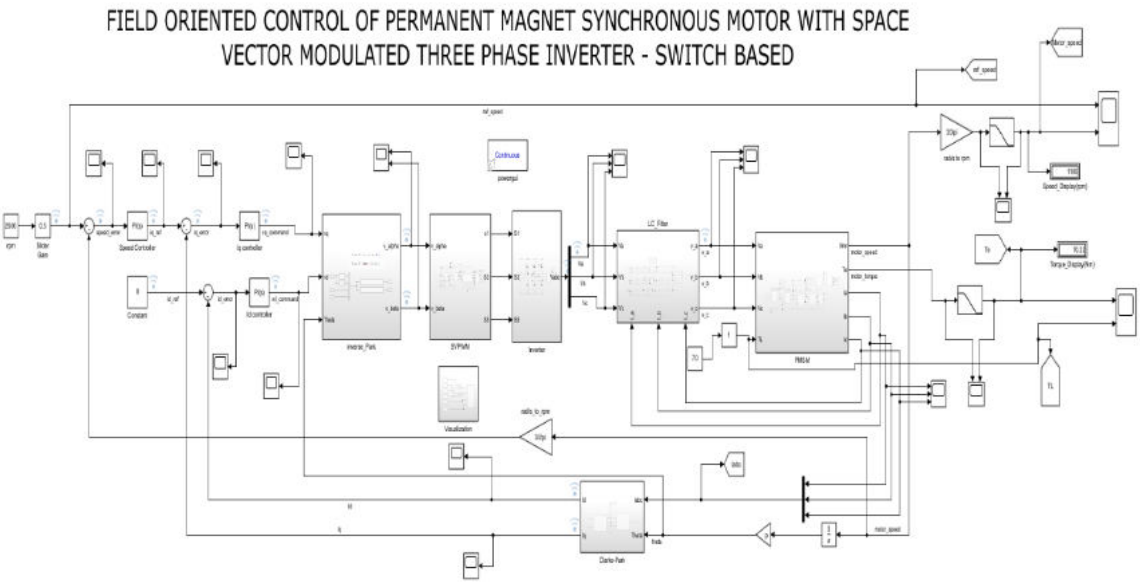

Fig4. MATLAB/Simulink model of PMSM using Field-Oriented Control and SVPWM

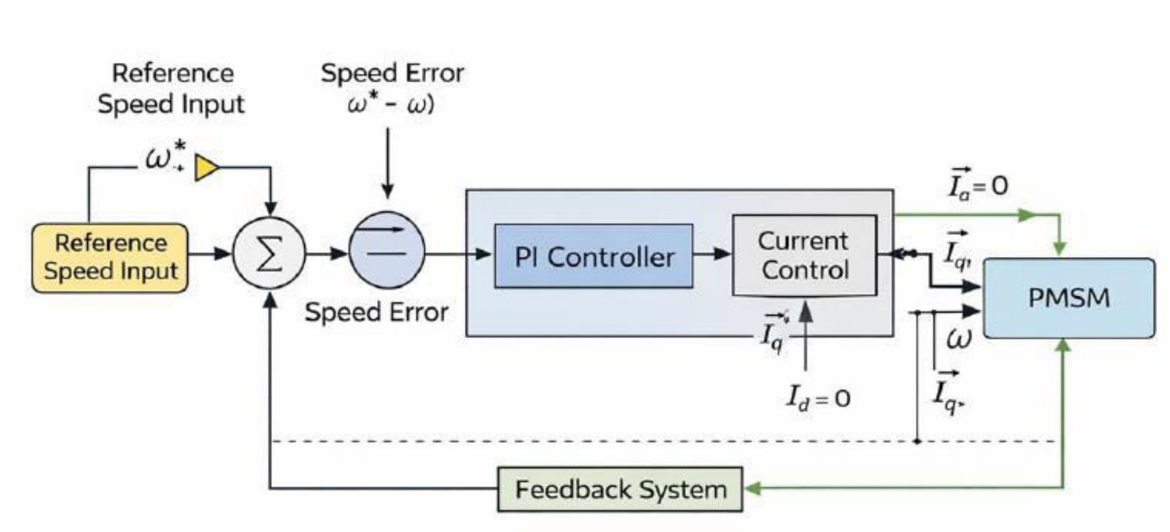

