

FUZZY CONTROLLER DESIGN OF MULTI-MACHINES SYSTEM

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Abstract: This work is devoted to a multi-machine system using vector control and fuzzy logic regulator. A six-phase asynchronous machine connected in series with a three-phase one fed by a single inverter and controlled independently. Thanks to the powerful means of calculation, which made possible the control of such systems and this allows its integration in applications where the constraints of space and weight require a particular. In a real machine, the stator and rotor resistances are altered by temperature and the inductances are altered by the magnetizing current values that change degrades the system performances. This problem is solving by using fuzzy logic controller (FLC). Simulation results shows that FLC presents better performances and high robustness compared to the conventional Proportional Integral (PI) controller.

Key words: Multimachines system (MSCS), Vector control; Hexa-phase inverter, Fuzzy control (FLC).

1. Introduction

AC machines, induction in particular have dominated the field of electric machines. Recently, researchers are interested in machines with a number of phases greater than three. These machines are often called «multiphase machines». This type of machine have large losses and to exploit these, it is possible to connect in series several machines supplied by a single static power converter with each machine in the group have an independent speed control. However, the use of multiphase converters associated with polyphase machines, generates additional degrees of freedom. Thanks to these, several polyphase machines can be connected in series in an appropriate transposition phases [1, 4].

For some applications, series connection of multi-phases induction machines can be very interesting. The global system is defined as the domination of a series connected multi-machines mon-converter system (MSCS). This system consists of several machines connected in series in an appropriate transposition of phases. The whole system is supplied by a single converter via the first machine. The control of each machine must be independent of others [5-7].

In [17], the author uses a classical PI controller to perform a speed control of series connected machines. However, PI controller parameters are highly affected by the system parameters, a temperature rise can cause a degradation of the control quality.

Seen from this major drawback, contribution of this paper is to change conventional controllers “PI” with fuzzy logic controllers and test its robustness.

2. Modeling of multi-machine system

The drive system is composed by two induction machines. The first one is a symmetrical six-phase induction motor M(1) which its windings are series connected with that of a second three-phase induction motor M(2). The two motors are supplied by a single power converter which is a six-phase Voltage Source Inverter.

Fig. 1 presents the connecting and supplying schematic of the two motors and the converter [7-9]. The six-phase machine has the spatial displacement between any two consecutive stator phases equal to 60° (i.e. $\alpha=2\pi/6$). Only phases 1, 3 and 5 are used by the second machine M(2), this phases are electrically displaced to each other by and angle of $2\pi/3$.

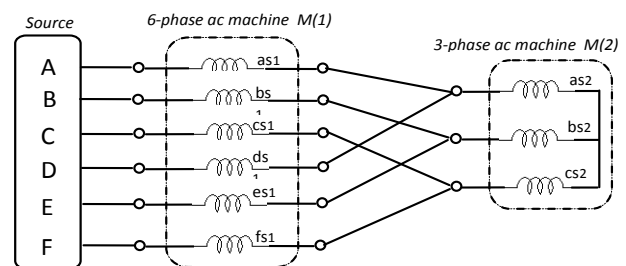


Fig. 1. Connection diagram for series connection of a six-phase and a three-phase machine.

We note that a simple series connection of stator windings fails to ensure the desired performances. A solution is adopted to overcome this constraint consists of using an adequate stator windings transposition [10, 11]. This transposition resides of connecting in one point each two (electrically displaced to each other by π) of six-phase windings and connect them in series with the windings of the M(1) [12-14].

In this way, currents pass through the six-phase windings going to neutralize at the connecting point. And in the same context, the current passing through the one winding of M(2) will be the half when passing through the windings of M(1). This will generate in air-gap of the M(1) a two (equal in magnitude and opposed in phase) Magneto-Motive Force (MMF).

Therefore, a natural decoupling of the two motors will be possible by adopting the connection diagram shown in Fig. 1. According to Fig. 1, the stator and rotor voltages of the two machines can be written as follows [1, 4]:

$$[v_s] = \begin{bmatrix} V_A \\ V_B \\ V_C \\ V_D \\ V_E \\ V_F \end{bmatrix} = \begin{bmatrix} v_{as1} + v_{as2} \\ v_{bs1} + v_{bs2} \\ v_{cs1} + v_{cs2} \\ v_{ds1} + v_{ds2} \\ v_{es1} + v_{es2} \\ v_{fs1} + v_{fs2} \end{bmatrix} \quad (1)$$

The relationship between the current source and the stator currents of each machine are given as follows:

$$\begin{aligned} [i_s] &= [I_A \ I_B \ I_C \ I_D \ I_E \ I_F] \\ &= [i_{as1} \ i_{bs1} \ i_{cs1} \ i_{ds1} \ i_{es1} \ i_{fs1}] \\ &= [i_{s1}] \end{aligned} \quad (2)$$

$$[i_{s2}] = [i_{as2} \ i_{bs2} \ i_{cs2}]^T = [I_A + I_D \ I_B + I_E \ I_C + I_F]^T \quad (3)$$

The electrical equations:

$$\begin{cases} [V_{sk}] = [R_{sk}] [i_{sk}] + \frac{d}{dt} [\varphi_{sk}] \\ [0] = [R_{rk}] [i_{rk}] + \frac{d}{dt} [\varphi_{rk}] \end{cases} \quad (4)$$

Where:

$$\begin{cases} [\varphi_{sk}] = [L_{ssk}] [i_{sk}] + [M_{srk}] [i_{rk}] \\ [\varphi_{rk}] = [L_{rrk}] [i_{rk}] + [M_{rrk}] [i_{sk}] \end{cases} \quad (5)$$

Knowing that $k=1$ for the M(1) and $k=2$ for the M(2)

With:

$$[R_{seq}] = [R_{s1}] + \begin{bmatrix} [R_{s2}] & [R_{s2}] \\ [R_{s2}] & [R_{s2}] \end{bmatrix};$$

$$[L_{seq}] = [L_{s1}] + \begin{bmatrix} [L_{s2}] & [L_{s2}] \\ [L_{s2}] & [L_{s2}] \end{bmatrix}$$

3. Modeling of MSCS into three subspaces (α, β), (x, y), (o^+, o^-)

The original six dimensional systems of the MSCS can be decomposed into three orthogonal subspaces,

(α, β), (x, y) and (o^+, o^-) [1], using the following transformation:

$$X_{\alpha\beta o} = [T_6(\theta)]^{-1} \cdot X_{abc} \text{ and } X_{dgo} = [T_6(\theta)]^{-1} \cdot X_{\alpha\beta o}.$$

where : X represents stator currents, stator flux, stator voltages in MSCS. The matrix $[T_6(\theta)]$ is given by:

$$[T_6] = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & \cos(\alpha) & \cos(2\alpha) & \cos(3\alpha) & \cos(4\alpha) & \cos(5\alpha) \\ 0 & \sin(\alpha) & \sin(2\alpha) & \sin(3\alpha) & \sin(4\alpha) & \sin(5\alpha) \\ 1 & \cos(2\alpha) & \cos(4\alpha) & \cos(6\alpha) & \cos(8\alpha) & \cos(10\alpha) \\ 0 & \sin(2\alpha) & \sin(4\alpha) & \sin(6\alpha) & \sin(8\alpha) & \sin(10\alpha) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1/\sqrt{2} & -1/\sqrt{2} & 1/\sqrt{2} & -1/\sqrt{2} & 1/\sqrt{2} & -1/\sqrt{2} \end{bmatrix} \quad (6)$$

$$[T_3] = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \cos 2\alpha & \cos 4\alpha \\ 0 & \sin 2\alpha & \sin 4\alpha \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \quad (7)$$

$$[\rho(\theta)] = \begin{bmatrix} \begin{bmatrix} \cos(\theta i) & -\sin(\theta i) \\ -\sin(\theta i) & \cos(\theta i) \end{bmatrix} & [0]_{2 \times 4} \\ [0]_{4 \times 2} & [I]_{4 \times 4} \end{bmatrix} \quad (8)$$

Application of the transformations matrix (6) and (7) in conjunction with the first row of (4) lead to the decoupled model of the six-phase two-motor drive system. Source voltage equations that include equations of the two stator windings connected in series can be given as:

$$\begin{cases} V_{s\alpha} = R_{s1} i_{s\alpha 1} + L_{s1} \frac{di_{s\alpha 1}}{dt} + M_1 \frac{di_{r\alpha 1}}{dt} \\ V_{s\beta} = R_{s1} i_{s\beta 1} + L_{s1} \frac{di_{s\beta 1}}{dt} + M_1 \frac{di_{r\beta 1}}{dt} \end{cases} \quad (9)$$

$$\begin{cases} V_{sx} = R_{eq} i_{sx1} + (l_{s1} + 2L_{s2}) \frac{di_{sx1}}{dt} + \sqrt{2} M_2 \frac{di_{rx2}}{dt} \\ V_{sy} = R_{eq} i_{sy1} + (l_{s1} + 2L_{s2}) \frac{di_{sy1}}{dt} + \sqrt{2} M_2 \frac{di_{ry2}}{dt} \end{cases} \quad (10)$$

$$\begin{cases} V_{so+} = R_{eq} i_{so+1} + (l_{s1} + 2L_{s2}) \frac{di_{so+1}}{dt} \\ V_{so-} = R_{eq} i_{so-1} + l_{s1} \frac{di_{so-1}}{dt} \end{cases} \quad (11)$$

Rotor voltage equations of six-phase machine and three-phase machine are:

$$\begin{cases} 0 = R_{r1} i_{r\alpha 1} + L_{m1} \frac{di_{s\alpha 1}}{dt} + L_{r1} \frac{di_{r\alpha 1}}{dt} + \omega_{r1} (L_{m1} i_{s\beta 1} + L_{r1} i_{r\beta 1}) \\ 0 = R_{r1} i_{r\beta 1} + L_{m1} \frac{di_{s\beta 1}}{dt} + L_{r1} \frac{di_{r\beta 1}}{dt} + \omega_{r1} (L_{m1} i_{s\alpha 1} + L_{r1} i_{r\alpha 1}) \end{cases} \quad (12)$$

$$\begin{cases} \frac{di_{sq,k}}{dt} = \frac{1}{\sigma_k L_{s,k}} \left[- \left(R_{s,k} + \frac{M_k^2}{L_{r,k} \tau_{r,k}} \right) i_{sq,k} - \frac{M_k}{L_{r,k} \tau_{r,k}} \varphi_{r,k} - \sigma_k \omega_{s,k} L_{s,k} i_{sd,k} + v_{sq,k} \right] \\ \frac{d\Omega_k}{dt} = \frac{p_k M_k}{J_k L_{r,k}} \varphi_{r,k} i_{sq,k} - \frac{1}{J_k} T_{1,k} \\ T_{em,k} = p \frac{M_{1,k}}{L_{r,k}} \varphi_{r,k} i_{sq,k} \end{cases} \quad (19)$$

$k = 1$: six-phase machine, $k = 2$: three-phase machine

The d-q components of stator voltage and currents are: $v_{sd,k}$, $v_{sq,k}$, $i_{sd,k}$, $i_{sq,k}$ and $\varphi_{r,k}$, Ω_k are the rotor flux and the rotor angular speed respectively. $R_{s,k}$, $R_{r,k}$, $L_{s,k}$, $L_{r,k}$, M_k , J_k and p_k are machines parameters with:

$$\sigma_k = 1 - \frac{M_k^2}{L_{s,k} L_{r,k}}, \quad \tau_{r,k} = \frac{L_{r,k}}{R_{r,k}}$$

By introducing the angular speeds of sliding, the obtained equation is the following shape:

$$\frac{d\theta_{sl,k}}{dt} = \omega_{sl,k} = (\omega_{s,k} - p_k \Omega_{m,k}) = \frac{M_k}{\tau_{r,k}} \frac{i_{s\beta,k}}{\varphi_{r,k}} \quad (20)$$

$$\text{With: } i_s = \begin{cases} i_{s\alpha} & \text{for } k=1 \\ \sqrt{2} i_{sy} & \text{for } k=2 \end{cases}$$

With this condition, the flux and torques for MSCS as:

$$\begin{cases} \varphi_{r\alpha 1} = \frac{M_1}{1 + \tau_{r1} S} i_{s\alpha 1} \\ T_{em1} = \frac{p_1 M_1}{L_{r1}} \varphi_{r\alpha 1} i_{s\beta 1} \end{cases} \quad (21)$$

$$\begin{cases} \varphi_{r\alpha 2} = \sqrt{2} \frac{M_2}{1 + \tau_{r2} S} i_{sx} \\ T_{em2} = \sqrt{2} \frac{p_2 M_2}{L_{r2}} \varphi_{r\alpha 2} i_{sy} \end{cases} ; \text{ with: } S = \frac{d}{dt} \quad (22)$$

According to 21 and 22, six-phase machine's flux/torque are controllable by inverter (α , β) axis current components, while flux and torque of the three-phase machine can be controlled using inverter (x , y) current components.

Let us consider as reference greatneses, rotors's flux $\varphi_{r,k}^*$ and electromagnetic torque $T_{em,k}^*$. From these two greatneses, we look for the values of command $i_{sd,k}$ and $i_{sq,k}$.

$$\begin{cases} i_{sd,k} = \frac{1}{M_k} \left(\tau_{rk} \frac{d\varphi_{r,k}^*}{dt} + \varphi_{r,k}^* \right) \\ i_{sq,k} = \frac{L_r}{p_k M_k \varphi_{r,k}^*} T_{em,k}^* \\ \omega_{sl,k} = \frac{M_k i_{sq,k}}{\tau_{r,k} \varphi_{r,k}^*} \\ \omega_{s,k} = \omega_{m,k} + \omega_{sl,k} \\ v_{sd,k} = \left(R_{s,k} + \frac{M_k^2}{L_{r,k} \tau_{r,k}} \right) i_{sd,k} + \sigma_k L_{s,k} \frac{di_{sd,k}}{dt} - A_k \\ v_{sq,k} = \left(R_{s,k} + \frac{M_k^2}{L_{r,k} \tau_{r,k}} \right) i_{sq,k} + \sigma_k L_{s,k} \frac{di_{sq,k}}{dt} + B_k \end{cases} \quad (23)$$

where:

$$A_k = \frac{M_k}{L_{r,k} \tau_{r,k}} \varphi_{r,k}^* + \sigma_k L_{s,k} \omega_{s,k} i_{sq,k}$$

$$B_k = \frac{M_k}{L_{r,k}} \omega_{m,k} \varphi_{r,k}^* + \sigma_k L_{s,k} \omega_{s,k} i_{sd,k}$$

It can be seen from (23) that the equation of the stator voltage components $v_{sd,k}$ Influence at the same time on the direct-axis stator current $i_{sd,k}$ and quadrature-axis stator current $i_{sq,k}$ thus, on the rotor flux and the torque (A_k), (B_k). It's the same for the component $v_{sq,k}$ [15]. Thus he exists, a coupling between the electromagnetic torque and the rotor flux in the model of the machine. One of the proposed solutions, to make axes d - q completely independent, is to add decoupling components. The decoupling or compensation components, are identical at the coupling components (A_k), (B_k) but of opposite sign ($-A_k$), ($-B_k$) (Fig. 3).

