JOURNAL OF CURRENT RESEARCH IN SCIENCE (ISSN 2322-5009)
2013, Vol. 1, No. 3, pp:118-122
Available at www.jcrs010.com

ORIGINAL ARTICLE

HIGH-PERFORMANCE SCALAR CONTROL OF INDUCTION MOTOR DRIVES USING A FUZZY LOGIC AND SLIDING MODE SPEED CONTROLLERS

Cherifi DJ[1], Miloud Y[2]
1- Department of Electrical Engineering, University of Sciences and Technology of Oran (USTO), Algeria
2- Department of Electrical Engineering, University Dr. Moulay Tahar Saida, Algeria

ABSTRACT: This paper presents a control method with fuzzy logic controller to regulate the speed of an induction motor. The performances of the fuzzy logic controller are compared with a sliding mode controller. Both controllers are implemented using a testing bench and a simple cassy card. The experiment results are very satisfactory.
KEYWORDS: Induction Motor, Sliding Mode, Fuzzy Logic, Scalar Method, Speed Control.

INTRODUCTION

Scalar control as the name indicates, is due to magnitude variation of the control variables only, and disregards the coupling effect in the machine. Scalar-controlled drives have been widely used in industry the fact that they are easy to implement (Bose, 2002; Bose, 1985; Kioskeredis and Margaris, 1996; Mudi and Pal, 1999). In this paper, a scalar control method is associated with fuzzy logic control to regulate the speed of an induction motor. A sliding mode controller is compared practically to fuzzy logic controller using a simple cassy card. The robustness of these regulators is also verified by changing the load torque and speed tracking at full load. The first part of this paper concerns the presentation of the volt/hertz scalar control scheme. Then, the topology of the fuzzy logic and sliding mode controller is presented. The results obtained experimentally with fuzzy logic controller are compared with sliding mode controller.

CONTROL STRATEGY

Scalar Volts/Hertz Control

The proposed strategy is based on simplified volts/Hertz control scheme with stator frequency regulation ω_s as shown in figure 1. For adjustable speed applications, voltage is required to be proportional to frequency so that the flux remains constant ($\psi_{s=} v_s/\omega_e$), neglecting the stator resistance Rs drop. Figure 1 shows the block diagram of the volts/Hz speed control method (Kioskeredis and Margaris, 1996). The power circuit consists of a diode rectifier with three-phase ac supply, LC filter, and PWM voltage-fed inverter. Neglecting the small slip frequency ω_{sl} of the machine, the frequency command ω_e is generated through the regulator and limiter. The frequency command ω_e also generates the voltages command (v^*_a, v^*_b, v^*_c) through a volts/Hz function generator, which incorporates the low-frequency stator drop compensation (V_0). The boost voltage V_0 is added so that the rated flux and corresponding full torque become available down to zero speed. At higher frequencies the boost voltage becomes negligible. The ω_e signal is integrated to generate the angle signal θ_e, and the corresponding phase voltages (v^*_a, v^*_b, v^*_c signals) are generated by the expressions shown in figure 1.

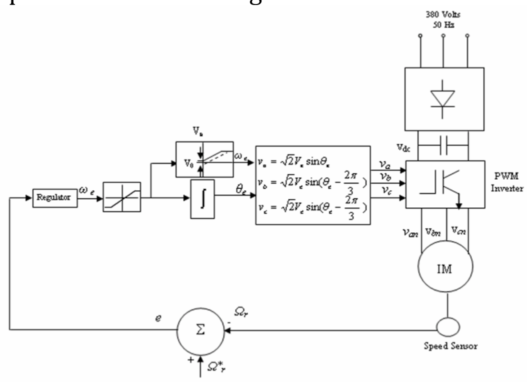

Figure 1: Scalar Control Scheme.

DESIGN OF A FUZZY LOGIC SPEED CONTROLLER

The fuzzy logic is utilized to design controllers for plants with complex dynamics that often cannot be precisely known. In a motor control system, the function of a fuzzy logic controller is to convert linguistic control rules into control strategy based on heuristic information or expert knowledge (Miloud and Draou, 2001). The fuzzy logic control approach is very useful for induction motor speed drives since no exact mathematical model of the induction motor or the closed-loop system is required (Mudi and

---

Corresponding Author: Cherifi DJ, Department of Electrical Engineering, University of Sciences and Technology of Oran (USTO), Algeria. **Email:** do_science@yahoo.com

Pal, 1999; Lai *et al.*, 1999).

