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Analysis of Speed Control in DC Motor Drive Based on Model Reference Adaptive Control

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This paper presents fuzzy and conventional performance of model reference adaptive control(MRAC) to control a DC drive. The aims of this work are achieving better match of motor speed with reference speed, decrease of noises under load changes and disturbances, and increase of system stability. The operation of nonadaptive control and the model reference of fuzzy and conventional adaptive control are studied for derive and adjustment of DC motor speed, and then are compared with each other. The model reference and fuzzy controller are designed based on improving of the whole system stability. Simulations are are carried out by Matlab-Simulink and under constant and variable loads conditions. Simulation results demonstrate that, the adaptive control is highly better performance, in compare with non-adaptive control, and also fuzzy adaptive control is more satisfactory than conventional adaptive control.

Keywords:Speed Control, Model Reference Adaptive Control, PI Controller, Fuzzy Logic Controller, DC Motor

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I INTRODUCTION

DC motors are one of the most widely used machines of industrial systems. These motors are used for applications such as product line, robot control and etc. A large tendency and effort exist to develop a highly perfect control tool for DC motors [1, 2]. In industrial drives and DC motor control, three methods are common: 1) A classic method : This control method uses PI and PID controllers which is not working well and flexible enough in the presence of changing system parameters and provides many limits and problems. 2) Adaptive control. This method commonly uses when sudden disturbances and changes exist in the system and a complete and stable design is not accessible by classical control methods 3) Smart methods, like fuzzy and neural network controllers [3-12]. Several methods for DC motor speed control have been developed which can be divided into three categories as shown in Fig. 1 [13-16]. A controller design method for networked DC motor system in the presence of time delays and packet losses is presented in [17], where estimation of distribution algorithm is used to optimize the control parameters and improve control system performance. An efficient implementation of neural multi-layer networks on field programmable gate array fabric is described in [18], where the implementation performances were tested using an approximation of some linear and non-linear functions. Model reference adaptive control is one of the modern techniques of solving control problems when the parameters of the controlled process are poorly known or vary during normal operation [19-21]. The conventional MRAC with traditional control techniques such as PI controller and model reference adaptive control scheme with fuzzy linear adaptation are presented in [22]. In [23] a MRAC method is proposed to regulate the major speed loop in the positioning system. It was designed with three closed control loop, where a compensatory measure is given to counterbalance the friction torque disturbances. It is possible to coincidentally use fuzzy and classic methods with adaptive controller. In model reference adaptive control method, a reference model is chosen which can work with one of common controllers such as PI or PID. The output of the method is desired speed that we expect from system. Incorrect choice of reference model makes the system instable, and controller would be unable to trace the reference speed. Adaptive controller would be an output which cause motor speed (ω_r) follows the desired speed (which is made by reference model (ω_m) and the error between output and reference model(e_d) closes to zero. In this paper, we proposed a perfect control method which simultaneously uses fuzzy and adaptive controller methods. we show that, reference model fuzzy adaptive control (RMFAC) operates much better in increase of stability and reduction of noises for systems which has unknown designs, than the conventional methods.

II MODEL REFERENCE ADAPTIVE CONTROL

The MRAC scheme is shown in Fig. 2. A separately excited dc motor which is supplied through a convertor is shown in the figure. The motor fed through a controller with gain of K_c. As it can be seen in Fig. 2 , the system has two inputs. The first input is difference between plant output and model reference output and the second one is difference between model output and reference signal. Both plant and reference models are used to train network. The block diagram of DC motor has been shown in Fig. 3. Here J_m and B_m are the moment of inertia and

