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SPEED BACKSTEPPING CONTROL OF THE DOUBLE-FED INDUCTION MACHINE DRIVE

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ABSTRACT

This paper presents a new strategy to improve the performances of speed control of a Double-Fed Induction Machine (DFIM), whose stator and rotor windings are connected to a voltage inverter PWM (Pulse Width Modulation) independently. This work shows the robustness of the adaptive Backstepping control strategy applied to the DFIM. The main objective of this work is to stabilize the speed of the machine to be used in the Aeolians systems. The overall stability of the system is shown through using Lyapunov technique. Therefore, this paper presents the study and analysis of the Backstepping control. Finally, the simulation results of the Backstepping technique are valid on Matlab / Simulink, followed by a detailed analysis and clearly show that the proposed system provides good static and dynamic performance.

Keywords: *Double-fed Induction machine (DFIM); Backstepping control non-adaptive; PWM; Robustness.*

1. INTRODUCTION

In the recent times, in the industrial areas, the Current Alternative rotating machines are more usable especially double-fed Induction machine (DFIM), because of its many advantages over other types of rotating electrical machines. Its advantages can be summarized as following variable speed, its construction is simple, low cost, dependability, durability, and especially its maintenance is simple and economical. These benefits have made it the target of a lot of research, mainly as far as the realization of robust controls and its operation with or without a speed sensor. Double-Fed Induction machine (DFIM), is the nonlinear machine, fed by two voltage source the stator and rotor, strongly Torqued (the coupling between the electromagnetic Torque and flux), they function as multivariate machines, hence the complexity and difficulty of operation and control. With the evolution and development of new technologies of electronics and computers, the problems inherent in the control and the operation of various applications of variable speed DFIM are solved and simplified; it gives opportunities for speed control with or without mechanical sensors, as well as flux control for the characteristics regimes hypo-synchronous and hyper-synchronous.

In this context, for a good and correct operation of the variable speed DFIM, the power converter (inverter / rectifier) PWM must be inserted to allow the design and performance of synchronization between DFIM machine and electrical network. With the use the development of modern control methods, such as the vector control flux oriented, DTC and Backstepping nonlinear control can control and stabilizes the system.

In this article, we present the non-adaptive Backstepping nonlinear control, as a method of recursive control and represents a tool for the research of dynamic stability, whose objective is to regulate the speed of the machine to the reference value regardless of external disturbances, we then apply this technique successfully to the DFIM, which gives a powerful tool for its control. In this technique we have to make sure that its parameters are constant and known. The disadvantage of this control is the sensitivity to changes in electrical and mechanical parameters of temperature, the skin effect, the magnetic saturation and the measurement errors. For this, in another study we estimate the state variables of the machine and make it more

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stable and powerful to all instant changes DFIM machine system. The performance of this control will be shown by simulation results and performances. First, DFIM modeling system in Reference Park (d-q) and presentation of electronic power components. Second, the analysis and the development of non-adaptive Backstepping control nonlinear speed of DFIM are studied.

Finally, there will be a discussion of interpretations of simulation results. In the below sample we provide a definition of general structure of an electric engine control, which is shown in Fig.1:

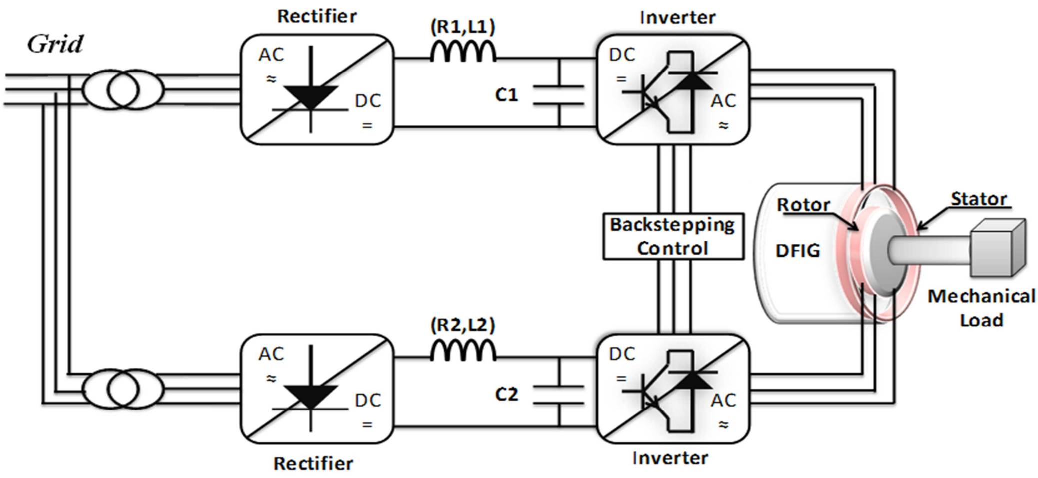

Figure 1: General Structure Of The DFIM Motor With The Backstepping Control Of Speed Regulation

2. MODEL OF DFIM CONTROL SYSTEM

The study and analysis of DFIM in the reference to PARK (d-q) allows us to state the following electrical equations:

$$\begin{cases} V_{sd} = R_s.I_{sd} + \dfrac{d\varphi_{sd}}{dt} - \omega_s.\varphi_{sq} \\ V_{sq} = R_s.I_{sq} + \dfrac{d\varphi_{sq}}{dt} + \omega_s.\varphi_{sd} \\ V_{rd} = R_r.I_{rd} + \dfrac{d\varphi_{rd}}{dt} - \omega_r.\varphi_{rq} \\ V_{rq} = R_r.I_{rq} + \dfrac{d\varphi_{rq}}{dt} + \omega_r.\varphi_{rd} \end{cases} \quad (1)$$

With:

$$\omega_r = \omega_s - P.\omega$$

$$\begin{cases} I_{sd} = \dfrac{1}{\sigma.L_s}.\varphi_{sd} - \dfrac{M_{sr}}{\sigma.L_r}.\varphi_{sd} \\ I_{sq} = \dfrac{1}{\sigma.L_s}.\varphi_{sq} - \dfrac{M_{sr}}{\sigma.L_s.L_r}.\varphi_{sq} \\ I_{rd} = \dfrac{1}{\sigma.L_r}.\varphi_{rd} - \dfrac{M_{sr}}{\sigma.L_r.L_s}.\varphi_{sd} \\ I_{rq} = \dfrac{1}{\sigma.L_r}.\varphi_{rq} - \dfrac{M_{sr}}{\sigma.L_r.L_s}.\varphi_{sq} \end{cases} \quad (2)$$

With:

$$\sigma = 1 - \frac{M^2}{L_r.L_s}$$

The equations of the magnetic flux in relation to the electric current are as follows:

$$\begin{cases} \varphi_{sd} = L_s.I_{sd} + M_{sr}.I_{rd} \\ \varphi_{sq} = L_s.I_{sq} + M_{sr}.I_{rq} \\ \varphi_{rd} = L_r.I_{rd} + M_{sr}.I_{sd} \\ \varphi_{rq} = L_r.I_{rq} + M_{sr}.I_{sq} \end{cases} \quad (3)$$

The electromagnetic Torque of the DFIM is:

$$C_{em} = P(\varphi_{rd}.\varphi_{sq} - \varphi_{rq}.\varphi_{sd}) \quad (4)$$

By applying of the fundamental principle of dynamics, we find the following Torque:

$$C_{em} = C_r + J.\frac{d\Omega}{dt} + f.\Omega \quad (5)$$

With:

- *d, q* : Indices components direct axis and quadrature axis.
- *S, R* : Indices of the stator and rotor.
- θ_s , θ_r : Angle tracking of the stator flux and rotor relative to the benchmark.
- ψ : mechanical rotor frequency (rad/s).
- *J* : Moment of inertia.
- *f* : Coefficient of viscous friction

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I_d, I_q : two-phase stator currents and rotor in a rotating frame.
V_d, V_q : two-phase stator voltages and rotor in a rotating frame.
$\varphi_{sd,q}$, $\varphi_{rd,q}$: stator and rotor resistances and Flux two-phase in a rotating frame.
R_s, R_r : stator and rotor resistances.
L_s, L_r : stator and rotor cyclic coefficient of inductance.
M_{sr} : coefficient of mutual inductance cyclic stator / rotor.
σ : dispersion coefficient.
P : number of pole pairs of the machine.
w_s, w_r : angular speed (pulsation) electrical stator and rotor.
C_r : load Torque.
C_{em} : Electromagnetic Torque.
Ω : Speed of rotation of the machine.

3. BACKSTEPPING CONTROL DFIM NONLINEAR NON-ADAPTIVE

3.1. Principle of Backstepping control non-adaptive

The principle of Backstepping control non-adaptive is to analyze the stability of the system, without solving non-linear differential equations in the following form:

$$\begin{cases} \dot{x}_1 = f(x_1) + x \\ \dot{x}_2 = u \\ f(0) = 0 \end{cases} \tag{6}$$

With:

$[x_1 \quad x_2]^T$: is the state vector.

u: is the control vector.

$x_1=0$ and $x_2=0$: is the equilibrium point of the system (the origin).

Lyapunov methods are a very powerful tool for testing and finding sufficient stability of dynamical system conditions.

The stability depends only on the variations (sign of the derivative), or a function which is equivalent, along the trajectory of the system.

The research of the stability system (6) characterized by a state vector $[x_1 \quad x_2]^T$, consists of finding a function $V(x)$ of definite sign, In order to illustrate the recursive procedure of backstepping method, considering that the output of the system follows the reference signal. The system (6) is of order 2 , the implementation is done in two stages.

3.1.2. Step 1:

We define the tracking error e1 such as:

$$e_1 = x_{1d} - x_1 \tag{7}$$

With x_{1d}: Output a desired trajectory.

Its derivative (7) is:

$$\dot{e}_1 = \dot{x}_{1d} - \dot{x}_1 = \dot{x}_{1d} - f(x) - x_2 \tag{8}$$

For such a system (6), we first construct the first Lyapunov function V_1 as a quadratic form:

$$V_1 = \frac{1}{2} e_1^2 \tag{9}$$

The derivative of the function is written:

$$\dot{V}_1 = e_1\dot{e}_1 = e_1(\dot{x}_{1d} - \dot{x}_1) = e_1(\dot{x}_{1d} - f(x) - x_2) \tag{10}$$

To ensure the stability of the system (6), we search to ensure the negativity of the Lyapunov function V_1 (9), from which the error convergence to 0 (7). For this we define a positive constant K_1 such that:

$$\begin{aligned} \dot{V}_1 &= e_1(-K_1e_1 + K_1e_1 + \dot{x}_{1d} - f(x) - x_2) \\ \dot{V}_1 &= -K_1e_1^2 + e_1(K_1e_1 + \dot{x}_{1d} - f(x) - x_2) \end{aligned} \tag{11}$$

With $K_1 > 0$ is a constant design.

In order to ensure the stability of the system (11), a virtual control is defined as follows:

$$x_{2k} = K_1e_1 + \dot{x}_{1d} - f(x_1) \tag{12}$$

With x_{2k} is the error value of x_2.

The derivative is:

$$\dot{x}_{2k} = K_1\dot{e}_1 + \ddot{x}_{1d} - \dot{f}(x_1) \tag{13}$$

This implies:

$$\dot{V}_1 = -K_1e_1^2 \le 0 \tag{14}$$

3.1.3. Step 2:

Now the new desired reference variable will be the previous virtual control, it is a new regulation error e_2 defined by the following equation:

$$\begin{aligned} e_1 &= x_{2k} - x_2 = K_1e_1 + \dot{x}_{1d} - f(x_1) - x_2 \\ &= K_1e_1 + \dot{e}_1 \end{aligned} \tag{15}$$

Its derivative is:

$$\dot{e}_1 = \dot{x}_{2k} - \dot{x}_2 = K_1\dot{e}_1 + \ddot{x}_{1d} - \dot{f}(x_1) - \dot{x}_2 \tag{16}$$

With:

$u = \dot{x}_2$

So:

$$\dot{e}_2 = K_1\dot{e}_1 + \ddot{x}_{1d} - \dot{f}(x_1) - u \tag{17}$$

To take account of this error (15), the Lyapunov function V_2 is in the form:

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$$V_2 = \frac{1}{2}e_1^2 + \frac{1}{2}e_2^2 \qquad (18)$$

Its derivative is:

$$\begin{aligned} \dot{V}_2 &= e_1\dot{e}_1 + e_2\dot{e}_2 \\ &= e_1(e_2 - K_1e_1) + e_2(K_1\dot{e}_1 + \ddot{x}_{1d} - \dot{f}(x_1) - u) \\ &= e_1(e_2 - K_1e_1) + e_2(K_1(e_2 - K_1e_1) + \ddot{x}_{1d} - \dot{f}(x_1) - u) \\ &= -K_1e_1^2 + e_2(e_1 + K_1e_2 - K_1^2e_1 + \ddot{x}_{1d} - \dot{f}(x_1) - u) \end{aligned} \qquad (19)$$

To ensure the negativity of the Lyapunov function (18), it is necessary that the expression in brackets (19) be equal to K_2e_2 with $K_2>0$, in this case the command u is:

$$\begin{aligned} u &= K_2e_2 + e_1 + K_1e_2 - K_1^2e_1 + \ddot{x}_{1d} - \dot{f}(x_1) \\ &= e_2(K_1 + K_2) + e_1(1 - K_1^2) + \ddot{x}_{1d} - \dot{f}(x_1) \end{aligned} \qquad (20)$$

With $K_2 > 0$ is a constant design.

