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Sensorless Speed And Position Estimation Of PMSM Based On Sliding Mode Observer With Tan Hyperbolic Function

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Abstract : *Sinusoidal Permanent Magnet synchronous motors have become more popular for new drives. Advantages of PMSMs includes high torque to inertia ratio, high efficiency and high power density. For the PMSMs it is necessary to estimate the rotor position and speed as well. A good error filtering, low angle error and dynamic performance can be obtained with feedback observers. The sliding mode observer (SMO) is one of the observers with a system model suitable for PM synchronous motors. The study deals with the analysis based on simulation of PMSM with space vector pulse width modulation in MATLAB environment. In this paper sensorless estimation of speed and position using SMO with tan hyperbolic function achieved. The result is compared with SMO using sigmoidal function. The simulation results shows that sliding mode observer with tan hyperbolic function gives smooth performance.*
Keywords: *PMSM, Sliding Mode observer,Sigmoidal function, tan hyperbolic function*

I. Introduction

With the development of permanent magnetic materials and control technology, permanent magnet synchronous motor PMSM is mostly used due to high torque/inertia ratio, high power density, high efficiency, and ease for maintenance being used in CNC machine tools, industrial robots and so on. In most variable speed drive systems, the rotor position is measured and optical encoder mounted on -torque estimation was studied in [6]. A sliding-mode control of surface-mount permanent magnet synchronous motor based on error model with unknown load is presented in [14]. In [12] an observer based terminal Sliding Mode control method to regulate the speed of PMSM with load torque is applied. Some of these controllers employ speed sensors and others are sensorless. In [3], a sliding-mode observer was used to estimate load disturbances for a permanent magnet synchronous motor at high speed. In the sensorless control of a PMSM drive two main strategies are applied, the fundamental excitation method and the saliency and signal injection method [9],[14]. The fundamental excitation method estimates the rotor position and speed from thestator voltages and currents and it does not need any additional test signal. At the same time, it is hard to estimate position at the low-speed region. In the saliency and signal injection method, the inductance varies depending on the rotor position. This feature of the salient-pole PMSM is used to estimate rotor position even at low speeds and standstill. Some fundamental excitation method approaches are based on the estimation of the back electromotive force (EMF) or flux linkage due to permanent magnets by means of a state observer or an extended Kalman filter [12]. Also other simple methods are based on the voltage or the shaft or a resolver. However, the uses of this sensor creates several disadvantages, sensorless control method has been developed for control of motor using the estimated values of the position and speed of the rotor. [4]. Currently, there are several sensorless methods available in the literature [6]-[10]. There are two kinds of approaches depending on the speed operating range required by the application. The first one is magnetic saliency methods and estimation of variables using state observers. In magnetic saliency methods the rotor position estimation is done through the injection of proper test signals.[9].These methods are relatively difficult to implement but they offer a proper solution for both standstill and low speed operation. State observer require the measured electrical quantities (applied voltages and currents) to estimate the rotor position and speed. These methods are preferred for medium or high speed operation. A different procedure in [5] was introduced to control speed and to estimate load torque. In [8], an adaptive controller was design toreject the variation in load inertia. A comparison of a sliding observer and a Kalman filter for directcurrenterror between the detected variables and the calculated variables from the motor model using state observer techniques. Among different observation methods used, the sliding mode observer (SMO) is apromising approach and an effective technique due to its outstanding robustness properties against system parameter uncertainties and external disturbances [4]-[7]. The sensorless strategy proposed in this study is based on sliding modes using the fundamental excitation method with a modified back EMF. A mathematical model of PMSM in an estimated α-β rotating reference frame is considered to estimate both rotor speed and position. In this paper, a comparison between SMO with tan hyperbolic function and SMO sigmoidal function is presented. The SMO with tan hyperbolic function is smooth switching function. Speed tracking of a permanent magnet synchronous motor is the ultimate objective with different load torques.

