Linearizing Control of the Asynchronous Motor with an Interconnected Observers for a Special Class of Nonlinear Systems

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Abstract: This article presents a study by simulation with the software MATLAB/SIMULINK linearizing control input-output of a synchronous motor interconnected to two observers state of a special class of the nonlinear systems. Indeed, the gain of this observer (two observers of state of a special class of the non-linear systems) does not require the resolution of any dynamic system, it is given analytically. The results of simulation obtained prove that the presence of this observer makes it possible to ensure a better control of the behavior of the actuator in spite of the absence the flux and velocity pick-ups.

Key–Words: Linearizing control, asynchronous motor, interconnected observers for a special class of nonlinear systems, rotor flux, rotating speed.

1 Introduction

Majority of the techniques of synthesis of the control systems are based on the knowledge of the process to control and its environment, but the industrial processes are by nature nonlinear and variable in time, the parameters can thus vary for various reasons (temperature, change of the point of operation, etc.). The performances of a linear control are degraded as the difference between the real parameters and those used in the calculation of control increases [1]. The technique of linearization input-output based on the differential geometry allows by a diffeomorphic transformation and a nonlinear return of state to uncouple and linearize the model put under canonical form [2]. The follow-up of the trajectories of reference is based on the principle of the imposition of the poles. This technique has the advantage of being able to separately control flux and the couple even in mode of variation of flux [3]. Speed is measured by a mechanical sensor, flux is estimated by an observer. In this article, we will present the linearizing control from the input-output point of view with two interconnected observers of a special class of nonlinear systems applied to the asynchronous motor in order to eliminate the sensors from flux and speed at the same time. Analysis of the asymptotic convergence of the error of state is assured if the linear part checks the condition of strict positivity and the nonlinear part satisfied the inequality of POPOV [4].

In the following section a short recall of the asynchronous motor model used, section 3 presents the interconnected observers; control by linearization input-output is in section 4; where stability (motor+observator) is checked. Lastly, the results of simulations with the software MATLAB/SIMULINK with an analysis of the performances and a conclusion of the interest of this method will be presented.

2 Dynamic Model of Asynchronous Motor

In this study, the model of the motor rests on the following hypothesis [5, 6]:

- The fluxes and the currents are proportional by the intermediary of inductances and the mutual.
- The losses iron are neglected.
- The air-gap is constant (squirrel-cage rotor).
- The homopolar components are null.

It results from these assumptions that the various mutual between rotor and stator can be expressed like functions sinusoidal of the rotor position. Its vector state is composed by the stator currents and rotor fluxes, as follows:

\[
\begin{bmatrix}
\frac{d\psi_r}{dt} \\
\frac{d\psi_{r\beta}}{dt} \\
\frac{d\psi_{r\alpha}}{dt}
\end{bmatrix} = \begin{bmatrix}
-\gamma & 0 & \frac{K}{L_r} \\
0 & -\gamma & -p\Omega \\
M & 0 & -p\Omega \\
0 & \frac{1}{L_r} & -p\Omega
\end{bmatrix}
\begin{bmatrix}
\psi_{r\alpha} \\
\psi_{r\beta} \\
\psi_{s\alpha}
\end{bmatrix}
\]
3 Synthesis of Interconnected Observers for a Special Class of Nonlinear Systems

The model of the asynchronous motor (1) can be rewritten in the shape of interconnected two subsystems:

\[
\frac{di_{ss}}{dt} = \begin{bmatrix} \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \end{bmatrix} \begin{bmatrix} i_{ss} \\ \Omega \end{bmatrix} + \begin{bmatrix} 0 \\ -p\Omega K \end{bmatrix} + \begin{bmatrix} -\gamma i_{ss} + K_T \psi_{r\alpha} \sigma L_s \end{bmatrix} \begin{bmatrix} i_{ss} \\ \Omega \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} + \begin{bmatrix} M \frac{p}{J} (i_{ss} \psi_{r\alpha} - i_{ss} \psi_{r\beta}) - C_{res} \end{bmatrix} \begin{bmatrix} 0 \\ \Omega \end{bmatrix} \]

