International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 07, July-2015

Speed Control of PMSM using Backstepping Method

Rini George
Dept.of Electrical & Electronics Engineering
Mar Baselios College Of Engineering & Technology
Thiruvananthapuram, India

Arun. S. Mathew
Dept. of Electrical & Electronics Engineering
Mar Baselios College Of Engineering & Technology
Thiruvananthapuram, India

***Abstract*—The Permanent Magnet Synchronous motor is a rotating electric machine where the stator is a classic three-phase stator like that of an induction motor and the rotor has permanent magnets. The speed controller of PMSM is designed using backstepping control. The Back stepping control is a systematic and recursive design methodology for nonlinear feedback control.A PMSM is modeled in the dqspace and an inverter is used for driving the motor. The switching pulses for inverter are generated using Space Vector Modulation (SPWM) method. The effectiveness of the proposed control scheme is verified using simulation.**

***IndexTerms*—PMSM, dq modeling, Space vector pulse width modulation(SPWM), Backstepping control.**

I.INTRODUCTION

Permanent magnet synchronous motors(PMSM) are widely used in low to medium power applications where torque density and efficiency are critical. The high efficiency, high steady state, torque density and simple controller of the PM motor drives compared to the induction motor drives make them a good alternative in certain applications. Field Oriented Control is the most popular control method for PMSM. They are applied by attaching a rotor reference frame to the rotor via the Park transform. In dealing with dc quantities PI loop can be used for regulation. Due to the electrical quantities and coupling between the motor speed PMSM model is nonlinear.

The field oriented technique (vector control) is one of the most effective control techniques for AC machines in variable speed applications[1]. The FOC method decouple the torque and flux so that each can be controlled separately. A PMSM has better dyanamic performance capabilities under vector control. But the performance is sensitive to parameter variation. So much attention has been given for identifying the changes in parameters of PMSM while the motor is in normal operation. This led to some research in PMSM vector control a;gorithm using non linear control theory[2].

Several nonlinear control techniques have been introduced in the last two decades due to new developments in nonlinear control theory. Backstepping is one of the nonlinear control methods that have been applied to the AC machines. Backstepping is a recursive and systematic design methodology for nonlinear feedback control. First the design of a first-order subsystem is performed, then an additional state is considered and the design for the second-order system is performed for incremental orders until the whole system is controlled. This is best suitable for strict feedback system. It guarantees global regulation and tracking of the linearizablenon linear feedback systems. It helps in accommodating nonlinearities and uncertainties and retain nonlinearities. The idea of backstepping control is to select some state variables as control inputs for lower order subsystems for the overall system. Each backstepping stage results into a new control design expressed in terms of control designs from the previous stage. When the procedure terminates, a feedback design of true control input results and achieves the original design objective by virtue of a Lyapunov function.[1]-[3].

In this paper, a backstepping control design based on FOC for speed control is proposed. The controller is designed such that it is robust to parameter uncertainties and nonlinearities. The paper is organized as follows. Section 2 shows the mathematical modeling of PMSM. Section 3 shows design of speed controller using backstepping control. Section 4 shows the simulation results. Finally some conclusions are drawn in section 4.

II. MODELING OF PMSM

Dynamic modeling of PMSM is useful in simulation of PMSM. It is derived using a two phase motor in direct and quadrature (dq) axes. This is also due to the conceptual simplicity with only one set of two windings. The rotor of PMSM has only magnets, but no windings. The dynamic model is used to determine the instantaneous effects of varying voltages/currents, stator frequencies and torque disturbance on the machine and drive systems. The magnets of PMSM are assumed as current or voltage source concentrating all its flux on one axis. A two phase PMSM stator with windings and rotor with PMs is shown in Fig.1.

The d and q axes stator voltages are derived as the sum of derivative of the flux linkages and resistive voltage drops in the respective windings as

$$v_d = Ri_d + \frac{d}{dt}\psi_d - \omega\psi_q \qquad (1)$$

$$v_q = Ri_q + \frac{d}{dt}\psi_q + \omega\psi_d \qquad (2)$$

$\psi_d = L_d i_d + \psi$:direct axis flux linkage

$\psi_q = L_q i_q$:quadrature axis flux linkage

where,

i_d, i_q= d and q axis component of the armature current

v_d, v_q= d and q axis component of terminal voltage

ψ = flux linkage constant

R =armature resistance
L_d,L_q=d and q axis components of armature inductance
ω = electrical angular velocity

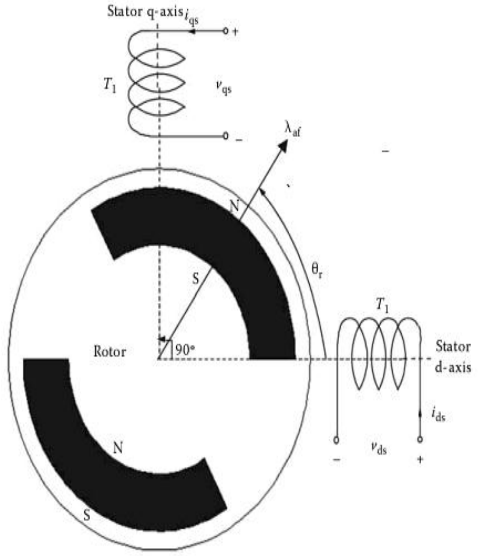

Fig.1. Two phase PMSM

This transformation also assumes that the magnetic circuit is linear and the back emf and inductance variations are sinusoidal quantities.

The electromagnetic torque for a p pole machine is

$$T_e = \frac{3}{2}\frac{p}{2}\left(\phi_m i_q + \left(L_q - L_d\right) i_q i_d\right) \quad (3)$$

The mechanical torque equation is

$$T_e = \tau + \beta\omega_r + J\frac{d}{dt}\omega_r \quad (4)$$

where,

β = damping coefficient
τ = load torque
J= rotor moment of inertia
ϕ_m=magnetic flux

The dq frame model of a PMSM is given as

$$\frac{di_d}{dt} = \frac{v_d}{L_d} - \frac{R}{L_d} i_d + p\omega_r \frac{L_q}{L_d} i_q \quad (10)$$

$$\frac{di_q}{dt} = \frac{v_q}{L_q} - \frac{R}{L_q} i_q - p\omega_r \frac{L_d}{L_q} i_d - p\omega_r \frac{\phi_m}{L_q} \quad (11)$$

$$\frac{d\omega_r}{dt} = \frac{3p\phi_m}{2J} i_q + \frac{3p}{2J}\left(L_q - L_d\right) i_d i_q - \frac{\beta}{J}\omega_r - \frac{\beta}{J} \quad (12)$$

Since the direct and quadrature inductances are equal, it simplifies the dynamics to

$$\frac{di_d}{dt} = \frac{v_d}{L} - \frac{R}{L} i_d + p\omega_r i_q \quad (13)$$

$$\frac{di_q}{dt} = \frac{v_q}{L} - \frac{R}{L} i_q - p\omega_r i_d - p\omega_r \frac{\phi_m}{L} \quad (14)$$

$$\frac{d\omega_r}{dt} = \frac{3p\phi_m}{2J} i_q - \frac{\beta}{J}\omega_r - \frac{\beta}{J} \quad (15)$$

III. Backstepping controller

It is assumed the parameters are known and invariant. By choosing variable states as $[i_d i_q \omega]^T$. The objective is to regulate the speed to its reference value. Defining the tracking errors as

$$\tilde\omega_r = \omega_r - \omega^*_r \quad (16)$$
$$\tilde i_d = i_d - i^*_d \quad (17)$$
$$\tilde i_q = i_q - i^*_q \quad (18)$$

where ω^*_r is the desired mechanical rotor speed and i_d^*,i_q^* are the target currents .

The complete error dynamic system is given as

$$\frac{d\tilde i_d}{dt} = \frac{v_d}{L_d} - \frac{R}{L_d} i_d + p\omega_r \frac{L_q}{L_d} i_q - \frac{di^*_d}{dt} \quad (19)$$

$$\frac{d\tilde i_q}{dt} = \frac{v_q}{L_q} - \frac{R}{L_q} i_q - p\omega_r \frac{L_d}{L_q} i_d - p\omega_r \frac{\phi_m}{L_q} - \frac{di^*_q}{dt} \quad (20)$$

$$\frac{d\omega_r}{dt} = \frac{3p\phi_m}{2J} - \frac{\beta}{J}\omega_r - \frac{\beta}{J} - \frac{d\omega^*_r}{dt} \quad (21)$$

$$\frac{d\tilde\theta_r}{dt} = \tilde\omega_r \quad (22)$$

A. Stabilization of the Mechanical Subsystem

We begin the design by defining a control Lyapunov function based solely on the output of mechanical subsystem defined as

$$V_1 = \frac{1}{2}\tilde\omega^2_r + \frac{1}{2}K_{\theta_r}\tilde\theta^2_r \quad (23)$$

where $K_{\theta r}$ is a positive design gain. Evaluating the time derivative of V_1

$$\dot V_1 = \tilde\omega_r \frac{d\tilde\omega_r}{dt} + K_{\theta_r}\tilde\theta_r \frac{d\tilde\theta_r}{dt}$$
$$= \tilde\omega_r\left[\frac{3p\phi_m}{2J} i_q - \frac{\beta}{J}\omega_r - \frac{\tau}{J} - \frac{d\omega^*_r}{dt} + K_{\theta_r}\tilde\theta_r\right] \quad (24)$$

Assume$(d\omega^*_r/dt) = 0$. We treat i_q as a virtual input to the motor speed dynamics and backstep through an integrator into the electrical dynamics governing the torque producing currents. Introducing an additional gain $K_{\omega_r} \geq 0$and the choosing the stabilization gain as

$$i^*_q = \frac{-K_{\omega_r}\tilde\omega_r + \frac{\beta}{J}\omega_r + \frac{\tau}{J} - K_{\theta_r}\tilde\theta_r}{\frac{3p}{2J}\phi_m} \quad (25)$$

will make the mechanical subsystem stable about the origin. This is done by substituting $i^*_q$for i_q in (24) and evaluating $\dot V_1$

$$\dot V_1 = -K_{\omega_r}\tilde\omega^2_r \leq 0 \quad (26)$$

So the above expression is negative semidefinite and hence the mechanical subsystem is asymptotically stable.

B. Stabilization of Electrical subsystem

To analyze the stability of the whole system we introduce a Lyapunov function

$$V_2 = V_1 + \frac{1}{2}K_q\tilde i^2_q + \frac{1}{2}K_d\tilde i_d^2 \quad (27)$$

$$\dot V_2 = \dot V_2 + K_q\tilde i_q \frac{d\tilde i_q}{dt} + K_d\tilde i_d \frac{d\tilde i_d}{dt} \quad (28)$$

(25) is differentiated as

$$\frac{di_d^*}{dt} = \frac{\left(-K_{\omega_r} + \frac{\beta}{J}\right)\dot{\tilde\omega}_r - K_{\theta_r}\tilde\omega_r}{\frac{3p}{2J}\phi_m} \quad (29)$$

The transformed system in state errors is given by

$$\frac{d\tilde i_d}{dt} = \frac{v_d}{L} - \frac{R}{L}\tilde i_d + p\omega_r i_q \quad (30)$$

$$\frac{d\tilde{i}_q}{dt} = \frac{v_q}{L} - \frac{R}{L} i_q - p\omega_r\left(\tilde{i}_d + \frac{\phi_m}{L}\right) + \frac{2JK_\theta\tilde{\omega}_r}{3p\phi_m} - \frac{2J}{3p\phi_m}\left(\left(K_{\omega_r}\tilde{\omega}_r + K_\theta\tilde{\theta} - \frac{3p\phi_m}{2J}\tilde{i}_q\right)\left(K_{\omega_r} - \frac{\beta}{J}\right)\right) \quad (31)$$

