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Optimized Torque Control via Backstepping Using Genetic Algorithm of Induction Motor

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Original scientific paper

This paper proposes a novel hybrid control of induction motor, based on the combination of the direct torque control DTC and the backstepping one, optimized by Genetic Algorithm (GA). First the basic evolution of DTC is explained, where the torque and stator flux are controlled by non linear hysteresis controllers which cause large ripple in motor torque at steady state operation. A Backstepping control is applied to overcome these problems, however the used parameters are often chosen arbitrarily, which may affect the controller quality. To find the best parameters, an optimization technique based on genetic algorithm is used. Also, in order to obtain accurate information about stator flux, torque and load torque, open loops estimators are used for this Backstepping control. At last, experimental results are presented in order to prove the efficiency of the above mentioned control technique.

Key words: induction motor, backstepping control, DTC, genetic algorithms

Optimizirano povratnokoračno upravljanje momentom indukcijskog motora korištenjem genetičkog algoritma. U ovom radu predstavljena je nova metoda hibridnog upravljanja indukcijskim motorom, bazirana na kombinaciji direktnog upravljanja momentom (DCT) i povratnokoračnog upravljanja, te optimizirana korištenjem genetičkog algoritma (GA). Prvo je objašnjena osnova razvoja DCT-a, gdje se momentom i tokom statora upravlja nelinearnim histereznim regulatorima što uzrokuje velike propade u momentu motora tijekom ravnotežnog rada. Povratnokoračno upravljanje se primjenjuje kako bi se uklonio ovaj problem, međutim korišteni parametri su najčešće proizvoljno odabrani što može utjecati na kvalitetu upravljanja. Kako bi se našli najbolji parametri koristi se tehnika optimizacije zasnovana na genetičkom algoritmu. Također kako bi se dobili točni podaci o toku statora, momentu i momentu opterećenja potrebni za povratnokoračno upravljanje koriste se estimatori u otvorenoj petlji. Na kraju su prikazani eksperimentalni rezultati kako bi se dokazala efikasnost navedene metode upravljanja.

Ključne riječi: indukcijski motor, povratnokoračno upravljanje, DTC, genetički algoritmi

1 INTRODUCTION

The torque control of induction motors was developed and presented by Takahashi as direct torque control (DTC) [1]. As demonstrated, both torque and flux of direct torque control based drive, are controlled in the manner of closed-loop system. More recently, several variations and improvements have been made for this control [2-6], which is based on non-linear hysteresis controller used in both torque and flux control loops. Since the beginning, this technique was characterized by simplicity, good performance and robustness. Also, it is possible to obtain a good dynamic control of the torque without any mechanical transducers on the machine shaft. On the other hand, it is well known that DTC presents some disadvantages; including difficulty to control torque and flux at very low speed, high current and torque ripple and high noise level at low speed. To overcome this problem, we propose a backstepping approach instead of the non-linear hysteresis controller. This technique presents very good position tracking response as well as rejection to load disturbance and is capable of keeping almost all the robustness properties [7-10]. It is important in such controller design, to have a good valuation of the used parameters that have to be optimized through an efficient method. In this case, genetic algorithms seem to be suitable as optimizing technique in order to generate the appropriate parameters. Fogel in [11] proposed an introduction to simulated evolutionary optimization. He stated that simulating the process of natural evolution on a computer results in stochastic optimization techniques that can often outperform classical methods of optimization when applied to difficult real-world problems. Some works have already showed the efficiency of such techniques to give best results for the optimum parameters [12-18].

This paper presents a design of a novel approach that combines direct torque control principle and backstepping design, as a contribution for induction motor control. So, this work will be divided into four parts. After given the principle of direct torque control in the first part, we will present in the second one the induction machine model and the Backstepping control. The optimization of the backstepping control parameters by GA is presented in the third part. The next part deals with the derivation of the stator flux, the torque and the load torque estimators. Finally, experimental tests are given to show the effectiveness of the proposed method.