(2)

\[
\frac{di_{s\beta}}{dt} = \begin{bmatrix} 0 \\ -p\Omega K \end{bmatrix} + \begin{bmatrix} 0 \\ -p\Omega \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} + \begin{bmatrix} M \frac{p}{J} (i_{s\beta} \psi_{r\alpha} - i_{s\alpha} \psi_{r\beta}) - C_{res} \end{bmatrix} \begin{bmatrix} 0 \\ \Omega \end{bmatrix} \]

(3)

The interconnected two subsystems (2) and (3) can be represented in a more compact interconnected form as follows:

\[
\begin{align*}
\dot{X}_1 &= \mathcal{F}_1(X_2)X_1 + \mathcal{G}_1(Y_1, X_1, X_2) \\
Y_1 &= C_1 X_1 \\
\dot{X}_2 &= \mathcal{F}_2(Y_2, X_1, X_2)X_2 + \mathcal{G}_2(U_2, X_1, X_2) \\
Y_2 &= C_2 X_2
\end{align*}
\]

(4)

(5)

Where

\[
X_1 = [i_{ss}, \Omega]^T, \quad X_2 = [i_{s\beta}, \psi_{r\alpha}, \psi_{r\beta}]^T, \quad C_1 = [1, 0] \quad C_2 = [1, 0, 0] \quad \mathcal{F}_1(X_2) = \begin{bmatrix} 0 & pK\psi_{r\beta} \\ 0 & 0 \end{bmatrix},
\]

\[
\mathcal{F}_2(X_1) = \begin{bmatrix} -\gamma i_{ss} + K_T \psi_{r\alpha} \sigma L_s \\ \frac{p}{J} (i_{s\beta} \psi_{r\alpha} - i_{s\alpha} \psi_{r\beta}) - C_{res} \end{bmatrix},
\]

\[
\mathcal{G}_1(Y_1, X_1, X_2) = \begin{bmatrix} -\gamma i_{s\beta} + K_T \psi_{r\beta} \sigma L_s \\ \frac{p}{J} (i_{s\beta} \psi_{r\alpha} - i_{s\alpha} \psi_{r\beta}) - C_{res} \end{bmatrix},
\]

\[
\mathcal{G}_2(U_2, X_1, X_2) = \begin{bmatrix} -\gamma i_{s\beta} + K_T \psi_{r\beta} \sigma L_s \\ \frac{p}{J} (i_{s\beta} \psi_{r\alpha} - i_{s\alpha} \psi_{r\beta}) - C_{res} \end{bmatrix},
\]

\[
U_1 = [v_{ss}, 0]^T, \quad U_2 = [v_{s\beta}, 0, 0]^T \quad \text{and} \quad Y = [i_{ss}, i_{s\beta}]^T.
\]

Before giving the hypothesis, we will make the remarks and one presents notations used hereafter.

1. Set \(A_1(X_2)\) et \(A_2(X_1)\) diagonal matrices defined by:

\[
A_1(X_2) = \begin{bmatrix} 1 & 0 \\ 0 & pK\psi_{r\beta} \end{bmatrix}
\]

(6)

\[
A_2(X_1) = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}
\]

(7)

2. Set \(S_1\) and \(S_2\) single solutions of the algebraic equations of LYAPUNOV:

\[
S_1 + A_1^T S_1 + S_1 A_1 - C_1^T C_1 = 0 \quad (8)
\]

\[
S_2 + A_2^T S_2 + S_2 A_2 - C_2^T C_2 = 0 \quad (9)
\]

Where \(A_1\) and \(A_2\) identities matrices.

\[
A_1 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \quad A_2 = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}
\]
One can show that the explicit solution (8) and (9) are given by:

\[ S(i,j) = (-1)^{i+j} C_{i+j}^{-1} \text{ where } C_{j} = \frac{j!}{d(j-i)!} \]

3. Set \( \overline{A}_1 = A_1(X_2)^T S_1 A_1(X_2) \), \( \overline{C}_1 = C_1 A_1(X_2), \overline{S}_2 = A_2(X_1)^T S_2 A_2(X_1) \) and \( \overline{C}_2 = C_2 A_2(X_1). \)

With an aim of designing two interconnected observers for the subsystems (4) and (5), we pose the following hypothesis:

**Hypothesis 1**

\[ H_1 : (\psi_{\alpha}, \psi_{\beta}, i_{\alpha}, i_{\beta}) \text{ are limited and supposed to be regularly persistent to guarantee the observability property of the subsystems (4) and (5) respectively.} \]

\[ H_2 : F_1 \text{ is global LIPSCHITZ compared to } X_2, i.e. \]

\[ \| \Delta_1^{-1} (F_1(\widehat{X}_2) X_1 - F_1(X_2) X_1) \| \leq \xi_1 \| \overline{S}_1 \| \]

\[ \xi_1 > 0 : \text{Constant of LIPSCHITZ} \]

\[ H_3 : G_1 \text{ is global LIPSCHITZ compared to } X_2, i.e. \]

\[ \| \Delta_1^{-1} (G_1(U_1, \widehat{X}_1, \widehat{X}_2) - G_1(U_1, X_1, X_2)) \| \leq \xi_2 \| \overline{S}_1 \| \]

\[ \xi_2 > 0 : \text{Constant of LIPSCHITZ} \]

\[ H_4 : F_2 \text{ is global LIPSCHITZ compared to } X_1, i.e. \]

\[ \| \Delta_2^{-1} (F_2(\widehat{X}_1) X_2 - F_2(X_1) X_2) \| \leq \xi_3 \| e_2 \| \]

\[ \xi_3 > 0 : \text{Constant of LIPSCHITZ} \]

\[ H_5 : G_2 \text{ is global LIPSCHITZ compared to } X_1, i.e. \]

\[ \| \Delta_2^{-1} (G_2(U_2, \widehat{X}_1, \widehat{X}_2) - G_2(U_2, X_1, X_2)) \| \leq \xi_4 \| e_2 \| \]

\[ \xi_4 > 0 : \text{Constant of LIPSCHITZ} \]

\[ H_6 : \text{There are four positive constants } \alpha_1, \alpha_2, \beta_1 \text{ and } \beta_2 \text{ such as:} \]

\[ 0 < \alpha_1^2 < F_1^T(\widehat{X}_2) F_1(\widehat{X}_2) < \beta_1^2 \]

\[ 0 < \alpha_2^2 < F_2^T(\widehat{X}_1) F_2(\widehat{X}_1) < \beta_2^2 \]

According to the contribution of [9] observers for the form of interconnected subsystems (4) and (5) are given by:

\[
\begin{aligned}
\dot{X}_1 &= F_1(\widehat{X}_2) X_1 + G_1(U_1, \widehat{X}_1, \widehat{X}_2) \\
& \quad -\theta_1 \Delta_1 \overline{S}_1^{-1} C_1^T (\dot{Y}_1 - Y_1) \\
\dot{Y}_1 &= \overline{C}_1 \dot{X}_1 \\
\dot{X}_2 &= F_2(\widehat{X}_1) X_2 + G_2(U_2, \widehat{X}_1, \widehat{X}_2) \\
& \quad -\theta_2 \Delta_2 \overline{S}_2^{-1} C_2^T (\dot{Y}_2 - Y_2) \\
\dot{Y}_2 &= \overline{C}_2 \dot{X}_2
\end{aligned}
\]

with \( \Delta_1 = \begin{bmatrix} 1 & 0 \\ 0 & \theta_1 \end{bmatrix} \) and \( \Delta_2 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \theta_2 & 0 \\ 0 & 0 & \theta_2^2 \end{bmatrix} \) for \( \theta_1 > 0 \) and \( \theta_2 > 0 \).

For the implementation of the two observers, it is clear that the totality of the vectors \( X_1 \) and \( X_2 \) considered as signals known on the assumption 1 is not necessary. The two observers only use \( \dot{i}_{\alpha} \) and \( \dot{i}_{\beta} \) as measured signals (known) which are the two components of the stator current in the reference mark \( (\alpha, \beta) \).

In order to prove the convergence of the error in estimation of the two observers, we present in what follows the stability analysis of the two observers based on THE LYAPUNOV THEORY.