The input of a fuzzy logic controller is the speed error and the output will generate the electromagnetic torque $T_{em,k}^*$ producing stator current component command $i_{sq,k}$. The flux of command $\varphi_{r,k}^*$ is obtained from a block of defluxage. Knowing torque/flux's reference $T_{em,k}^*$ and $\varphi_{r,k}^*$, the block of field rotation command " F.O.C " calculates the value of the pulsation $\omega_{gl,k}$ (to define the angle $\theta_{s,k}$) and the reference currents $i_{sd,k}$, $i_{sq,k}$. The current fuzzy logic controllers' outputs are added to the corresponding d and q axis components of the decoupling stator voltage A_k and B_k (equation 22) to generate in the inverter the voltage vector for the motor. The currents errors are the input of two fuzzy logic controllers to produce the stator voltages in the synchronous reference and then transformed to the stationary reference system to generate in the inverter the voltage vector for the motor.

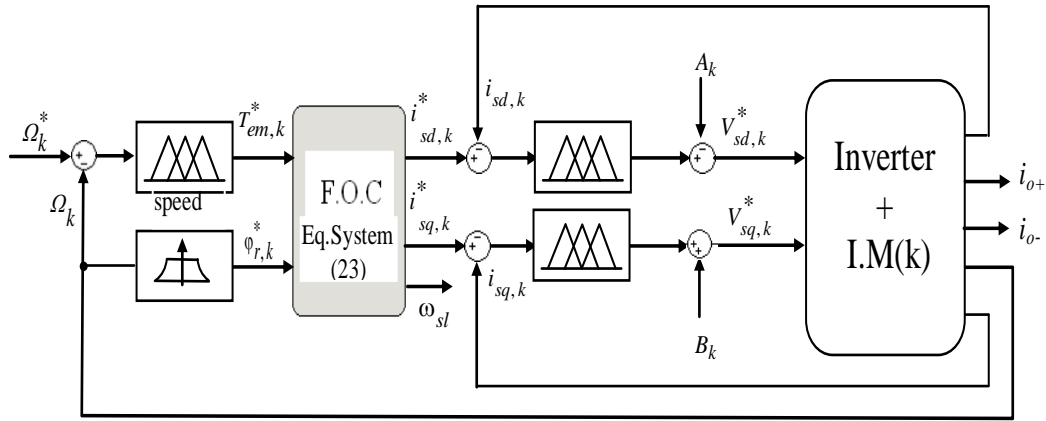


Fig. 3. Diagram of the induction motor M(k) indirect vector control with the fuzzy controller. with: $k = 1$ six-phase machine, $k = 2$ three-phase machine.

6. Fuzzy logic controller

In a real, parameters machine are change by temperature for example, for these reasons, the induction machine shows properties of nonlinear and time-varying systems, so the parameter variations degrade the system performance over the full range of motor operation and in extreme conditions this can lead to instability. To solve this problem the controller parameters have to be continuously adapted. This adaptation can be achieved using fuzzy logic controller.

Because the fuzzy logic approach is based on linguistic rules, the controller design does not need to use any machine parameters to make a controller adjustment, so the controller robustness is high [16].

Fuzzy logic controller (FLC) is usually used in induction machine drives. Due to its simplicity, (no mathematical model or speed closed-loop is required), the FLC method became very useful in induction machine drives used in speed control systems.

The membership function (MF) of the associated input and output 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 (gains) 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 [18-20].

The fuzzy logic control is based on these four elements: a bases rule, an inference mechanism, a fuzzification interface and a defuzzification interface. The interface used in this work is Mamdani's procedure based on max-min decision. For the defuzzification, the Center of Area (COA) method is employed [21].

The structure of FLC is shown in Fig. 4. For our study, the input of the fuzzy controller is the error of speed E_k , as well as its variation ΔE_k , the output of the regulator will be the Torque's increment $\Delta T_{em,k}$. It is enough to integrate to have the value of the electromagnetic couple of command $T_{em,k}$.

The if-then rules for fuzzy scalar control for speed control will be forty nine rules. Fig. 5 (a), (b) and (c) shows membership functions of input variables E and ΔE respectively and output variable, which are with conventional triangular shapes. Each membership is divided into seven fuzzy.

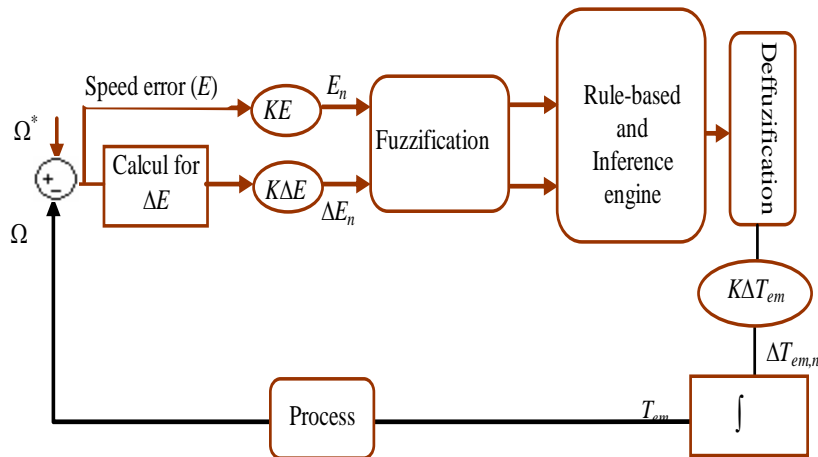


Fig. 4. Block diagram of speed fuzzy controller.

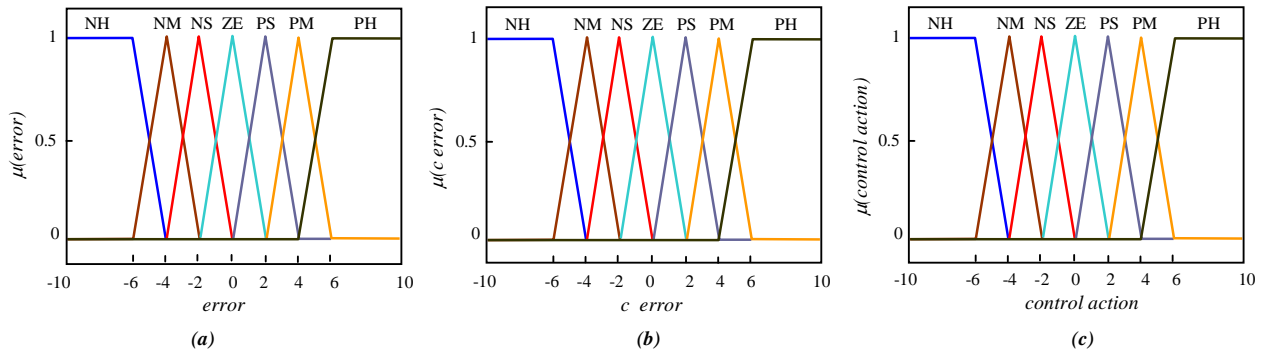


Fig. 5. Membership functions of input/output variables; a) input speed error; b) input change speed error; c) output

The membership is divided into seven fuzzy sets:
 NH: Negative High, PS: Positive Small, ZE: Zero
 NM: Negative Medium, PM: Positive Medium
 NS: Negative Small, PH: Positive High

The rule-based table for output variable was shown in table 1, it consists of 49 linguistic rules and gives the change of the output of fuzzy logic controller in terms of two inputs E_k and ΔE_k .

Table 1
 The rule base for controlling the speed

$E_{\Omega,k}$	NH	NM	NS	ZE	PS	PM	PH
$\Delta E_{\Omega,k}$	NH	NH	NH	NH	NM	NS	ZE
NM	NH	NH	NH	NM	NS	ZE	PS
NS	NH	NH	NM	NS	ZE	PS	PM
ZE	NH	NM	NS	ZE	PS	PM	PH
PS	NM	NS	ZE	PS	PM	PH	PH
PM	NS	ZE	PS	PM	PH	PH	PH
PH	ZE	PS	PM	PH	PH	PH	PH

In Table 1, some of the rules are interpreted:

If E_k is PM and ΔE_k is PM Then $\Delta T_{em,k}$ is PH. Here, both the speed error and the change error are positive medium. Therefore, we need positive high $\Delta T_{em,k}$ to achieve a fast response.

The same steps used for the conception of the speed controller (FLC) will be repeated for the currents controller as shown in Fig. 6, only we have:

- Input error E_k : instead of being equal to $E_k = \Omega_k^* - \Omega_k$, it will be equal in $E_k = i_{ds,k}^* - i_{ds,k}$ for the first fuzzy controller of current $i_{ds,k}$ and $E_k = i_{qs,k}^* - i_{qs,k}$ for the second fuzzy controller of current $i_{qs,k}$;
- The output of the fuzzy controller is $V_{ds,k}$ or the $i_{ds,k}$ current controller and $V_{qs,k}$ or the controller of the current $i_{qs,k}$ current.

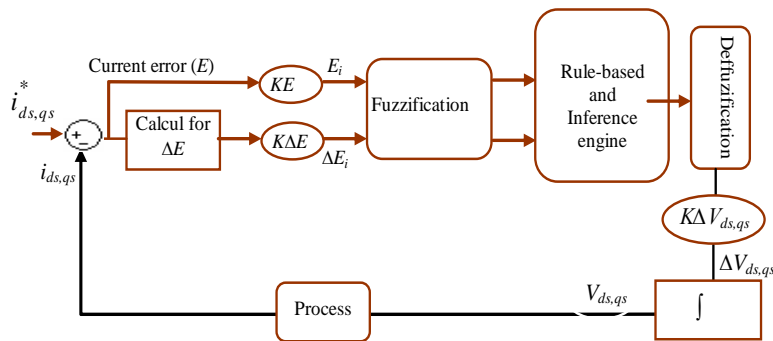


Fig. 6. Block diagram of currents fuzzy controller

So that the internal loop is faster than the external one (condition of subjection). We represent the input/output variables by membership function, as shown in Fig. 7, each one divided into 3 fuzzy.

The rule-based table for output variable is presented in table 2, it consists of 9 linguistic rules and gives the

change of the output of fuzzy logic controller in terms of two inputs E_k and ΔE_k for each current's controller ($i_{ds,k}$ and $i_{qs,k}$). Each membership function is also assigned with three fuzzy sets: P (positive), N (negative) and ZE (zero).

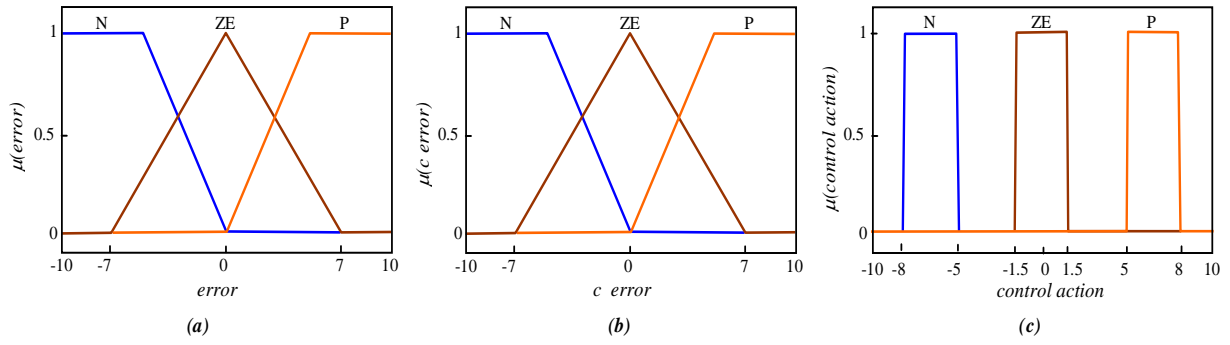


Fig. 7. Membership functions of input/output variables; a) input current error; b) input change current error; c) output

Table 2
The rule base for controlling the currents.

$\Delta E_{i,k}$	$E_{i,k}$	N	ZE	P
N		N	N	ZE
ZE		N	ZE	P
P		ZE	P	P

7. Simulation results

The simulation results of vector speed control of the two series connected machines in (MSCS) with the implementing of the fuzzy controller is developed in the MATLAB. The decoupling and independent control of the two machines is demonstrated.

The first test consists in presentation of the global system simulation results: two series-connected machine with their drive: The three-phase induction machine is accelerating from standstill to reference speed $N_2 = 100\text{rad/s}$, a load torque of 4N.m is applied between time $t = 1\text{s}$ and $t = 2.5\text{s}$, where the six-phase induction machine is started at $t = 1.5\text{s}$ after the acceleration transient time expired the speed settled at $N_1 = 50\text{rad/s}$ a torque of 39N.m is applied to it at the time $t = 2\text{s}$.

Fig. 8 shows the speeds, torques and stator currents. It is clear that the dynamic performances are good and we can-notice that the I.M(2)'s electromagnetic torque and speed are not affected by the starting operation of the I.M(1).

In the Fig. 9 : The six-phase induction machine turn at a constant speed equal to 50rad/s , a load torque of 39N.m is applied at $t = 1\text{s}$ while the three-phase motor is started at $t = 1.5\text{s}$ to settle at speed of 100rad/s at the end of acceleration transient time. We notice that, the speed and torque of the I.M(1) are not affected by the acceleration period of the I.M(2).

Figs. 10 and 11 shows the performances when the speed of I.M(1) is changed from $+50\text{rad/s}$ to -50rad/s at $t = 1.5\text{s}$ while the other I.M(2) direction is kept unchanged and vice versa, the direction of the I.M(2) is changed from $+100$ to -100rad/s while that of I.M(1) is

kept unchanged. Simulation results show that the performances (the electro-mechanical quantities)–of both machines are unaffected and decoupled control is preserved.

The second test consists of the robustness test of the system. An example of the robustness of the fuzzy controller compared with the conventional PI controllers. We change the motor parameters and without realizing any adjustment in the controllers the speed regulation is tested in a motor control. The new six-pahse motor parameters are: $R_r = 6 \Omega$, $R_s = 4.6 \Omega$, $L_m = 0.2 \text{ H}$, $L_r = 0.12 \text{ H}$, $L_s = 0.184 \text{ H}$, $J = 0.12 \text{ Kg.m}^2$. Figure 12 shows the stator currant and speed of the six-phase machine controlled with PI and fuzzy logic controllers, a load torque of 39N.m is applied at $t = 1\text{s}$ to the new machine, without readjusting the controllers. The Fig. 12 (a) shows the response of the six-phase machine controlled with PI controllers. The performance of the system becomes wrong when the load changes at $t = 1\text{s}$, the system becomes instable. But, with the fuzzy logic controllers the speed regulation is correct as shown in Fig. 12 (b).

For the stator currant it is clear that the harmonics is also considerably low while using FLC (Fig. 12 (a)) than PI (Fig. 12 (b)). This is an example of the robustness of the FLC controller compared with the conventional PI controllers.

