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Vector Control Technique for Permanent Magnet Synchronous Motor (PMSM) Drives

Monika Gairola[1] and Dr. A. K. Swami[2]
Ph.D. Scholar, Department of Electrical Engineering[1]
Professor and Head, Department of Electrical Engineering[2]
Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Abstract: *The importance of permanent magnet synchronous motors (PMSM) is that they have high performance and efficiency for motor drives. The control characteristic of the high-performance motor is that it runs smoothly on the entire speed range, torque can be controlled even at zero speed, and acceleration and deceleration are fast. Optimization of the performance of speed control under various constraints and uncertainties is one of the biggest concerns in PMSMs. In this sense, various speed-control mechanisms have been proposed to identify better ways to control PMSM drives with high-speed characteristics and desired torque response. However, it is necessary to have a suitable control mechanism where better adjustment of performance can be achieved for a different operating condition. However, due to the complexity of the PMSM system, it is quite difficult to differentiate the system characteristics and dynamic control parameters when running in real-time. This paper intends to present a vector control method for PMSM drive called field oriented control (FOC) and results is studied using MATLAB/SIMULINK.*

Keywords: Permanent Magnet Synchronous Motors, Vector Control, Field Oriented Control etc

I. INTRODUCTION

Environment and energy have recently been the two major themes for social development. Many social issues, including air pollution, global warming, a lack of fossil fuel resources, and combustion, have attracted great attention for the construction of pollution-free and efficient traction systems in electric vehicles (EV) **.** Due to the advancement in power electronics, automatic control technology, and computer technology, the performance of the AC speed control system improves. Due to all these advancements, it challenges the dominant position of DC speed control in the field of high-performance speed regulation **.** It is undeniable that the AC speed control system is being used more and more in place of the DC speed control system **.** The advantages of synchronous motors in speed control are their high power factor, small inverter power capacity, and low moment of inertia. The advantages of synchronous motor speed control systems in high-power AC transmission systems are self-evident. Three-phase induction motors are frequently used in industry because of their reliability, simple design, robust construction, and low cost. However, the induction motor requires magnetizing current from the power supply, which negatively affects the power factor. Loss also increased due to the presence of rotor winding. Therefore, synchronous motors with permanent magnets (PMs) in the rotor are used to overcome these limitations . In industries with lower power ratings, such as those for pumps, robotics, power tools, domestic appliances, and medical equipment, PMSM motors are frequently used in place of induction motor drives. While operating engines in industrial applications, all operating points are known in advance. However, while driving an electric vehicle, the operating points cannot be known in advance because it depends upon the driver's driving style and road conditions. For this reason, three-phase asynchronous motors cannot be used in electric vehicles. Due to their light weight and low losses, PMSMs are commonly used in electric motors and aerospace applications. In terms of performance, the PMSM must have an improved transient response time in the majority of applications. The uninterrupted running of the motor across the full speed range, the ability to manage torque even at zero speed, and quick acceleration and deceleration are characteristics of PMSM control's excellent performance. The primary concern in PMSM is the optimization of the speed control performance under various restrictions and uncertainties. To find the best method of controlling PMSM drive control with high-speed features and the necessary torque response, a variety of speed control techniques were given . The basic design of PMSM is the same as that of synchronous motor. A distinctive feature is the engine's rotor. In the case of PMSM there is no excitation winding and permanent magnets are mounted on the rotor core. Depending on the configuration of the rotor's magnets, PMSMs are divided into two types: Internal and Surface Mounted Permanent Synchronous motor. For surface mount PMSM, permanent magnets are presented on the surface of the rotor, whereas permanent magnets are embedded in the rotor instead of the surface in interior type shown in figure 1.