### 3.1 Stability analyze of the two observers

To study the stability of the observer, one defines the equations of the errors in estimation as follows:

\[ e_1 = \dot{X}_1 - X_1 \quad (14) \]
\[ e_2 = \dot{X}_2 - X_2 \quad (15) \]

one can easily check that:

\[ A_1(\widehat{X}_2) F_1(\widehat{X}_2) = A_1(\widehat{X}_2) \]
\[ A_2(\widehat{X}_1) F_2(\widehat{X}_1) = A_2(\widehat{X}_1) \]

Thus, by multiplying the left and right side of the equation (8) by \( A_1^T(\widehat{X}_2) \) and \( A_1(\widehat{X}_2) \) respectively, in a similar way by multiplying the equation (9) by \( A_2^T(\widehat{X}_1) \) and \( A_2(\widehat{X}_1) \), we get:

\[ \theta_1 \overline{S}_1 + F_1^T(\widehat{X}_2) \overline{S}_1 + \overline{S}_1 F_1(\widehat{X}_2) - C_1^T \overline{C}_1 = 0 \]

\[ \theta_2 \overline{S}_2 + F_2^T(\widehat{X}_1) \overline{S}_2 + \overline{S}_2 F_2(\widehat{X}_1) - C_2^T \overline{C}_2 = 0 \]

The dynamic ones of these errors are given by:

\[ \dot{e}_1 = (F_1(\widehat{X}_2) - \theta_1 \Delta_1 \overline{S}_1^{-1} C_1^T) e_1 + F_1(\widehat{X}_2) X_1 - F_1(\widehat{X}_2) X_1 \quad (18) \]
\[ \dot{e}_2 = (F_2(\widehat{X}_1) - \theta_2 \Delta_2 \overline{S}_2^{-1} C_2^T) e_2 + F_2(\widehat{X}_1) X_2 - F_2(\widehat{X}_1) X_2 \quad (19) \]
Set \( \tau_j = \Delta j^{-1} e_j \) for \( j = 1, 2 \), then:
\[
\begin{align*}
\Delta_1^{-1} \mathcal{F}_1(\hat{x}_2) \Delta_1 &= \theta_1 \mathcal{F}_1(\hat{x}_2) \\
\Delta_2^{-1} \mathcal{F}_2(\hat{x}_1) \Delta_2 &= \theta_2 \mathcal{F}_2(\hat{x}_1)
\end{align*}
\]

Where
\[
\tau_1 = \theta_1 \left( \mathcal{F}_1(\hat{x}_2) - \mathcal{S}_1^{-1} \mathcal{C}_1 \right) \tau_1 + \Delta_1^{-1} \left\{ \mathcal{F}_1(\hat{x}_2) X_1 - \mathcal{F}_1(\hat{x}_2) X_2 \right\} + \Delta_1^{-1} \left\{ \mathcal{G}_1(U_1, \hat{x}_1, \hat{x}_2) - \mathcal{G}_1(U_1, \hat{x}_1, \hat{x}_2) \right\}
\]
\[
\tau_2 = \theta_2 \left( \mathcal{F}_2(\hat{x}_1) - \mathcal{S}_2^{-1} \mathcal{C}_2 \right) \tau_2 + \Delta_2^{-1} \left\{ \mathcal{F}_2(\hat{x}_1) X_2 - \mathcal{F}_2(\hat{x}_1) X_2 \right\} + \Delta_2^{-1} \left\{ \mathcal{G}_2(U_2, \hat{x}_1, \hat{x}_2) - \mathcal{G}_2(U_2, \hat{x}_1, \hat{x}_2) \right\}
\]

**Lemma 2** If the hypothesis 1 are satisfied, then the system (12)-(13) is an exponential observer of the system (4)-(5) for \( \theta_1 \) and \( \theta_2 \) are positives.

### 3.2 Proof of the lemma 2

To prove convergence, let us consider the following equation of LYAPUNOV:
\[
V = V_1 + V_2
\]
where \( V_1 = \tau_1^T S_1 \tau_1 \) and \( V_2 = \tau_2^T S_2 \tau_2 \).

