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From classical command to hybrid fuzzy logic strategies appliedfor brushless motor electric drive

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Abstract:

Various strategies have been developed to control the rotational speed of electric motors. Among them, the classic PI control strategy is one of the most basic of all. With the development of artificial intelligence, control by fuzzy logic has evolved rapidly and still provides effective control results in various fields. The combination of this control with other robust control strategies such as sliding mode and new technic such as variable-gain PI hasthereforeemerged. In this article, the brushless electric drive, AC, is considered in light of its prevalence from the conventional PI control to the hybrid control. The objective is then to combine all these classic and hybrid controllers to extract the best possible performance. All these strategies were simulated using Matlab-Simulink for comparison. An experiment, where all the commands were implemented on an MSK23335 board with a PM50 module and a 90W BLAC motor is used to validate all the results. From these comparisons, hybrid controls combine speed, performance, and robustness.

Keywords: Brushless Motor, Classical, Fuzzy Logic, Sliding Mode, Variable Gain PI, Hybrid Controller.

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I. INTRODUCTION

Due to its high performance against electromagnetic disturbances, noises, and suitability, brushless AC motors are used for all safety-critical applications [1] such as defense, industry, robotics, etc. It belongs to the family of permanent magnet synchronous motors. The absence of commutators and brushes help users to choose more motor lengths for all required applications.

The advantages of these motors are: better speed versus torque characteristics, high dynamic response, high efficiency and reliability, long life, quiet operation, higher speed ranges, and reduced interference electromagnetic fields (EMI) [2]. Its main features are that it is an electric motor that does not require an electrical connection between stationary and rotating parts, and is classified according to PMs mounting and back-EMF form.

Mathematical modeling makes it possible to better understand the system before controlling it. More control strategies are developed but an intelligent controller can provide high accuracy when the mathematical model is more complicated [3].

Here, vector control using conventional PI control is proposed, initially, to show the effectiveness of the command and control of the said motor. This strategy is more popular in industrial applications [4]. The fuzzy logic controller is an interesting choice when precise mathematical formulations are not possible [5], [6]. One type of these controllers is the sliding mode controller, in [7], which gives more details on all possibilities for all applications. But, here, a simple sliding mode controller is adopted. In [8], they developed and proposed a method using variable gain PI control strategy to optimize PI control techniques applied to wind power control systems.

The hybrid controller, presented in [9] and [10], was developed to combine the performance of variable gain PI and fuzzy logic controllers. The experimentation of all these methodologies is done through an MSK development kit [11], [12].

First, all engine parts were modeled. Then, the various control strategies are discussed. Hybrid controllers are also briefly described before their applications to our control system. Simulation and experimental results of all these methods and their comparison are discussed. Finally, the conclusion gives the main framework of the proposed study.

II. METHODS AND MATERIALS

The system taken into account, illustrated in Figure 1, is composed of a DC voltage source or an AC/DC converter, a three-phase PWM inverter, a control device as a controller, and the motor without three-phase brooms itself.

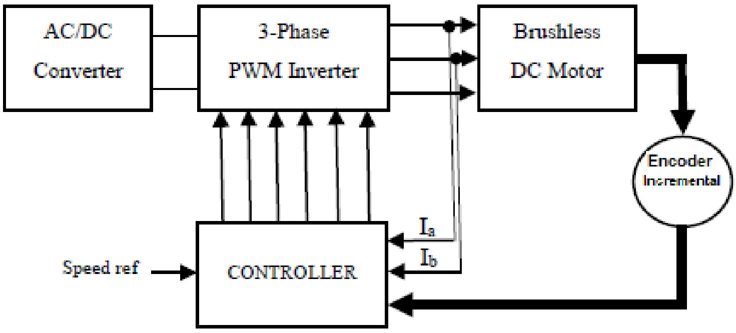

Fig. 1Block diagram of the system

Closed-loop control of the brushless motor is used to minimize the occurrence of parameter variations and load disturbances [1].

Modeling of system elements

To be able to apply the various control strategies to the motor in question, it is necessary to know its characteristics.

