Inverse Fuzzy Model Control for a Speed control Induction Motor Based dSPACE Implementation

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Abstract - **In this paper, a new control strategy for a three-phase induction motor is designed and implemented. In order to obtain high performance speed response, field oriented control techniques are usually used to control the torque and flux separately as in direct current machines. The application of fuzzy logic in modeling of uncertainly dynamical systems is in progress; however fuzzy modeling is one of the major topics in the field of modeling of dynamical systems. The authors has made an effort to develop an inverse fuzzy model of the field oriented control applied to the induction motor to successfully improve the classical approach of the field oriented control. Experimental results based on the use of DS1103 DSP of DSPACE verify the robustness of the proposed control.**

Keywords: Fuzzy Modeling, Inverse fuzzy model, Induction Motor Control, Vector Control, dSPACE implementation.

I. Introduction

Vector control has been widely used for the high-performance drive of the induction motor. As in dc motor, torque control of the induction motor is achieved by controlling torque and flux components independently. Vector control techniques can be separated into two categories : direct and indirect flux vector orientation control schemes. For direct control methods, the flux vector is obtained by using stator terminal quantities, while indirect methods use the machine slip frequency to achieve field orientation.

The overall performance of field-oriented-controlled induction motor drive systems is directly related to the performance of current control. Therefore, decoupling the control scheme is required by compensation of the coupling effect between q-axis and d-axis current dynamics [1,2 and 3].

All high-performance vector-controlled induction motor drives require accurate rotational speed or rotational position information for feedback control. This information is provided by an incremental encoder, which is the most common positioning transducer used today in industrial applications. The use of this sensor implies more electronics, higher cost, lower reliability, difficulty in mounting in some cases such as motor drives in harsh environment and high speed drives, increase in weight, increase in size, and increase electrical susceptibility.

Due to new developments, the fuzzy modeling is the application of fuzzy set theory (FST) to the representation of the essential features of a system [4,5,9,10,14 and 15]. An important characteristic of FST is that it provides a suitable representation of uncertainty in system knowledge and dynamic models. The basic principle of fuzzy modeling was stated by as follows [4 and 5]:

1- The use of "linguistic variables" in place of or in addition to numerical variables.

2- The characterization of simple relations between variables by "conditional fuzzy statement".

3- The characterization of complex relations by "fuzzy algorithms".

Fuzzy modeling has been investigated by different researchers [6,7,8,9,10 and 11]. As discussed in [12], there are different approaches to fuzzy modeling found in the literature. In this paper we use a category of description of dynamic process behavior by means of fuzzy functional equations, assuming knowledge about the structure of the process being studies. We concentrate in this paper on inverse fuzzy model of the field oriented control applied to the induction motor to successfully improve a field oriented control and to give a simple model of field oriented control bloc using a fuzzy sets theory such as simplicity of implementation and performance of fuzzy sets.

II. Classical Vector control

The induction motor is controlled in a synchronously rotating reference frame with the d-axis oriented along the rotor-flux vector position. In this way, a decoupled control between the electromagnetic torque and the rotor excitation current is obtained. Consequently, the dynamic equation of the induction motor model established in the oriented d-axis rotor flux field is then given by [14 and 15]:

$$\frac{d}{dt}\begin{pmatrix} i_{ds} \\ i_{qs} \\ \Phi_r \\ \Omega \end{pmatrix} = \begin{pmatrix} -\gamma i_{ds} + \omega_{ss} i_{qs} + \frac{k}{T_r}\Phi_r + \frac{1}{\sigma L_s} v_{ds} \\ -\gamma i_{qs} - \omega_{ss} i_{ds} - pk\Phi_r\Omega + \frac{1}{\sigma L_s} v_{qs} \\ \frac{L_m}{T_r} i_{ds} - \frac{1}{T_r}\Phi_r \\ \frac{pL_m}{JL_r}(\Phi_r i_{qs}) - \frac{C_r}{J} \end{pmatrix}$$

Where

s, r : subscripts denoting stator and rotor

i_{ds}, i_{qs} : stator current $d-q$ axis components

v_{ds}, v_{qs} : stator voltage $d-q$ axis components

R_s, R_r : stator, rotor resistances

L_s, L_r : stator, rotor inductances

L_m : mutual inductance

T_r : rotor time constant

σ : total leakage coefficient

p : number of pole pairs

Ω : mechanical angular speed

Φ_{dr}, Φ_{qr} : rotor flux $d-q$ axis components

Φ_r : rotor flux command

ω_s : stator pulsation

C_e : electromagnetic torque

C_r : load torque

J : moment of inertia

III. Fuzzy Modeling Algorithm

Four steps are necessary for the proposed algorithm [7, 14 and 15]:

Step1:

The starting point of the proposed Inverse Fuzzy modeling approach is to defined and construct a fuzzy partition of the universe of discourse of each component of the control input vector.

Step 2:

Now, the problem is how to construct the fuzzy map $\tilde{f}^{-1}(.)$, given the functions $f^{-1}(.)$, and the fuzzy partitions defined in Step 1.

Step 3:

A fuzzy partition is realized by associating by membership function to each interval.

Step 4:

Finally in this step we define the fuzzy rules. In summary, the above four steps generate the inverse fuzzy model.

IV. ARCHITECTURE OF THE PROPOSED INVERSE FUZZY MODEL

The architecture of the Inverse Fuzzy Model is shown in Fig. 1 [14 and 15]. The bloc consists of the intelligent inverse model of the induction motor with the use of the classical field oriented control principle using fuzzy modeling approach to construct a new intelligent control schema of the motor.

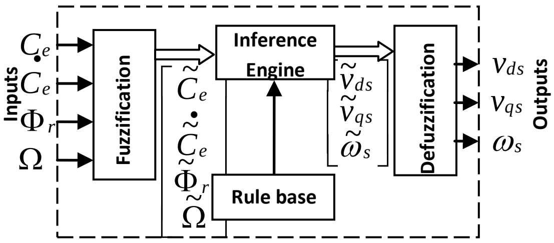


Fig. 1. Architecture of the Inverse Fuzzy Model

The new model is equipped with a fuzzy tuning algorithm that updates the values of the statorique voltage and synchronous pulsation. This new bloc has four inputs and three output [14 and 15]. The inputs are the electromagnetic torque, the derivative of electromagnetic torque, the rotor flux and rotor speed, with each of these inputs corresponding to a fuzzy variable [14 and 15]. The output is the fuzzy control decision.

In this way, for any given value of the inputs, the degree of membership µ, to which it belongs to each of these sets, can be determined from the classical field oriented control equations with the use in consideration of the parameters variation, and a control decision based on this information can be obtained.

The next step in the design of the inverse fuzzy model is the determination of the fuzzy IF-THEN inference rules. The number of fuzzy rules that are required is equal to the product of the number of
fuzzy sets that make up each of the four fuzzy input variables. For the inverse fuzzy model described in, the inputs variables representing the electromagnetic torque, the derivative of electromagnetic torque, the rotor flux and rotor speed consists of four fuzzy sets each. Thus, a total of 6561 fuzzy rules are required. The fuzzy inference rules have been determined using the model of the induction motor [14 and 15]. A typical fuzzy rule is of the form:

$$R^{(k_1,k_2,\ldots,k_n)}:$$

$$IF \quad \underline{y} \quad is \quad F_{\underline{y}}^{(k_1,k_2,\ldots,k_n)} = [F_{y_1}^{k_1},\ldots,F_{y_n}^{k_n}]_T,$$

$$THEN \quad \underline{u} \quad is \quad F_{\underline{u}}^{(k_1,\ldots,k_n)} = [F_{u_1}^{(k_1,k_2,\ldots,k_n)},\ldots,F_{u_m}^{(k_1,k_2,\ldots,k_n)}],$$

Where **y** is the output of the model, **u** the input.

The rule strength represents the degree of membership of the outputs variables. The fuzzy inference engine uses the appropriately designed knowledge base to evaluate the fuzzy rules and produce an output for each rule. Subsequently, the multiple outputs are transformed to a crisp outputs by the defuzzification interface. Once the aggregated fuzzy set representing the fuzzy outputs variables has been determined, an actual crisp control decision must be made. The process of decoding the outputs to produce an actual value for the control signal is referred to as defuzzification.

V. SIMULATION AND EXPERIMENTALRESULTS

The simulation test fig. 2 it consisted of a no load starting of the motor with a reference speed $\Omega^* = 100 rad/s$ and $\Phi_r = 1Wb$. A load torque $C_r = 10N.m$ was then applied between $t = 1s$ and $t = 2s$, followed by an inverse of speed from $\Omega^* = 100 rad/s$ to $\Omega^* = -100 rad/s$ is applied at $t = 3s$.