A fuzzy logic controller (FLC) has a fixed set of control rules, usually derived from expert's knowledge. The membership function (MF's) of the associated input and output linguistic variables is generally predefined on a common universe of discourse. For the successful design of FLC's proper selection of input and output scaling factors (SF's) and/or tuning of the other controller parameters are crucial jobs, which in many cases are done through trial and error to achieve the best possible control performance (Bose, 2002).

The block diagram showing the implementation of the FLC is illustrated in Figure 2. It includes four major blocks: knowledge base, fuzzification, inference mechanism, and defuzzification. The knowledge base is composed of a data and a rule base. The database, consisting of input and output membership functions, provides information for the appropriate fuzzification operations, the inference mechanism and defuzzification. The rule base is made of a set of linguistic rules relating the fuzzy input variables to the desired fuzzy control actions. The actual inputs to the fuzzy system are e_N and Δ_{eN}, which are a scaled version of the speed error and the change in speed error as defined by (1) and (2). The gains G_e and $G_{\Delta e}$, can be varied to tune the fuzzy controller for a desired performance. The output gain, $G_{\Delta u}$ can also be tuned.

$$e_N = G_e\,(\Omega^*-\Omega_r) = G_e\, e \qquad (1)$$

$$\Delta_{eN} = G_{\Delta e}\,\Delta e \qquad (2)$$

FUZZIFICATION, INFERENCE AND DEFUZZIFICATION

The input variables are normalized to an 'universe of discourse' with scaling factors.

Using these normalized quantities, the fuzzy logic controller inputs can be described by membership factors for every linguistic code. This operation which is called ''Fuzzification'', requires the definition of linguistic sets and their membership functions. We have chosen three linguistic sets (NB, ZE, PB) for the error, the change of error and for the output.

We have used trapezoidal and asymmetric triangular shapes for the error, the change of error and output. The membership functions are defined in the interval [-1, 1]. The values of the actual inputs e and Δ_e are mapped onto [-1, 1] by the input SF's G_e and $G_{\Delta e}$, respectively.

The inference engine, based on the input fuzzy sets, uses the appropriate IF-THEN rules in the knowledge base to make decisions, where the Max operation is used for the premises and the Min operation is used for the implication. The implied fuzzy set is transformed to a crisp output by the center of gravity defuzzification technique as given by the formula (3), Z_i is the numerical output at the ith number of rules and $\mu(Z_i)$ corresponds to the value of fuzzy membership function at the ith number of rules as shown in Figure 3. The summation is from one to n, where n is the number of rules that apply for the given fuzzy inputs. The output of the fuzzy controller is integrated to give the stator speed command.

$$Z_0 = \frac{\sum_{i=1}^{n} z_i \cdot \mu(z_i)}{\sum_{i=1}^{n} \mu(z_i)} \qquad (3)$$

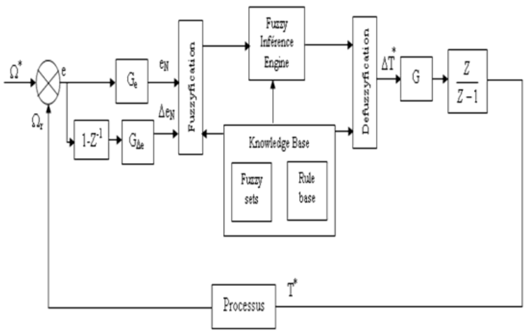

Figure 2: Fuzzy Controller block diagram.

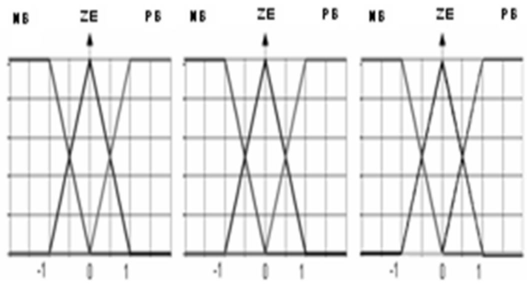

Figure 3: Input and output membership functions.

The fuzzy controller's strongest asset is the knowledge base. By carefully designing the knowledge base, the expert's experience is incorporated into the fuzzy controller.