Case of a three-phase brushless motor

A brushless motor, in [1] and [2], can be modeled as:

$$\begin{cases} V_a = R_a i_a + (L_a - M)\dfrac{di_a}{dt} + e_a \\ V_b = R_b i_b + (L_b - M)\dfrac{di_b}{dt} + e_b \\ V_c = R_c i_c + (L_c - M)\dfrac{di_c}{dt} + e_c \end{cases} \quad (1)$$

The electromagnetic torque is expressed according to currents and fluxes by:

$$T_{em} = \frac{3}{2} p\left[\left(L_d - L_q\right) i_d i_q + \phi_f i_q\right] \quad (2)$$

The equation of motion looks like this:

$$J_m \frac{d\Omega}{dt} + f\Omega = T_{em} - T_m \quad (3)$$

where, J_m isthe total inertia, f is the coefficient of viscous friction.
Then, in the presentation in the static (d,q) frame, a three-phase brushless motor can be modeled as:

$$\begin{cases} V_d = R_d i_d + L_d \dfrac{di_d}{dt} - \omega L_q i_q \\ V_q = R_q i_q + L_q \dfrac{di_q}{dt} + \omega\left(L_d i_d + \phi_f\right) \end{cases} \quad (4)$$

Case of the three-phase PWM inverter

Fig. 2, below, presents the principle of pulse width modulation, based on triangle sines, which is taken into account in this study.

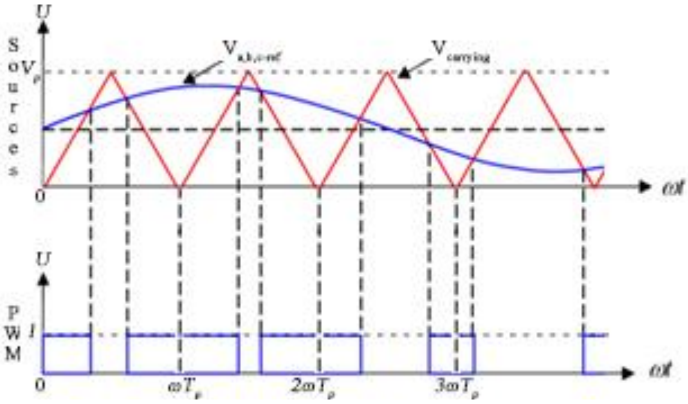

Fig. 2The used PWM or PWM techniques

The inverter is then modeled as:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{V_{dc}}{3} \begin{pmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{pmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \tag{5}$$

Case of DC voltage source

Our DC voltage source comes from a simple single-phase rectifier. The idea is to be able to ensure the demand of the three-phase inverter at PWM above. Thus, a full-wave AC-DC converter was considered.

Incremental encoder case

This system generates a measurable value of the rotational speed of the brushless motor. This quantity is intended to be used and to be compared with the speed setpoint in the said control device.

Devices and control strategies

In this part, classical PI-based vector control, fuzzy logic control, sliding mode control, variable gain PI mode control, and hybrid controllers are presented for a better understanding of the considered control system.

Vector command

This strategy, mentioned in [3] and [4], consists in maintaining the induced reaction flux in quadrature with the flux of the rotor or replacing the magnets witha coil traversed by a constant current I $_f$ which produces a flux equivalent to that magnets.

$$\begin{cases} i_d = 0 \Rightarrow I = i_q \\ \phi_f = L_f I_f \end{cases} \tag{6}$$

The evolution of the couple follows that of I $_q$ because the flux and the current remained in quadrature. Then, the electromechanical torque is defined by:

$$T_{em} = \frac{3}{2} p \phi_f I_q \tag{7}$$

In this article, a classic PI controller, which we have adopted, is expressed in the form:

$$G_R(p) = K_p + \frac{K_i}{p} \tag{8}$$

Fuzzy logic control

Formed by reasoning close to human perception, the fuzzy controller begins to take an important place in electrical applications. It can be used for optimization and control, [5] and [6]. The common diagram for a fuzzy controller is given in figure 3 below:

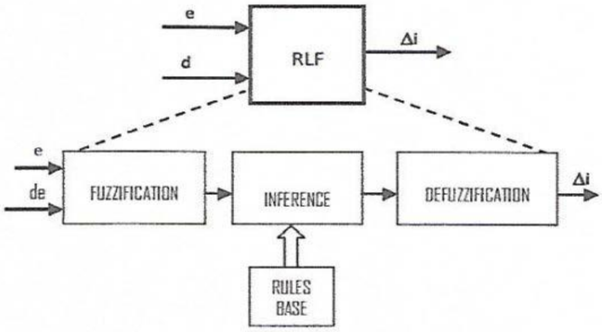

Fig. 3Fuzzy logic control

With, e: error, de: error variation, Delta_I: regulator output.

