Some Consideration about Using Fuzzy Logic for Speed Control of Electrical Drives

Constantin Volosencu
Facultatea de Automaticã ºi Calculatoare
Universitatea "Politehnica" din Timiºoara
Bd. V. Pârvan nr. 2
Timiºoara, 1900, România
Phone: +4-056-204332/198, Fax : +4-056-192049
e-mail: cvolos@aut.utt.ro

ABSTRACT: The paper presents a synthesis of some author's activity. Three speed control systems for d. c., induction and permanent magnet synchronous motors, based on PI fuzzy controllers with integration at the output, with a simple rule base with only 9 rules were developed, analyzed and simulated. The sum-prod or max-min inferences were used with the center of gravity defuzzification. The fuzzy controllers were implemented as memories. The performance criteria of the fuzzy control systems are compared with the performance criteria of the conventional speed control systems based on linear PI controllers. By simulation is shown that the fuzzy control systems have better performance criteria and they are more robust at the parameter identification errors than the conventional linear PI control systems.

KEYWORDS: fuzzy control, speed control, electrical drives, d. c motors. Induction motors, synchronous motors.

THE SPEED CONTROL SYSTEMS

In the last few years fuzzy control was developed for electrical drives, many papers in this field appeared in the international journals and conferences [2, 6]. The majority of those papers treated particular cases of fuzzy speed controller. This paper presents a comparison between the conventional linear PI control and a fuzzy control with a fuzzy PI controller with integration at the output, for three important practical application of electrical drives. The fuzzy controllers have a 9 rules base, they use the sum-prod and the max-min inference and the defuzzyfication with the center of gravity. The comparison is made based on the performance criteria of the control systems, took from the transient characteristics obtained for tuned and detuned parameters.

We have chosen the following performance criteria: the overshoot $\sigma_{1\omega}$%, the maximum deviation of the controlled speed σ_{1M}% for the load torque perturbation, the settling time $t_{r\omega}$ for 2% of the final value, the reversing time t_r^r, an integral criteria $I=\int e^2 dt$, were e is the speed error and the energy conversion ratio *ICE*=output mechanical energy/input electrical energy, over the simulation time.

We used Matlab with the Fuzzy Toolbox and Simulink to do simulation.

THE SPEED CONTROL SYSTEM FOR A DC MOTOR

A speed control system of a d.c. drive has the most used cascade closed-loop diagram shown in Fig. 1.Here *MCC* is the d.c. motor, *T*ω is the speed sensor, *CONV* is the power static converter, *Ti* is the current sensor, *RG-i* is the current controller and *RG*-ω is the speed controller. The dc motor has the following equations:

$$u_a = R_a i_a + L_a \frac{di_a}{dt} + k\omega, \quad J\frac{d\omega}{dt} = ki_a - k_f\,\omega - M_s \qquad (1)$$

with the following rated parameters for a particular example: power P_N=1,1kW, speed n_N=3000rpm, current I_N=6A, torque M_N=3,1Nm, voltage U_N=220V, maximum current I_M=10,8A, rotor inertia J=0.001kgm^2, friction coefficient k_f=0.00015 Nms, e.m.f. and current coefficient k=0,561, rotor resistance R_a=2.01 Ω and rotor inductance L_a=10 mH. The power

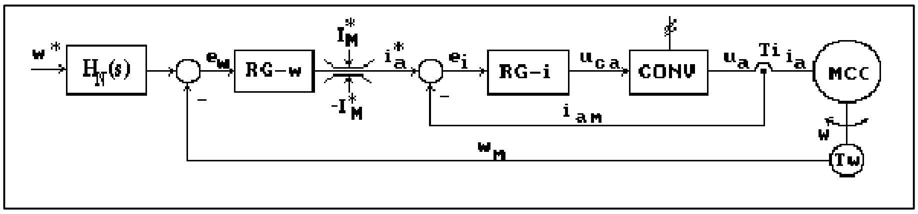

Figure 1. The speed control system for a d. c. motr

converter, the current sensor and the speed sensor have the following transfer functions: $H_{CONV}(s)$=220/(1+0.002s), H_{Ti}(s)=1/(1+0.005s) and $H_{T\omega}(s)$=10/314(1+0.01s). The power converter has a voltage limitation: U_M=110%U_N. The current reference is limited to the value I_M*=10,8 A.

For the conventional linear PI control we choose the design method presented in Leonhard 1985. The speed *RG*-ω and current *RG*-*i* controllers have PI transfer functions. The current controller is designed with Kessler's modul criterion. His transfer function is H_{RGi}(s)=0.2(1+s/0.017). The speed controller is designed with Kessler's symmetric criterion. His transfer function is: $H_{RG\omega}(s)$=2(1+s/0.8). At the input of the speed reference is inserted a lag term with the following transfer function: $H_N(s)$=1/(1+0.06s), to eliminate the lead effect of PI speed controller. This design procedure is a classical and a large accepted one. We made simulations for tuned parameters: R_a, J and k_f and detuned parameters: $J^d=2J$, $R_a^d=2R_a$ and $k_f^d=2k_f$. In the second case we assumed an error at the parameter identification.

THE SPEED CONTROL SYSTEM FOR AN INDUCTION MOTOR

We simulate the vector control structure of voltage-source inverter-fed induction motor drives with indirect rotor flux orientation current control represented in Fig. 2. The speed control system of the induction motor shown in Fig. 2 has the most conventional notations.

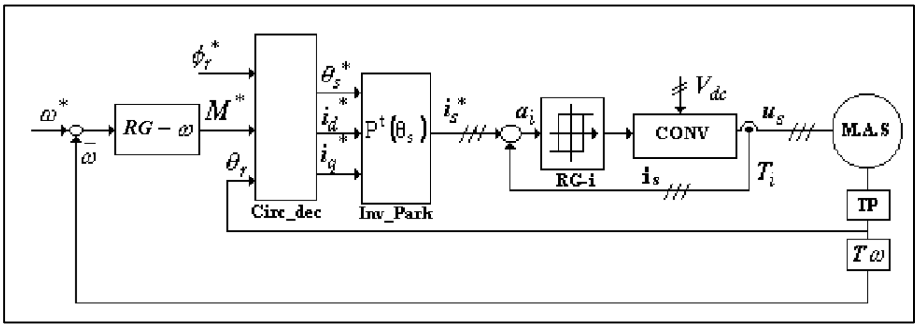

Figure 2. The speed control structure of an induction motor

For the induction motor we used the following equations in simulations:

$$u_d = R_s i_d + \frac{d\Phi_d}{dt} - \omega_f \Phi_q, \quad u_q = R_s i_q + \frac{d\Phi_q}{dt} + \omega_f \Phi_d$$

$$u_{dr} = R_r i_{dr} + \frac{d\Phi_{dr}}{dt} - (w_f - w_r)\Phi_{qr}, \quad u_{qr} = R_r i_{qr} + \frac{d\Phi_{qr}}{dt} + (\omega_f - \omega_r)\Phi_{dr} \qquad (2)$$

$$M = \frac{3}{2} p(\Phi_d\, i_q - \Phi_q\, i_d) = \frac{3}{2} pL_m(i_{dr} i_q - i_{qr} i_d), \quad \frac{d\theta_f}{dt} = \omega_f$$

In the particular example from the paper the motor has the following rated parameters: P_N=550 W, n_0=750rpm, I_{sN}=1,77A, M_N=7Nm, U_{sN}=220V, I_{sM}=8A, J=0,01kgm^2, k_f=0.008 Nms, $R_s=R_r$=12,4 Ω, $L_{s\sigma}=L_{r\sigma}$=0,06 H, L_m=0,8 H, p=4, M_{Mt}=24 Nm.

The power converter has the following equations:

$$u_a = \frac{1}{3}U_d(2S_a - S_b - S_c),\; u_b = \frac{1}{3}U_d(-S_a + 2S_b - S_c), u_c = \frac{1}{3}U_d(-S_a - S_b + 2S_c) \qquad (3)$$

were U_d is the dc voltage of the inverter.

The current controllers *RG*-*i* are bipositional with histeresis. The speed controller *RG*-ω has a PI transfer function for the conventional control system. The speed controller is designed with Kessler's symmetric criterion. His transfer function is: $H_{RG\omega}(s)$=12(1+s/0,09). At the entry of the speed reference is inserted a lag term with the following transfer function: $H_N(s)$=1/(1+0,025s), to eliminate the lead effect of PI speed controller. This design procedure is a classical and a large accepted one. We made simulations for tuned parameters: R_s, R_r J and k_f and detuned parameters: J^d=2J, R_s^d=2R_s, R_r^d=2R_r and k_f^d=2k_f.