FIG5. Speed Control Loop

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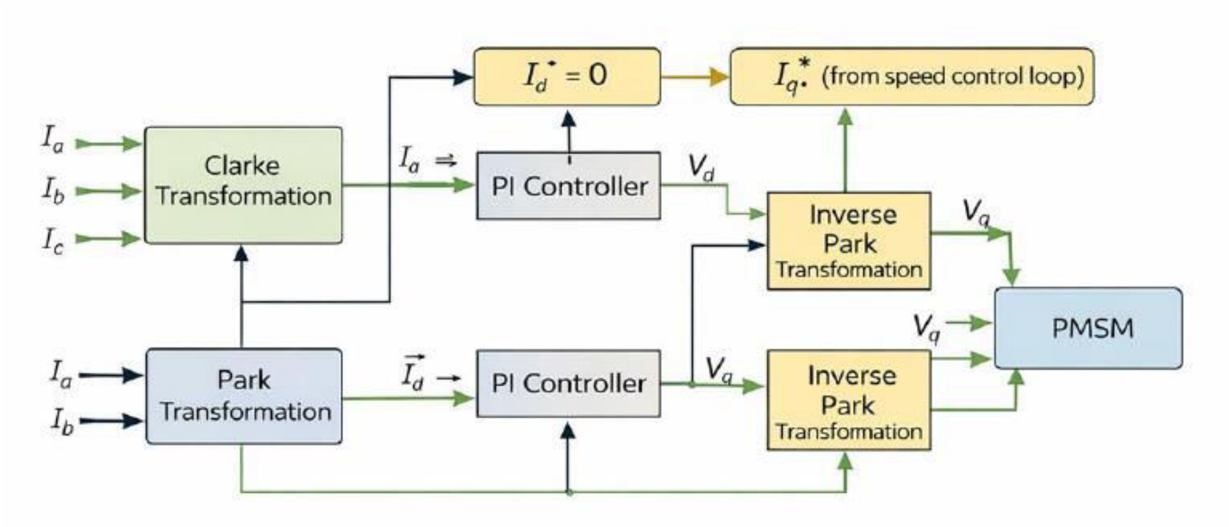