Table 1. Rule base for N=5

		e				
		NB	NS	Z	PS	PB
of	NB	NB	NB	NB	NS	Z
	NS	NB	NB	NS	Z	PS
	Z	NB	NS	Z	PS	PB
	PS	NS	Z	PS	PB	PB
	PB	Z	PS	PB	PB	PB

For the two entries (e, de), the triangular and trapezoidal shapes are used. The number of membership functions N=5 is retained. For the output, the membership function of the output is as a singleton. Table 1 gives the inference matrix from which we took.

Sliding mode control

The basic idea of SMC is to bring a system into a properly selected area and then design a control law to keep the system in that area [7]. Usually, the SMC goes through three steps including the definition of the sliding surface, and the convergence condition followed by the proposal of the control algorithm.
The equivalentcontrol signal considered in this study is calculated as follows:

$$S(x) = 0 \Rightarrow \dot{S}(x) = 0,\ u_n = 0 \tag{9}$$

In the cases,generals, relation (13) gives the function for the switching control term,

$$\begin{aligned} u_n &= K.sign(S(x)) \\ u_n &= K.sat(S(x)) \end{aligned} \tag{10}$$

In relation (10), a proportional term is added to the first expression of relation (11). It is made to increase attraction.

$$u_n = k.sign\big(S(x)\big) + k_1.S(x) \tag{11}$$

Where k and k_1 are positive constants

Variable gain PI control

A VGPI controller is a generalization of the classic PI controller where the proportional and integrator gains vary along a tuning curve. Each gain of the proposed controller has four tuning parameters [8].The VGPI controller in DFIG vector control is used as shown in Fig. 4 below:

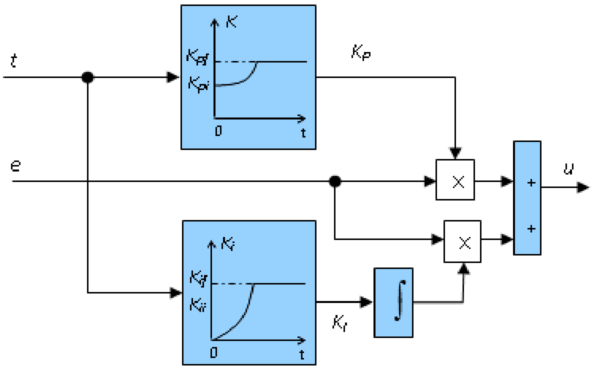

Fig. 4Structure of variable gain PI control

For the VGPI synthesis, the parameters of the classic PI regulator and these gains of the classic PI regulator are taken as the terminal values of the VGPI regulator. These conditions are adopted:

$$n = 1,\ Ts = 0,1[s] \tag{12}$$

Hybrid control

The first hybrid control studied is a derivative of the scheme proposed in [9], [10].

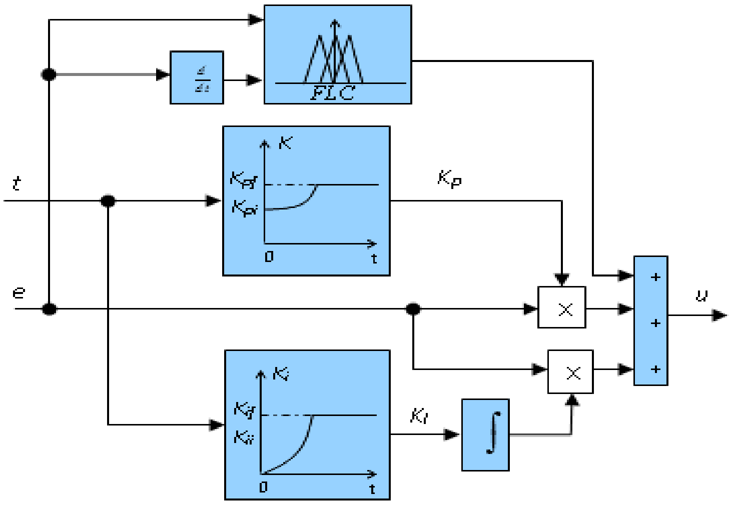

Fig. 5Basic diagram of the second proposed hybrid control

Here, the term switch command is replaced by a command from the fuzzy logic controller (FLC). This results in relation (13):

$$\begin{cases} u = u_{eq} + u_n \\ u_n = u_{FLC} \end{cases} \tag{13}$$

The second is built from the combination of fuzzy control topologies and that of variable gain PI. Fig. 5 shows the system block diagram of the fuzzy variable gain PI control.

III. RESULTS

Simulations

Matlab-Simulink application is used for the implementation of modeling and control of the said brushless motor. And the model is presented infigure 6 below.

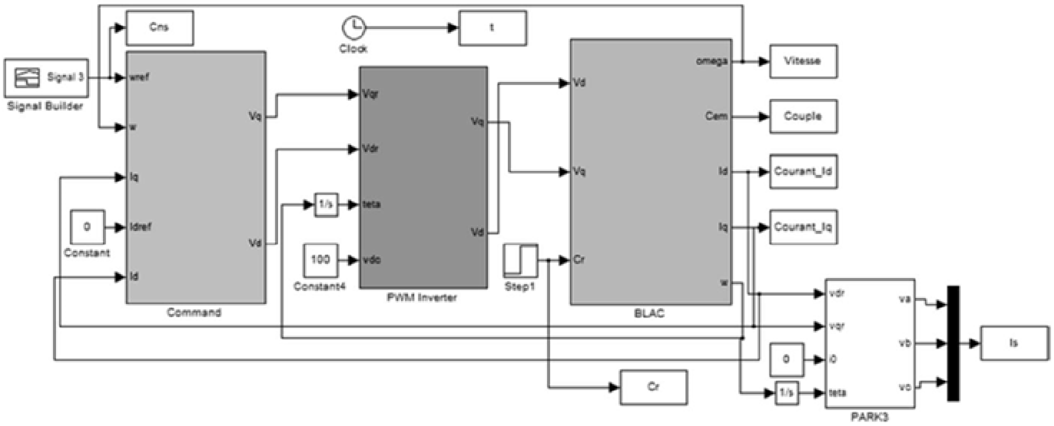

Fig. 6Model used for simulation in Matlab –Simulink

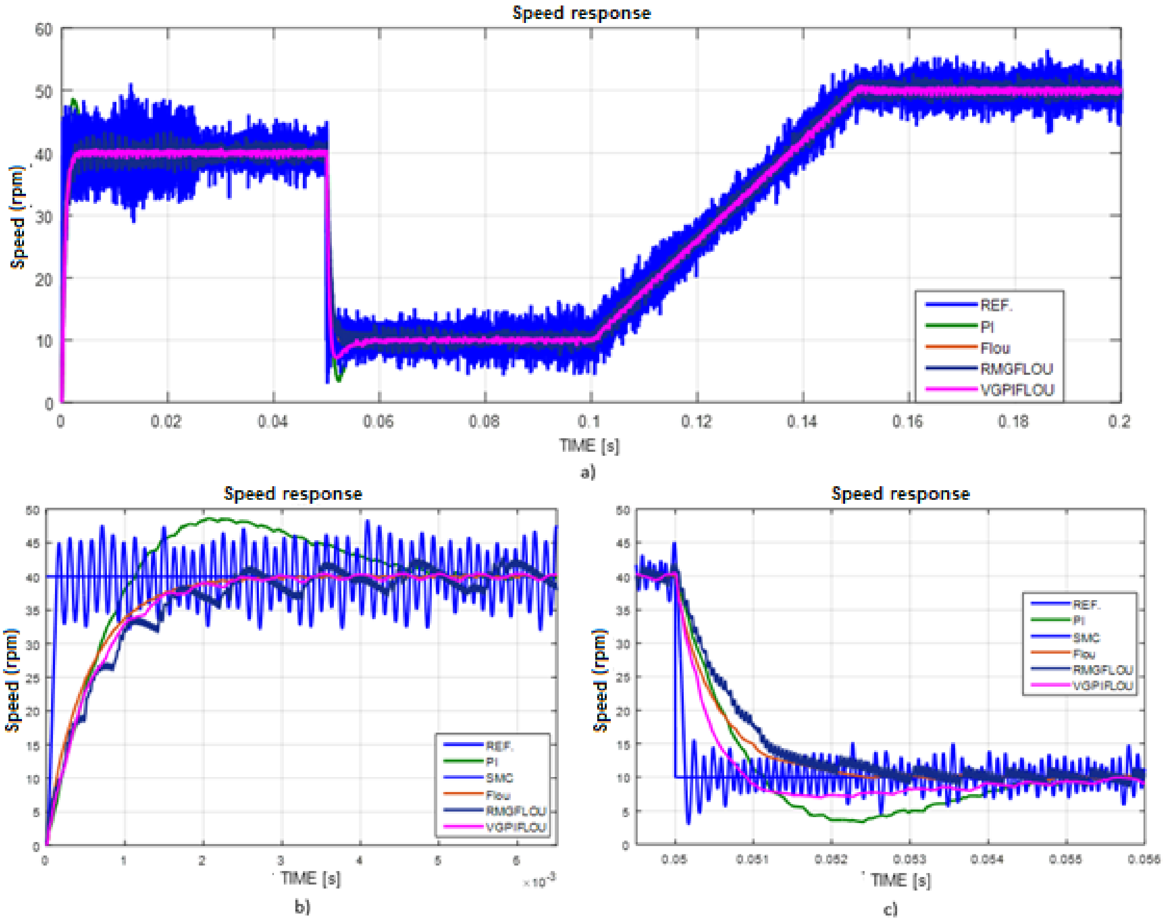

Fig. 7 Simulation results

