Certificate of Attendance

POSTER PRESENTATION

Name & Surname ABDERRHAMEN BOUGUERRA

Paper Title INTERVAL TYPE 2 FUZZY GAIN-ADAPTIVE PI CONTROLLER OF BRUSHLESS DC MOTOR

ICAME 2019

5TH INTERNATIONAL CONFERENCE ON ADVANCES IN MECHANICAL ENGINEERING

DECEMBER 17-19, 2019

ISTANBUL

Assoc. Prof. Dr. Orhan ÇAKIR
ICAME 2019 Conference Co-Chairman

Assoc. Prof. Dr. Orhan ÇAKIR
YILDIZ TECHNICAL UNIVERSITY
Faculty of Mechanical Engineering
Vice Dean

PROCEEDINGS BOOK OF

FIFTH INTERNATIONAL CONFERENCE ON ADVANCES IN MECHANICAL ENGINEERING: ICAME 2019

ISBN 978-605-9546-16-4

SUPPORTED BY

JOURNAL OF THERMAL ENGINEERING

ICAME 2019

DECEMBER 17-19, 2019

ISTANBUL, TURKEY

INTERVAL TYPE 2 FUZZY GAIN-ADAPTIVE PI CONTROLLER OF BRUSHLESS DC MOTOR

Abderrahmen Bouguerra*[1], Izzeddine Dilmi[1], Samir Zeghlache[2], Keltoum Loukal[1]

ABSTRACT

This paper presents a comparison between an Interval Type 2 Fuzzy Gain Adaptive PI and a Conventional PI controllers used for speed control of an Electronically Commutated Motor (BrushLess DC Motor). In particular, the introduction of this paper presents a type 2 fuzzy logic Gain Adaptive PI controller of machines, in the first part we presents a description of the mathematical model of BLDCM, and an strategy method is proposed for the speed control of this motor in the presence of the variations parametric, A interval type-2 fuzzy inference system is used to adjust in real-time the controller gains. The obtained results show the efficacy of the proposed method.

Keywords: *ECM, BLDCM, IT2FGAPI, Interval Type-2 Fuzzy Gain Adaptive PI, BrushLess DC*

INTRODUCTION

Modern drive technology requires more and more precise and continuous control of speed, torque and position, while ensuring the highest stability, speed and efficiency possible. The DC motor has satisfied some of these requirements but it is provided with brushes rubbing on the collectors, which limits the power and the maximum speed and presents difficulties of the maintenance and interruptions of operation. For all these reasons, the research is moving towards a better exploitation of robust actuators, with improved characteristics, the DC motors have been gradually replaced by the BLDC motors. The BLDC motor has the low inertia, large power to volume ratio, and low noise as compared with the permanent magnet DC servo motor having the same output rating [1-3]. The special feature of the BLDC machine is the stator is equipped with sensors that detect the position of the rotor to control the electronics that ensures the switching of the currents in the phases. Hall Effect sensors are mainly encountered, but optical devices are also used. The BLDC motor is found in different applications such as electric and hybrid vehicles, spacecraft, aeronautics, robotics, space mission tools, factory automation and the field of robotics…etc[4-6]. The control strategy based on PI gain scheduling, a number of methods have been proposed in the literature for PID gain scheduling [7] a stable gain-scheduling PID controller is developed based on grid point concept for nonlinear systems. Different gain scheduling methods were studied and compared [8, 9], a new PID scheme is proposed in which the controller gains were scheduled by a fuzzy inference scheme. Many method and research works in this domain in [10-13], the author in [14] Optimized the Fuzzy System by Genetic Algorithm for the gains Adaptive PI Controller of Induction Motor Control, the type 1 Fuzzy Gain Adaptive PI of BLDCM in [15], Adaptive Fuzzy Gain Scheduling of PI Controller for control of the Wind Energy Conversion Systems in [16] The interested readers can find a brief review of different fuzzy PID structures in [17]. The present work deals with an IT2FGAPI Controller method for controlling the speed of BLDCM.

The remainder of this paper is organized as follows. In section I, the model of three-phase BLDCM Section II develops the dynamic model. Section III is devoted to the PI gain adaptive control based on the interval type-2 fuzzy logic. The simulation results to demonstrate the effectiveness of the proposed approach is presented in Section IV.

THEORY

The model simplified of the BLDCM is shown in figure 1:

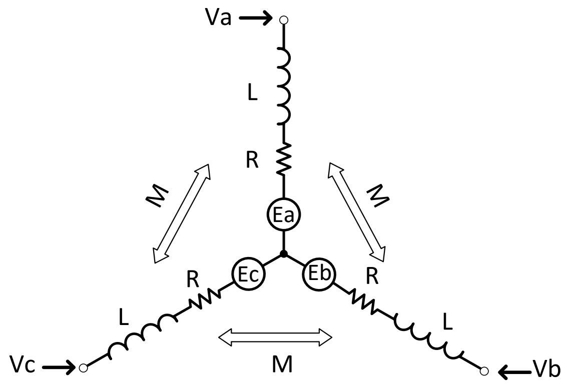


Figure 1. The model simplified of the BLDCM.

For a symmetrical winding and a balanced system (Fig. 1), the vector of voltages across the three phases of the BLDC motor is given by:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{1}$$

Where v_a, v_b and v_c are the phase voltages of the BLDCM, i_a, i_b and i_c are the phase currents, R and L are the resistance and inductance of the machine, e_a, e_b and e_c are the electromotive forces of the phases.
The electric torque is given by:

$$C_e = \frac{(e_a i_a + e_b i_b + e_c i_c)}{\omega_r} \tag{2}$$

Where C_e is the electromagnetic torque and ω_r is the angular velocity.

Figure 2 show the equivalent diagram of the motor-switch assembly of BLDCM:

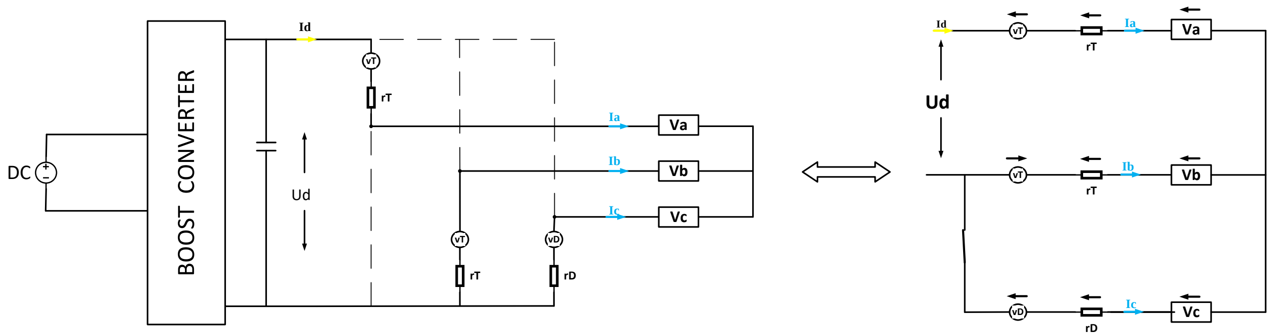
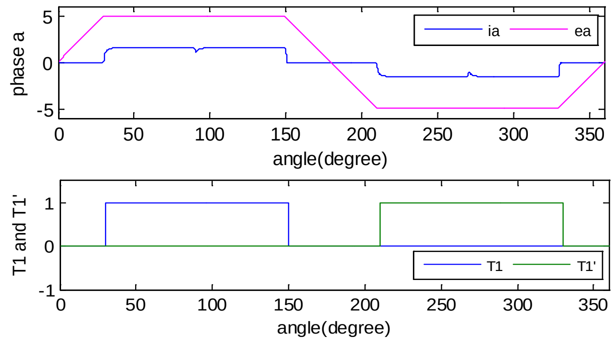


Figure 2. The model simplified of the BLDCM.

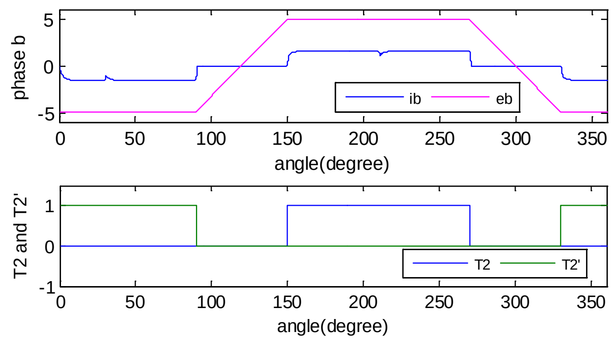
Tthe model can be written as follows:

$$\begin{cases} V_a = Ri_a + L_c \dfrac{di_a}{dt} + e_a & (3) \\ V_b = Ri_b + L_c \dfrac{di_b}{dt} + e_b & (4) \\ V_c = Ri_c + L_c \dfrac{di_c}{dt} + e_c & (5) \end{cases}$$

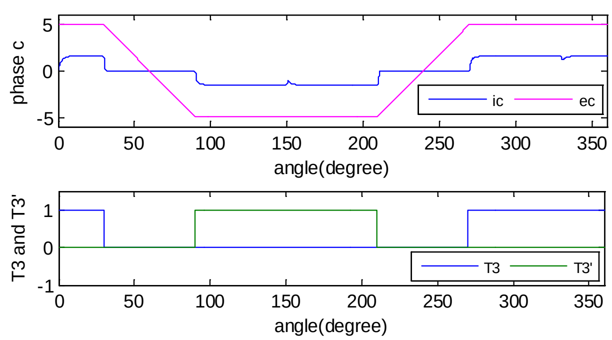
Depending on the position of the inductor, the current i_d is switched in phase at the time the trapezoidal FCEM in this phase has its flat part positive or negative (Fig. 3).



a) Current ia and FCEM ea and pulses T1 and T1'



b) Current ib and FCEM eb and pulses T2 and T2'



c) Current ic and FCEM ec and pulses T3 and T3'

Figure 3. Control pulses of transistors for the direct sense.

From the signals of the Hall sensors, the sequence is generated by choosing a sequence of notice pulses of transistors well defined (Fig. 3), there are 6 distinct intervals noted *IT*. The opening of the 2 transistors of an arm of the electronic switch produces the conduction of a diode D_p and D_n. This corresponds to setting a series of phase with the remaining 2 in parallel in these intervals are denoted *ID* and *ID*'.

CONTİNUOUS MODEL OF BLDCM

Is characterized by two distinct modes:

A. DC1 MODE

DC1 mode corresponds to the two phases in series (Fig.4):

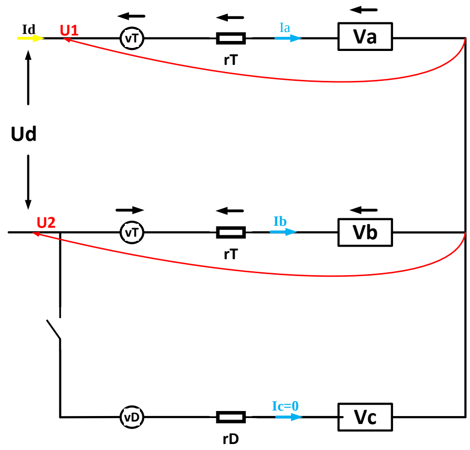


Figure 4. Structure of the BLDC motor when two phases are supplied.

This mode is then *ITj* intervals, we assume that the dynamic resistances of the components are identical:

$$r_{\tau} = r_D = r \tag{6}$$

In this case the voltage node checks:

$$u_d = u_1 - u_2 \tag{7}$$

Where u_1 and u_2 are respectively represented the voltage of the neutral point to positive terminal and the voltage of the neutral point to the negative terminal of the continuous bus.

$$\begin{cases} u_1 = V_a + v_T + ri_a \\ u_2 = V_b - v_T + ri_b \end{cases} \tag{8}$$

By replacing v_a and v_b their respective expression (3) and (4), as $i_a = i_d$ and $i_b = -i_d$, u_1 and u_2 are givens by:

$$\begin{cases} u_1 = Ri_d + L_c \dfrac{di_d}{dt} + e_a + v_T + ri_d & (9) \\ u_2 = -Ri_d + L_c \dfrac{di_d}{dt} + e_b - v_T - ri_d & (10) \end{cases}$$

Therefore u_d is given by:

$$u_d = 2(R + r)i_d + 2L_c \frac{di_d}{dt} + (e_a - e_b) + 2v_T \tag{11}$$

For the two phases in series, the FCEM present their party platform in opposition, so we have:

$$-e_b = e_a = E = k_e|\omega_r| \tag{12}$$

With k_e the coefficient of the FCEM and ω_r the rotation speed of the motor. Finally in this mode dynamics DC1 current id is expressed by:

$$2L_c\frac{di_d}{dt} = u_d - 2(R+r)i_d - 2E - 2v_T \tag{13}$$

B. DC2 MODE

This mode, a phase in series with the other two phases in parallel (Fig.5):

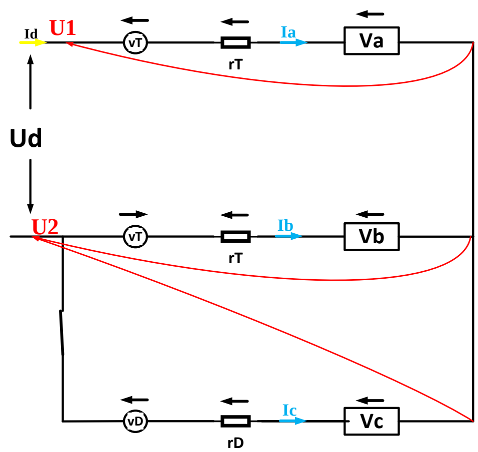


Figure 5. Structure of the BLDC motor when three phases are supplied.

In this case the dynamics of the current i_d check in DC2 mode: are given by:

$$3L_c\frac{di_d}{dt} = 2u_d - 3(R+r)i_d - 2E - 3v_T + v_D \tag{14}$$

INTERVAL TYPE 2 FUZZY GAİN-ADAPTİVE PI STRATEGY

A. CONTEXT OF TYPE-2 FUZZY LOGİC

The classic fuzzy logic now called Type-1 has been generalized to a new type of fuzzy logic called fuzzy logic-2. In recent years, Mendel and O. Castillo and his colleagues have been working on this new logic; they have built a theoretical basis, and demonstrated its effectiveness and superiority to the type-1 fuzzy logic [18, 19]. Type-2 fuzzy set is characterized by a fuzzy membership function, ie, the value of membership (membership degree) of each element of the set is a fuzzy set in [0, 1]. Such sets can be used in situations where we have uncertainty about the values of belonging themselves. Uncertainty can be either in the form of the membership function or one of its parameters [20]. The structure of a fuzzy system Type-2 is shown in the figure 6.

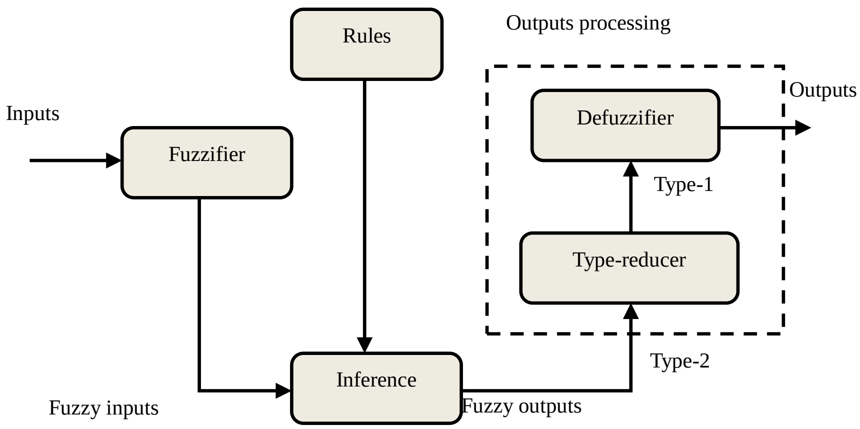


Figure 6. Structure of type-2 fuzzy logic system [20].

B. INTERVAL TYPE-2 FUZZY GAİN-ADAPTİVE

A set of linguistic rules in the form of (15) is used in the IT2FGAPI Controller structure to determine integral gain K_i of IP gains:

$$if\ e(k)\ is\ A_i\ and\ \Delta e(k)\ is\ B_i\ then\ K_p\ is\ C_i \quad (15)$$

Where A_i, B_i and C_i are fuzzy sets corresponding to $e(k)$, $\Delta e(k)$ and K_i respectively, $e(k)$and $\Delta e(k)$ represent the output error and its derivative, respectively. For the speed Ω the error and its derivative are given by

$$e(k) = \Omega_d - \Omega \quad (16)$$

$$\Delta e(k) = \frac{e(k+1) - e(k)}{T} \quad (17)$$

The speed errors, their variation and the control signal K_i are chosen to be Gaussian identical shapes as indicated in Figure 7.

They are quantized into seven levels represented by a set of linguistic variables which are: negative big (NB), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (PM) and positive big (PB).

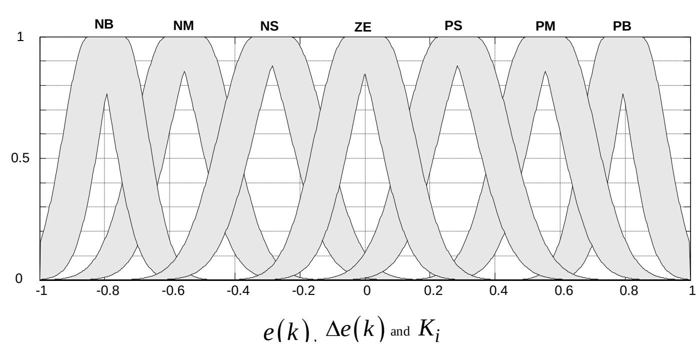


Figure 7. Fuzzy membership functions of the speed error, their variation and the control signal K_i [21].

Table 1 show the linguist rules used in the IT2FGAPI Controller.

Table 2. Fuzzy tuning rules for Ki [22].

de \ e	B	M	S	E	S	M	B
B	B	B	B	M	S	VS	E
M	B	B	M	S	VS	E	VS
S	B	M	S	VS	E	VS	S
E	M	S	VS	E	VS	S	M
S	S	VS	E	VS	S	M	B
M	VS	E	VS	S	M	B	B
B	E	VS	S	M	B	B	B

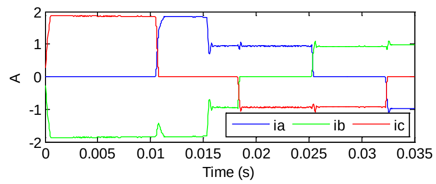
SİMULATİON RESULTS

The machine used is characterized by the following:

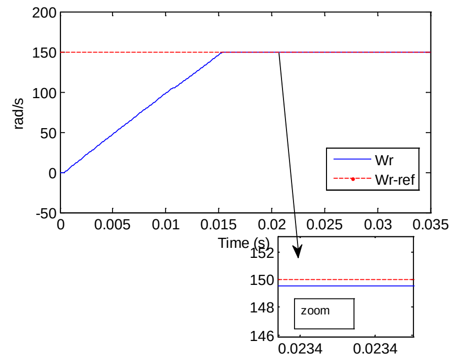
Table 2. Parameters of BLDC Motor [23].

Item	Symbol	Data
resistance of phase	R	4Ω
phase inductance	L_c	0.002H
inertia constant	J	4.65e-6kg.m2
Back-EMF Constant	k_e	26.1e-3V/rd.s-1
coefficient of friction	k_f	1.5e-006N.m/rd.s-1
supply voltage	u_n	24(V)
rated current	I_n	1(A)

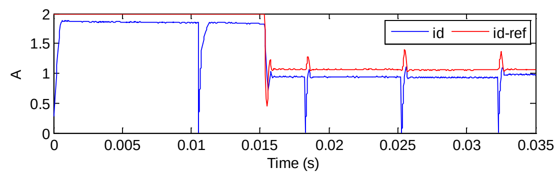
The power components are modeled by conduction regime threshold voltages and resistances following dynamics: $v_T=0.8$ (V),$v_D=0.8$(V),$r_T=0.075\Omega$, $r_D=0.05$ Ω.
The motor control is based on the cascade structure of Figure 2; the output I_c of the speed controller *PI-add* and the current setting i_d is made by the regulator *PI* and that provides the signal u_c. The test of control by Fuzzy Gains PI adaptive and PI controllers is performed to a level of speed value *(150rd/s)* for the direct sense during the time interval *[0s, 0.035s]*. The nominal load torque *0.5N.m* and parametric perturbations are applied throughout the test.