Fig6: Current Control Loop

V. THREE-PHASE VOLTAGE SOURCE INVERTER (VSI) WITH SVPWM

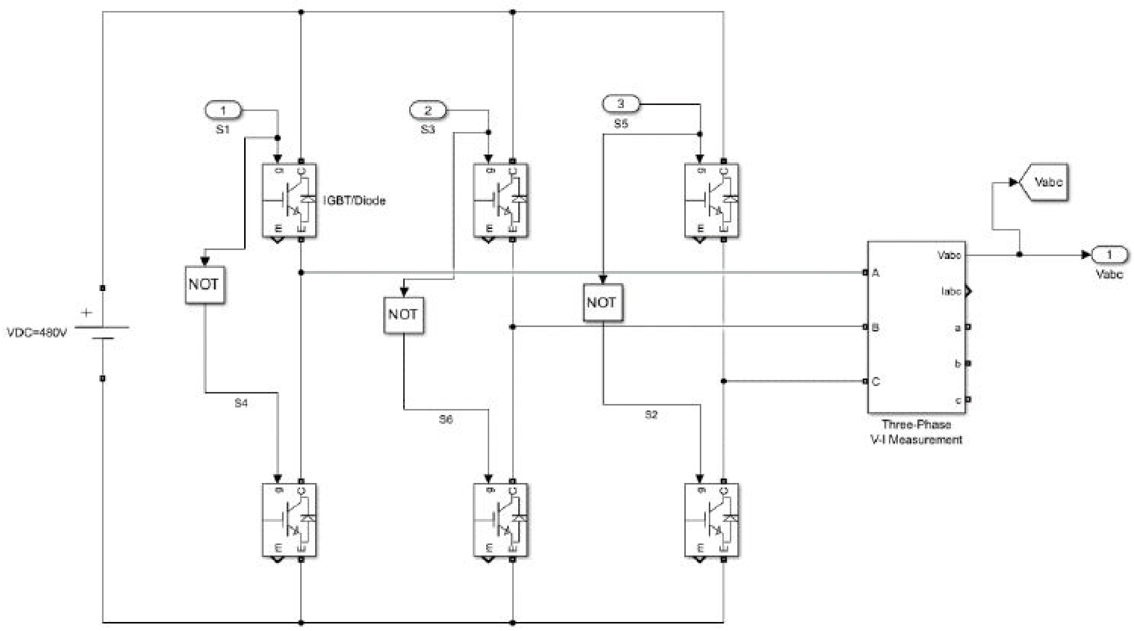

Fig7. Three-Phase IGBT-Based Inverter with PWM Switching and V–I Measurement

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VI. SIMULATION MODEL DESCRIPTION

Motor Type: Interior Permanent Magnet Synchronous Motor (IPMSM)

Number of Poles	8
Rated Power:	80 Kw
Rated Speed:	3000 rpm
Maximum Speed:	8000 rpm
Rated Voltage:	400 V DC-link
Rated Current:	150 A (peak)

VII. SPEED RESPONSE ANALYSIS

The speed response of the PMSM under FOC control is observed during starting and load variation conditions.
The motor reaches the reference speed smoothly without overshoot.
The settling time is reduced compared to conventional control methods.
The speed remains stable even during sudden changes in load.
This confirms that the FOC algorithm provides fast dynamic response and accurate speed tracking. The speed response of the PMSM under FOC control is shown in the figure. The motor quickly reaches the reference speed of 1250 rpm, indicating a fast dynamic response. At around 1.86 s, a half-load is applied, causing a small drop in speed, which is quickly corrected by the controller. Similarly, at 2.92 s, a full-load condition is applied, resulting in a slightly larger dip, but the speed is restored smoothly.

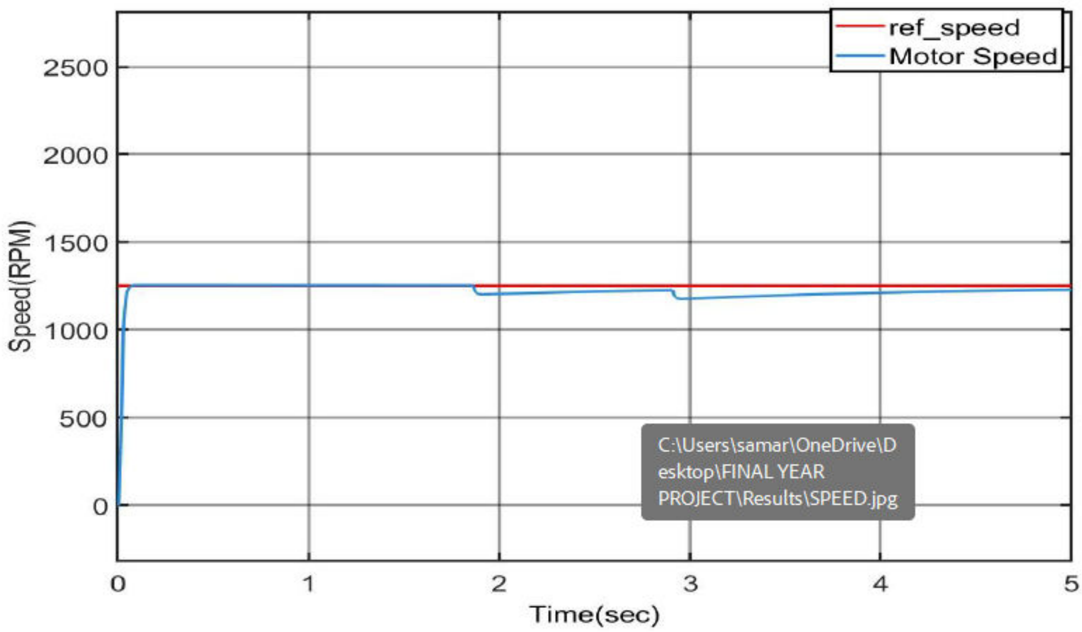

Fig. 8 PMSM speed response under varying load condition

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These results show that the FOC controller provides good speed regulation, fast recovery under load changes, and stable operation, making it suitable for variable-load applications such as electric vehicles.

