Sampled Data High Gain Observer Design Combined with State Predictor For Synchronous PMSMs

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Introduction

- This work is devoted to Sampled Data High Gain Observer design for a class of uniformly observable systems.
- The design of nonlinear observers with sampled measurements has received a great attention.
- This interest is motivated by many applications such as Networks Communication Systems.
- Recently, a hybrid samples data observer dedicated of a class of nonlinear systems has been presented.
- This approach is based on an inter - sample time predictor, which estimates the output between two sampling instants.
- The advantage of this algorithm is in the fact that the state estimates remain continuous time model.
- At each sampling instant, the predictor is reset to the actual output .
- This work presents observer with sampled data measurements and his application to a surface permanent magnet synchronous motor.

Modelling and Observability Study of Synchronous PMS Machines

Because the rotor position is not supposed to be available, the PMSM model is considered in the (α - β) frame :

- The objective is to determine under what conditions all the state of the SPMSM motor, is i_s, φ ω_m and T_L can be determined from the output and input measurements, namely the current and the voltage measurements i_s and u, respectively.

$$\begin{pmatrix} \frac{di_{s\alpha}}{dt} \\ \frac{di_{s\beta}}{dt} \\ \frac{d\varphi_{r\alpha}}{dt} \\ \frac{d\varphi_{r\beta}}{dt} \\ \frac{d\omega_m}{dt} \\ \dot{T}_L \end{pmatrix} = \begin{pmatrix} -\frac{R_s}{L_s} i_{s\alpha} + \frac{p}{L_s}\omega_m \varphi_{r\beta} \\ -\frac{R_s}{L_s} i_{s\beta} - \frac{p}{L_s}\omega_m \varphi_{r\alpha} \\ -p\omega_m \varphi_{r\beta} \\ p\omega_m \varphi_{r\alpha} \\ \frac{2p}{3J} L_{sv} [i_{s\alpha\beta}]^T R(\theta_e)[i_{s\alpha\beta}] + \frac{p}{J}(\varphi_{r\alpha} i_{s\beta} - \varphi_{r\beta} i_{s\alpha}) - \frac{f}{J}\omega_m \\ \varepsilon(t) \end{pmatrix} + \begin{pmatrix} \frac{1}{L_s} & 0 & 0 \\ 0 & \frac{1}{L_s} & 0 \\ 0 & 0 & -\frac{1}{J} \end{pmatrix} . \begin{pmatrix} u_\alpha \\ u_\beta \\ T_L \end{pmatrix}$$

The mechanical rotor position is $\theta_r = \frac{1}{p} \tan^{-1}\left(\frac{\psi_{r\beta}}{\psi_{r\alpha}}\right)$

Now, let us consider the following change of state variables.

$$\Phi : \mathbf{R}^6 \to \mathbf{R}^6, x \to z = \begin{pmatrix} z_1 \\ z_2 \\ z_3 \end{pmatrix} = \Phi(x) = \begin{pmatrix} \Phi_1(x) \\ \Phi_2(x) \\ \Phi_3(x) \end{pmatrix}$$

Let J_Φ be the Jacobian of Φ (x). According to (6), one has:

$$J_{\Phi\,(x)} = \begin{bmatrix} I_2 & 0_2 & 0_2 \\ 0_2 & \frac{\partial \Phi_2(x)}{\partial x_2} & \frac{\partial \Phi_2(x)}{\partial x_{31}} \\ \frac{\partial \Phi_3(x)}{\partial x_1} & \frac{\partial \Phi_3(x)}{\partial x_2} & \frac{\partial \Phi_3(x)}{\partial x_3} \end{bmatrix}$$

It is clear that the matrix $J_{\Phi\,(x)}$ is of full rank if and only if the following square matrix is also of full rank:

$$G_{\Phi\,(x)} = \begin{pmatrix} \frac{\partial \Phi_2(x)}{\partial x_2} & \frac{\partial \Phi_2(x)}{\partial x_{31}} \\ \frac{\partial \Phi_3(x)}{\partial x_2} & \frac{\partial \Phi_3(x)}{\partial x_3} \end{pmatrix} \triangleq \begin{pmatrix} G_1(x) & G_2(x) \\ G_3(x) & G_4(x) \end{pmatrix}$$

det $G_{\Phi\,(x)}$ = det(G1G4 - G3G2) , det $G_{\Phi\,(x)} = \frac{p^5}{JL_s}\left(1 + \frac{2p}{J}\right) x_{31}^3 x_2^T\ x_2$

Then, the considered transformation has a full rank in each x as soon as:

$x_{31}{}^3 x_2^T\ x_2 \neq 0$ or in the original motor variables, $\psi_r\ \omega_m^3 \neq 0$

the following dynamical system is an observe

$$\dot{\hat{x}} = f(x,u) - \theta J_{\Phi\,(x)}^{-1} \Delta\theta^{-1} K\,(C(\hat{x}) - w(t))$$

$$\dot{w}(t) = f_1(\hat{x}, u) \qquad t \in [t_k, tk+1)$$

$$w(t_k) = y(t_k) + v\,(t_k)$$

Maximum Allowable Sampling Period τ_{MASP}:

Theorem 1: Under assumptions (A1- A2), system (22) is a sampled data observer for system (16) with the following property: For sufficiently large values of parameters θ and ki = 1;2;3, there exists a real positive bounded τ_{MASP} such for all $\tau \in (0, \tau_{MASP})$, the observation error is ultimately bounded and the corresponding ultimate bound can be made as small as desired by choosing values of θ high enough.

- We derive a condition on the maximum allowable sample period that ensures a convergence of the observation error.

$$\tau_{MASP} = \lim \rho \to 0\ \left(\frac{1}{\sigma^2}(\arctan(\lambda^{-1}) - \arctan(\lambda))\right) = \frac{1}{\theta}\left[\frac{\lambda^2 \max(P)\lambda^2 \max(K) + (\theta + \xi_1)^2}{\theta\lambda\max(Q) - 2\lambda\max(P)\ \xi_1} + c\lambda\min(P)\right]\left(\frac{\pi}{2} - \arctan(\lambda)\right)$$

- Then, the observer is exponentially stable whatever the initial conditions. The error vector $e_z = \hat{z}(t) - z(t)$ converges exponentially to a compact neighborhood of the origin and the size of this compact set can be made small by choosing the design parameters θ sufficiently large.

Mathematical Results:

Table I. Mechanical and Electrical Characteristics for Surface – Mounted PMSM .

Parameter	Symbol	Value
DC / AC converter	V_{dc}	600 V
Modulation Frequency	F_m	10 Hz
Nominal Power	P	3 kW
Nominal flux	ψ_n	0. 3 Wb
Stator resistance	R_s	0. 6 Ω
Stator inductance	L_s	0.0094 H
Rotor and load Viscous damping coefficient	F	0. 003819 SI
Moment of inertia	J	0.02765 SI
Number of pole pairs	p	2

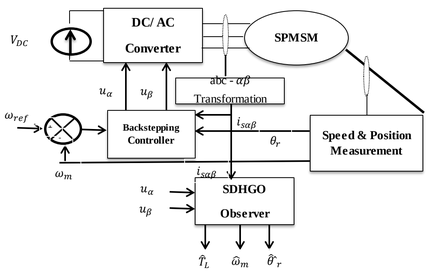

Fig. (I): Single Line Diagram of Proposed Case Study of SPMSM

- The simulation results illustrate that the proposed SDHGO observer has fast transient response, good external load torque rejection response ,accurate tracking response and accurate recovery from any external disturbance.

Table (II): Sampled Data High Gain Observer Design Parameters.

θ	K_1	K_2	K_3	$\tau_{sampling}$	τ_{max}	Eta η	a
64 (Med.)	30.2	241	258	0.56	0.77ms	20	0.75
61(Small)	30.2	241	258	0.01 min.	0.77ms	20	0.75
69 (Large)	30.2	241	258	0.77 (max)	0.77 ms	20	0.75

Simulation Results:

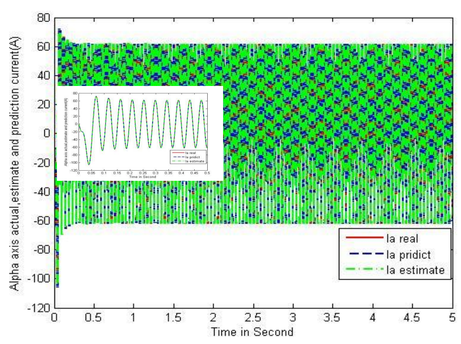

Fig. (1): Real Current $i_{s\alpha}$ (solid), Predicted $w_{s\alpha}$ (dashed) and Estimate Current $\hat{i}_{s\alpha}$ (dash – dot).

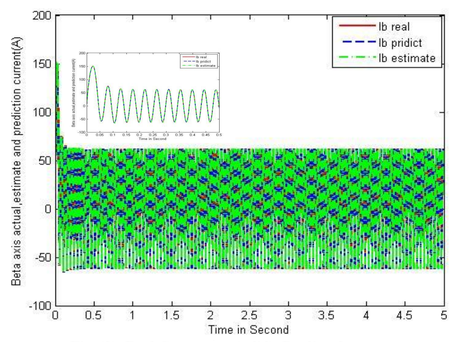

Fig. (2): Real Current $i_{s\beta}$ (solid), Predicted $w_{s\beta}$ (dashed) and Estimate Current $\hat{i}_{s\beta}$ (dash – dot).

