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Control Methods For Hybrid Regulators Used For DC Motor Drive

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Abstract – The goal of this work is to study the performances of a hybrid controller used to control DC Motor drives. This study is made using computer simulation. In the first part, the basic notions of conventional and fuzzy controller will be presented. The second part is devoted to the control system of the DC Motors. The third part is the design of the hybrid controller. The last parts are devoted to the control methods for hybrid controllers and to the analyse of the results of simulation.

Keywords: DC Motor, Control System, PI, PID, Fuzzy, Hybrid Controller.

I. INTRODUCTION

During the past several years, there has been a general incorporation of automatization systems in a wide range of industrial processes because of the necessity of decreasing costs and making the task of the plant operator easier.

The PID conventional regulator is the most frequently control element in the industrial world. It is estimated that, at least, the 90% of the controllers employed in the industry are PIDs or its variations. But it needs a quantitative model of the process, which is not always available. Specially, if the process is too complex to achieve a good physical description, conventional methods are not able to guarantee the final control aims, and the controller synthesis has to be based mainly on intuitions and heuristic knowledge. So, expert control strategies have been favored since they are based on the process operator's experience and do not need accurate models.

One of the most successful expert system techniques applied to a wide range of control applications has been the Fuzzy Set Theory. Its attraction, from the Process Control Theory point of view, comes because the fuzzy approach provides a good support for translating the heuristic skilled operator's knowledge about the process and control procedures into numerical algorithms.

Obviously, the behavior of the control systems has to reach very high levels of reliability and robustness. The modern control algorithms have not succeeded in replacing the PID regulators. Some of the reasons may be:

- Its robustness and simplicity in the design.
- There exists a clear relation between PID parameters and the system response specifications. Most of the industrial controllers are PID, and in these conventional regulators only three parameters are available.
- There are many PID tuning techniques, elaborated during the last decades that make easier the operator's task.
- Because of its flexibility, the PID control could have been benefited from the technology advances. The clearest test of the evolution of the PID is that, actually, most of the classical industrial controllers have procedures to automatizate the adjustment of its parameters (automatic tuning or self-tuning).

Then, if we can get a good model of the process, given by analytic linear equations, direct techniques of control are the simplest and less cost alternatives. The classical PID controller will provide an accurate and efficient solution to lineal control problems.

But the involved processes are in general complex, time variant, with delays and non-linearities and, very often, with a poorly-defined dynamics. When the processes are too complex to be described by analytic models, they are hardly controlled by drastic approaches that simplify them but do not get the required efficiency.

An alternative for difficult processes is Adaptive Control. One of the most successful expert system techniques has been fuzzy logic. Hence, the employment of fuzzy logic and/or classical strategies it is a direct function of the problem to solve. But each one of these strategies does not exclude the other. There are a lot of experience about conventional

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methods, and it is reasonable to rely on it in the design of new techniques. So, fuzzy technology is not only incompatible with conventional control systems, but rather they could work jointly in order to achieve more robust controllers.

A fuzzy controller is based on imprecise information, set theory and fuzzy logic, for both the knowledge representation and inference. It may be described as "a rule-based control able to emulate the human expert's actions" [1]. Fuzzy controllers have been shown efficient and robust for non-linear and complex systems.

II. CONTROL SYSTEM FOR DC MOTORS

The control system for DC Motors is based of a cascade structure with two loop controllers (fig. 1).

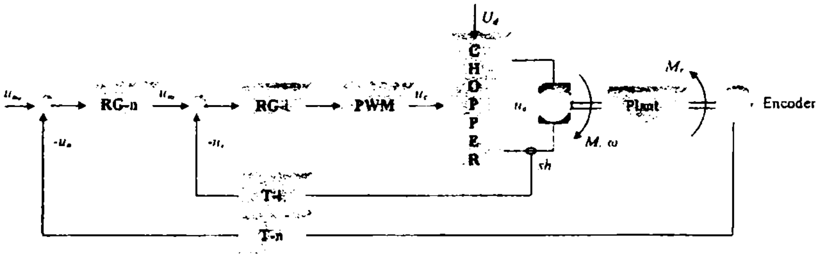

Fig. 1. Control Block Diagram used for DC Motor Drives.

The external loop is the speed control loop. The speed controller need to ensure fast and smooth speed response, small overshoot, short settling time, zero steady-state error and robustness to load variations. The developments of this controller are based on a PI digital control algorithm in its incremental (speed type) version:

$$u_k = u_{k-1} + q_0 \cdot e_k + q_1 \cdot e_{k-1} \qquad (1)$$

The internal loop is the current control loop. This loop is affected by the most important disturbances and, for this reason, the controller mast have a very speed response time. All this features can be obtained by using a PI controller.

Lineal control problems can not be accurate and efficient solved with fuzzy controllers (we can not obtaining zero steady-state error and a smooth speed response with small overshoot and without swinging). The classical PI (or PID) numeric controllers are the simplest and less cost.

For non-liniar systems, fuzzy controllers have been more simplest, efficient and robust. They can be implementated without a dedicated hardware because all fuzzy operations are very simple and the fuzzy control algorithm can work, with very good results, in critical applications in point of view of response time.

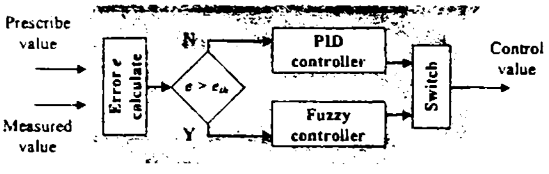

Fig. 2. Current Hybrid Controller

A very good choice for DC Motor Drives combine the two control metodes for obtain a hybrid controller who can to be associated with a classical or a fuzzy controller in function of the lineal or the non-lineal controled process. If the error e between the prescribe and the measured value are smaller that the threshold value e_{th} we use the classical PI (can be a PID) numeric controller, but if the error e between the prescribe and the measured value are bigger that the threshold value e_{th} we use the fuzzy controller (fig.2.) [2]. The used fuzzy controller must be a PI fuzzy controller with dynamics which can be obtaining with the integral component on either the input or the output of the controller.

III. DESIGN THE HYBRID CONTROLLERS

The control system performance enhancement can be ensured by modifying the controller structure based on using a numeric controller and a PI fuzzy controller in parallel connection, with alternative action on the controlled plant (fig. 3):

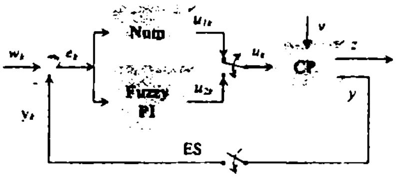

Fig. 3. Control System with Hybrid Structure

- the numeric controller (1) – actuates the controlled plant only in the situations when the absolute value of control error is small ($e_k \le e_{th}$);
- the PI-Fuzzy controller (2) – actuates the controlled plant only in the situations when the absolute value of control error is big ($e_k > e_{th}$) [4].

By considering, for instance, that the hybrid controller consists of a numeric controller and a PI fuzzy controller, the control signal (fig. 4.) is expressed as:

$$u_k = \begin{cases} u_{1k}, & \text{if } |e_k| \in [0, \alpha_1 \cdot e_M) \\ u_{1k} + C_1(e_k - \alpha_1 \cdot e_M), & \text{if } |e_k| \in [0, \alpha_1 \cdot e_M) \\ u_{2k}, & \text{if } |e_k| \in [\alpha_2 \cdot e_M, e_M) \end{cases} \quad (2)$$

The parameters $0 < \alpha_1 < \alpha_2 < 1$ and $C_1 > 0$ are chosen by the designer on the basis of his „experience". The relations (2) ensure a bumpless transfer from one controller to another [3].

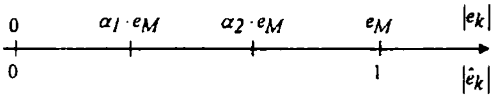

Fig. 4. The control signal that ensure a bumpless transfer from one controller to another

The parameters of the classical controller (1) are expressed from the parameters of the conventional PI controller (relationship 1).

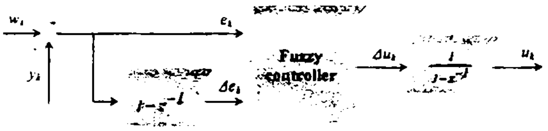

Fig. 5. Block diagram of standard PI fuzzy controller

The development of the fuzzy controller (2) (fig.5.) starts with the expression of the discrete equation of the PI quasi-continuous digital control algorithm in its incremental version:

$$u_k = u_{k-1} + k_p \cdot \Delta e_k + k_i \cdot e_k \quad (3)$$

where the parameters *kp* and *ki* are functions of the parameters of the conventional continuous time PI controller:

$$H_c(s) = \frac{k_c}{s \cdot T_i} \cdot (1 + s \cdot T_i) \quad (4)$$

and the dependence is:

$$k_p = k_c \cdot (1 - \frac{T_s}{2 \cdot T_i}) \qquad k_i = \frac{k_c \cdot T_s}{T_i} \quad (5)$$

