DC Motor Drive with PFC Rectifier

As.ing. Băbăiță Mircea, Prof.dr.ing. Popescu Viorel, Conf.dr.ing. Popovici Adrian,
Prof.dr.ing. Lascu Dan, Conf.dr.ing. Lascu Mihaela, Ş.l.dr.ing. Negoițescu Dan*
* Applied Electronics Departament,
„Politehnica” University of Timişoara, Electronics and Telecommunications Faculty,
Timişoara, România, mircea.babaita@etc.upt.ro

Abstract – The goal of this work is to study the performances of a hybrid controller used to control DC Motor drive with a single-phase power factor correction rectifier. This study is made using computer simulation (Simulink). The first part is devoted to the control system of the DC Motors. In the second part, the design of the hybrid controller will be presented. The third part is the design of the fast response single-phase boost power factor correction rectifier. The last parts are devoted to simulation and experimental results.

Keywords: DC Motor, Power Factor Correction Control System, Fuzzy, Average Current Control.

I. INTRODUCTION

The PID conventional regulator is the most frequently control element in the industrial world - 90% or more, of the controllers employed in the industry are PIDs.

The modern control algorithms have not succeeded in replacing the PID regulators. The reasons may be:

- its robustness and simplicity in the design;
- 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; most of the classical industrial controllers have procedures to automatizate the adjustment of its parameters.

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-linearity’s and, very often, with a poorly-defined dynamics. When the processes are too complex to be described by analytic models, 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 techniques has been fuzzy logic. But this strategy does not exclude the other. There are a lot of experiences about conventional 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.

The control system for DC Motors is based of a cascade structure with two loop controllers (fig. 1). The external loop is the speed control loop. The speed controller needs to ensure fast and smooth speed response, small overshoot, short settling time, zero steady-state error and robustness to load variations.

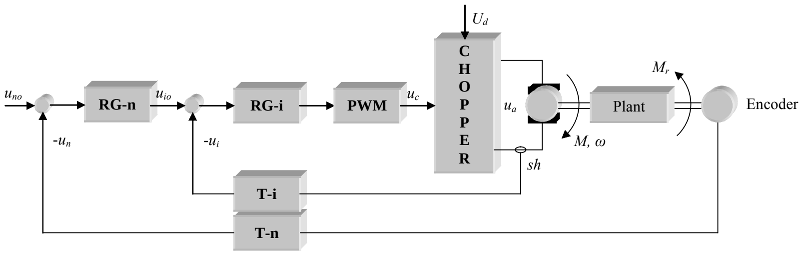

Fig. 1. Control Block Diagram used for DC Motor Drives.

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

A very good choice for DC Motor Drives combine the two control methods (classical and fuzzy) for obtains a hybrid controller who can to be associated with a classical or a fuzzy controller in function of the lineal or the non-lineal controlled 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 [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.

II. 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. 2):

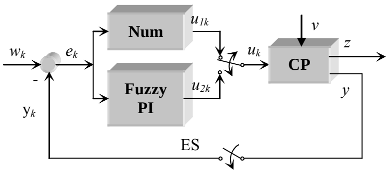

Fig. 2. Control System with Hybrid Structure.

- 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 ($e_k > e_{th}$) [3].

By considering, for instance, that the hybrid controller consists of a numeric controller and a PI fuzzy controller, the control signal (fig. 3.) is expressed as:

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

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].

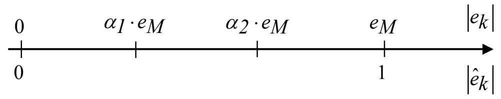

Fig. 3. The control signal that ensure a bumpless transfer from one controller to another

The parameters of the classical controller (1) are expressed from the parameters of the conventional PI controller (relationship 1). The development of the fuzzy controller (2) are present in [5], [6].

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):

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

To switch the control to the controller (2), the new computed value must be [4]:

$$x_{2,k-1}{}^{(2)}{}_{nec} = x_{1k}{}^{(2)}{}_{nec} \qquad (7)$$

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:

$$u_{1k+i} - u_{2k+i} = (0{,}1 - 0{,}15) \cdot u_{1k+i} \qquad (8)$$

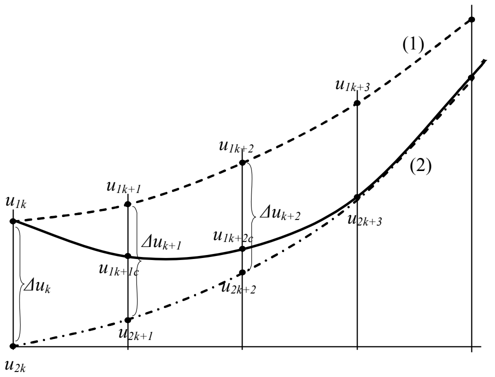

Fig. 4. The proposal control algorithm.

