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Induction machine control using robust eigenstructure assignment

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Abstract

Control of induction machines is well known to be difficult owing to the fact that the models of induction motor are highly non-linear and time variant. In this paper, we propose a very simple approach based on linear eigenstructure assignment and eigenstructure projection to design an efficient control law. This is the first step to a more global approach using multimodel eigenstructure assignment and self-scheduling. The controller, which is proposed here, is not scheduled (with the rotor speed) but still has correct performance over the entire operating range of the induction motor. A Kalman filter is used to estimate the flux vector. The simulation is based on the non-linear model and the application is made on an experimental bench.
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Keywords: Induction motor; State feedback; Linear matrix inequalities; Eigenstructure assignment; Kalman filter; Robustness

1. Introduction

Induction motors are used intensively in industry, due to their power density and robustness. However, they are significantly more difficult to control than dc motors. Indeed, a lot of applications require an accurate control of torque and magnetizing flux and the torque of dc motors depends on decoupled variables which can be separately controlled. In order to give to induction motors the same properties as dc motors, we ideally undertake a vector field orientation control (Leonard, 1991). However, the flux, which must be controlled, is unknown and the electrical parameters drift with temperature, saturation, sliding frequency and rotor speed. This involves new coupling of current and magnetizing state and thus a decrease in performance. Moreover, the majority of the control laws require the recognition speed and are thus dependent on the measuring accuracy of the rotor speed sensor. In many applications, the brittleness of this sensor limits the use of an induction motor in industrial application. Linear parameter variant or predictive controllers are ideally used to correct these drawbacks but they are complex and require the recognition speed (Prempain et al., 2002; Dumur et al., 1998). The objective is to synthesize a robust linear controller taking into account noise attenuation, load torque variations, robust stability in spite of these drifts and rotor speed variations. Overviews of the important induction motor control techniques are given in Bose (1998) and Leonhard (1990).

In this paper, we propose a design procedure based on eigenstructure assignment and eigenvector projection. Eigenstructure assignment is often assumed to lead to poor robustness. This is essentially due to the choice of eigenvectors. In fact, the variation of eigenvalues from parametric variations is directly related to the closed loop eigenvectors. The simple idea, which is applied here, is to preserve the natural parametric behaviour of the open-loop system using minimization of eigenvector variations i.e. using eigenvector projection. Here, we use

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Nomenclature

L_{f}	Leakage inductance (0.0037, H)
L_{m}	Magnetizing inductance (0.116, H)
R_{s}	Stator resistance (1, Ω)
R_{r}	Rotor resistance (1.18, Ω)
J	Moment of inertia (0.1, $\mathrm{kg\,m^2}$)
f	Viscous damping constant (0.07, N m s)
p	Number of pole pairs (2)
ω_{s}	Stator current pulsation ($2^*\pi^*50$, $\mathrm{rad\,s^{-1}}$)
ω_{m}	Mechanical pulsation (297.25, $\mathrm{rad\,s^{-1}}$)
$\omega_{\mathrm{sl}} = \omega_{\mathrm{s}} - \omega_{\mathrm{m}}$	Rotor current pulsation ($\mathrm{rad\,s^{-1}}$)
Ω	Mechanical speed (148.63, $\mathrm{rad\,s^{-1}}$)
N_{r}	Speed (1420, rpm)
T_{e}	Electromagnetic torque (37, N m)
T_{c}	Load torque (N m)
ϕ_{dr}	Rotor flux component on d-axis (Wb)
ϕ_{qr}	Rotor flux component on q-axis (Wb)
T_d	Sampling period (s)

a method detailed in Le Gorrec, Magni, Kubica, Chiappa (1998a) and Le Gorrec, Magni, Döll, and Chiappa (1998b), Magni et al. (1998), Döll et al. (2001) which provides robust control by orthogonal projections of open-loop eigenvectors. If the problem is under specified, a strategy consists in solving the equation by minimizing a quadratic (frequency domain specifications) criterion.

It is assumed that only the stator currents and the rotor speed are available for measurement. The rotor speed will only be used in the flux observer and not in the controller structure. Realistic simulation results show that this control law is robust with respect to electrical parameter uncertainties, measurement noise and load torque variations. The proposed control law is easy to synthesize and to implement due to the low orders of the feedback controller. A further step will consist in considering multimodel design procedure and scheduling to improve the performance over the entire operating range.

The first part of our paper will present the basis of the method: the modal behaviour analysis and the eigenstructure assignment by static feedback. Then, the second part deals with the application to the flux and torque control of an induction machine. An extended Kalman filter provides the rotor flux, the rotor resistance and the magnetizing inductance tracking. Simulation and experimental results will validate the approach.

2. Eigenstructure assignment

2.1. Principle

The method, which is proposed in this paper, is based on traditional eigenstructure assignment with some improvements which allow dealing with problems of robustness (Le Gorrec et al., 1998a, b; Magni et al., 1998).

A preliminary step consists in adding integrators and eventually filters to deal with steady state error and frequency domain specifications (note that these points can be directly dealt with using controller structuring as explained in Le Gorrec et al. (1998a,b)). The first step of the design consists in the analysis of the modal behaviour of the system. In fact, a nominal system is chosen (corresponding to the average model in the meaning of the parametrical variations). The closed-loop eigenvalues are chosen to deal with performance specifications. The closed-loop eigenvectors are chosen either by orthogonal projection of the open-loop eigenvectors or by constraints guaranteeing some decouplings. In a second step, it is possible to adjust the controller by modifying the nominal system or the eigenvalues which are assigned after robustness analysis. In order to improve the results, current research consists in considering multimodel constraints.

The main advantage of this method is that it is very simple. It is easy to take into account the initial constraints, to deal with both performance and robustness in a very natural manner. The obtained controller is very simple. It is possible, for better results, to consider multimodel designed controller or self scheduled controllers.

To summarize, the design procedure is as follows:

Step A. *Global system*: We define the structure of the system, the inputs and the outputs. All the components of the control law must be taken into account in the synthesis (filters, integrators...). If the system is nonlinear, it must be linearized around an operating point.

Step B. *Preliminary analysis*: We proceed to the analysis of the global system eigenvalues displacement under parametric variations and different points of operations. At this stage, the nominal model and the constraints on the closed-loop eigenstructure are chosen.

Step C. *Design*: We realize the synthesis of the controller using eigenstructure assignment with constraints on the initial model to deal with parametric robustness.

Step D. *Eigenvalues variations analysis*: We proceed to the closed-loop (with the current controller) parametric variation analysis. If the entire parametric configuration is suitable, we finish the design procedure. On the contrary, we go back to step C and change the constraints or placement.

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