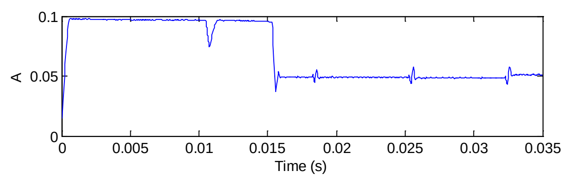
a) The 3 phase currents



b) Form of speed

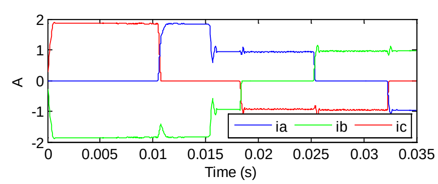


c) Form of the continuous current i_d

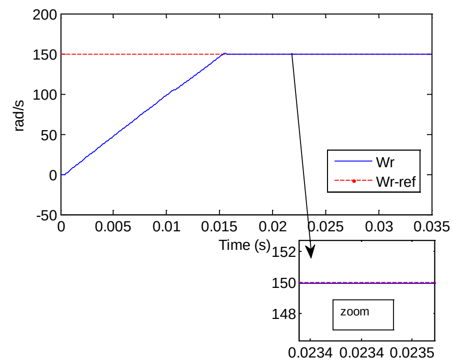


d) The engine torque C_e

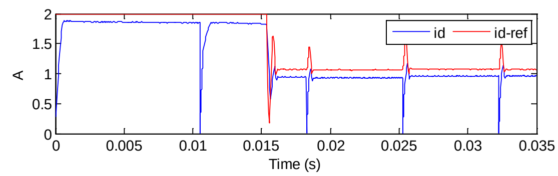
Figure. 8 Response of the motor using PI controller.



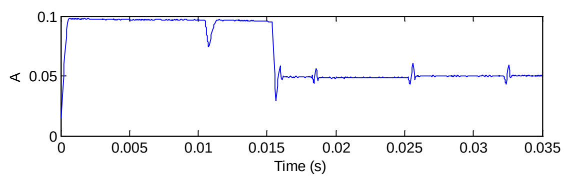
a) The 3 phase currents



b) Form of speed



c) Form of continuous current i_d



d) The engine torque C_e

Figure. 9 Response of the motor using IT2FGAPI controller.

Finally, Figure 8 and 9 show the simulation results of the proposed method with error of *0.472 rd/s* (Fig. 8. b) for PI controller and *0.011 rd/s* (Fig. 9. b) for IT2FGAPI controller. We note that I_{ref} is saturated to the value *1.95(A)* until the speed is away from the reference value. Then when ω_r achieved static value adjustment, the value I_{ref} is necessary to compensate the load torque. During operation mode of the motor I_d is positive, it follows strong reference I_{ref} .

CONCLUSION

In this paper, the speed regulation of BLDCM with two controllers, traditional PI and IT2FGAPI controllers has been designed and simulated. To do this, we have established the dynamic model of the DC input of the switch. The comparative study shows that the IT2FGAPI controller can be improve the performances of speed of the BLDCM control. The simulation results have confirmed the efficiency of the IT2FGAPI.

REFERENCES

[1]T. J. E Miller, "Brushless Permanent-Magnet and Reluctance Motor Drives", Clarendon Press, Oxford 1989.
[2]P. Pillay and R. Krishnan, "Application Characteristics of Permanent Magnet Synchronous and Brushless dc Motors for Servo Drives", IEEE Trans. Ind. Appl., 27(5), 986-996 Sept./Oct. 1991.