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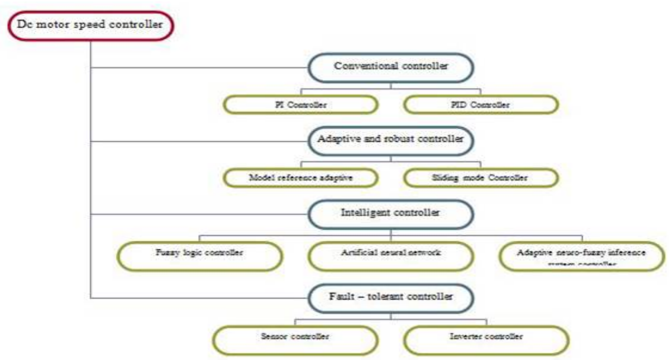

Figure 1: General classification of dc motor speed Controller

friction coefficient, R_a and L_a are the motor armature resistance and inductance. U_a is the adaptive controller output and K_{F1} and K_{F2} are converter gains.

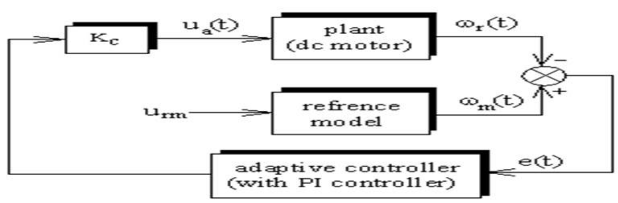

Figure 2: The MRAC scheme of DC drive

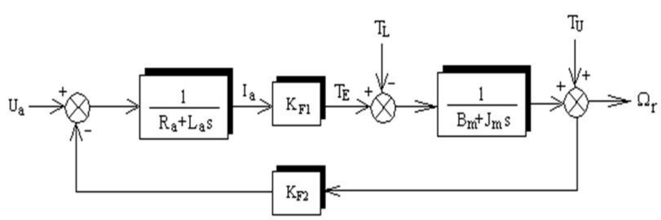

Figure 3: Block diagram of DC motor

There are three inputs in Fig. 3 ; the input signal to the plant or adaptive controller output U_a, load torque T_L, and output disturbance due to system uncertainties T_u. The resultant or ultimate speed of the motor is defined as:

$$\omega_r = \omega_0 + d_1 + d_u = \omega_0 + d \tag{1}$$

$$d = d_1 + d_u \tag{2}$$

where ω_0 is the plant output speed without disturbance and ω_r is the plant output speed with disturbance. d_l and d_u are effects of load torque and uncertainties on output speed, respectively. The dynamics of a separately excited DC motor with negligible load torque and disturbance due to uncertainties is governed by [24, 25]:

$$\frac{\mathrm{d}\omega_0(\mathrm{t})}{\mathrm{dt}} = \dot{\omega}_o(t) = -\frac{\mathrm{B_m}}{\mathrm{J_m}}\omega_0(\mathrm{t}) + \frac{\mathrm{K_{F1}}}{\mathrm{J_m}}\mathrm{i_a}(\mathrm{t}) \tag{3}$$

$$\mathrm{T_e} = \mathrm{K_{F1}}\mathrm{i_a}(\mathrm{t}) \tag{4}$$

The motor is fed from a convertor whose input is obtained from the output of adaptive controller U_a and it is expressed as:

$$\frac{\mathrm{di_a}(\mathrm{t})}{\mathrm{dt}} = \dot{i}_a(t) = -\frac{\mathrm{K_{F2}}}{\mathrm{L_a}}\omega_0(\mathrm{t}) - \frac{\mathrm{R_a}}{\mathrm{L_a}}\mathrm{i_a} + \frac{\mathrm{K_C U_a(t)}}{\mathrm{L_a}} \tag{5}$$

where K_C is the back emf constant. The transfer function of the plant with no load torque and uncertainties ($U_a \neq 0$, $d_1 = 0$, $d_u = 0$) is obtained from as follow as:

$$\mathrm{G_T(s)} = \frac{\omega_0(\mathrm{s})}{\mathrm{U_a(s)}} = \frac{\mathrm{K_T}}{\mathrm{s^2 + a_1 s + a_0}} \tag{6}$$

where a_1, a_0 and K_T are given by:

$$\begin{aligned} \mathrm{a_1} &= \frac{\mathrm{B_m}}{\mathrm{J_m}} + \frac{\mathrm{R_a}}{\mathrm{L_a}} \\ \mathrm{a_0} &= \frac{\mathrm{B_m R_a + K_F K_{F1}}}{\mathrm{J_m L_a}} \\ \mathrm{K_T} &= \frac{\mathrm{K_{F1} K_C}}{\mathrm{J_m L_a}} \end{aligned} \tag{7}$$