This ensures that the negative of the derivative of the Lyapunov function scope:

$$\dot{V}_2 = -K_1e_1^2 - K_2e_2^2 \le 0 \qquad (21)$$

The equation (18) is a Lyapunov function in the system (6), which proves the asymptotic stability to the origin.

The overall advantage of the Backstepping control is its flexibility, by a correct choice of the gains K_1 and K_2, the equation (19) gives a convergence error to zero and consequently the output of the system follows its reference.

In this part, the main idea of the Backstepping control is demonstrated by its application to the Double-fed Induction Machine consists in establishing a control law of the machine via a Lyapunov function selected. It has the advantage of being robust towards the parametric variations of the machine and a good continuation of the references. The association of Backstepping control and orientation of rotor flux gives the control of the machine, the good qualities of interesting robustness and consolidates the overall stability of the system.

The primary purpose of non-adaptive backstepping control is to regulate the speed of *DFIM* to its reference value Ω_{ref} irrespective of external disturbances. We suppose in this study that machine parameters are constant and known.

The general structure of the non-adaptive Backstepping control non-linear of the Double-fed Induction Machine (*DFIM*) in rotor flux oriented is detailed in the following sample:

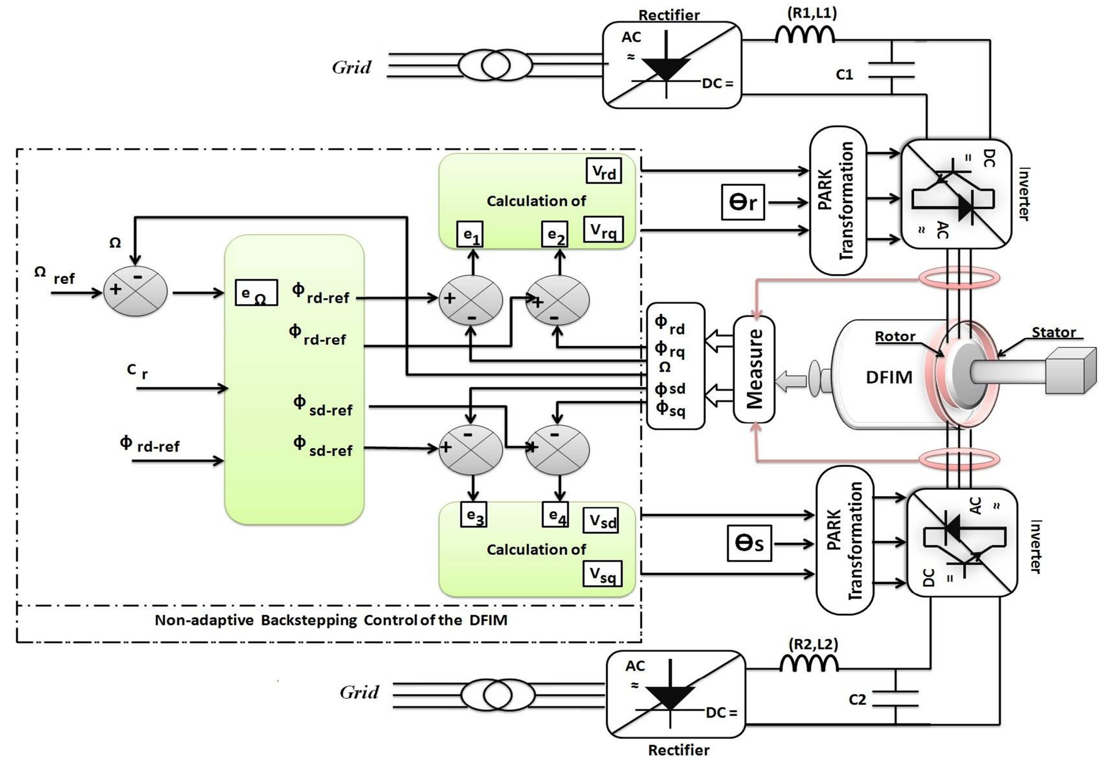

Figure 2: General structure of the non-adaptive Backstepping control the DFIM

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3.1 Backstepping control applied to DFIM

From the electrical equations (2) of the Doubly Fed Induction Machine, we can write the following expressions:

$$\frac{d\varphi_{rd}}{dt} = V_{rd} + \left(\frac{R_r.M}{\sigma.L_s.L_r}\right)\varphi_{sd} - \left(\frac{R_r}{\sigma.L_r}\right)\varphi_{rd} + \omega_r.\varphi_{rq}$$
$$\frac{d\varphi_{rq}}{dt} = V_{rq} + \left(\frac{R_r.M}{\sigma.L_s.L_r}\right)\varphi_{sq} - \left(\frac{R_r}{\sigma.L_r}\right)\varphi_{rq} - \omega_r.\varphi_{rd}$$
$$\frac{d\varphi_{sd}}{dt} = V_{sd} + \left(\frac{R_s.M}{\sigma.L_s.L_r}\right)\varphi_{rd} - \left(\frac{R_s}{\sigma.L_s}\right)\varphi_{sd} + \omega_s.\varphi_{sq}$$
$$\frac{d\varphi_{sq}}{dt} = V_{sq} + \left(\frac{R_s.M}{\sigma.L_s.L_r}\right)\varphi_{rq} - \left(\frac{R_s}{\sigma.L_s}\right)\varphi_{sq} - \omega_s.\varphi_{sqd}$$
(22)

With:

The flux φ_{rd}, φ_{rq}, φ_{sd} and φ_{sq} are the instantaneous Torque control.

It is obvious that the dynamic model (22) is highly non-linear due to the coupling between the velocity and magnetic flux.

For the study of stability, the system is characterized by:

$[X]=[\varphi_{rd} \quad \varphi_{rq} \quad \varphi_{sd} \quad \varphi_{sq} \quad \Omega]^T$: is the state vector (the flux and speed are measurable).

$[U]=[V_{rd} \quad V_{rq} \quad V_{sd} \quad V_{sq} \quad]^T$: is the control variable (voltage stator and rotor).

To find a Lyapunov function two steps are needed one for the control of speed and the other for the control of the Flux.

