dSPACE Implementation of Improved Indirect Field-oriented Control of Asynchronous Motor using Adaptive Fuzzy Proportional Integral Controller for Electric Vehicle Applications

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Keywords: Indirect Field-Oriented Control; Adaptive Fuzzy Proportional Integral Controller; Adaptive Gains; Conventional Proportional Integral Controller.

Abstract: This paper deals with the Indirect Rotor Field-Oriented Control of asynchronous motor whose speed is controlled by an adaptive fuzzy proportional integral controller. This motor drive is used to propel an electric vehicle. The design and the experimental implementation of the Adaptive Fuzzy Proportional Integral Controller are presented. This controller is proposed as a solution to compensate for the effect of the variation of the machine parameters and the external conditions. The characteristic of this controller is its capacity to adapt in real time its gains in order to reject the machine parameter disturbances. A series of experimental tests were performed to test the performance the improved drive using the proposed controller. Simulation and Experimental results showed the high-speed tracking and the rejection disturbance capacity of the adaptive fuzzy proportional integral controller.

This paper presents the design and the experimental implementation of the adaptive fuzzy proportional integral controller applied to the indirect field oriented control of asynchronous motor used to propel the electric vehicle. This intelligent controller is proposed to reduce the impact of the variation of the machine parameters and the external conditions on the performances of the drive, and so, to improve the performances of the electric vehicle control. The experimental implementation was carried out using dSPACE system and the experimental results showed the high-speed tracking and the rejection disturbance capacity of the adaptive fuzzy proportional integral controller compared to the conventional proportional integral controller.

1 INTRODUCTION

Limitations on the emission of greenhouse gases and the traffic restrictions in the urban areas imposed by the environmental protection requirements have given a strong impulse toward the development of electrical propulsion systems for electric vehicles.

The robustness, the high power-to-weight ratio, the low cost and the ease of maintenance make the use of the asynchronous motor advantageous in a propulsion chain of an electric vehicle.

High efficient drives are indispensable in automotive applications. The indirect field-oriented control (IFOC) is an established strategy for high dynamic performance induction motor drives.

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Its characteristic is the decoupling of the torque and the flux and hence the fast torque response. This command was proposed by Blaschke and Hasse in early 1970s. Since then, great efforts have been made to improve the performance and the robustness of this drive (Abbou , et al, 2009) (Bennassar , et .al 2013).

The proportional integral (PI) controller is the conventional controller used in said command. However, the linearity, the sensitivity to the variation of the machine parameters and the incapacity to control the nonlinear systems are major weaknesses of this controller (Khuntia, et .al, 2009),(Singh, G , et .al 2014).
The adaptive fuzzy proportional integral controller has been developed to correct these problems. Its ability to adjust its gains when a disturbance of the machine parameters occurred makes it the most recommended controller to deal with systems subject to disturbances (M.Masiala; et.al, 2006), (Chebre, et.al; 2007).
In this paper, we present the model and the experimental implementation of the indirect rotor field-oriented control using both the adaptive fuzzy proportional integral controller and the conventional proportional integral (PI) controller. Experimental results are presented to highlight the improved performances of the drive obtained by using the adaptive fuzzy proportional integral controller in comparison with the conventional PI controller.

2 INDIRECT ROTOR FIELD-ORIENTED CONTROL

The principle of the field oriented control (FOC) is based on the separate control of the torque and the flux in similarity to the DC machine with separate excitation. The algorithm of the indirect rotor field-oriented control (IRFOC) is based on the orientation of the rotor flux Φ_r on the direct axis of the rotating reference frame.
This implies (Abbou, et.al, 2009):

$$\Phi_{rd} = \Phi_r \text{ and } \Phi_{rq} = 0 \tag{1}$$

By applying this principle, the expressions of the rotor flux and the torque are given by the following equations:

If Φ_r is constant [3]:

$$\Phi_r = M i_{sd} \tag{2}$$

$$C_{em} = p \frac{M}{L_r} \Phi_r i_{sq} \tag{3}$$

These equations show that decoupling between the flux and the torque is ensured. In fact, the magnitude of the rotor flux Φ_r is determined only by the direct component of the stator current i_{sd} while the electromagnetic torque C_{em} is determined by the quadrature component of the stator current i_{sq}.
The block diagram of speed regulation by the indirect rotor field oriented control of an induction motor intended for a propulsion chain of an electric vehicle is presented by the Figure1.