Let us consider the case with only load disturbances ($T_L \neq 0$):

$$\Delta\mathrm{L(s)} = \frac{-\mathrm{T_L(s)(R_{at} + sL_{at})}}{\mathrm{s^2 + a_1 s + a_0}} \tag{8}$$

where:

$$\mathrm{R_{at}} = \frac{\mathrm{R_a}}{\mathrm{J_m L_a}}, \mathrm{L_{at}} = \frac{1}{\mathrm{J_m}} \tag{9}$$

Similarly when load torque and uncertainties in the input supply are present, the resultant speed is obtained by:

$$\omega_\mathrm{r}(\mathrm{s}) = \frac{\mathrm{U_a(s) - T_L(s)\,(R_{at} + sL_{at})}}{\mathrm{s^2 + a_1 s + a_0}} + \mathrm{d_u(s)} \tag{10}$$

A reference model is chosen such a way that poles position improve stability of the whole system. For an output ω_m, which is the desired speed response of plant, the input of reference model is U_{rm}. The parameters of the reference model are selected such that the poles of the transfer function at x_1 and x_2 are placed on the left hand side of the s-plane. The transfer function $G_m(s)$ of the reference model is defined as:

$$\mathrm{G_m(s)} = \frac{\omega_\mathrm{m}(\mathrm{s})}{\mathrm{U_{RM}(s)}} = \frac{\mathrm{K_M}}{\mathrm{(s + x_1)(s + x_2)}} \tag{11}$$

The error signal $e_d(t)$ is derived as follows. The error vector is defined as difference between the plant and the reference model states:

$$\mathrm{e(t)} = \mathrm{x_m(t)} - \mathrm{x_p(t)} \tag{12}$$

where $e_r(t)$ and $e_0(t)$ is defined as error when the disturbance is present ($d \neq 0$) and when the disturbance is absent ($d = 0$). That is:

$$\mathrm{e_0(t) = \omega_0(t) - \omega_m(t)} \tag{13}$$

When the disturbances are present, the error in the output speed $e_r(t)$ is obtained as:

$$\mathrm{e_r(t) = \omega_r(t) - \omega_m(t)} \tag{14}$$

Therefore $e_r(t)$ is given by:

$$\mathrm{e_r(t) = \omega_0(t) + d(t) - \omega_m(t) = e_0(t) + d(t)} \tag{15}$$

The adaption process can be explained on the basis of the abone control laws. When the scalar speed error $e_r(t)$ converges to zero ,the controller output also converges to a constant quality and the speed of the motor becomes constant. In the adaption process, the motor output speed ω_r can actually tends to the reference speed ω_m and they exactly approaches to a same value. If disturbances or changes in torque and load are present, the adaption process works again till error between ω_r and ω_m converges to zero.

III MODEL REFERENCE FUZZY ADAPTIVE CONTROL

A schematic representation of MRFAC was shown in Fig. 4. Fuzzy implementation of model reference adaptive control can also use a reference model for better function of control process. In this method, the reference model approaches the desired speed and direction. The error between the output of the reference model and the plant is applied to drive the fuzzy controller. Reference model is designed based on desired speed, control specifications and the speed controller. Appropriate selection of reference model leads to stability of the whole system. To design the fuzzy adaptive controller, we can use the motor behavior and reference model output. The motor behavior follows reference input with an error as shown in Fig 5. According to the fuzzy implementation of adaptive process, the error approaches zero by laps of time.