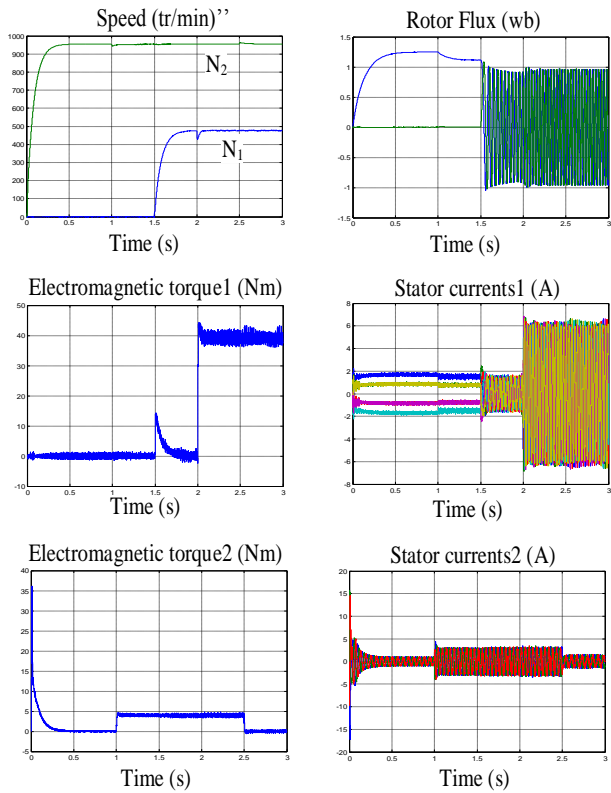


Fig. 7. Performance of indirect vector controlled system: Acceleration of I.M(2) from 0 to 100 rad/s using fuzzy controller.

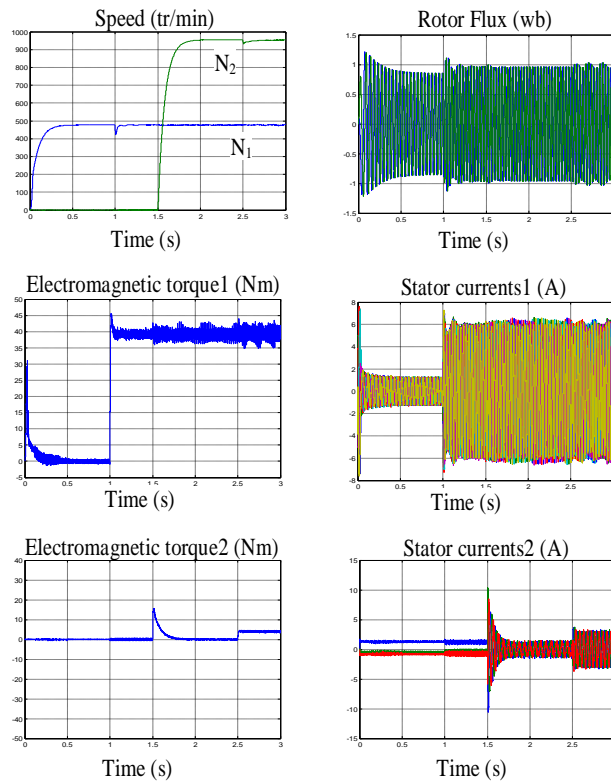


Fig. 8. Performance of indirect vector controlled system: Acceleration of I.M(1) from 0 to 50 rpm using fuzzy controller.

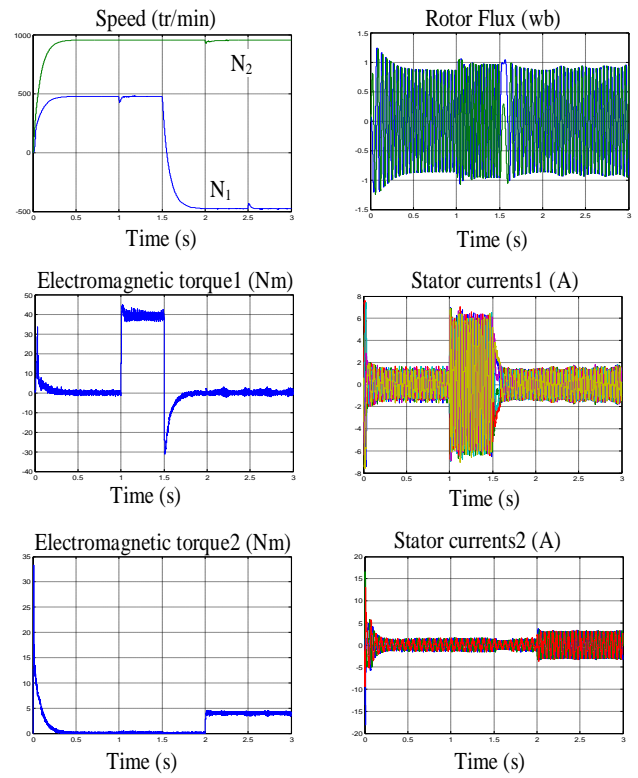


Fig. 9. Performance of indirect vector controlled system: The M(1) reverses from +50 to -50 rad/s using fuzzy controller.