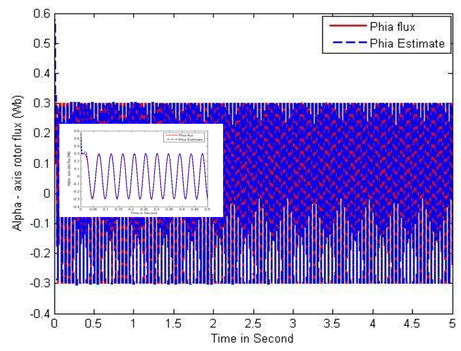

Fig. (3): Real Rotor Flux $\psi_{r\alpha}$ (solid), Observed Rotor Flux $\hat{\psi}_{r\alpha}$ (dashed) (Wb).

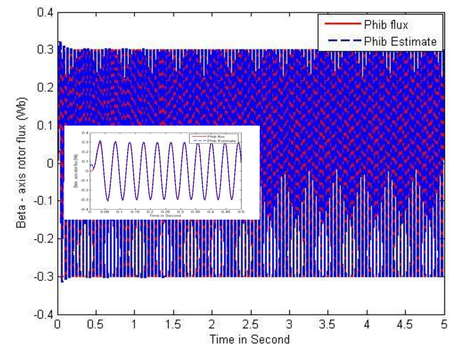

Fig. (4) : Real Rotor Flux $\psi_{r\beta}$ (solid), Observed Rotor Flux $\hat{\psi}_{r\alpha}$ (dashed) (Wb).

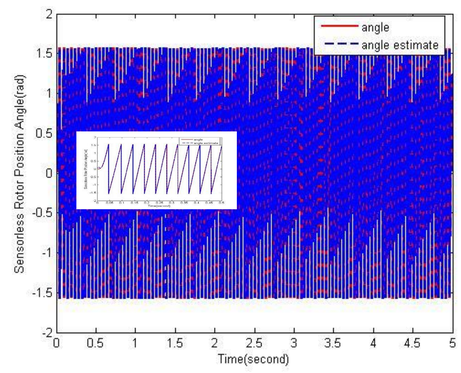

Fig. (5): Tracking Performance of Real Rotor Angle θ_r (solid), Observed Rotor Angle $\hat{\theta}_r$ (dashed).

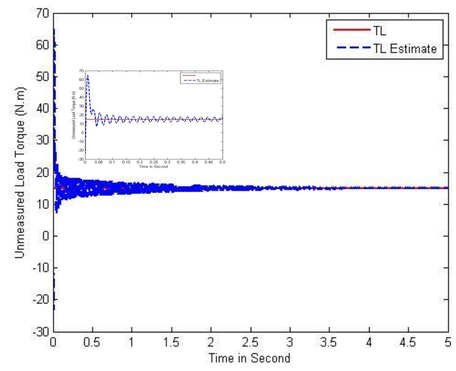

Fig. (6): Tracking Performance of Real Torque T_L (solid), Observed Torque $\hat{T}_L$ (dashed) ($N.m$).

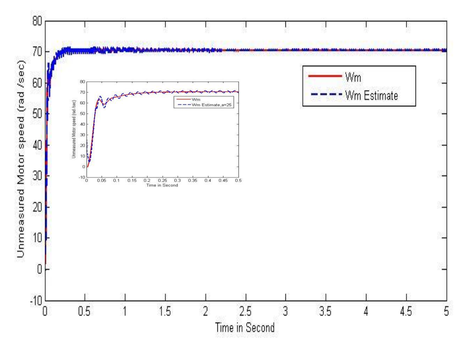

Fig. (7): Tracking Performance of Real Speed ω_m (solid), Observed Speed $\hat{\omega}_m$ (dashed) (rad/sec).

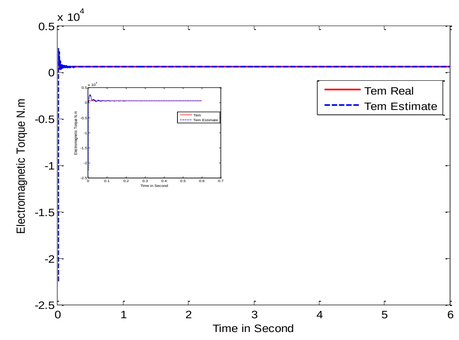

Fig. (8): Torque T_{em} (solid), Observed Torque $\hat{T}_{em}$ (dashed)) in case of zero crossing ($N.m$).