A Global Bivalued-Observer for the Sensorless Induction Motor*
Jaime A. Moreno * H. Mujica-Ortega **
G. Espinosa-Pérez **

* Instituto de Ingeniería, ** Facultad de Ingeniería, Universidad Nacional Autónoma de México (UNAM), Coyoacán, Ciudad de México, 04510, México. Email: JMorenoP@ii.unam.mx, hoovertec@gmail.com, gerardoe@unam.mx

Abstract: Sensorless control of Induction Motors has received a lot of attention both from the applied as well as from the theoretical perspectives. In its more formal approach, a complete observability analysis of this machine, assuming the load torque is known, has been developed and several nonlinear observers have been reported in the literature. Since the system has indistinguishable trajectories, none of the existing observers is able to operate correctly under all operating conditions of the machine. In this paper we present a novel observer that is able to estimate all (non trivial) distinguishable or indistinguishable trajectories exhibited by the induction motor model under sensorless operation. The structure of the estimator comes from a detailed observability analysis under assumption that the load torque is unknown, that shows that the non trivial indistinguishable trajectories always appear in pairs, i.e. for each actual trajectory there exists at most another indistinguishable one. Hence we propose a Bi-valued observer which is always well-behaved and its convergence is guaranteed for any operation regime. The usefulness of the proposed scheme is validated by numerical simulations.

© 2017, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.

Keywords: Sensorless Machines, Nonlinear Observers, Lyapunov Functions

1. INTRODUCTION
Sensorless control of induction motors (IM) is a control technique intended to improve both reliability and cost of the available drives by using measurement of only electrical variables, i.e. avoiding the use of speed/position sensors.

After its formulation, the community dedicated to this topic realized the existence of operation regimes that preclude the achievement of the desired objective (Harnefors, 2000) and some ad hoc solutions were proposed (Holtz and Quan, 2002) that unfortunately were not capable to entirely attain the prescribed behavior.

With the aim to better understand the problem and provide formal solutions, a non linear observability analysis was performed for the IM under sensorless operation, with the assumption that the load torque is known. In (Canudas et al., 2000) a local while in (Ibarra-Rojas et al., 2004) a global observability analysis was presented. In these references it was clearly stated that the machine is neither local nor global observable under some operation regimes due to the existence of some (input–dependent) trajectories that are not distinguishable if only electrical variables measurement is considered. Moreover, some indistinguishable trajectories are not convergent and thus the IM is not detectable as well. On the other hand, a series of nonlinear observers were designed exploiting different techniques, e.g., based on dynamical observers (Ghanes et al., 2005), high–gain observers (Aurora and Ferrara, 2007) and algebraic structures (Li et al., 2005), immersion based observers (Ticlea and Besançon, 2006), among many others.

The existence of (non converging) indistinguishable trajectories precludes the possibility that a (single-valued) observer performs correctly under all operating conditions of the IM, and the best one can hope for is that the designed observer will converge only for distinguishable trajectories. As a consequence, the performance of the proposed observation schemes is always compromised under this kind of operations, leading to the necessity to include heuristic mechanisms with the objective to cope with these undesirable behaviors.

In this paper we propose a novel multi-valued nonlinear observer for sensorless operation of the IM, that is able to perform correctly in presence of indistinguishable trajectories. To construct the observer we first extend the global observability analysis of (Ibarra-Rojas et al., 2004), assuming that the load torque is unknown, and we are able to show that (non trivial) indistinguishable trajectories appear only in pairs. This situation leads to the natural possibility to implement a bi-valued observer, that is always well behaved in the sense that its convergence properties are guaranteed for all operation regimes. For operation regimes with distinguishable trajectories the observer provides the actual trajectory. When an indistinguishable trajectory is at play, the observer gives both possible trajectories.
2. MOTOR MODEL AND PROBLEM STATEMENT

In this paper it is considered the standard 2φ equivalent model of the unsaturated IM given by (Meisel, 1966)

\[
\frac{d}{dt} = \beta[(a\mathbf{I} + n_p\omega \mathbf{J})\psi - (Ma + b)i + cu] \\
\dot{\psi} = -(a\mathbf{I} + n_p\omega \mathbf{J})\psi + Mai \\
\dot{\omega} = -f\omega + \alpha\psi^T \mathbf{J} = -\frac{T_L}{J} 
\]

where \(\mathbf{I} = [i_a, i_b] \in \mathbb{R}^2\) are the stator currents, \(\psi = [\psi_a, \psi_b] \in \mathbb{R}^2\) are the rotor fluxes, \(\omega \in \mathbb{R}\) is the rotor speed, \(f = B/J\) is the friction coefficient and \(n_p\) is the number of pole pairs. Matrices \(\mathbf{J} \in \mathbb{R}^{2 \times 2}\), \(\mathbf{I} \in \mathbb{R}^{2 \times 2}\) are given by

\[
\mathbf{J} = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} = -\mathbf{J}^T, \quad \mathbf{I} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}.
\]

Under sensorless operation, the only measured variables are the stator currents \(i\) and the control voltages \(u\), i.e. the controller design must be carried out by assuming that the rotor fluxes \(\psi\) and the motor speed \(\omega\) cannot be measured. In addition, we assume the rather realistic situation that the load torque \(T_L\) is an unknown external disturbance and that it is an arbitrary time-varying signal.