THE SPEED CONTROL SYSTEM FOR A PERMANENT MAGNET SYNCHRONOUS MOTOR

We simulate the vector control structure of voltage-source inverter-fed synchronous motor drive with indirect rotor flux orientation current control represented in Fig. 3.

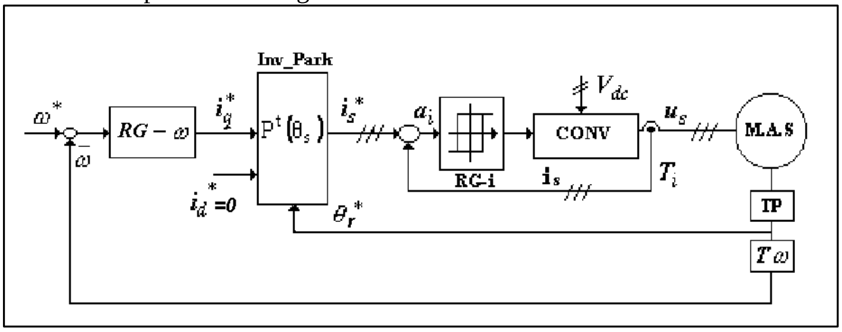

Figure 3. The speed control system of the synchronous motor

The speed control system of the permanent magnet synchronous motor shown in Fig. 3 has the most known conventional notations.
For the permanent magnet synchronous motor we used in simulation the following equations:

$$\underline{\Phi}_s' = -R_s \underline{i}_s + \underline{u}_s - j\omega \underline{\Phi}_s\,, \quad \underline{\Phi}_s = \Phi_e + L_d i_d + jL_q i_q\,, \quad \underline{u}_s = u_d + ju_q\,, \quad \theta' = \omega$$

$$\omega' = \frac{1}{J}[-k_f\omega + p(M - M_s)]\,, \quad M = 3/2\,p[\Phi_e i_q + (L_d - L_q) i_d i_q] \tag{3}$$

In the particular example from the paper the motor has the following rated parameters: I_n=3A, n_{mu}=3000rpm, M_n=1,3Nm, J=0.001 kgm^2, k_f=0.0001 Nm/radel, L_d= 4mH, L_q= 5mH, p=4, Φ_e=0,072Wb.
The power converter has the same equations. The direct voltage is U_d=200V. The current controllers *RG-i* are bipositional with histeresis. The speed controller *RG*-ω has a PI transfer function for the conventional control system. It is designed with Kessler's symmetric criterion. His transfer function is: $H_{RG\omega}(s)$=5(1+s/0,01). At the entry of the speed reference is inserted a lag term with the following transfer function: $H_N(s)$=1/(1+0,01s), to eliminate the lead effect of PI speed controller. We made simulations for tuned parameters: R_s, J and k_f and detuned parameters: J^d=2J, R_s^d=2R_s and k_f^d=2k_f.

THE FUZZY SPEED CONTROLLER

We chose a classical structure: the PI fuzzy control with output integration. We have tested different fuzzy controllers, with 9, 25 and 49 rules, with equidistant or non-equidistant membership functions, with max-min or sum-prod inference, and defuzzyfication with the center of gravity. We presents the results for using for the d. c. motor the sum-prod inference and for the induction and synchronous motors max-min inference. The structure of the fuzzy speed controller is presented in Fig. 4. We introduced it in the place of the linear PI speed controller *RG*-ω this fuzzy PI controller with output integration*: RF*-ω-*IE*. The current controllers *RG-i* rested the same. Also, the limitation of the current references are the same: +/-I_M*, considering the same current control system, analogical implemented.

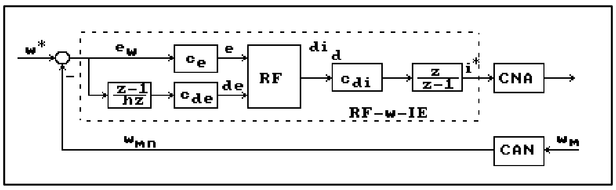

Figure 4. The speed fuzzy controller

The reference is the armature current i* for the d. c. motor, the electromagnetic torque M* for the induction motor and the current i_q* for the synchronous motor.
For the fuzzy control, digital implemented, appear analog to digital and digital to analog converters: CAN, CNA with the following coefficients: $K_{CAN}=2^{11}/10$ and $K_{CNA}=1/K_{CAN}$.
Because the fuzzy control system must control a motor which work in four quadrants, we choose a symmetric rule base, symmetric universes of discussion, for both positive and negative values of the physical variables and symmetric membership functions.

