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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 \( x_r, \varphi, \omega_m \) and \( T_C \) can be determined from the output and input measurements, namely the current and the voltage measurements \( i_s \) and \( u_s \), respectively.

\[
\frac{dx}{dt} = \begin{pmatrix}
   -\frac{R_s}{L_s} i_s + \frac{1}{L_s} \varphi_s \\
   \frac{1}{L_s} \varphi_s - \frac{1}{L_s} \omega_m \varphi_s \\
   \frac{1}{L_s} \omega_m \varphi_s - \frac{1}{L_s} \varphi_s \\
   \frac{1}{L_s} \omega_m \varphi_s - \frac{1}{L_s} \varphi_s
\end{pmatrix} + \begin{pmatrix}
   0 \\
   0 \\
   0 \\
   0
\end{pmatrix} \frac{d\varphi}{dt} + \begin{pmatrix}
   0 \\
   0 \\
   0 \\
   0
\end{pmatrix} \frac{d\omega_m}{dt} + \begin{pmatrix}
   u_s \\
   u_s \\
   u_s \\
   u_s
\end{pmatrix}
\]

The mechanical rotor position is:

\[
\varphi = \frac{1}{p} \tan^{-1}\left( \frac{\omega_m}{\omega_s} \right)
\]

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

\[
\Phi : \mathbb{R}^6 \rightarrow \mathbb{R}^6, x \rightarrow z = \begin{pmatrix} z_1 \\ z_2 \\ z_3 \end{pmatrix} = \Phi(x) = \begin{pmatrix} \Phi_1(x) \\ \Phi_2(x) \\ \Phi_3(x) \end{pmatrix}
\]

Let \( J_\Phi \) be the Jacobian of \( \Phi(x) \). According to (6), one has:

\[
J_\Phi(x) = \begin{bmatrix}
   I_2 & 0_2 & 0_2 \\
   0_2 & \frac{\partial \Phi_2(x)}{\partial x_2} & \frac{\partial \Phi_2(x)}{\partial x_3} \\
   \frac{\partial \Phi_3(x)}{\partial x_2} & \frac{\partial \Phi_3(x)}{\partial x_3} & \frac{\partial \Phi_3(x)}{\partial x_3}
\end{bmatrix}
\]

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:

\[
G_\Phi(x) = \begin{pmatrix}
   \frac{\partial \Phi_3(x)}{\partial x_2} & \frac{\partial \Phi_3(x)}{\partial x_3} & \frac{\partial \Phi_3(x)}{\partial x_3}
\end{pmatrix} \begin{pmatrix}
   \frac{\partial \Phi_3(x)}{\partial x_2} & \frac{\partial \Phi_3(x)}{\partial x_3} & \frac{\partial \Phi_3(x)}{\partial x_3}
\end{pmatrix} \Delta x
\]

\[
\det G_\Phi(x) = \det(G_{1G4} - G_{3G2}). \det G_\Phi(x) = \frac{p^i}{L_\psi} \left( 1 + \frac{2p}{J} \right) x_2^3 x_2^2 x_2
\]

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

\[
x_{31} x_2^2 x_2 \neq 0 \quad \text{or in the original motor variables,} \quad \psi, \omega_m \neq 0
\]

The following dynamical system is an observer:

\[
\dot{\tilde{x}} = f(x, u) - \theta^\top \Phi(x) \Delta \theta^{-1} K(C(\tilde{x}) - w(t))
\]

\[
w(t) = f_s(\tilde{x}, u) + v(t)
\]

\[
w(t) = y(t) + v(t)
\]

Maximum Allowable Sampling Period \( T_{MASP} \):

**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 \( \theta \) and \( k_i = 1:2:3 \), there exists a real positive bounded \( T_{MASP} \) such for all \( t \in (0, T_{MASP}) \), the observation error is ultimately bounded and the corresponding ultimate bound can be made as small as desired by choosing values of \( \theta \) high enough.

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

\[
t_{MASP} = \lim_{\rho \rightarrow 0} \left( \frac{1}{\rho} \left( \arctan \left( \frac{2}{\rho} \right) - \arctan(32) \right) \right) = \frac{1}{\rho} \left( \frac{\arctan \left( \frac{2}{\rho} \right) - \arctan(32) \right) \leq \arctan \left( \frac{2}{\rho} \right)
\]

• Then, the observer is exponentially stable whatever the initial conditions. The error vector \( e_s = \dot{z}(t) - z(t) \) 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 \( \theta \) sufficiently large.

Mathematical Results:

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

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power</td>
<td>3 kW</td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>600 V</td>
</tr>
<tr>
<td>No. of Poles</td>
<td>4</td>
</tr>
<tr>
<td>Max. Speed</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Max. Current</td>
<td>25 A</td>
</tr>
<tr>
<td>Max. Torque</td>
<td>1.5 N.m</td>
</tr>
<tr>
<td>Efficiency</td>
<td>90 %</td>
</tr>
</tbody>
</table>

Simulation Results: