Simulation and Control of AC/DC Converter & Induction Machine Speed Using Adaptive Fuzzy Controller

A. Ghamri*, M.T. Benchouia*, M.E.H. Benbouzid,**, A. Golea*, S.E. Zouzou*.
*Laboratory L.G.E.B., Department of Electrical Engineering, Biskra University, Algeria
benchouiat@yahoo.fr
**Laboratory L.I.M.E., Department GEII – IUT, Brest University, France
m.benbouzid@ieee.org

Abstract- **This paper investigates the application of fuzzy adaptive controller to the control of induction machine speed (AFCS) and the DC-link voltage of the AC/DC converter (AFCV). The proposed controller consists of two parts: the first one, is the classical fuzzy logic controller constituted by fuzzy If-Then rules, whose inputs are the speed or voltage error, and the change of speed or voltage error, and its output is the reference torque or current . The second part is the adaptation mechanism, which adjusts the output gain of the Fuzzy controller. The gain must be adapted at every situation of the system as a function of the error and its variation. We study the robustness of the controller using simulation results for different operating modes and parameters variation.**

I. INTRODUCTION

In last years, the induction motor (I.M) has find an increasing interest in many industrial applications, due to considerations of cost, size, low maintenance, speed capability and simplicity of design. However, the induction motor presents a coupled nonlinear multivariable control structure which calls for complex nonlinear design in order to achieve good dynamic performance. Control based on linear approximation do not always meet high dynamical performance requirements for variable speed regulation [1], [2]. A high performance motor drive system must provide good dynamic speed command tracking and load regulating. Moreover, the performances must be insensitive to the drive and load parameters variation. With the advent of fast microprocessors, high power switching, and considerable price of reduction, it has been possible to design more powerful control algorithms. Presently, typical control strategy for induction motors is the field oriented control, where suitable transformation of control inputs allows linear dynamic model and partly linear rotor speed to be obtained. The fundamental drawback of this decoupling approach is that highly accurate values of the motor parameters, such as rotor resistance or inductance and the rotor flux are required in order to produce the control signal. The controller performance is sensitive to “Inaccurate Decoupling” [3], [4].

In electric motor drives and motion control the Fuzzy controller is considered as promising alternative for conventional control approaches in the control of complex nonlinear plants. The Fuzzy controller is applied to static power converters, induction and DC motors. It has been reported that fuzzy controllers are more robust to plant parameter changes and have better disturbance rejection. The main advantage of fuzzy control as compared to conventional control resides in the fact that no mathematical model of the plant is required and the human experience can be implanted in the controller as fuzzy rules . However, classical Fuzzy controllers can not adapt themselves to changes in their environment or in operating conditions. Then, it is necessary to add some form of adaptation that updates the controller parameters in order to maintain and improve the control performance in wide range of changing conditions[5], [6].

The power converter connected to the line is usually used for both last drive cases as the well known three phase diode-bridge rectifier. In this converter, the power can only flow from the utility AC side to the DC side and the line current is not continuous. Because this type of AC-DC conversion does not controlled line current harmonics, the displacement power factor is poor and the DC side voltage is not constant .To remedy these disadvantages, a solution is a reversible converter to replace the diode-bridge rectifier and to permit a reversible power line flow which allows the energy recovered from motor-load inertia to be fed back to the utility supply. The DC-link voltage can be regulated by fuzzy logic controller [7], [8], [9].

In this paper, an adaptive fuzzy controller is applied in all regulation loops, starting from speed regulation of I.M until the control of DC-link voltage.

II. Model of the I.M

It is well known that the dynamic performance of the I.M can be analysed mathematically by using the d-q axis theory. By choosing the synchronous reference frame d-q, which is rotating synchronously with the supply voltage phasor, the electrical and mechanical instantaneous characteristics are given by the following equations [2], [13]:

$$\begin{bmatrix} v_{qs} \\ v_{ds} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + SL_s & \omega_s L_s & SL_m & \omega_s L_m \\ -\omega_s L_s & R_s + SL_s & -\omega_s L_m & SL_m \\ SL_m & \omega_{sl} L_m & R_r + SL_r & \omega_{sl} L_r \\ -\omega_{sl} L_m & SL_m & -\omega_{sl} L_r & R_r + SL_r \end{bmatrix} . \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \qquad (1)$$

$$T_{em} - T_l = J \frac{d\Omega}{dt} + B\Omega \qquad (2)$$

$$T_{em} = P \frac{L_m}{L_r} \left(\phi_{dr} i_{qs} - \phi_{qr} i_{ds} \right) \qquad (3)$$

