Response and Analysis of Permanent Magnet Synchronous Motor According to Different Reference Signals

M.K. Döşoğlu, and M. Dursun

***Abstract*— Permanent magnet synchronous motors (PMSM) are frequently used in many applications, and so great importance in response to variable speed conditions. These engines, which are also used in electric vehicles, can be given to the best response in different road conditions. For this reason, a simulation is performed using vector control technique in MATLAB / Simulink environment. By giving different reference signals, the response of the motor is analyzed with current, speed and torque curves, and the study to be done in the future is provided with light.**

Index Terms— **PMSM, MATLAB/Simulink, Vector control.**

I. INTRODUCTION

THE field oriented control (vector control) method developed in 1965 started to be implemented only in the 1980s. The propose of this application allows to discrete control rotating in field-based electric machines, and free-excitation DC motors. Nowadays vector control method is widely used in industrial drive systems. Thus, it is possible to use asynchronous motor, synchronous motors in alternating current motors, and in servo systems classically designed with only direct current free excitation motors [1].

Besides, in the DC motor, torque control can also be achieved by controlling motor currents in AC motors. However, only the currents controlled as amplitude in DC motors can be controlled both in amplitude and phase and angle in AA motors. That is, the current can be controlled not only as amplitude but also as a space vector. In this way control of the current space vector has occurred to the vector control terminology [2].

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A new simulation model for the brushless motor drive system has been proposed in the MATLAB environment, and it is stated that the proposed model is very easy to use because it is cost-effective in the design phase and is prepared in MATLAB environment [3]. Simulation of engine control with PMSM's Direct Torque Control (DTC) has been discussed in detail. The simulation results, the system performance and the effect of PI controller are examined [4]. The vector control performance of the PMSM fed from the matrix converter is discussed in detail with the Matlab / Simulink model [5].

Detailed field oriented control of the PMSM driver system has been performed in Simulink. All components of the system are designed to depending on mathematical reality. The application was carried out in Matlab/Simulink. Simulation results were obtained from two reference speeds, above and below of the nominal speed, and the validity of the experiment was tried to be proved [6]. Modeling, simulating and implementing of vector control for variable-speed drive systems of multi-phase PMSMs is described. A simplified model in Matlab / Simulink was developed depending on this control method. Then the application was done using DSP [7]. In the study, PMSM vector control system application is developed by using the SVPWM algorithm, the PMSM vector control was implemented with the TMS320F2812 DSP, photoelectric encoder, hall current sensor and IPM module [8].

In this study, field oriented control method of PMSM was performed using space vector pulse width modulation (SVPWM) technique in various operating conditions. Under various operation conditions, field oriented control method enhanced in PMSM is successful on parameters such as speed, currents, and torque.

II. PMSM DYNAMIC MODELING

The mathematical modeling of the PMSMs fed by the sinusoidal current is carried out in the rotor reference frame. The model obtained by transferring of the stator magnitudes, rotor reference plane, similar to free excitation DC motor model. The motor control structure is created using this model. Thus, the PMSM can be controlled such as a free-excitation motor. Another advantage of the rotor plane is faster in solution because the equation level is reduced. The equivalent circuit of the PMSM in the rotor reference plane is given in Figure 1.

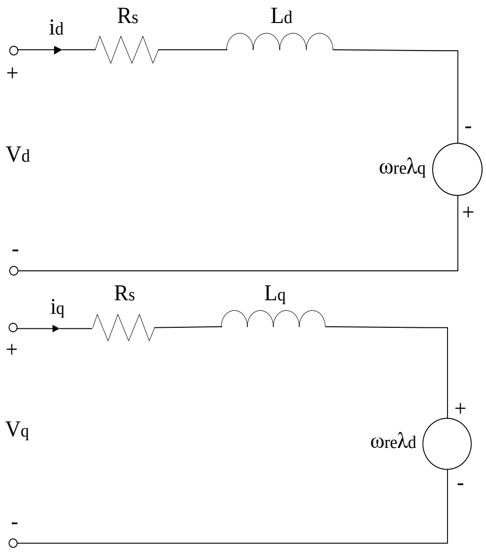


Fig.1. dq-axis dynamic equivalent circuits of PMSM

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} R_s & -\omega_{re}L_q \\ \omega_{re}L_d & R_s \end{bmatrix} . \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} L_d & 0 \\ 0 & L_q \end{bmatrix} . p \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega_{re}\lambda_d \begin{bmatrix} 0 \\ 1 \end{bmatrix} \tag{1}$$

