A New Flux Observer for Induction Machines

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January 14, 1993

1 Introduction

High performance induction motor drives can emulate the characteristics of separately excited DC motors, while avoiding most of their drawbacks. The initial work on 'field oriented' or 'vector' control, done in early '70s by Blashke and Leonhard, has found many applications, and drives utilizing some form of field orientation are presently commercially available.

Control in the field coordinates of an induction motor (field oriented control) requires the accurate knowledge of the position (angle) and amplitude of the rotor flux linkages. The estimation of the rotor flux linkages in the stator system of coordinates requires the construction of a reduced order observer. The measured outputs are the currents and possibly rotor speed or position. The observer driving function can be selected as the difference between the applied input and its value calculated from the measured currents and the esimated rotor flux linkages.

A serious problem in this estimation is the variation of motor parameters. The rotor resistance in particular, can vary with temperature by more than 50%. This has led to the introduction of two versions of field orientation: the 'direct field orientation', which is based on the calculation of rotor flux linkages only from the stator voltage equation, corresponds to a particular construction of the observer and value of the gain matrix. This scheme breaks down at low frequencies, when the voltage drop on the stator resistance dominates over the drop on the stator reactance. As the stator resistance varies also with temperature, the estimates of the rotor flux linkages become more inaccurate. The classical approach is to revert to the estimates based on the rotor circuit equations, the 'indirect field orientation' method, which uses the rotor resistance.

As the estimate of the flux linkages becomes more inaccurate either because of the parameter variation or because of disturbances, the response of the drive to torque commands becomes sluggish and unstable. It is therefore important that the controller be robust to variations of the rotor and stator resistance.

Beyond the original work on the development of the direct and indirect field orientation methods, work by Verghese and Sanders presented a selection of the gain of the observer leading to damping of the oscillations due to transients. Hori et al. presented a detailed categorization of the observer construction developed in the past, and proposed a new observer using as driving function the error in the estimate of the derivative of the stator currents.

At present a series of problems remain unsolved: Firstly, although the transient oscillations due to the initial conditions can be dampened, the steady state error is not affected by the proposed observer schemes. Secondly, in these observers only the effect of the error in one of the resistances (usually rotor) is dealt with, while the combined effect of the stator and rotor resistances is not considered except in some special cases. Lastly, the selection of the optimal observer gain in the system is often very close to a value that can cause instability.

In this work a new observer is proposed, that can minimize the steady state error resulting from rotor resistance mismatch, as well as increase damping. This observer is based on the modified state equations of the system and is derived from the Lyapunov analysis of the error.

2 Analysis

When the machine variables are referred to the stator system of coordinates, the rotor flux linkages are rotating at synchronous speed. The common choice for variables are the stator current (referred to the direct and quadrature axes), and the rotor flux linkages. The inputs of the system are the direct and quadrature voltages applied to the stator. From electromagnetic considerations:

$$\dot{\lambda_r} = \left[-\frac{1}{T_r}I + \omega J\right]\lambda_r + \frac{1}{T_r}Mi_s \tag{1}$$

$$u_s = \frac{M}{L_r}\dot{\lambda_r} + \sigma L_s \dot{i_s} + R_s i_s \tag{2}$$

$$= \frac{M}{L_r}\left[-\frac{1}{T_r}I + \omega J\right]\lambda_r + \left(R_s + \frac{M^2}{L_r T_r}\right)i_s + \sigma L_s \dot{i_s} \tag{3}$$

where

$$I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \tag{4}$$

the estimator equations then become:

$$\dot{\widehat{\lambda_r}} = \left[-\frac{1}{T_r}I + \omega J\right]\widehat{\lambda_r} + \frac{1}{T_r}Mi_s + K[\widehat{u_s} - u_s] \tag{5}$$

The difficulty posed by the presence of the the derivative of the current in the equation of the estimator can be removed by grouping all the terms with derivatives in the left-hand side and renaming that expression as $\dot{z}$. The estimate of the rotor flux linkages can be subsequently recovered from z by subtracting a quantity proportional to the current.

The choice of the gain K takes generally the form

$$K = k_1 I + k_2 J \tag{6}$$

Selecting as Lyapunov function:

$$V = \frac{1}{2}e^T e \tag{7}$$

where e is the error:

$$e = \widehat{\lambda_r} - \lambda_r \tag{8}$$

and for the case of invariable stator resistance, the steady state error satisfies a bound of the form

$$|e| \leq f(k_1, k_2, \omega)\left|R_r - \widehat{R_r}\right| b \tag{9}$$

where b is a constant and $f(\cdot)$ is a function of the gain and speed. Based on this expression, optimal gain values are derived independently of the speed.

The proposed observer rejects disturbances effectively, with the resulting error decreasing with speed.

Results will be presented comparing this observer to observers described in the literature, as well as extensions for the case of varying stator resistance.