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Fuzzy, Neural and Neuro-Fuzzy Hybrid PID Controllers for a DC Machine

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Abstract: This paper deals with control of a DC motor using conventional and unconventional techniques namely the exploitation of artificial neural networks, fuzzy logic controller and PID controller. After studying the performances of the PID controller, the idea is to determine a partial fuzzy or partial neuronal PID controller. For the control of the position of the DC motor, an hybrid controller combination of classic and unconventional method is proposed.

Keywords: DC motor, Control, Artificial Neural Networks, Fuzzy Controller, PID Controller, Neural model.

1. INTRODUCTION

In a few years, neural networks have become an important tool in many different fields of industry and services. Using unconventional approaches, several models were proposed for the characterization of the DC machine. These models are based on the concepts of the artificial neural networks, fuzzy logic, genetic algorithms [1-3]. Nevertheless, they have not reached a development even if they are used to build a model and to provide the reactions of various static and dynamic systems [18-19]. This advanced technology also makes it possible to produce the states of outputs of complex systems without having to provide the mathematical model which in some cases seems impossible to provide.

Neural networks represent a family of nonlinear functions that can build a very large class of models thanks to their learning ability and generalization [6-9].

During last years, a major interest is consecrated to fuzzy control of systems including industrial applications [10]. Fuzzy logic control technique has been successfully applied in many engineering areas and consumer products since the pioneer work of Mamdani in 1974 [11-12].

Many varieties of control schemes, such as proportional P, proportional integral (PI), proportional derivation integral (PID), adaptive, Artificial Neural Networks (ANNs) and fuzzy logic controller (FLCs), have been developed for position control of DC motors [15].

The main idea of this paper is to combine conventional and non conventional control techniques for PID design. This combination for example consists of a conventional control parameters derivate D, integral I and a fuzzy proportional parameter P improving control performance to obtain (P*ID). In comparison with the existing fuzzy PID controllers, the proposed fuzzy P*ID controller merge the advantages of fuzzy controller with the conventional regulator. The fuzzy (P) term has an important role in improving an overshoot and accelerating response time. The conventional integral (I) term reduces the steady-state error, and the conventional D which can be realized in practice as shown in [16] is responsible for the stability. As it has only one additional parameter to be adjusted according to the original PID controller, it is easy to be designed and the fuzzy P*ID controller keeps the simple structure of the PID controller. It is not necessary to modify any hardware parts of the original control system for implementation.

After the description of the DC machine in section II, the problem statement in section III, the proposed hybrid controllers and applied is designed for the DC machine.

2. ELECTRIC MOTOR DESCRIPTION

A DC motor is an electromechanical device that converts electrical energy into mechanical energy input. The electrical energy is supplied by a power converter which feeds the winding arranged on the rotor (armature) by means of brushes and adapted collector, permanent or not, due to the stator. The current flows through the spires of the motor armature, electric forces are applied there to and, thanks to the device brushes / collector, these additional forces participate in the rotation of the motor. The armature voltage is considered as the input of motor and the output is the rotational speed of the rotor [13] [5][28] [30]. The system based on the DC motor is considered as a benchmark for the study and analysis of speed and position problems, figure 1.

In this way, the process is represented by the following mathematical system.

$$\begin{cases} u(t) = e(t) + Ri(t) + L \frac{di(t)}{dt} \\ c_m(t) - c_r(t) = fw(t) + j \frac{dw(t)}{dt} \\ c_m(t) = k_c i(t) \\ e(t) = k_e w(t) \end{cases} \quad (1)$$

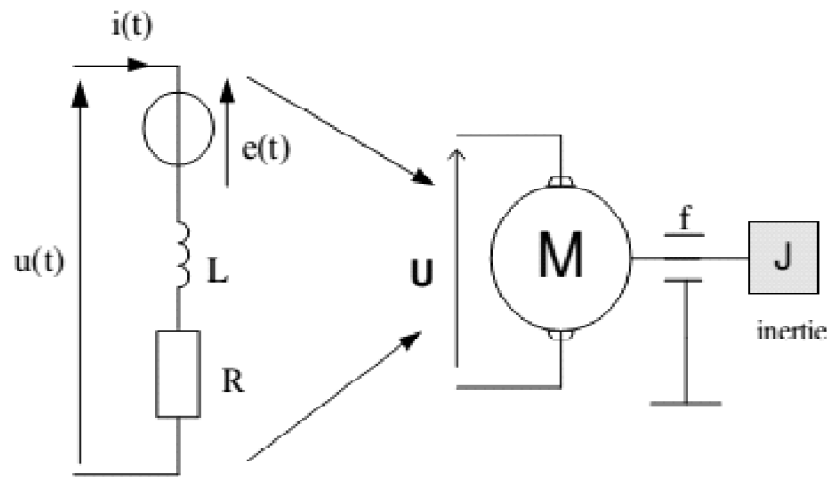


Figure 1: Diagram of a DC motor

k_c and k_e are the conversion constants u is the motor armature voltage. i is the armature current. e is the back

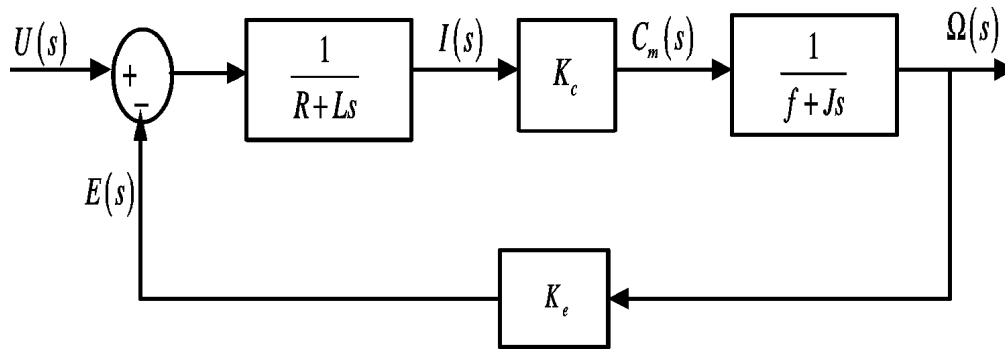


Figure 2: Bloc diagram of a DC motor regulation (speed response)

electromotive-force voltage. ω is the shaft speed, c_m the mechanical couple and c_r the resistant torque [4], [5].

$$U_{nom} = 24V \quad U_{max} = 32V \quad I_{max} = 2,2A \quad J = 10^{-4} Kgm^2 \quad L = 0,63mH \quad f = 2,510^{-6} Nms$$

The system (1) could be represented in the block diagram, shown in the figure 2.

The transfer function of the motor is given by equation (2):

$$H(s) = \frac{\Omega(s)}{U(s)} = \frac{K_e}{LJs^2 + (RJ + Lf)s + Rf + K_e K_c} \quad (2)$$

3. PROBLEM STATEMENT

Conventional Proportional Integral Derivative (PID) type controller is most widely used in industry due to its simple control structure, easy of design, and inexpensive cost. Due to parameters fluctuations, it is necessary to use conventional robust controllers. Different robust control strategies are considered in the literature. The H_∞ control ensures stability and an acceptable level of performance for ordered systems despite uncertainties in parameters and / or neglected dynamic process [25]. The internal model placed in parallel with selected process, takes the difference between the measured output vector and the model output in feedback. The aim of controlling by sliding mode is primarily to attract states of the system in a properly selected region and then designing a control law always maintaining the system in this area. There are also non conventional robust control methods such as fuzzy control which presents a relevant solution to provide the complex studied system desired dynamic behavior. It uses the human operator expertise usually handling the process for building simple and efficient systems control [11] [26] [27]. Neural network control attempts to emulate learning ability and retrieve knowledge by the human brain [2] [16]. The main advantages of neural controller lie in the fact that it is not necessary to perform a mathematical analysis of the process.

This paper deals with the influence of the choice of a partially fuzzified PID controller, where one parameter of the original PID is fuzzified, or partially neuronal PID controller where one of the parameter of PID is replace by a neural model, on the closed loop system performances.

3. HYBRID CONTROL OF THE DC MOTOR

To integrate a human expertise, a hybrid controller of the DC motor is developed. Conventional and non conventional methods of controller are used. The response position of the DC machine is unstable and divergent, figure 3.

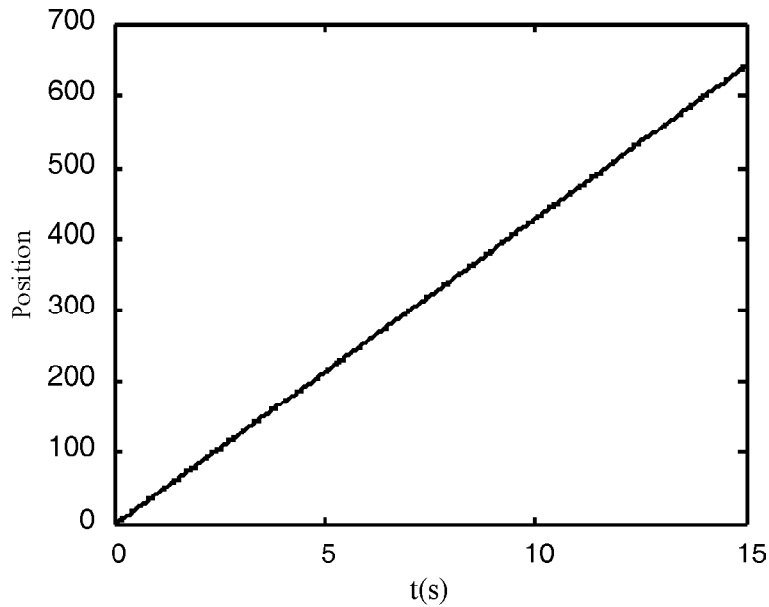


Figure 3: The response position of the DC machine

3.1. Basic idea

To adapt the controller to the desired operating requirements, a combination of a classical control technique and a non conventional technique is considered [22], [23] and [24]. In order to improve the performances of the studied system, a classical ID controller and a proportional fuzzy controller are combined. The proposed controller uses, for integral term, fuzzy logic strategy instead of conventional strategy, while the proportional and derivative terms remain unchanged [24].

The PID controller is a conventional standard control process. This type of controller is characterized by a control signal u derived from the signal error e as following

$$u = K_p e(t) + K_i \int e(t) dt + K_d \dot{e}(t) \quad (3)$$

where K_p is the proportional gain, K_i the integration gain and K_d the derivative gain, figure 4.

The determination of the controller parameters can be achieved by different approaches either linearization with a choice of PID parameters according to desired performance and adapted to optimal or unoptimal dynamic, or by pole placement or PIDtool command of Matlab [32].

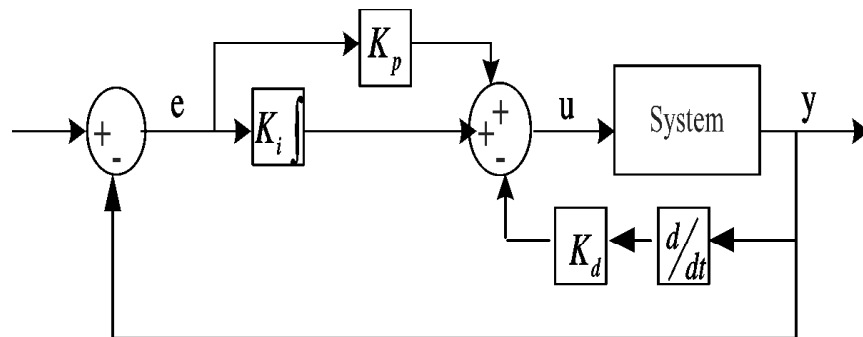


Figure 4: Control loop by conventional PID

The proposed approach for the synthesis for such a fuzzy controller requires two steps. The first is to determine the parameters of conventional PID controller defined in relation with desired performance for a system characterized by its nominal parameters. It is envisaged in a second step, to introduce in series to the integral term of the PID the fuzzy control module of figure 5 which allows conferring to the corrected studied systems of figure 6.

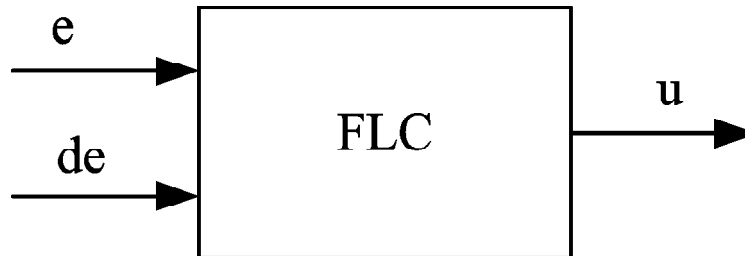


Figure 5 : Control module with Fuzzy Logic Controller (FLC)

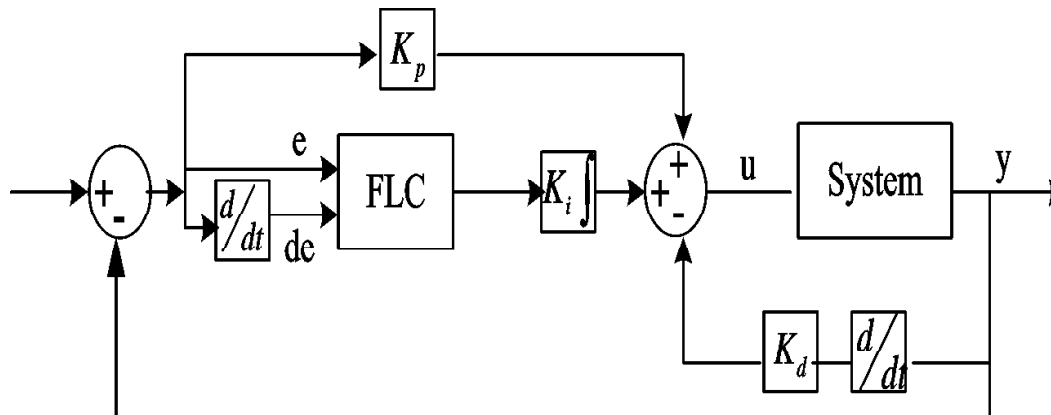


Figure 6: Control with PI*D

3.1. Control of the position of DC motor by conventional PID

PID control parameters used to impose the desired performance are $K_p = 0.6$, $K_i = 0.6$ and $K_d = 0.5$. They are determined using the PID tool command of Matlab

The response of the DC machine is given by figure 7 and the control signal by figure 8. The position has a response time of 5s and an overshoot of about 25.22 %.

3.2. Fuzzy logic Integral I* plus conventional Proportional Derivative controller PD (PI*D)

The many possibilities of formulating membership functions and inference rules lead obviously to a great diversity of these characteristics [17]. In this section, the formulation of the controller with two inputs, e and de , and one output u is expanded.

In this study, the fuzzification of variables e , de and u is based on three sets distributed in the normalized domain $[-1,1]$. The membership functions of the proposed controller are trapezoidal or triangular as shown in Figure 9 [20].

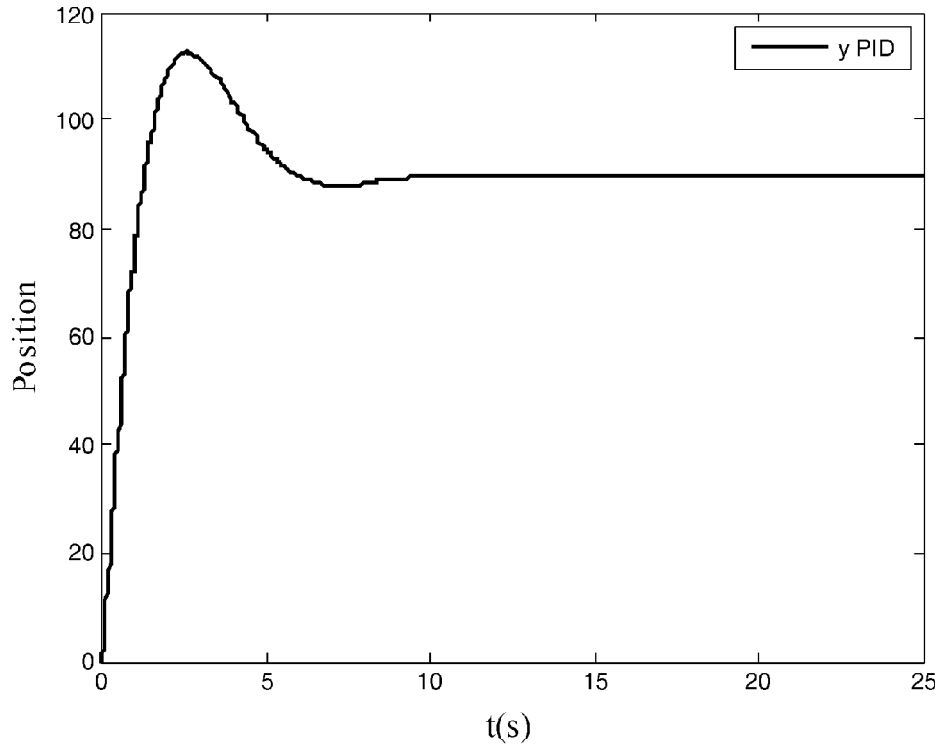


Figure 7: Evolution of the system output controlled by PID

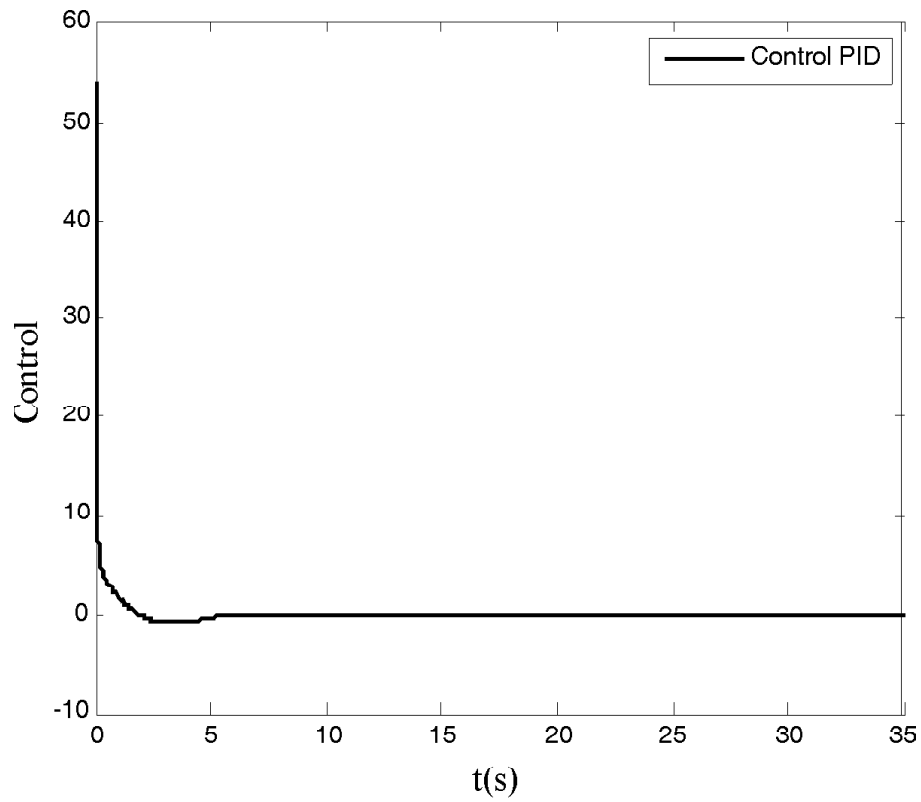


Figure 8: Evolution of the control signal for PID

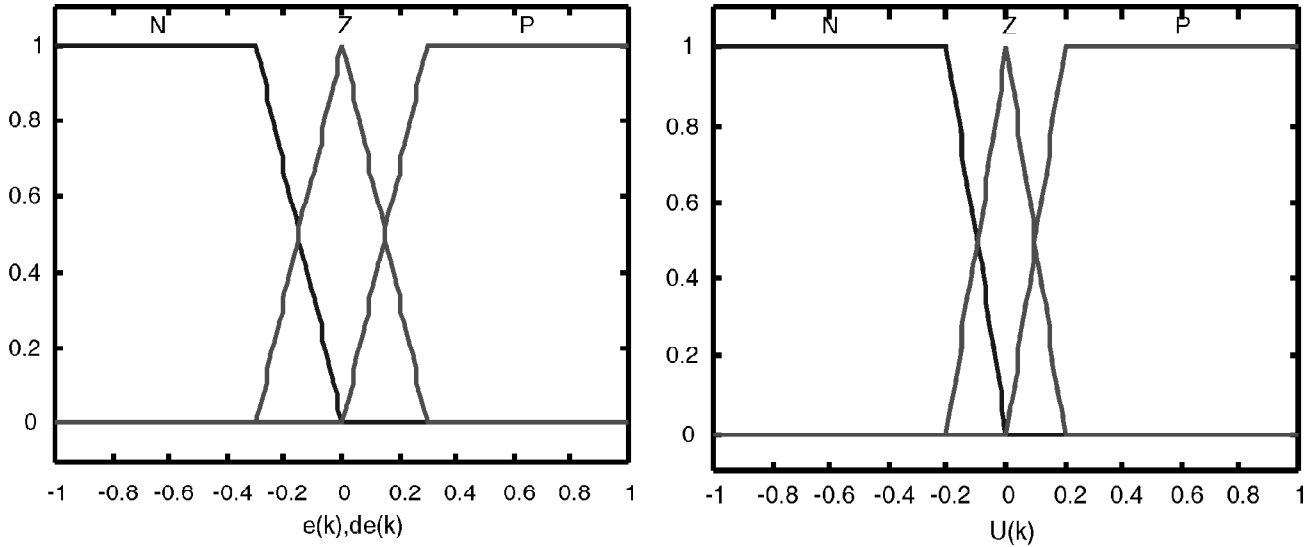


Figure 9: Membership function of the inputs e , de and the output u

In this study, for each variable three subsets are considered leading to the inference rules of Table I. The commonly used inference engine is the Max-Min method.

Table I
Rule table

e			
de	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

Since the control actions are described in a fuzzy sense, a defuzzification method is required to transform fuzzy control actions into a crisp output value of the fuzzy logic controller. For the incremental fuzzy logic controller, a widely used defuzzification method is the centroid.

For the proposed controller, uses in series the integral term of the PID the fuzzy control module of figure 5, the response time is about 6.4s without an overshoot. The figures show that the position response of the DC machine without a fuzzy controller is divergent. When adding a controller the position response becomes a stable response. The response of the DC machine is given by figure 10 and the control signal by figure 11.

For the proposed controller (PI* D), the response time is about 3s without an overshoot.

To test the robustness of the proposed controller relative to the external disturbance, a disturbance of a lasted 1s is applied at time $t = 15s$. Figures 12 and 13 respectively represent the response of the DC machine and the control signal of the proposed controller following a disturbance.

Comparing the results presented in Figure 12, the PID controller fuzzy integral action proposed is more robust in terms of rejection of the disturbance over the conventional PID controller.

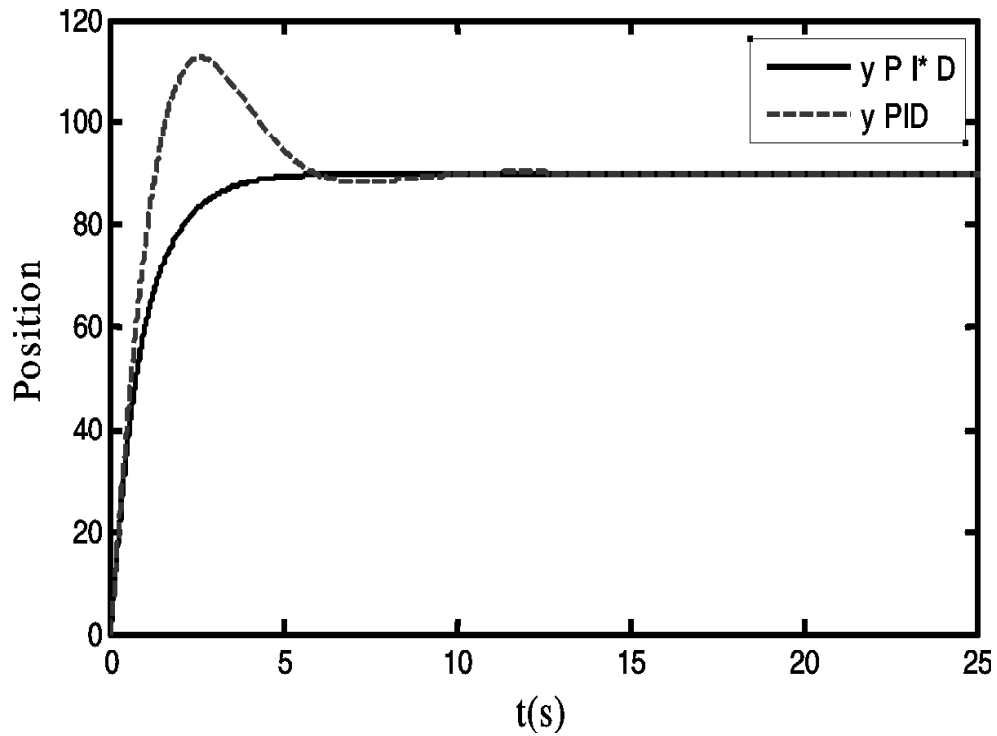


Figure 10: Evolutions of the system outputs with PI* D and PID controllers

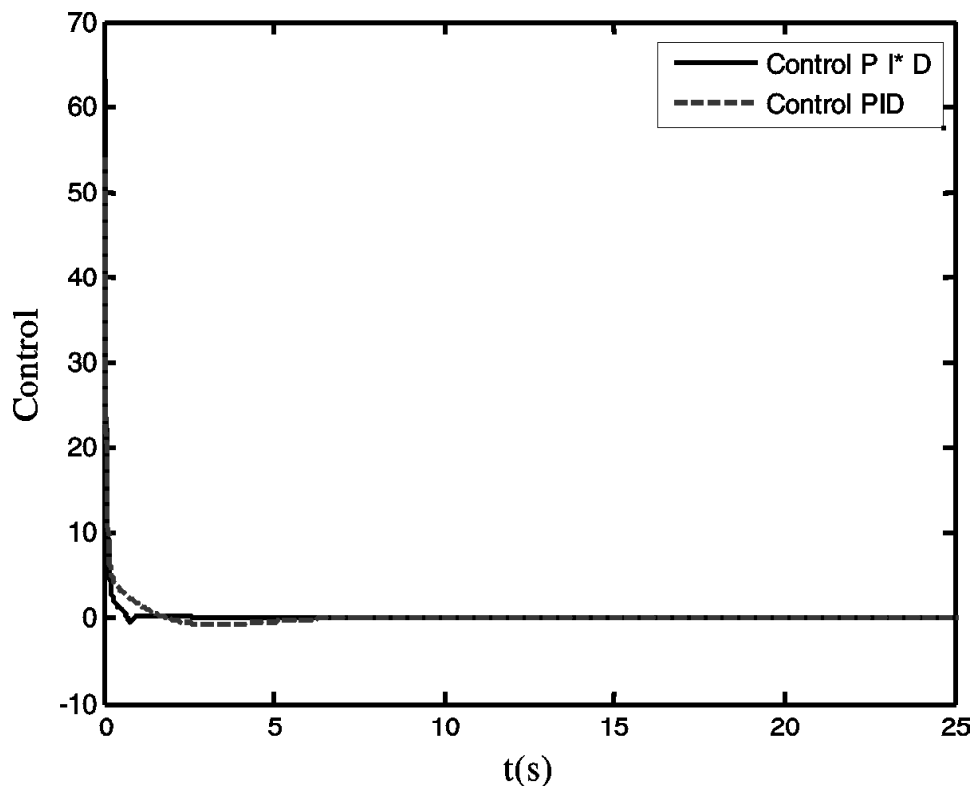


Figure 11: Evolutions of the control signal with PI* D and PID controllers

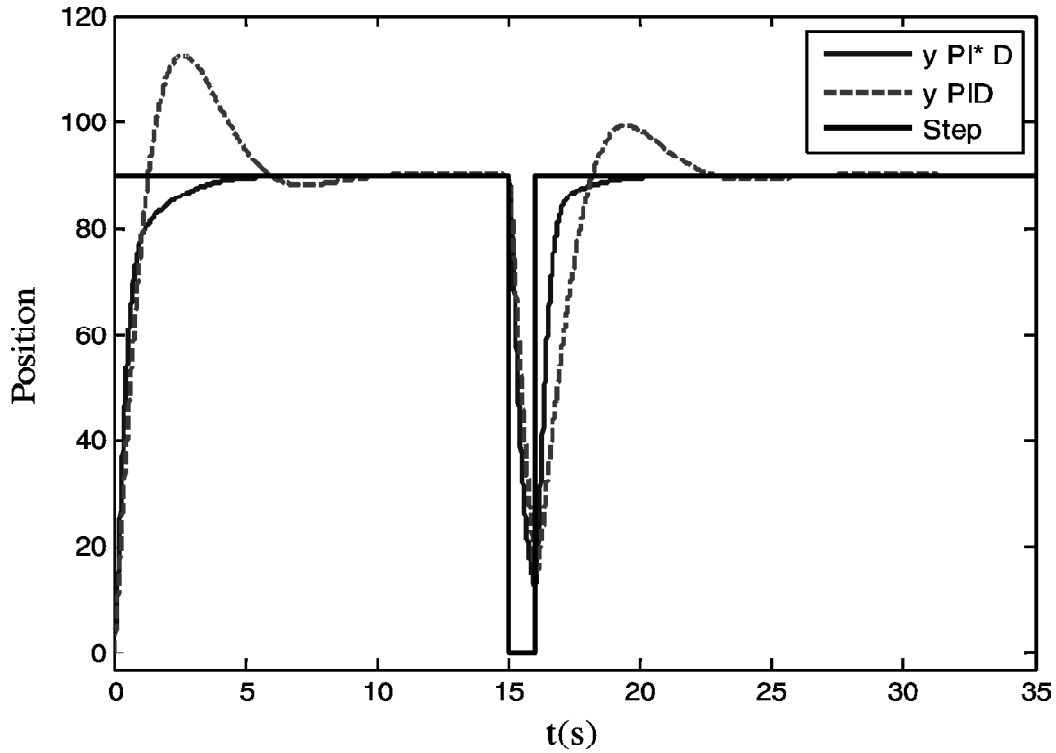


Figure 12: Evolutions of the output of the position of MCC with PI*D and PID controllers following a disturbance applied to 15s

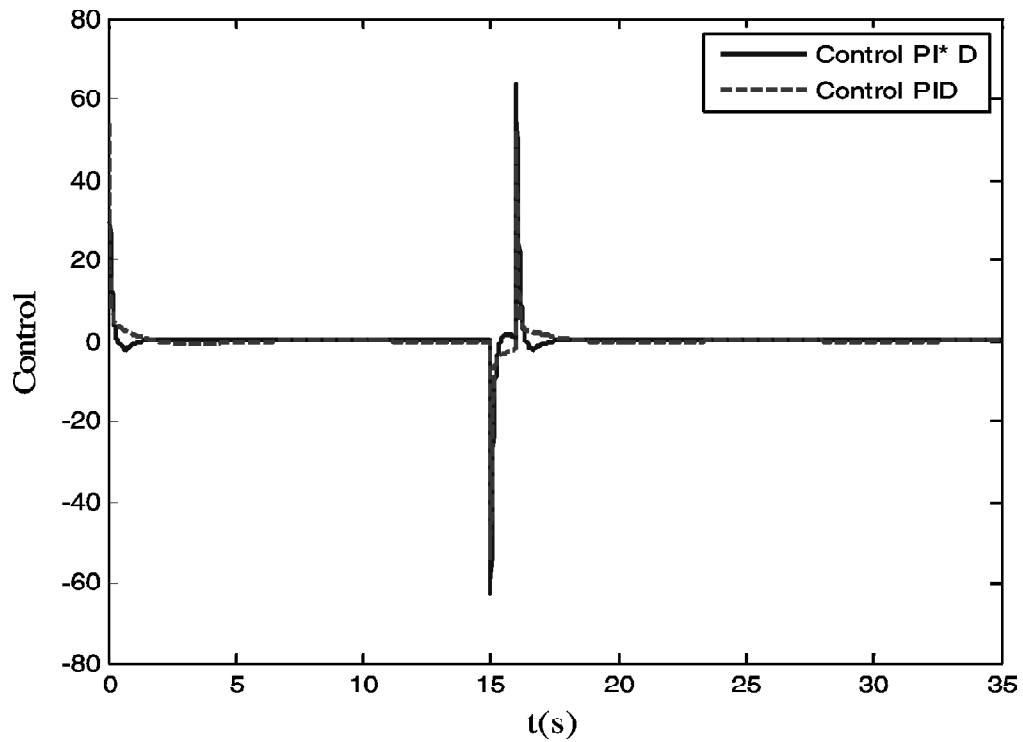


Figure 13: Evolutions of control signal of the position of MCC with PI*D and PID controllers following a disturbance applied at 15s

3.3. Fuzzy logic Proportional P* plus conventional Integral Derivative controller ID (P* ID)

The proposed controller uses, for proportional term, fuzzy logic strategy instead of conventional strategy, while the integral and derivative terms remain unchanged, Figure 14 [12]. The proposed controller is then applied to DC machine to test its robustness. The responses of DC machine and control signal are respectively in Figures 15 and 16.

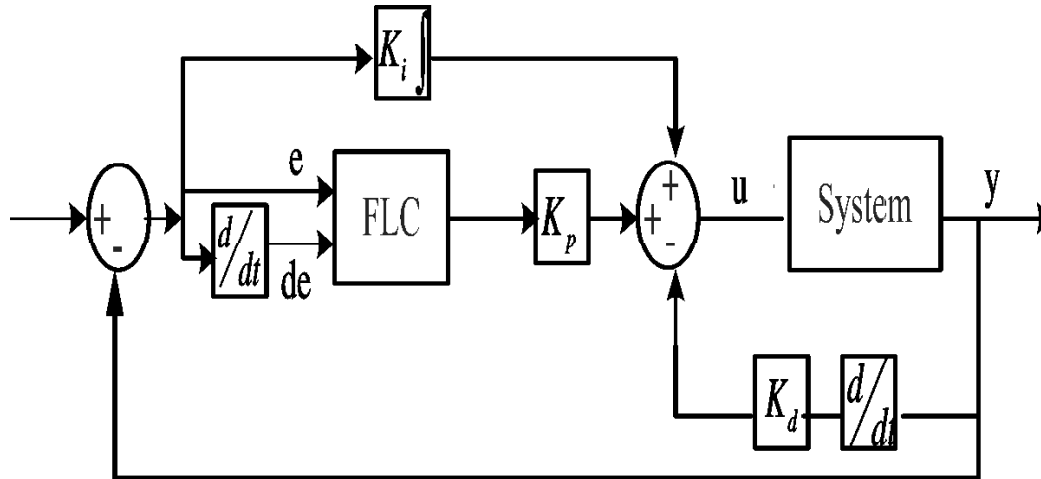


Figure 14 : Control with P* ID

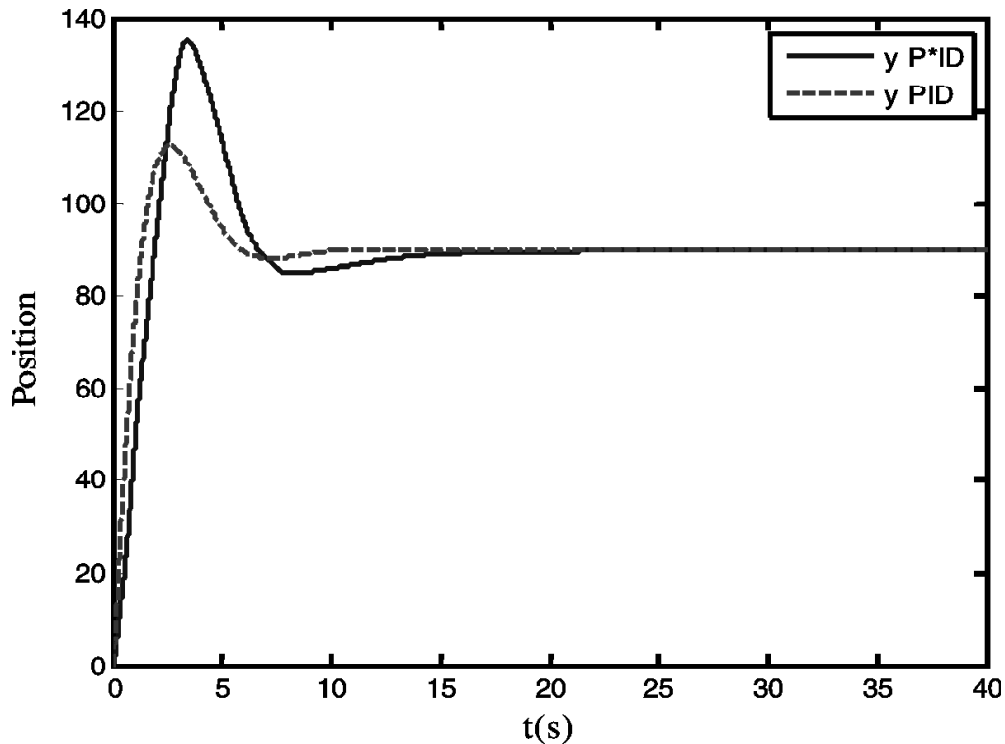


Figure 15: Evolutions of the system outputs with P*ID and PID controllers

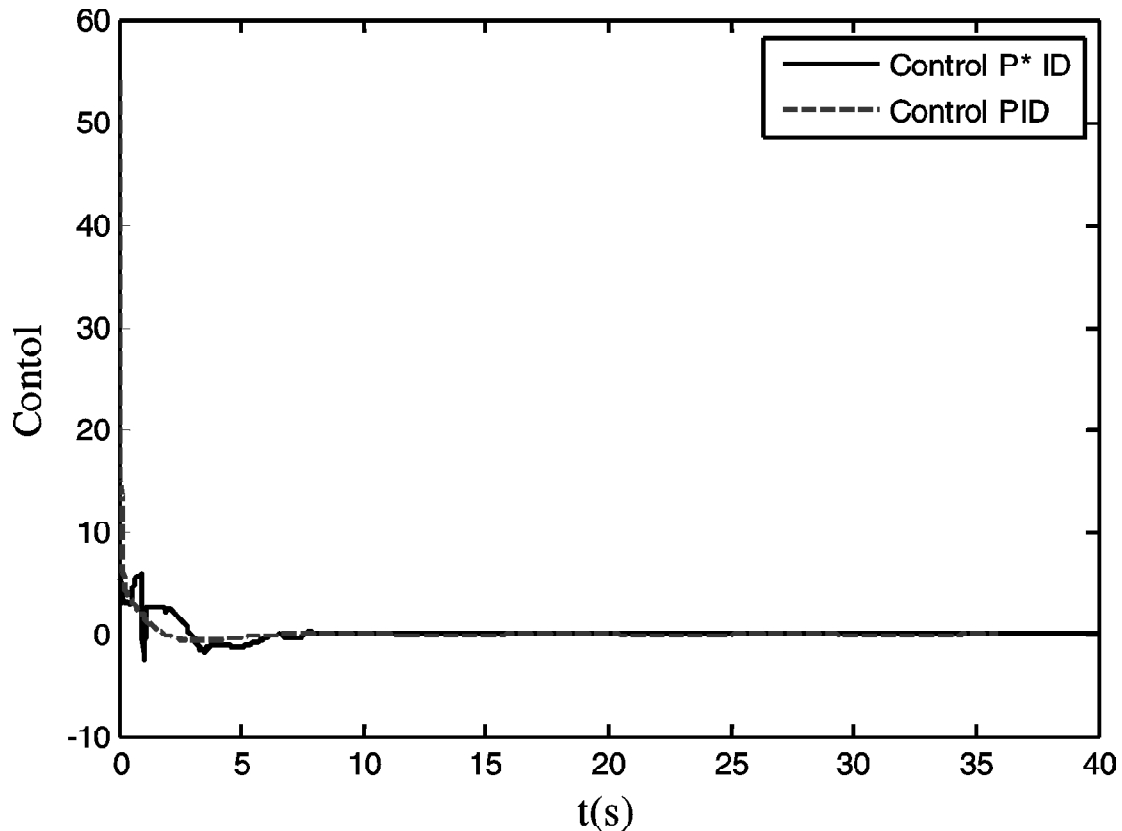


Figure 16: Evolutions of the control signal with P*ID and PID controllers

The proposed controller has very good performance compared to the response time and overshoot. For the controller (P*ID), the response time is about 9.23s and the overshoot of 50.4%, although at first the system is divergent.

To test the robustness [29, 31] of the proposed controller relative to the external disturbance, a disturbance of a lasted 1s is applied at time $t = 40s$ and a set point step from 90° to 180° . The PID controller fuzzy proportional action proposed, figure 17 is more robust in terms of rejection of the disturbance and the set point step over the conventional PID controller.

3.4. Fuzzy logic Integral I*, conventional Proportional plus neural derivative controller (PI*Dn)

The use of the diverter block is not recommended in automatic. The idea in this part is to replace the derivative block by a neural model. In order to improve the performances of the studied controller, a classical Proportional controller, an Integral fuzzy controller and derivative neural are combined. The PID control by fuzzy integral action and derivative neural action using a fuzzy logic controller associated with the integral term and the derivative term is replaced by a neural model, while the proportional term is remained unchanged, Figure 18.

The response, Figure 19, of the position of the MCC and the control signal Figure 20, using the proposed controller succeeded in achieving the desired output.

3.5. Fuzzy logic Proportional P*, conventional Integral plus neural derivative controller(P*IDn)

This fuzzy proportional and derived neuronal action is synthesized from the P* ID and only derivative action is modelled exploiting neural networks, Figure 21.

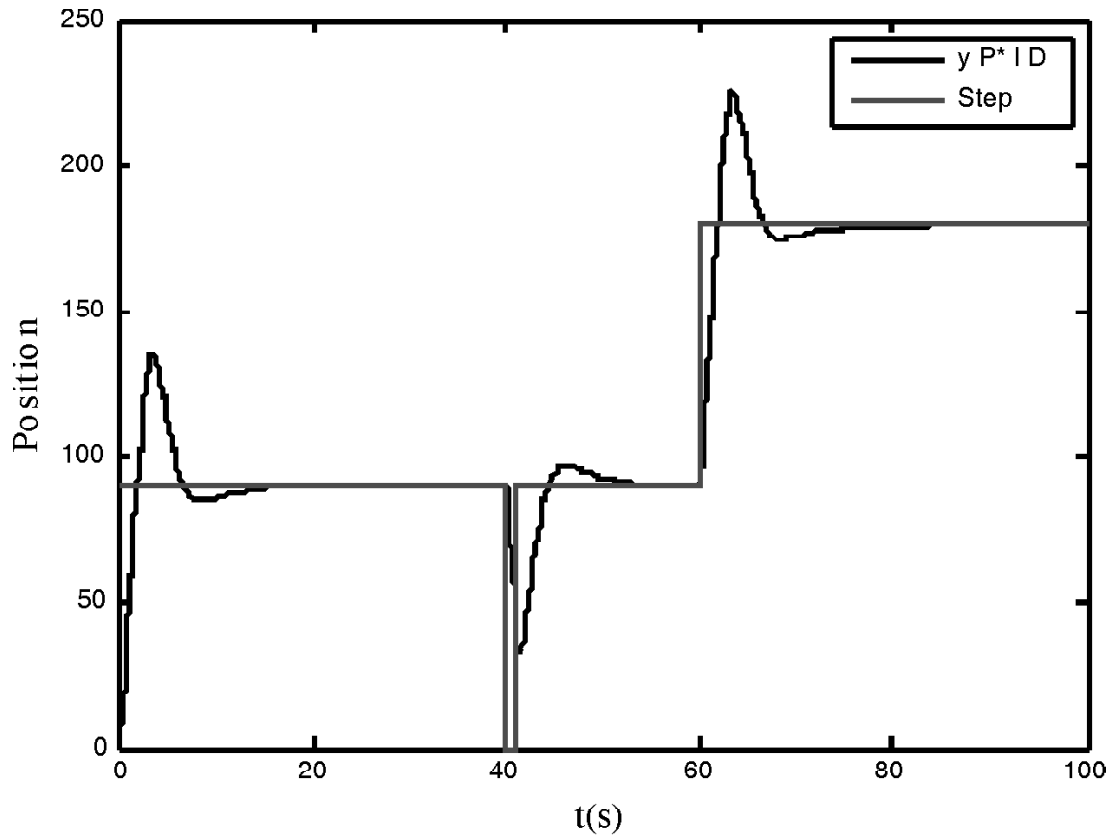


Figure 17: Evolutions of the output of the position of MCC with P*ID and PID controllers following a disturbance applied to 15s and set point

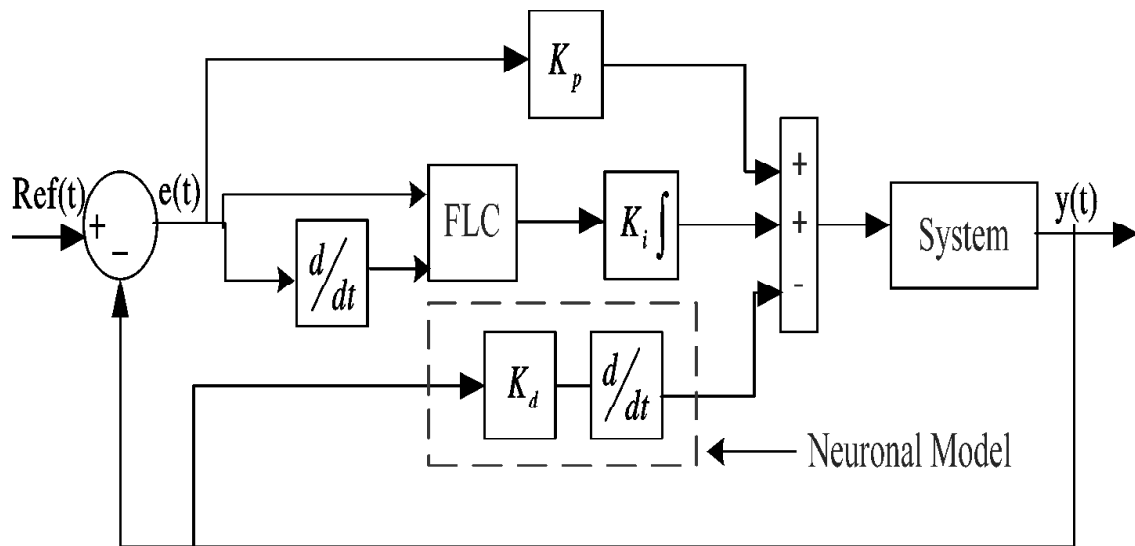


Figure 18: Control PID with fuzzy integral action and neural derivative action (PI*Dn)

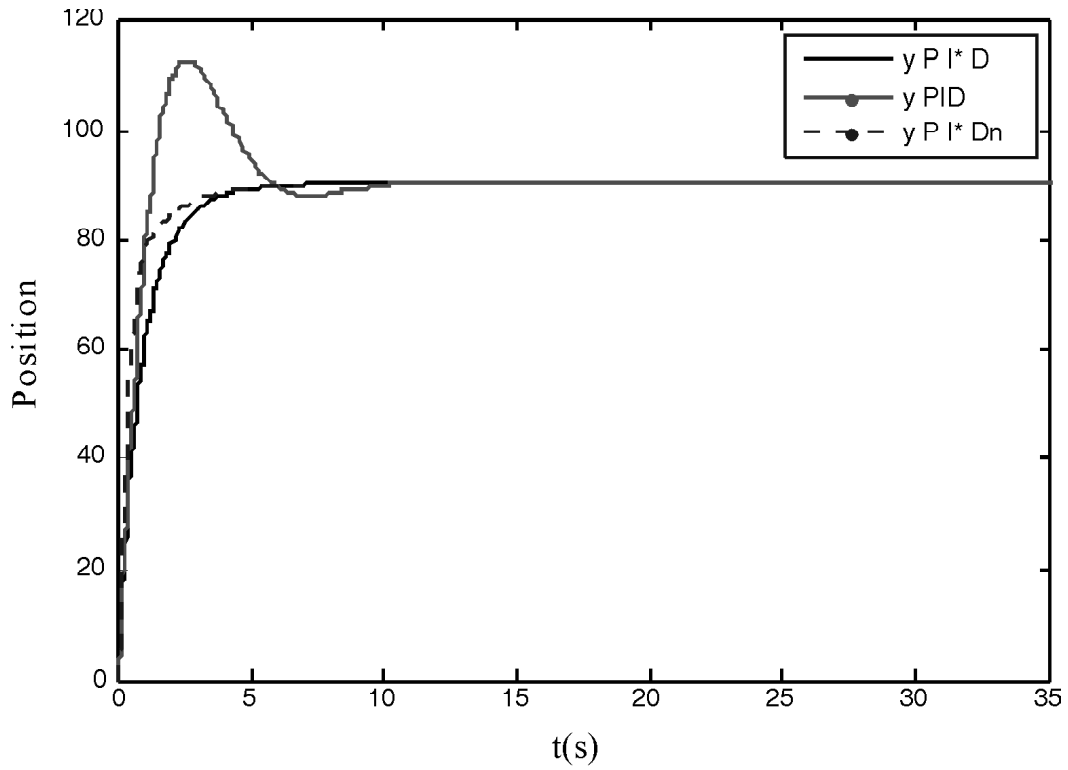


Figure 19: Evolution of the output of the MCC by PI* D, PID et P I* Dn

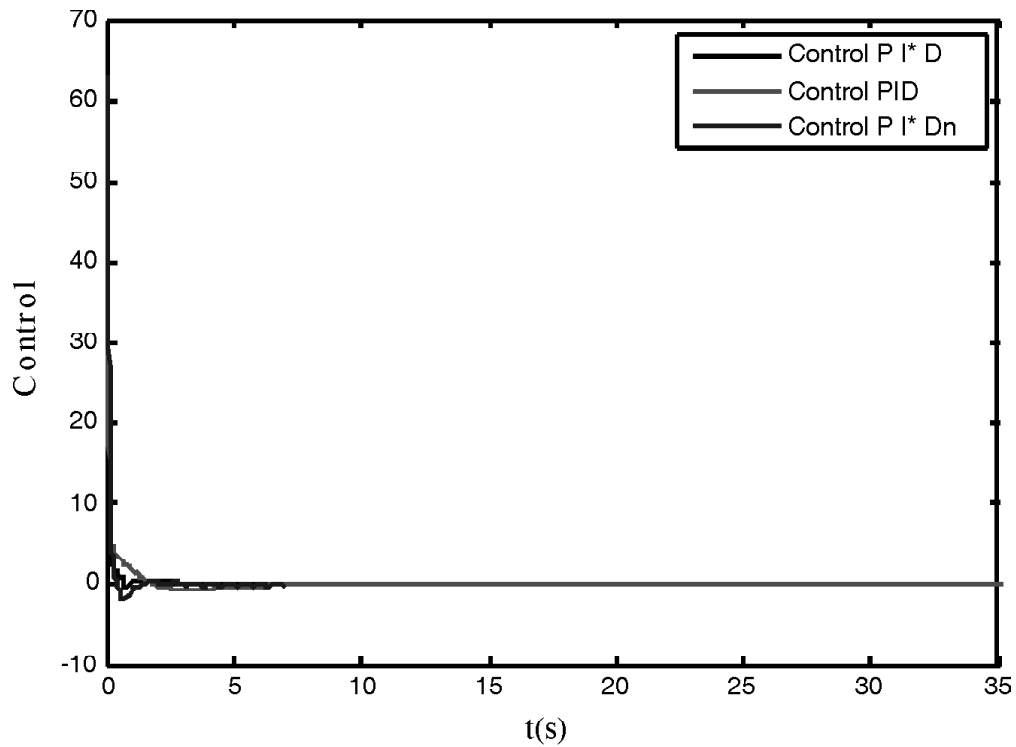


Figure 20: Evolutions of the control signal with PI* D, PID, P I* Dn controllers

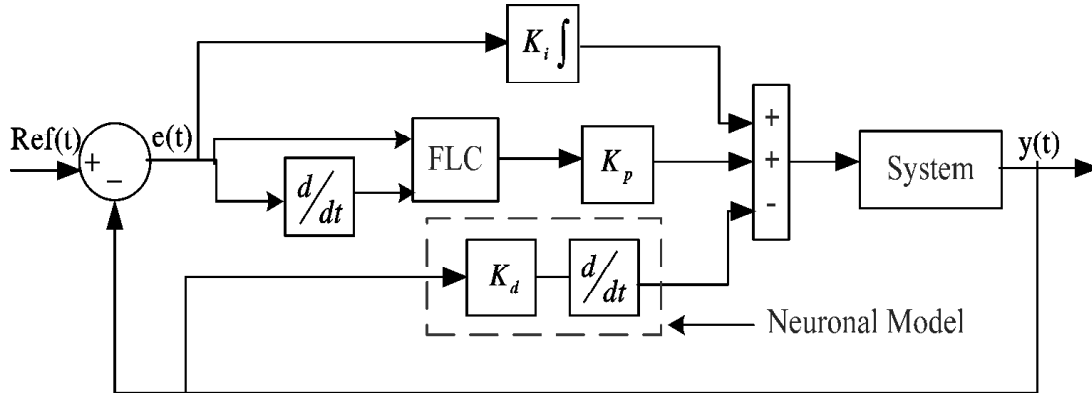


Figure 21: Control PID with fuzzy proportional action and neural derivative action (P*I Dn)

Figures 22 and 23 present the response of the MCC controlled by proposed controller and the control signal. The proposed controller (P* I Dn) has very good performance compared to the response time and overshoot.

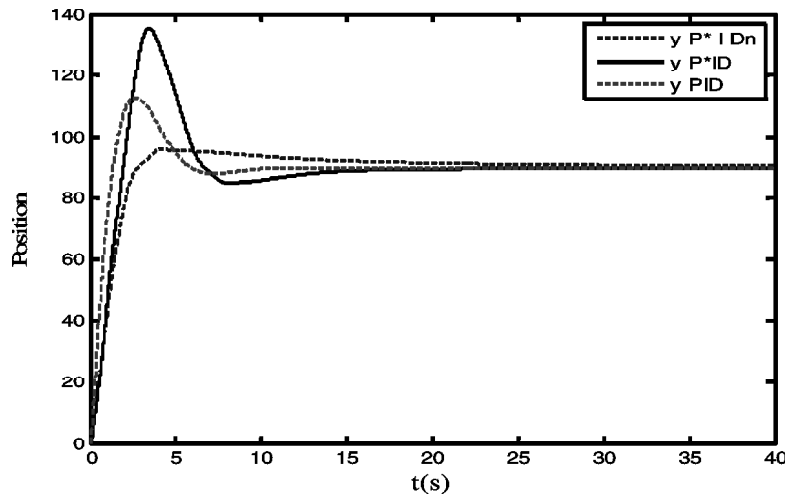


Figure 22: Evolution of the output of the MCC by PI* D, PID et P* I Dn

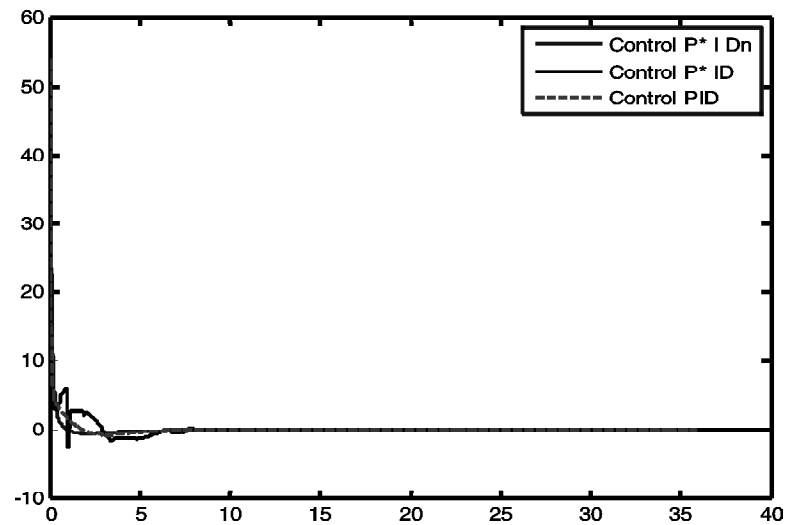


Figure 23: Evolutions of the control signal with PI* D, PID, P* I Dn controllers

For a comparative study of the four proposed controllers, the different values of the response time and the overshoot are shown in Table II.

Table II
Response times and overshoots according to different controllers

	<i>PID</i>	<i>P*ID</i>	<i>PI*D</i>	<i>P*IDn</i>	<i>PI*Dn</i>
Response time(s)	5	9.23	3	4.03	2.18
overshoot (%)	25.22	50.4	×	×	×

The use of the proposed hybrid PID controller leads to a good control performance for the position of the DC machine compared with the PID controller. Therefore the proposed controllers is more robust, this robustness is tested by different mechanisms. For this different response time the PI*D and PI* Dn are faster than the P*ID, P*IDn and PID. For the control of the position we use the PI*Dn because he have the response time 2.18s and without overshoot, the overshoot is not recommended in control.

4. CONCLUSION

This paper deals with the synthesis of four hybrid PID controllers. For the first proposed controller (PI* D), the term I of the conventional PID is replaced by an incremental fuzzy logic controller. As for the second controller (P* ID), the term P of the conventional PID is replaced by an incremental fuzzy logic controller. The last proposed controllers (PI* Dn) and (P* IDn) replaces the derivative term by a neural model. Then a control law using a hybrid controller was developed to stabilize the response position of the machine. These proposed results show the efficiency of the neural model and the hybrid controller.

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