Amine CHENAFA[1], Mohammed CHENAFA[1], Abdellah MANSOURI[1] , Abdelkader CHAKER[1]

National Polytechnic University Oran, Algeria(1)

doi:10.15199/48.2019.01.47

Global Stability of Backsteping Control with Robust Nonlinear Observer of Induction Motor in (α, β) Frame

***Abstract**. This paper deals with the design of an advanced control law by backstepping with an observer for a special class of nonlinear systems. We design an observer with a single adjustment gain as a function of speed. Our contribution is developed by demonstrating a nonlinear control law by backstepping using the global Lyapunov stability of the controller, the nonlinear observer and the induction motor. We study the behavior of the torque tracking and the rotor flux of the induction motor in the natural frame(α,β). The control algorithm obtained is studied through simulations and applied in many configurations (flux and speed and torque disturbances), and is shown to be very efficient.*

Streszczenie.** Niniejszy artykuł dotyczy projektowania zaawansowanego prawa kontroli poprzez odtwarzanie z obserwatorem specjalnej klasy systemów nieliniowych. Projektujemy obserwatora z jednym wzmocnieniem regulacji w funkcji prędkości. Nasz układ jest rozwijany przez demonstrowanie nieliniowego prawa kontrolnego poprzez odtwarzanie za pomocą globalnej stabilności Lapunowa kontrolera, nieliniowego obserwatora i silnika indukcyjnego. Badamy zachowanie śledzenia momentu i strumienia wirnika silnika indukcyjnego w naturalnej ramie (α, β). Uzyskany algorytm sterowania jest badany za pomocą symulacji i stosowany w wielu konfiguracjach (strumień i zakłócenia prędkości i momentu obrotowego) i jest bardzo wydajny. **Globalna stabilność sterowania silniiem indukcyjnym z odpornym nieliniowym obserwatorem

Keywords: nonlinear observer, backstepping control, global stability, Lyapunov stability.
Słowa kluczowe: nieliniowy obserwator, kontrola cofania, stabilność globalna, stabilność Lapunowa

Introduction

Induction motors are nonlinear, coupled, multivariable process. Nevertheless, they become more and more appealing because of their reliability, robustness and low cost or maintenance [3]. We built a globally stable nonlinear control law with real effectiveness for the adopted strategies and we describe a speed dependent observer. We based the initial strategy on backstepping control. Here we design the observer based on a nonlinear control law in order to ensure the globally stability of the process observer-controller system. The main contributions of the paper are the following: First, we propose a new observer modified for a special class of nonlinear systems applied to the induction motor [1]. Secondly, the model is nonlinear in the frame (α, β) without making the FOC. Third, the demonstration of global stability (system-controller-observer). Lastly, intensive simulations in different conditions are performed to show that the general strategy proposed is very satisfied.

We organize the paper as follow: we present in Section 2 the induction motor model. In Section 3, we present a nonlinear observer, an application to the induction motor, the control algorithm and the global stability proof. In Section 4, we give simulation results and comment on them with implementation in Matlab-Simulink.

Modeling of the induction motor

The model used is a classical induction model of Park in a frame (α, β) fixed to stator, given by [1]:

(1) $$\dot{x} = f(x) + gu$$

with: $x = \left[i_{s\alpha}, i_{s\beta}, \varphi_{r\alpha}, \varphi_{r\beta}, \Omega\right]^T$, $u = \left[u_{s\alpha}, u_{s\beta}\right]^T$

Here x contains four electrical states (flux and currents components, respectively $\varphi_{r\alpha}$, $\varphi_{r\beta}$ and $i_{s\alpha}, i_{s\beta}$) and one mechanical state Ω governed by a mechanical equation. The motor is driven by two voltage components, $u_{s\alpha}$ and $u_{s\beta}$. We define the control input matrix by

$$g = \begin{bmatrix} \frac{1}{\sigma L_s} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{\sigma L_s} & 0 & 0 & 0 \end{bmatrix}^T$$

with

$$T_r = \frac{L_r}{R_r} \ , \quad \sigma = 1 - \frac{M^2}{L_s L_r}$$

$$K = \frac{M}{\sigma L_s L_r} \quad , \quad \gamma = \frac{R_s}{\sigma L_s} + \frac{R_r M^2}{\sigma L_s L_r^2}$$

(2) $$f(x) = \begin{bmatrix} -\gamma i_{s\alpha} + \frac{K}{T_r}\varphi_{r\alpha} + p\Omega K \varphi_{r\beta} \\ -\gamma i_{s\beta} - p\Omega K \varphi_{r\alpha} + \frac{K}{T_r}\varphi_{r\beta} \\ \frac{M}{T_r} i_{s\alpha} - \frac{1}{T_r}\varphi_{r\alpha} - p\Omega\varphi_{r\beta} \\ \frac{M}{T_r} i_{s\beta} + p\Omega\varphi_{r\alpha} - \frac{1}{T_r}\varphi_{r\beta} \\ \frac{pM}{J_m L_r}\left(\varphi_{r\alpha} i_{s\beta} - \varphi_{r\beta} i_{s\alpha}\right) - \frac{f_m \Omega}{J_m} - \frac{1}{J_m}\tau_l \end{bmatrix}$$

where L_r, L_s, M are rotor, stator and mutual inductances, respectively, R_r and R_s are the rotor and stator resistances respectively, σ is the scattering coefficient, T_r is the time constant of the rotor dynamics, $\mathrm{J_m}$ is the rotor inertia, f_m is the mechanical viscous damping, p is the number pole pairs, τ_l is the external load torque.

Nonlinear control with globally stability

We can solve the global stability problem using global tools such as Lyapunov function. In this section, we first design an observer. It is an observer for a special class of nonlinear system applied to the induction motor and enriched for a further analysis. Secondly, we design a control law. We base this control la on backstepping control and we modify it in order to ensure global stability. We then establish global stability using a Lyapunov function.

Backstepping control

Consider the system:

(3) $$\dot{x} = f(x) + g(x)u$$

Where $x \in \mathbb{R}^n$ is the state and $u \in \mathbb{R}$ is the control input. Let $u = \alpha(x)$, $\alpha(0) = 0$ be a desired feedback control law, which, if applied to the system in (3), guarantees global boundedness and regulation of $x(t)$ to the equilibrium point $x = 0$ as $t \to 0$, for all $x(0)$ and $V(x)$ is a control Lyapunov, where:

(4) $$\frac{\partial V(x)}{\partial x}[f(x) + g(x)\alpha(x)] < 0, \quad V(x) > 0$$

Consider the following cascade system:

(5) $$\dot{x} = f(x) + g(x)u \ , \ f(0) = 0$$

(6) $$\dot{\xi} = m(x, \xi) + \beta(x, \xi)u$$

(7) $\qquad y = h(x)$

We assume that both f, g, m and β are known. This system can be viewed as a cascade connection of two components, as shown in figure (1), the first component is (5), which ξ as input, and the second component (6). Where for the system in (5), a desired feedback $\alpha(x)$

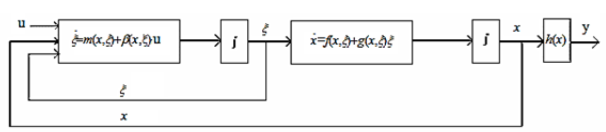

Fig. 1. The block diagram of system (5, 6, 7).

In addition, a control Lyapunov function $V(x)$ are known. Then, using the nonlinear bloc backstepping theory in [2]-[8], the error between the actual and the desired input for the system in (5) can be defined as $e = y - \alpha$, and an overall control Lyapunov function $V(x,\xi)$ for the systems in (5) and (6) can be defined by adding a quadratic term in the error variable e with $V(x)$:

(8) $$V(x,\xi) = V(x) + \frac{1}{2}e^2$$

Taking the derivative of both sides gives:

(9) $$\dot{V}(x,\xi) = \dot{V}(x) + e\dot{e}$$

From which solving for $V(x,\xi)$, which renders $\dot{V}(x,\xi)$ negative definite, yields a feedback control law for the full system in [5]-[7]-[9]. One particular choice is [2]:

(10) $$u = \left(\frac{\partial h(\xi)}{\partial \xi}\beta(x,\xi)\right)^{-1}\left\{-c(y-\alpha) - \frac{\partial h(\xi)}{\partial \xi}m(x,\xi) + \frac{\partial \alpha(x)}{\partial x}\dot{x} - \frac{\partial V(x)}{\partial x}g(x)\right\} \quad c > 0$$

Application to asynchronous motor

We are applied backstepping control (see Fig. 2).

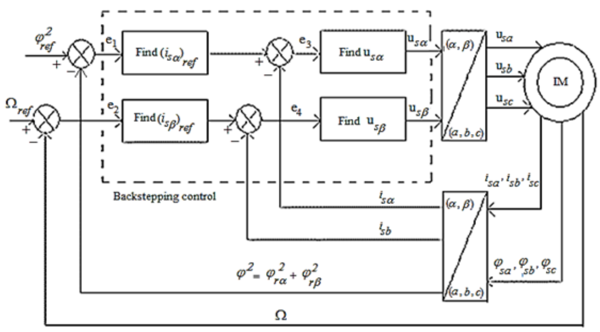

Fig. 2. Scheme of the backstepping control with an induction motor.

Step 1:

We define e_1 and e_2 respectively represent the error between the actual speed Ω and Ω_{ref} the reference speed and the error between the module of the flux φ and φ_{ref} its reference.

$$e_1 = \Omega_{ref} - \Omega$$
$$e_2 = \varphi_{ref}^2 - \varphi^2$$

where $\qquad \varphi^2 = \varphi_{r\alpha}^2 + \varphi_{r\beta}^2$

The first Lyapunov function is chosen as follows:

$$V_1 = \frac{1}{2}(e_1^2 + e_2^2)$$

Its derivative is:

$$\dot{V}_1 = -k_1e_1^2 - k_2e_2^2 + e_1\left[\dot{\Omega}_{ref} - \frac{pM}{JL_r}(\varphi_{r\alpha}i_{s\beta} \frac{f}{J}\Omega + \frac{C_r}{J}) + k_1e_1\right] + e_2\left[2(\dot{\varphi}_{ref}\varphi_{ref} - \dot{\varphi}_{r\alpha}\varphi_{r\alpha} - \dot{\varphi}_{r\beta}\varphi_{r\beta}) + k_2e_2\right]$$

For $\dot{V}_1 < 0$ must select reference components of currents representing stabilizing functions as follows:

(11) $$(i_{s\alpha})_{ref} = \frac{1}{\varphi^2}\left[\frac{T_r}{2M}\varphi_{r\alpha}\left(k_2e_2 + 2\dot{\varphi}_{ref}\varphi_{ref} + \frac{2}{T_r}\varphi^2\right) - \frac{JL_r}{pM}\varphi_{r\beta}\left(\dot{\Omega}_{ref} + \frac{f}{J}\Omega + \frac{C_r}{J} + k_1e_1\right)\right]$$

(12) $$(i_{s\beta})_{ref} = \frac{1}{\varphi^2}\left[\frac{JL_r}{pM}\varphi_{r\alpha}\left(\dot{\Omega}_{ref} + \frac{f}{J}\Omega + \frac{C_r}{J} + k_1e_1\right) + \frac{T_r}{M}\varphi_{r\beta}\left(2\dot{\varphi}_{ref}\varphi_{ref} + \frac{2}{T_r}\varphi^2 + k_2e_2\right)\right]$$

where $\quad k_1, k_2$: positive constants

Step 2:

We define other tracking errors concerning the components of the stator current and reference

$$e_3 = (i_{s\alpha})_{ref} - i_{s\alpha}$$
$$e_4 = (i_{s\beta})_{ref} - i_{s\beta}$$

The final Lyapunov function is given by:

$$V_2 = V_1 + \frac{1}{2}(e_3^2 + e_4^2)$$
$$V_2 = \frac{1}{2}(e_1^2 + e_2^2 + e_3^2 + e_4^2)$$

Its derivative is:

$$\dot{V}_2 = e_3\left[(i_{s\alpha})_{ref} - \Delta_1 - \frac{1}{\sigma L_s}u_{s\alpha} + k_1e_1\right] + e_4\left[(i_{s\beta})_{ref} - \Delta_2 - \frac{1}{\sigma L_r}u_{s\beta} + k_4e_4\right] - k_1e_1^2 - k_2e_2^2 - k_3e_3^2 - k_4e_4^2$$

where

$$\Delta_1 = -\gamma i_{s\alpha} - \frac{K}{T_r}\varphi_{s\beta} - p\Omega K\varphi_{r\beta}$$
$$\Delta_2 = -\gamma i_{s\beta} + p\Omega K\varphi_{r\alpha} + \frac{K}{T_r}\varphi_{r\beta}$$

The control voltages $u_{s\alpha}$ and $u_{s\beta}$ chosen as:

(13) $$u_{s\alpha} = \sigma L_s\left[(i_{s\alpha})_{ref} - \Delta_1 + k_3e_3\right]$$

(14) $$u_{s\beta} = \sigma L_s\left[(i_{s\beta})_{ref} - \Delta_2 + k_4e_4\right]$$

We can write the equations:

(15) $$\dot{e}_1 = -k_1e_1$$
(16) $$\dot{e}_2 = -k_2e_2$$
(17) $$\dot{e}_3 = -k_3e_3$$
(18) $$\dot{e}_4 = -k_4e_4$$

Moreover, from equations (15), (16), (17), (18), we can write:

$$\dot{E} = AE$$

where

$$A = \begin{bmatrix} -k_1 & 0 & 0 & 0 \\ 0 & -k_2 & 0 & 0 \\ 0 & 0 & -k_3 & 0 \\ 0 & 0 & 0 & -k_4 \end{bmatrix}$$
$$E = [e_1 \quad e_2 \quad e_3 \quad e_4]^T$$

Nonlinear observer and application to the Induction Motor:

In this section, based on extensions of the observer design strategy to the multi-output case [4] and the application to the induction motor, we propose a new observer with nonlinear terms. We are going to apply the result given in the preceding part to construct a full order observer for an induction motor written in the (α, β) frame

[5]. The proposed observer uses the measurements of the stator voltage and current, and the rotor speed. More precisely, we design the observer up to an injection of the speed measurements so that only the electrical equations are considered. First, we define

$$x_e = \left[i_{s\alpha}\ i_{s\beta}\ \varphi_{r\alpha}\ \varphi_{r\beta}\right]^T$$
$$\hat{x}_e = \left[\hat{\imath}_{s\alpha}\ \hat{\imath}_{s\beta}\ \hat{\varphi}_{r\alpha}\ \hat{\varphi}_{r\beta}\right]^T$$
$$\tilde{x}_e = x_e - \hat{x}_e$$

Wherex_e, $\hat{x}_e$ and $\tilde{x}_e$ real states, estimated and observation error vectors respectively.

$$\dot{\hat{x}}_e = \begin{bmatrix} -\gamma & 0 & \frac{K}{T_r} & p\Omega K \\ 0 & -\gamma & -p\Omega K & \frac{K}{T_r} \\ \frac{M}{T_r} & 0 & -\frac{1}{T_r} & -p\Omega \\ 0 & \frac{M}{T_r} & p\Omega & -\frac{1}{T_r} \end{bmatrix} \hat{x}_e + g - \begin{bmatrix} -K_1 & 0 \\ 0 & -K_1 \\ -\frac{K_2}{T_r} & p\Omega K_2 \\ -p\Omega K_2 & -\frac{K_2}{T_r} \end{bmatrix} \begin{bmatrix} \tilde{\imath}_{s\alpha} \\ \tilde{\imath}_{s\beta} \end{bmatrix} + \begin{bmatrix} f_{i\alpha} \\ f_{i\beta} \\ 0 \\ 0 \end{bmatrix}$$

where $f_{i\alpha}$ and $f_{i\beta}$ are nonlinear functions which will be defined later from the overall stability with:

$$K_1 = 2\theta$$
$$K_2 = \frac{T_r^2\theta^2}{K[1 + (p\Omega T_r)^2]}$$

This leads to dynamic matrix equation of the following error:

$$\dot{\tilde{x}}_e = \begin{bmatrix} -\gamma & 0 & \frac{K}{T_r} & p\Omega K \\ 0 & -\gamma & -p\Omega K & \frac{K}{T_r} \\ \frac{M}{T_r} & 0 & -\frac{1}{T_r} & -p\Omega \\ 0 & \frac{M}{T_r} & p\Omega & -\frac{1}{T_r} \end{bmatrix} \tilde{x}_e - \begin{bmatrix} -K_1 & 0 \\ 0 & -K_1 \\ -\frac{K_2}{T_r} & p\Omega K_2 \\ -p\Omega K_2 & -\frac{K_2}{T_r} \end{bmatrix} \begin{bmatrix} \tilde{\imath}_{s\alpha} \\ \tilde{\imath}_{s\beta} \end{bmatrix} - \begin{bmatrix} f_{i\alpha} \\ f_{i\beta} \\ 0 \\ 0 \end{bmatrix}$$

We show the diagram block of this observer (see Fig. 3).

We will show now overall stability of the entire member constituting the total control system to know the motor, the observer and controller since the separation cannot be generalized to the nonlinear system that the motor is a nonlinear system and coupled. Call was made to the Lyapunov function to prove stability.

Control Algorithm

We will define a Lyapunov function $V_1(x)$ between the motor and the observer and other Lyapunov function $V_2(x)$ between the motor and controller as:

$$V_1(x) = \frac{\tilde{\imath}_{s\alpha}^2 + \tilde{\imath}_{s\beta}^2 + \tilde{\varphi}_{r\alpha}^2 + \tilde{\varphi}_{r\beta}^2}{2}$$
$$V_2(x) = \frac{e_1^2 + e_2^2 + e_3^2 + e_4^2}{2}$$

Therefore the Lyapunov function of all

$$V(x) = V_1(x) + V_2(x)$$

Its derivative is:

$$\dot{V}(x) = -k_1e_1^2 - k_2e_2^2 - k_3e_3^2 - k_4e_4^2\frac{1}{T_r}\left(\varphi_{r\alpha}^2 + \varphi_{r\beta}^2\right)$$
$$+(K_1 - \gamma)\left(\tilde{\imath}_{s\alpha}^2 + \tilde{\imath}_{s\beta}^2\right) + \frac{(K+M+K_2)}{T_r}(\tilde{\imath}_{s\alpha}\tilde{\varphi}_{r\alpha}$$
$$+\tilde{\imath}_{s\beta}\tilde{\varphi}_{r\alpha}) + (K + K_2)p\Omega\left(\tilde{\imath}_{s\alpha}\tilde{\varphi}_{r\beta} - \tilde{\imath}_{s\beta}\tilde{\varphi}_{r\alpha}\right)$$
$$-\left(\tilde{\imath}_{s\alpha}f_{r\alpha} + \tilde{\imath}_{s\beta}f_{r\beta}\right)$$

For $\dot{V} < 0$

- $K_1 - \gamma < 0$
- $\frac{(K + M + K_2)}{T_r}\left(\tilde{\imath}_{s\alpha}\tilde{\varphi}_{r\alpha} + \tilde{\imath}_{s\beta}\tilde{\varphi}_{r\alpha}\right) + (K + K_2)p\Omega\left(\tilde{\imath}_{s\alpha}\tilde{\varphi}_{r\beta} - \tilde{\imath}_{s\beta}\tilde{\varphi}_{r\alpha}\right) - \left(\tilde{\imath}_{s\alpha}f_{r\alpha} + \tilde{\imath}_{s\beta}f_{r\beta}\right) = 0$

Hence

- $K_1 < \gamma$

(19) $$f_{i\alpha} = \frac{(K+M+K_2)}{T_r}\tilde{\varphi}_{r\alpha} + (K + K_2)p\Omega$$

(20) $$f_{i\beta} = \frac{(K+M+K_2)}{T_r}\tilde{\varphi}_{r\beta} - (K + K_2)p\Omega\tilde{\varphi}_{r\alpha}$$

$V(x)$ is then a Lyapunov function for the overall system. Consequently, the whole process is stable and the convergence is exponential. We ensure flux, speed and torque tracking.

Results and simulations

We used a first-order filter after each time derivative in order to eliminate the large amplitude of the pulses produced by the derivatives; we placed a filter of the first order of unity gain and of fast time constant so as not to influence it on the behavior and shape of the signal that is derived.

We design the general block diagram as shown (see Fig. 3) In addition to that; we perform a simulation with Matlab-Simulink by using the Benchmark (see Fig. 4) and the motor parameters in Table 1 [6].

Table 1. Parameters of the induction motor

Designation	Parameter	*Value*
Rotor resistance	R_r	4.3047 Ω
Stator resistance	R_s	9.65 Ω
Mutual inductance	M	0.4475 H
Stator inductance	L_s	0.4717 H
Rotor inductance	L_R	0.4718 H
Rotor inertia	J_m	0.0293 kgm^2
Pole pair	p	2
Viscous friction coefficient	f_m	0.0038 N m sec rad^{-1}
Mecanical power	P_{mec}	1.1 KW
Nominal voltage	V_{sn}	220 V
Nominal current	I_{sn}	2.6 A
Nominal speed	Ω_{sn}	1410 Nm

This benchmark [1] (see Fig. 4) reveals the following profile: a rise in speed, a load, inversion speed and a load in recovery, and a return at a low speed.

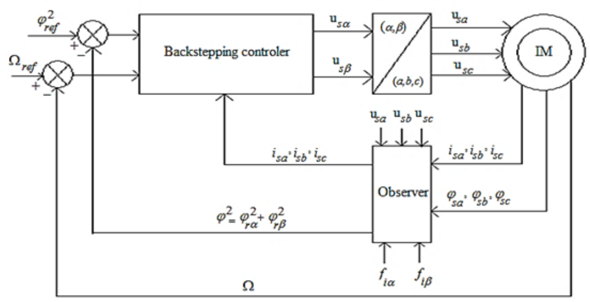

Fig.3. Scheme of the backstepping with an observer.

It is placed after each impulse derivative in order to eliminate the large amplitudes of the pulses produced by derivatives, we have placed a filter of the first order of unity gain and of fast time constant $\tau = 0.008$s so as not to eliminate it, Influence on the behavior and shape of the derived signal.

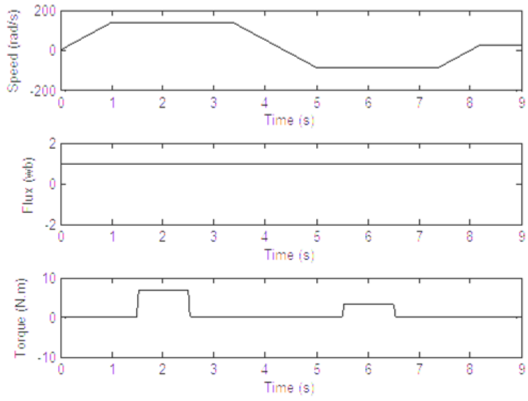

Fig. 4. Reference trajectories.

We have used first-order filter (see Fig. 5).

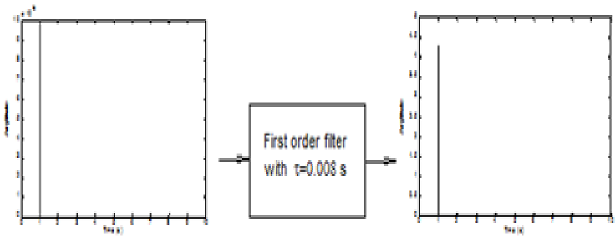

Fig.5. first order filter

Torque

We note that the drive torque follows the load torque when the speed is constant. During an increase or decrease in the speed, a difference of ± 4Nm appears between the two torques, (see Fig. 6).

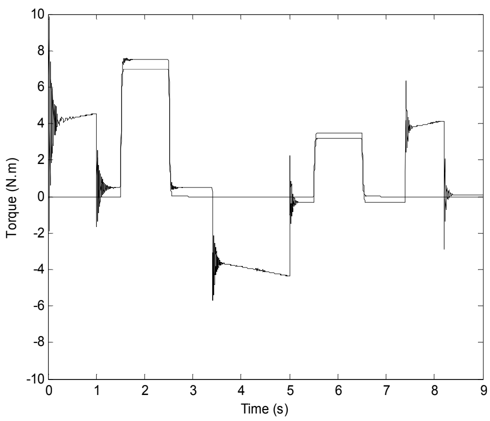

Fig .6. Motor and load torque with observer, $\theta = 10$.

Stator current norm

We show the plot of the norm stator current in (see Fig.7). The norm of the current is equal 3.2 A, in the interval of $t = [0\ 1]$s, $t = [3.4\ \ 5]$s and $t = [7.4\ \ 8.3]$s because the speed increase or decrease and the load torque are zero.

Between $t = [1\ 1.5]$s, $t = [2.5\ \ 3.4]$s, $t = [5\ \ 5.4]$s, $t = [6.5\ \ 7.4]$s and $t = [8.3\ \ \ 9]$s, the norm is minimal and equal to 2.3A. In this phase, the speed is constant and the load torque is zero. The amplitude of the current reaches a maximum value of 4.7A at $t = [1.5\ 2.5]$s because the load torque of 7 Nm appears at that point. Speed remains always constant. Therefore, the behavior of the norm of the stator current is normal.

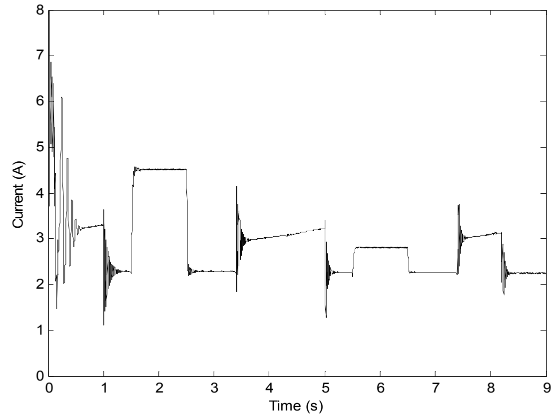

Fig. 7. Stator current norm with observer, $\theta = 10$.

Stator voltage control

The three stator control voltages follow the profile of the norm current, except if speed varies linearly. Their amplitude varies in the same propositions, (see Fig. 8) and their shape for each time interval, has a normal physical relationship with a speed, motor torque, stator current and control voltage.

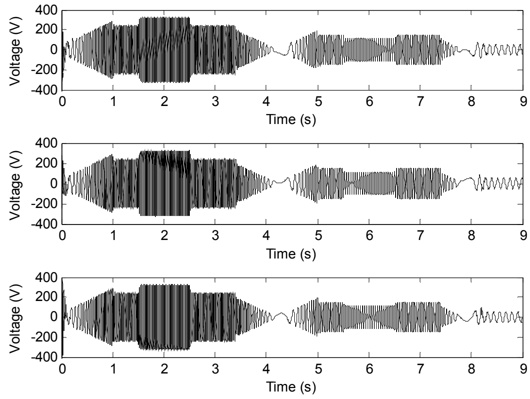

Fig. 8. Stator control with observer $\theta = 10$.

Speed and flux errors tracking

We note a good tracking by looking at the two errors of observation and regulation ; (see Fig. 9, 10, 11, 12). During an increase or a decrease in the speed of ± 0.3 rad/s is observed.

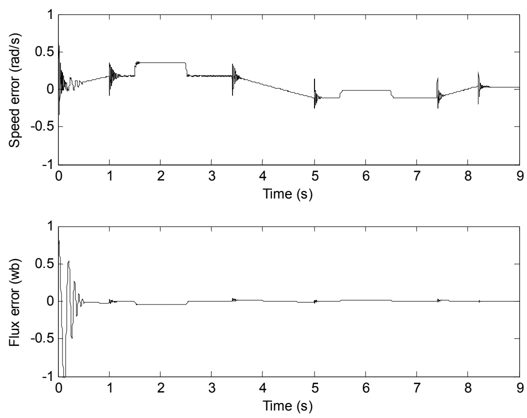

Fig. 9. Speed and flux errors with observer, $\theta = 10$.

We study sensitivity to rotor and stator resistance disturbances for three values of $R_r = 4.3047\Omega$, 7.318Ω, $8.6094\,\Omega$ and $R_s = (9.65;\ 16.4050;\ 18.30)\Omega$, i.e. an increase by 20% and 70% and 100%. In the error curve tracking flux (see Fig. 10, 11, 12), we note the appearance of the waves at time $t = 4.4s$ and $t = 8s$ because the induction motor not observable in zero speed, moreover variation of R_s and R_r. The greater the variation in the R_s and R_r, increased the amplitude of waves.

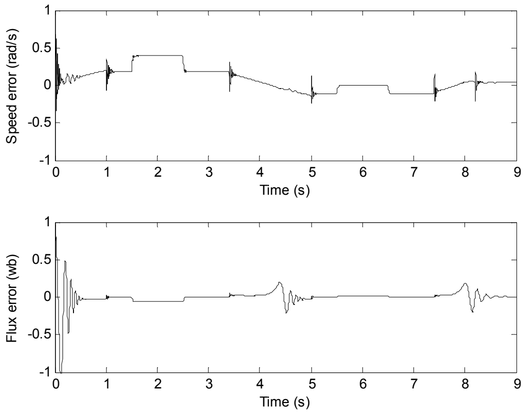

Fig. 10. Speed and flux errors with observer, $\theta = 10$ and variation of R_s and R_r 20%.

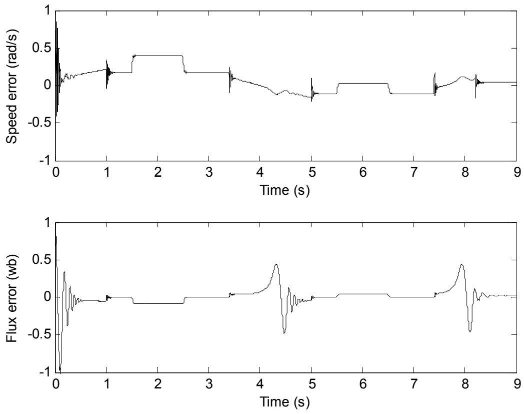

Fig. 11. Speed and flux errors with observer $\theta = 10$ and variation of R_s and R_r 70%.

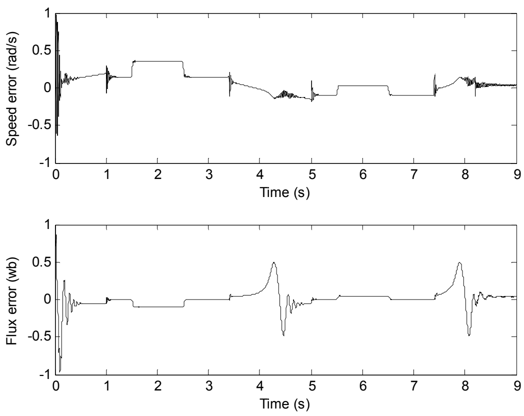

Fig. 12. Speed and flux errors with observer $\theta = 10$ and variation of R_s and R_r 100%.

Simulation results

The simulation was done by software MATLAB-Simulink. The diagram gives the simulation algorithm; (see Fig. 3) which shows the closed loop global system, asynchronous motor, the backstepping controller that represents the nonlinear control and the nonlinear observer this one gain control θ.

The results simulation have been chip for $\theta = 10$ and for a variable load torque, as shown by the load torque (see Fig. 3). The "Fig." 10, 11 and 12 respective the variable of rotor and stator resistance. The comment for each curve is presented as follows:

For load torque

We notice a good and logical behavior of the motor torque Γ_m.

$$J\dot{\Omega} = \Gamma_m + \Gamma_f + \Gamma_l$$
$$\Gamma_m = J\dot{\Omega} - \Gamma_f - \Gamma_l$$

For $t \in [0\ \ 1]$s: the speed is a line of constant slope and no load torque.
For $t \in [1\ \ 1.5]$s: the speed is constant and its load torque and no variation in the behavior is normal.
For $t \in [1.5\ \ 2.5]$s: the speed is constant and but there is load torque $\Gamma_l = 6.5\ N.m$ and no variation of resistance. The motor torque follows the load torque during this interval, the behavior is normal.
For $t \in [2.5\ \ 3.5]$s: the speed is constant without load torque $\Gamma_l = 0\ N.m$, the motor torque almost cancels out this error is due to the motor torque.
For $t \in [3.5\ \ 4.2]$s: the speed decreases, its slope is negative, the load torque is zero $\Gamma_l = 0\ N.m$, the motor torque changes the direction of rotation to become negative, which translates the normal behavior. At the point $t = 4.2\ s$ and around it we speak of low speed, it is a singular point are almost discontinuous, and continues the process of the system.
For $t \in [\,4.2\ \ 5]$s: the speed passes through $\Omega = 0$tr/s and changes sign (sense) to become negative (a negative slope), the motor torque also changes direction and becomes negative, which is normal.
For $t \in [5\ \ 7.5]$s: the speed is constant with a zero slope $(\Omega = Cte < 0)$ and $(\dot{\Omega} = 0)$. The motor torque follows the load torque from $t = 5.5\ s$ to $t = 6.5\ s$.
For $t \in [7.5\ \ 8]$s: the speed changes sign and start to become an acceleration $(\dot{\Omega} = C)$ passing through $\dot{\Omega} = 0$, the motor torque also becomes positive and its behavior follows the evolution of the speed which is normal.
For $t \in [8\ \ 9]$s: the speed is zero, the motor torque is zero also in the absence of the load torque.

Conclusion

We have presented two contributions in this article. The first is the use of the dynamic model in the frame $(\alpha\beta)$ of the asynchronous motor, model approximated. The second is the demonstration of the overall stability of the system composed of the asynchronous motor (nonlinear coupled system) and multivariable of the observer with a single adjustment parameter θ (which also nonlinear) and the controller which used the backstepping, to produce a nonlinear control law. We used the Lyapunov function, which involves the errors of the current, flux and their variable in square form to approach a form of energy.

We have disturbed the rotor and stator resistors in order to show the robustness of this control and the good estimate of the observer and the results were conclusive.

Authors
Amine CHENAFA: National Polytechnic University Oran, Algeria, E-mail: chenafaamine31@gmail.com.
Mohamed CHENAFA: Pr., ENSET, Department of Electrical Engineering, Oran, Algeria, 31100, E-mail: mchenafa@yahoo.fr
Abdellah MANSOURI : Pr., ENSET, Department of Electrical Engineering, Oran, Algeria, 31100, E-mail: ammansouri@yahoo.fr.

Abdelkader CHAKER : Pr., ENSET, Department of Electrical Engineering, Oran, Algeria, 31100, E-mail: chekeraa@yahoo.fr.

REFERENCES

[1] Chenafa M and others. Global stability of linearizing control with a new robust nonlinear observer of the induction motor. Int. J. Appl. Math. Comp. Sci., 2005, Vol. 15, No. 2, 235-243.
[2] A. R. Benaskeur. Aspects de l'application du Backstepping adaptatif à la commande décentralisée des systèmes non-linéaires. PhD thesis, Departement of Electrical and Computer Engineering, Universite Laval, Quebec City, Canada, 2000.
[3] Van Raumer T. (1994): Commande non-linéaire d'une machine asynchrone. PhD. Thesis, Laboratoire d'Electrotechnique et d'Electronique Industrielle de Toulouse, France.
[4] Busawwon K. Farza M. and Hmmouri H. (1998): Observer de signs for a special class of nonlinear systems. Int. J. Contr., Vol. 71, No. 3, pp. 405-418.
[5] Verghese G.C. and Sanders S.R. (1998): Observer for flux estimation in induction machines. IEEE Trans. Int. Electron., Vol. 35, No. 1, pp. 85-94.
[6] Cauët S. (2001): Contribution à l'analyse et la synthèse de loi de commande robustes pour la machine asynchrone. PhD. Thesis, Université de poitiers, Ecole Supérieur d'Ingénieurs de poitiers, Ecole Doctorale des Sciences pour l'Ingénieurs, France
[7] Hassan K.Khalil , "Nonlinear Control", global edition, Michigan State University, © Pearson Education Limited 2015.
[8] Shubhobrata Rudra, Ranjit Kumar Barai, Madhubanti Maitra (auth.); "Block Backstepping Design of Nonlinear State Feedback Control Law for Underactuated Mechanical Systems"; Springer Singapore (2017).
[9] Marcin MORAWIEC, Arkadiusz LEWICKI, Zbigniew KRZEMIŃSKI, Obserwator prędkości kątowej wirnika maszyny indukcyjnej klatkowej oparty na metodzie backstepping ze ślizgowymi funkcjami przełączającymi, PRZEGLĄD ELEKTROTECHNICZNY