The rule base of the fuzzy speed controller is developed based upon the knowledge about the process. We chose a simple 9 rules base, presented in Fig. 5. For a permanent regime we may do the following reasoning: "*If* $e_\omega=0$ *and* $dw/dt=0$ ($de_w/dt=0$) *then the electromagnetic torque must mach the load torque* ($M=M_R$), *the current must stay at a value of a permanent regime, then the current increment must be zero:* $Di_a=0$." This is the first rule, or the rule for the permanent regime. For the other positive and negative values of e_ω and dw/dt we may develop the fuzzy do other reasoning and construct the rule table from Fig. 5.

di_d		e		
		NB	ZE	PB
de	NB	NB_2	NB_4	ZE_6
	ZE	NB_8	ZE_1	PB_9
	PB	ZE_7	PB_5	PB_3

Figure 5. The rule base

The universes of discussion for the fuzzy controller variables are chosen based on the process knowledge, the static characteristic speed-torque, defined by the rated and the maximum variable values of speed and torque. We assumed that the current control system has an equivalent time constant T_i. Then, the speed control system can't give a current increment Di_a greater then $I_M/5T_i$. In Fig. 6 we present the universes of discussion. The values of the universes of discussion are:

$$e_b = K_{CAN} K_{T\omega} \omega_b,\ e_m = 2e_b$$
$$de_c = K_{CAN} K_{T\omega}(M_N + k_f \omega_b)/J,\ de_t = K_{CAN} K_{T\omega}(M_M + k_f \omega_b)/J \quad (4)$$
$$di_N = \frac{I_N}{5K_{CNA}K_i T_i},\ di_M = \frac{I_M}{5K_{CNA}K_i T_i}$$

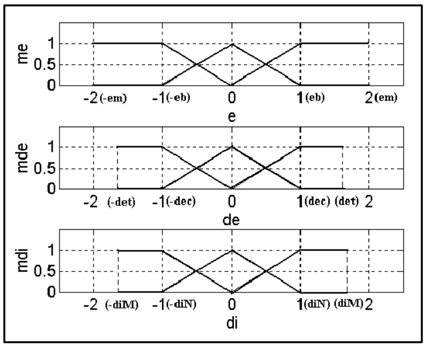

Figure 6. The membership functions

were K_i=1 is the gain of the current control loop. The universes of discussion are scaled with the scaling factors: e_b, de_c and di_N.

For the fuzzy variables we choose the membership functions presented in Fig. 7.

Absolute values greater then e_b, de_c or di_N are considered PB (or NB) with a membership degree equal to 1.

The fuzzy sped controller has the characteristics $di_d=f(e)$, with de parameter from Fig. 7. Also it has the surface $di_d=f(e, de)$ from Fig. 8.

If we do a coordinate translation with the relation:

$$x_t = T[e \quad de]^t = [x_{t1} \quad x_{t2}]$$

we may obtain the translated characteristics $di_d=f(x_{t1})$, from Fig. 9, and also the gain characteristics $K_R=di_d/x_{t1}$, from Fig. 10, both with de parameter.

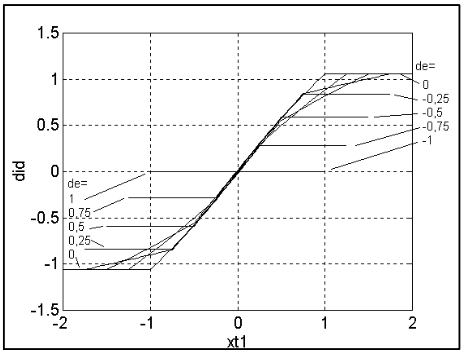

Figure 9. The translated characteristics

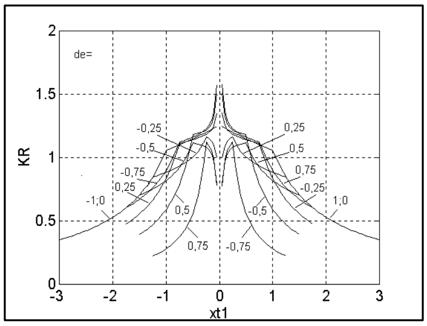

Figure 10. The gain characteristics

THE MAIN ALGEBRAIC PROPERTY OF THE FUZZY CONTROLLERS

The fuzzy controller has the nonlinear characteristic

$$di_d = F(x_e),\ x_e = [e \quad de]^t \qquad (6)$$

We may transform it, based on the algebraic properties: commutative law, existence of the neutral element and the existence of the symmetric elements, in an interesting one:

$$di_d = K_R(e,de)(e+de),\ with\ \ 0 < K_R(e,de) < K_{\max} \qquad (7)$$

This property helps us to use the circle criterion in the stability analysis of the fuzzy control system. Also, we may develop a method to choose the value of the open loop gain c_{di} for different fuzzy controllers with the above property.

