

Sensorless PMSM Speed Observer with Stator Resistance Estimation

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Abstract: The sensorless method presented in this paper is implemented using a modified back Electromotive Force (EMF) observer connected in cascade with a flux/current Sliding Mode Observer (SMO). Both observers are considered in an estimated γ - δ rotating reference frame instead of α - β stationary reference frame. Permanent Magnet Synchronous Motor (PMSM) stator voltages and current errors are used in flux/current observer to detect the modified back EMF errors. In sliding mode phase rotor position information is derived from these errors by means of the back EMF observer without initial rotor position knowledge. An adaptation scheme for the stator resistance is developed to improve the estimation accuracy. Simulation results show good properties of the proposed estimation approach.

Keywords: Sensorless Control; Permanent Magnet Synchronous Motor (PMSM); Sliding Mode Control; Sliding Mode Observer (SMO); Parameter Estimation; Position Estimation; Speed Estimation; Modified Back EMF;

NOTATION

ω = angular speed

u_d, u_q = d-q axis voltages

i_d, i_q = d-q axis currents

λ_m = permanent magnet flux

r_s = stator resistance

L_d, L_q = d-q axis inductances

λ_d, λ_q = d-q axis magnetic fluxes

u_γ, u_δ = γ - δ axis voltages

i_γ, i_δ = γ - δ axis currents

$\lambda_\gamma, \lambda_\delta$ = γ - δ axis magnetic fluxes

$\lambda_{m\gamma}, \lambda_{m\delta}$ = γ - δ axis partial magnetic fluxes

E_γ, E_δ = γ - δ axis modified back EMF

p = number of pole pairs

θ = angular position

T_e = electrical motor torque

T_l = load torque

J = inertia of the rotor

1. INTRODUCTION

Permanent magnet synchronous motors (PMSM) are widely used in industrial applications due to their torque density, smooth output torque, small size and high efficiency. Vector control of a PMSM requires accurate angle information of rotor flux, since it is directly connected to the produced torque. Sensorless techniques usually extract rotor angle information from the measured electrical quantities, such as stator voltages and currents, e.g. Morimoto S. et al. (2001), Chen Z. et al. (2003), and Xu Z. et al. (2004). PMSM sensorless rotor position detection approaches can be classified into two main strategies: saliency and signal injection and fundamental excitation method. Saliency and Signal injection methods are based on phase inductance variation property by injection of high frequency signals e.g. Xie Yue et al. (2003), and Mathew J. et al. (1998). These approaches provide rotor position information at low speeds and during standstill operation. Fundamental excitation methods are based on detecting the rotor position from the stator voltages and currents without requirement of additional test signals. The back EMF induced in stator windings or flux linkage due to permanent magnets are often used to estimate rotor position by means of state observers or extended Kalman filters, e.g. Liu Jaxi, et al. (2007) and Changsheng Li et al. (2001). However it is hard to estimate rotor position at low speeds.

The fundamental excitation methods used for sensorless control are based on mathematical models of the PMSM.

Hence, the model parameters are needed for the speed and position estimation. Among different observation methods used, the sliding mode observer (SMO) is an effective technique due to its outstanding robustness properties against motor parameter uncertainties and external torque disturbances, e.g. Utkin V. (1992, 1993), Zhang Yan et al. (2002), Slotine J-J. E. et al. (1991) and Karel Jezernik (2008).

Fig. 1. shows the proposed estimation method in block diagram. Implementation of the proposed approach is mainly based on a stator flux/current observer and a modified back EMF observer connected in cascade. The flux/current observer ensures stator currents convergence using sliding mode techniques, while the modified back EMF observer provides accurate rotor position estimation at a wide range of motor speeds. The influence of the stator resistance variation is compensated introducing an adaptive non-linear observer.

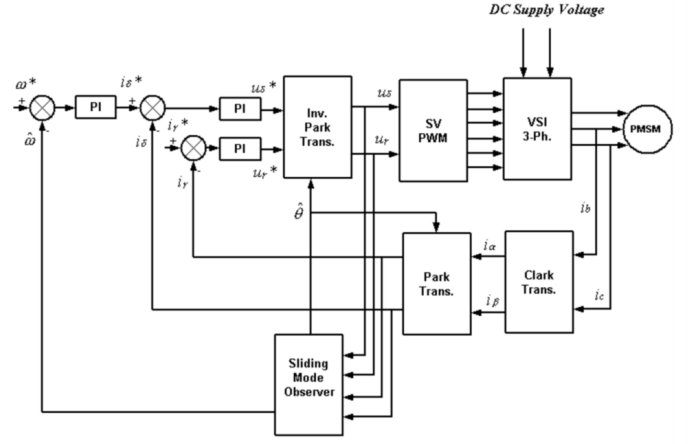


Fig. 1. Block diagram of PMSM controlled system using Sliding Mode Observer.