$$V_d = R_s i_d + L_d \frac{di_d}{dt} - \omega_{re}\lambda_q \tag{2}$$

$$V_q = R_s i_q + L_q \frac{di_q}{dt} + \omega_{re}L_d i_d + \omega_{re}\lambda_m \tag{3}$$

Where, R_S is stator resistance, V_d and V_q are dq-axis voltages, i_d and i_q are dq-axis currents, ω_{re} is electrical rotor angular speed, λ_d and λ_q are dq-axis fluxes.

$$\lambda_d = L_d i_d + \lambda_m \tag{4}$$

$$\lambda_q = L_q i_q \tag{5}$$

Where, λm represents the mutual magnetic flux occurring due to the permanent magnet. The induced electrical moment is given in equation 6 [9].

$$T_e = \frac{3}{2} P \lambda_m i_q + \underbrace{\frac{3}{2} P \cdot (L_d - L_q) i_d i_q}_{Reluctance\ Moment} \tag{6}$$

Where, P indicates the number of poles. In the case of the moment expression, the first term is the moment produced by the magnet, and the second term is the reluctance moment achieved by difference reluctance. In the surface SMSM, the reluctance moment will be zero since the d-q axis inductances are equal to each other. So,

$$T_e = \frac{3}{2} P (\lambda_m i_q) \tag{7}$$

From Equation 7, it is clear that the control of the torque in the motor resulting from the interaction of the magnetizing flux and the vertical axis current is only dependent on the q-axis current. The torque obtained by energy conversion is used to meet the mechanical load. Electromagnetic moment in terms of motor dynamic equations s given in equation 8.

$$T_e = J \frac{d\omega_r}{dt} + B\omega_r + T_L \tag{8}$$

Where T_e is the torque generated by the motor and shows the ω_r, the mechanical speed, J, the moment of inertia, B, the friction coefficient, TL, the load torque in the equation according to the selected reference plane. If we subtract ω_r from this equation, the equation becomes as follows [9].

$$\frac{d\omega_r}{dt} = \frac{T_e - B\omega_r - T_L}{J} \tag{9}$$

III. FIELD ORIENTED CONTROL

The general block diagram of the field oriented control in the PMSM drive system is shown in Fig 2.

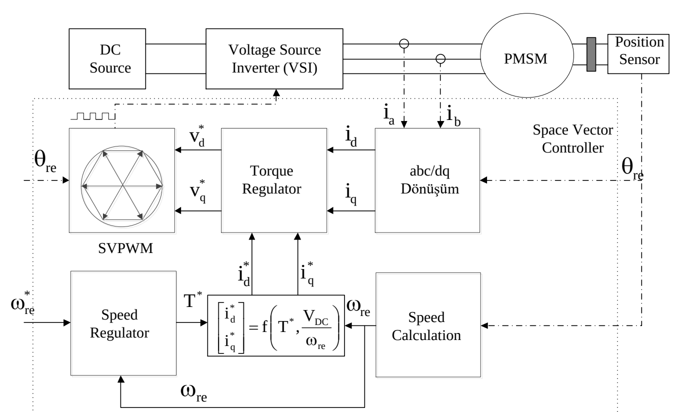


Fig.2. Field oriented control design

While, the reference torque obtained from the output of the speed controller, The i_q reference current is obtained by using Equation. The error value obtained by comparing the reference and measured i_q currents is applied to the input of the Proportional Integral (PI) controller, which is a torque controller. The V_q value is obtained from the output of the controller. Similarly, the error value obtained by comparing the reference and measured id currents is applied to the input of the PI controller which is also the torque controller. The V_d value is obtained from the output of the controller. These voltages are sent to the switching block. The switching signals obtained from the SVPWM switch block are sent to the voltage source inverter and three-phase sinusoidal voltages.