$$\frac{d\tilde{\omega}_r}{dt} = \frac{3p\phi_m}{2J}\tilde{i}_q - K_{\omega_r}\tilde{\omega}_r - K_{\theta_r}\tilde{\theta}_r \quad (32)$$

$$\frac{d\tilde{\theta}_r}{dt} = \tilde{\omega}_r \quad (33)$$

The expressions (30)-(33) require the following control laws

$$v_q = -K_q\tilde{i}_q + Ri_q^* + p\omega_r(L\tilde{i}_d + \phi_m)L\left(\frac{di_q^*}{dt} - \frac{3p\phi_m\tilde{\omega}_r}{2K_qJ}\right) \quad (34)$$

$$v_d = -K_d\tilde{i}_d - Lp\omega_r i_q^* - L\tilde{i}_q p\omega_r \quad (35)$$

Finally (28) becomes

$$\dot{V}_2 = -K_{\omega_r}\tilde{\omega}_r^2 - \left(\frac{K_q+R}{L}\right)\tilde{i}_q^2 - \left(\frac{K_d+R}{L}\right)\tilde{i}_d^2 \quad (36)$$

is negative semi definite.

III. SIMULATION RESULTS

To prove the effectiveness of the proposed control scheme, simulations were carried out using Matlab/Simulink software. The machine parameters are given in Table I. The plant is started on a constant load of 25 N-m and a reference speed of 100 rpm. Also a reference speed of 1200 rpm is given and the effectiveness of backstepping controller is checked.

Table I. The parameters of the PMSM

Sl.No.	Parameter	Value
1	Resistance (R_s)	1.4Ω
2	Direct axis inductance(L_d)	0.0066H
3	Quadrature axis inductance(L_q)	0.0058 H
4	Magnetic flux (ϕ_m)	0.1546 wb
5	Moment of Inertia(J)	0.00176 kgm^2
6	Viscous friction(B)	0.00038818(Nm/(rad/s))
7	No. of poles(p)	6

The actual speed converges with the reference speed in less time with less steady state error(ω_r=100 rpm). But there is oscillations in the responses of the PMSM. In the case of ω_r=1200 rpm, there is a large overshoot and take more time to settle down.

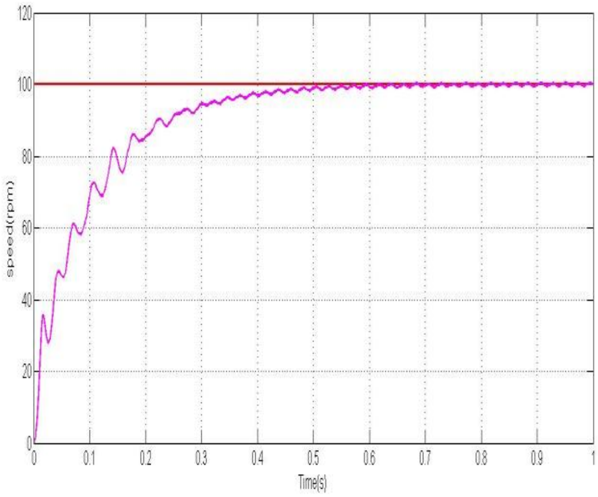

Fig 2. Response of rotor speed(ω_r=100 rpm)

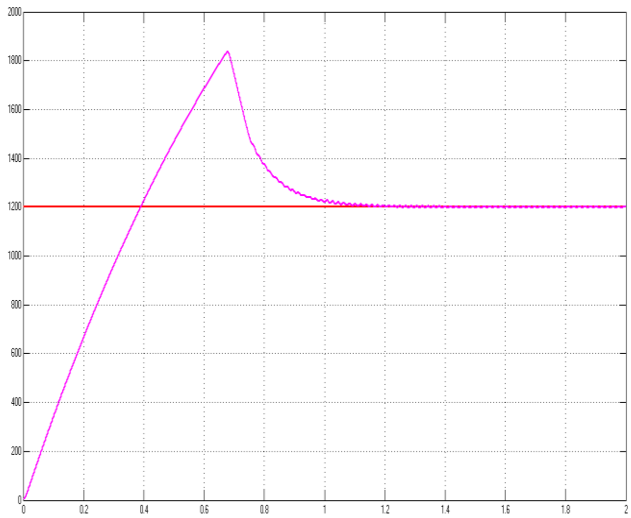

Fig3. Response of rotor speed(ω_r=1200 rpm)

With ω_r=1200 rpm, there is large overshoot and take more time to track the reference speed. But the backstepping can handle the parameter variation without much variation in speed.