2. MATHEMATICAL MODEL OF PMSM IN γ - δ AXIS

2.1 PMSM Model using Estimated Rotating Reference Frame

The proposed PMSM mathematical model of sliding mode observer is defined in a γ - δ estimated reference frame rotating at an angular velocity $\hat{\omega}$ and lagging behind the d-q reference frame by electrical angle $\bar{\theta}$. The conventional d-q axis model is converted to γ - δ axis as follows (see Appendix A).

$$\dot{\lambda}_\gamma = -r_s i_\gamma + u_\gamma + \left(\omega - \dot{\bar{\theta}} \right) \lambda_\delta \quad (1)$$

$$\dot{\lambda}_\delta = -r_s i_\delta + u_\delta - \left(\omega - \dot{\bar{\theta}} \right) \lambda_\gamma \quad (2)$$

$$\lambda_\gamma = L_d \cdot i_\gamma + \lambda_{m\gamma} \quad (3)$$

$$\lambda_\delta = L_q \cdot i_\delta + \lambda_{m\delta} \quad (4)$$

Here the partial fluxes $\lambda_{m\gamma}$ and $\lambda_{m\delta}$ are defined by

$$\lambda_{m\gamma} = L_2 \left[i_\gamma (1 - \cos 2\bar{\theta}) - i_\delta \sin 2\bar{\theta} \right] + \lambda_m \cos \bar{\theta},$$

$$\lambda_{m\delta} = L_2 \left[-i_\gamma \sin 2\bar{\theta} - i_\delta (1 - \cos 2\bar{\theta}) \right] + \lambda_m \sin \bar{\theta} \text{ and}$$

$$L_2 = (L_q - L_d) / 2.$$

2.2 Properties of the PMSM Model in γ - δ Reference Frame

1. In (1) and (2) the term $(\omega - \dot{\bar{\theta}})$ is used instead of ω . The real and estimated reference frames coincide when $\dot{\bar{\theta}} = \bar{\theta} = 0$.
2. The first parts of (3) and (4) are due to the stator currents and the second to the saliency and rotor angle error. Therefore partial fluxes could be used to extract rotor position information

3. OBSERVER ANALYSIS

3.1 Sliding mode Observer – Flux/Current Observer

A sliding mode observer scheme involves two steps: the hyperplane or manifold design and the sliding mode control design based on the sliding conditions. The sliding manifold design is defined using as sliding surfaces $s_\gamma = L_d \bar{i}_\gamma$ and $s_\delta = L_q \bar{i}_\delta$, where $\bar{i}_\gamma = i_\gamma - \hat{i}_\gamma$ and $\bar{i}_\delta = i_\delta - \hat{i}_\delta$ are the stator current errors. The proposed flux/current sliding mode observer is defined as follows.

$$\begin{aligned} \dot{\hat{\lambda}}_\gamma = & -\hat{r}_s i_\gamma + u_\gamma + \left(\omega - \dot{\bar{\theta}} \right) \hat{\lambda}_\delta + \left(\omega - \dot{\bar{\theta}} \right) L_q \bar{i}_\delta \\ & + K_\gamma \operatorname{sgn} \left(L_d \bar{i}_\gamma \right) \end{aligned} \quad (5)$$

$$\begin{aligned} \dot{\hat{\lambda}}_\delta = & -\hat{r}_s i_\delta + u_\delta - \left(\omega - \dot{\bar{\theta}} \right) \hat{\lambda}_\gamma - \left(\omega - \dot{\bar{\theta}} \right) L_d \bar{i}_\gamma \\ & + K_\delta \operatorname{sgn} \left(L_q \bar{i}_\delta \right) \end{aligned} \quad (6)$$

$$\hat{\lambda}_\gamma = \hat{L}_d \cdot \hat{i}_\gamma + \hat{\lambda}_{m\gamma} \quad (7)$$

$$\hat{\lambda}_\delta = \hat{L}_q \cdot \hat{i}_\delta \quad (8)$$

Here $K_\gamma, K_\delta > 0$ are the observer gains.

The flux errors dynamics due the stator currents could be written in a convenient form as follows.

$$\overbrace{(L_d \bar{i}_\gamma)}^\dot{} = -\bar{r}_s i_\gamma + \bar{E}_\gamma - K_\gamma \operatorname{sgn} \left(L_d \bar{i}_\gamma \right) \quad (9)$$

$$\overbrace{(L_q \bar{i}_\delta)}^\dot{} = -\bar{r}_s i_\delta + \bar{E}_\delta - K_\delta \operatorname{sgn} \left(L_q \bar{i}_\delta \right) \quad (10)$$

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