[3]K. Ohishi, M. Nakao, K. Ohnishi and K. Miyachi, “Microprocessor-Controlled DC Motor for Load-Insensitive Position Servo System”, IEEE Trans. Ind. Electron., 34(1), 44-49, 1987.
[4]J. F. Gieras, R. J. Wang, M. J. Kamper, “Axial Flux Permanent Magnet Brushless Machines”, Kluwer Academic Publishers, United States of America, 2005.
[5]Y. Dal, Ohm and J. H. Park, “About commutation and current control Methods for brushless motors” , 29th annual IMCSD symposium, San Jose 1999.
[6]K. Ang, G. Chong, and Y. Li, “PID control system analysis, design, and technology," IEEE Trans. Control System Technology, 13, 559-576, July 2005.
[7]T. C. T. Ng, F. H. F. Leung and P. K. S. Tam, “A simple gain scheduled PID controller with stability consideration based on a grid-point concept”, in Conf. Rec. IEEE Int. Conf. Industrial Electronics, 1997, 1090–1094.
[8]F. Karray, W. Gueaieb and S. Al-Sharhan, “The hierarchical expert tuning of PID controllers using tools of soft computing”, IEEE Trans. Systems. Man, and Cybernetics-Part B: Cybernetics, 32(1), 2002, pp. 77-90.
[9]Z. Zhao, M. Tomizuka and S. Isaka, “Fuzzy gain scheduling of PID controllers”, IEEE Trans. Systems. Man, and Cybernetics, 23(5), 1993, 1392–1398.
[10]K. Yu and J. Hsu, “Fuzzy gain scheduling PID control design based on particle swarm optimization method” In Second International Conference on Innovative Computing, Information and Control, Kumamoto, Japan, 2007.
[11]Y. Guo and T. Yang, “A new type of computational verb gain-scheduling PID controller”, In International Conference on Counterfeiting Security and Identification in Communication, Chengdu, China, 2010, pp. 235-238.
[12]L. Yao and C. Lin, “Design of gain scheduled fuzzy PID controller”, World Academy of Science, Engineering and Technology, 1, 2005, 152-156.
[13]M. M. El Emary, W. Emar and M. J. Aqel, “The adaptive fuzzy designed PID controller using wavelet network”, journal of Computer Science and Information System, 6(2), 2009, 141-163.
[14]I. K. Bousserhane, A. Hazzab, M. Rahli, M. Kamli, B. Mazari, “Adaptive PI Controller using Fuzzy System Optimized by Genetic Algorithm for Induction Motor Control”, 2006 IEEE International Power Electronics Congress, Puebla, Mexico, 2006.
[15]A. Bouguerra, K. Loukal, S. Zeghlache, “Speed control of a brushless DC motor (BLDCM) based on fuzzy gain-adaptive PI”, 10th International Conference on Electrical and Electronics Engineering (ELECO), Bursa, Turkey, 2017.
[16]K. Bedoud, M. Ali-rachedi, T. Bahi, R. Lakel, “Adaptive Fuzzy Gain Scheduling of PI Controller for control of the Wind Energy Conversion Systems”, Energy Procedia, 74, 211- 225, 2015.
[17]B. Hu, G. K. I. Mann and R. G. Gosine, “A systematic study of fuzzy PID controllers-function-based evaluation approach”, IEEE Trans. Fuzzy Systems, 9(5), 2001, 699-712.
[18]J. M. Mendel, “Computational Intelligence Magazine”, IEEE, 2(1), 72-73, 2007.
[19]O. Castillo, P. Melin, “Information Siences”, 279, 615-631, 2014.
[20]N. Ezziani “Commande adaptative floue backstepping d’une machine asynchrone avec et sans capteur mecanique”, Automatic and signal processing, Reims University, France, Avril 2010.
[21]K. Loukal, L. Benalia, “Interval Type-2 Fuzzy Gaın-Adaptıve Controller of a Doubly Fed Inductıon Machıne (DFIM) ”, J. Fundam. Appl. Sci., 8(2), 470-493, 2016.
[22]S. Barkati, E. M. Berkouk, M. S. Boucherit, “Application of type-2 fuzzy logic controller to an induction motor drive with seven-level diode-clamped inverter and controlled infeed”, Electr Eng, , 90(5), 347-359, 2008.
[23]K. Loukal, L. Benalia, A. Bouguerra, M. Chemachema, S. Zeghlache and H. Chekireb, “Super Twisting Control Algorithm Applied to the Brushless DC Motor (BLDCM) ”, 4th international conference on electrical engineering, May 07-09, Algiers Algeria, 2012.