dSPACE Implementation of Improved Indirect Rotor Field-Oriented Control of Asynchronous Motor using Fuzzy Self-Adjustable Proportional Integral Controller for Electric Vehicle Applications

Chaymae Laoufi, Ahmed Abbou, Mohammed Akherraz, Zouhair Sadoune

Abstract*: This paper deals with the indirect rotor field-oriented control of asynchronous motor whose speed is controlled by a fuzzy self-adjustable proportional integral controller. This motor drive is used to propel an electric vehicle. The designing and the implementing of the fuzzy self-adjustable proportional integral controller are presented. This controller is proposed as a solution to compensate for the effect of the machine parameters variation 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 parameters disturbances. A series of measurements has been achieved to prove the performances of the improved drive using the proposed controller. Experimental results showed the high-speed tracking and the rejection disturbances capacity of the fuzzy self-adjustable proportional integral controller.

***Keywords:* Indirect rotor-field-oriented control, fuzzy self-adjustable proportional integral controller, standard proportional integral controller, Electric vehicle, dSPACE Package.**

I. 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.

Current automotive engines use asynchronous motor, powerful, economical and robust. In addition to the electro-mechanical characteristics, the low cost and the reliability are determining criteria for the choice of the asynchronous motor 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 dynamics performances asynchronous motor drive. Its feature 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 performances and robustness of this drive [1],[2],[3].

The proportional integral (PI) controller is the standard controller used in the said command. However, this controller is linear, sensitive to the variation of the motor parameters and unable to control the nonlinear systems [4].

The fuzzy self-adjustable proportional integral controller has been developed to correct these problems. Its ability to adjust its gains when a disturbance of the motor parameters occurred makes it the most recommended controller to deal with systems subject to disturbances [5],[6],[7].

This paper features the designing and the implementing of the indirect rotor field-oriented control using both the fuzzy self-adjustable proportional integral controller and the standard Proportional Integral (PI) controller. Experimental results are presented to highlight the improved performances of the drive obtained by using the fuzzy self-adjustable proportional integral controller in comparison with the standard PI controller.

II. INDIRECT ROTOR FIELD-ORIENTED CONTROL

The principle of the Indirect Rotor Field-Oriented Control (IRFOC) is founded on the separate control of the torque and the flux in similarity to the DC machine with separate excitation. The rotor flux Φ_r is oriented on the direct axis of the rotating reference frame.

This implies [8]:

$$\Phi_{rd} = \Phi_r \text{ and } \Phi_{rq} = 0 \quad (1)$$

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

If Φr is constant [8]:

$$\Phi_r = M i_{sd} \quad (2)$$

$$C_{em} = p \frac{M}{L_r} \Phi_r i_{sq} \quad (3)$$

These equations show that the rotor flux Φ_r and the electromagnetic torque C_{em} are identified separately by the two decoupled components of the

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stator current i_{sd} and i_{sq}. Therefore, the problem of the coupling between the two parameters, the couple and the torque is solved.

The block diagram of the speed regulation by the indirect rotor field oriented control of asynchronous motor intended for a propulsion chain of electric vehicle is presented by the Figure 1.

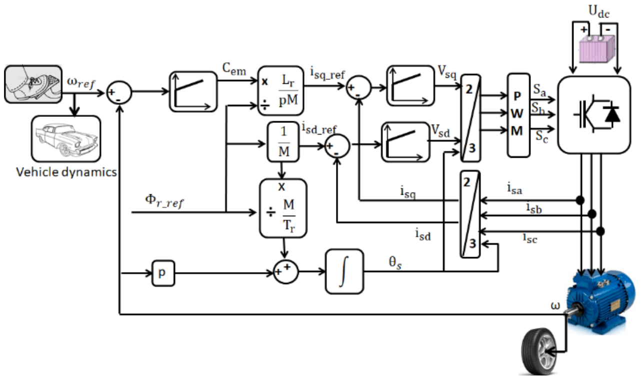

Fig. 1. Structure of IRFOC used in a propulsion chain of an electric vehicle.