By calculating the derivative of \( V \) along the trajectories of \( \tau_1 \) and \( \tau_2 \), we obtain:
\[
\dot{V} = 2\tau_1^T S_1 \dot{\tau}_1 + 2\tau_1^T \Lambda_1^T S_1 \Lambda_1 \tau_1 + 2\tau_2^T S_2 \dot{\tau}_2 + 2\tau_2^T \Lambda_2^T S_2 \Lambda_2 \tau_2
\]
\[
\dot{V} = \theta_1 \left( 2\tau_1^T S_1 \mathcal{F}_1(\hat{x}_2) \tau_1 - 2\tau_1^T \mathcal{C}_1 \tau_1 \right) + \Delta_1^{-1} \left\{ \mathcal{F}_1(\hat{x}_2) X_1 - \mathcal{F}_1(\hat{x}_2) X_2 \right\} + \Delta_1^{-1} \left\{ \mathcal{G}_1(U_1, \hat{x}_1, \hat{x}_2) - \mathcal{G}_1(U_1, \hat{x}_1, \hat{x}_2) \right\}
\]
\[
\dot{V} = \theta_2 \left( 2\tau_2^T S_2 \mathcal{F}_2(\hat{x}_1) \tau_2 - 2\tau_2^T \mathcal{C}_2 \tau_2 \right) + \Delta_2^{-1} \left\{ \mathcal{F}_2(\hat{x}_1) X_2 - \mathcal{F}_2(\hat{x}_1) X_2 \right\} + \Delta_2^{-1} \left\{ \mathcal{G}_2(U_2, \hat{x}_1, \hat{x}_2) - \mathcal{G}_2(U_2, \hat{x}_1, \hat{x}_2) \right\}
\]
\[
\dot{V} = -\theta_1 V_1 - \theta_1 \left\{ \Delta_1^{-1} \left\{ \mathcal{F}_1(\hat{x}_2) X_1 - \mathcal{F}_1(\hat{x}_2) X_2 \right\} \right\} + \Delta_1^{-1} \left\{ \mathcal{F}_1(\hat{x}_2) X_1 - \mathcal{F}_1(\hat{x}_2) X_2 \right\} + \Delta_2^{-1} \left\{ \mathcal{F}_2(\hat{x}_1) X_2 - \mathcal{F}_2(\hat{x}_1) X_2 \right\} + \Delta_2^{-1} \left\{ \mathcal{F}_2(\hat{x}_1) X_2 - \mathcal{F}_2(\hat{x}_1) X_2 \right\}
\]
\[
\dot{V} = -\theta_1 V_1 + c_1 V_1 - \theta_2 V_2 + c_2 V_2
\]

By taking account of the hypothesis 1, and by introducing the norms, then:
\[
\dot{V} \leq -\theta_1 V_1 - \theta_1 \left\{ \Delta_1^{-1} \left\{ \mathcal{F}_1(\hat{x}_2) X_1 - \mathcal{F}_1(\hat{x}_2) X_2 \right\} \right\} + \Delta_1^{-1} \left\{ \mathcal{F}_1(\hat{x}_2) X_1 - \mathcal{F}_1(\hat{x}_2) X_2 \right\} + \Delta_2^{-1} \left\{ \mathcal{F}_2(\hat{x}_1) X_2 - \mathcal{F}_2(\hat{x}_1) X_2 \right\} + \Delta_2^{-1} \left\{ \mathcal{F}_2(\hat{x}_1) X_2 - \mathcal{F}_2(\hat{x}_1) X_2 \right\}
\]

\[
\dot{V} \leq -\theta_1 V_1 + c_1 V_1 - \theta_2 V_2 + c_2 V_2
\]

Finally, while taking:
\[
\zeta = \min (\pi_1, \pi_2)
\]
It follows that:
\[
\dot{V} \leq -\zeta (V_1 + V_2) \leq -\zeta V
\]

This finishes the proof of convergence of the observer. Thus \( V \) is a LYAPUNOV function.
4 Synthesis of the Control by Linearization Input-Output