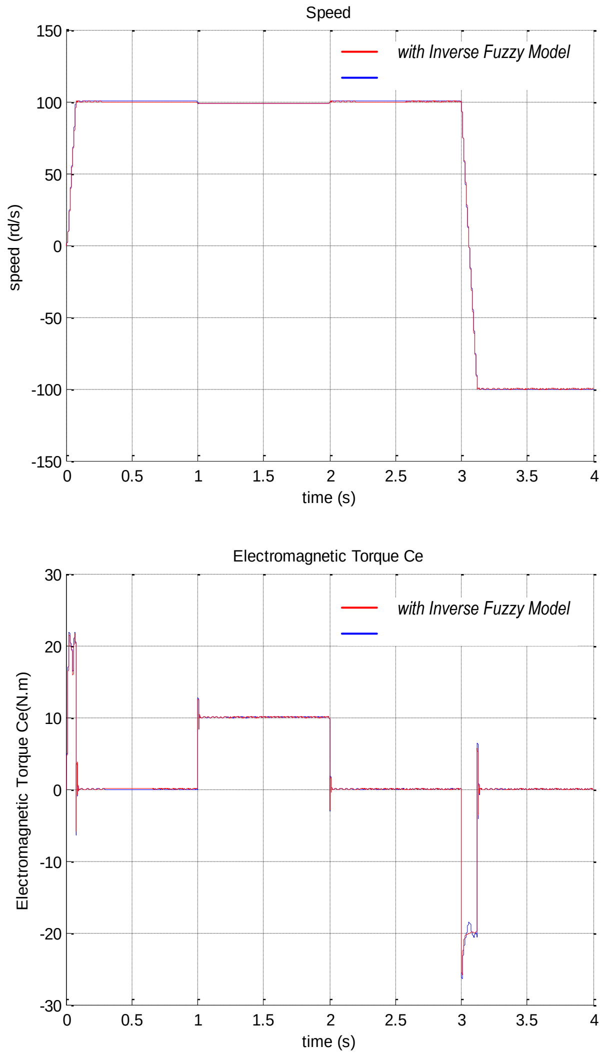


Fig. 2. Simulation results of the comparison between the Inverse Fuzzy Model and the Vector Control of the Induction Motor

The control system topology is composed of four major elements: the dSPACE DS1103 DSP-board, controlled process (induction motor coupled with DC generator as a dynamic load), driving circuit, and the personal computer (PC). The dSPACE DS-1103 DSP board [16] forms the core of the closed loop system. Aside from the duties of controlling the operator interface, it performs the acquisition of the feedback signal, computes an speed signal, delivers the speed signal to the control algorithm, and executes the control algorithm to determine a control signal. The control algorithm is build within Simulink environment combined with the Real-Time Interface (RTI) provided by dSPACE and is implemented by the main processor of the DS-1103 board in real-time fig. 3.

The motor is 1425 r/min three-phase. It is equipped with tachometric generator and is coupled via a torque transducer. The motor is also coupled with a DC Generator as a dynamic load. A variable resistive load is connected to the terminals of the DC generator. To achieve sudden disturbances, the switches of the resistive load are turned ON and OFF. The DS815 driver board is interfaced with the PC through the DS1103 board. After programming the driving board the actual speed can be monitored and serve as a source of feedback signal for the control algorithms.

A lowpass third order Butterworth filter is used for noise elimination and the cut-off frequency is 5 rad/s. A variable auto-transformer is used to supply the driving circuit with ac voltage of 230V. A power supply is also used to supply the inverter component of the driving circuit with 24V DC. The PC is a Pentium III 700-MHz with Windows XP. Fig. 4 displays a photo of the experimental apparatus.