2 DIRECT TORQUE CONTROL

Figure 1. shows the block diagram of the classical DTC of the induction motor drives. The control system consists of two parallel loops for direct torque and stator flux control and an outer loop for the linear control of the rotor angular velocity. Both torque and stator flux, are controlled by hysteresis controllers, which have the function to compare the torque reference with actual torque and the flux reference with actual one.

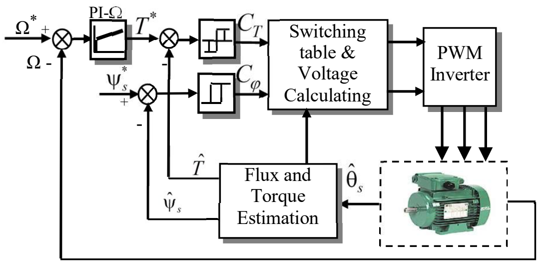

Figure 1. Direct torque control of induction motor.

Fig. 1. Direct torque control of induction motor.

It is well known that the three phase inverter can produce eight output states, which represent eight space vectors. Six are of equal magnitude and arranged 60° apart in space diagram, and two vectors are null as shown in Figure 2.

The selection of the appropriate voltage vector is based on a functional block labelled switching table given by table 1, that generates binary signals applied to the inverter branches. The input quantities are the stator flux sector and the outputs of the two hysteresis comparators, when the outputs are the voltage vectors.

In the direct torque control, the motor torque has large ripple due to the existing torque and stator flux hysteresis [4]. To reduce the effect of hysteresis, we have omitted the comparator from the DTC, and then we have replaced it by using the Backstepping approach.

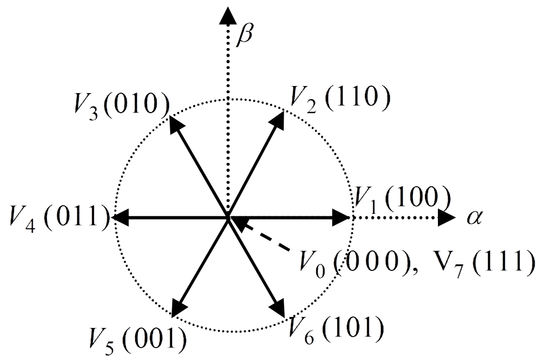

Fig. 2. Voltage vectors used in DTC.

Table 1. Control strategy with hysteresis comparators

Sector		N=1	N=2	N=3	N=4	N=5	N=6
$C_\varphi = 0$	$C_T = 1$	V_3	V_4	V_5	V_6	V_1	V_2
	$C_T = 0$	V_4	V_5	V_6	V_1	V_2	V_3
	$C_T = -1$	V_5	V_6	V_1	V_2	V_3	V_4
$C_\varphi = 1$	$C_T = 1$	V_2	V_3	V_4	V_5	V_6	V_1
	$C_T = 0$	V_1	V_2	V_3	V_4	V_5	V_6
	$C_T = -1$	V_6	V_1	V_2	V_3	V_4	V_5

3 BACKSTEPPING CONTROL DESIGN

3.1 Induction Motor Model

The induction motor model expressed in α-β stationary reference frame is given by:

$$\begin{cases} \frac{d\Omega}{dt} = \frac{p}{J}(\varphi_{s\alpha} i_{s\beta} - \varphi_{s\beta} i_{s\alpha}) - \frac{T_L}{J} \\ \frac{d\varphi_{s\alpha}}{dt} = -R_s i_{s\alpha} + V_{s\alpha} \\ \frac{d\varphi_{s\beta}}{dt} = -R_s i_{s\beta} + V_{s\beta} \\ \frac{di_{s\alpha}}{dt} = \lambda\varphi_{s\alpha} + p\Omega\gamma\varphi_{s\beta} + \delta i_{s\alpha} - p\Omega i_{s\beta} + \gamma V_{s\alpha} \\ \frac{di_{s\beta}}{dt} = \lambda\varphi_{s\beta} - p\Omega\gamma\varphi_{s\alpha} + \delta i_{s\beta} + p\Omega i_{s\alpha} + \gamma V_{s\beta} \end{cases} \tag{1}$$