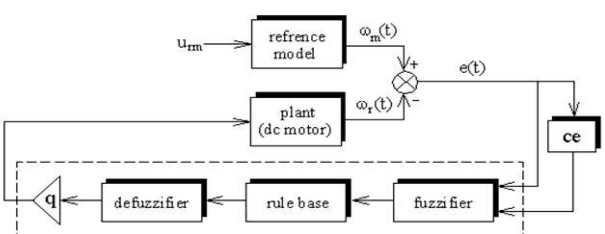

Figure 4: Basic control diagram for model reference fuzzy adaptive control scheme

The error (e) and the error change (ce) are defined as:

$$e(x) = \omega_m(x) - \omega_r(x) \tag{16}$$

$$ce(x) = e(x) - e(x-1) \tag{17}$$

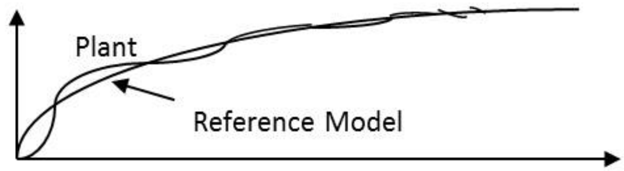

Figure 5: Motor behavior and reference model

$\omega_m(x)$ is the reference model response,$\omega_r(x)$ is the rotor position signal , $e(x)$ is the error signal and $ce(x)$ is the error change signal at xth samples The fuzzy if-then rules are provided according to the Table I. The fuzzy controller input is selected as error (e) (between the output speed and the reference model speed) and error change(ce). The membership functions are chosen triangular type for simplicity. The membership functions are shown for two inputs of controllers in Fig. 6 and for output in Fig. 7. Middle of maximums method (mom) is used as de-fuzzification method which gets the best results in several applications. In order To obtain more exact results, nine language terms is used which totally result 81 rules. Appropriate scale factors are presented to define desired output. We can see output shape by attention to changes of e (error value) or ce (error change) as shown in Fig. 8.

Table 1: LINGUISTIC RULES

e \ ce	nvb	nb	nm	ns	ze	ps	pm	pb	pvb
nvb	nvb	nvb	nb	nb	nm	nm	ns	ze	ze
nb	nvb	nb	nb	nm	nm	ns	ze	ze	ze
nm	nb	nb	nm	nm	ns	ns	ze	ze	ps
ns	nb	nm	nm	ns	ns	ze	ze	ps	pm
ze	nm	nm	ns	ns	ze	ps	ps	pm	pm
ps	nm	ns	ze	ze	ps	ps	pm	pm	pb
pm	ns	ze	ze	ps	ps	pm	pm	pb	pb
pb	ze	ze	ze	ps	pm	pm	pb	pb	pvb
pvb	ze	ze	ps	pm	pm	pb	pb	pvb	pvb

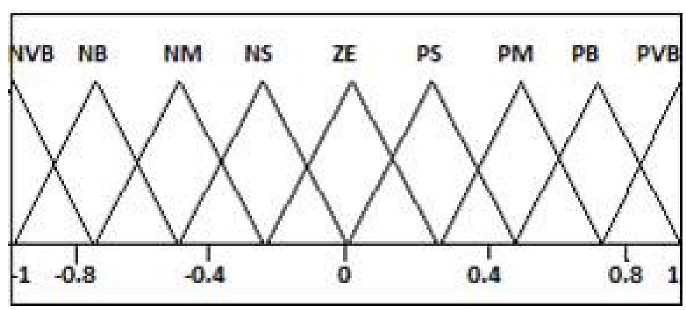

Figure 6: Inputs membership functions (e and ce)

IV NON-ADAPTIVE CONTROL

Non-adaptive control means the classic control methods which uses a constant quantity as the reference quantity instead of a function as the reference model. In non-adaptive control, controller parameters are constant during the process. In the case