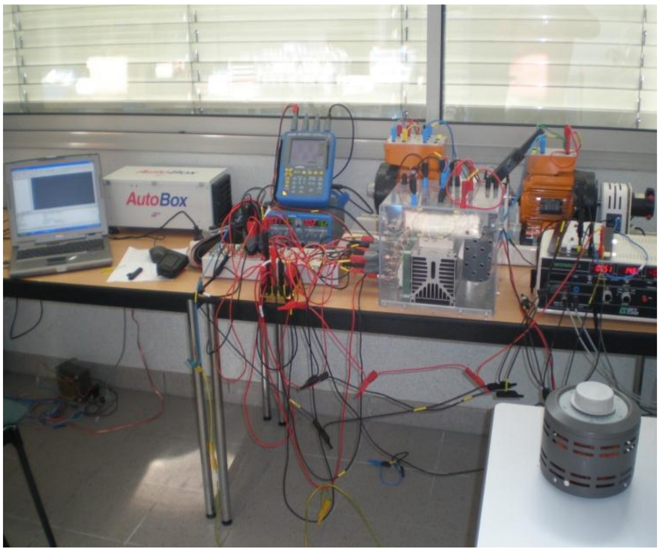
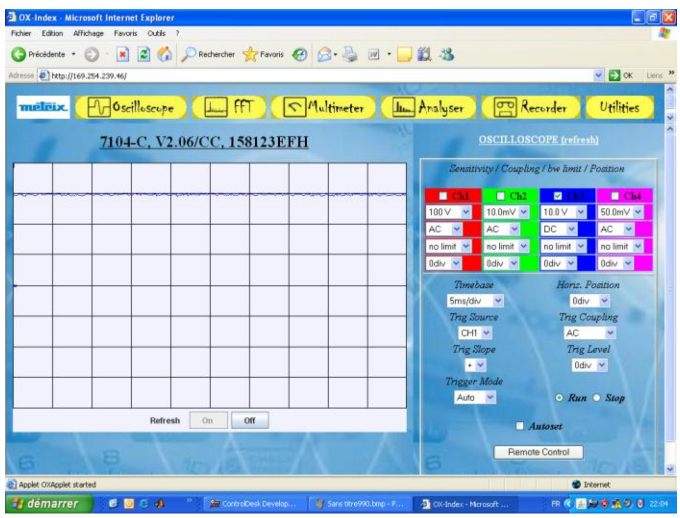


Fig. 4. Photo of the experimental apparatus

We operated the hardware and observed the closed loop performance of the proposed inverse fuzzy model. Fig. 5 illustrate the closed loop speed response for input step signal, the fed voltage and courant signal of induction motor. It has been observed that the speed response has a slight steady state error, even though the system is stable. We believe that the slight steady state error is due to the non-ideal characteristics of the induction motor drive system.

The controller based Inverse Fuzzy Model prototype has been set up with the same parameters as the simulation [14 and 15]; the results are similar to the simulation results.



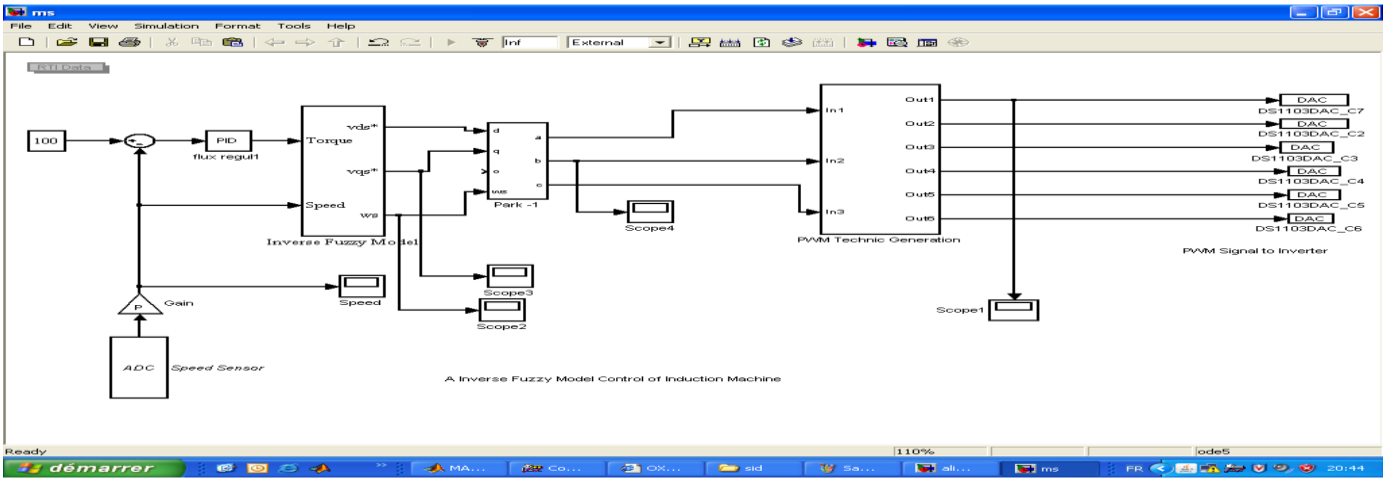
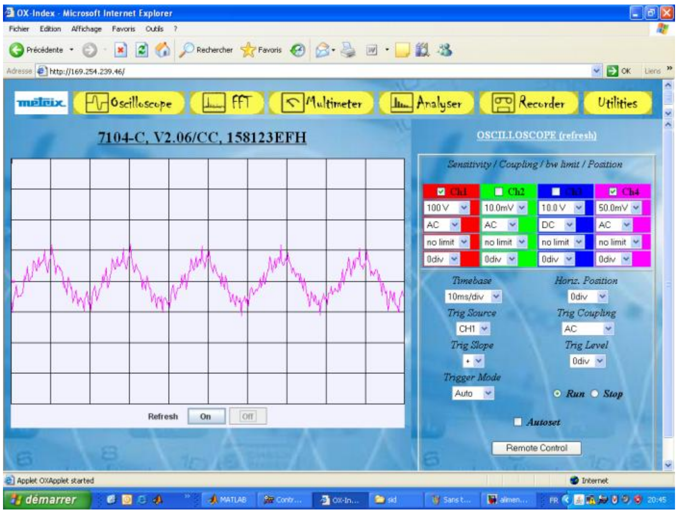
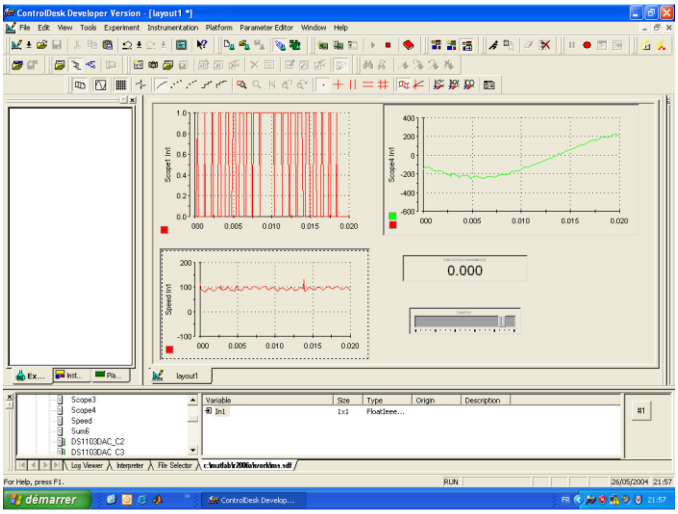