II. Mathematical Model Of Pmsm

The PMSM model in stationary reference frame (α-β) is

$$L\frac{di_\alpha}{dt} = -i_\alpha R - e_\alpha + v_\alpha \tag{1}$$

$$L\frac{di_\beta}{dt} = -i_\beta R - e_\beta + v_\beta \tag{2}$$

$$e_\alpha = -\lambda_0 \omega \sin\theta \tag{3}$$

$$e_\beta = \lambda_0 \omega \sin\theta \tag{4}$$

where R is the stator resistance (ohm), L is stator self inductance (H), i_α, i_β, v_α, v_β and e_α, e_β are the phase currents (amp), phase voltages (volt) and back emf (volt) in the stationary reference frame, respectively. The ω is electrical angular velocity (rad/sec), λ_0 is the flux linkage of permanent magnet (volt.sec/rad) and θ is the electrical rotor position (rad). Here, it is observed that the information of rotor speed and back emf can be obtained from above equations.

III. Sliding Mode Controller Design

The control objective is to track a reference speed ω_{ref} with the rotor actual speed ω (i.e. the position and acceleration are not considered). The error signal between the reference and actual speeds can be written as $e=\omega_{ref}-\omega$, which will represent the sliding surface s. Since the speed control loop of the PMSM is essentially a first order system, the SMC design is conventional in its derivation, and is based on the Lyapunov stability concept.

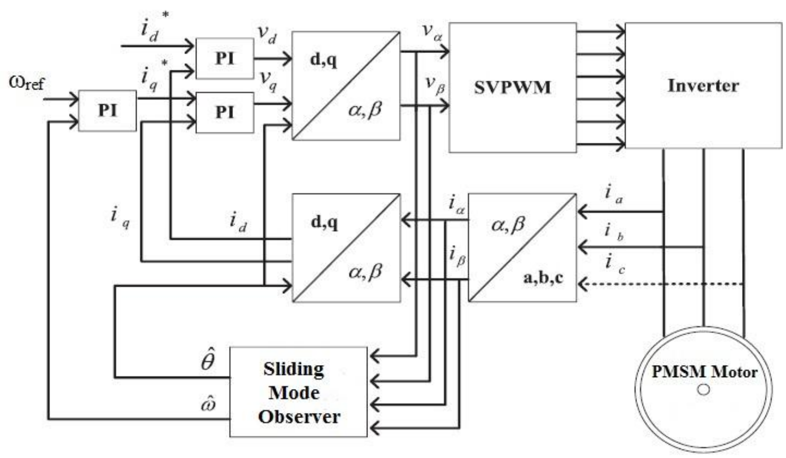

Fig.1 Overall control structure of PMSM

1. Sliding Mode Observer with Sigmoidal Function

Fig. 2 shows Sliding Mode Observer when Sigmoidal function is used. Generally, equivalent controls of conventional sliding mode observer can be obtained in [7].

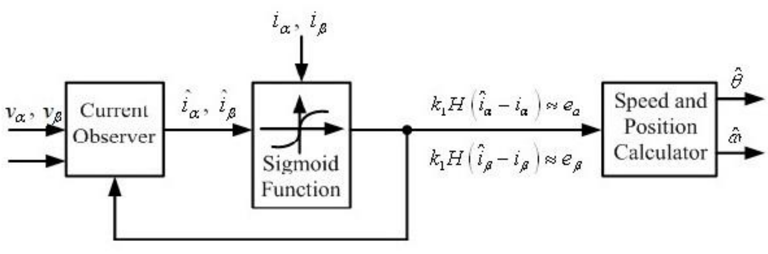

Fig.2 Sliding Mode Observer with Sigmoidal function

The Sigmoidal function is defined as

$$H(x) = \left[\frac{2}{1+e^{-ax}}\right] - 1 \tag{5}$$

Where, a is a parameter which can be adjusted accordingly. The Sliding Mode Observer Sigmoidal Function is given by following equations

$$L_S \frac{d\hat{i}_\alpha}{dt} = -\hat{i}_\alpha R_S + v_\alpha - kH\left(\hat{i}_\alpha - i_\alpha\right) \tag{6}$$

$$L_S \frac{d\hat{i}_\beta}{dt} = -\hat{i}_\beta R_S + v_\beta - kH\left(\hat{i}_\beta - i_\beta\right) \tag{7}$$