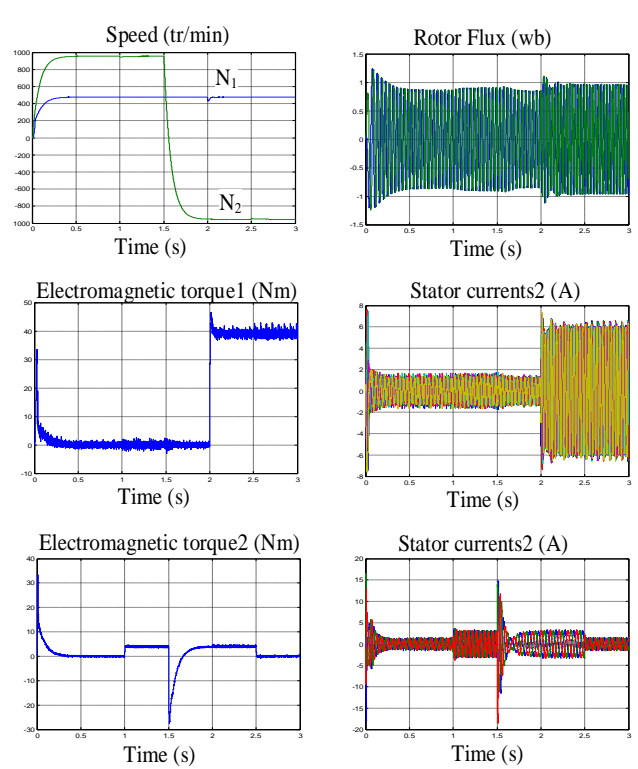


Fig. 10. Performance of indirect vector controlled system: The I.M(2) reverses from +100 to -100 rad/s using fuzzy controller.

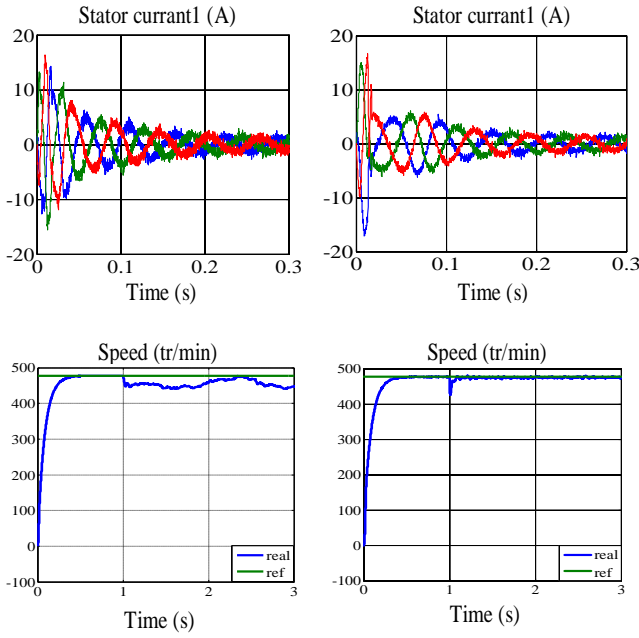


Fig. 11. Test of robustness of the fuzzy controller and PI with applied load torque 39N.m at t=1s. a) PI controllers. b) Fuzzy controllers

8. Conclusion

With the aim of improving the behavior of a MSCS the object of the study presented in this paper is the application of a fuzzy controller, with its main modules such as Fuzzification, Rules, Inferences, and Defuzzification. The robustness has been compared with classical PI and fuzzy controllers. Simulation results showed better performance of the proposed FLC of the two machines and a very high robustness over the conventional PI controller. For a further work in this subject, we propose: a fault diagnostic of the system.

Table 3

The values parameters for the tow machines

Six-phase induction motor	
Rated power:	$P_n = 5.5\text{kw}$
Nominal current:	$I_n = 6\text{A}$
Stator resistance:	$R_s = 2.3 \Omega$
Rotor resistance:	$R_r = 3 \Omega$
Stator inductance:	$L_s = 0.203\text{H}$
Rotor inductance:	$L_r = 0.203\text{H}$
Mutual inductance:	$L_m = 0.2\text{H}$
Rated phase stator voltage:	$V_n = 220\text{v}$
Pole pair number:	$P = 1$
Rotor speed:	$N = 1000 \text{ tr/min}$
Friction coefficient:	$K_f = 0.006 \text{ Nms/rad}$
Moment of inertia :	$J = 0.06\text{Kg.m}^2$
Three-phase induction motor	
Puissance nominale:	$P_{n2} = 1 \text{ kw}$
Stator resistance:	$R_{s2} = 4.67 \Omega$

Rotor resistance:	$R_{r2} = 8 \Omega$
Stator inductance:	$L_{s2} = 0.374\text{H}$
Rotor inductance:	$L_{r2} = 0.374\text{H}$
Mutual inductance:	$L_{m2} = 0.2433\text{H}$
Rated phase stator voltage:	$V_{n2} = 220\text{v}$
Pole pair number:	$P_2 = 3$
Rotor speed:	$N_2 = 2830 \text{ tr/min}$
Friction coefficient:	$K_{f2} = 0.001 \text{ N.m.s/rd}$
Moment of inertia :	$J_2 = 0.023\text{Kg.m}^2$

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