The same algebraic properties are valid for other fuzzy controllers with a larger number of rules, with min-max inference and for the fuzzy controllers which use other defuzzification methods.

To use the main property demonstrated above we do a linear transformation of the state space. For this purpose we do a linear transformation of the input variables:

$$x_t = [x_{t1} \quad x_{t2}]^T = Tx_e = T[e \quad de]^T = [e+de \quad 0]^T, \; x_e = T^{-1}x_t \tag{8}$$

The linear transformation gives:

$$di_d = K_R[1 \quad 1]x_e = K_R[1 \quad 1]T^{-1}x_t = K_R.(e+de) = K_R x_{t1} \tag{9}$$

were:

$$[1 \quad 1]T^{-1} = [1 \quad 0] \tag{10}$$

And for the transformation matrix results:

$$T = \begin{bmatrix} 1 & 1 \\ -1 & 1 \end{bmatrix} \tag{11}$$

Now the nonlinear characteristic of the fuzzy controller may be expressed as follows:

$$di_d = K_R(x_t)x_{t1} \tag{12}$$

with

$$K_R = f(x_{t1}) = \frac{di_d}{x_{t1}} = \frac{di_d}{e+de} \tag{13}$$

For the fuzzy controllers we present the following characteristics: $di_d=f(x_{t1})$ and $K_R=K_R(x_{t1})=di_d/x_{t1}$, with de as a parameter. The values of this parameter are -1, -0,75, -0,5, -0,25, 0, 0,25, 0,5, 0,75 and 1.

We notice that the translated characteristics are only in the first and the third quadrant of the coordinate plane, and the gain K_R has only positive values:

$$K_1 < K_R(e,de) < K_2, \; with \;\; K_1 = 0 \tag{14}$$

The gain characteristics $K_R=f(x_{t1})$ have a minimum gain 0 and a maximum gain $K_m=K_2$.

For the fuzzy speed controller with integration at the output *RF*-ω-*IE* we may write the following relation in the *z*-domain:

$$i_q^{*}(z) = \frac{z}{z-1}c_{di}K_{Rf}(e,de)[e(z)+de(z)] = \frac{z}{z-1}c_{di}K_{Rf}(e,de)\left(c_e + c_{de}\frac{z-1}{hz}\right)e_\omega \tag{15}$$

For the controller gain we choose in the design procedure the maximum value K_{Rmax}, taken from the gain characteristics from Fig. 10. With this value the transfer function of the fuzzy PI controller become:

$$H_{Rf}(z) = \frac{i_q^{*}(z)}{e_\omega(z)} = \frac{z}{z-1}c_{di}K_{R\max}\left(c_e + c_{de}\frac{z-1}{hz}\right) \tag{16}$$

And in a continuous time form:

$$H_{Rf}(s) = \frac{i_q^{*}(s)}{e_\omega(s)} = H_{Rf}(z)\Big|_{z=\frac{1+sh/2}{1-sh/2}} = \frac{c_{di}K_{R\max}}{h}\left(c_{de} + \frac{h}{2}c_{de}\right)\left[1 + \frac{c_e}{(c_{de}+c_e h/2)s}\right] \tag{17}$$

We notice the equivalence with the following transfer function of a PI linear controller:

$$H_{R\omega}(s) = K_{R\omega}\left(1 + \frac{1}{sT_i}\right) \tag{18}$$

We may equalized the coefficient of two transfer functions and we obtained the following equations:

$$K_{R\omega} = \frac{c_{di}K_{R\max}}{h}\left(c_{de} + \frac{h}{2}c_{de}\right), \;\; T_i = \frac{c_{de} + hc_e/2}{c_e} \tag{19}$$

From the above relations we obtain the design relations for the fuzzy controller:

$$c_e = \frac{hK_{R\omega}}{c_{di}K_{R\max}T_i}, \quad c_{de} = c_e(T_i - h/2) \tag{20}$$

We choose for the discretization period the value h=0,003 s.