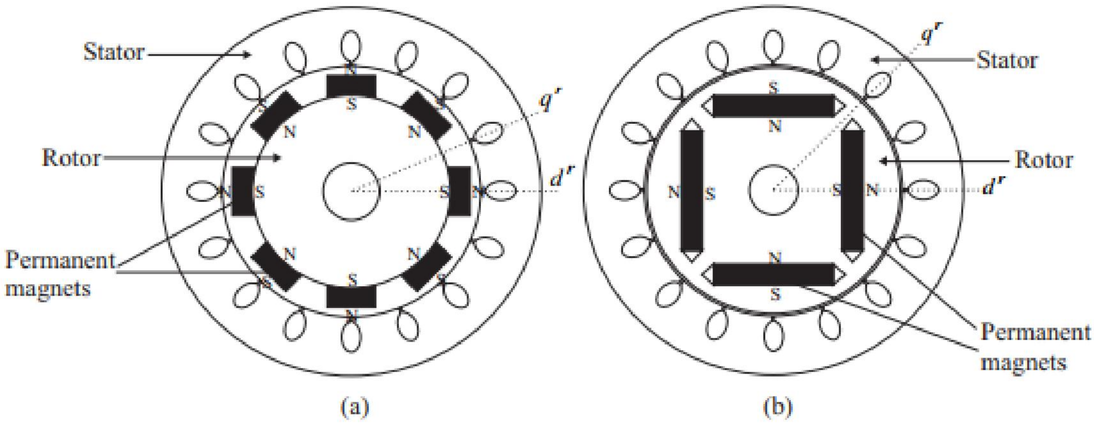

Fig.1. Different rotor configurations for PMSMs. (a) Surface magnets type (b) Interior magnets type.

The PMSM operates on the same principle as a synchronous motor. If the 3-phase supply is used to power the three phase stator windings , a rotating magnetic field is produced place in the air gap. Advantage and disadvantage of PMSM is shown in table 1 .

Table 1: Advantage and disadvantage of PMSM

S.No.	Advantage of PMSM	Disadvantage of PMSM
1.	Low Torque Ripples	Requires a drive
2.	High Efficiency	Complex control system
3.	High Power Density	Higher initial cost
4.	Low maintenance cost	
5.	Low heat generation	

II. PMSM SPEED CONTROL TECHNIQUES

PMSMs are capable to run at different speeds by the help of variable frequency drive. Classically, there are three different category of control theory of PMSM: scalar control, field- oriented control (FOC), and direct torque control (DTC) which is shown in figure 2. Here only the FOC control of PMSM drives is discussed. They are summarized as follow:

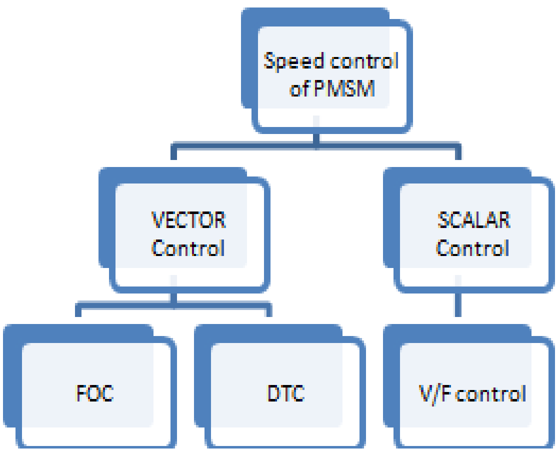

Fig. 2. Speed Control Methods of PMSM

III. REVIEW OF LITERATURE

Sinha and Misra (2021) This research paper suggested that the control of an electric vehicle (EV) can be achieved by managing the electric motor in accordance with the load and speed profile. Due to their high efficiency and power density, permanent magnet synchronous motors (PMSM) are preferred as electric motors; however, field-oriented control (FOC), which offers independent control over the magnetizing and torque-producing components, is used to test the control performance of e-rickshaws.

Biyam Jinesh, R., TA, T. E. and VS, S. S.(2021) This study compared various control schemes for PMSM drives i.e. scalar control and vector control. In this work, mathematical modeling of PMSM was also introduced. Under vector control, Field Oriented Control (FOC), Direct Torque Control (DTC) and Direct Torque Control with Space Vector Modulation (DTC-SVM) are extensively studied. With the help of MATLAB/Simulink, these control algorithms are discussed for a PMSM motor drive.

IV. OBJECTIVE OF THE STUDY

1. To develop MATLAB/SIMULINK model of Field Oriented Control Method (FOC) for PMSM drive.
2. To understand the nature of outcome for Field Oriented Control .

V. FIELD ORIENTED CONTROL

This control strategy control the stator currents which is represented in the form of vector**.** This control is based on projections that change a three-phase, time- and speed-dependent system into a two-coordinate, time-invariant system using only the d and q co-ordinates based on (15) Clarke and Park transformation respectively**.** In Clarke transformation the measured value is transformed to 2-axis reference frame .

$$f_{\alpha\beta\gamma} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} f_{abc}$$

Three phase currents of motor are first measured and then transformed to 2- phase. Measured speed (w) is compared with the reference speed and output is passed through a PI controller, which generates reference signal for the torque. The *q*-axis component is responsible for the torque production hence the reference signal of torque generated by the PI controller is compared with the stator current's q-axis component **[2]**. As in PMSM, rotor flux is fixed which is produced by the PM mounted on rotor; hence, reference for the flux is set to be zero. Here, stator current's d- axis component is responsible for the flux generation hence reference for d-axis stator current is set zero.

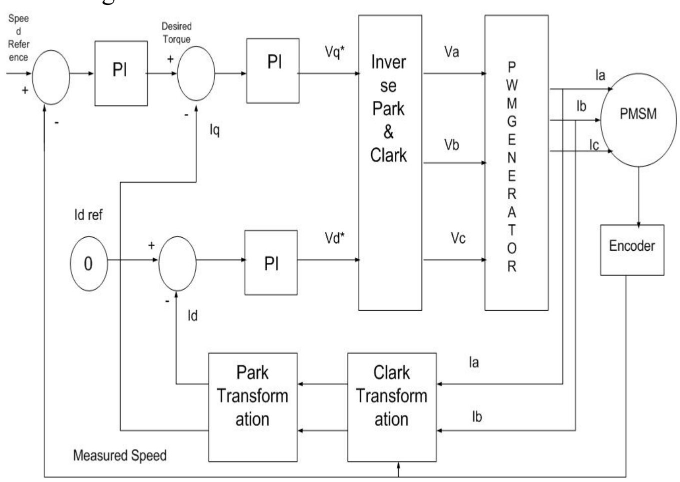

Fig. 3. Block Diagram of Field Oriented Control (FOC)

The inverse Park and then inverse Clark transformations are applied using the present regulators' outputs, Vsdref and Vsqref. The results of this projection are the stator vector voltage components Vsref and Vsref in the stationary orthogonal reference frame ($\alpha\beta$) .Then after the Inverse Clark Transformation, three reference signals are generated. These reference signals are passed through a Pulse Width Modulated (PWM) generator block. In PWM generator block reference signals V_a, V_b, V_c are compared with a high frequency carrier wave and output of this comparator generates the gate pulses for the inverter **[6]**. Fig. 1 shows the basic block diagram of FOC.

VI. MATLAB MODELING AND SIMULATION RESULTS

Complete simulation model for FOC is shown in figure 4 below with parameters for controller block as : For PI Controller: $K_p = 1$ and $K_i = 0.09$ for speed loop and $K_p = 70$ and $K_i = 5$ for current loop.

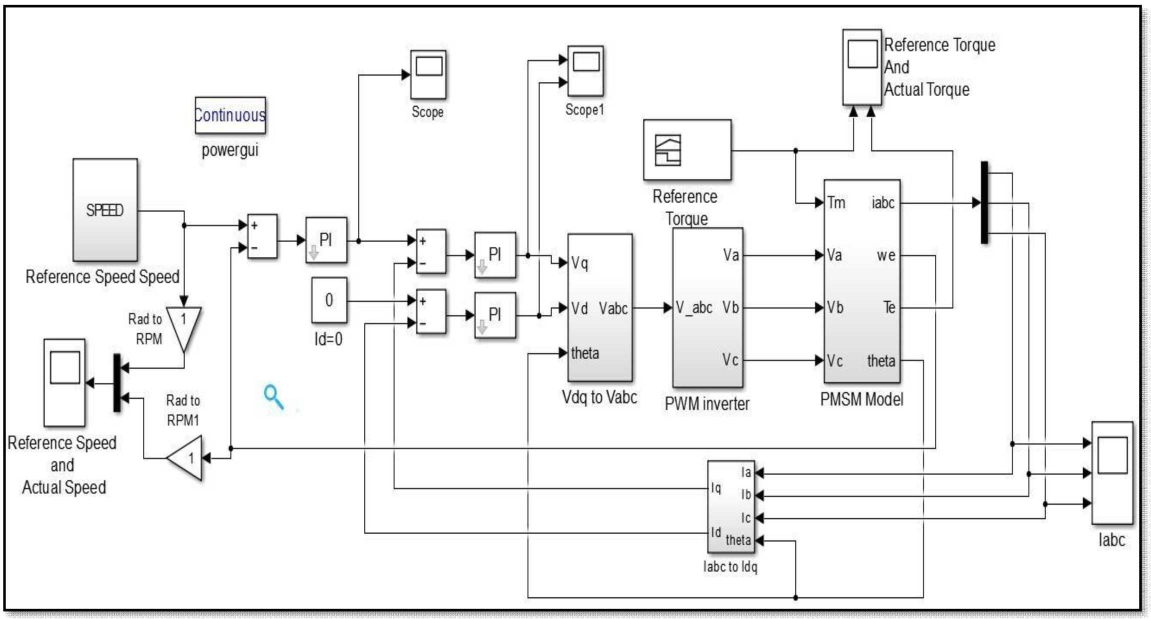

Fig.4. MATLAB Model of FOC

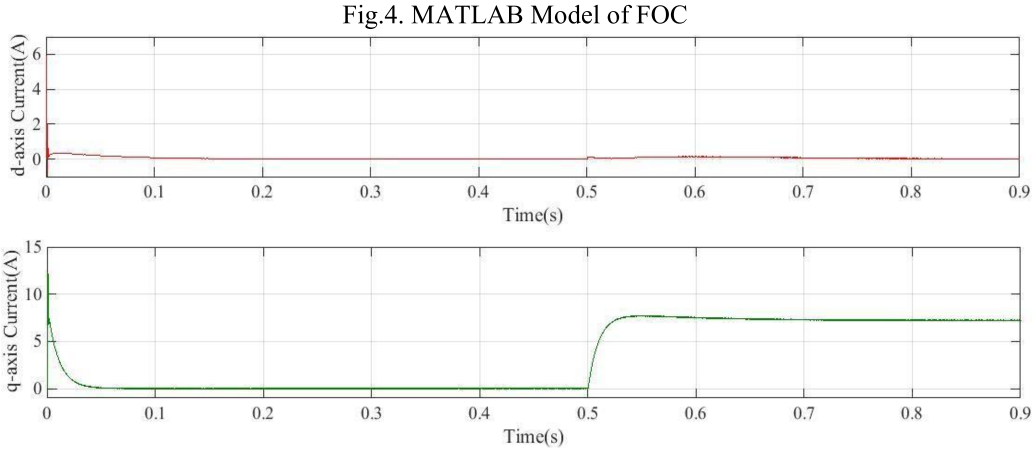

Fig.5.(a). d and q axis Current of FOC

Figure 5-(a) and 5-(b) shows the simulation of FOC of PMSM, when a speed reference command of 100rad/s and a load of 5Nm are applied at 0.5s. It can be seen from the outputs of simulation that *d*-axis component of current which is responsible for flux production is kept zero because in PMSM flux is produced by permanent magnet. *q*-axis component which is responsible for torque production is zero when load torque is zero.

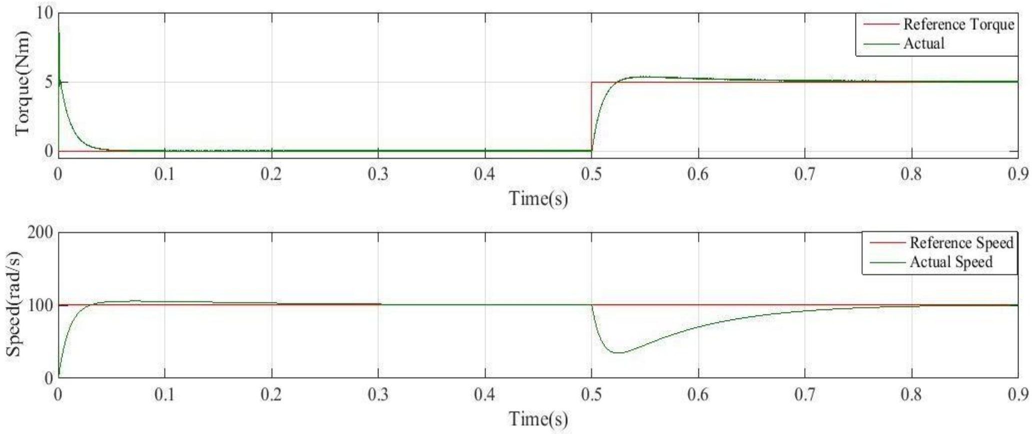

Fig.5.(b).Torque and Speed

VII. CONCLUSION

This study shows that field oriented control (FOC) for PMSM drive is suitable for applications where dynamic response time due to change in load conditions is not a concern .This approach helps to improve the responses for both the steady state as well as transient. This technique is used to decouple the torque and flux by transforming the phase and stator current quantities to flux generating current quantities .

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