It is well-known (Ibarra-Rojas et al., 2004) that the IM under sensorless operation (and assuming the knowledge of the load torque \(T_L\)) has indistinguishable trajectories, and therefore that there exists no (uni-valued) observer able to provide the actual unmeasured states of the IM for all possible operation modes. The objective of this paper is to design an observer that is able: (1) for distinguishable trajectories to provide correct estimates of the actual values of the unmeasured variables, and (2) for indistinguishable trajectories to provide correct estimates of all indistinguishable trajectories compatible with the actual Input-Output measurements.

3. OBSERVABILITY ANALYSIS

The observability analysis consists in finding from equations (1–3) an expression for the unmeasured variables \(\omega\), \(\psi\) and \(T_L\) in terms of the measurable ones, \(i\) and \(u\), and their time derivatives. For this, consider the change of variables

\[
\zeta = (a\mathbf{I} + n_p\omega \mathbf{J})\psi \quad \text{leading to the rotor fluxes representation} \quad \psi = (a\mathbf{I} + n_p\omega \mathbf{J})^{-1} \zeta 
\]

where

\[
(a\mathbf{I} + n_p\omega \mathbf{J})^{-1} = \frac{1}{a^2 + n_p^2\omega^2}(a\mathbf{I} - n_p\omega \mathbf{J}).
\]

Taking the time derivative of \(\zeta\) we obtain

\[
\dot{\zeta} = (a\mathbf{I} + n_p\omega \mathbf{J})\dot{\psi} + n_p\omega \mathbf{J}\psi.
\]

leading to the equivalent IM model representation

\[
\frac{d}{dt} = \beta[\zeta - (Ma + b) i + cu] \\
\dot{\zeta} = (a\mathbf{I} + n_p\omega \mathbf{J})(-\zeta + Mai) + n_p\left(-f\omega + \alpha\psi^T \mathbf{J} - \frac{T_L}{J}\right) \times \mathbf{J}^{-1} \zeta
\]

\[
\dot{\omega} = -f\omega + \alpha\psi^T \mathbf{J}^{-1} \zeta
\]

which, allows, from (5), to obtain a unique value for \(\zeta\) in terms of the measurements given by

\[
\zeta = \frac{1}{\beta}\frac{d}{dt} + (Ma + b) i - cu.
\]

while, premultiplying (6) by \((a\mathbf{I} + n_p\omega \mathbf{J}) \mathbf{J}\), is obtained that

\[
\zeta T_L = \frac{J}{n_p} (a\mathbf{I} + n_p\omega \mathbf{J}) \dot{\zeta} - \frac{J}{n_p} (-2n_p\omega aI + (a^2 - n_p^2\omega^2) \mathbf{J}) (-\zeta + Mai) + \mathbf{J}^{-1} \zeta
\]

\[
(a\mathbf{I} + n_p\omega \mathbf{J}) \mathbf{J} (a\mathbf{I} + n_p\omega \mathbf{J}) = -2n_p\omega aI + (a^2 - n_p^2\omega^2) \mathbf{J}
\]

From (9) we can obtain expressions for \(\omega\) and for \(T_L\) in terms of the variables \(i, \psi, \zeta\), which are available from the measurements. Premultiplying (9) by \(\zeta^T\) leads to

\[
0 = -a\zeta^T \zeta - n_p\omega \zeta^T \mathbf{J} \zeta + 2n_p\omega Ma^2 \zeta^T \mathbf{J} i + Ma \left(a^2 - n_p^2\omega^2\right) \zeta^T i - a^2 \zeta^T \zeta + n_p^2\omega^2 \zeta^T \zeta
\]

since \(\mathbf{J}\) is skew-symmetric. This last expression can be written as a quadratic function of \(\omega\) as

\[
p_1(\omega) \triangleq \kappa_1 n_p^2 \omega^2 + \kappa_2 n_p \omega + \kappa_0 = 0
\]

\[
\kappa_2 = (\zeta^T \zeta - Ma \zeta^T i), \quad \kappa_1 = (2Ma^2 \zeta^T \mathbf{J} i - \zeta^T \mathbf{J} \zeta), \quad \kappa_0 = a \left(Ma^2 \zeta^T i - a \zeta^T \zeta - \zeta^T \zeta\right)
\]

from which it is possible to determine the two values of the speed \(\omega\) that satisfy equation (9).

Once the speed has been obtained, the corresponding load torque can be computed by premultiplying (9) by \(\zeta^T\) to obtain that

\[
T_L = \tau_L(\omega),
\]

where the function \(\tau_L(\omega)\) is given by

\[
\tau_L(\omega) \triangleq \frac{J}{n_p n_p^2 \omega^2} (a\mathbf{I} + n_p\omega \mathbf{J}) \zeta^T (a\mathbf{I} + n_p\omega \mathbf{J}) \zeta^T i + Ma \left(a^2 - n_p^2\omega^2\right) \zeta^T \mathbf{J} i + \mathbf{J}^{-1} \left(-2a + f\right) \omega + \left(\frac{a (\zeta^T \mathbf{J} i - n_p\omega \zeta^T \mathbf{J} i)}{a^2 + n_p^2\omega^2}\right)
\]

(12)
دریافت فوری متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات