State observer and slow and fast time-scale design for permanent magnet synchronous motors.*

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***Abstract*—In the presentation, the state observer is applied to the PMSM(permanent magnet synchronous motors) to estimate torque. The observer is commonly used for sensorless control using the estimation of the torque in the PMSM(permanent magnet synchronous motor).**

***Index Terms*—PMSM(permanent magnet synchrnous motor), Luenberger state observer, two stage method, slow and fast subsystem**

I. Introduction

The sensorless control have been studied and researched over years in [1], [2]. Recently, a sliding observer method is applied for the PMSM, [3]. In the proposed design described in [3], the extended EMF in the rotating reference frame is utilized in order to estimate both position and speed.

The following contribution in this paper is stated.

- Despite the various observer-based control methods, the experiment was conducted concentrating on the state observer incorporated into PMSM simulator introduced in MATLAB/SIMULINK recently.
- The estimation of the back EMF signal is used for control, which means the method can replace the role of the sensor.
- Furthermore, the estimation of the torque and position experiment is implemented based upon the state observer similar to the experiment in [6] .

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A. Method of Design of State Observer

The system modeling of the input and output of PMSM is explain as

$$\begin{aligned}&\dot{X}(t) = AX(t) + Bu(t)\\&Y(t) = CX(t)\\&\rightarrow \begin{bmatrix}\dot{i'}_a(t)\\\dot{i'}_b(t)\\\dot{i'}_c(t)\end{bmatrix} = \begin{bmatrix}A_1 & 0 & 0\\0 & A_2 & 0\\0 & 0 & A_3\end{bmatrix}\begin{bmatrix}i_a^{'}(t)\\i_b^{'}(t)\\i_c^{'}(t)\end{bmatrix}\\&+\begin{bmatrix}B_1 & 0 & 0\\0 & B_2 & 0\\0 & 0 & B_3\end{bmatrix}\begin{bmatrix}v_a(t)\\v_b(t)\\v_c(t)\end{bmatrix}\\&\rightarrow \begin{bmatrix}i_a(t)\\i_b(t)\\i_c(t)\end{bmatrix} = \begin{bmatrix}C_1 & 0 & 0\\0 & C_2 & 0\\0 & 0 & C_3\end{bmatrix}\begin{bmatrix}i_a^{'}(t)\\i_b^{'}(t)\\i_c^{'}(t)\end{bmatrix}\end{aligned} \tag{1}$$

Where $A_1, A_2, A_3 \in R^{2\times2}$, $B_1, B_2, B_3 \in R^{1\times1}$,$C_1, C_2, C_3 \in R^{1\times1}$
The system design method in MATLAB code is given as

$$\begin{aligned}&sys = tfest(u1, y1, np)\\&b = [01138019.49]; , a = [13235055.32];\\&[A1, B1, C1, D1] = tf2ss(b, a)\\&sys2 = tfest(u2, y2, np)\\&b1 = [00.16450.001052]; , a1 = [10.48650.001113];\\&[A2, B2, C2, D2] = tf2ss(b1, a1)\\&sys3 = tfest(u3, y3, np)\\&b2 = [00.16450.001052]; , a2 = [10.48650.001113];\\&[A3, B3, C3, D3] = tf2ss(b2, a2)\\&A = [A1zeros(2, 4); zeros(2, 2)A2zeros(2, 2); zeros(2, 4)A3];\\&B = [B1zeros(2, 2); zeros(2, 1)B2zeros(2, 1); zeros(2, 2)B3]\\&C = [C1zeros(1, 4); zeros(1, 2)C2zeros(1, 2); zeros(1, 4)C3]\end{aligned} \tag{2}$$

The state observer design for equation 1 is given as

$$\begin{aligned}\dot{\hat{X}}(t) &= A\hat{X}(t) + Bu(t) + K(Y(y) - \hat{Y}(t)) \\ Y(t) &= CX(t)\end{aligned} \tag{3}$$

The observer gain K is produced using the pole placement method, given as

II. Two stage method for Luenberger state observer

The equation (1) can be rewritten as

$$\begin{aligned}\dot{X}_1(t) &= A_{11}X_1(t) + A_{12}X_2(t) + B_1u_1(t) \\ \dot{X}_2(t) &= \frac{1}{\epsilon}A_{21}X_1(t) + \frac{1}{\epsilon}A_{22}X_2(t) + \frac{1}{\epsilon}B_1u_1(t) \\ Y(t) &= CX(t)\end{aligned} \tag{4}$$