2. Sliding Mode Observer with Tan Hyperbolic Function

The tan hyperbolic function can be defined as

$$F(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \tag{8}$$

Now, the SMO with Tan hyeperbolic function is given by

$$L_S \frac{d\hat{i}_\alpha}{dt} = -\hat{i}_\alpha R_S + u_\alpha - kF\left(\hat{i}_\alpha - i_\alpha\right) \tag{9}$$

$$L_S \frac{d\hat{i}_\beta}{dt} = -\hat{i}_\beta R_S + u_\beta - kF\left(\hat{i}_\beta - i_\beta\right) \tag{10}$$

In order to verify the smoothness, the sigmoidal function is replaced by tan hyperbolic function.

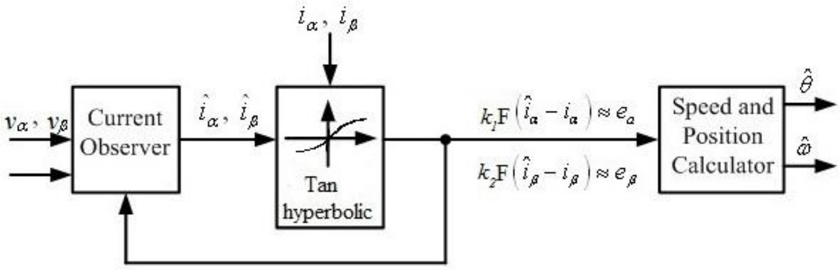

Fig. 3 Sliding Mode Observer with Tan Hyperbolic Function

Though Sigmoidal and tan hyperbolic functions look alike but a big difference lies in the smoothness. The tan hyperbolic function is much smoother than sigmoidal function. The performance is tested for both function to evaluate the most suitable function for sliding mode observer in respect to the chattering, robustness, etc.

IV. simulation results

Simulations with both the functions have been run for each of the observers to verify the estimation performance of the sliding mode observer and examine the related sensorless control of their performance regarding convergence, robustness to parameter errors, robustness regarding uncertainties. Major attention is given in testing start-up behavior for each observer. To evaluate the robustness in all the simulations some of the parameters like R = 1.6 ohm, L= 0.006365H and Φ = 0.1852 are kept fixed.

Figures 4, 5, and 6 shows position, speed and the back emf when SMO with a sigmoidal function is used and Figures 7, 8 and 9 shows the position, speed and back emf when proposed SMO with a tan hyperbolic function is used. These show the simulation results at instant when motor was started from initial rest position to 1000 rpm. Here, the initial position of the actual rotor position is assumed to be known. Later on this information is used to initialize the initial position of the sliding mode observer. Chattering phenomenon is reduced and the accuracy with rotor position and speed estimation is improved to some extend when tan hyperbolic function is used.