3.2 Backstepping Controller speed.

The first step of the Backstepping control is defined Lag error of the state variable by the following calculation:

$$e_\Omega = \Omega_{ref} - \Omega \qquad (23)$$

Its derivative gives:

$$\dot{e}_\Omega = \frac{de_\Omega}{dt} = \dot{\Omega}_{ref} - \dot{\Omega} \qquad (24)$$

With:

$$\dot{\Omega} = \left(\frac{P(1-\sigma)}{J.\sigma.M}\right)(\varphi_{rd}.\varphi_{sq} - \varphi_{rq}.\varphi_{sd}) - \frac{f}{J}\Omega - \frac{C_r}{J}$$
(25)

One finds:

$$\dot{e}_\Omega = \dot{\Omega}_{ref} - \left(\frac{P(1-\sigma)}{J.\sigma.M}\right)(\varphi_{rd}.\varphi_{sq} - \varphi_{rq}.\varphi_{sd}) - \frac{f}{J}\Omega - \frac{C_r}{J} \qquad (26)$$

With the application the principles of rotor flux orientation:

$$\begin{cases}\varphi_{sd} = 0 \\ \varphi_{rq} = 0\end{cases} \qquad (27)$$

It results in the following expression:

$$\dot{e}_\Omega = \dot{\Omega}_{ref} - \left(\frac{P(1-\sigma)}{J.\sigma.M}\right)(\varphi_{rd}.\varphi_{sq}) + \frac{f}{J}\Omega + \frac{C_r}{J} \qquad (28)$$

Subsequently we define the Lyapunov function of the form:

$$V_1 = \frac{1}{2}{e_\Omega}^2 \qquad (29)$$

Its derivative gives:

$$\dot{V}_1 = e_\Omega \dot{e}_\Omega$$
$$= e_\Omega(\dot{\Omega}_{ref} - \left(\frac{P(1-\sigma)}{J.\sigma.M}\right)(\varphi_{rd}.\varphi_{sq}) + \frac{f}{J}\Omega + \frac{C_r}{J}) \qquad (30)$$

Using the Backstepping design method, to ensure the stability of the sub system, for this we need to make equation (29) more negative, we consider the flux φ_{rd}, φ_{sq} as virtual inputs of our system (22) and define the following equations:

$$\begin{cases}\varphi_{rd\_ref} = \varphi_r \\ \varphi_{sq\_ref} = \dfrac{1}{\left(\dfrac{P(1-\sigma)}{J.\sigma.M}\right).\varphi_{rd\_ref}}\left(K_\Omega e_\Omega + \dfrac{f}{J}\Omega + \dfrac{C_r}{J}\right)\end{cases} \qquad (31)$$

With K_Ω this is a positive constant.

We substitute equation (30) in the derivative of the Lyapunov function equation V_1 (29) and assuming that Ω_{ref} is constant we have the negativity of the function as:

$$\dot{V}_1 = -K_\Omega {e_\Omega}^2 \le 0 \qquad (32)$$

Hence the asymptotic stability of the origin of the equation system (22)

3.3 Backstepping Controller flux

The objective of the section is the elimination of the flux regulators by calculation of the control voltages and for this we define the following errors:

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$$\begin{cases} e_1 = \varphi_{rd\_ref} - \varphi_{rd} \\ e_2 = \varphi_{rq\_ref} - \varphi_{rq} \\ e_3 = \varphi_{sd\_ref} - \varphi_{sd} \\ e_4 = \varphi_{sq\_ref} - \varphi_{sq} \end{cases} \quad (33)$$

With:

$$\begin{cases} \varphi_{rq\_ref} = 0 \\ \varphi_{sd\_ref} = 0 \\ \varphi_{rd\_ref} = \varphi_r \\ \varphi_{sq\_ref} = \varphi_s \end{cases} \quad (34)$$

The results of the derivative of equation (32) are

$$\begin{cases} \dot{e}_1 = \dot{\varphi}_r - V_{rd} - \left(\frac{R_r.M}{\sigma.L_s.L_r}\right)\varphi_{sd} + \left(\frac{R_r}{\sigma.L_r}\right)\varphi_{rd} - \omega_r.\varphi_{rq} \\ \dot{e}_2 = -V_{rq} - \left(\frac{R_r.M}{\sigma.L_s.L_r}\right)\varphi_{sq} + \left(\frac{R_r}{\sigma.L_r}\right)\varphi_{rq} + \omega_r.\varphi_{rd} \\ \dot{e}_3 = -V_{sd} - \left(\frac{R_s.M}{\sigma.L_s.L_r}\right)\varphi_{rd} + \left(\frac{R_s}{\sigma.L_s}\right)\varphi_{sd} - \omega_s.\varphi_{sq} \\ \dot{e}_4 = \dot{\varphi}_s - V_{sq} - \left(\frac{R_s.M}{\sigma.L_s.L_r}\right)\varphi_{rq} + \left(\frac{R_s}{\sigma.L_s}\right)\varphi_{sq} + \omega_s.\varphi_{sd} \end{cases} \quad (34)$$

The laws of real machine control are V_{sd}, V_{sq}, V_{rd} and V_{rq} appear in equation (33), then to analyze the stability of this system, we define a new Lyapunov final function V_2 is given by the following form:

$$V_2 = \frac{1}{2}\left(e_\Omega{}^2 + e_1{}^2 + e_2{}^2 + e_3{}^2 + e_3{}^2\right) \quad (35)$$

The result of the derivative of equation (34) is:

$$\begin{aligned} \dot{V}_2 \; = & -K_\Omega e_\Omega - K_1 e_1 - K_2 e_2 - K_3 e_3 - K_4 e_4 + \\ & e_\Omega\left(K_\Omega e_\Omega - \left(\frac{P(1-\sigma)}{J.\sigma.M}\right)(\varphi_r.\varphi_s) + \frac{f}{J}\Omega + \frac{C_r}{J}\right) + \\ & e_1\left(K_1 e_1 + \dot{\varphi}_r - V_{rd} - \left(\frac{R_r.M}{\sigma.L_s.L_r}\right)\varphi_{sd} + \left(\frac{R_r}{\sigma.L_r}\right)\varphi_{rd} - \omega_r.\varphi_{rq}\right) + \\ & e_2\left(K_2 e_2 - V_{rq} - \left(\frac{R_r.M}{\sigma.L_s.L_r}\right)\varphi_{sq} + \left(\frac{R_r}{\sigma.L_r}\right)\varphi_{rq} + \omega_r.\varphi_{rd}\right) + \\ & e_3\left(K_3 e_3 - V_{sd} - \left(\frac{R_s.M}{\sigma.L_s.L_r}\right)\varphi_{rd} + \left(\frac{R_s}{\sigma.L_s}\right)\varphi_{sd} - \omega_s.\varphi_{sq}\right) + \\ & e_4\left(K_4 e_4 + \dot{\varphi}_s - V_{sq} - \left(\frac{R_s.M}{\sigma.L_s.L_r}\right)\varphi_{rq} + \left(\frac{R_s}{\sigma.L_s}\right)\varphi_{sq} + \omega_s.\varphi_{sd}\right) \end{aligned} \quad (36)$$