The problem in this design procedure is to choose the value of the gain factor c_{di}. After numberless attempt to ensure the control system stability and to obtain by simulations an appropriate transient regime we choose c_{di}=204.8. The equivalent transfer function of the fuzzy PI controller is $H_{Rf}(s)=37.3(1+1/0.11s)$, with $c_e=9.765.10^{-4}$ and $c_{de}=3.395.10^{-4}$.

Identically rule bases, discourse universes, membership functions, controller characteristics, equivalent transfer function were obtained for the fuzzy controllers for the induction and synchronous motors.

MEMORY IMPLEMENTATION OF THE FUZZY CONTROLLER

The fuzzy controllers were implemented as memories. This implementation gives the highest speed of the real time control system. To control in real time an electrical drive we need a high speed. Such memory has one output and two-address a_e and a_{de}. At the output the memory present the real value di_d memorized at the address (a_e, a_{de}). The addresses are integer. A matrix DI_d with the elements $di_d(a_e, a_{de})$ corresponds to this memory. The universes of discussion of e and de are digitized in n_c parts. An 8 bit analog-to-digital converter is presumed: $n_c=2^8=256$. We obtain n_c+1 digital values for e and de and $(n_c+1)^2$ values $di_{dk}=f_R(e_{ae}, de_{ade})$, with $a_e=1,...,n_c$ and $a_{de}=1,...,n_c$. Such a matrix is called a fuzzy memory.
The values of the addresses are obtained in the following mode. The values of e and de were translated from the domain [-2, 2] in the domain [1, n_c+1] with the following relations:

$$e_t = \frac{n_c}{4} e + \frac{n_c + 2}{2}, \quad de_t = \frac{n_c}{4} de + \frac{n_c + 2}{2} \tag{21}$$

The addresses a_e and a_{de} are the integers of e_t and de_t. So, in practice the function of the controller is implemented with an approximation of it:

$$di_d = f_R(e, de) \cong di_d(a_e, a_{de}) = f_R^*([e_t],[de_t]) \tag{22}$$

In this case we may fixe the permanent regime condition (e=0, de=0, di_d=0) putting zero at the adequate location.

PERFORMANCE CRITERIA AND TRANSIENT CHARACTERISTICS

In the following tables we presents the values of the performance criteria obtained for the fuzzy speed controller for the three control systems.

Table 1. The performance criteria for the d.c. motor

Analysis case		$\sigma_{1\omega}$ [%]	$t_{r\omega}$ [s]	σ_{1M} [%]	t_{rM} [s]	$\sigma_{1\omega}^r$ [%]	t_r^r [s]	I 10^{-5}	ICE [%]	$\Delta\sigma_{1\omega}$ [%]	$\Delta\sigma_{1M}$ [%]	$\Delta t_{r\omega}$ [s]	Δt_{rM} [s]
T	F	0	1,3	3,5	0,1	0	2	1,0	91	7,4	2,9	0	0,5
	C	7,4	1,3	6,4	0,6	40	8,5	1,2	91				
D	F	0	1,3	4,7	0,3	9,8	2,5	2,1	89	40	2	0,8	0,4
	C	40	2,1	6,7	0,7	32	12	2,4	84				

Table 2. The performance criteria for the induction motor

Analysis case		$\sigma_{1\omega}$ [%]	$t_{r\omega}$ [s]	σ_{1M} [%]	t_{rM} [s]	$\sigma_{1\omega}^r$ [%]	t_r^r [s]	I 10^{-2}	ICE [%]	$\Delta\sigma_{1\omega}$ [%]	$\Delta\sigma_{1M}$ [%]	$\Delta t_{r\omega}$ [s]	Δt_{rM} [s]
T	F	0	0,12	4,3	0,06	0	0,14	6,5	91	5,6	0,4	0,03	0,04
	L	5,6	0,15	4,7	0,1	5,6	0,15	7,0	90				
D	F	1,3	0,13	4,4	0,07	18,4	0,36	7,6	85	13,7	0,3	0,12	0,03
	L	15	0,25	4,7	0,1	29	0,68	8,4	84				