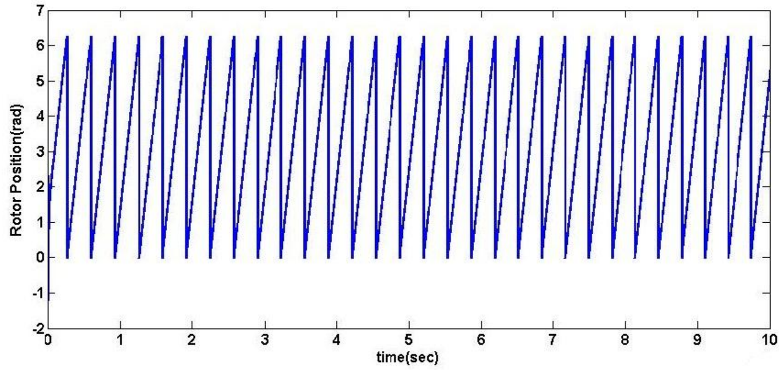

Fig.4 Rotor position with sigmoidal function

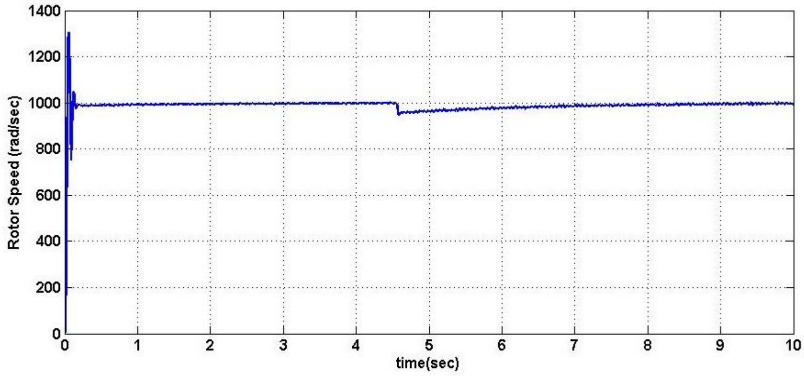

Fig.5 Rotor Speed with sigmoidal function

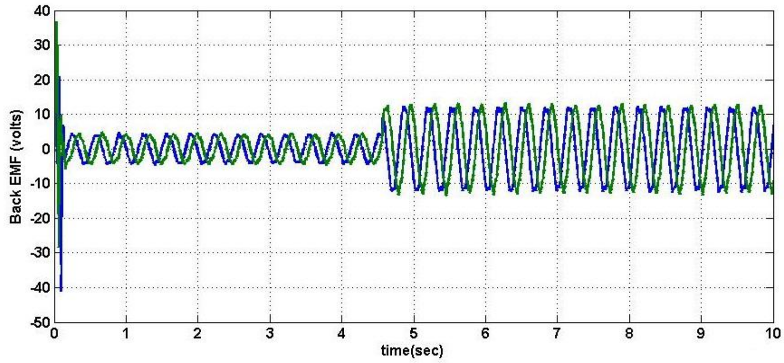

Fig.6 Back EMF with sigmoidal function

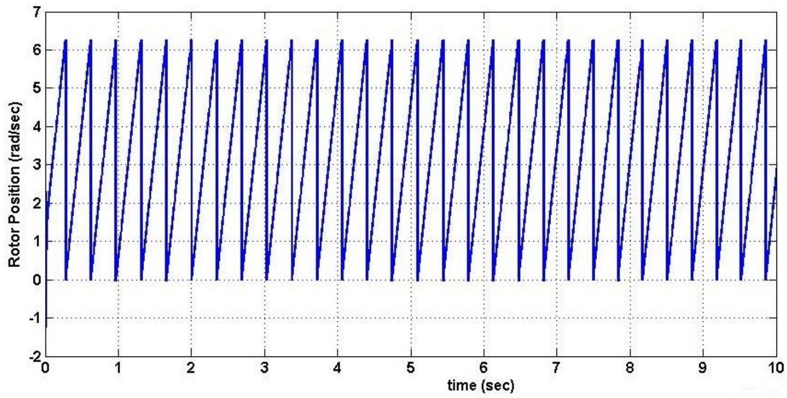

Fig.7 Rotor position with tan hyperbolic function

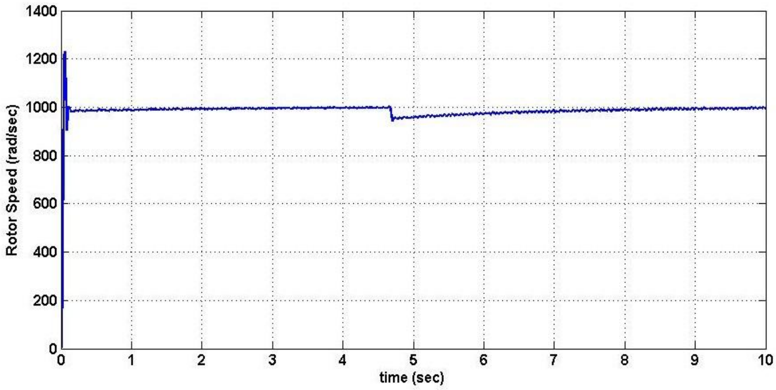

Fig.8 Rotor speed with tan hyperbolic function

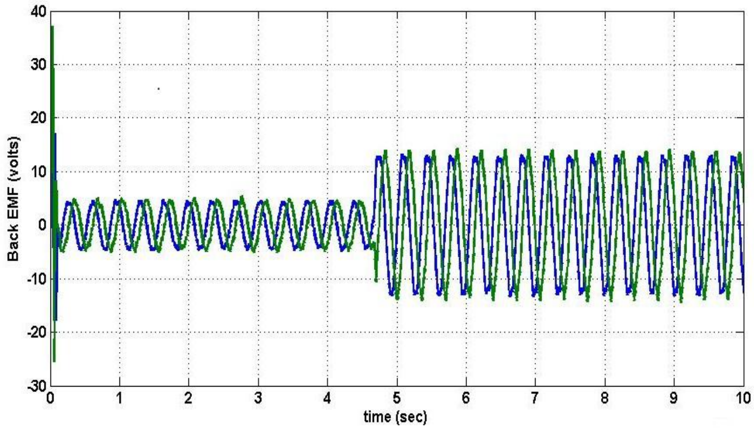

Fig.9 Back EMF with tan hyperbolic funtion

The simulation results in Fig.7 , Fig.8 and Fig.9 shows the satisfactory rotor position, rotor speed and back emf waveform estimated by SMO using tan hyperbolic function. The rotor position is however same for both of the observers. The peak value of rotor speed is reduced from 1170 to 1040 as well as the peak back EMF is reduced from 44 volts to 40 volts when proposed controller is used. The variation of resistance and inductance could give a position estimation error, and may drive system unstable. This is due to the effect of delay time of low pass filter. The estimated rotor position should be further compensated by adding an offset according to operating speeds. When using the improved sliding mode observer, the slow component could be extracted directly from the tan hyperbolic function without low pass filter. Which could represent the back emf. The rotor position error is greatly reduced as shown in Fig7. In SMO with tan hyperbolic function, the slow components are obtained from the low pass filters. It is obvious that the magnitude of slow component is significantly reduced when the control with tan hyperbolic function is being used rather control with sigmoidal function which means that the high oscillation, causing chattering problem, on the observed back emf is lessened. Following table shows the difference in the values of rotor speed and back emf for both observers. Table 2 shows the parameters of PMSM for which controller are designed in the paper.

Table 1 Comparison between peak values for Sigmoidal and tan hyperbolic functions

Parameters		**Sliding Mode observer with sigmoidal function**	**Sliding Mode observer with tan hyperbolic function**
	Units	**Maximum value**	**Maximum value**
Rotor position	radians	6.2	6.2
Rotor Speed	rad/sec	1320	1211
Rotor Back EMF	volts	42	38

V. Conclusion

The proposed sliding mode observer has been presented to estimate peak in the rotor speed and back emf at the output of the PMSM. This observer is very easy to implement and requires a few parameters to be adjusted. The proposed sliding mode observer greatly improves the estimations, comparing with the conventional sliding mode observers using sigmoidal functions. The chattering problem as well as peak overshoot in rotor speed and back emf is significantly reduced as mentioned in the above table when using this proposed observer.

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