VIII. TORQUE RESPONSE ANALYSIS

The electromagnetic torque produced by the motor is proportional to the quadrature-axis current (Iq).
∟ Smooth torque profile with minimal ripple
∟ Quick torque response during acceleration
∟ Stable torque under steady-state conditions
The reduction in torque ripple improves motor efficiency and reduces mechanical vibrations, making the system suitable for electric vehicle applications.

The figure shows the electromagnetic torque (Te) and load torque (Tl) of the PMSM under different load conditions. Initially, a high starting torque is observed, which helps the motor overcome inertia and reach the desired speed quickly.

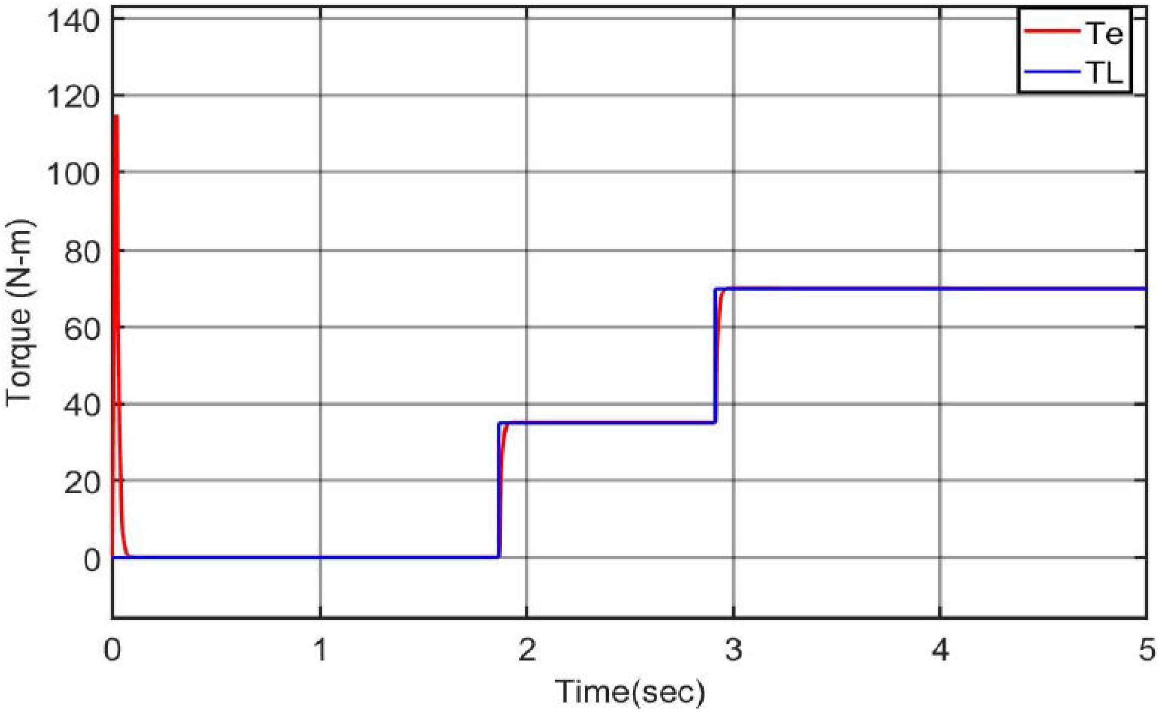

Fig. 9 Electromagnetic torque and load torque response of PMSM under half-load and full-load additions

At around 1.86 s, a half-load torque is applied, causing the electromagnetic torque to rise and match the load torque. Later, at approximately 2.92 s, a full-load condition is applied, and the motor torque increases accordingly to maintain speed. In both cases, the electromagnetic torque closely follows the load torque with minimal delay, indicating good torque tracking capability of the FOC controller.
This confirms that the FOC strategy provides fast torque response, good load disturbance rejection, and stable operation under varying load conditions.