With K_1, K_2, K_3 and K_4 are positive constants.
Extracted from equation (35) expressions the controls voltages V_{sd}, V_{sq}, V_{rq} and V_{rd} as following:

$$\begin{cases} V_{rd} \;=\; \left(K_1 e_1 + \dot{\varphi}_r - \left(\frac{R_r.M}{\sigma.L_s.L_r}\right)\varphi_{sd} + \left(\frac{R_r}{\sigma.L_r}\right)\varphi_{rd} - \omega_r.\varphi_{rq}\right) + \\ V_{rq} \;=\; e_2\left(K_2 e_2 - \left(\frac{R_r.M}{\sigma.L_s.L_r}\right)\varphi_{sq} + \left(\frac{R_r}{\sigma.L_r}\right)\varphi_{rq} + \omega_r.\varphi_{rd}\right) + \\ V_{sd} \;=\; e_3\left(K_3 e_3 - \left(\frac{R_s.M}{\sigma.L_s.L_r}\right)\varphi_{rd} + \left(\frac{R_s}{\sigma.L_s}\right)\varphi_{sd} - \omega_s.\varphi_{sq}\right) + \\ V_{sq} \;=\; e_4\left(K_4 e_4 + \dot{\varphi}_s - \left(\frac{R_s.M}{\sigma.L_s.L_r}\right)\varphi_{rq} + \left(\frac{R_s}{\sigma.L_s}\right)\varphi_{sq} + \omega_s.\varphi_{sd}\right) \end{cases} \quad (37)$$

This equation (36) implies the negativity of the following Lyapunov function V_2:

$$V_2 \;= -K_\Omega e_\Omega - K_1 e_1 - K_2 e_2 - K_3 e_3 - K_4 e_4 \le 0 \quad (38)$$

4. SIMULATION AND TEST PERFORMANCE & DISCUSSION

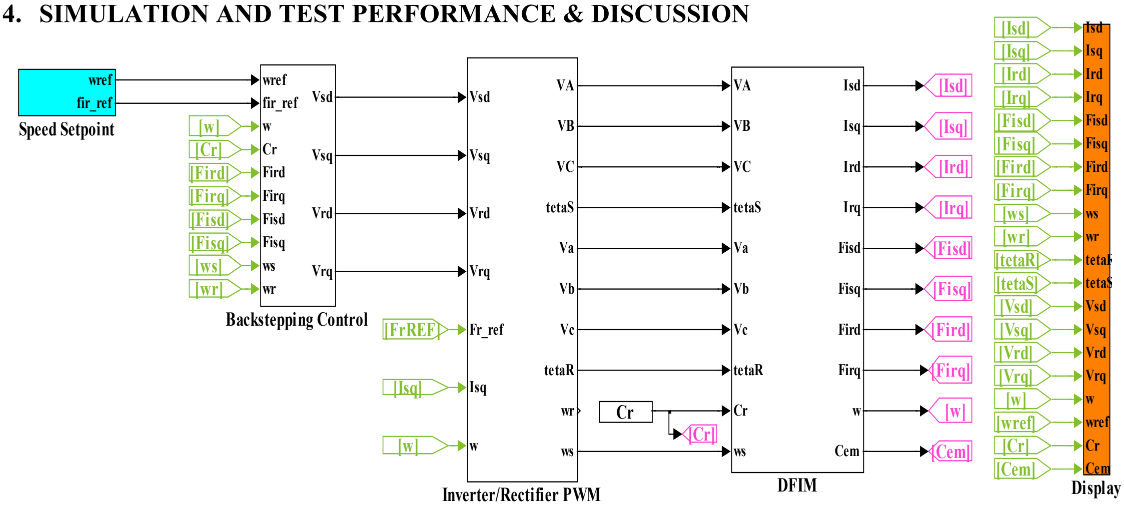

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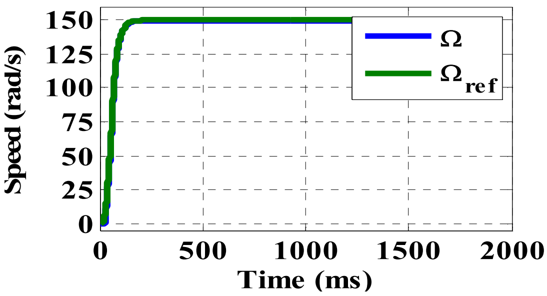
Figure 3: Simulation scheme of the non-adaptive Backstepping Control on Matlab & Simulink environment

To verify the performance and the asymptotic stability of the non-adaptive Backstepping control, The DFIM is object to the tests of robustness for varying conditions of functioning at a nominal charge, rated speed, variation in speed, machine parameters and load change. We implemented the system in Matlab / Simulink environment according to the scheme following principle (Fig.3).

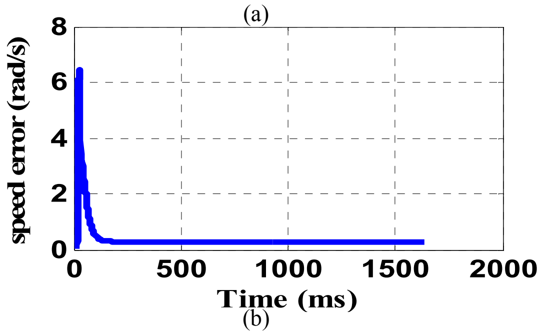
The values of the gains of the non-adaptive Backstepping control are selected after several tests adjustment (K_{Ω}=550; K_1=700; K_2=500; K_3= 800; K_4= 900). The different results of simulation tests obtained are subsequently exposed.

4.1 Followed of the trajectory with constant speed

The study makes for a constant speed Ω_{ref}=150rad/s to 0s, φ_{rd_ref}=10wb and C_r = 0N.m. the following figures (4, 5, 6) show the performance of the control input and output linearization.