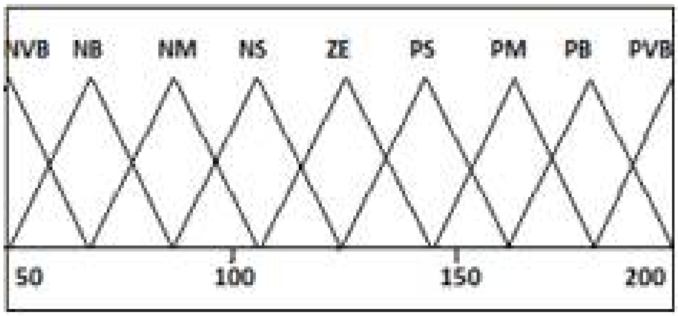

Figure 7: output membership function

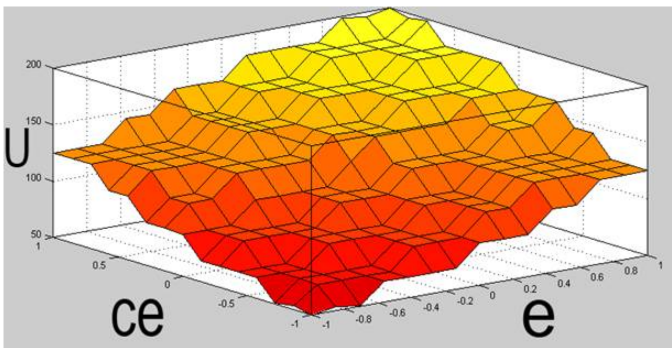

Figure 8: Output graphical shape

of motor speed control, the error is two large. This causes that vibrations can be damped and the motor output reaches to reference quantity.

V SIMULATION RESULTS

The simulations have been performed with the help of Simulink software. In the simulation, all the blocks are assumed according to the formulas and DC motor model according to Fig. 3. The Simulink model of the system is shown in Fig. 9. K_{F1} and K_{F2} are two constant values for exciter of DC motor. These constants and variable loads are applied to test of implementation of fuzzy controller. The reference model is defined by the previous formulas. The U_{rm} which drives the reference model can be a constant quantity or a step function with desired start time. Amplitude of reference model is defined by desired reference speed quantity. PI controller is used for conventional model reference adaptive control method. In this paper, a 3hp, 2400 V, 1500 rpm, separately excited DC motor is considered. The different parameters of the system are show in Table II.

Transfer function of reference model (RM) with poles of -6 and -4 is defined as:

$$\mathrm{G_m(s)} = \frac{150}{\mathrm{s^2 + 10s + 24}} \tag{18}$$

The desired speed is chosen as 1500 rpm in non-adaptive control methods. Constant and variable loads are applied for comparision. Variable load is applied to the system at times of 3.5 and 5 seconds.

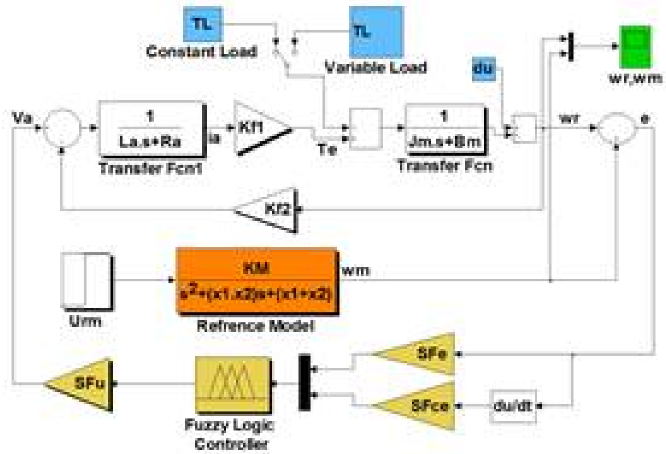

Figure 9: System model in Simulink/Matlab

Table 2: System Parameters

Parameter	Value	Unit
K_C	10	
K_{F1}	0.55	
K_{F2}	0.55	
R_a	1	Ω
L_a	0.046	H
J_m	0.093	$kg-m^2$
B_m	0.08	H
K_I	3	
K_P	16	

A Adaptive and Non-adaptive control under constant load

Driving a system with non-adaptive control is shown in Fig. 10. The results show that motor's speed is 1000 rpm higher than the reference speed at starting time. However, conventional and fuzzy adaptive control in Figs. 11 and 12 show that, the motor speed exactly traces the reference speed.