Where

$$\lambda = \frac{1}{T_r L_s \sigma},\ \delta = -\frac{1}{\sigma}\left(\frac{1}{T_s} + \frac{1}{T_r}\right),\ \gamma = \frac{1}{L_s \sigma}, \sigma = 1 - \frac{M^2}{L_s L_r}$$

$V_s = (V_{s\alpha},\ V_{s\beta})$ and $i_s = (i_{s\alpha},\ i_{s\beta})$ indicate the stator voltage and stator current, expressed respectively by their $(\alpha,\ \beta)$ orthogonal components. p is the pole pair number, σ is the total leakage factor; $R_s$and R_r are the stator and rotor resistances, L_s, L_r and M denote respectively stator, rotor and mutual inductances. T_s and T_r are stator and rotor time constants. Whereas, Ω is the mechanical frequency of the electrical rotor speed and T_L is the load torque.

To have a control similar to the DTC, the novel approach of Backstepping design is presented to control the rotor speed Ω, the torque T and the stator flux φ_s. We consider the proposed new state variables as follows:

$$\begin{cases} x_1 = \Omega \\ x_2 = p(\varphi_{s\alpha} i_{s\beta} - \varphi_{s\beta} i_{s\alpha}) \\ x_3 = \varphi_s^2 = \varphi_{s\alpha}^2 + \varphi_{s\beta}^2 \end{cases} \tag{2}$$

Their derivatives are:

$$\begin{cases} \dot{x}_1 = \frac{1}{J} x_2 - \frac{T_L}{J} \\ \dot{x}_2 = p(\varphi_{s\alpha} \frac{di_{s\beta}}{dt} + i_{s\beta} \frac{d\varphi_{s\alpha}}{dt} - \varphi_{s\beta} \frac{di_{s\alpha}}{dt} - i_{s\alpha} \frac{d\varphi_{s\beta}}{dt}) \\ \dot{x}_3 = 2(\varphi_{s\alpha} \frac{d\varphi_{s\alpha}}{dt} + \varphi_{s\beta} \frac{d\varphi_{s\beta}}{dt}) \end{cases} \tag{3}$$

From (1), the derivative of the model (3) is obtained as following.

$$\begin{cases} \dot{x}_1 = \frac{1}{J} x_2 - \frac{T_L}{J} \\ \dot{x}_2 = pU_T + Q_1 \\ \dot{x}_3 = 2U_\varphi - 2R_s Q_2 \end{cases} \tag{4}$$

Where Q_1 and Q_2 are non linear functions given by:

$$\begin{cases} Q_1 = \delta x_2 - p^2 \gamma x_1 x_3 + p x_1 Q_2 \\ Q_2 = \varphi_{s\alpha} i_{s\alpha} + \varphi_{s\beta} i_{s\beta} \end{cases} \tag{5}$$

The torque variable x_2 is controlled by the torque control U_T and the square of the flux x_3 is controlled by the flux control U_φ, given by:

$$\begin{bmatrix} U_T \\ U_\varphi \end{bmatrix} = \begin{bmatrix} (i_{s\beta} - \gamma\varphi_{s\beta}) & -(i_{s\alpha} - \gamma\varphi_{s\alpha}) \\ \varphi_{s\alpha} & \varphi_{s\beta} \end{bmatrix} \begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} \tag{6}$$

Our object is to find the expression of the control $[U_T \; U_\varphi]^t$ that stabilizes the state variables of the motor according to the desired references.

3.2 Backstepping Control

The Backstepping design procedure consists of two steps. The first one is to identify the error e_1 which represents the difference between the actual speed (x_1) and its reference (x_{1ref}) in order to generate the reference torque, while changing the PI speed controller in a conventional DTC by a reference calculator, based on the Lyapunov theory.