Table1: Fuzzy controller rule base.

Δ_{eN} / e_N	NB	ZE	PB
NB	NB	NB	ZE
ZE	NB	ZE	PB
PB	ZE	PB	PB

This experience is synthesized by the choice of the input-output membership functions and the rule base. In general uniformly distributed triangular membership functions are used in order to simplify the digital implementation. The ranges for the input and output membership functions are as shown in Figure 3. The complete control rules used in our system are shown in table 1. They are developed based on expert knowledge. The linguistic labels contained in the table are:

NB	:	Negative Big
ZE	:	Zero
PB	:	Positive Big

Given these rules and membership functions, the fuzzy controller produces the crisp and continuous non-linear I/O map as shown in figure 4.

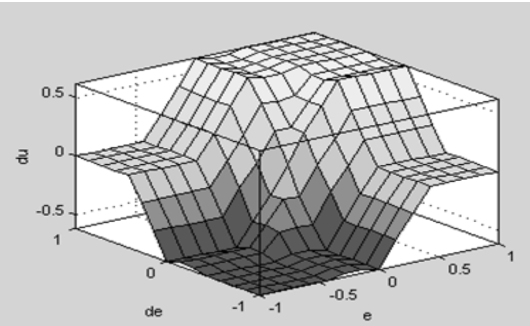

Figure 4: Output of fuzzy logic controller

DESIGN OF A SLIDING MODE SPEED CONTROLLER

A sliding mode control (SMC) with a variable control structure is basically an adaptive control that gives robust performance of a drive with parameter variation and load torque disturbance. The control is nonlinear and will be applied to a linear or nonlinear plant (Bose, 1985; Garcia *et al.*, 1998). In a SMC, as the name indicates, the drive response is forced to tract or "slide" along a predefined trajectory or "reference model" in a phase plane by a switching control algorithm, irrespective of the plant's parameter variation and load disturbance, Figure 5. This is achieved by using a set of switching control laws. In performance, it is somewhat similar to a MRAC, but the design and implementation of a SMC are somewhat simpler. SMCs can be applied to servo drives with dc motors, induction motors, and synchronous motors for applications such as robot drives, machine tool control, etc. (Bose, 2002; Koga *et al.*, 1990).

A typical SMC drive system is shown in Figure 6. In speed control drive using the SMC, the actual speed is required as feedback signal. It is easy to obtain. We will now apply a SMC to a scalar method for an induction machine drive and develop design criteria for the controller's parameters (Edward, 1991). The sliding line equation is given by:

$$\sigma = cx_1 + x_2 = 0 \qquad (4)$$

Where:

c: represents the slope of the sliding line

x_1: The speed error ($x_1 = \Omega_r^* - \Omega_r$)

x_2: The acceleration ($x_2 = \frac{dx_1}{dt}$)

SMC law can be defined mathematically as:

$$U = \psi_1 x_1 + \psi_2 x_2 \qquad (5)$$

Where:

$\psi_1 = \alpha_1$ if $\sigma x_1 \geq 0$

$=\beta_1$ if $\sigma x_1 \langle 0$

$\psi_2 = \alpha_2$ if $\sigma x_2 \geq 0$

$=\beta_2$ if $\sigma x_2 \langle 0$

As indicated in Figure 6.

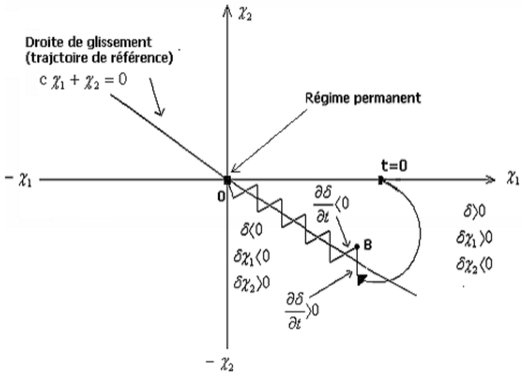

Figure 5: Sliding line control in phase plane X_1–X_2.

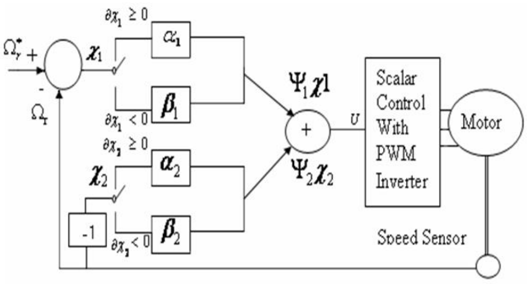

Figure 6: Scalar control showing sliding mode control in detail.