IV. SIMULATION RESULTS

Simulation studies of PMSM's field oriented control were performed in Matlab / Simulink environment. This simulation were first carried out using equations relation with the mathematical model of the previously given PMSM. The contents of PMSM's Matlab / Simulink simulation block are shown in Fig 3.

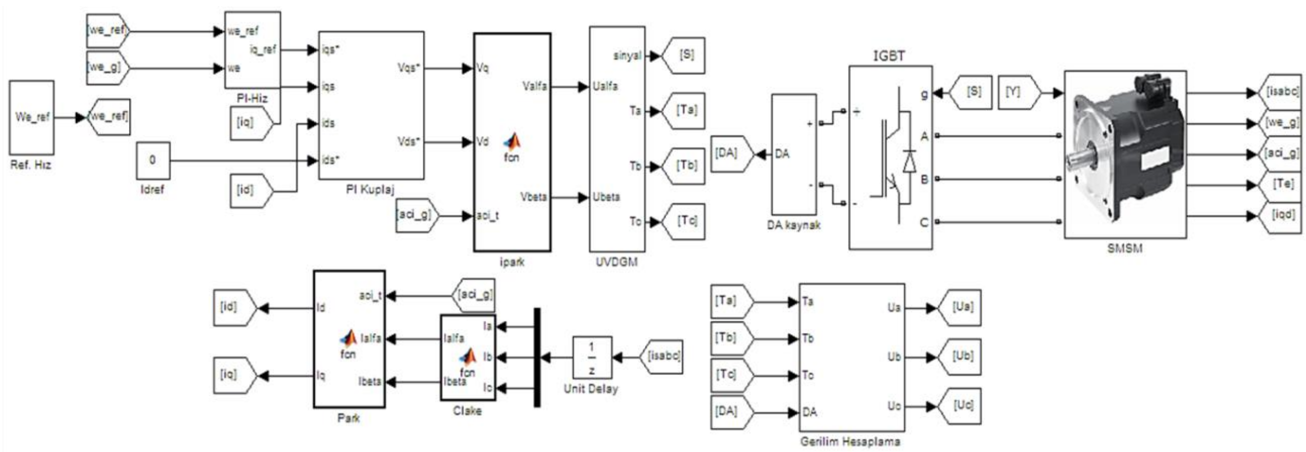
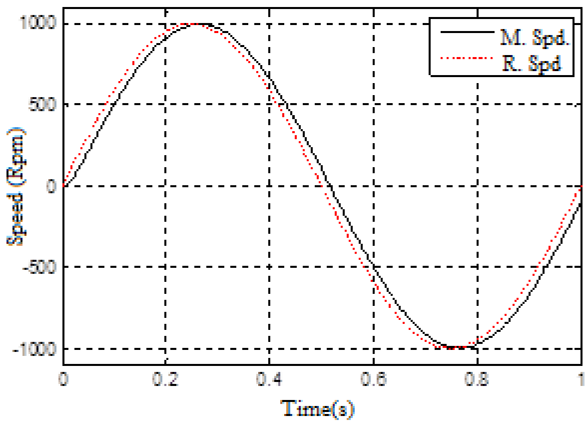
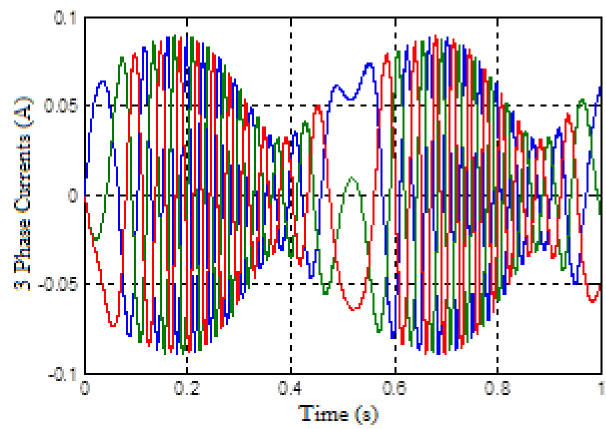