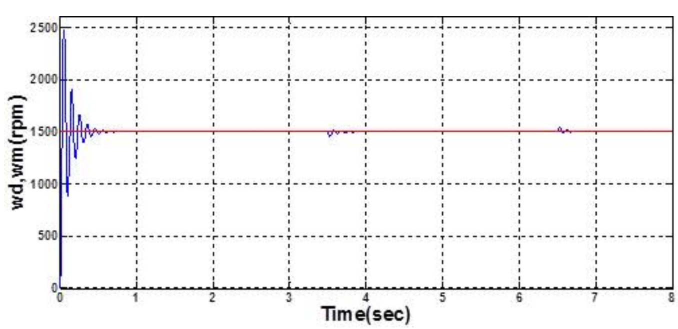

Figure 10: Motor output speed by non-adaptive reference control

B Conventional and Fuzzy adaptive control under variable load

In conventional and Fuzzy adaptive control methods, the motor speed exactly traces the reference speed at starting and under a constant load. But at the time of load increases (from 7 N.M to 30N.M), conventional adaptive controller has a speed error

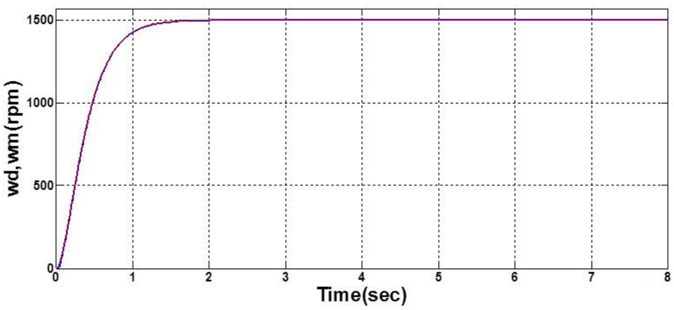

Figure 11: Motor output speed and constant load by conventional MRAC method

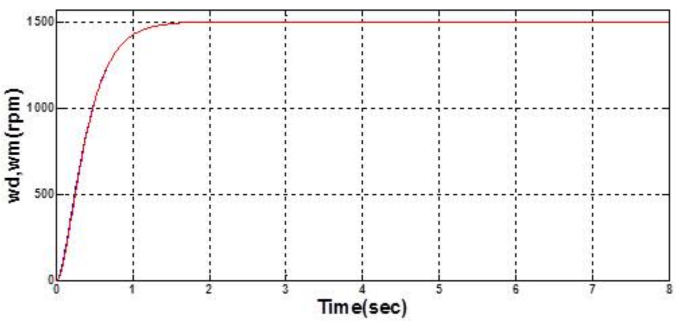

Figure 12: Motor output speed and constant load by MRFAC method

about 20 rpm, whereas fuzzy adaptive controller has a speed error about 3 rpm. The simulation results are shown in Figs. 13-16. The oscillations damping time is about 0.5 seconds for the conventional adaptive controller while it is 0.15 second for the fuzzy adaptive controller. For the heavy load changing, when the load increases from 7 N.M to 70 N.M, the conventional and fuzzy adaptive controllers have speed errors about 72 rpm , 11 rpm, respectively. Also oscillations Damping times under this loading case are 0.9 second for the conventional adaptive controller, and 0.15 second for the fuzzy adaptive controller. The comparison results are shown in the Table III.