IMPLEMENTATION

Description of the Control System

The fuzzy control is implemented on the test bed on figure 7. This variable speed drive includes a 1 Kw three-phase induction motor fed by an IGBT (Insulated Gate Bipolar Transistor) PWM voltage source inverter. The rotor speed is captured with a classical sensor which gives 1000-rpm for 1V. A DC generator allows producing simple load variations. The control algorithms are developed in Turbo Pascal language in a Pentium I. A cassy card is used to transfer the input speed to the computer after being filtered and then will be compared to the reference. The speed error is then introduced to the regulator to give the frequency command ω_e which will be used as an input to the inverter through the cassy card. The sampling frequency for the FLC, sliding mode controller is 600 Hz and the maximum frequency for the cassy card is only 1 Khz. However, the program for the FLC should be optimized to have less computational time. For that reason, only 9 rules are used.

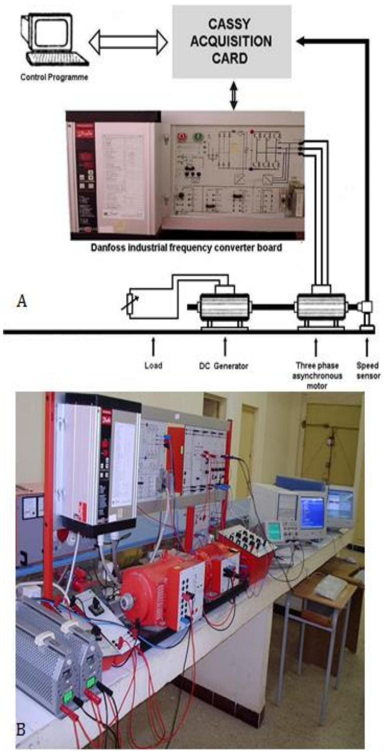

Figure 7: Test bed of a scalar controlled induction motor. **A,** Test bed structure; **B,** Test bed photograph.

RESULTS

In this section, the experimental results for a 1 Kw cage rotor induction machine, using the fuzzy controller described in section III, is compared to a sliding mode controller. The machine parameters are given in table 2.

Table 2: Induction motor parameters

1Kw, 2880rpm	R_s=6.18Ω L_s=695mH
380V, 2.2A	R_s=4.38Ω L_s=695mH
3 phases, 50Hz, 2 poles	L_m=678mH

Figure 8 and 9 show the disturbance rejection of each controller when the machine is fully loaded and operated at 2000 rpm and a load disturbance torque (1-Nm) is suddenly applied first at 7.8 s and then at 13s. The fuzzy controller rejects the load disturbance very quickly whereas; the sliding mode controller takes much longer to return to speed command. The hardiness of the regulator to fuzzy logic is very fattening pond in the experimental results by contribution to the sliding mode. Figure 10 and 11 Show the speed tracking performance with load, for both sliding mode and Fuzzy controllers respectively. One notes that the control by fuzzy logic is more effective and more robust than the control by sliding mode.

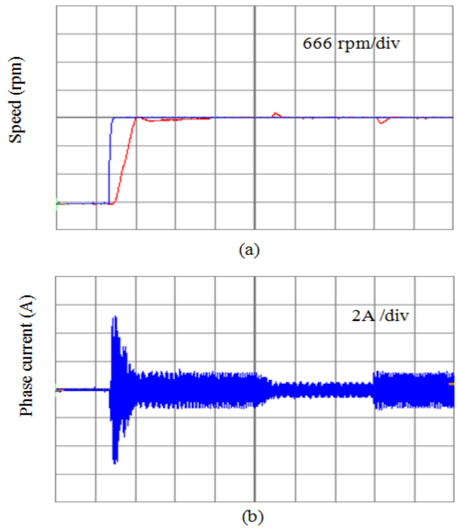

Figure 8: Experimental sliding mode controller Load Torque Disturbance ±(1Nm); (a) Speed, (b) Phase Current.