It can be seen from the above equations that an induction motor is a non-linear system with cross-coupled control variables. However, according to the decoupling theory, the motor currents are decomposed into i_{ds} and i_{qs} components which are respectively flux and torque components. When the decoupling conditions are satisfied, namely, $\phi_{qr} = 0$ and $\phi_{dr} = \phi_r$ .Hence, the flux and the electromechanical torque are decoupled from each other and can be separately controlled as desired [1]. The operation of the drive is then similar to that of a current controlled dc motor. The drive behaviour can be adequately described by a simplified model expressed in the following equation[2].

$$T_{em} = P \frac{L_m}{L_r} i_{qs} \phi_r \qquad (4)$$

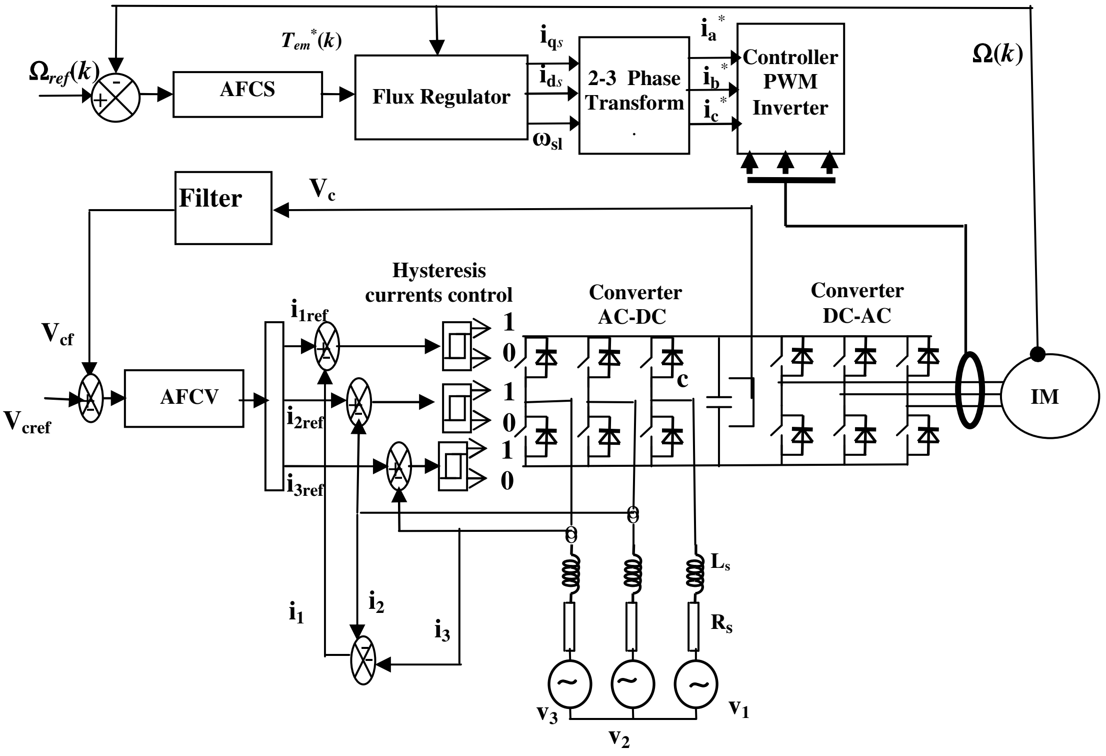

Fig.1. Main circuit with proposed control system.

III. CONTROL STRATEGY

The proposed system configuration is shows in Fig.1. The first controller (AFCS) is related to speed loop; its inputs are speed error and the change of speed error and generate the reference electromagnetic torque. The second controller (AFCV) is related to voltage loop, whose inputs are the error voltage and its variation. The output of the AFCV is reference current. The proposed control system shown in Fig. 1, it's composed by:

A. *Fuzzy Voltage Control*

The control of DC-voltage consists of two parts:

1. DC voltage control

The block diagram of fuzzy logic DC-link voltage control is shown in Fig.2 . The fuzzy controller is constituted by four stages: fuzzification, rules execution, defuzzification and adaptation mechanism of the gain.