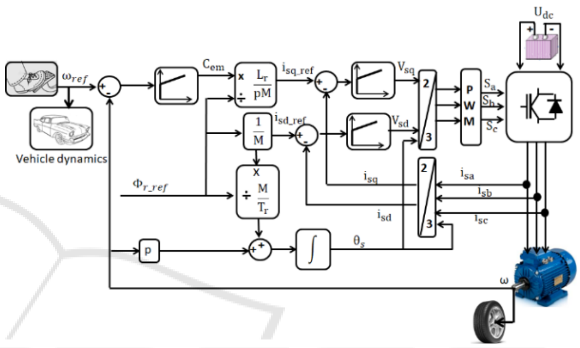


Figure 1: Structure of IRFOC used in a propulsion chain of an electric vehicle.

3 ADAPTIVE FUZZY PROPORTIONAL INTEGRAL CONTROLLER

The adaptive fuzzy proportional integral controller is a hybrid controller including a conventional proportional integral (PI) controller and a fuzzy logic regulator. This controller is developed with the aim of ensuring a robustness with respect to the variation of the machine parameters and the experimental conditions by tuning in real time the gains of the conventional PI controller via a fuzzy logic regulator. As shown by its architecture (Figure 2), the fuzzy logic controller compares the measured rotor speed with the desired speed and generates the adaptive factors ΔK_p and ΔK_i. These are used to calculate the new gains of the conventional PI controller according to the following algorithm:

$$Kp_f(i+1) = Kp_i(i) + \Delta Kp(i) \tag{4}$$

$$Ki_f(i+1) = Ki_i(i) + \Delta Ki(i) \tag{5}$$

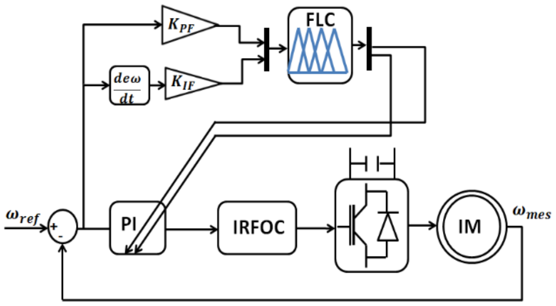


Figure 2: Design of adaptive fuzzy proportional integral controller.

The structure of the fuzzy logic regulator is determined as follows:

The input variables; the speed error (e_{ω}) and its derivative ($\frac{de_{\omega}}{dt}$); are described by the following linguistic variables:

- HN : High Negative
- AN : Average Negative
- LN : Low Negative
- Z : Zero
- LP : Low Positive
- AP : Average Positive
- HP : High Positive

The output variables; ΔK_p and ΔK_i; are described by:

- H : High
- L : Low

The membership functions for input and output variables are defined in the interval [-0.1 0.1] as follows: (Laoufi , et.al, 2013), (Laoufi , et.al, 2014):

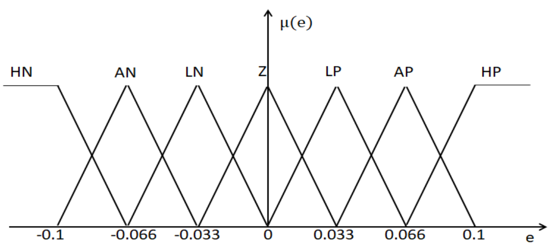


Figure 3. Membership functions for input variables

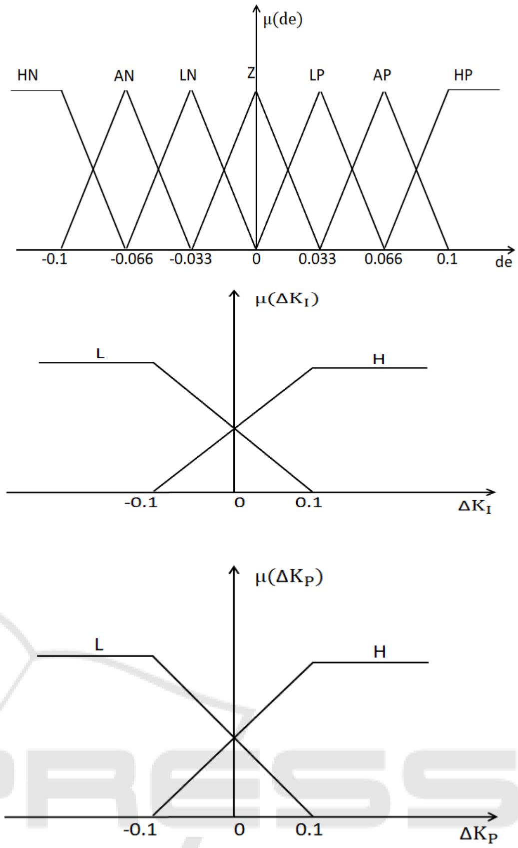


Figure 4. Membership functions for output variables

The adaptive factors; ΔK_p and ΔK_i; are calculated by the bases rules described in Tables 1 and 2.

Table 1: Matrix inference used to control the output variable ΔK_p

	HN	AN	LN	Z	LP	AP	HP
HN	H	H	H	H	H	H	H
AN	L	H	H	H	H	H	H
LN	L	L	H	H	H	L	L
Z	L	L	L	H	L	L	L
LP	L	L	H	H	H	L	L
AP	L	H	H	H	H	H	L
HP	H	H	H	H	H	H	H

Table 2: Matrix inference used to control the output variable ΔKi

	HN	AN	LN	Z	LP	AP	HP
HN	H	H	H	H	H	H	H
AN	H	H	L	L	L	H	H
LN	H	H	H	L	H	H	H
Z	H	H	H	L	H	H	H
LP	H	H	H	L	H	H	H
AP	H	H	L	L	L	H	H
HP	H	H	H	H	H	H	L

4 EXPERIMENTAL RESULTS AND ANALYSIS

The experimental setup used to implement in real time the proposed adaptive fuzzy proportional integral controller applied to the indirect rotor field-oriented control is shown in Figure 5:

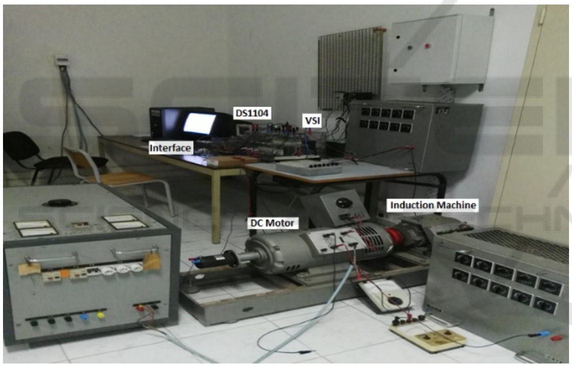


Figure 5. The used test bench

The main components of the used test bench are:

- The squirrel asynchronous motor of 3 KW power, characterized by the nominal values of the current, voltage and speed: 7.2A/12.5A, 220V/380V and 1400rpm;
- The two-level voltage inverter type SEMIKRON;
- The dSPACE acquisition card (DS1104) comprising a Real-Time Interface (RTI), which is the link between the dSPACE hardware and the development software MATLAB/Simulink/Stateflow from MathWorks.
- The adaptation card developed to ensure the compatibility of the dSPACE I/O board with the inverter and the induction machine.
- The DC motor used to apply a resistive torque.

In order to examine the performance of the adaptive fuzzy proportional integral controller, a series of measurement has been accomplished. In the first test, a step change of 100 rad/s has been applied to the speed reference. The second test consist to test the performance of the proposed control in the nominal reference speed (146 rad/s:1400 rpm). The third and fourth tests aim to investigate the efficiency of the proposed controller to reject the perturbation. So, a resistive torque of 10 N.m has been applied as a disturbance. In the fifth and sixth tests; and in order to evaluate the robustness of the control to the change of direction of rotation of the machine; the speed has been changed between 100 rad/s and -100 rad/s and between 10 rad/s and -10 rad/s.

The figures 6 and 7 show the precise speed tracking and the better stator current signal when using the adaptive fuzzy proportional integral controller with less ripples. As shown in figure 7, by the use of the adaptive fuzzy proportional integral controller, the current remains a periodic sinusoidal signal. In fact, from the frequency spectrum of the stator current (Figures 11), the adaptive fuzzy proportional integral controller gives a reduced THD (27.35%) compared to the conventional PI controller (THD=29.98%).

The feature of the adaptive fuzzy proportional integral controller is its capacity to reject the disturbances. In fact, unlike the conventional PI controller, the effect of the perturbation (resistive torque) is not observed on the speed response of the indirect rotor field oriented control using the adaptive fuzzy proportional integral controller (Figure 12 to 15).

Also, the adaptive fuzzy proportional integral controller gives a fast speed response to the change of the rotational direction and a good dynamic behavior even at low speed (Figure 16 and 17). This high performance of this controller is due to its adaptive gains which adapt in real time to compensate the parameter variation as shown in Figure 18.

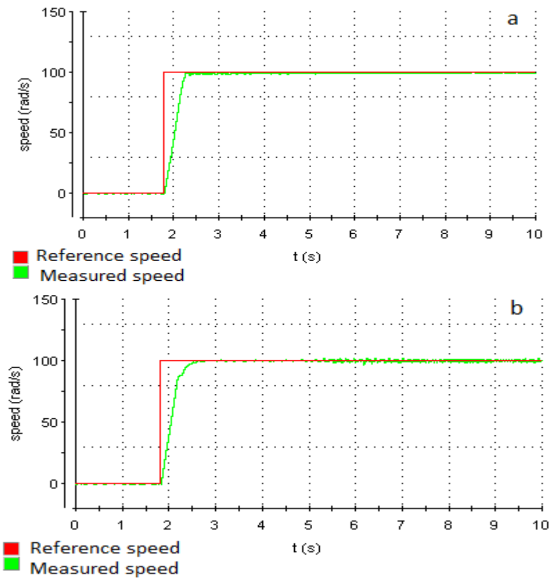


Figure 6. (a) Speed response of IRFOC using the adaptive fuzzy proportional integral controller; (b) the conventional PI controller.

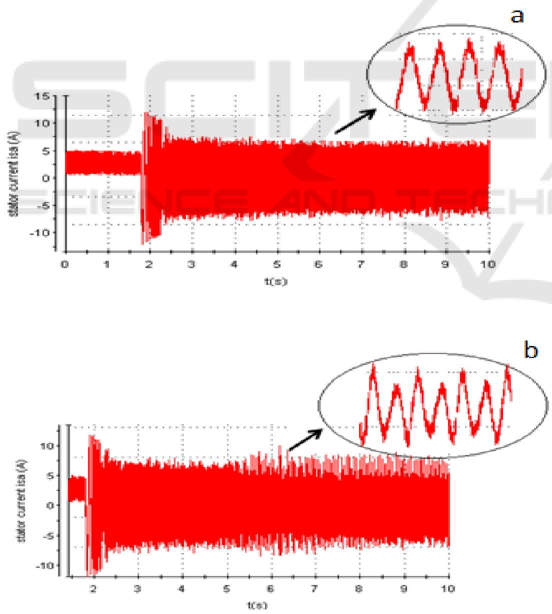


Figure 7. (a) Measured stator current of asynchronous motor controller by IRFOC using the adaptive fuzzy proportional integral controller; (b) the conventional PI controller

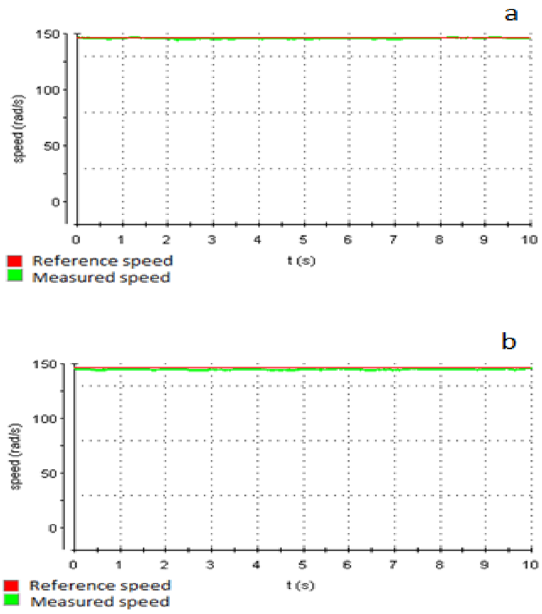


Figure 8. (a) Speed response of IRFOC using the adaptive fuzzy proportional integral controller; (b) the conventional PI controller (case of the nominal reference speed).

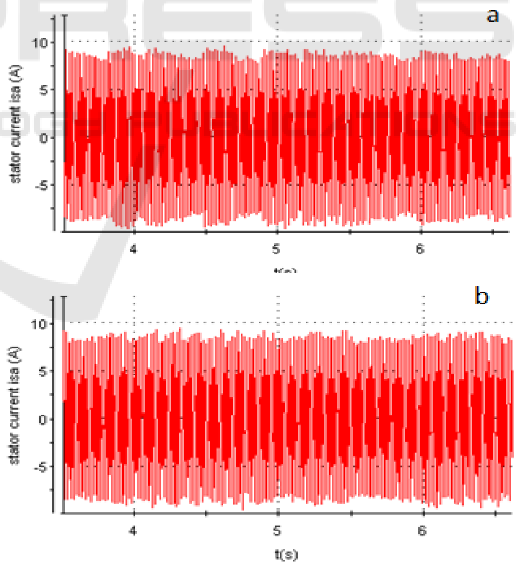


Figure 9. (a) Measured stator current of asynchronous motor controller by IRFOC using the adaptive fuzzy proportional integral controller; (b) the conventional PI controller (case of the nominal reference speed).

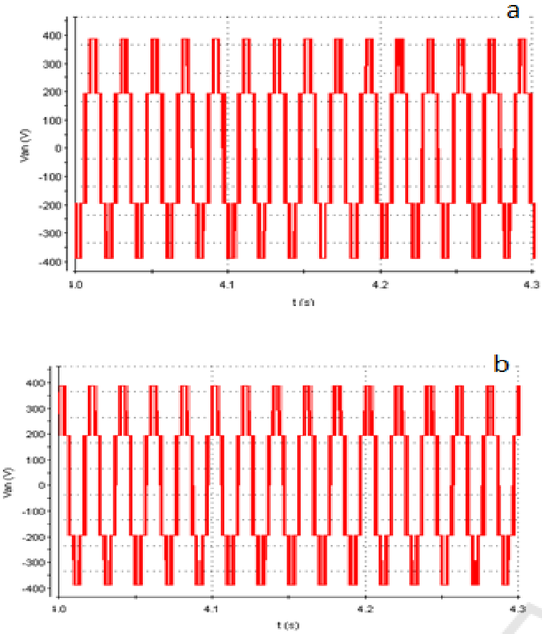
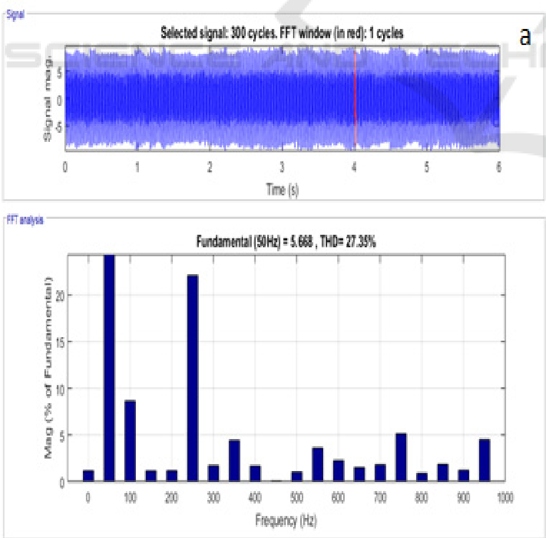


Figure 10. (a) Measured phase voltage of asynchronous motor controller by IRFOC using the adaptive fuzzy proportional integral controller; (b) the conventional PI controller (case of the nominal reference speed).



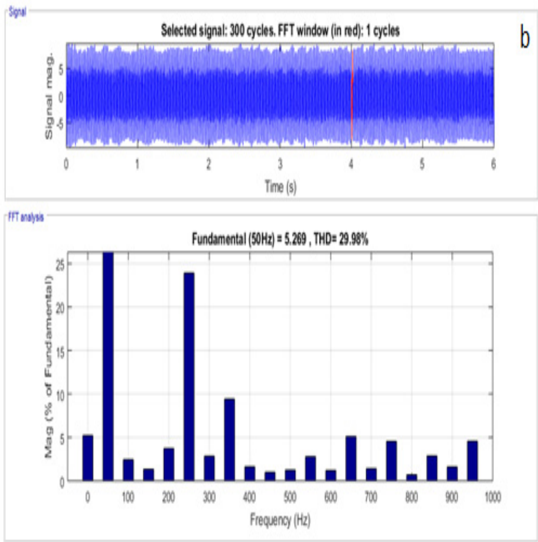


Figure 11. (a) Frequency spectrum of the measured stator current in the case of using the adaptive fuzzy proportional integral controller; (b) the conventional PI controller

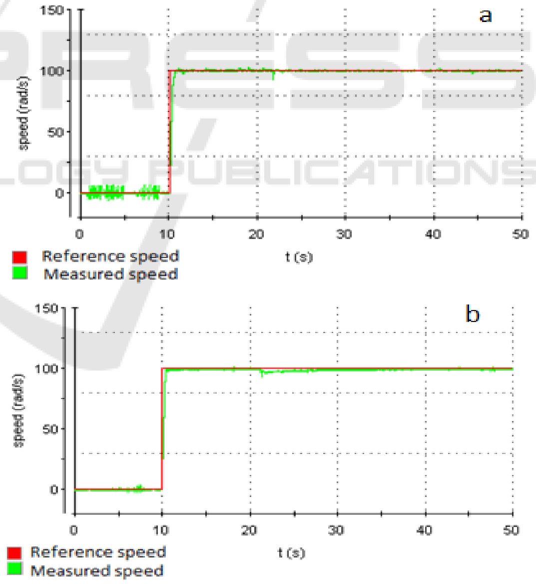


Figure 12. (a) Speed response of IRFOC using the adaptive fuzzy proportional integral controller; (b) the conventional PI controller; in the case of applying a resistive torque.

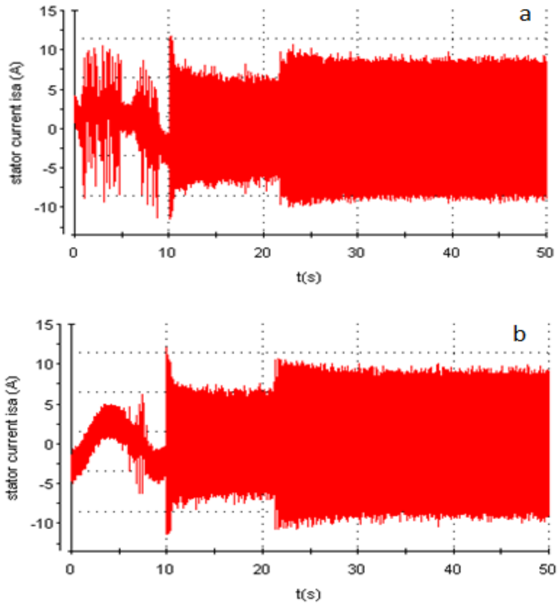


Figure 13. (a) Measured stator current of asynchronous motor controlled by IRFOC using the adaptive fuzzy proportional integral controller; (b) the conventional PI controller; in the case of applying a resistive torque.

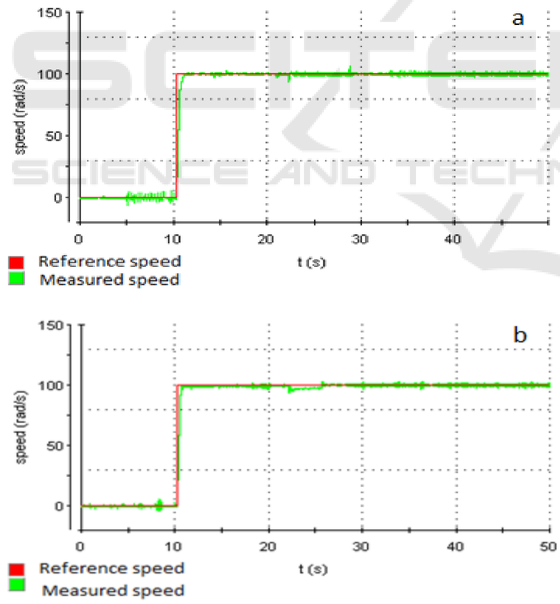


Figure 14. (a) Speed response of IRFOC using the adaptive fuzzy proportional integral controller ; (b) the conventional PI controller; in the case of applying a resistive torque in a given time interval.

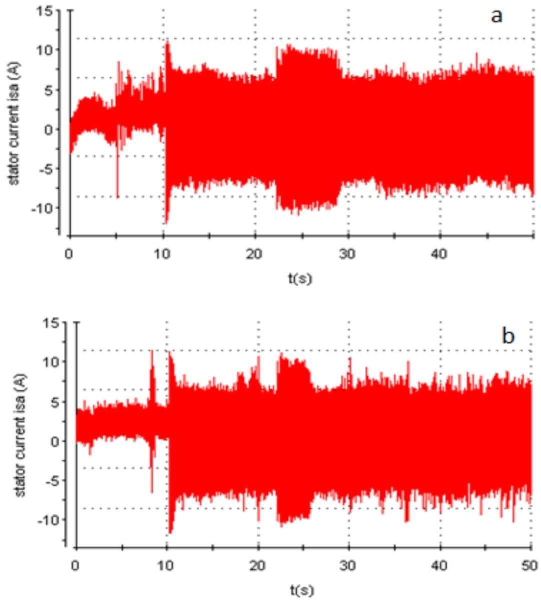


Figure 15. (a) Measured stator current of asynchronous motor controller by IRFOC using the adaptive fuzzy proportional integral controller; (b) the conventional PI controller; in the case of applying a resistive torque in a given time interval.

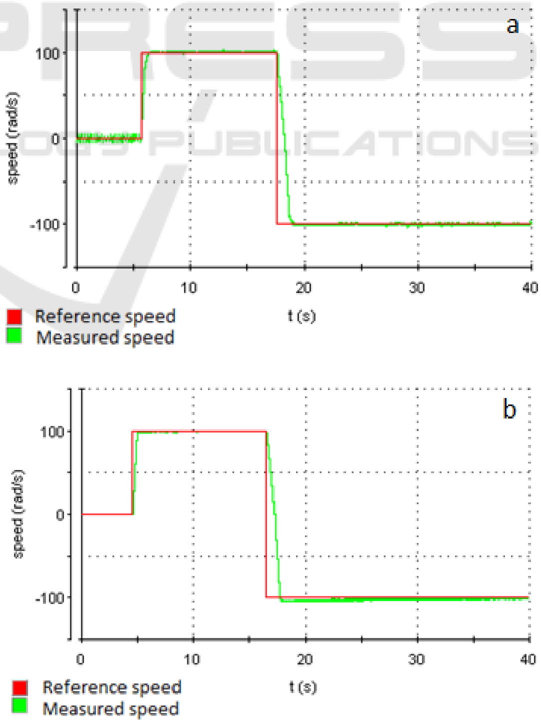


Figure 16. (a) Speed response of IRFOC using the adaptive fuzzy proportional integral controller; (b) the conventional PI controller; in the case of changing the direction of rotation of the machine (high speeds).

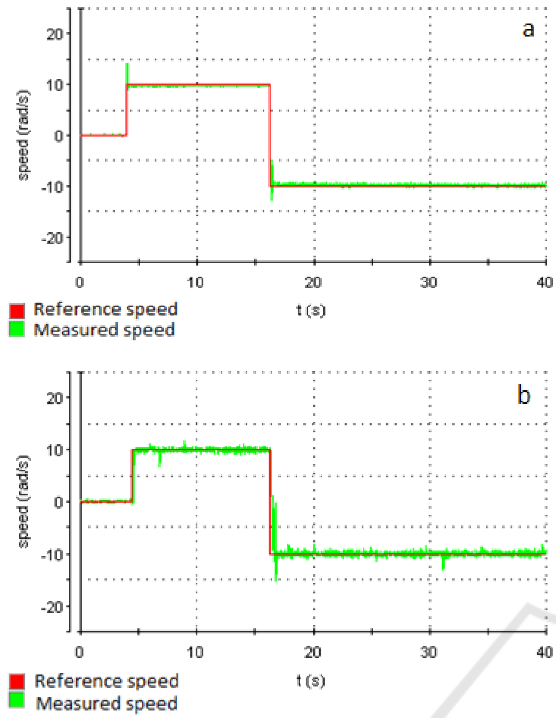


Figure 17. (a) Speed response of IRFOC using the adaptive fuzzy proportional integral controller; (b) the conventional PI controller; in the case of changing the direction of rotation of the machine (low speeds).

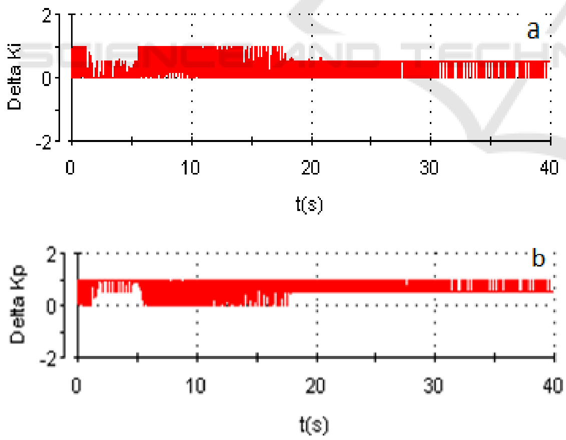


Figure 18. Adaptive gains of the adaptive fuzzy proportional integral controller K_P (a), K_I (b)

5 CONCLUSION

In this paper, the authors propose an intelligent controller, the adaptive fuzzy proportional integral controller, to improve the performance of an indirect rotor field oriented control for induction motor used in a propulsion chain of an electric vehicle. This drive has been implemented in real time using dSPACE Package and the experimental results were satisfactory. The proposed controller presents a high performance of speed tracking even in low speeds and a high capacity to reject the disturbance of the induction machine parameters.

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