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

From (4), the error dynamic is given by

$$\dot{e}_1 = \dot{x}_{1ref} - \frac{1}{J} x_2 + \frac{T_L}{J} \tag{8}$$

The first Lyapunov function V_1 is introduced by:

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

Differentiating (9), we obtain:

$$\dot{V}_1 = e_1 \dot{e}_1 = e_1 (\dot{x}_{1ref} - \frac{1}{J} x_2 + \frac{T_L}{J}) \tag{10}$$

To have a convergence of the error e_1 towards zero, it is necessary that the Lyapunov function derivative $\dot{V}_1$ is negative, which will allow the following choice.

$$\dot{e}_1 = -k_\Omega e_1 = \dot{x}_{1ref} - \frac{1}{J} x_2 + \frac{T_L}{J} \tag{11}$$

Where k_Ω is positive constant that determine the closed loop dynamic. Therefore, taking the derivative of V_1 we obtain:

$$\dot{V}_1 = -k_\Omega e_1^2 \; < \; 0 \tag{12}$$

Thus, the tracking objectives will be satisfied if we choose the torque x_2 as a virtual control noted by x_{2ref}.

$$x_{2ref} = J k_\Omega e_1 + T_L + J \dot{x}_{1ref} \tag{13}$$

The second step is done to generate control torque and control flux $(U_{T,} U_\varphi)$ by using Lyapunov function to replace the hysteresis controllers. It is to identify the errors $e_{2,}$ and e_3 which represent respectively the errors between the torque and his virtual control (x_{2ref}) and the stator flux and his reference (x_{3ref} is constant).

$$\begin{cases} e_2 = x_{2ref} - x_2 \\ e_3 = x_{3ref} - x_3 \end{cases} \tag{14}$$

Whereas in the first equation of (14), (11) can be expressed as:

$$\dot{e}_1 = -k_\Omega e_1 + \frac{1}{J} e_2 \tag{15}$$

From equations (4) and (14), the errors dynamics are given by:

$$\begin{bmatrix} \dot{e}_2 \\ \dot{e}_3 \end{bmatrix} = \begin{bmatrix} \dot{x}_{2ref} - Q_1 \\ \dot{x}_{3ref} + 2R_s Q_2 \end{bmatrix} + \begin{bmatrix} -p & 0 \\ 0 & -2 \end{bmatrix} \begin{bmatrix} U_T \\ U_\varphi \end{bmatrix} \tag{16}$$

In the errors dynamics expressions (16), the actual control inputs $(U_{T,} U_\varphi)$ have appeared and will be calculated. Stability analysis is done by the following Lyapunov function candidate:

$$V_2 = \frac{1}{2} e_1^2 + \frac{1}{2} e_2^2 + \frac{1}{2} e_3^2 \tag{17}$$

By using (15), the derivative of the Lyapunov function is given by:

$$\dot{V}_2 = -k_\Omega e_1^2 + e_2 (\frac{1}{J} e_1 + \dot{e}_2) + e_3 \dot{e}_3 \tag{18}$$

To have a negative derivative of the Lyapunov function, we choose:

$$\begin{matrix} \dot{e}_2 = -k_T e_2 - \frac{1}{J} e_1 \\ \dot{e}_3 = -k_\varphi e_3 \end{matrix} \tag{19}$$

With $k_T > 0$ and $k_\varphi > 0$

To ensure that $\dot{V}_2 < 0$ ÿ, we must choose U_T and U_φ as follows:

$$\begin{bmatrix} U_T \\ U_\varphi \end{bmatrix} = \begin{bmatrix} \frac{1}{p}(\dot{x}_{2ref} + \frac{e_1}{J} + k_T e_2 - Q_1) \\ \frac{1}{2}(k_\varphi e_3 + \dot{x}_{3ref}) + R_s Q_2) \end{bmatrix} \tag{20}$$

This reflects the overall stability of the system and a good convergence of the speed, torque and stator flux towards their desired values. From the control torque U_T and control stator flux $U_\varphi$which are expressed by (20), and according to (6), we can have the stator voltages $V_{s\alpha}$ and $V_{s\beta}$ as following:

$$\begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} = \frac{1}{Q_2 - \gamma\varphi_s^2} \begin{bmatrix} \varphi_{s\beta} & (i_{s\alpha} - \gamma\varphi_{s\alpha}) \\ -\varphi_{s\alpha} & (i_{s\beta} - \gamma\varphi_{s\beta}) \end{bmatrix} \begin{bmatrix} U_T \\ U_\varphi \end{bmatrix} \tag{21}$$

Then, the derivative of the second Lyapunov function will be negative.

$$\dot{V}_2 = -(k_\Omega e_1^2 + k_T e_2^2 + k_\varphi e_3^2) \leq -(k_\Omega e_1^2) \tag{22}$$

This equation guarantees the asymptotically convergence of speed, torque and flux errors, given by:

$\lim\limits_{t\to\infty} e_1 = 0$, $\lim\limits_{t\to\infty} e_2 = 0$ and $\lim\limits_{t\to\infty} e_3 = 0$

4 OPTIMIZED BACKSTEPPING CONTROL BY GENETIC ALGORITHMS

The major problem of the Backstepping control is the choice of the gains $\begin{bmatrix} k_\Omega & k_T & k_\varphi \end{bmatrix}$. To resolve this problem, it seems necessary to appeal to stochastic techniques of optimization. So, we proposed here a genetic algorithm applied to the discrete model of the dynamical errors equations of the system. To show eigenvalues of all states, we can rearrange the dynamical equations from (15) and (19) as:

$$\begin{bmatrix} \dot{e}_1 \\ \dot{e}_2 \\ \dot{e}_3 \end{bmatrix} = A \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} -k_\Omega & \frac{1}{J} & 0 \\ -\frac{1}{J} & -k_T & 0 \\ 0 & 0 & -k_\varphi \end{bmatrix} \times \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} \tag{23}$$

Where A can be shown to be Hurwitz and which proves the eigenvalues of all the states.

The discrete model of the dynamical errors is given by:

$$\begin{aligned} e(k+1) &= (1 + T_e A + \tfrac{1}{2} T_e^2 A^2)\ e(k) \\ &= \begin{bmatrix} A_\Omega & B_{\Omega T} & 0 \\ -B_{\Omega T} & A_T & 0 \\ 0 & 0 & A_\psi \end{bmatrix} \begin{bmatrix} e_1(k) \\ e_2(k) \\ e_3(k) \end{bmatrix} \end{aligned} \tag{24}$$

with T_e is the sampling time.

$$\begin{aligned} &A_i = 1 - T_e k_i + \tfrac{T_e^2}{2}(k_i^2 - \tfrac{1}{J^2}),\ i = \Omega\ or\ T \\ &A_\psi = 1 - T_e k_\psi + \tfrac{T_e^2}{2} k_\psi^2 \\ &B_{\Omega T} = \tfrac{T_e}{J} - \tfrac{T_e^2}{2}(\tfrac{k_\Omega + k_T)}{J} \end{aligned} \tag{25}$$

A Genetic algorithm (GA) was proposed at first by Holland [12], in which he described it as a control structure with which representations, and operations on these representations could be managed in order to evolve representations that were well adapted to the concerned problem. Given certain conditions, the mentioned method would tend to converge on solutions that were globally optimal or nearly so, even applied to difficult problems optimized in large and complicated search spaces. The GA starts with an initial population of individuals, which is a set of randomly generated solutions also called chromosomes. Genetic operators (crossover and mutation) are then applied to this population in an attempt to improve the quality of the solutions by the evaluation of the search progress based on the fitness function alone. After the reproduction operations, the new generation is constituted through the replacement procedure. The usual replacement methods consist in maintaining a given percentage of the best individuals, of the current population in the following one. Although genetic algorithms were primarily used for adaptive search and adaptive system design, they became in recent years an important tool to resolve optimization problems.

However, due to the computational cost of the standard GAs based on binary representation, the real representation approach has taken a significant place in the real optimization problems. In this kind of representation the genotype space is identified to the phenotype space, and so the operators applied to such problems are all continuous. So the real-coded GAs were suggested and have proved that the algorithm gains better performance with such representation [12].

The crossover is the key of the GA's power by exchanging genetic material from two parent chromosomes allowing beneficial genes on different parents to be combined in their offspring [15]. The discrete crossover was used for the parameters $\begin{bmatrix} k_\Omega & k_T & k_\varphi \end{bmatrix}$ and is given by:

$$\forall i \in \{1, ..., n\}\,,\ x_i^{'} = x_i^{(S)}\ or\ x_i^{(T)} \tag{26}$$

Where *n* is the size of the real vector and *S* and *T* are two individuals selected from the parent population.

In order to ensure that every part of the search space may be reached, the mutation acts as a weak perturbation in the chromosomes which should make small changes to our design and not leaping to a radically difference [16]. The most important kind of mutation proposed for the GA is the Gaussian mutation, performed by adding a normally distributed random value with zero mean and standard deviation σ as:

$$\forall i \in \{1, ..., n\}\,,\quad x_i^{'} = x_i + N(0, \sigma) \tag{27}$$

The parameters $\begin{bmatrix} k_\Omega & k_T & k_\varphi \end{bmatrix}$ are generated by a GA that uses a tournament, which is based on the choice by chance of a group of *(q)* individuals in the population and to select the best one in this group as a parent to be crossed selection. Here a Gaussian mutation is used according to a fitness function defined by:

$$Fitnesse = \sum_{k=1}^{500} \frac{1}{e_1(k)^2 + 2e_2(k)^2 + 3e_3(k)^2} \tag{28}$$

Where: $e_1\left(k\right)$, $e_2\left(k\right)$ and $e_3\left(k\right)$ are respectively the discrete errors corresponding to speed, torque and stator flux on a period of 0.1s, which represents 500 samples. The initial population is composed by 100 random chromosomes, each expressed as $\begin{bmatrix} k_\Omega & k_T & k_\varphi \end{bmatrix}$. To constitute the first generation, we take a random selection of the three parameters k by applying linear discrete crossover, where two parents produce two children using discrete crossover and a deterministic elitist replacement. The obtained gains are $\begin{bmatrix} 1000 & 980 & 89 \end{bmatrix}$

5 STATOR FLUX, TORQUE AND LOAD TORQUE ESTIMATIONS

By using only current and voltage measurements, it is possible to estimate the instantaneous stator flux and torque. The stator flux vector φ_s, can be estimated as follows:

$$\begin{cases} \hat{\varphi}_{s\alpha} = \int (V_{s\alpha} - R_s i_{s\alpha}) dt \\ \hat{\varphi}_{s\beta} = \int (V_{s\beta} - R_s i_{s\beta}) dt \end{cases} \tag{29}$$

The electromagnetic torque estimation is calculated by the following equation:

$$\hat{T} = p\left(\hat{\varphi}_{s\alpha}\, i_{s\beta} - \hat{\varphi}_{s\beta}\, i_{s\alpha}\right) \tag{30}$$

The Backstepping control depends on load torque, whose variation may degrade the performance of the control. A simple approach based on a mechanical model, combined with the use of a proportional-Integrator controller is used to estimate the load torque.

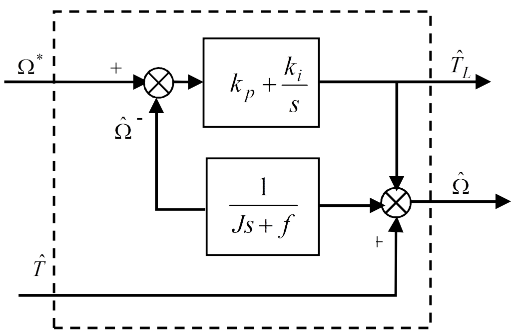

Fig. 3. Load torque estimation.

The load torque is calculated from the observed output of the integrator of this model, the input is the error between the measured speed and the estimated one (Fig.4). This method requires the use of a speed sensor [19]. The regulator's role is to cancel the speed error, which results in the convergence of the estimated load torque to the applied one.

The dynamic model of this structural method is given by:

$$\begin{bmatrix} \hat{T}_L \\ \hat{\Omega} \end{bmatrix} = \begin{bmatrix} -\frac{k_p}{J} & k_i - f\frac{k_p}{J} \\ -\frac{1}{J} & -\frac{f}{J} \end{bmatrix} \begin{bmatrix} \hat{T}_L \\ \hat{\Omega} \end{bmatrix} + \begin{bmatrix} \frac{k_p}{J} & -k_p s - k_i \\ \frac{1}{J} & 0 \end{bmatrix} \begin{bmatrix} \hat{T} \\ \Omega^* \end{bmatrix} \tag{31}$$

Where: [$\hat{T}_L$,$\hat{\Omega}$] are the estimated states variables and [$\hat{T}$,Ω^*] are the control inputs. The estimated load torque is given by:

$$\hat{T}_L = \frac{\frac{1}{J}\left(k_p s + k_i\right)}{s^2 + s\left(\frac{k_p + f}{J}\right) + \frac{k_i}{J}} \hat{T} + \frac{-\left(k_p s + k_i\right)\left(s + \frac{f}{J}\right)}{s^2 + s\left(\frac{k_p + f}{J}\right) + \frac{k_i}{J}} \Omega^* \tag{32}$$

The controller is determined by the pole placement technique imposing the desired dynamics. Identifying (30) to a second order system (ξ, ω_o), we obtain:

$$\begin{cases} k_i = \omega_0^2 J \\ k_p = 2\xi\omega_0 J - f \end{cases} \tag{33}$$

After chosen $\omega_0 = 0.1\ rd/s$ and $\xi = 0.7$, the coefficients gains become $k_i = 4.9\ 10^{-5}$ and $k_p = -0.0023$.

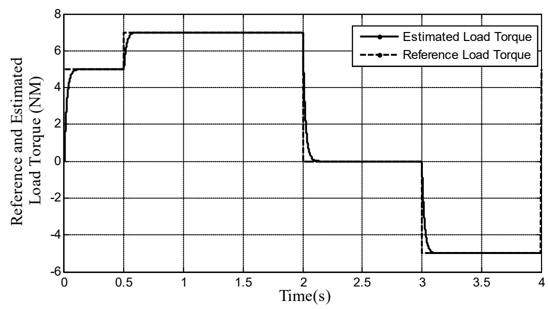

Fig. 4. Reference and Load torque estimation

Figure 4 presents the evolution of the estimated load torque and the signal delivered by the output of the load torque sensor. The error between them is quite zero.

6 EXPERIMENTAL RESULTS

To display the effectiveness of the direct torque and stator flux Backstepping control of induction motor, the control scheme, was implemented on a DSPACE card 1104 with Matlab and Real Time Workshop Software. The experimental setup, shown in Figure 5, was based on a 1.5 kW induction motor, whose parameters are given in Table 2. Furthermore, we used a voltage-source inverter with a switching frequency equal to 10 kHz.

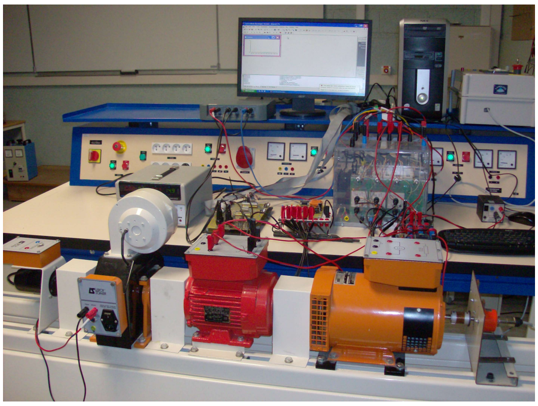

Fig. 5. Experimental System in the L.T.I laboratory, consisting of a 1.5 Kw induction motor, a voltage-source inverter, and a digital signal processor (DSP)

Table 2. 1.5 kW, 4 poles, 220 V, 50 Hz Motor Parameters

R_s	4.2Ω	L_s	$0.362H$
R_r	2.9Ω	L_r	$0.288H$
M	$0.288H$	J	$0.0108Kgm^2$

The obtained experimental results are represented by figures 6. 7. and 8.

Figure 6., show the rotor speed evolution of the system. The induction motor is accelerated from standstill to (+100rd/s), afterwards it is decelerated to zero speed (0d/s) and decelerated again to the inverse rated speed (-100rd/s) and finally, accelerate to low speed (0rd/s). Additionally, the rotor speed is compared with the reference one. The results show a good pursuit of rotor speed to its reference.

Figures 7 and 8 present the Stator flux trajectory that steadily runs at a variable speed and given flux linkage of 0.8 wb. This latter, can improve obviously the accuracy of the stator flux well and make wave like a circle.

For the same test, figure 9 and figure 10 show the α-axis stator voltage and α-axis stator current. Similar results were found for β-axis components.

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

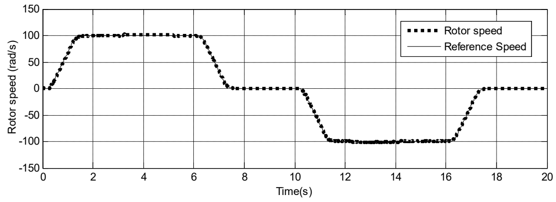

Fig. 6. Rotor speed Evolution

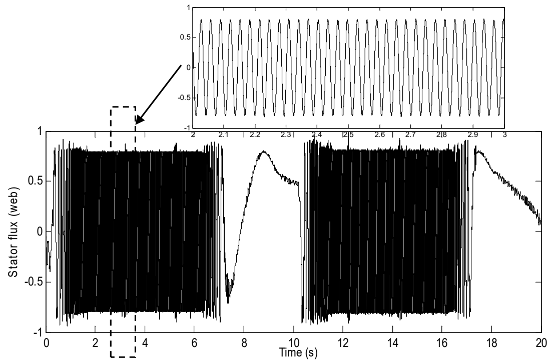

Fig. 7. Stator flux response

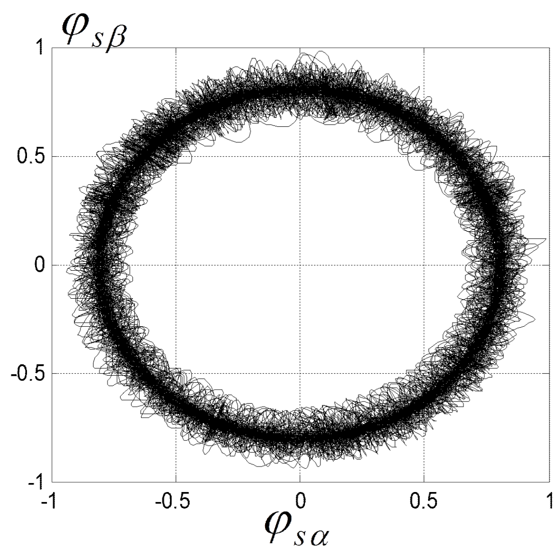

Fig. 8. Stator flux Linkage

7 CONCLUSION

In this paper, a new approach for the design of the torque and stator control of induction motor has been proposed. The structure of the proposed controller is based on the backstepping principle, which is able to yield a good dynamic response of the system. Two new controls of torque and flux are used to calculate the stator voltages required to cause the torque and flux to be equal to their respective references values. So, the Genetic Algorithm is used to optimize the set of unknown controller parameters. The obtained experimental results verifed very well

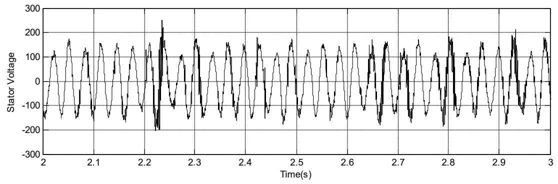

Fig. 9. Stator Voltage response

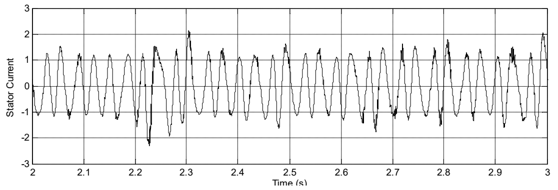

Fig. 10. Stator Current response

the capability of the proposed control approach. Then, in comparison with the results in the literature, the use of the optimized backstepping controller is better than the traditional DTC control from the standpoint of simplicity and efficiency. Indeed, the Lyapunov stability conditions has allows us to avoid the use of the hysteresis controllers and the switching table.

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