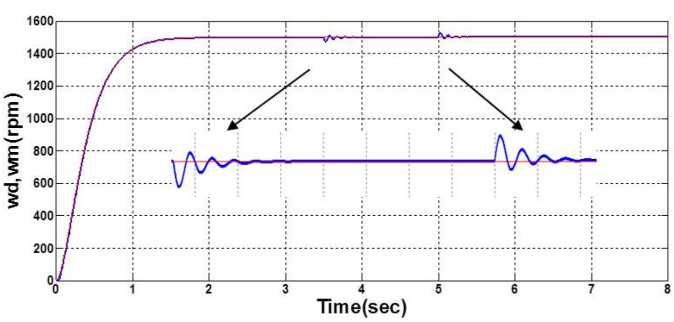

Figure 13: output speed and variable load (7N.M to 30N.M) by conventional MRAC

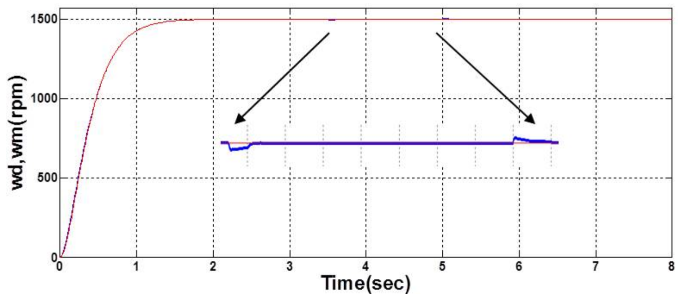

Figure 14: output speed and variable load (7N.M to 30N.M) by MRFAC

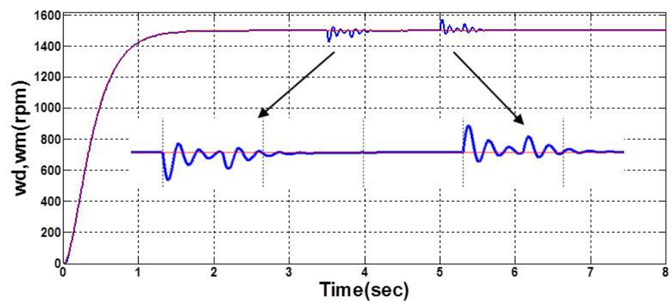

Figure 15: output speed and variable load (7N.M to 70N.M) by conventional MRAC

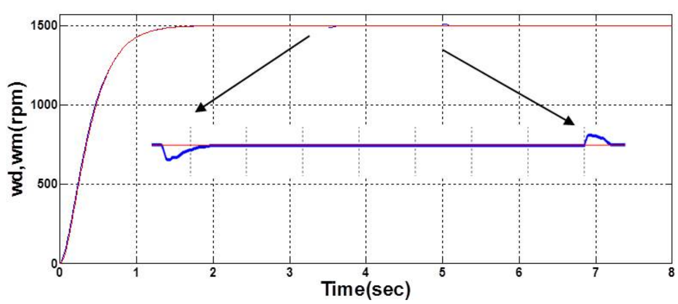

Figure 16: output speed and variable load (7N.M to 70N.M) by MRFAC

Table 3: Comparison results

		Speed error rpm	Settling time Sec
MRFAC	7 to 30 Nm	3	0.15
	7 to 70 Nm	11	0.15
MRAC	7 to 30 Nm	20	0.5
	7 to 70 Nm	72	0.9
Non-adaptive		1000	-

VI CONCLUSION

This paper basically explains advantage of model reference adaptive control over non-adaptive control and especially model reference fuzzy adaptive control. Simulation results show that, for dc motor drive, fuzzy adaptive controller is much better than the conventional adaptive and non0adaptive controller and more economical solution. Furthermore, MRFAC enhances the performance of motor starting and the motor speed exactly follows reference value. The work can also be effectively and easily applied to higher order systems. The simulation results show that whenever a load disturbance or sudden load variation exists, adaptive controller works better than nonadaptive controller, and fuzzy adaptive controller works better than conventional adaptive controller.

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