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IX. THREE-PHASE STATOR CURRENT WAVEFORMS OF PMSM UNDER VARYING LOAD CONDITIONS

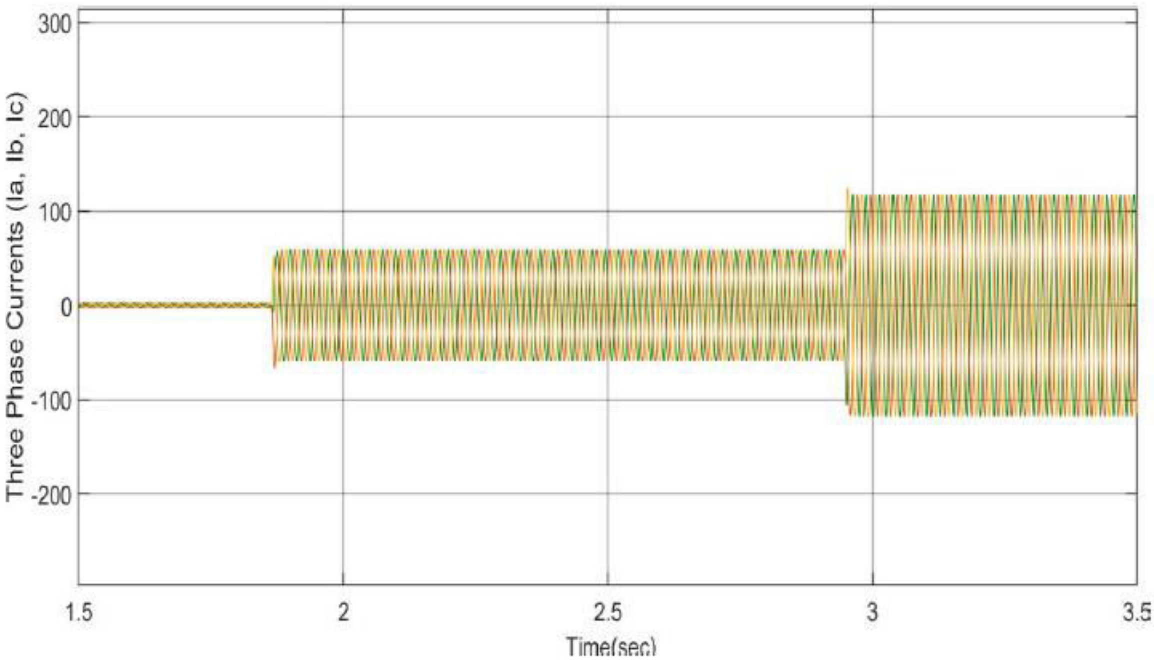

Fig .9 Three-phase stator current waveforms of PMSM under varying load conditions

The currents remain balanced, sinusoidal, and 120° phase-shifted, indicating proper operation of the inverter and effective implementation of the Field-Oriented Control (FOC) technique. The smooth transition in current magnitude during load changes confirms good dynamic performance and stable current control**.**

X. CONCLUSION

MATLAB/Simulink was used to successfully design and simulate a Permanent Magnet Synchronous Motor (PMSM) drive system based on Field-Oriented Control (FOC). The main objective was to achieve precise speed and torque control by decoupling the flux and torque components of the motor.

From the simulation results, it is observed that the motor achieves fast and smooth speed response with minimal overshoot. The speed remains almost constant even when load variations are applied, which proves the effectiveness of the closed-loop control system. The torque response shows that the electromagnetic torque closely follows the load torque, indicating proper torque control through the q-axis current.

The outcomes of the simulations show that the proposed FOC scheme offers:
• Fast dynamic response
• Accurate speed tracking
• Effective torque control
• Stable operation under load variations

The d-axis current (Id) was maintained close to zero, ensuring maximum torque per ampere operation, while the q-axis current (Iq) varied according to load demand, confirming proper torque control. The use of SVPWM improved inverter performance by reducing harmonic distortion and increasing DC bus utilization.