The two stage method for the Luenberger state observer is derived described in [5], hence the slow and fast subsystem can be given as

$$\begin{aligned}&\dot{\hat{X}}_s(t) = (A_s - K_sC_{sq})\hat{X}_s(t) + K_sY(t) \\ &\epsilon\dot{\hat{X}}_{fnew}(t) = (A_{fq} - K_{f2}C_{fnew})\hat{X}_s(t) - \epsilon K_{f2}C_{sq}\hat{X}_{fnew}(t) \\ &+ \epsilon K_{f2}Y(t)\end{aligned} \tag{5}$$

where

$$\begin{aligned}A_{sq} &= A_{11} - A_{12}L, A_{fq} = A_{22} + \epsilon LA_{12} \\ C_{sq} &= C_1 - C_2L, C_{fq} = \epsilon C_1H + C_2(I_m - \epsilon LH)\end{aligned} \tag{6}$$

L, H is the solution of the Sylvester equation described in [5].

III. Experimental Result

The experiment was implemented using MATLAB/Simulink PMSM simulator.

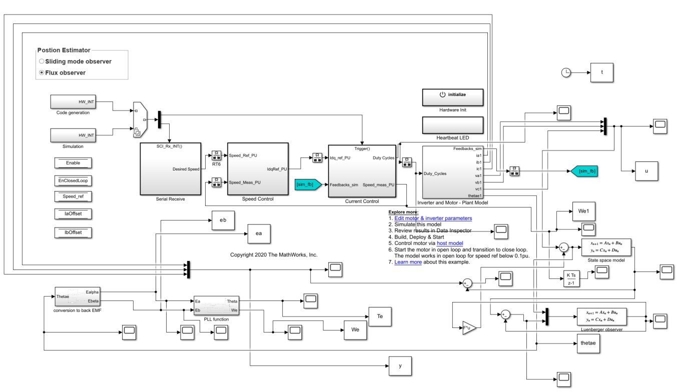

Fig. 1. State observer design for PMSM simulator in MATLAB/Simulink

The estimation of the speed of the motor is given as

The blue line is the estimation of the speed of the motor using composite state observer, the red line is the estimation of the slow subsystem of the state observer using (5)

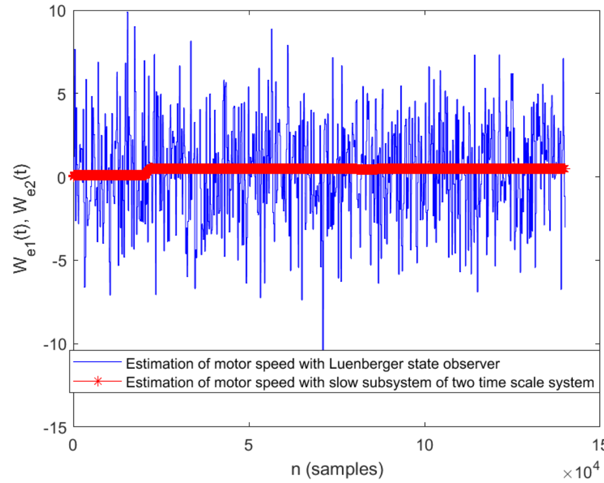

Fig. 2. The motor speed comparison using Luenberger state observer and slow subsystem of the Luenberger observer

IV. Discussion

In Fig. 1, we conclude that the slow and fast dynamics exists in the Luenberger state observer design. Hence, we need to decompose slow and fast dynamics using the two stage method and Sylvester approach described in [4], [5]. Furthermore, if 4 PMSM is used in the mobile platform, the sensorless control can be applied to the 4 wheel mobile platform described in [6]

V. Conclusion

In this paper, the disturbance observer based rejection control was modeled to PMSM system. Firstly, the system state model is designed using transfer function estimation. After modeling of the system, the design of the state observer is implemented to estimate the speed of the motor. In addition to that, the two time-scale method is proposed to attenuate the noise of the multiple time-scale system.

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