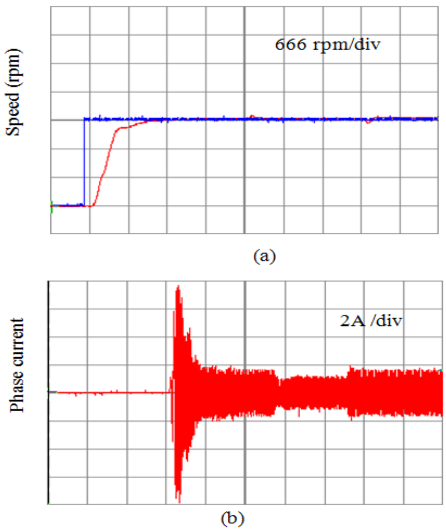

Figure 9: Experimental Fuzzy controller Load Torque Disturbance ± (1Nm); (a) Speed, (b) Phase Current.

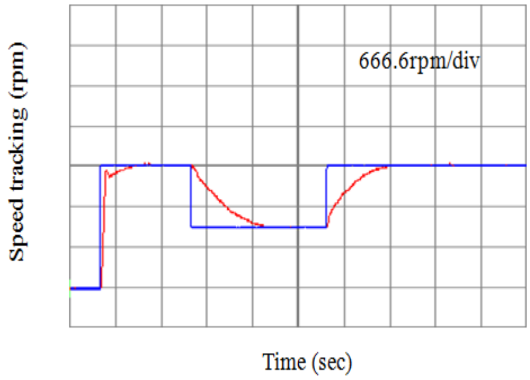

Figure 10: Experimental speed tracking of sliding mode controller.

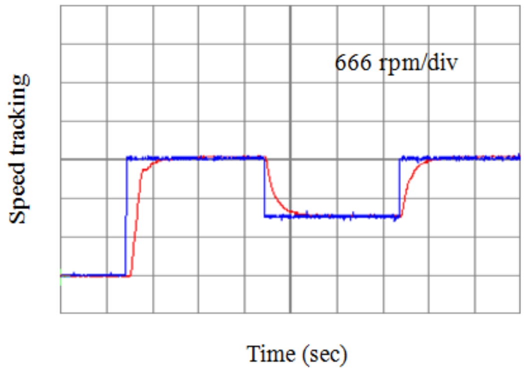

Figure 11: Fuzzy Experimental Speed Tracking.

CONCLUSION

A comparison between a FLC controller and a sliding mode controller for scalar control has been presented in this paper. The proposed FLC controller consisting of three linguistic sets in the output of the rule base and uniformly distributed triangular membership functions gave very satisfactory results in terms of load disturbances rejection and tracking speed. The implementation of the whole system was carried out by using very simple equipment with good experimental results.

REFERENCES

Bose BK. Modern Power Electronics and AC Drives. Prentice-Hall, Upper Saddle River, NJ 2002.

Bose BK. Sliding mode control of induction motor. IEEE IAS Annu. Meet Conf Rec 1985;pp:479-486.

Edward YY-HO. Control Dynamic of Speed Drive systems using sliding mode controller with integral compensation. Member IEEE and paresh c. sen. Fellow. IEEE 1991.

Garcia AM, Lipo TA, Novotny DW. A New Induction Motor V/f Control Method Capable of High-Performance Regulation at Low Speeds. IEEE Trans on Industry Applications 1998;34(4):813-221.

Kioskeredis I, Margaris N. Loss Minimization in Scalar-Controlled Induction Motor Drives with Search Controllers on Power Electronics 1996;11(2):213-220.

Koga K, Ueda R, Sonoda T. Constitution of V/f Control for reducing the steady state speed error to zero in induction motor drive system. Conf Rec. IEEE-IAS Annu. Meeting 1990;pp:639-646.

Lai M-F, Nakano M, Hsieh G-C. Application of Fuzzy Logic in the Phase-Locked Loop Speed Control of Induction Motor Drive. IEEE Trans Industrial Electronics 1999;43(6):630-638.

Miloud Y, Draou A. Fuzzy Logic Speed Control of an Indirect Field-Oriented Induction Machine Drive. Conf. Rec. IEEE/IECON'01 Denver, USA 2001;pp:2111-2116.

Mudi RK, Pal NR. A Robust Self-Tuning Scheme for PI-and PD-Type Fuzzy Controllers. IEEE Trans Fuzzy Systems 1999;7:2-14.