Journal of Advanced Research in Science and Technology
ISSN: 2352-9989

A New Robust Control for Doubly fed Induction Machine based on Type-2 Fuzzy Logic Controller

Saidi. Abderazak[1*], Naceri. Farid[2]

[1-2] Department of Electrical Engineering, Batna2 University, Algeria.

Abstract. The objective of this paper is design a New Robust Control for Doubly fed Induction Machine based on Type-2 Fuzzy Logic Controller , The term fuzzy Presented by a controller (FLC, Fuzzy Logic Controller). from which we have presented the theory of fuzzy logic type - 2 with the basic concepts on the theory of fuzzy sets. We applied this nonlinear technique to the control of the DFIM whose purpose is the speed adjustment. Simulations and a comparsion are presented for the contribution of this approach.

Keywords: *Robust control , Fuzzy Logic Controller ,Fuzzy logic type 2, regulator , stability*

1. Introduction

Three-phase induction machine powered by a voltage inverter is a drive system with many advantages: a simple, robust and inexpensive machine structure and efficient control techniques thanks to advances in semiconductors Power and digital technologies. However, this converter / machine assembly remains limited to the lower limit of the high power range (up to a few MW) due to the electrical stresses experienced by the semiconductors and their low switching frequency[1,13].

In the field of high power drives, there are other solutions using the alternative machine operating in a somewhat particular mode, these are the The asynchronous machine double feed "DFIM" [1], [2].

The asynchronous machine with double feed (DFIM) is very popular since it profit from certain advantages compared to all the other types at variable speed, sound use in the chains of electromechanical conversion as an aero generator or engine knew a spectacular growth during last years. Indeed, it converter of energy used in order to rectify-undulate the alternating currents of the rotor has a fractional nominal output nominal of that of the generator, which reduces its cost by report/ratio with concurrent topologies[3].

The DFIM is essentially non linear, due to the coupling between the flux and the electromagnetic torque. The vector control or field orientation control allows a decoupling between the torque and the flux [2], [6].

The theory of fuzzy logic has been established by L. Zadeh ,This logic allows the representation and processing of imprecise or approximate knowledge. The number of applications based on the theory of fuzzy logic has increased considerably in recent years. This is due to the fact that fuzzy logic is usually expressed by linguistic rules of the IF-THEN form, it is used to solve the problems of decisions in control or to describe the dynamic behavior of an unknown or ill-defined system[4, 5].

* Corresponding author.
E-mail: Abderazak_saidi@yahoo.com (Saidi A.).
Address: BP 88 Batna2 University, Algeria.

The classical fuzzy logic called today fuzzy type-1 logic has been generalized to a new fuzzy logic called fuzzy logic type-2. In recent years, many researchers have worked on this new logic [7], [8],they have built its theoretical foundation[9],[10]., and have demonstrated its effectiveness and superiority over fuzzy type-1 logic.

2. Dfim Dynamic Model

dynamic model expressed in the synchronous reference frame is given by voltage equations[3]:

$$\begin{cases} \overline{V_s} = R_s \bar{I}_s + \dfrac{d\overline{\phi_s}}{dt} + j\omega_s \overline{\phi_s} \\ \overline{V_r} = R_r \bar{I}_r + \dfrac{d\overline{\phi_r}}{dt} + j\omega_r \overline{\phi_r} \end{cases} \tag{1}$$

Expressions of the fluxes are given by:

$$\begin{cases} \overline{\phi_s} = L_s \bar{I}_s + M_{sr} \bar{I}_r \\ \overline{\phi_r} = L_r \bar{I}_r + M_{sr} \bar{I}_s \end{cases} \tag{2}$$

From (1) and (2) the all currents state model is written as follows:

$$\begin{cases} \dfrac{d\bar{I}_s}{dt} = -\dfrac{R_s}{\sigma L_s}\bar{I}_s + \dfrac{M_{sr}R_r}{\sigma L_s L_r}\bar{I}_r + \dfrac{1}{\sigma L_s}\bar{V}_s - \dfrac{M_{sr}R_r}{\sigma L_s L_r}\bar{V}_r \\ \dfrac{d\bar{I}_r}{dt} = -\dfrac{R_r}{\sigma L_r}\bar{I}_r + \dfrac{M_{sr}R_s}{\sigma L_s L_r}\bar{I}_s + \dfrac{1}{\sigma L_r}\bar{V}_r - \dfrac{M_{sr}R_r}{\sigma L_s L_r}\bar{V}_s \end{cases} \tag{3}$$

The mechanical equation is expressed by (4):

$$\frac{J}{P}\frac{d\omega}{dt} = T_{em} - \frac{f\omega}{P} - T_r \tag{4}$$

With : ω=p.Ω

And the electromagnetic torque is given by:

$$T_{em} = pM_{sr} I_m(\bar{I}_s \bar{I}_r^*) \tag{5}$$

So, the equation for the speed variation becomes:

$$\frac{J}{P}\frac{d\omega}{dt} = pM_{sr} I_m(\bar{I}_s \bar{I}_r^*) - \frac{f\omega}{P} - T \tag{6}$$

3. Dfim Dynamic Model

In this section, the DFIM model can be described by the following state equations in the synchronous reference frame whose axis d is aligned with the stator flux vector [3]:

$$\Phi_{sd} = \Phi_s \; ; \; \frac{d\Phi_{sq}}{dt} = \Phi_{sq} = 0$$

$$i_{rd} = -\frac{L_s}{PM \quad \Phi_s^*} \tag{7}$$

$$i_{rd} = \frac{\Phi_s}{M} \quad (8)$$

$$\frac{d\theta_s}{dt} = w_s = \left(\frac{R_s \cdot M}{L_s} i_{rq} + V_{sq}\right) / \Phi_s^* \quad (9)$$

$$V_{rd} = \left(R_r + \frac{M^2}{L_s T_s}\right) i_{rd} + \sigma L_r \frac{di_{rd}}{dt} + \frac{M}{L_s} V_{sd} - \frac{M}{L_s T_s} \Phi_{sd} - \sigma L_r (w_s - w) i_{rq} \quad (10)$$

$$V_{rq} = \left(R_r + \frac{M^2}{L_s T_s}\right) i_{rq} + \sigma L_r \frac{di_{rq}}{dt} + \frac{M}{L_s} V_{sq} - \frac{M}{L_s} w \Phi_{sd} - \sigma L_r (w_s - w) i_{rd} \quad (11)$$

With:

$$T_r = \frac{L_r}{R_r}, T_s = \frac{L_S}{R_s}$$

4. General information on fuzzy logic type-2

Initially, the fuzzy type-2 concept was introduced by the founding father of fuzzy logic Zadeh [11, 12] as an extension of the concept of the fuzzy type-1 set. A type-2 fuzzy set is characterized by a fuzzy membership function, that is, the degree of belonging of each element of the set is itself a fuzzy set in [0,1]. Such sets are advisable in the case where we have an uncertainty at the level of the value of the membership itself. The uncertainty can be either in the form of the membership function or in one of its parameters.

The transition from an ordinary set to a fuzzy set is the direct consequence of the indeterminism of the value of belonging to an element by 0 or 1. Similarly, when we can not determine the functions of an element, Belonging to fuzzy numbers in real numbers in [0,1], we then use the fuzzy sets type-2. For this purpose, the fuzzy sets type-1 can be considered as a first order approximation of the uncertainty and the fuzzy sets type-2 as an approximation of the second order.

4.1. Rpresentation of fuzzy set type-2

A fuzzy type-2 set, noted Ã is characterized by a three-dimensional membership function uÃ(x,u) , so[13]:

$$\tilde{A} = \{((x,u)u_{\tilde{A}}(x,u) \quad \forall x \in X, \forall u \in J_x \subseteq [0,1]\} \quad (12)$$

In which $0 \le u_{\tilde{A}}(x,u) \le 1$. For a universe of continuous discourse, Ã Can be expressed as:

$$\tilde{A} = \int_{x \in X} \int_{u \in I_x} u_{\tilde{A}}(x,u)/(x,u) \quad J_x \subseteq [0,1] \quad (13)$$

With $\iint$ denote the union of all the elements of the Cartesian product sur x etu.

Ã Each fixed point x of X, Jx is the primary membership of x, and x is called the primary variable [13].

For each value dex, denoted by x=x', the dimensional plane 2 whose axes are u and uÃ (x,u) is called a vertical slice of uÃ(x,u) ,a secondary membership function is a vertical slice of uÃ(x,u).

So for $X' \in X$ et $\forall u \in J_x \subseteq [0,1]$, we have :

$$u_{\tilde{A}}(x = x', u) = u_{\tilde{A}}(x') = \int_{u \in J_x} f_{x'}(u)/u \quad J_x \subseteq [0,1] \tag{14}$$

With $0 \leq f\ x'(u) \leq 1$. Since $\forall x'$ this x' Will belong to X its meaning $x' \in X$, Then we denote the secondary membership function by uÃ(x) Which is a fuzzy membership function type-1. On the basis of the concept of secondary sets, we can reinterpret a type-2 fuzzy set as the union of all the secondary sets, ie, using equation (14), we can write Ã in the following form [14]:

$$\tilde{A} = \int_{x \in X} u_{\tilde{A}}(x)/(x) = \int_{x \in X} \left[\int_{u \in J_x} f_x(u)/(u) \right] / x \quad J_x \subseteq [0,1] \tag{15}$$

The type-2 interval fuzzy sets reflect the uniformity of the uncertainty at the primary membership function, this type of membership functions is most often used in type-2 fuzzy systems. Note that this type of membership functions is represented only by its domains (intervals), which can be expressed in terms of the left and right boundaries [l , r] or by their centers and widths [C-S , C+S]

Or C = (L+ R) / 2 and C= (l- r) / 2

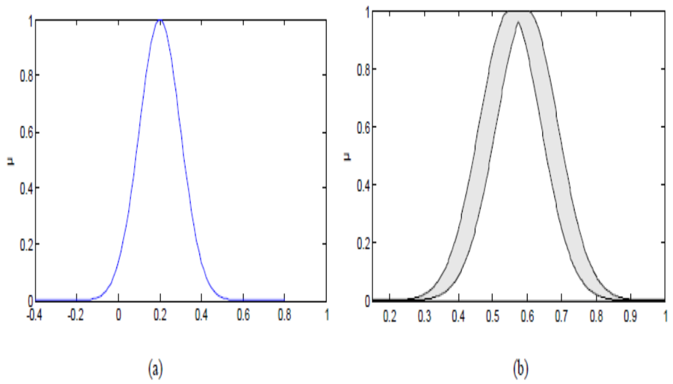


Fig. 1 (A) Schematic representation of a fuzzy type-2 Gaussian set. The secondary belongings are represented in (b), where we note that they are Gaussian [13].

The uncertainty in a fuzzy type-2 set, Ã is represented by a bounded region called "Footprint Of Uncertainty" FOU. It is the union of all the primary belongings [13-15]:

$$FOU(\tilde{A}) = \bigcup_{x \in X} J_x \tag{16}$$

4.2. Types of fuzzy sets type-2

Depending on the form of the primary belonging, there are mainly three types of fuzzy type-2 sets: interval, Gaussian, and triangular.

4.2.1. Gaussian type-2 assembly

In this type of set, the degree of belonging of each point is a Gaussian type-1 set whose definition domain is included in the interval [0, 1]. Note that it is not necessary that the principal belonging function is also Gaussian [14].

4. 2.2 . Triangular type-2 set

In this type of set, the degree of belonging of each point is a triangular type-1 set whose definition domain is included in the interval [0, 1], [11, 15].

4. 2.3. Set type-2 Interval

In this type of set, the degree of belonging to each point is an ordinary set whose definition domain is included in the interval [0, 1], [15-16]. In this case, all secondary belongings are equal to 1. Noting that, although each degree of a set of type-2 intervals is an ordinary set, the set itself is of type -2, Belonging are sets and not ordinary numbers.

4.3. Structure of a fuzzy system type-2

A conventional fuzzy controller consists of a fuzzification interface, a rule base, an inference system and a defuzzification interface. The structure of the type-2 fuzzy controller is similar to the conventional one with the particularity of using a type reducer to convert the type-2 fuzzy sets to the inference system output in type-1 fuzzy sets before Phase of defuzzification. Its different operations are illustrated in the following figure [14,17- 18]:

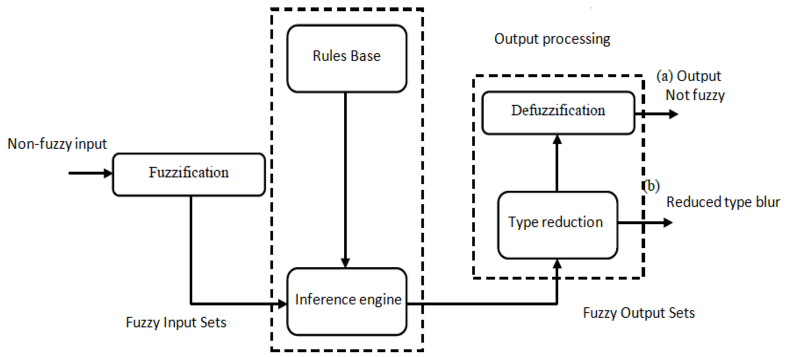


Fig. 2. Structure of a type-2 fuzzy system, with its two outputs: (a) the defuzzified output (b) the reduced type set.

4.3.1. Fuzzification

Unlike the membership function type-1, the membership function type-2 gives several degrees of membership (or dimensions) for each entry. Therefore, uncertainty will be better represented. This representation allows us to take into account what has been neglected by the type-1 [19]. In this thesis, only fuzzification of Gaussian type will be used, in other words, the fuzzy input is a singular point having a value of unitary belonging.

4.3.2. Rule base

The difference between type-1 and type-2 lies only in the nature of the membership functions, so the structure of the rules in the case of type-2 will remain exactly the same. The only difference being that some (or all) membership functions will be type-2; then Jème Rule of a fuzzy system type-2 will have the form [13]:

if x1 and $\tilde{F}_1^j$ and x2 and $\tilde{F}_2^j$ and xn is $\tilde{F}_n^j$, So $y = \tilde{G}^j$ (17)

or $x_i(i = 1.....,n)$ Are the fuzzy system inputs, $\tilde{F}_i^j$

Is the fuzzy set of type-2 corresponding to the input xi , $\tilde{G}^j$ Is a type-2 singleton and y It is not necessary that all the functions of belonging to the premises and the consequences be Type-2. It is enough that a single membership function in a premise or a consequence is of type-2 so that the whole system is of type -2 [20].

4.3.3. Inference

The inference system in a fuzzy type-2 system uses the fuzzy rule base (4.9) to perform a relation between an input vector $\underline{x} = (x_1, x_2, ... x_n)^T$ And the scalar output y. The first step in the fuzzy inference operation is the calculation of the activation interval associated with J[ième] The output blur assembly [21]:

$$F^l(x) = \prod_{i=1}^{n} u_{\tilde{F}_i^l}(x) \tag{18}$$

Then, if we $\tilde{B}^l$ The output fuzzy set corresponding to the composition of the l[ième] rule $\tilde{R}^l$ and the input blur assembly $\tilde{X}'$, all $\tilde{F}^l(x')$ is combined with the consequent fuzzy set $\tilde{G}^l$ of the l[ième] Rule with the selected t-norm operator $\cap$ to obtain the output fuzzy set corresponding to l[ième] Rule:

$$u_{\tilde{B}^l}(y) = u_{\tilde{G}^l}(y) \cap u_{\tilde{F}^l}(\underline{x}') \tag{19}$$

Using a Gaussian fuzzification, that is, the degree of belonging to the fuzzy set $\tilde{X}'$ Has a value which is unitary only when $\underline{x} = \underline{x}'$ so :

$$u_{\tilde{B}^l}(y) = u_{\tilde{G}^l}(y) \cap \prod_{i=1}^{n} u_{\tilde{F}^l}(x_i) \tag{20}$$

Since only fuzzy sets type-2 interval are used and the operation t-standard product is implemented, then the activation interval associated with l[ième] Set output blur is the fuzzy set type-1 interval defined by:

$$F^l(\underline{x}) = \left[\underline{f}^l(\underline{x}),\ \bar{f}^l(\underline{x}) \right] \tag{21}$$

Or $\underline{f}^l = \underline{u}_{\tilde{F}_1^l}(x_1) * \underline{u}_{\tilde{F}_2^l}(x_2) * ... * \underline{u}_{\tilde{F}_n^l}(x_n)$ and $\bar{f}^l = \bar{u}_{\tilde{F}_1^l}(x_1) * \bar{u}_{\tilde{F}_2^l}(x_2) * ... * \bar{u}_{\tilde{F}_n^l}(x_n)$

Terms $\underline{u}_{\tilde{F}_n^l}(x_i)$ and $\bar{u}_{\tilde{F}_n^l}(x_i)$ Are respectively lower and higher degrees of belonging to $u_{\tilde{F}_n^l}(x_i)$

4.3.4. Type reduction

Since the output of the inference system is a type-2 fuzzy set, its type must be reduced before the defuzzification step so that it can be used to generate an actual output. This is the main structural difference between type-1 and type-2 fuzzy systems [15]. The expression of the type fuzzy set $GC_{\tilde{A}}$ Reduced by the method of set centers is given by [19, 21]:

$$GC_{\tilde{A}} = \int_{z_1 \in Z_Z} ......\int_{z_n \in Z_n} \int_{w_1 \in W_1} ......\int_{w_n \in W_n} \frac{\left[T_{i=1}^n u_z(z_i) * T_{i=1}^n u_W(z_i)\right]}{\dfrac{\sum_{i=1}^n z_i w_i}{\sum_{i=1}^n w_i}} \tag{22}$$

Where Tet * denotes the t-norms chosen (prod or min).$w_i \epsilon W_i$ and $z_i \epsilon Z_i$ for i=1,2,…n Since the fuzzy

sets used are type-2 interval, then each z_i and w_i is a set type-1 interval, which results in $u_z(z_i)=u_w(w_i)=1$
Equation (22) can be rewritten [13]:

$$GC_{\tilde{A}} = \int_{y^1\in[y_l^1,y_r^1]} \cdots \int_{y^m\in[y_l^m,y_r^m]} \cdots \int_{f^1\in\left[\underline{f}^1,\bar{f}^1\right]} \cdots \int_{f^M\in\left[\underline{f}^M,\bar{f}^M\right]} \frac{1}{\frac{\sum_{i=1}^{M} f^i y^i}{\sum_{i=1}^{M} f^i}} \tag{23}$$

Also, since each set in equation (22) is a set-type-1 interval, then $GC_{\tilde{A}}$ is also a set type-1 interval and therefore its domain is an interval located on the axis of the real [20]:

$$GC_{\tilde{A}}=[y_l(x),y_r(x)] \tag{24}$$

4.3.5. Defuzzification

The reduced type (23) will be determined by its two extremes of right and left respectively y_l and y_r . Applying the center of gravity to the reduced type of Karnik Mendel Algorithms [13, 22], the numerical output will be given by:

$$Y(x) = \frac{y_l(x) + y_r(x)}{2} \tag{25}$$

With:

$$y_l(x) = \frac{\sum_{i=1}^{M} f_l^i y_l^i}{\sum_{i=1}^{M} f_l^i} \quad , \quad y_r(x) = \frac{\sum_{i=1}^{M} f_r^i y_l^i}{\sum_{i=1}^{M} f_r^i} \tag{26}$$

Or : f_l^i, f_r^i Indicate the degree of activation (either $\underline{f}_l^i$ or $\bar{f}_l^i$) Contributing to the extreme left point y_l ,

and (either $\underline{f}_r^i$ or $\bar{f}_r^i$) contribuant au point extrême de gauche. y_r

5. Application of fuzzy logic type-2

For the DFIM speed setting The proposed fuzzy type-2 controller will have two input variables whose structure is represented by Figure 3:

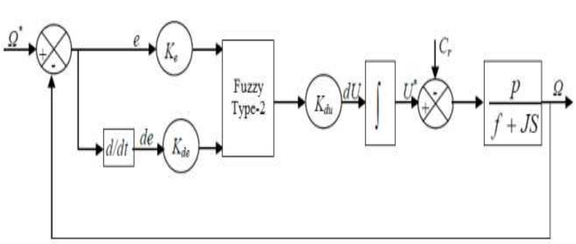
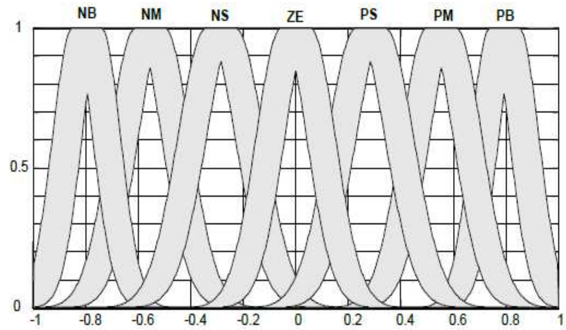


Fig. 3. Structure of the PI-blur type-2 controller.

The membership functions are defined by Gaussian forms (Figure 4).



e (k) , de (k) and u(k)

Fig. 4. Membership functions e (k) , de (k) and u(k)

The rules table for type 2 will remain exactly the same as type-1.

The area generated for ΔKp is shown in Figure 5.

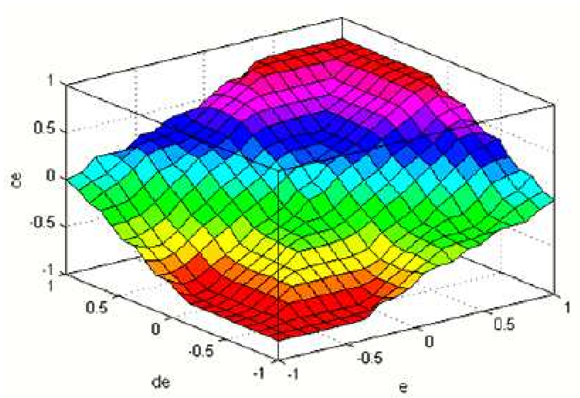
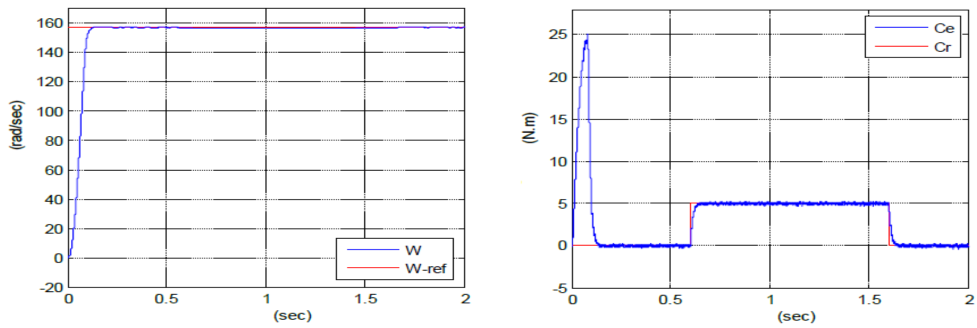


Fig. 5. Surface. K_P

6. Simulation results

The figures below illustrate the different simulation tests of the DFIM by applying the fuzzy type 2 command. Figure 6, illustrates the behavior of the DFIM when the load is changed.



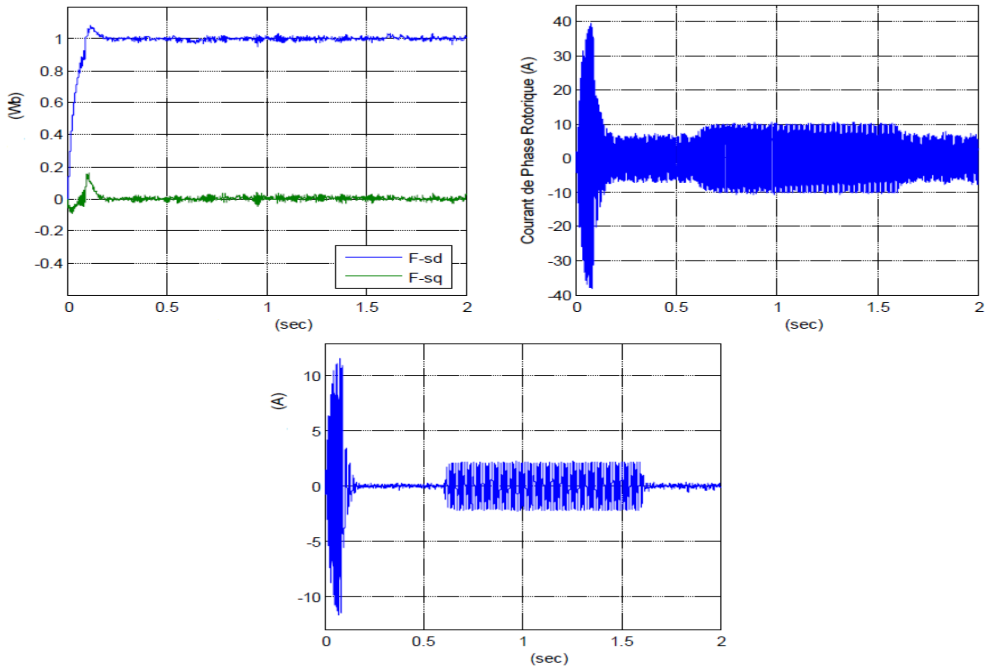


Fig. 6. Simulation results of the DFIM control using fuzzy logic type-2 followed by a load applied to the interval t = [0.6, 1.6] sec.

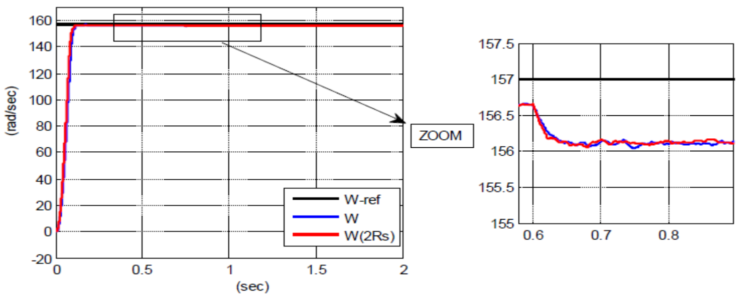
From these results, it can be seen that control by fuzzy logic type 2 has better regulation (precision and stability) of the velocity and the stator flux, where the introduction of the charges has no influence on the Evolution of speed and flow.

6.1. Robustness test

To judge correctly this command, several tests are carried out. (Parametric variation of the machine).

A- Variation at the stator resistance

Figure 7. shows the simulation results obtained for a 100% increase in the nominal value of the stator resistance.



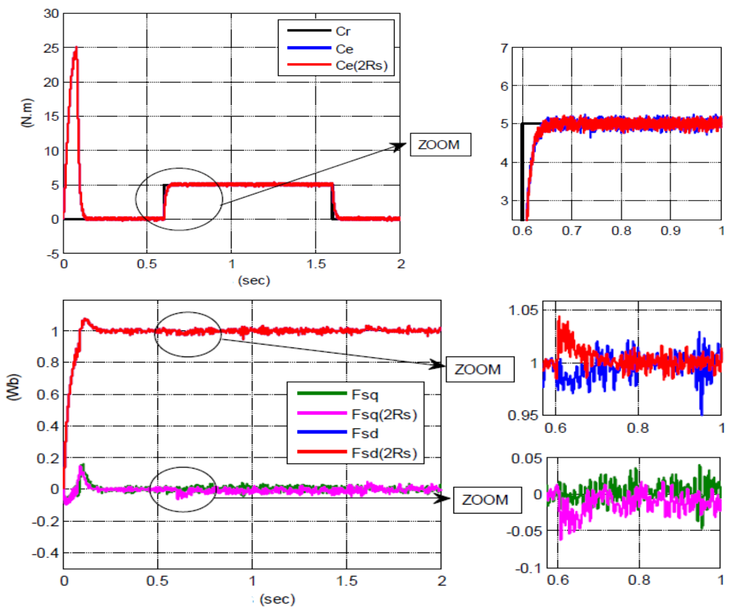
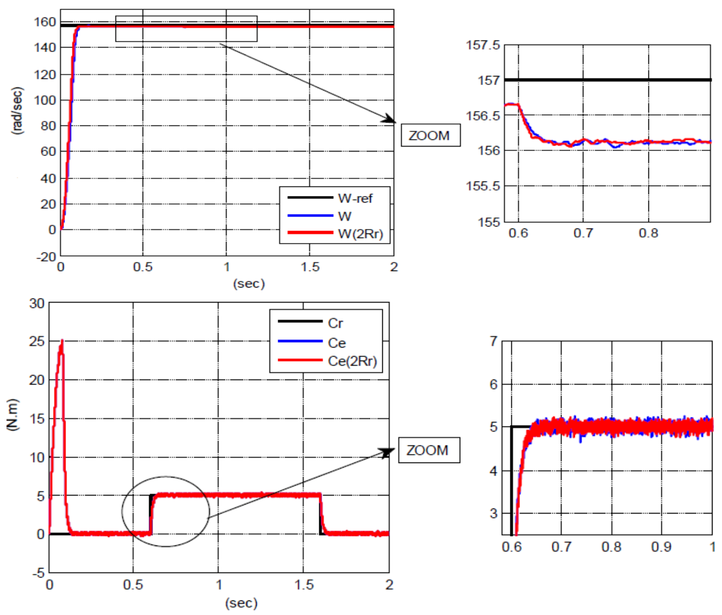


Fig. 7. Robustness test for a variation of Rs of + 100%, with a speed control of the DFIM by fuzzy logic type2.

B- Variation in the rotor resistance

Figure 8. illustrates the velocity, torque and flux responses of the DFIM when increasing the rotor resistance by + 100% of its nominal value



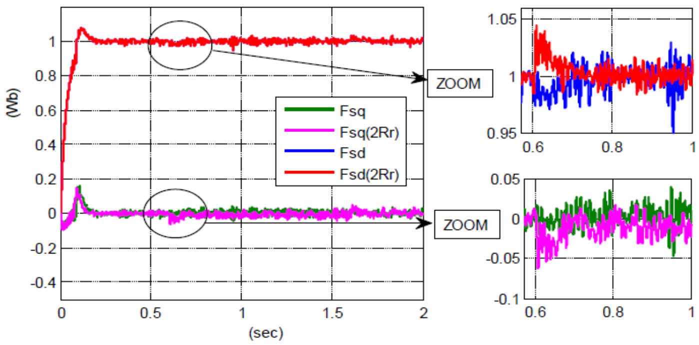


Fig. 8. Robustness test for a variation of Rr of + 100%, with a speed control of the DFIM by the type-2 fuzzy logic.

C- Variation in moment of inertia

In this test, the moment of inertia is varied by + 50% of its nominal value. The simulation results obtained are illustrated in Figure 9.

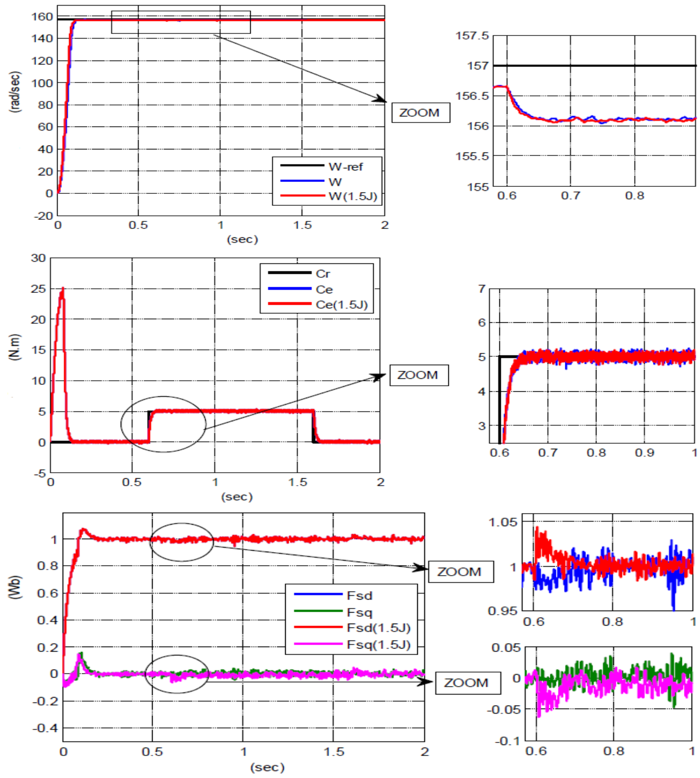


Fig. 9. Robustness test for a variation of J of + 50%, with a speed control of the DFIM by fuzzy type-2 logic.

6. 2.Interpretation of Results

The results obtained from control by the fuzzy type-2 logic with an increase in the stator and rotor resistance of + 100% of its nominal values represented in Figs.7 and.8 show excellent performance, not only in tracking but also in regulation , With good tracking of the reference speed with zero static error and a fast response time compared to previous commands. The insensitivity and rejection of disturbances are excellent. It is also noted that the stator flux is well realized, moreover the electromagnetic torque represents a good response. The increase of the moment of inertia by + 50% of its nominal value has no influence on the behavior of the machine. Therefore despite these variations the fuzzy type-2 control always remains robust with a decoupling always assured.

7. Conclusion and future works

In this paper we have presented a main control, fuzzy logic type-2 control, from which we have presented the theory of fuzzy logic type - 2 with the basic concepts on the theory of fuzzy sets. We applied this nonlinear technique to the control of the DFIM whose purpose is the speed adjustment. The results of the simulation of the DFIM velocity control have shown that fuzzy type-2 control ensures good dynamic performance with respect to fuzzy type-1 control even in the presence of parametric variations and external disturbances. in order to improve the performance of the system.

Another technique based on the application of the adaptive control by fuzzy logic type 1 and type 2 will be presented in futures works

APPENDIX

Rated Data of the simulated doubly fed induction motor:
Rated values: 0.8 KW; 220/380 V-50 Hz; 3.8/2.2 A, 1420 rpm.
Rated parameters:
$R_s = 11.98\ \Omega$
$R_r = 0.904\ \Omega$
$L_s = 0.414$ H
$L_r = 0.\ 556$ H
M= 0.126 H
P = 2.0
Mechanical constants:
J = 0.01 $Kg.m^2$
f = 0.00 I.S.

8. References

[1] S. Aissi, L. Saidi, R. Abdessemed ,F.Ababsa. "Comparative Study of Passivity and RST Regulator Applied to Doubly Fed Induction Machine ".Journal of Electrical Engineering & Technology Vol. 4, No. 4, pp. 521~526, 2009

[2] H Hassani , J Zarei . " Interval Type-2 fuzzy logic controller design for the speed control of DC motors", journal Systems Science & Control Engineering, Volume 3, 2015 - Issue 1, Pages 266-273

[3] Saidi A , Naceri F . " Comparative study between Sliding mode controller and Fuzzy Sliding mode controller in a speed control for doubly fed induction motor", Proceedings of IEEE International Conference on Control Engineering & Information Technology (CEIT), 2016 , pp. 1-6

[4] El Merabet, H Amimeur, F Hamoudi, R Abdessemed" Self–Tuning Fuzzy Logic Controller for a Dual Star Induction Machine",Journal of Electrical Engineering & Technology Vol. 6, No. 1, pp. 133~138, 2011

[5] Gnanavadivel J, Senthil Kumar N ,Yogalakshmi P" Comparative Study of PI, Fuzzy and Fuzzy tuned PI Controllers for Single-Phase AC-DC Three-Level Converter",

[6] F Payam, HKashiha . " Robust Speed Sensorless Control of Doubly-fed Induction Machine Based on Input-output Feedback Linearization Control Using a Sliding-mode Observer ", World Appl. Sci. J., 10(11): pp1392-1400, 2010

[7] Kh Chafaa , M Salah Khireddine , N Slimane , M Ghanai , " Fuzzy estimation based on type-2 fuzzy logic for adaptive Control", Proceedings of IEEE International Conference on Computer Applications & Research (WSCAR) ,07 October 2014 Sousse, Tunisia.

[8], A Tlemçani , H Nouri , " Noninteracting Adaptive Control of PMSM Using Interval Type-2 Fuzzy Logic Systems ", IEEE Transactions on Fuzzy Systems, Volume 19 Issue 5, October 2011 , Page 925-936 .

[9] H Ying , J Duan " Adaptive control using interval type-2 fuzzy logic ", Proceeding FUZZ-IEEE'09 Proceedings of the 18th international conference on Fuzzy Systems Pages 836-841 Jeju Island, Korea — August 20 - 24, 2009 .

[10] S Zeghlache, M Zinelaabidine G Abderrahmen Bouguerra,"Adaptive Type-2 Fuzzy Sliding Mode Control Using Supervisory Type-2 Fuzzy Control for 6 DOF Octorotor Aircraft "International Journal of Intelligent Engineering and Systems, Vol.10, No.3, 2017.

[11] O. Hazil. « Modélisation et commande prédictive flou robuste des convertisseurs DC-DC en utilisant le formalisme LMI », Mémoire de Magister, Université de Constantine-1,Algérie, 2013.

[12] G.J. Klir et B. Yuan. « Fuzzy Sets, Fuzzy Logic, and Fuzzy Systems: Selected Papers by Lotfi A. Zadeh »,World Scientific Pub Co Inc, 1996.

[13] K.Loukal et L. Benalia. «Interval Type-2 Fuzzy Logic Control of a Doubly-Fed Induction Machine (DFIM) », Advances in Fuzzy System journal, Vol.2016 (2016),Dec 2015.

[14] A. Hamizi. «Commande Adaptative Floue Type-2 d'un Bras Manipulateur », Mémoire de Magister, Université de Batna, Algérie, 2012.

[15] A. Khemis. « Application de la logique floue type-2 intervalle à la commande adaptative de la machine asynchrone », Mémoire de Magister, Université de Batna, Algérie, 2012.

[16] N.N. Karnik, J.M. Mendel et Q. Liang. « Type-2 fuzzy logic systems », IEEE Transaction, Fuzzy Syst., Vol. 7, No. 6, Dec, 1999, pp. 643-658.

[17] Q. Liang, and J. M. Mendel, "Interval type-2 fuzzy logic systems: Theory and design," IEEE Transaction. Fuzzy Syst., Vol. 8, No. 5, Oct, 2000, pp. 535-550.

[18] N. Ezziani. « Commande adaptative floue backstepping d'une machine asynchrone avec et sans capteur mécanique », Thèse de doctorat, Université de Reims Champagne Ardenne, France, 2010.

[19] K. Chafaa, M. Ghanai and K. Benmahammed. « Fuzzy modeling using Kalman Filter »,IET Control Theory & Applications, Vol.1,No.1,2007, pp. 58 – 64.

[20] P. Ioannou et J. Sun. « Robust Adaptive Control ». Prentice Hall, Englewood Cliffs, NJ, 1996.

[21] A. El Ougli. « Intégration des Techniques Floues à la Synthèse de Contrôleurs Adaptatifs », Thèse de Doctorat, Université Sidi Mohamed Ben Abdallah Fès, Maroc, 2009.

[22] J. M. Mendel. « Rule-Based Fuzzy Logic Systems: Introduction and New Directions », Prentice Hall, Englewood Cliffs, NJ, 2001