Table 3. The performance criteria for the permanent magnet synchronous motor

Analysis case		$\sigma_{1\omega}$ [%]	$t_{r\omega}$ [s]	σ_{1M} [%]	t_{rM} [s]	$\sigma_{1\omega}^r$ [%]	t_r^r [s]	I 10^{-2}	ICE [%]	$\Delta\sigma_{1\omega}$ [%]	$\Delta\sigma_{1M}$ [%]	$\Delta t_{r\omega}$ [s]	Δt_{rM} [s]
T	F	0	0,06	8,2	0,05	0	0,12	0,66	92	6,7	2,1	0,01	0,01
	L	6,7	0,07	6,1	0,04	52	0,11	0,74	91				
D	F	8,9	0,13	6,6	0,06	27	0,21	1,36	85	27,1	0,5	0,03	0,02
	L	36	0,16	6,1	0,04	104	0,22	1,75	85				

Also in the following pictures we presents the transient characteristics for the three speed control systems, with continuous line (–) for fuzzy control and with dash-dot line (-.) for conventional control.

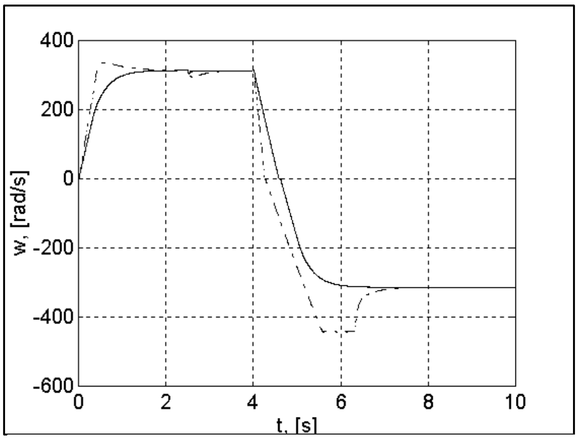

Figure 11. The speed of the dc motor, tuned parameters

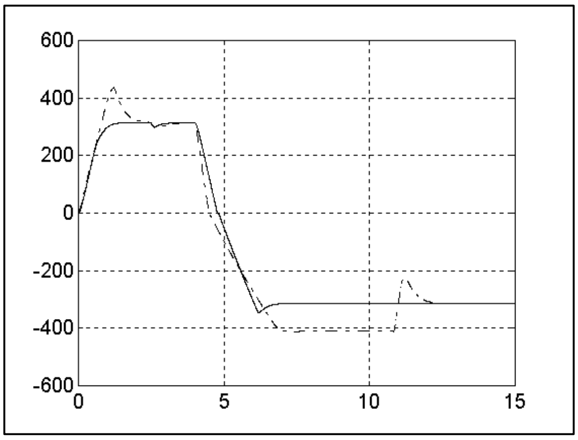

Figure 12. The speed of dc motor, detuned parameters

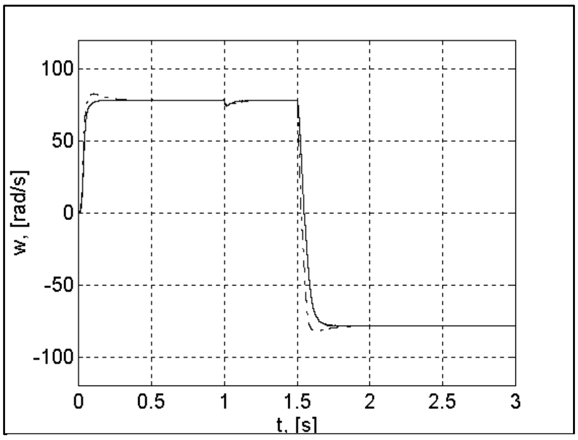

Figure 13. The speed of the induction, tuned parameters

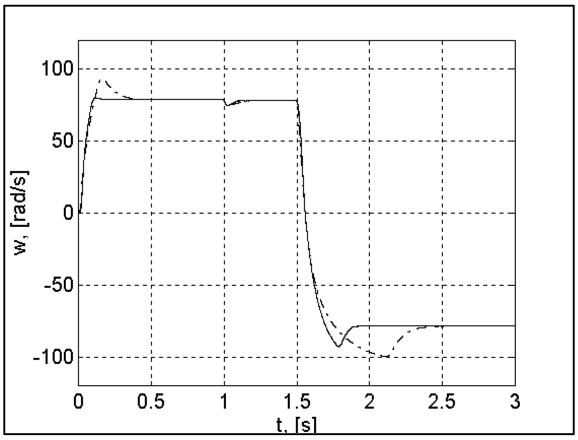

Figure 14. The speed of the induction, detuned parameters

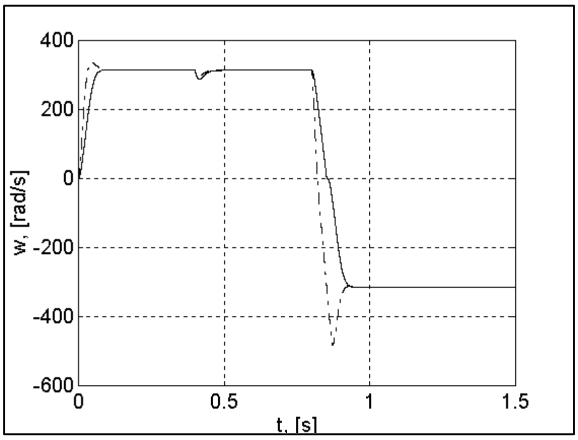

Figure 15. The speed of the synchronous, tuned parameters

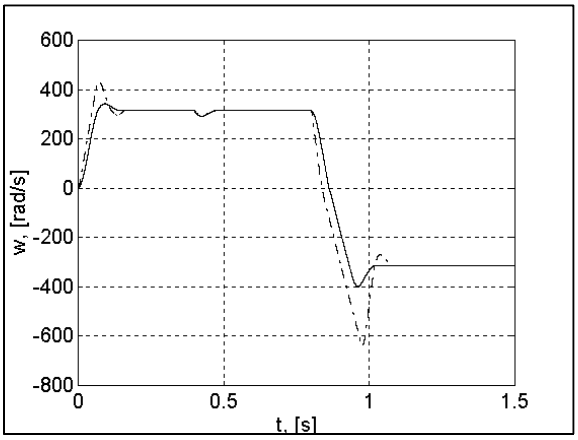

Figure 16. The speed of the synchronous, detuned parameters

CONCLUSION

After the comparative analysis of the speed performance criteria we present the following notifications:
-The overshoot of the fuzzy control system for speed reference is zeros.
-The settling times for speed reference at start of both control systems is equal. If we will design a zero overshoot for the conventional control the conventional settling time will be greater.
-The deviation of speed for perturbation of the fuzzy control system is a little smaller then in the conventional case.
-The overshoot at reversing for the fuzzy control system is zero for tuned parameters. So, if we will want such condition, in the case of using a fuzzy speed controller too, we must do an accurate identification of the motor parameters.