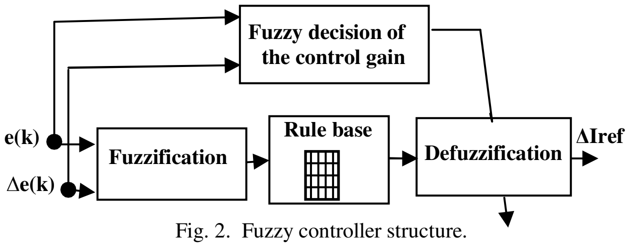

Fig. 2. Fuzzy controller structure.

The rule base is the principal component of the fuzzy controller; it indicates how the controller behaves to response to any input situation. The rule base is constituted by collection of If-Then rules of the form:

$$R_j : If\ e(k) is A_j\ and\ \Delta e(k) is B_j\ Then\ I_{ref}(k) is C_j \qquad j = 1..m \tag{5}$$

where A_j, B_j and C_j are fuzzy sets such as: NL (negative large), NM (negative medium), etc. defining fuzzy partition on the controller input space. With e(k) and Δe(k) are scaled and normalised version of the error $e_v(k)$ and the change of error $\Delta e_v(k)$ given by:

$$\begin{aligned} e_v &= v_{cf}(k) - v_{cref}(k) \\ \Delta e_v &= e_v(k) - e_v(k-1) \end{aligned} \tag{6}$$

where

$$\begin{aligned} e(k) &= \text{ge.}\ e_v(k) \\ \Delta e(k) &= \text{gce.}\ \Delta e_v(k) \end{aligned} \tag{7}$$

with ge and gce, constant inputs gain which play an essential role, since they determine the control performances. The expression "$e(k)$ *is* A_j" is implemented by membership function indicating the grade of membership of $e(k)$ in the fuzzy set A_j, this operation is called fuzzification. The shape of the membership function is quite arbitrary and depends on the user's preference. For simplicity, triangular and trapezoidal shapes are usually used. The logical operators "*and*" and "*Then*" can be interpreted as *min* or algebraic product, and various inference and defuzzification algorithms can be used to produce crisp output value. If the operators "*and*" and "*Then*" are implemented as algebraic product, the max-product inference and the center of gravity defuzzification methods are adopted in this paper.

In most fuzzy control studies, the gain associated with the control output must be constant and as low possible in order to a void the instability problem. This increases considerably the response time of the system. To solve this problem, we consider the output gain as a fuzzy variable[10]. Therefore the gain must be adapted at every situation of the system as a function of the error and its variation. We chose fuzzy sets of variable gain whose corresponding membership functions is represented by Fig.3. The decision matrix on the control gain is given in table I.

2. *Calculation of Reference Current*

The amplitude of the reference current is given by the following equation:

$$I_{ref}(k) = I_{ref}(k-1) + g_u(k).\Delta I_{ref}(k) \qquad (8)$$

If a sinusoidal line current is required, the current command (reference) should have the form:

$$I_{i\,ref}(k) = I_{ref}(k)\sin\left(\omega t - (k-1)\frac{2\pi}{3}\right) \qquad (9)$$

with i=1,2, or 3.

To obtain a very fast of the input converter, a hysteresis current technique can be adopted, which ensures that each line current follows its reference within the hysteresis band Δi The AC line current is controlled by the transistors converter in a bang-bang mode. A high switching frequency is given by the following equation:

$$f_{max} = \frac{U_{max}}{8L_s\Delta i} \qquad (10)$$

U_{max}: max value of line to line supply voltage.
L_s: the AC side inductance.
Δi: hysteresis band.

The achievable bandwidth of the current control loop depends on the switching frequency of the PWM converter.

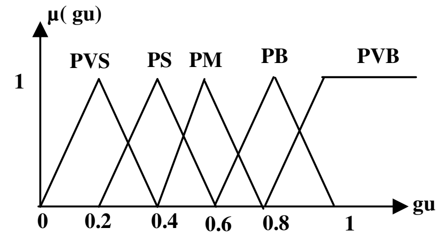

Fig. 3. Membership functions of the output gain.

TABLE I
Decision Control Gain

e / Δe	NB	NM	NS	ZE	PS	PM	PB
NB	PVB	PVB	PB	PM	PS	PVS	PVS
NM	PVB	PB	PM	PS	PVS	PVS	PVS
NS	PB	PM	PS	PVS	PVS	PVS	PS
ZE	PM	PS	PVS	PVS	PVS	PS	PM
PS	PS	PVS	PVS	PVS	PS	PM	PB
PM	PVS	PVS	PVS	PS	PM	PB	PVB
PB	PVB	PVB	PS	PM	PB	PVB	PVB

B. *Fuzzy Speed Control*

To control the speed of I.M using the fuzzy logic control, the input variables, are the speed error *e(k)* and the error change Δ*e(k)* defined as :

$$e(k) = \Omega_{ref}(k) - \Omega(k)$$
$$\Delta e(k) = e(k) - e(k-1) \qquad (11)$$

In loops speed regulation, we considerate the same strategy proposed for DC-voltage control. The output of AFCS can be calculated by:

$$T^*_{em}(k+1) = T^*_{em}(k) + g_u(k).\Delta T^*_{em}(k) \qquad (12)$$

g_u: variable gain.

IV. SIMULATION RESULTS

Simulation results for modeling and simulation of variable speed drive system with adaptive fuzzy controller are represented.

A . *Speed control*

The performances of AFCS control of induction motor speed is compared to conventional PI regulator by extensive simulation for various operating conditions and parameters variation. The coefficients of the designed PI are k_p=1.04; and k_i=20.08. First, transient responses to step change in reference speed (i.e., speed inversion) are obtained (see fig.4). It can be seen that the AFCS provides mush fast and robust speed response compared to the PI. The fig.5 shows that AFCS robustness to its fast response to any load torque variation (from zero to 12 Nm at 0.5s.).

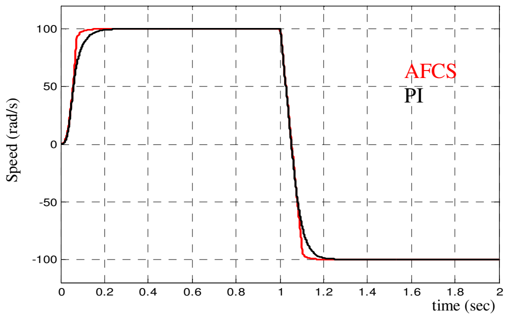

Fig.4 . Speed response (speed inversion).

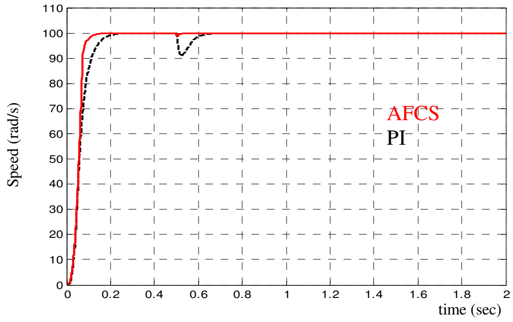

Fig.5 . Speed response (load torque change).

When the inertia moment change from J_n to $6.J_n$, the speed response with PI regulator (see fig.6) is affected considerably compared with the response of AFCS (see fig.7).

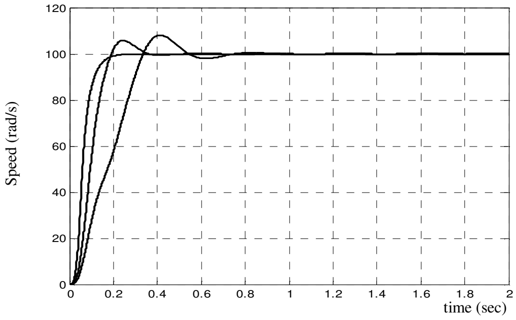

Fig.6 . Speed response with PI (inertia change).

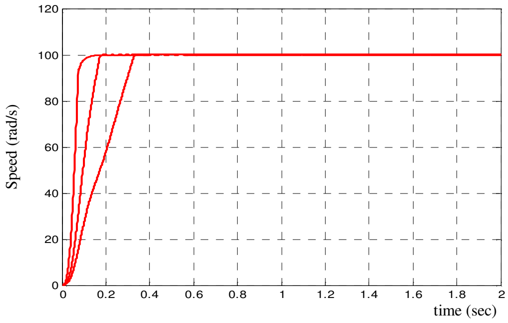

Fig.7 . Speed response with AFCS (inertia change).

B. Voltage control

Simulation results for the control of DC output voltage with adaptive fuzzy controller are represented. The following parameters: V_{RMS} =220V, Ls = 0.006mH, C = 200μF, Vcref = 440 V, τ_0 = 0.00025 s, τ_2 = 0.005 s, Δi = 0.5 A and sampling time Ts = 0.01 ms are used in simulation. Switch delay, dead times, on state voltages and snubbed network were neglected, unless the on-off behavior of all semiconductors.

The results show, a rapid transient response due to the starting of the machine and the DC voltage is well regulated around the reference V_{cref} = 440V (see fig. 8.). Fig.9, shows that the input current has a sinusoidal form and in phase with supply voltage, witch minimizes the reactive power consumed by the rectifier (see Fig.10.) .

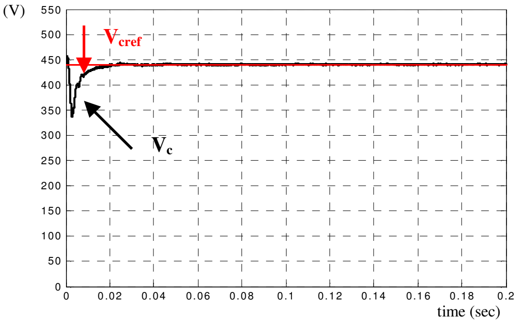

Fig. 8. DC link voltage.

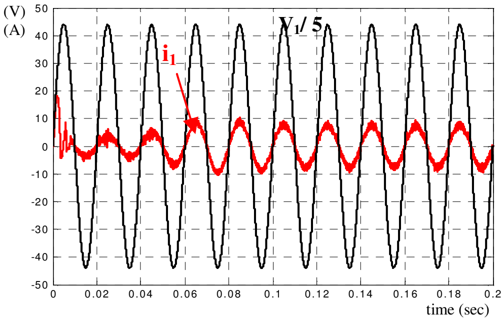

Fig. 9. Line voltage and supply current.

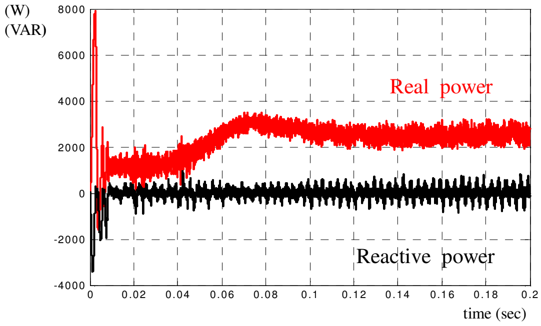

Fig.10. Input real and reactive powers.

To confirm the effectiveness of the proposed control, a double change of the reference is shown 440-540 and 400V. It can be noted that after the transient response, the DC voltage follows its reference; there is no overshoot and the settling time is very small (see Fig. 11). The stator currents are represented by Fig.12.

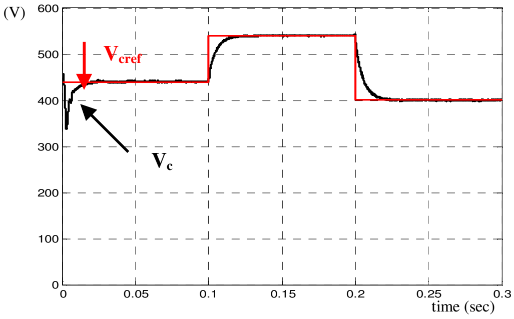

Fig. 11 DC link voltage.

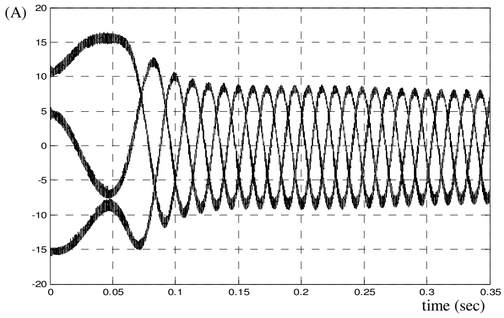

Fig.12. Stator currents.

V. CONCLUSION

In this paper, the fuzzy adaptive controller is applied in all regulation loops, starting from speed regulation of I.M until the minimization of reactive power consumed by the rectifier including the control of the DC-link voltage. Several tests have been performed in order to prove the efficiency of the type of the control. The Simulation has confirmed the validity of this technique. It can be readily implemented using conventional microprocessors or microcontrollers.

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