The detailed theory of linearization input-output [3] of the nonlinear systems found its first applications to the asynchronous motor in [8] then in [10]. It ensures the decoupling and linearization of the input and output relations. Supposing initially that all the state is measurable. We can thus conceive a nonlinear return of state which ensures stability [7]. The two outputs of the system to be controlled are the module of flux and the rotating speed in the motor, which are given by:

\[ \hat{h}_1 = \frac{p M}{f L_r} \left( \hat{i}_{s \beta} \hat{\psi}_{r \alpha} - \hat{i}_{s \alpha} \hat{\psi}_{r \beta} \right) \quad \text{(Speed)} \] (29)
\[ \hat{h}_2 = \hat{\psi}_{r \alpha}^2 + \hat{\psi}_{r \beta}^2 \quad \text{(Norm flux)} \] (30)

The following notations are used for the directional derivative (of Lie) of the function of state \( \hat{h} : \mathbb{R}^n \to \mathbb{R} \) along the field of the vector \( f = [f_1, \ldots, f_n] \). The reader will be able to refer to [3]:

\[ L_f h = \sum_{i=1}^n \frac{\partial h}{\partial x_i} f_i \] (31)

Repeatedly, we have

\[ L_f^i h = L_f \left( L_f^{i-1} h \right), \quad i \geq 2 \] (32)

By applying the derivative of Lie to the outputs until the appearance of the inputs along the field of vector \( f + g_u \), we obtain:

\[ \dot{\hat{h}}_1 = L_f \hat{h}_1 + L_{g_1} \hat{h}_1 v_{s \alpha} + L_{g_2} \hat{h}_2 v_{s \beta} \] (33)
\[ \dot{\hat{h}}_2 = L_f \hat{h}_2 \] (34)
\[ \ddot{\hat{h}}_2 = L_f^2 \hat{h}_2 + L_{g_1} L_f \hat{h}_2 v_{s \alpha} + L_{g_2} L_f \hat{h}_2 v_{s \beta} \] (35)

with \( g_1, g_2 \) two vectors of columns of \( g \) and

\[ L_f \hat{h}_1 = -\frac{p M}{f L_r} \left[ \frac{1}{T_r} + \gamma \right] \left( \hat{i}_{s \beta} \hat{\psi}_{r \alpha} - \hat{i}_{s \alpha} \hat{\psi}_{r \beta} \right) + p \hat{\Omega} \left( \hat{i}_{s \alpha} \hat{\psi}_{r \alpha} + \hat{i}_{s \beta} \hat{\psi}_{r \beta} \right) + p \hat{\Omega} K \hat{\psi} \] \[ L_f \hat{h}_2 = \frac{2}{T_r} \left[ M \left( \hat{i}_{s \alpha} \hat{\psi}_{r \alpha} + \hat{i}_{s \beta} \hat{\psi}_{r \beta} \right) - \hat{\psi} \right] \] \[ L_f^2 \hat{h}_2 = \left( \frac{4}{T_r^2} + \frac{2 K}{T_r} M \right) \hat{\psi} - \left( \frac{6 M}{T_r^2} + \frac{2 \gamma M}{T_r^2} \right) \] \[ \left( \hat{i}_{s \alpha} \hat{\psi}_{r \alpha} + \hat{i}_{s \beta} \hat{\psi}_{r \beta} \right) + 2 \hat{\psi} \right) + \left( \frac{4}{T_r^2} + \frac{2 K}{T_r} M \right) \hat{\psi} \] (36)

with

\[ D = \left[ \begin{array}{cc} L_{g_1} \hat{h}_1 & L_{g_2} \hat{h}_1 \\ L_{g_1} L_f \hat{h}_2 & L_{g_2} L_f \hat{h}_2 \end{array} \right] \] nonsingular matrix

and the nonlinear law of control is thus given by:

\[ \left[ \begin{array}{c} v_{s \alpha} \\ v_{s \beta} \end{array} \right] = D^{-1} \left[ \begin{array}{c} -L_f \hat{h}_1 + v_1 \\ -L_f^2 \hat{h}_2 + v_2 \end{array} \right] \] (37)

This regulator linearizes and uncouples the system such as:

\[ \left\{ \begin{array}{l}
\dot{\hat{h}}_1 = v_1 \\
\dot{\hat{h}}_2 = v_2
\end{array} \right. \] (38)