The new proposal control algorithm (fig. 4.) allows to calculating the values for control parameters at:

- time $k+1$:

$$u_{1k+1c} = u_{1k+1} - \frac{1}{2}\Delta u_{k+1} \qquad (9)$$

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

- time $k+2$:

$$u_{1k+2c} = u_{1k+2} - \frac{3}{4}\Delta u_{k+2} \qquad (10)$$

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

- time $k+3$:

$$u_{1k+3c} = u_{1k+3} - 0{,}85\Delta u_{k+3} \qquad (11)$$

where: $\Delta u_{k+3} = u_{1k+3} - u_{2k+3}$

or: $u_{1k+3c} = u_{2k+3}$ (12)

if: $\Delta u_{k+3} \leq (0{,}1 - 0{,}15) \cdot u_{2k+3}$ (13)

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

III. DESIGN THE PFC RECTIFIER

The PFC rectifier used as a power supply for the DC motor is present in fig. 5. This is a ACC scheme of a typical boost PFC rectifier with feedforward of the rectifier input voltage.

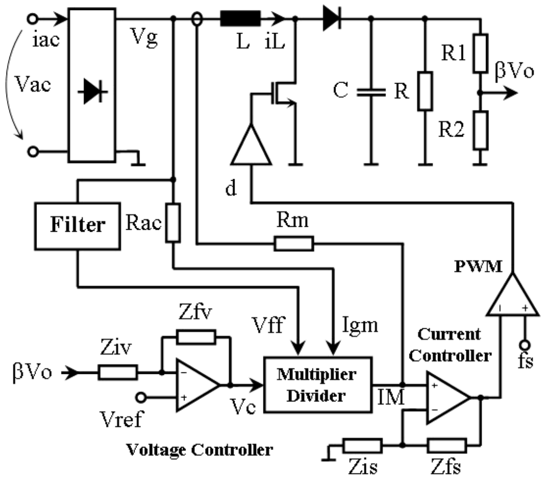

Fig. 5. Boost rectifier with ACC.

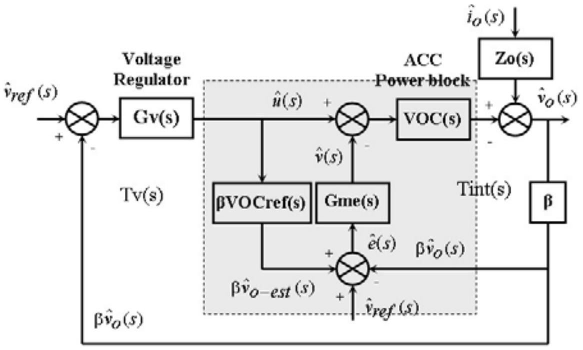

Fig.6 The proposed ACC scheme.

A linear small-signal model of the ACC-controlled boost PFC rectifier is present in [4], [7], [8]. The proposed ACC scheme is shown in Fig.6. Design of the ACC scheme is present in [7], [8].

The proposed ACC scheme have been applied to a boost PFC rectifier with: $V_{ac} = 220V$, $f = 50Hz$, $V_o = 400V$, $P_o = 200W$, $L = 1mH$, $C = 470\mu F$, $f_s = 100kHz$, $R_s = 0{,}2\Omega$, [7], [8].

The values of L and C have been chosen so that the inductor current ripple $\Delta i_L \approx 1A$, with a holdup time $\Delta t \approx 64ms$. Δt is defined as the time at which the output voltage decreases to $V_o = 300V$ after disconnecting the line voltage.

A current regulator $G_s(s)$ designed by means of conventional loop-shaping techniques [3] has been chosen. The current loop crossover frequency is about 16kHz with a phase margin of 60°. The voltage loop with ACC is closed with a voltage regulator. The theoretical crossover frequency with that controller is about 8 Hz. If the gain of $T_{int}(s)$ at 100Hz has been designed to be small, also the gain of $T_v(s)$ results as small. Following that approach, the transfer functions of the chosen regulators are present in [7], [8].

IV. SIMULATION AND EXPERIMENTAL RESULTS

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

TABLE 1. DC Motor characteristics.

Parameter	Te [*ms*]	Tc [*ms*]	U1 [*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 characteristics of the controllers are calculate in [7], [8].

The simulation has a length of 600ms. After 300ms appears a load disturbance. The block diagram of the simulation circuit is present in [7], [8]. The simulation result, namely the motor current (*Ia*) and the motor speed (*w*), are present in fig. 7 and fig. 8.

The motor reaches the steady state speed in 124ms corresponding to the execution of about 40 fuzzy logic loops. The starting current is 112A (nominal current is 12A for SMU 750). The overshoot of the motor speed is highest 23%.

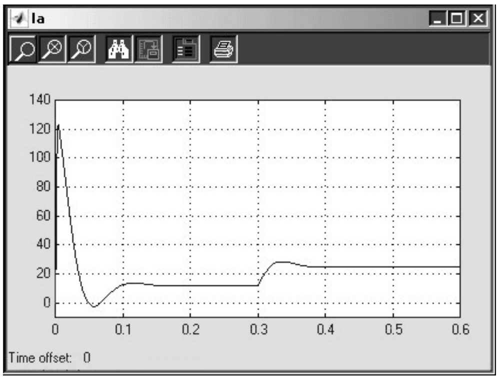

Fig. 7. Current Step Response for Loaded DC Motor.

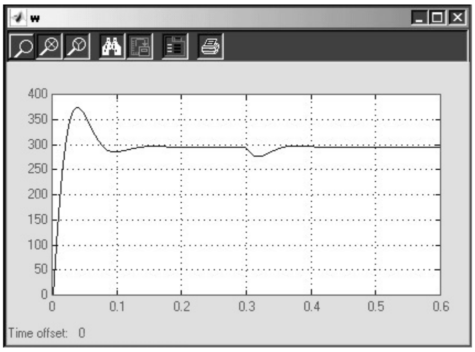

Fig. 8. Speed Step Response for Loaded DC Motor.

Upon the load variations, the motor recovered the targeted speed in 48,6ms without any speed overshoot. The speed variation due the load variations is highest 7,5%.

A boost PFC rectifier has been simulated (in CASPOC), built and tested. Fig.9 shows the input current, the line voltage and the normalized harmonic spectrum of the line current for 220V, $P_O = 200W$ with ACC.

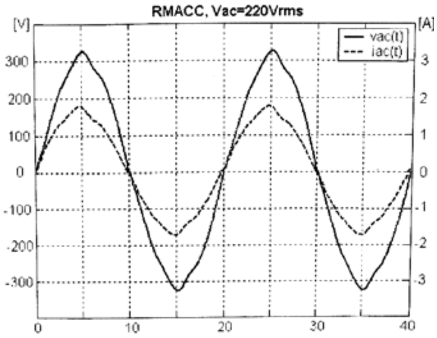

Fig.9. The line voltage and the input current with ACC.

The experimental results (line voltage 220V, input current 1,2A) with ACC control scheme are: the input voltage distortions THDv 3,6%, the line current distortion THDi 5,8% and the power factor PF 0,99.

VI. CONCLUSIONS

The goal of this work is to study the performances of a hybrid controller used to control DC Motor drive with a single-phase PFC rectifier with ACC loop (fig.10).

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

This study shows that the dynamic response of the output voltage to load steps is faster. The improvement of the transient response is achieved with similar values of the input current distortion and of the power factor as with conventional ACC.

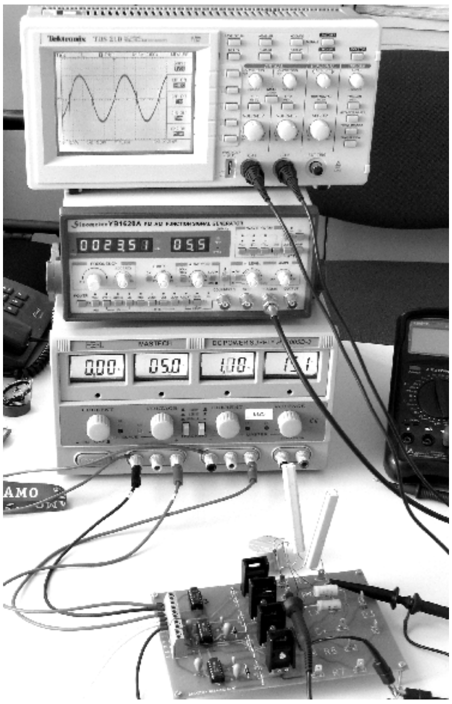

Fig. 10. The experiment.

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