From the results, it is clear that the FOC technique offers superior performance compared to conventional control methods and is highly suitable for applications such as electric vehicles, industrial drives, and robotics.

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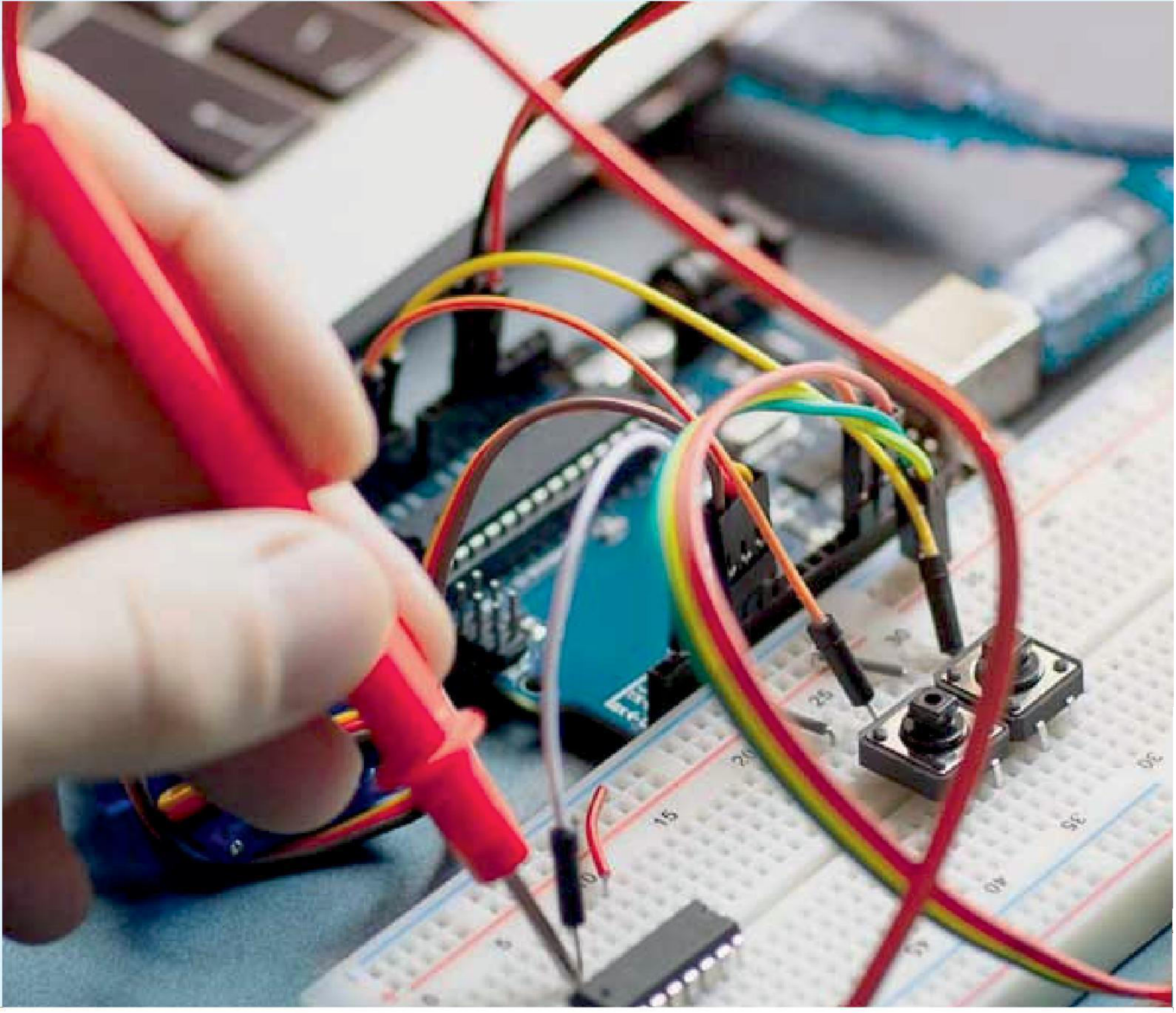

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