The results, illustrated in Fig. 7, by numerical simulation of the speed control of a brushless motor with permanent magnets give us the possibility of carrying out a comparison between the various control strategies: from the control by traditional PI to hybrid controls.

Experiments on a real electric drive
Our system, a DSP card offered by Tecnosoft during our three-month doctoral research internship in Romania, is represented by the figure below.

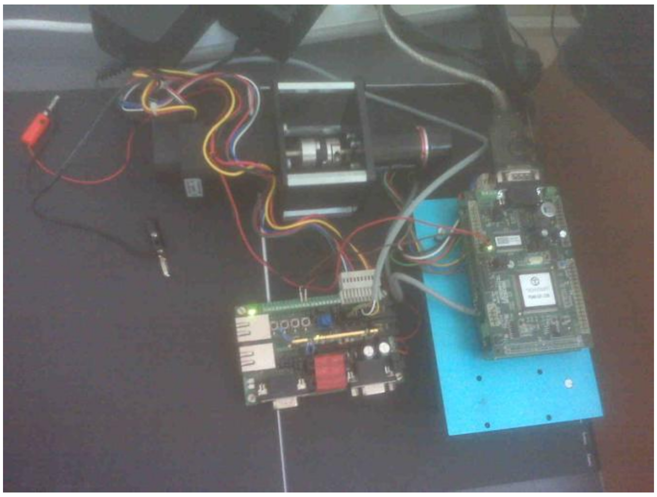

Figure 1: Motorization and cards coupled to the computer

It is composed of MSK23335 based on: 1, the controller and the power card, 2, the three-phase brushless motor,