Table II. Performance characteristics of the controller

Response characteristics	Speed(rpm)	
	100	1200
Rise time(t_r)	0.3s	0.38s
Peak time(t_p)	0	0.7s
Settling time(t_s)	0.6s	1.1s
Peak overshoot(M_p)	0	51.66%

IV. CONCLUSION

In this paper, a backstepping controller is presented in order to accommodate the nonlinearities and uncertainties. The design of backstepping control for the speed control of a PMSM has been done. The virtual control states of the PMSM drive have been identified using recursive method and stabilizing laws are developed using Lyapunov stability theory. The proposed controller has been analysed using MATLAB/Simulink software. The simulation results show its effectiveness at tracking a reference speed under parameter uncertainties and nonlinearities. But there are oscillations in response which can be reduced by adjusting the parameters of the plant.

REFERENCES

[1] Gideon Prior, MiroslavKrstic, " Quantized – Input Control LyapunovApproachPermanent Magnet Synchronous Motor Drives", *IEEE Trans. Control Syst. Technol*., vol.21, no.5, pp 1784-1794, September 2013

[2] S. Li and Z. Liu, "Adaptive speed control for permanent-magnet synchronous motor system with variations of load inertia," *IEEE Trans. Ind.Electron.*, vol. 56, no. 8, pp. 3050–3059, Aug. 2009.

[3] M. Ouassaid, M. Cherkaoui, and Y. Zidani, "A nonlinear speed control for a PM synchronous motor using an adaptive backstepping control approach," in *Proc. IEEE Int. Conf. Ind. Technol.*, vol. 3. May 2004, pp. 1287–1292.

[4] S. Underwood and I. Husain, "Online parameter estimation and adaptive control of permanent-magnet synchronous machines," *IEEETrans. Ind. Electron.*, vol. 57, no. 7, pp. 2435–2443, Jul. 2010.

[5] D. Dawson, J. Carroll, and M. Schneider, "Integrator backstepping control of a brush DC motor turning a robotic load," *IEEE Trans.Control Syst. Technol.*, vol. 2, no. 3, pp. 233–244, Sep. 1994.

[6] K. Basu, J. S. S. Prasad, G. Narayanan, H. K. Krishnamurthy, and R. Ayyanar, "Reduction of torque ripple in induction motor drives using an advanced hybrid PWM technique," *IEEE Trans. Ind. Electron.*, vol. 57, no. 6, pp. 2085–2091, Jun. 2010.

[7] J. Solsona, M. Valla, and C. Muravchik, "Nonlinear control of a permanent magnet synchronous motor with disturbance torque estimation," *IEEE Trans. Energy Convers.*, vol. 15, no. 2, pp. 163–168, Jun. 2000.

[8] KiranBoby, Prof.Acy M Kottalil, N.P.Ananthamoorthy, "Mathematical Modeling of PMSM Vector Control System Based on SVPWM with PI Controller Using MATLAB", *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 2, Issue 1, January 2013.

[9] C. Ortega, A. Arias, C. Caruana, J. Balcells, and G. M. Asher, "Improved waveform quality in the direct torque control of matrixconverter- fed PMSM drives," *IEEE Trans. Ind. Electron.*, vol. 57, no. 6, pp. 2101–2110, Jun. 2010.

[10] J. Beerten, J. Verveckken, and J. Driesen, "Predictive direct torque control for flux and torque ripple reduction," *IEEE Trans. Ind. Electron.*, vol. 57, no. 1, pp. 404–412, Jan. 2010.