III. FUZZY SELF-ADJUSTABLE PROPORTIONAL INTEGRAL CONTROLLER

The fuzzy self-adjustable proportional integral controller is a hybrid controller including a standard 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 adjusting online gains of the standard PI controller via a fuzzy logic regulator. As shown by its architecture (Figure 2), the fuzzy logic regulator compares the measured rotor speed with the desired speed and generates the adaptive factors ΔK_p and ΔK_p. These are used to calculate the new gains of the standard PI controller according to the following algorithm:

$$Kp_f(i+1) = Kp_i(i) + \Delta Kp(i) \quad (4)$$

$$Ki_f(i+1) = Ki_i(i) + \Delta Ki(i) \quad (5)$$

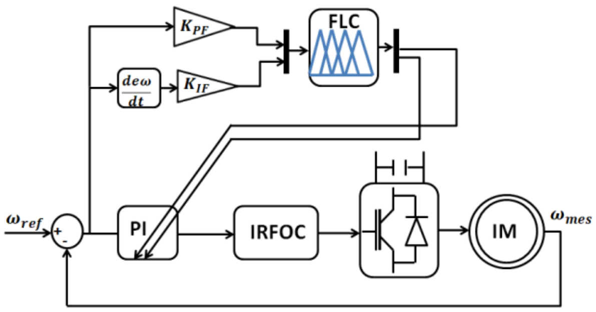

Fig. 2. Fuzzy self-adjustable proportional integral controller for induction machine

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:

- MN : Major Negative
- IN : Intermediate Negative
- LN : Little Negative
- Z : Zero
- LP : Little Positive
- IP : Intermediate Positive
- MP : Major Positive

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

- M : Major
- L : Little

The fuzzy sets, as defined above, are described by the following membership functions [9]:

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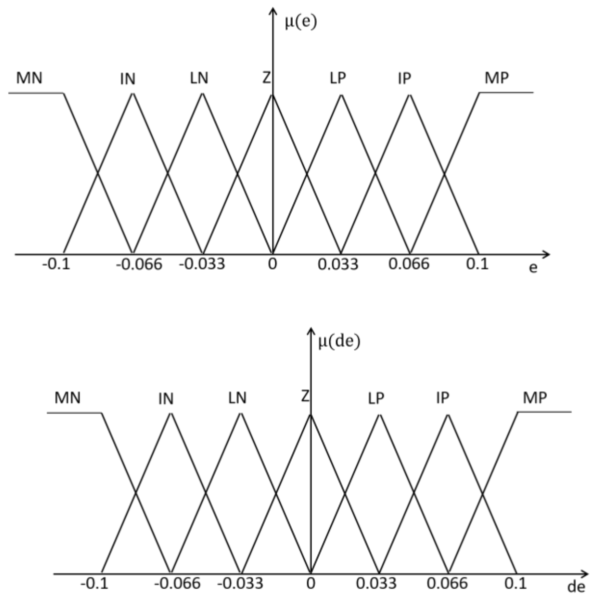

Fig. 3. Membership functions of input variables

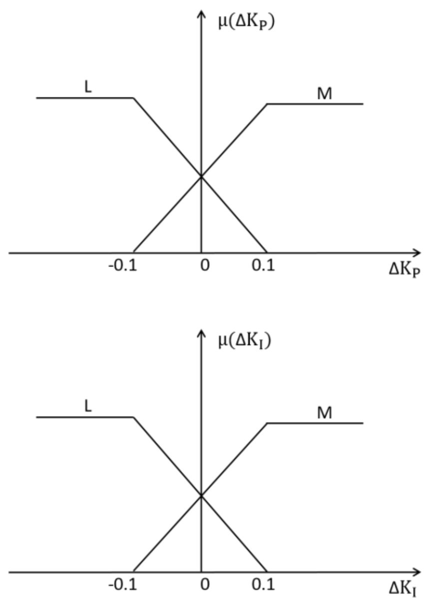

Fig. 4. Membership functions of output variables

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

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Table- I: Matrix inference used to calculate the output variable ΔKp

	MN	IN	LN	Z	LP	IP	MP
MN	M	M	M	M	M	M	M
IN	L	M	M	M	M	M	M
LN	L	L	M	M	M	L	L
Z	L	L	L	M	L	L	L
LP	L	L	M	M	M	L	L
IP	L	M	M	M	M	M	L
MP	M	M	M	M	M	M	L

Table II. Matrix inference used to calculate the output variable ΔKi

	MN	IN	LN	Z	LP	IP	MP
MN	M	M	M	M	M	M	M
IN	M	M	L	L	L	M	M
LN	M	M	M	L	M	M	M
Z	M	M	M	L	M	M	M
LP	M	M	M	L	M	M	M
IP	M	M	L	L	L	M	M
MP	M	M	M	M	M	M	L

IV. EXPERIMENTAL RESULTS AND ANALYSIS

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

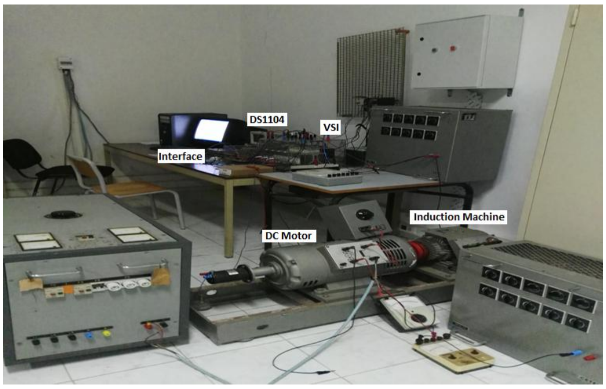


Fig. 5. The used test bench

The main components of the used test bench are:

- The squirrel asynchronous motor of 3KW of power, characterized by the nominal values of the current, voltage and speed: 7.2A/12.5A, 220V/380V and 1400 rpm;
- The two levels 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 asynchronous machine;
- The DC motor used to apply a resistive torque.

In order to examine the performances of the fuzzy self-adjustable 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 consists to test the performances of the proposed control in 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 perturbations. Therefore, 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 at the change of direction of rotation of the motor; the speed has been changed between 100 rad/s and -100 rad/s and between 10 rad/s and -10 rad/s.

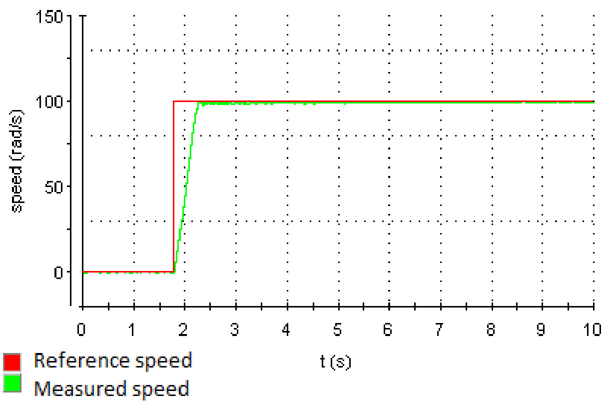
The figures 6 and 7 show the high tracking responses of the speed and the better stator current signals when using the fuzzy self-adjustable proportional integral controller with less ripples.

As shown in figure 7, by the use of the fuzzy self-adjustable proportional integral controller, the current remains a periodic sinusoidal signal. In fact, from the frequency spectrum of current, the fuzzy self-adjustable proportional integral controller gives a reduced total harmonic distortion THD (27.35% instead of 29.98% in the case of the standard PI controller (Figure 10).

The feature of the fuzzy self-adjustable proportional integral controller is its capacity to reject the parameters disturbances.

In fact, unlike the standard PI controller, the effect of the perturbation (a change of load torque) is not observed on the speed response of IRFOC using the fuzzy self-adjustable proportional integral controller (Figure 11 to 14).

In addition, the fuzzy self-adjustable proportional integral controller gives fast speed response when changing the rotational direction and good dynamic behavior even at low speed (Figure 15 and 16). This high performance of this controller is due to its adaptive gains, which adapt in real time to compensate the parameters change as shown in Figure 17.