Like it was given in [7], to ensure a perfect regulation of flux and speed towards their respective references \( \psi_{r e f} \) and \( \Omega_{r e f} \), the variables \( v_1 \) and \( v_2 \) are calculated in the following way:

\[ \begin{array}{l}
\dot{v}_1 = -k_v (\hat{\psi} - \psi_{r e f}) + \dot{\Omega}_{r e f} \\
\dot{v}_2 = -k_v (\hat{\psi} - \psi_{r e f}) - \dot{k}_v (\hat{\psi} - \psi_{r e f}) + \dot{\psi}_{r e f}
\end{array} \] (39)

The reader finds the stability of control in [15]. Since the stability of the linearizing control has realized, as well as the convergence of the outputs of the observer towards the variables of states of the induction motor was shown and checked, we note that the global stability of the system is checked.

5 Results and Simulations

The vector of state of the motor is initialized with the stopped state \[ \begin{bmatrix} \hat{i}_{s \alpha} & \hat{i}_{s \beta} & \psi_{r \alpha} & \psi_{r \beta} & \Omega \end{bmatrix}^T = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \end{bmatrix}^T \]; whereas that of the observer in a functional state \[ \begin{bmatrix} \hat{i}_{s \alpha} & \hat{i}_{s \beta} & \psi_{r \alpha} & \psi_{r \beta} & \hat{\Omega} \end{bmatrix}^T = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \end{bmatrix}^T \].

\[ \begin{array}{l}
L_{g_1} \hat{h}_1 = -\frac{p K}{J} \hat{\psi}_{r \beta} \\
L_{g_1} L_f \hat{h}_2 = 2 \Omega K \hat{\psi}_{r \alpha} \\
L_{g_2} \hat{h}_1 = \frac{p K}{J} \hat{\psi}_{r \alpha} \\
L_{g_2} L_f \hat{h}_2 = 2 \Omega K \hat{\psi}_{r \beta}
\end{array} \]
and the results are given for the motor of which a direct starting, i.e. a resistive torque null \((C_{res} = 0)\) and these characteristics are given in table (Tab.1):

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Notation</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poles pairs</td>
<td>(p)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Stator resistance</td>
<td>(R_s)</td>
<td>9.65</td>
<td>(\Omega)</td>
</tr>
<tr>
<td>Rotor resistance</td>
<td>(R_r)</td>
<td>4.3047</td>
<td>(\Omega)</td>
</tr>
<tr>
<td>Stator inductance</td>
<td>(L_s)</td>
<td>0.4718</td>
<td>(H)</td>
</tr>
<tr>
<td>Rotor inductance</td>
<td>(L_r)</td>
<td>0.4718</td>
<td>(H)</td>
</tr>
<tr>
<td>Mutual Inductance</td>
<td>(M)</td>
<td>0.4475</td>
<td>(H)</td>
</tr>
<tr>
<td>Rotor inertia</td>
<td>(J)</td>
<td>0.0293</td>
<td>(Kg.m^2)</td>
</tr>
<tr>
<td>Resistive torque</td>
<td>(C_{res})</td>
<td>0</td>
<td>(N.m)</td>
</tr>
</tbody>
</table>

We conceived simulation by carrying out the diagram general in blocks as the figure shows it (Fig.1).

Simulation was made by MATLAB-SIMULINK. The results of simulation are given by the curves obtained law of linearizing control which coefficients \(k_a = 120000, k_{a1} = 200000, k_{a2} = 12000\) and with interconnected observers of which gains of observation \(\theta_1 = 4.1, \theta_2 = 0.2\).

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**Figure 2:** Curves of flux of linearizing control with interconnected observers for a special class of nonlinear systems and desired flux.

**Figure 3:** Curve error of flux of linearizing control with interconnected observers for a special class of nonlinear systems.

**Figure 4:** Curves of speed of linearizing control with interconnected observers for a special class of nonlinear systems and desired speed.
6 Conclusion

In this article, we presented a linearizing control of input-output with two observers for a special class of nonlinear systems interconnected. The gain of the observer proposed is obtained starting from the algebraic equations of LYAPUNOV and it is simple to calculate. The synthesis of the control with the observer is illustrated through an application of the estimate of rotor flux and rotating speed of the asynchronous motor. Simulation was made with SIMULINK, and the results are satisfactory.

References:


