Lyapunov and Backstepping Control Design of Induction Motor System

Souad Chaouch[1,2], Abdelghafour Herizi[1], Hocine Serrai[1] and Med said Nait said[2]
1. University Med Boudiaf of Msila
Department of Electronic
28000 M'sila, Algeria
TEL/Fax : 00 213 35 55 15 49
2. Laboratory of electromagnetic induction and propulsion systems,
Electrical Engineering departmen,
University of Batna, Algeria
chaouchsouad@yahoo.fr & medsaid.naitsaid@yahoo.fr

Abstract- **In this paper, a novel field-oriented induction motor drive using backstepping control design is presented. Backstepping control is proposed for replacing the existing PI controller to obtain high performance motion control systems, for the speed, flux and currents control loops. Stability analysis based on Lyapunov theory is also performed to guarantee the convergence of the speed tracking error from all possible initials conditions. Also, the computer simulations confirm that the proposed backstepping control scheme offers improved performance in terms of the trajectory tracking ability to time-varying reference input and robustness against parameters variation.**

Keywords- **Induction motor, field-oriented control, Backstepping control, Lyapunov theory.**

NOMENCLATURE

s, r	Stator and rotor subscripts
d, q	Direct and quadrate Park subscripts
v, i, ϕ	Voltage/ Current/ Flux variables
R_s, R_r	Stator, rotor resistance
L_s, L_r	Stator, rotor inductance
M	Mutual magnetizing inductance
σ	Total leakage factor
ω_s	Stator frequency
ω_r	Slip frequency
Ω	Rotor speed
J	Inertia
f	Friction coefficient
p	Pole pair number
T_L	Load torque
IM	Induction Motor

I . INTRODUCTION

INDUCTION motor drives, controlled by field oriented technique, have been widely used in industrial applications because their low cost, high reliability, power efficiency and easy maintenance. Induction motors are difficult to control for several reasons: (1) their dynamics are intrinsically non-linear and multivariable, (2) not all of the state variables and not all of the outputs to be controlled may be available for feedback; (3) there are critical parameters (for instance, load torque, stator and rotor resistances) which may considerably vary during operations. The concept of field orientation can be viewed as a nonlinear feedback transformation that achieves torque-flux decoupling technique [1]. More recently, various variations and improvements have been made for this control [2-4], which is based on a PI controller. In this approach, PI controllers are used in both the speed and inner flux and currents control loops. In many motion control applications, the PI controller works well and presents certain acceptable performance. However, when the system parameter uncertainties and mismatch become significant due to load disturbances, it is difficult to achieve satisfactory performance based on the classical PI scheme.
On the other hand, the PI controller strategy does not consider the cross-relation between the outer and inner control loops, which essentially limits its performance.
The backstepping algorithm, which is used to replace the PI controller, presents very good position tracking response as well as rejection to load disturbance. In the past decade, research about backstepping control has been increased [5-16]. The backstepping theory is a systematic and recursive design methodology for nonlinear feedback control. In many cases, the feedback linearization method using geometric approach is only valid in some local region and with a disturbance-free setting. The backstepping design alleviates some of these limitations [5]. Moreover, the backstepping design offers a choice of design tools for accommodation of uncertainties and nonlinearities and can avoid wasteful cancellations. In addition, the backstepping control approach is capable of keeping almost all the robustness properties [6], [8-10].
In this paper, we propose an approach that combines field orientation principle and backstepping design. The idea of backstepping design is to select recursively some appropriate functions of state variables, in our case the speed and flux, as pseudo-control inputs for lower dimension subsystems of the overall system. When the procedure terminates, a feedback design for the true control input results which achieves the original design objective by virtual of a final Lyapunov function, which is formed by summing up the Lyapunov functions associated with each individual design stage. The paper is organized as follows.

ISBN 978-9973-959-06-5 / SSD © 2007

Section 2 gives the induction motor model in field-oriented control. Then, the backstepping control design with Lyapunov theory is shown in section 3. The simulation results presented in section 4 for an induction motor verifies the validity of the proposed control. Finally, some conclusions are given in section 5.

II. Induction Motor Model

The dynamic model of IM in (α, β) stationary reference frame, which includes both the electrical and mechanical dynamics, is a fifth order system of nonlinear equations and can be described by the following differential equations.

$$\begin{aligned}
\frac{d\Omega}{dt} &= \frac{pM}{J\,L_r}\left(\phi_{r\alpha} i_{s\beta} - \phi_{r\beta} i_{s\alpha}\right) - \frac{T_L}{J} \\
\frac{d\phi_{r\alpha}}{dt} &= -\frac{R_r}{L_r}\phi_{r\alpha} - P\Omega.\phi_{r\beta} + \frac{R_r}{L_r} M\, i_{s\alpha} \\
\frac{d\phi_{r\beta}}{dt} &= -\frac{R_r}{L_r}\phi_{r\beta} + P\Omega\phi_{r\alpha} + \frac{R_r}{L_r} M\, i_{s\beta} \\
\frac{di_{s\alpha}}{dt} &= \frac{MR_r}{\sigma L_s L_r^2}\phi_{r\alpha} + \frac{PM}{\sigma L_s L_r}\Omega\phi_{r\beta} - \frac{M^2 R_r + L_r^2 R_s}{\sigma L_s L_r^2} i_{s\alpha} + \frac{1}{\sigma L_s} V_{s\alpha} \\
\frac{di_{s\beta}}{dt} &= \frac{MR_r}{\sigma L_s L_r^2}\phi_{r\beta} - \frac{PM}{\sigma L_s L_r}\Omega\phi_{r\alpha} - \frac{M^2 R_r + L_r^2 R_s}{\sigma L_s L_r^2} i_{s\beta} + \frac{1}{\sigma L_s} V_{s\beta}
\end{aligned} \tag{1}$$

The above model for the induction motor is obviously a highly coupled multivariable nonlinear system. It is very difficult to control such a system directly based on this model. According to the vector control principle, the q-axis flux ϕ_{rq} is always forced to be zero in order to orient all the rotor flux in the d-axis and a decoupled system for linear torque control is achieved. This control technique involves a transformation of the representation for the state vector in the fixed stator frame (α, β) into that in a frame (d, q)

The stator field angle θ_s is estimated as:

$$\theta_s = \arctan\left(\frac{\phi_{r\beta}}{\phi_{r\alpha}}\right) \tag{2}$$

Transformation between the two different frames is:

$$\begin{bmatrix} x_{sd} \\ x_{sq} \end{bmatrix} = \begin{bmatrix} \cos(\theta_s) & \sin(\theta_s) \\ -\sin(\theta_s) & \cos(\theta_s) \end{bmatrix} . \begin{bmatrix} x_{s\alpha} \\ x_{s\beta} \end{bmatrix} \tag{3}$$

Where x can be used for current i, flux ϕ and voltage v. Using equation (2), we obtain:

$$\begin{aligned}
\overline{\phi_r} &= \phi_{r\alpha} + j\phi_{r\beta} = \sqrt{\phi_{r\alpha}^2 + \phi_{r\beta}^2}\left[\frac{\phi_{r\alpha}}{\sqrt{\phi_{r\alpha}^2 + \phi_{r\beta}^2}} + j\frac{\phi_{r\beta}}{\sqrt{\phi_{r\alpha}^2 + \phi_{r\beta}^2}}\right] \\
\overline{\phi_r} &= \sqrt{\phi_{r\alpha}^2 + \phi_{r\beta}^2}\left[\cos(\theta_s) + j\sin(\theta_s)\right]
\end{aligned} \tag{4}$$

Therefore the equations (3) become:

$$i_{sd} = \frac{\phi_{r\alpha} i_{s\alpha} + \phi_{r\beta} i_{s\beta}}{\sqrt{\phi_{r\alpha}^2 + \phi_{r\beta}^2}} \tag{5}$$

$$i_{sq} = \frac{\phi_{r\alpha} i_{s\beta} - \phi_{r\beta} i_{s\alpha}}{\sqrt{\phi_{r\alpha}^2 + \phi_{r\beta}^2}} \tag{6}$$

$$\begin{aligned}
\phi_{rd} &= \sqrt{\phi_{r\alpha}^2 + \phi_{r\beta}^2} \\
\phi_{rq} &= 0
\end{aligned} \tag{7}$$

$$V_{sd} = \frac{V_{s\alpha}\phi_{r\alpha} + V_{s\beta}\phi_{r\beta}}{\sqrt{\phi_{r\alpha}^2 + \phi_{r\beta}^2}} \tag{8}$$

$$V_{sq} = \frac{V_{s\beta}\phi_{r\alpha} - V_{s\alpha}\phi_{r\beta}}{\sqrt{\phi_{r\alpha}^2 + \phi_{r\beta}^2}} \tag{9}$$

Using this transformation, the state equations (1) can be rewritten in the new state variables as:

$$\begin{aligned}
\frac{d\Omega}{dt} &= \frac{\mu}{J}\phi_d i_{sq} - \frac{T_L}{J} \\
\frac{d\phi_d}{dt} &= -\tau_r\phi_d + \tau_r M\, i_{sd} \\
\frac{di_{sd}}{dt} &= -\eta i_{sd} + \tau_r\lambda\phi_d + P\Omega i_{sq} + \tau_r M\frac{i_{sq}^2}{\phi_d} + \frac{1}{\sigma L_s}V_{sd} \\
\frac{di_{sq}}{dt} &= -\eta i_{sq} - \lambda P\Omega\phi_d - P\Omega i_{sd} - \tau_r M\frac{i_{sq}\, i_{sd}}{\phi_d} + \frac{1}{\sigma L_s}V_{sq} \\
\frac{d\theta_s}{dt} &= P\Omega + \tau_r M\frac{i_{sq}}{\phi_d}
\end{aligned} \qquad 10)$$

Where

$\mu = \frac{PM}{L_r}$, $\tau_r = \frac{R_r}{L_r}$, $\eta = \frac{M^2 R_r + L_r^2 R_s}{\sigma L_s L_r^2}$ and $\lambda = \frac{M}{\sigma L_s L_r}$

Using the decoupled control approaches, the dynamic behavior of the induction motor is rather similar to that of a separately excited DC motor. However, the decoupled relationship is obtained by means of a proper selection as state co-ordinates, under the hypothesis that the rotor flux is kept constant [1], [5] and [10]. Therefore, the rotor speed is only asymptotically decoupled from rotor flux, and the speed is linearly related to torque current only after the rotor flux becomes the steady-state values. So, the induction motor system (10) leads a simplified system structure with two approximately decoupled subsystems. The first one is a subsystem with state vector (Ω, i_{sq}) and control V_{sq}, and the second one with (ϕ_d, i_{sd}) as states and V_{sd} as control input. Particularly, this structure allows as to conveniently applying backstepping design techniques to replace the traditional nonlinear feedback PI control of the field oriented control technique for better performance. Thus, we will take a different path than the linearzing control of the field oriented control technique. The subsystem structure will be fully exploited in our control design as detailed in the next section.

III. BACKSTEPPING CONTROL

The backstepping is a systematic and recursive design methodology for nonlinear feedback control. The backstepping design offers a choice of design tools for accommodation of uncertainties and nonlinearities and can avoid wasteful cancellations. The idea of backstepping design is to select recursively some appropriate functions of state variables as pseudo-control inputs for lower dimension subsystems of the overall system. Each backstepping stage results in a new pseudo-control designs from preceding design stages When the procedure terminates, a feedback design for the true control input results which achieves the original design objective by virtue of a final Lyapunov function, which is formed by summing the Lyapunov functions associated with each individual design stage [14-16]. The backstepping design procedure consists of the following three steps.

Step 1

This first step consists in identifying the errors z_1 and z_2 which respectively represent the error between real speed Ω and reference speed Ω_{ref}, as well as between the rotor flux module ϕ_d and its reference ϕ_{ref}

$$\begin{aligned} z_1 &= \Omega_{ref} - \Omega \\ z_2 &= \phi_{ref} - \phi_d \end{aligned} \tag{11}$$

The derivative of (11) is computed as

$$\begin{aligned} \dot{z}_1 &= \dot{\Omega}_{ref} - \dot{\Omega} = \dot{\Omega}_{ref} - \frac{\mu}{J}\phi_d\, i_{sq} + \frac{T_L}{J} \\ \dot{z}_2 &= \dot{\phi}_{ref} - \dot{\phi}_d = \dot{\phi}_{ref} + \tau_r\phi_d - \tau_r M i_{sd} \end{aligned} \tag{12}$$

The first Lyapunov candidates v_1 is chosen as

$$v_1 = \frac{1}{2}\left(z_1^2 + z_2^2\right) \tag{13}$$

So, the derivative of (13) is computed as

$$\begin{aligned} \dot{v}_1 &= z_1(\dot{\Omega}_{ref} - \frac{\mu}{J}\phi_d i_{sq} + \frac{T_L}{J}) \\ &\quad + z_2(\dot{\phi}_{ref} + \tau_r\phi_d - \tau_r M i_{sd}) \end{aligned} \tag{14}$$

Thus, the tracking objectives will be satisfied if we choose

$$\begin{aligned} (i_{sq})_{ref} &= \frac{1}{\phi_d}\frac{J}{\mu}\left(k_1 z_1 + \dot{\Omega}_{ref}\right) + \frac{T_L}{\mu} \\ (i_{sd})_{ref} &= \frac{1}{\tau_r M}\left(k_2 z_2 + \dot{\phi}_{ref} + \tau_r\phi_d\right) \end{aligned} \tag{15}$$

Where k_1 and k_2 are positive design constants that determine the closed loop dynamics. Then (12) can be expressed as

$$\begin{aligned} \dot{z}_1 &= -k_1 z_1 \\ \dot{z}_2 &= -k_2 z_2 \end{aligned} \tag{16}$$

Therefore, (14) can be rewritten as

$$\dot{v}_1 = -k_1 z_1^2 - k_2 z_2^2 < 0 \tag{17}$$

So, the control $(i_{sq})_{ref}$ and $(i_{sd})_{ref}$ in (15) is asymptotically stabilizing.

Step 2

Define other errors signals between the current and the reference currents.

$$\begin{aligned} z_3 &= (i_{sq})_{ref} - i_{sq} \\ &= \frac{1}{\phi_d}\frac{J}{\mu}\left(k_1 z_1 + \dot{\Omega}_{ref}\right) + \frac{T_L}{\mu} - i_{sq} \\ z_4 &= (i_{sd})_{ref} - i_{sd} \\ &= \frac{1}{\tau_r M}\left(k_2 z_2 + \dot{\phi}_{ref} + \tau_r\phi_d\right) - i_{sd} \end{aligned} \tag{18}$$

With this definition, (12) can be expressed as

$$\begin{aligned} \dot{z}_1 &= -k_1 z_1 + \frac{\mu}{J} z_3 \\ \dot{z}_2 &= -k_2 z_2 + \tau_r M z_4 \end{aligned} \tag{19}$$

From (18), the errors dynamics are given by

$$\begin{aligned} \dot{z}_3 &= (\dot{i}_{sq})_{ref} - \dot{i}_{sq} \\ &= (\dot{i}_{sq})_{ref} - \delta_1 - \frac{1}{\sigma L_s}V_{sq} \\ \dot{z}_4 &= \frac{1}{\tau_r M}\left(k_2\dot{z}_2 + \ddot{\phi}_{ref} + \tau_r\dot{\phi}_d\right) - \dot{i}_{sd} \\ &= (\dot{i}_{dr})_{ref} - \delta_2 - \frac{1}{\sigma L_s}V_{sd} \end{aligned} \tag{20}$$

Where

$$\delta_1 = -\eta i_{sq} - \lambda p\Omega\phi_d - p\Omega i_{sd} - \tau_r M\frac{i_{sq} i_{sd}}{\phi_d}$$

$$\delta_2 = -\eta i_{sd} + \tau_r\lambda\phi_d + p\Omega i_{sq} + \tau_r M\frac{i_{sq}^2}{\phi_d}$$

Step 3

Since the actual control inputs V_{sd}, V_{sq} have appeared in the above equations, we can go to the final step. Now, we define the following Lyapunov function candidate.

$$v_2 = \frac{1}{2}\left(z_1^2 + z_2^2 + z_3^2 + z_4^2\right) \tag{21}$$

Taking the time derivative of v_2, we obtain

$$\dot{v}_2 = z_1\dot{z}_1 + z_2\dot{z}_2 + z_3\dot{z}_3 + z_4\dot{z}_4 \tag{22}$$

This equation can be rewritten in the following from

$$\begin{aligned}\dot{v}_2 = & -k_1 z_1^2 - k_2 z_2^2 - k_3 z_3^2 - k_4 z_4^2 + z_3\left(k_3 z_3 + (\dot{i}_{sq})_{ref} - \delta_1 - \frac{1}{\sigma L_s}V_{sq}\right) \\ & + z_4\left(k_4 z_4 + (\dot{i}_{sd})_{ref} - \delta_2 - \frac{1}{\sigma L_s}V_{sd}\right)\end{aligned} \tag{23}$$

The choice of $k_3 > 0$ and $k_4 > 0$ can be made such that $\dot{v}_2 < 0$. At last, in order to make the derivative of the complete Lyapunov function (23) be negative definite, the d-axis and q-axis voltage control input is chosen as follows.

$$\begin{aligned} V_{sd} &= \sigma L_s\left((\dot{i}_{sd})_{ref} + k_4 z_4 - \delta_2\right) \\ V_{sq} &= \sigma L_s\left(k_3 z_3 + (\dot{i}_{sq})_{ref} - \delta_1\right)\end{aligned} \tag{24}$$

Then, (20) can be expressed as

$$\begin{aligned}\dot{z}_3 &= -k_3 z_3 - z_1\frac{\mu}{J} \\ \dot{z}_4 &= -\tau_r M z_2 - k_4 z_4\end{aligned} \tag{25}$$

To show boundedness of all states, we can rearrange the dynamical equations from (19) and (25) as

$$\dot{Z} = \begin{bmatrix}\dot{z}_1 \\ \dot{z}_2 \\ \dot{z}_3 \\ \dot{z}_4\end{bmatrix} = \begin{bmatrix} -k_1 & 0 & \frac{\mu}{J} & 0 \\ 0 & -k_2 & 0 & \tau_r M \\ -\frac{\mu}{J} & 0 & -k_3 & 0 \\ 0 & -\tau_r M & 0 & -k_4\end{bmatrix}\begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4\end{bmatrix} = AZ \tag{26}$$

Where A can be shown to be Hurwitz, this proves the boundedness of all the states.

The block diagram of the proposed backstepping control scheme is presented in figure (1). The blocks 'i_{sdref}' calculation and 'i_{sqref}' calculation provide the currents references from the rotor flux and speed errors, through the equation (15) which represent the fictive control. The voltage command based on currents errors are given by the two blocks 'V_{sd}' Calculation and 'V_{sq}' Calculation which are implemented by equations (24). The block $(dq - \alpha\beta)$ makes the conversion between the synchronous rotating and stationary reference frames and is implemented by equation (3). So, the calculations blocks replace the classical regulators PI in field control induction motor

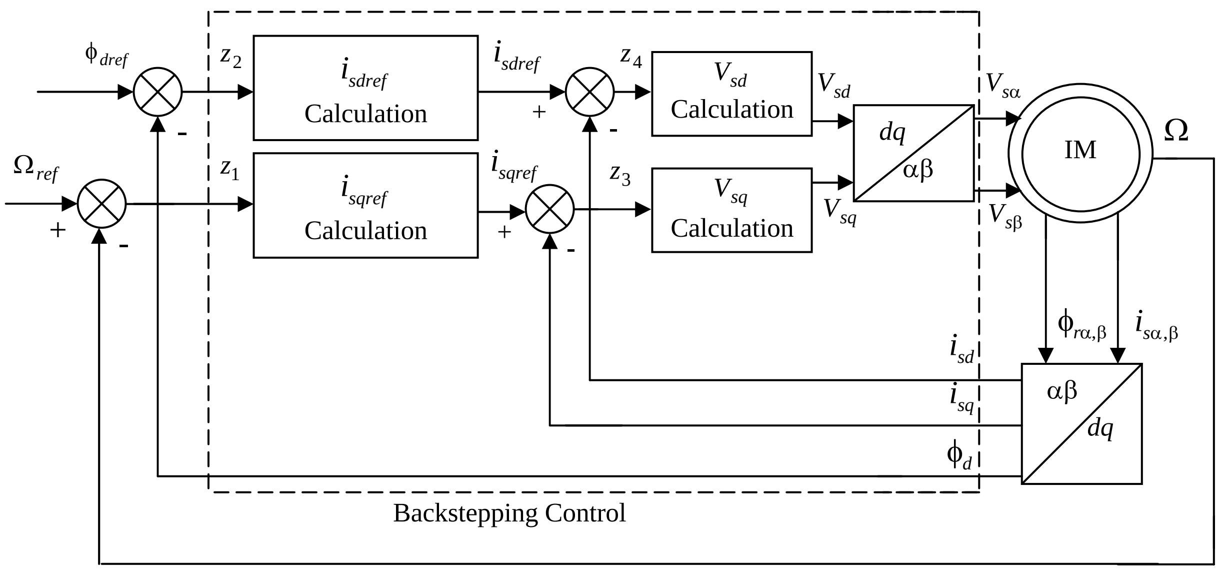
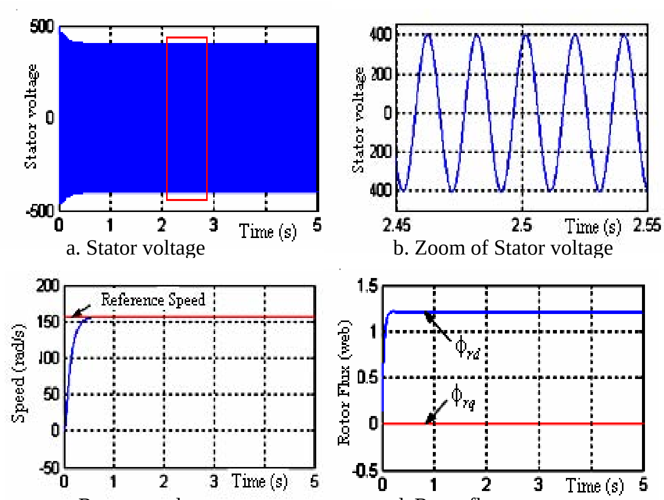


Fig. 1 Block diagram of the proposed Backstepping field oriented control of induction machine

IV. Simulation Results

Digital simulation is implemented to display the effectiveness of the backstepping control combined with field oriented control of induction motor. The system parameters of induction motor are given in Appendix. The parameters k_1, k_2, k_3 and k_4 are chosen as follows: $k_1 = 120, k_2 = 100, k_3 = 400$ and $k_4 = 30$ to satisfy convergence conditions.

Fig. 2 shows the control variable; the stator voltage in (α, β) frame, the rotor speed and the rotor flux components in (d, q) frame which present the performance of the backstepping control in the nominal case. It is observed that the rotor speed is very close to the reference one without instabilities effects. It should be noted that the decoupling between the torque and the flux is quite good.



a. Stator voltage b. Zoom of Stator voltage
c. Rotor speed d. Rotor flux

Fig. 2 Dynamic responses of backstepping control for IM

To test the speed evolution of the system, the induction motor is accelerate from standstill to nominal speed (+157rd/s), afterwards it is decelerate to the inverse rated speed (-157rd/s) and accelerate again to low speed (30rd/s). The performances are presented in Fig. 3. Note that the decoupling control is very quite maintained with the speed variation. The speed response is merged with the reference one and the flux is very similar to the nominal case. We can find also, that the rotor speed error and rotor flux error given by z_1 and z_2 converge to zero rapidly.

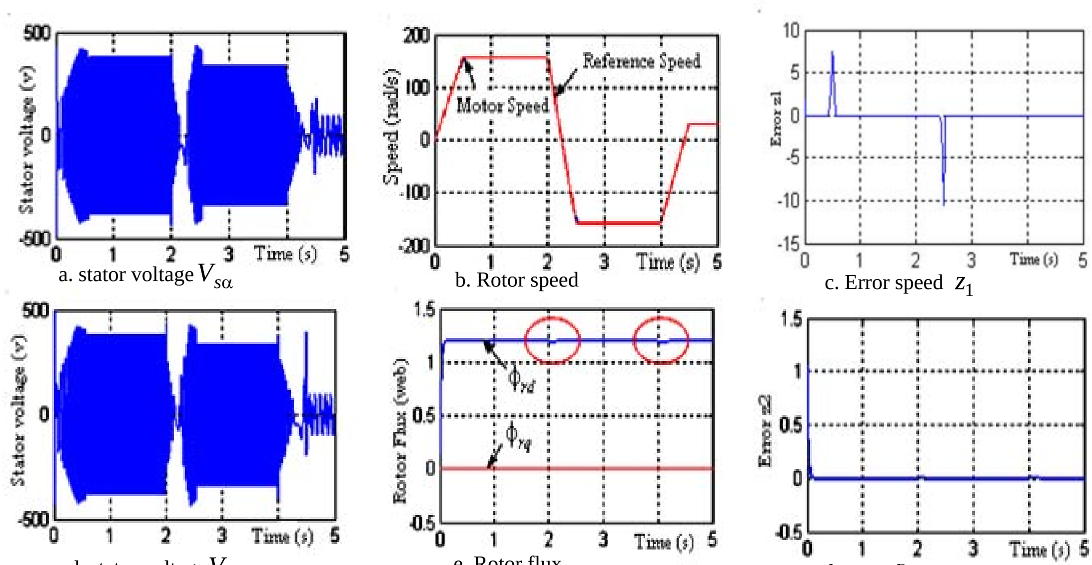
Thus, in the nominal case, the control gives good quality results. Furthermore, the interest is to verify the robustness of the control with respect to parameter variation. With this aim, we have tested the control according to stator resistance variation.

The results with resistance variation (+50%) between 1.5s and 3.5s are presented in Fig.4. the speed response is merged with the nominal case (Fig. 2). The flux is very similar to the nominal case, we can remark that the increase of the stator resistance amplifies the static error and it appears a small static error in steady condition with respect to nominal case.

From these simulation results, it is obvious that the proposed backstepping controller is quite successful and presents an excellent performance.

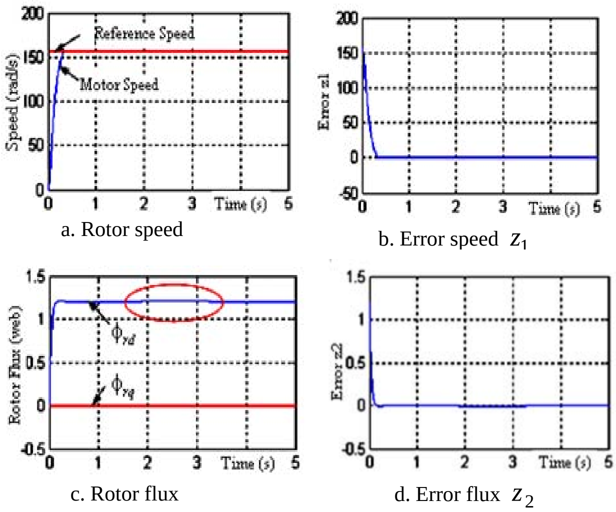
V. Conclusion

In this paper, we have proposed a backstepping controller for the induction motor with fifth order nonlinear dynamic model which is controlled by primary voltage source. Field oriented control and backstepping design are combined to design the nonlinear model for an induction motor. Step by step control designs are given. The simulation results have demonstrated the effectiveness of our design scheme and have shown that backstepping control can achieve superior performance in comparison to the conventional PI controller.



a. stator voltage $V_{s\alpha}$ b. Rotor speed c. Error speed z_1
d. stator voltage $V_{s\beta}$ e. Rotor flux f. Error flux z_2

Fig. 3 Backstepping control of IM with rotor speed variation



a. Rotor speed b. Error speed z_1

c. Rotor flux d. Error flux z_2

Fig. 4 Backstepping control of IM with stator resistance variation.

APPENDIX

Parameters	Rated Values	Unity
Output power	1.08	[kW]
Stator voltage	220/380	[V]
Stator frequency	50	[Hz]
Pole pair number	2	
Stator resistance	8	[Ω]
Rotor resistance	4	[Ω]
Mutual inductance	0.42	[H]
Stator inductance	0.47	[H]
Rotor inductance	0.42	[H]
Inertia	0.06	[Kgm^2]
Friction coefficient	0.00	[SI]

REFERENCES

[1] Blaschke. F. “The principle of field orientation as applied to the new transvector closed-loop control system for rotating-field machines”. Siemens Rev., vol. 34, pp. 217-220, 1972.

[2] Kim. Y-R, Sul. S-K, Park, M-H. “Speed sensorless vector control of induction motor drive using extended kalman filter” IEEE Trans. On Indus. Appl., Sept./Oct. 1994, Vol. IA-30, No. 5, pp. 1225-1233.

[3] Chaouch. S, Nait Said. M.S. “Speed sensorless stator flux oriented control of the induction motor” Journal of electrical Engineering, vol. 4, pp. 47-52, Romania 2004.

[4] Chaouch. S, Nait Said. M.S. “A high performance direct stator flux orientation control (DSFO) for speed sensorless induction motor drive” Second International Conference on Electrical Systems ICES’06 May 8-10 2006, Oum-Elbouaghi, pp 294-299.

[5] Lin F.J, Lee C.C. Adaptive backstepping control for linear induction motor drive to track periodic references. IEE proceeding on electronic power application, Vol. 147, No 6; November 2000; pp. 449-458.

[6] Tan Y, Chang J and Tan H. “Adaptive backstepping control and fiction compensation for AC Servo with inertia and load uncertainties”.

[7] Sheng S.K, Lin J.S. Sensorless speed tracking control with backstepping design scheme for permanent magnet synchronous motors. Proceedings of the 2005 IEEE conference on control applications, Toronto, Canada; August 28-31 2005; pp. 487-492.

[8] Tan Y, Chang J, Tan H and Hu J. Integral backstepping control and experimental implementation for motion system. Proceedings of the 2000 IEEE international conference on control applications, Anchorage, Alaska, USA, September 25-27 2000, pp. 367-372.

[9] Chih-Min. L, Chun-Fei. H. “Recurrent-Neural-Network-Based Adaptive-Backstepping Control for Induction Servomotors”. IEEE Transactions on industrial electronics, Vol 52, No 6; December 2005; pp. 1677-1684.

[10] Rong-Jong. W, Han-Hsiang. C. “Backstepping Wavelet Neural Network Control for Indirect Field-Oriented Induction Motor Drive”. IEEE Transactions on neural networks, Vol 15, No 2; March 2004; pp. 367-382.

[11] Ghanes M, Glumineau A, DeLeon J. “Backstepping observer validation for sensorless induction motor on low frequencies Benchmark”. IEEE International conference on industrial Technology (ICIT); 2004; pp. 1368-1373.

[12] Tan H, Chang J. “Adaptive position control of induction motor systems under mechanical uncertainties”. IEEE International conference on power electronics and drive systems, PEDS'99, July 1999; Hong Kong; pp. 597-602.

[13] Huang C, Chen K.L, Lee H.T and Fu L.C. “Nonlinear adaptive backstepping motion control of linear induction motor”. Proceedings of the American control conference anchorage, AK May 8-10, 2002, pp. 3099-3104.

[14] Tan. H, Chang J. “Adaptive Backstepping control of induction motor with uncertainties”. Proceedings of the American control conference, San Diego California; June 1999; pp. 1-5.

[15] Huang C and Fu L.C. “Adaptive backstepping speed/position control with friction compensation for linear induction motor”. Proceedings of the 41 st IEEE conference on decision and control, Las Vegas, Nevada USA, December 2002, pp. 474-479.

[16] Yokoi K, Hung N.V.Q, Tuan H.D and Hosoe S. “Adaptive control design for n-th order nonlinearly multiplicative parameterized systems with triangular structure and application”. Proceedings of the 42nd IEEE conference on decision and control, Maui, Hawaii USA, December 2003, pp. 3268-3273.