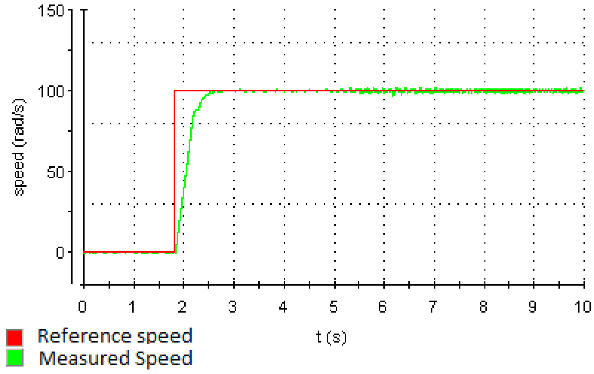


Fig. 6. (a) Response of the rotor speed of asynchronous motor drived by IRFOC using the fuzzy self-adjustable proportional integral controller; (b) the standard PI controller.

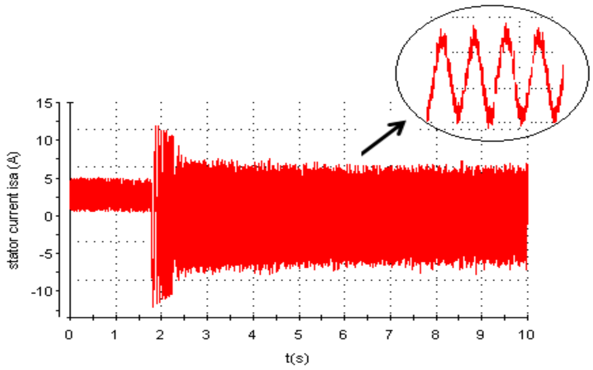


Fig. 7. (a) Measured stator current of asynchronous motor drived by IRFOC using the fuzzy self-adjustable proportional integral controller; (b) the standard PI controller.

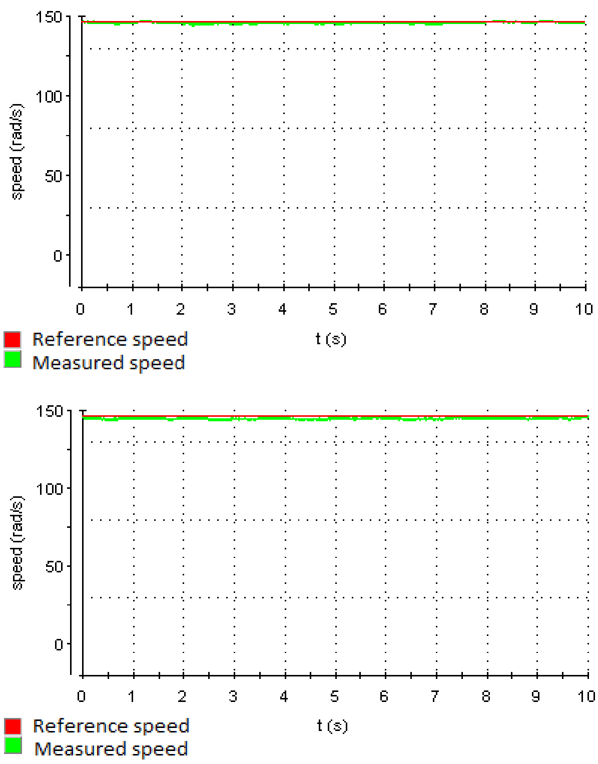


Fig. 8. (a) Response of the rotor speed of asynchronous motor drived by IRFOC using the fuzzy self-adjustable proportional integral controller; (b) the standard PI controller (case of nominal reference speed).

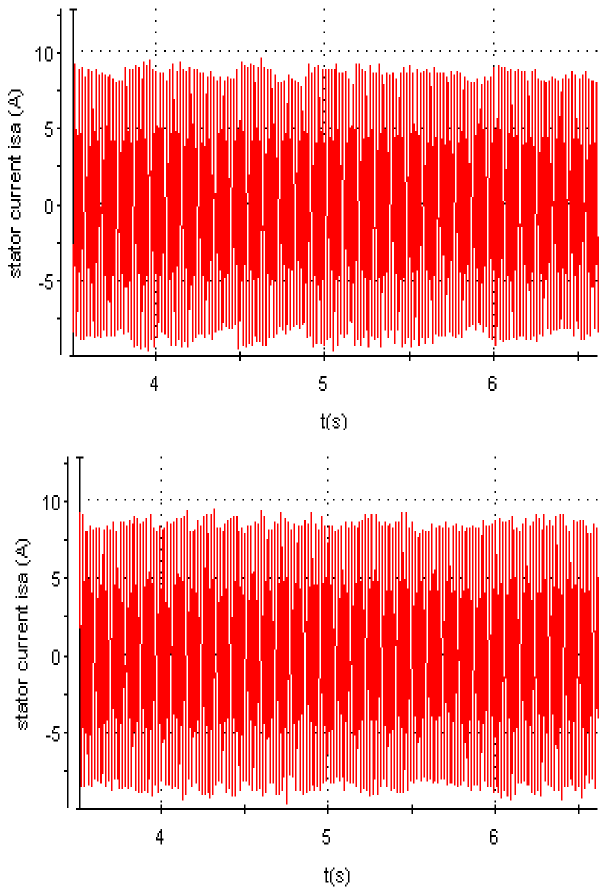
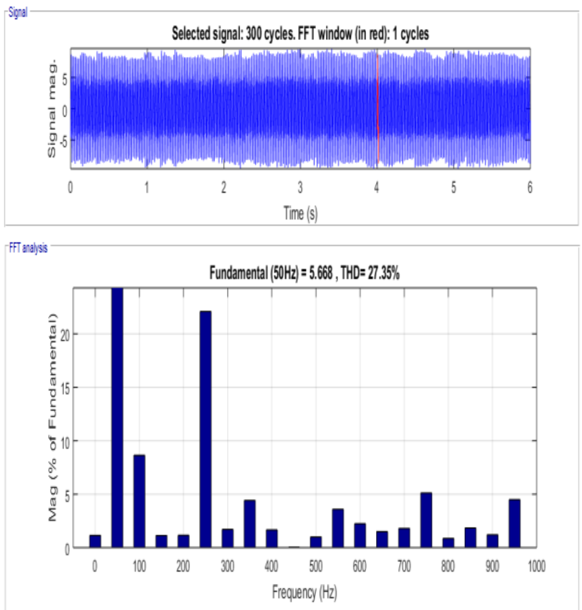


Fig. 9. (a) Measured stator current of asynchronous motor drived by IRFOC using the fuzzy self-adjustable proportional integral controller; (b) the standard PI controller (case of nominal reference speed).



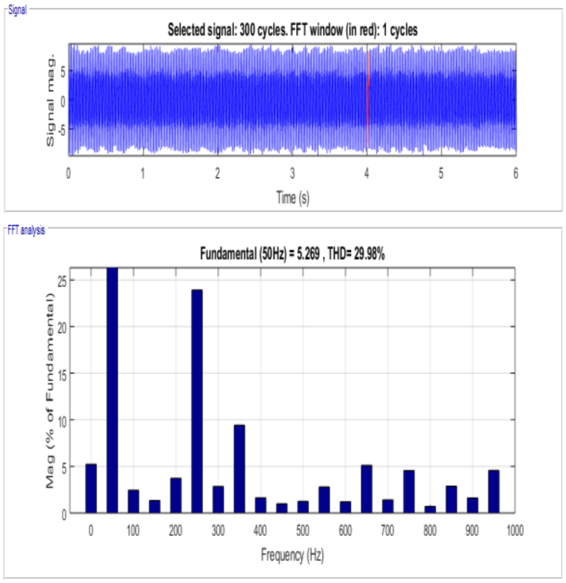


Fig. 10. (a) Frequency spectrum of the measured stator current in case of the fuzzy self-adjustable proportional integral controller; (b) the standard PI controller.