Fig. 3 Field oriented control Simulink overall blocks



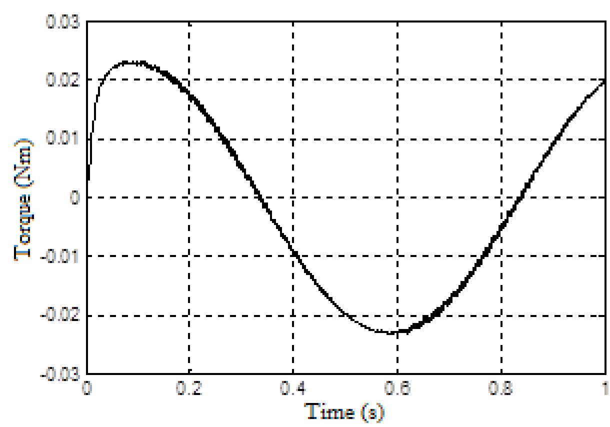
a)



b)

The figures of the field oriented control of the PMSM made at variable input speed reference values are given below. In the following, the speed change of the sinusoidal wave from 1000 rpm to -1000 rpm is e investigated, then the speed change of the square wave from 1000 rpm to -1000 rpm, and the speed change of the triangle wave from 1000 rpm to -1000 rpm were investigated.

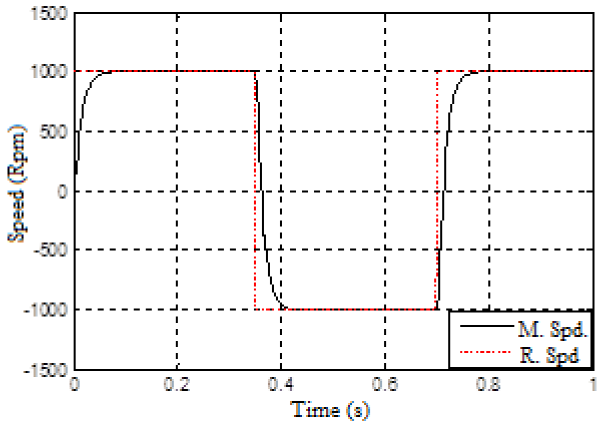
When the simulation results in Fig. 4 are examined, it is seen that the field oriented control is steadily following the reference speed. In addition, when the results of PMSM speed, stator three phase currents are examined, it can be seen that the stator currents increase in first in parallel with the moment of inertia of the motor.



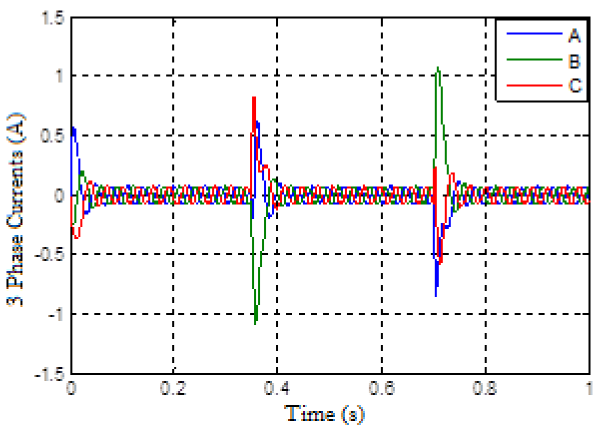
c)

Fig. 4 1000 rpm. -1000 rpm. results for sinus reference speed a) speeds b) three phase currents c) moment