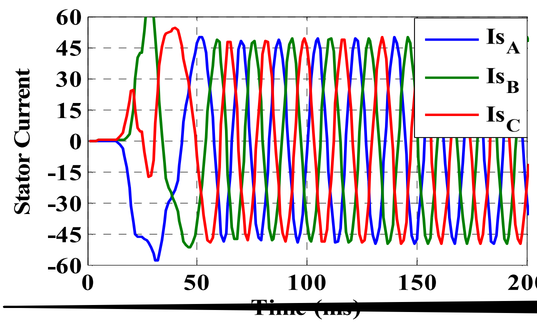


(a)

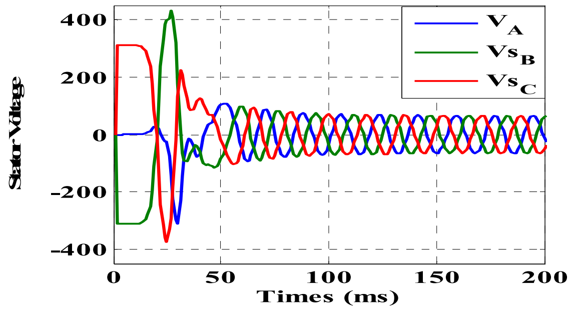


(b)

Figure 4: (a) Speed of Rotation; (b) Speed error.

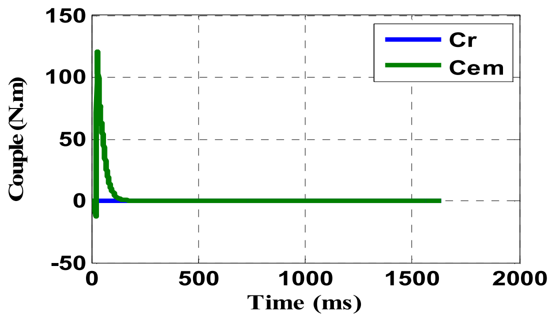


(a)

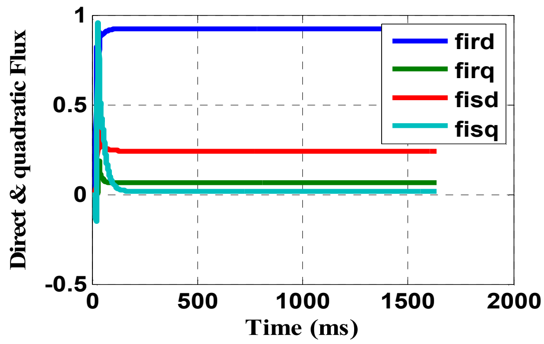


(b)

Figure 5: (a) Stator Current; (b) Stator Voltage



(a)



(b)

Figure 6: (a) Torque; (b) Direct and quadratic Flux

The results obtained by the application of non-adaptive Backstepping control of the DFIM show excellent performance and good pursuit speed to its reference.

The good decoupling between the flux and Torque is maintained, the flux is similar to the nominal case. Voltages and currents present variations according to regime change, the static error rapidly converging to zero for this study profile.

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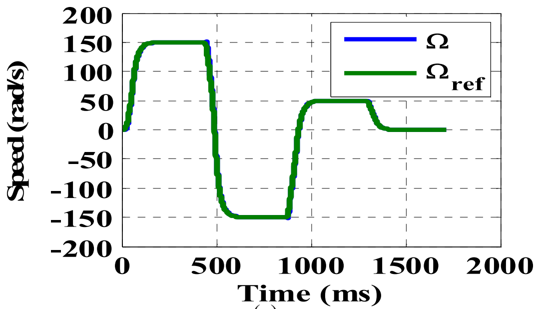
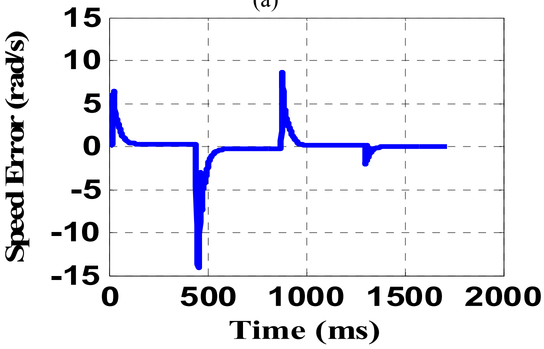
4.2 Followed by the trajectory with variable speed and a change of rotation direction

In figures (7, 8, 9) following, the Flux is constant (φ_{rd_ref}=10wb) and null load Torque (C_r=0N.m), the *DFIM* accelerated to the nominal speed (150rad/s), Then, the machine decelerates and the direction of rotation is reversed *(-150rad/s)*, after a moment the machine is accelerated again but at a low speed (*50 rad/s*).

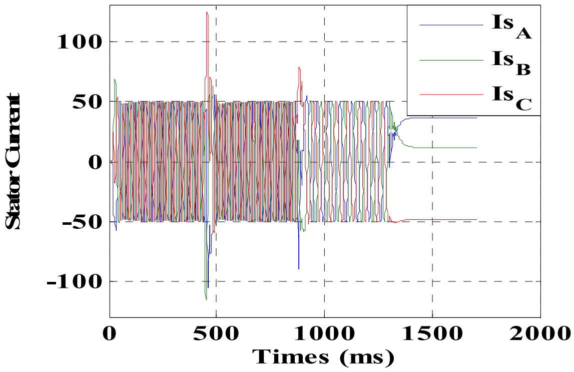


(a)

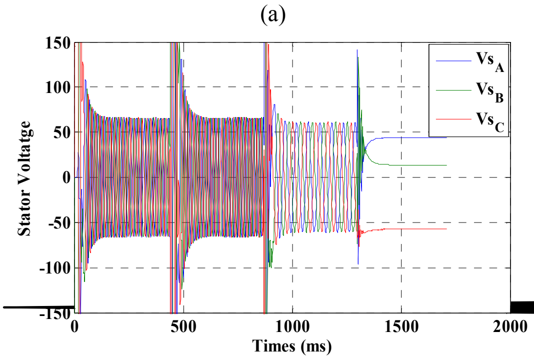


(b)

Figure 7: (a) Speed of Rotation; (b) Spped error.