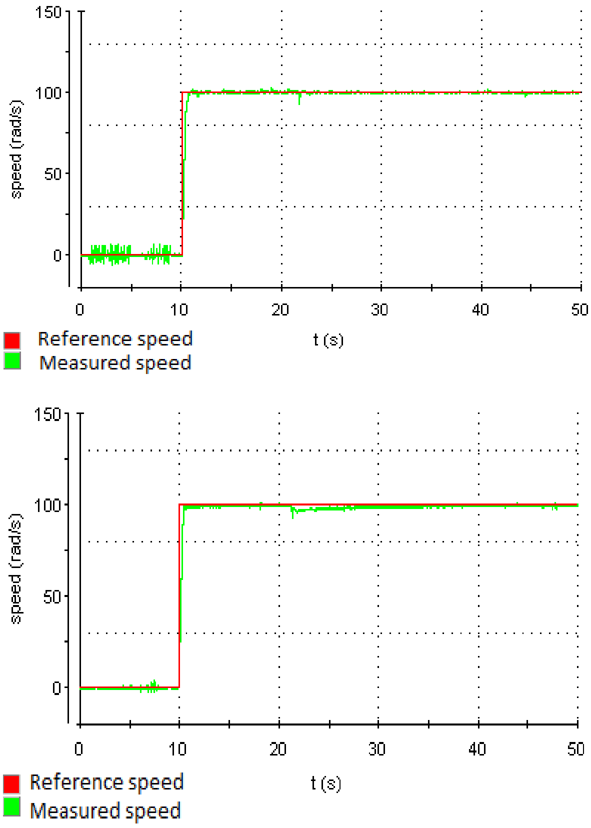


Fig. 11. (a) Response of the rotor speed of asynchronous motor drived by IRFOC using the fuzzy self-adjustable proportional integral controller; (b) the standard PI controller to change in load torque.

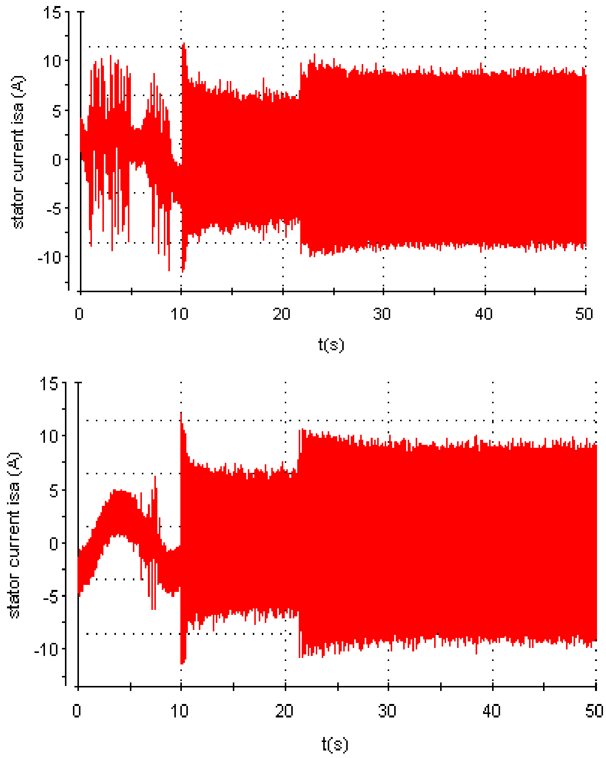


Fig. 12. (a) Measured stator current of asynchronous motor controlled by IRFOC using the fuzzy self-adjustable proportional integral controller; (b) the standard PI controller in case of a change in load torque

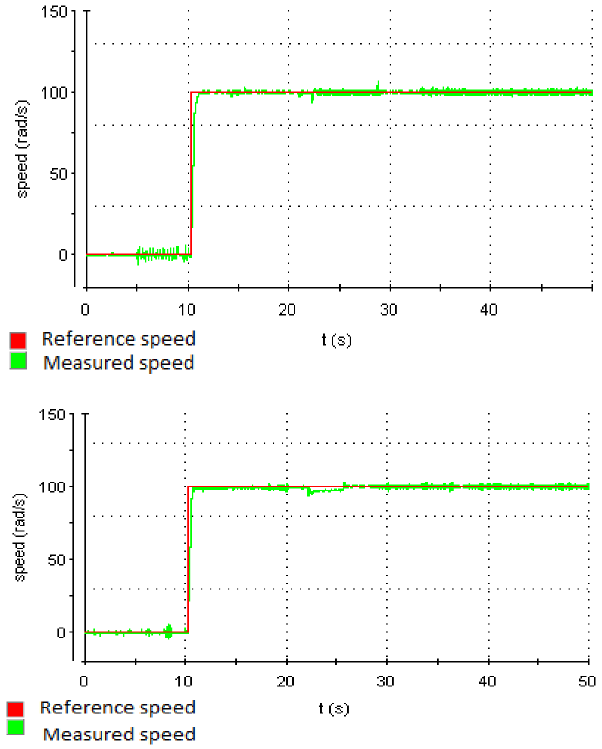


Fig. 13. (a) Response of the rotor speed of the asynchronous motor drived by IRFOC using the fuzzy self-adjustable proportional integral controller; (b) the standard PI controller to change in load torque.

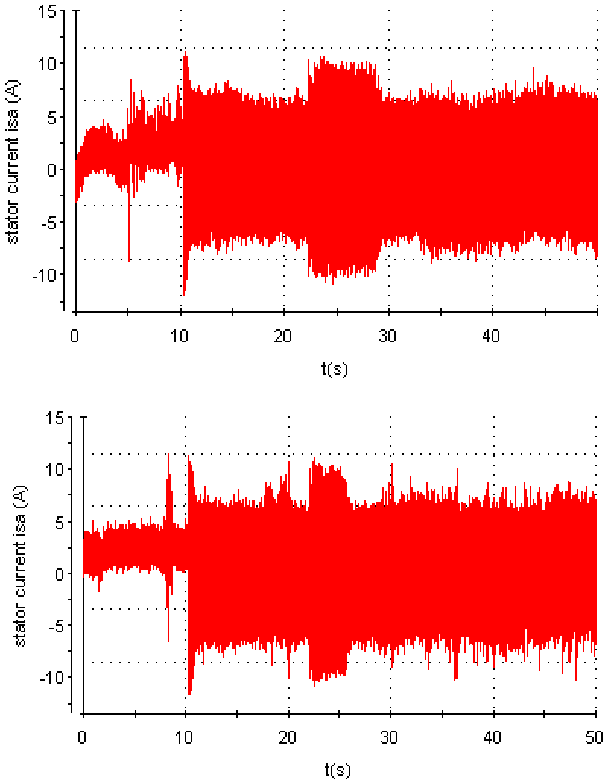


Fig. 14. (a) Measured stator current of asynchronous motor drived by IRFOC using the fuzzy self-adjustable proportional integral controller; (b) the standard PI controller in case of a change in load torque