Fig. 3. Real-Time control prototyping





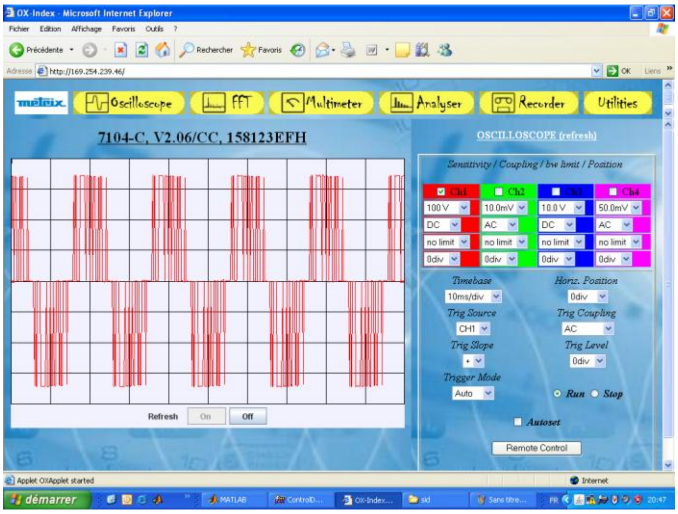


Fig. 5. Experimental fed and speed response of the induction motor

Control Desk is a user interface that allows the user to run simulations on different platforms such as the real-time DS1103 Controller Board, fig. 6 shown a speed response in Control Desk for download to dSPACE [16 and 17].

VI. CONCLUSION

This paper makes a contribution to the issue of FOC of induction motor drive using an new approach by an inverse fuzzy model control scheme. A new method has been presented that is able to perform at nominal and low speed control of induction motor drive. What is really new, compared to previous works in the literature, is the use of the fuzzy modeling to control method the induction motor. Particularly, good performances have been obtained at locked rotor condition, while degradation due to stator resistance variation caused by temperature is taken into account, it is an intelligent control schema. Simulation and experimental results have shown the practical feasibility of the proposed approach that allows robust control of the induction. All experimental results confirm the good dynamic performances of the developed drive systems and show the validity of the proposed method. The combination of dSPACE DS1103 DSP and MATLAB/Simulink/RTW effectively created a rapid control prototype environment, in which the designer focused on control design rather than programming details or debugging control languages. In this way, the environment offers an unparalleled experience and is a great source of attracting motion control engineers and practitioner and exciting their interest.

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