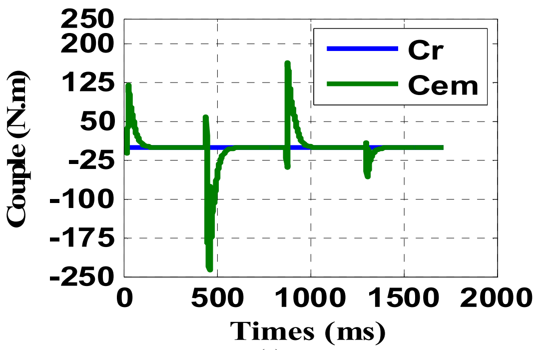


(a)

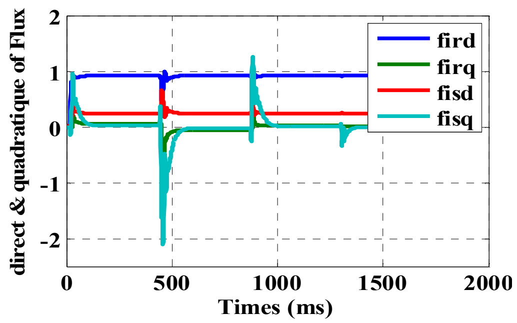


(b)

Figure 8: (a) Stator Current; (b) Stator Voltage



(a)



(b)

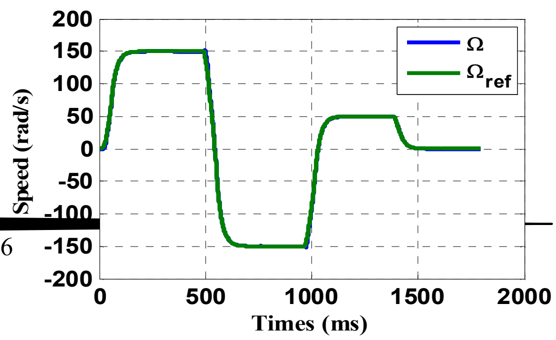
Figure 9: (a) Torque; (b) Direct and quadratic Flux

In this part of the profit studies are perfect, the modules of voltages and currents are constant, observed speed almost perfectly follows its reference.

The flux and Torque are constant modules, decoupling between the flux and the Torque is quite good.

4.3 Followed by the trajectory with a variation of the nominal load

In the same preceding conditions, the machine runs to a nominal variable speed, initially without load, at time *t = 0.7s* is applied to the machine a nominal load C_r*=20N.m*, then the Torque load demined to C_r*=5N.m* at time *t = 1.5s*.



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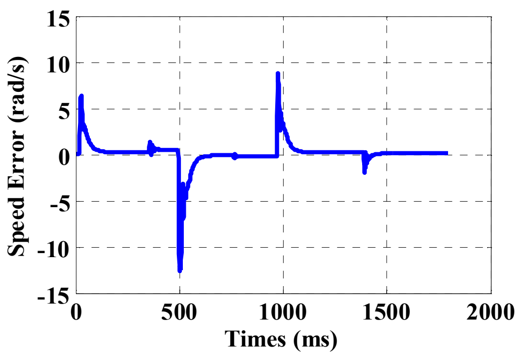
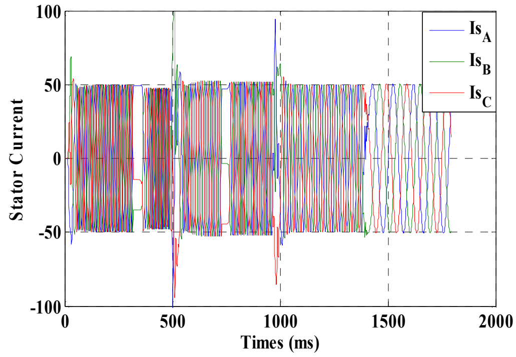
(a)

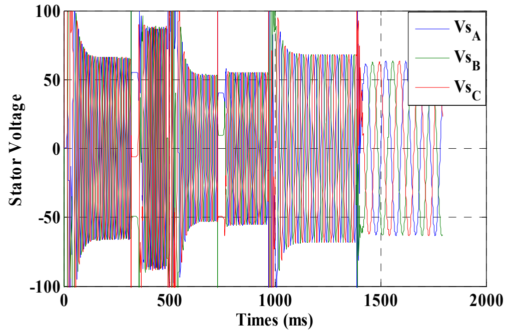


(b)

Figure 10: (a) Speed of Rotation; (b) Spped error.

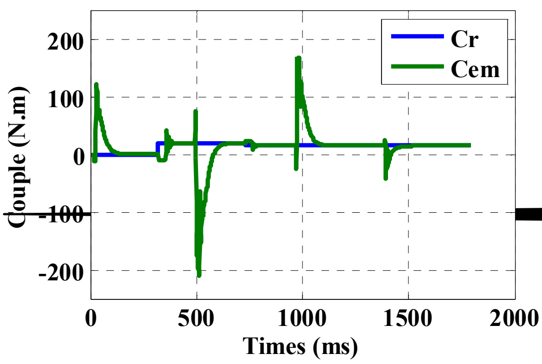


(a)

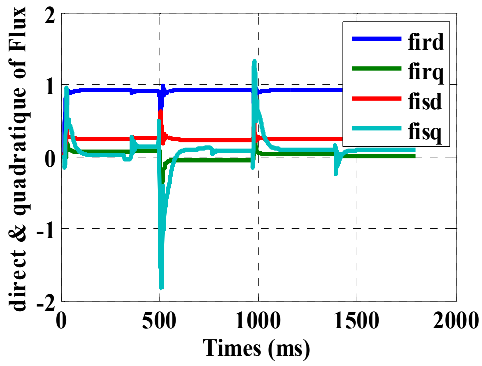


(b)

Figure 11: (a) Stator Current; (b) Stator Voltage



(a)



(b)

Figure 12: (a) Torque; (b) Direct and quadratic Flux

The simulation results show a good function of the machine in spite of the variation of the load, the voltage and the stator current experience an increase proportionally to that of the machine load, the speed and the Torque have a good track their set point, the decoupling of Torque and flux is always achieved.

We also note that the orientation of the rotor flux is perfectly realized and verified. This shows the perfect adaptation of the Backstepping control to the orientation of the rotor flux. In order to test the robustness of the controller, the electrical and the mechanical parameters are varied in the non-adaptive controller.

Indeed, the values of the resistor, the inductance changes are some percentages of the nominal value.

5. CONCLUSION

The aim of this work is devoted to modeling, development and simulation of non- adaptive Backstepping control for double-fed Induction Machine, connected directly to voltage converter PWM.

In the following, we highlight the improvement made by the non-adaptive Backstepping control on the dynamic performance of DFIM.

The originality of our work is to combine the simulation experiments of different control algorithms to define a control structure realizing the best value simplicity and performance.

Finally, we believe that the proposed solutions will improve the tracking performance of the trajectory and disturbance rejection load Torque

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and parameter variations and also enhance stability through the robust look of the non-adaptive Backstepping control. The disadvantage of this control is that it is unable to eliminate the non-zero errors.