The transfer from one controller with parameters namely $\{p_1^{(1)}, q_0^{(1)}, q_1^{(1)}\}$, to another controller with parameters namely $\{p_1^{(2)}, q_0^{(2)}, q_1^{(2)}\}$, must ensure a bumpless control (fig. 3):

$$u_{2k} = u_{1k} = u_k \quad (6)$$

This need to recompute the initial conditions. If the controller (1) is in use:

$$u_{1k} = q_1^{(1)} x_{1k}^{(1)} + q_0^{(1)} x_{2k}^{(1)} \quad (7)$$

To switch the control to the controller (2), must be computed the value:

$$x_{1k}^{(2)} = x_{2,k-1}^{(2)} \quad (8)$$

The relationship for x_{2k} is:

$$u_{2k} = q_1^{(2)} x_{1k}^{(2)} + q_0^{(2)} x_{2k}^{(2)} \quad (9)$$

If the controller (2) is in use:

$$u_{2k} = q_1^{(2)} x_{1k}^{(2)} + q_0^{(2)} x_{2k}^{(2)} \quad (10)$$

or:

$$u_{2k} = q_1^{(2)} x_{1k}^{(2)} + q_0^{(2)} e_k - q_0^{(2)} p_1^{(2)} x_{1k}^{(2)} \quad (11)$$

But $u_{2k} = u_{1k}$:

$$x_{1k}^{(2)}{}_{nec} = \frac{1}{q_1^{(2)} - q_0^{(2)} p_1^{(2)}} [q_1^{(1)} x_{1k}^{(1)} + q_0^{(1)} x_{2k}^{(1)}] - \frac{q_0^{(2)}}{q_1^{(2)} - q_0^{(2)} p_1^{(2)}} e_k$$

And: $x_{2,k-1}^{(2)}{}_{nec} = x_{1k}^{(2)}{}_{nec}$ (12)

IV. CONTROL METHODS FOR HYBRID CONTROLLERS

At time *k*, the error *e* is bigger that e_{th}. The transfer from PI controller (1) to fuzzy controller (2) must be very quickly and ensure a bumpless control. The value of u_{1k+i} and u_{2k+i} have been computed and the control is translated to the fuzzy controller when:

$$u_{1k+i} - u_{2k+i} = (0{,}1 - 0{,}15) \cdot u_{1k+i} \quad (13)$$

The control algorithm (fig. 6.) allows to calculating the values for control parameters at:

- time $k+1$:

$$u_{1k+1c} = u_{1k+1} - \frac{1}{2} \Delta u_k \quad (14)$$

where: $\Delta u_k = u_{1k} - u_{2k}$

- time $k+2$:

$$u_{1k+2c} = u_{1k+1c} - \frac{1}{2} \Delta u_{k+1} \quad (15)$$

where: $\Delta u_{k+1} = u_{1k+1c} - u_{2k+1}$

At time $k+r$, the control is translated to the fuzzy controller, if:

$$\Delta u_{k+r-1} \le (0,1-0.15) \cdot u_{2k+r-1} \tag{16}$$

or: $\Delta u_{k+r} = u_{1k+rc} - u_{2k+r} < 0$ (17)

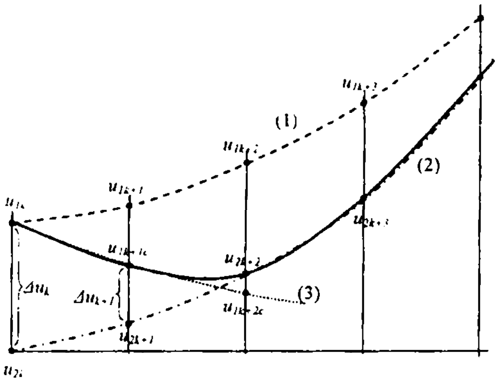

Fig. 6 The first proposal control algorithm

For ensure more bumpless. the control algorithm can be:

$$u_{1k+i+1c} = u_{1k+ic} - \frac{\Delta u_{k+i}}{2^i} \tag{18}$$

but the steps number is possible to rise.

A second control algorithm (fig. 7.) allows to calculating the values for control parameters at:

- time $k+1$:

$$u_{1k+1c} = u_{1k+1} - \frac{1}{2}\Delta u_k \tag{19}$$

where: $\Delta u_k = u_{1k} - u_{2k}$

- time $k+2$:

$$u_{1k+2c} = u_{1k+2} - \frac{3}{4}\Delta u_{k+1} \tag{20}$$

where: $\Delta u_{k+1} = u_{1k+1} - u_{2k+1}$

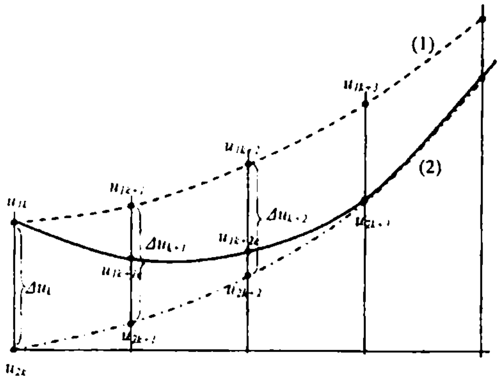

Fig. 7 The second proposal control algorithm

- time $k+3$:

$$u_{1k+3c} = u_{1k+3} - 0{,}85\Delta u_{k+2} \tag{21}$$

where: $\Delta u_{k+2} = u_{1k+2} - u_{2k+2}$

or: $u_{1k+3c} = u_{2k+3}$ (22)

if: $\Delta u_{k+2} \le (0{,}1-0{,}15) \cdot u_{2k+2}$ (23)

This second proposal algorithm has de advantage that we can get the translation in 2, maxim 3, steps and the transfer is more bumpless.

V. SIMULATION

The Motor used for test is a SMU750 DC Servomotor with following characteristics (table 1):

Table 1

Parameter	Te [ms]	Tc [ms]	Ul [V]	Ra [Ω]
Value	1	0.81	80	0.5
Parameter	Ta [ms]	Ke [$\frac{V}{rad/s}$]	J [$Kgcm^2$]	Mr [Nm]
Value	0.2	0.2	11	2.38

The caracteristics of the controllers are shown in table 2.

Table 2

Parameter	Kv	Ti [s]	N	Te [s]
Value	0.000644	0.013	1000	0.001
Parameter	Krn	Trn [s]	Kri	Tri [ms]
Value	2200	0.019	43,1	0.2
Parameter	Kmi	Kmn	Kio	Tio [ms]
Value	0.29	0.01	0,3	0,5
Parameter	Kfi	Tfi [s]	K_E	T_E [ms]
Value	1	0.0025	21,66	0,5

The simulation hase a lenght of 600ms. After 300ms appears a load disturbance (fig. 8). The block diagram of the simulation circuit is present in fig. 9. The simulation result, namely the motor current (*Ia*) and the motor speed (*w*), are present in fig. 10 and fig. 11.

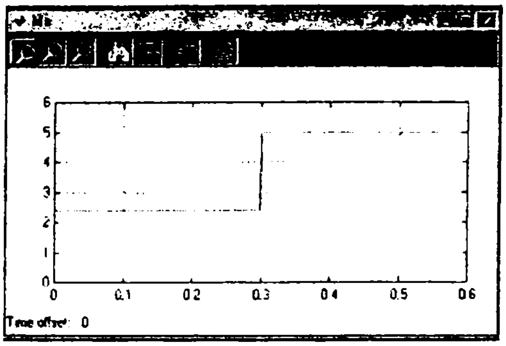

Fig. 8. Load disturbance Ms

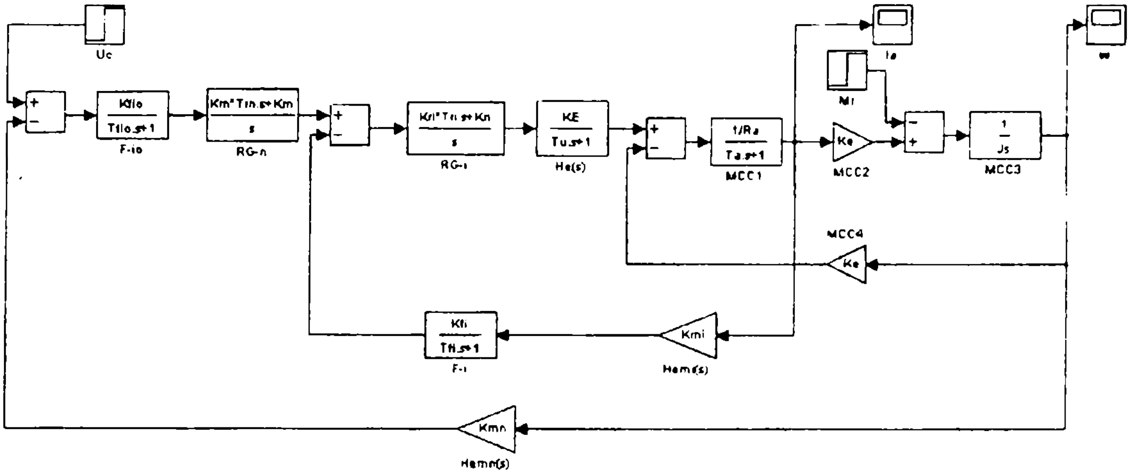

Fig. 9. The block diagram of the simulation circuit

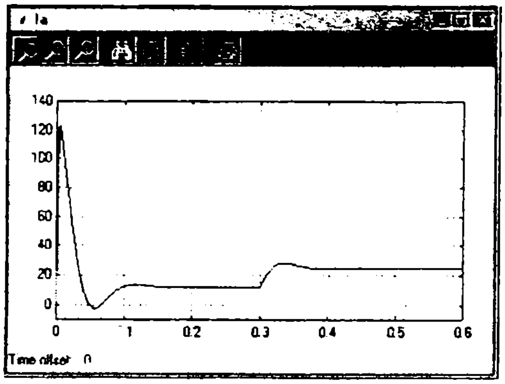

Fig. 10 Current Step Response versus Time for Loaded DC Motor

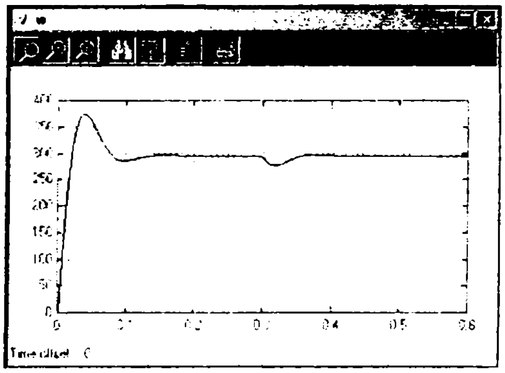

Fig. 11 Speed Step Response versus Time for Loaded DC Motor

VI. CONCLUSION

The motor reaches the steady state speed in 124ms corresponding to the execution of about 40 fuzzy logic loops. The starting current is 123,25A (nominal current is 12A for SMU 750). The overshoot of the motor speed is highest 25%.

Upon the load variations, the motor recovered the targeted speed in 51,1ms without any speed overshoot. The speed variation due the load variations is highest 8%.

PI, PID controlled systems shows good results in terms of response time and precision when there parameters are well adjusted.

Fuzzy controllers have the advantage that can deal with nonlinear systems and use the human operator knowledge, but fuzzy controlled system doesn't have much better characteristics in time domain that PID controlled system.

PID controller can not be applied with the systems which have a fast change of parameters, because it would require the change of PID constants in the time. That's means that a non linear system with a fast change of parameters, like DC Motor drive, can be well controlled by PID which is supervised by a fuzzy system.

REFERENCES

[1] M. Santos, J. M. de la Cruz, S. Dormido, A. P. de Madrid „Between Fuzzy-PID and PID-Conventional Controllers: a Good Choice", 1996, Dpto. de Informática y Automática. Facultad de Ciencias. (UNED) Senda del Rey s/n. 28040-MADRID (Spain).

[2] Jelena Godjevac, „Comparison between PID and fuzzy control", Internal Report R93 361, 1999, Ecole Polytechnique Fédérale de Lausanne, Département d'Informatique

[3] R.E.Precup, Şt.Preitl, „Fuzzy Controllers", Editura Orizonturi Universitare, Timişoara, 1999, ISBN: 973-9400-61-2

[4] M.Băbăiţă, A.Popovici „Comanda Fuzzy a Convertoarelor Electronice Performante Utilizate în Acţionarea Motoarelor de Curent Continuu" Raport final Contract ANSTI Nr.6153/2000, tema B4

[5] M.Băbăiţă, V Popescu, A.Popovici, "Hybrid Regulator For DC Motor Drives", Oradea 2004