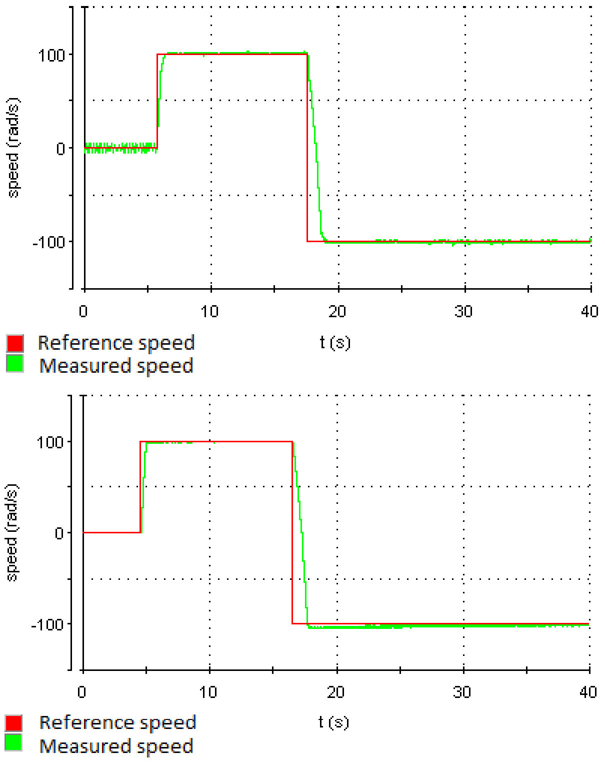


Fig. 15. (a) Response of the rotor speed of the asynchronous motor drived by IRFOC using the fuzzy self-adjustable proportional integral controller; (b) the standard PI controller in case of change of direction of rotation of the rotor (high speeds).

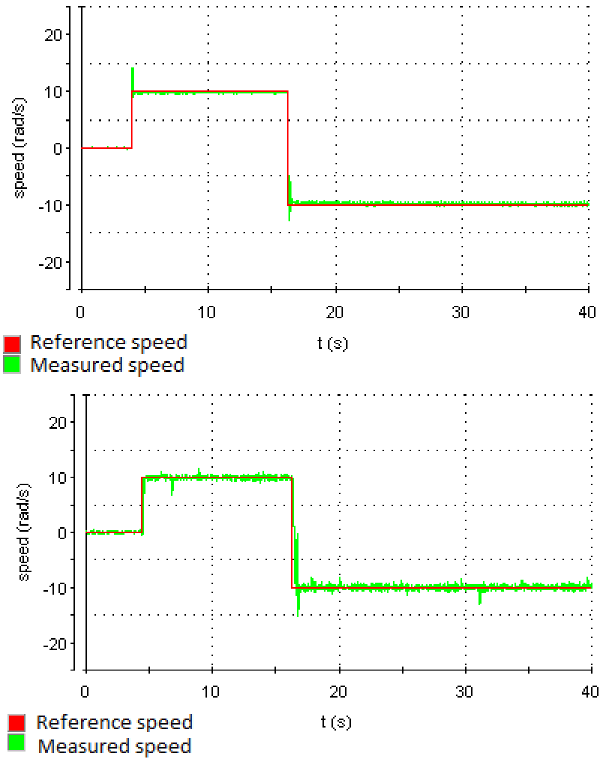


Fig. 16. (a) Response of the rotor speed of the asynchronous motor drived by IRFOC using the fuzzy self-adjustable proportional integral controller; (b) the standard PI controller in case of change of direction of rotation of the rotor (low speeds).

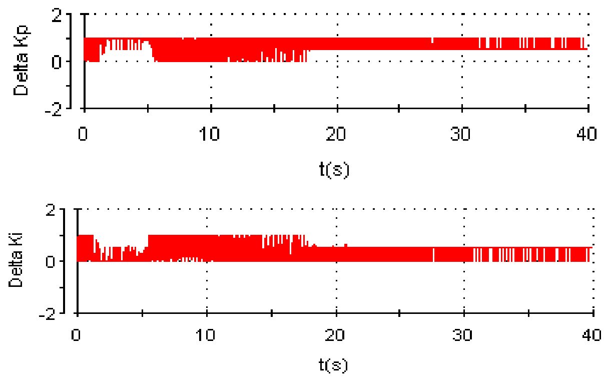


Figure 17. Response of adaptive gains of the fuzzy self-adjustable proportional integral controller ΔK_P (a), ΔK_I (b)

V. CONCLUSION

In this paper, the authors propose an intelligent controller, the fuzzy self-adjustable proportional integral controller, applied to the indirect rotor field oriented control to enhance its performances. This drive has been implemented in real time using dSPACE system and the experimental results were satisfactory. The proposed controller presents high performance of speed tracking even in low speeds and a high ability to oppose the disturbances of the parameters of the asynchronous motor.

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