Discussion on: “Observer Scheme for Asynchronous Motors with Application to Speed Control”

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The paper by Ticlea and Besançon is an interesting contribution to the area of state and parameter estimation for both speed sensorless operation and insensitivity to parameter variation of an induction motor drive. It treats the problem of simultaneous state and parameter estimation in induction motor. It is to be noted that simultaneous estimation of speed and rotor resistance was, for a long time, considered impossible by many researchers in this area. This is because under constant flux operation in rotor flux oriented control, the rotor model is reduced to one equation containing both speed and rotor resistance. So, a change in either rotor speed or rotor resistance has an equal effect on the electrical behaviour of the motor. The aim of this discussion is to highlight the essential points about the proposed observer that can help the reader to better appreciate the significance of the paper.

The authors present a method of simultaneous estimation based on an exact Kalman-like observer. The use of such an observer is made possible by an immersion of the nonlinear model of the machine into a model which is affine with respect to variables to be estimated. The choice of this observer is due to the drawbacks of the extended Kalman filter, usually used for this kind of problem [2], such as uncertain global, low accuracy at small speeds and the required computational time. The theoretical background of the machine modeling in order to use an exact Kalman-like observer is interesting and the simulation results are satisfactory for state and parameter estimation and speed control. The method developed is weakened by the large amount of computations, when all variables of state and parameter are to be estimated as Ticlea and Besançon have mentioned in their conclusion and it can be seen in the state vector size of the developed machine model. Also, the load torque is considered as a constant parameter which is not always the case, and this reduces the application area of the study. These disadvantages will not reduce the interest generated by this work.

The machine model takes into account the coupling between the electrical and mechanical modes, and is expressed in a reference frame fixed to stator (α, β), and made under an affine representation of the form:

\[
\begin{align*}
X &= A(u, y, \Omega)X + Bu \\
Y &= CX
\end{align*}
\]

The modeling approach used in the work aims to develop a linear model of the machine by reorganising the nonlinear model and using new states. However, the matrix \( A \) in (1) is varied and depends on the measured inputs and outputs. The machine variables and parameters are combined to create new states in order to get a state-affine system. This representation form allows the use, under condition of regularly persistent, of Kalman observer

\[
\dot{X} = A(u, y, \Omega)X + Bu - S^{-1}C^T(C\dot{X} - Y)
\]

\[
\dot{S} = -\lambda S - A^T(u, y, \Omega) - SA(u, y, \Omega) + C^T C,
\]

\( S(0) > 0 \)

Fast exponential convergence through the tuning parameter \( \lambda > 0 \), used in Lyapunov differential equation, for \( \dot{X}(0) \). It can be explained as follows:

If \((u, y, \Omega)\) are strictly persistent, (2) can be used as an observer for (1). More precisely

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where $k$ depends on initial state and $(u, y, \Omega)$. Therefore, the persistency of the measured and bounded motor inputs $(u, y, \Omega)$ must be verified, such as the condition:

$$
\int_{t_0}^{t+t_0} \Phi_r(\tau, t) C^T \Phi_r(\tau, t) d\tau \geq \alpha I, \forall t \geq t_0 \tag{4}
$$

is satisfied for some $t_0$, $T, \alpha > 0$, where $\Phi_r$ denotes the transition matrix of the system (1). For more details about the synthesis of this observer the reader can refer to [1].

The developed observer is used for various cases of unknown variables to be estimated such as:

- Flux and parameter estimation (from measured current and speed).
- State estimation (the current is measured and the electrical parameters are known).
- Full state and parameter estimation (from only current is measurement).

In our point of view, the most important result of this work is the combination of variables and parameters used to create the affine model of the machine, which can be used for other applications as adaptive control for example. The most affected machine parameters during operation are the stator resistance and rotor time constant which vary with the motor temperature. Then, take these two parameters with the state variables of the machine and apply the proposed observer followed by a comparison with another method of estimation as, for instance, extended Kalman filter of reducing model order of the motor described in [3], in order to overcome the disadvantages of standard Kalman filter, or with standard Kalman filter as the machine model becomes linear (1). This comparison will improve the quality of paper further.

The work by Țiclea and Besançon is interesting and thanks to these developments, the method of modeling and observation of induction motor, if followed by a study of the closed loop controlled system characteristics, and the affine model built for the machine may help for the development of new control strategies.

References


Final Comments by the Authors

A. Țiclea and G. Besançon

The authors would like first of all to thank the contributors to the discussion section for the interest they have manifested towards the results presented in the paper and for providing valuable complementary comments that help the reader to gain a deeper insight into the induction motor observation problem.

We feel, however, that additions can be made with respect to some of the issues that are mentioned in those discussions; in particular, we would like to address the following points:

- the comparison between the exponential forgetting factor observer and the Kalman observer (including its extended form);
- the regular persistence property of the input;
- the implementation of the solution in discrete-time.

1. The Exponential Forgetting Factor Observer Vs. the (Extended) Kalman Observer

In our opinion, as far as the solutions based on these observers for the estimation of the IM are concerned, the computational cost is not a significant comparison criterion.

Let us first notice that when observing state-affine systems, one can either use an exponential forgetting factor observer, or the deterministic version of the Kalman observer. So both designs can be used in our approach. Moreover, in both cases, the gain is obtained from the solution of a Riccati equation, so the amount of computations is basically the same. Regarding the extended Kalman observer, although