ANNEXE

Table 1: DFIM parameters used in simulation

Stator resistance	Rs=1.2 mΩ
Rotor resistance	Rr=1.8 mΩ
Stator inductance	Ls = 0.1554 mH
Rotor inductance	Lr = 0.1554 mH
mutual inductance	M=0.15
Inertia moment	J=0.07 Kg.m2
Coefficient of viscous friction	f=0.001
Number of pairs of poles	P=2

REFERENCES

[1] Y.Y. Tzou, H.J. Hsu: "FPGA Realization of Space-Vector PWM Control IC for Three Phase PWM Inverters," IEEE Trans, Power Electron., vol.12, n°6, pp.953-963, nov.1997.

[2] Melicio, R; Mendes, VMF; Catalao, JPS "Modeling, Control and Simulation of Full-Power Converter Wind Turbines Equipped with Permanent Magnet Synchronous Generator" vol 5 (issue 2) pg 397-408 Mar - Apr 2010.

[3] B.Bossoufi, M.Karim, A.Lagrioui, M.Taoussi, A.Derouich "Modeling and Backstepping Control of DFIG Generators for Wide-Range Variable-speed Wind Turbines" *Journal of Journal of Electrical Systems JES,* pp317-330. Vol.10 No.3, September 2014.

[4] B.Bossoufi, M.Karim, A.Lagrioui, M.Taoussi, M.L.EL Hafyani "Backstepping control of DFIG Generators for Wide-Range Variable-Speed Wind Turbines " *IJAAC International Journal of Automation and Control* , pp 122-140, Vol.8 No.2, July 2014.

[5] B.Bossoufi, M.Karim, A.Lagrioui, M.Taoussi, "FPGA-Based Implementation nonlinear backstepping control of a PMSM Drive"*IJPEDS International Journal of Power Electronics and Drive System,* pp 12-23 Vol.4 No.1, March 2014.

[6] B.Bossoufi, M.Karim, A.Lagrioui, "Matlab & Simulink Simulation with FPGA-Based Implementation adaptative and not adaptative Backstepping nonlinear Control of a Permanent Magnet Synchronous Machine Drive" *WSEAS TRANSACTIONS on SYSTEMS and CONTROL*, pp86-100, Vol.9 No.1, February 2014.

[7] B.Bossoufi, M.Karim, S.Ionita, A.Lagrioui, "Nonlinear Non Adaptive Backstepping with Sliding-Mode Torque Control Approach for PMSM Motor" *Journal of Journal of Electrical Systems JES,* pp236-248. Vol.8 No.2, June 2012.

[8] B.Bossoufi, M.Karim, S.Ionita, A.Lagrioui, "Low-Speed Sensorless Control of PMSM Motor drive Using a NONLINEAR Approach BACKSTEPPING Control: FPGA-Based Implementation" *Journal of Theoretical and Applied Information Technology JATIT*, pp154-166, Vol. 36 No.1, 29th February 2012.

[9] B.Bossoufi, M.Karim, S.Ionita, A.Lagrioui, "DTC CONTROL BASED ARTIFICIAL NEURAL NETWORK FOR HIGH PERFORMANCE PMSM DRIVE" *Journal of Theoretical and Applied Information Technology JATIT*, pp165-176, Vol. 33 No.2, 30th November 2011.

[10] B.Bossoufi, M.Karim, S.Ionita, A.Lagrioui, "The Optimal Direct Torque Control of a PMSM drive: FPGA-Based Implementation with Matlab & Simulink Simulation" *Journal of Theoretical and Applied Information Technology JATIT*, pp63-72, Vol. 28 No.2, 30th June 2011.

[11] J. J. Chen and K. P. Chin, "Automatic flux-weakening control of permanent magnet synchronous motors using a reduced-order controller," IEEE Trans. Power Electron., vol. 15, pp. 881-890, Sept. 2000.

[12] M. Rodic, K. Jezernik, "Speed Sensoless Sliding Mode Torque Control of Induction Motor ", *IEEE Trans on. Industrial Electronics,* February 2002.

[13] Hisn-Jang Shieh and Kuo-Kai Shyu, "Non Linear Sliding Mode Torque Control With Adaptive Backstepping Approach For Induction Motor Drive", *IEEE Transactions on Industrial Electronics*, Vol. 46, N° 2, April 1999, pp. 380-388.

[14] Z. P. Jiang and H. Nijmeijer, "Tracking control of mobile robots: A case study in Backstepping," *Automatica*, vol. 33, no. 7, pp. 1393–1399, Jul. 1997.

[15] T. C. Lee, K. T. Song, C. H. Lee, and C. C. Teng, "Tracking control of unicycle-modeled mobile robots using a saturation feedback controller," *IEEE Trans. Control Syst. Technol.*, vol. 9, no. 2, pp. 305–318, Mar. 2001.

[16] T. H. Li, S. J. Chang, and Y. X. Chen, "Implementation of humanlike driving skills by autonomous fuzzy behavior control on an FPGA based car-like mobile robot," *IEEE*

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Trans. Ind. Electron., vol. 50, no. 5, pp. 867–880, Oct. 2003.

[17] S. S. Solano, A. J. Cabrera, I. Baturone, F. J. Moreno-Velo, and M. Brox, "FPGA implementation of embedded fuzzy controllers for robotic applications," *IEEE Trans. Ind. Electron.*, vol. 54, no. 4, pp. 1937– 1945, Aug. 2007.

[18] Y. F. Chan, M. Moallem, and W. Wang, "Design and implementation of modular FPGA-based PID controllers," *IEEE Trans. Ind. Electron.*, vol. 54, no. 4, pp. 1898–1906, Aug. 2007.

[19] S. H. Han, M. H. Lee, and R. R. Mohler, "Real-time implementation of a robust adaptive controller for a robotic manipulator based on digital signal processors," *IEEE Trans. Syst., Man, Cybern. A, Syst., Humans*, vol. 29, no. 2, pp. 194–204, Mar. 1999.

[20] D. Zhang and H. Li, "A stochastic-based FPGA controller for an induction motor drive with integrated neural network algorithms," *IEEE Trans. Ind. Electron.*, vol. 55, no. 2, pp. 551–561, Feb. 2008.

[21] C. F. Jung and C. H. Hsu, "Temperature control by chip implemented adaptive recurrent fuzzy controller designed by evolutionary algorithm," *IEEE Trans. Circuits Syst. I, Reg. Papers*, vol. 52, no. 11, pp. 2376–2384, Nov. 2005.

[22] C. F. Jung and J. S. Chen, "Water bath temperature control by a recurrent fuzzy controller and its FPGA implementation," *IEEE Trans. Ind. Electron.*, vol. 53, no. 3, pp. 941–949, Jun. 2006.