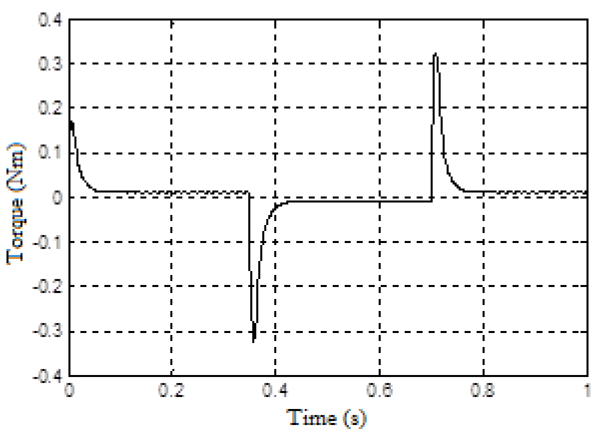
In Figure 5, when the simulated results of the square wave reference velocities is examined, the system response is fast and as steady it is in the same sine wave.



a)



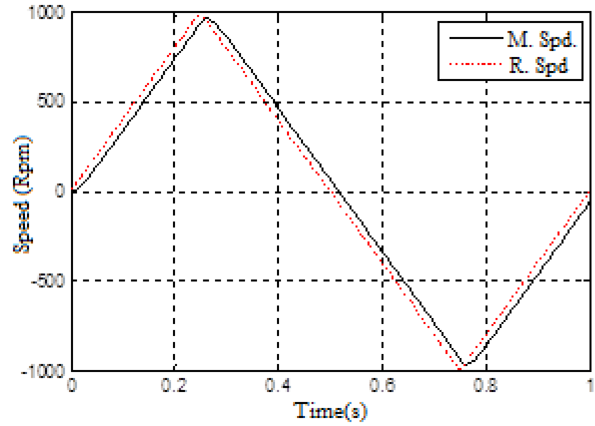
b)



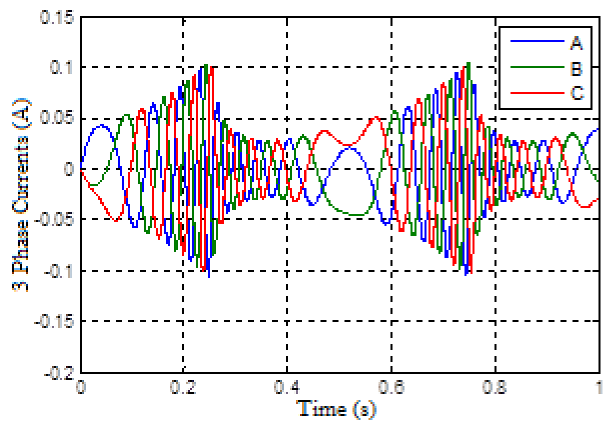
c)

Fig. 5 1000 rpm. -1000 rpm. results for square wave reference speed a) speeds b) three phase currents c) moment

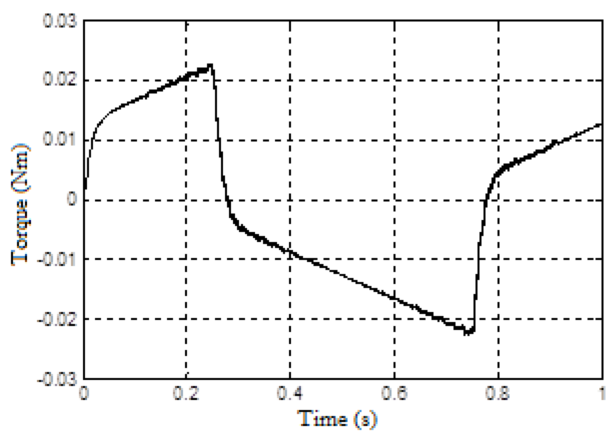
In figure 6, when the simulated results of the triangular wave reference velocities is examined, the system response is fast and as steady it is in the same sine wave and square wave.



a)



b)



c)

Fig. 6 1000 rpm. -1000 rpm. results for triangle wave reference speed a) speeds b) three phase currents c) moment

V. RESULTS AND DISCUSSION

The FOC performance of the PMSM for these three variable speeds it is clear that the motor speed follows the reference speed. In general, simulation carried out for field-oriented control of PMSM has shed a light on us before going to a real-time system. In this respect, it proved the validity of the study in order to determine the situations that can occur without conducting experimental work and to contribute to the research both in terms of cost and time.

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BIOGRAPHIES

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