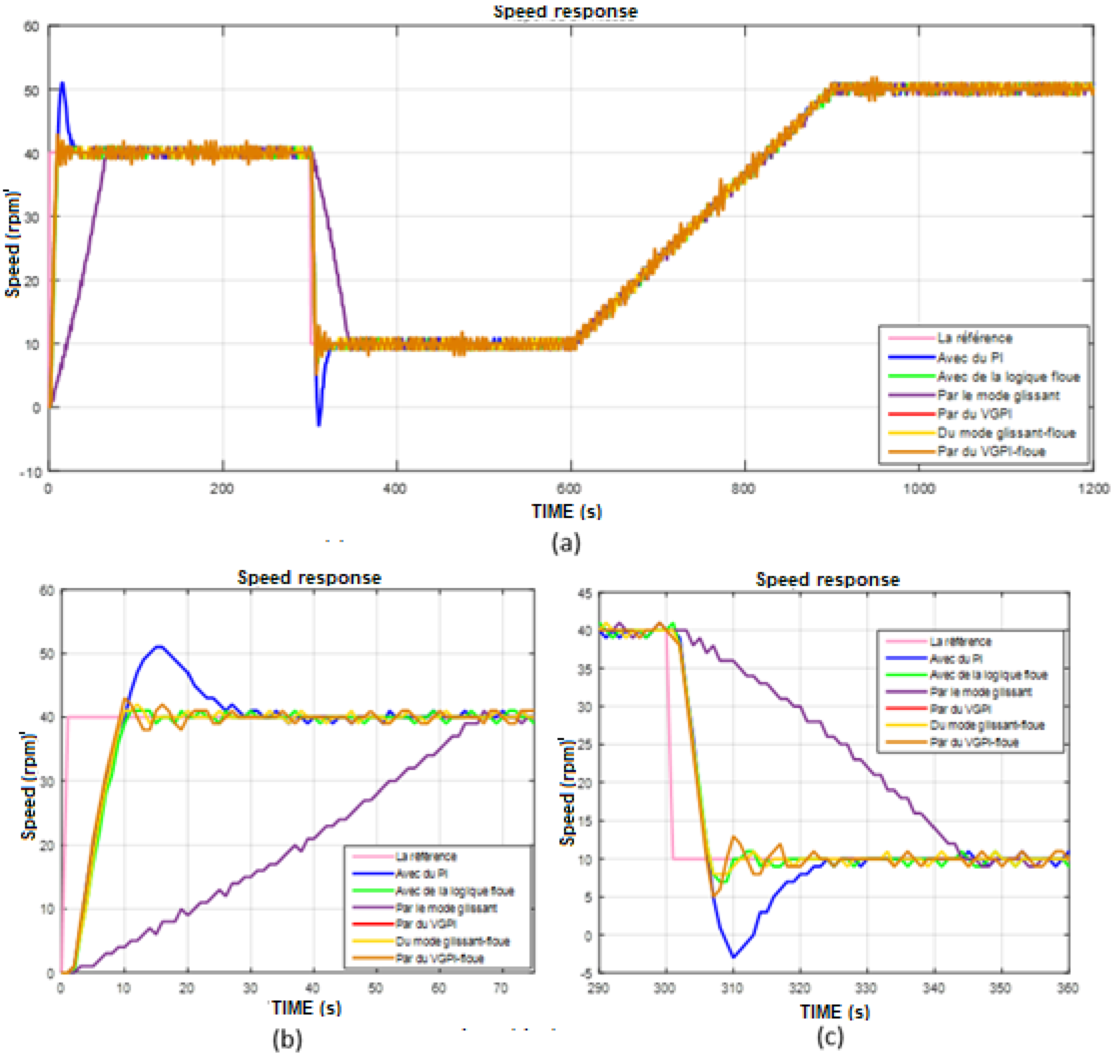

Fig. 8 Experimental results

3, the intelligent control card for the generation of resistive torque, and 4, the load (another synchronous motor permanent magnets). The card must be connected with our motor to be able to control it [11], [12]. Fig. 9 groups together all the results obtained during the implementation of these various commands under said DSP card.

IV. DISCUSSIONS

Fig. 7 summarizes the results of our simulations which (a) shows all the results, (b) gives a zoom at the starting time, and (c) illustrates the zoom at the time of 0.05s. From these results, we deduce:

- The SMC controller application shows more oscillations in the speed results.
- Then, using the fuzzy sliding mode control on the system rejects the disturbance and reduces the overshoot.
- Fuzzy sliding mode and fuzzy variable gain PI hybrid controls continue to stay out of the way even if the log is changed to 10RPM.

All experimental results are summarized in Figure 8(a). The configuration used here resembles the simulation setpoint. In (b), the use of fuzzy sliding mode controls (SMC-FLC) and fuzzy variable gain PI (VGPI-FLC) gives a conclusive result for the control of the available kit.

These results demonstrate the effectiveness of our regulatory system. Note that the measured speeds always manage to follow the setpoint. Following these results, we can still reaffirm the importance of fuzzy logic in improving the performance of various control and tuning strategies of a system.

All the simulations and experimental results show that the proposed hybrid controllers are feasible and give good performance in terms of disturbance rejection, and good behavior concerning the variation parameter.

The various parameters are summarized in the tables below.

Table 1: Parameter of the studied brushless motor

Appointments	Symbols	Value
Resistance	R	4.3[Ohms]
Electrical Constant	TAU_EL	82.8e $^{-6}$ [s]
constant torque	K	36.8e-3[Nm/A]
Inertia	J	11.0e-7[Kgm ^{2}]
Constant Friction	F	0.0[Nms /rad]
Number of lines	NLines	500 [lines/rot]
Pair of pole	p	1
Power	P_n	90 [W]

Table: Fuzzy logic control parameter

The constants	Value
ke	4.2e $^{-4}$
kde	0.08
kdi	1000

V. CONCLUSION

The objective of this communication is to situate the place of hybrid controls in the speed control of electric motors. Classical vector control, fuzzy logic control, sliding mode control, variable gain PI control, and fuzzy hybrid controls have been successively applied on an electric drive based on a brushless AC motor.

The method based on hybrid controllers is proposed and applied. The result shows the efficiency and performance of this method. In this article, it is pointed out that the SMC-FLC and the VGPI-FLC are among the best controllers available.

BIBLIOGRAPHY

[1]. Morlaye Sekou CAMARA and al., “Modeling and control of a permanent magnet synchronous generator for the production and injection of offshore energy into a network”, Electrical Engineering Symposium. July 8-9, 2014, Cachan

[2]. Gwo-Jen Chiou , Jeng -Yue Chen, Yao-Chun Tung , Fuh-Shyang Juang , " Implementation of a novel brushless DC motor controller ", The 12th IEEE Conference on Industrial Electronics and Applications (ICIEA), Siem Reap , Cambodia , 2017

[3]. O. Sandre-Hernandez, JJ Rangel-Magdaleno , R. Morales-Caporal, " Implementation of direct torque control for a PM synchronous machine based on FPGA", Power Electronics (CIEP) 2016 13th International Conference on, pp. 155-160, 2016.

[4]. WKWIBOWO, S. JEONG, "Genetic algorithm tuned PI controller on PMSM simplified vector control", Berlin Heidelberg, 2013.

[5]. FP Andriniriniaimalaza, NJ Razafinjaka and LM Kreindler, "Parameter optimization for a fuzzy logic control of a Permanent Magnet Brushless Motor," 2017 10th International Symposium on Advanced Topics in Electrical Engineering (ATEE), 2017, pp. 211-216.

[6]. Bapayya Naidu Kommula , Venkata Reddy Kota, Mathematical modeling and fuzzy logic control of a brushless DC motor employed in automobile and industrial applications, IEEE First International Conference on Control, Measurement and Instrumentation (CMI), Kolkata , India , 2016.

[7]. Utkin , Sliding mode control design-principles and applications to electric drives, IEEE T - Ind . Electron., vol. 40, pages 23-46, 1993.

[8]. Fanambinantsoa Philibert Andriniriniaimalaza, Nirinarison Jean Razafinjaka , Charles Bernard Andrianirina . Fuzzy -Variable Gain PI Mode Control Applied to a Brushless AC Motor Drive. Engineering and Applied Sciences. Flight. 4, No. 1, 2019, p. 1-10.

[9]. F. Philibert Andriniriniaimalaza, N. Jean Razafinjaka, Charles B. Andrianirina. New Approach to a Hybrid Fuzzy-Sliding Mode Control to a Brushless AC Motor Scheme. International Journal of Engineering Research & Technology (IJERT), Vol. 7 Issue 12, December-2018, p. 83-88.

[10]. Razafinjaka and al., Fuzzy -Variable Gain PI Control of WECS based on a Doubly Fed Induction Generator, The international Conference on Modeling and Applied Simulation, 2017. 51.

[11]. Meixi Wu, Yuchi Lin, Control System of Two -phase Brushless DC Gyro Engine Based on DSP, The Second International Conference on Instrumentation, Measurement , Computer, Communication and Control, Harbin, China, 2012.

[12]. Ali Mousmi , Ahmed Abbou, Yassine El Houm , Trapezoidal control of Brushless DC motor based on DSP F28335, International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS), Fez, Morocco , 2017.