-The settling time at reversing of the fuzzy control system is sensitive smaller then in the conventional control.
-So, we can say that the performance criteria of the fuzzy control in the case of detuned parameters are sensitive better then the performance criteria for conventional control. So we may say the fuzzy control system is more robust at the identification errors of resistance, moment inertia and friction coefficient then the conventional control system.
-The period of the transient phenomena for motor current at reversing is smaller for fuzzy control.
-The conversion of energy for fuzzy control has a small greater ratio, but for thousand of such applications, using fuzzy control will produce a sensitive energy saving.
-The fuzzy speed control makes the field orientation at the a.c. drives more robust at the error of the parameters identification.

REFERENCES

Bose, B.K. 1986 Power Electronics and AC Drives, Prentice Hall, Englewood Cliffs, N. J.
Bose, B.K. 1994 Expert Fuzzy System, Fuzzy Logic and Neural Network Application in Power Electronics and Motion Control, Proceedings of the IEEE, No. 8, Aug.
Buhler, H. 1994 Reglage par logique floue, Presses Polytechniques et Universitaires Romandes, Lausanne.
De Doncker, R.W.; Novotny, D.W. 1994 The Universal Field Oriented Controller, IEEE Trans. On Industry Applications, Vol. 30, No.1.
Guillemin,P. 1996 Fuzzy Logic Applied to Motion Control, IEEE Transactions on Industrial Application, No.1.
Leonard, W. 1985 Control of Electrical Drives, Springer-Verlag Berlin.
Mohan, N. 1994 Simulation of Power Electronic and Motion Control Systems - An Overview, Proceedings of the IEEE, No. 8, Aug.
Volosencu, C-tin 1997 Reglare fuzzy si neuronalã, Ed. Eurobit, Timisoara.
Volosencu, C-tin 1998 Speed Control of DC Motors Based upon Fuzzy Logic-A Synthesis, World Multi-Conference on Systems, Cybernetics and Informatics, SCI'98, Orlando, Florida.