Applying Fuzzy Control Based on Model Reference Adaptive Control for Speed Adjustment and DC Motor Drive

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Abstract

This paper presents Model Reference Adaptive Control (MRAC) and the Fuzzy (MRFAC) and conventional performance of it. The aims of this work are increase in correspondence of motor speed with defined reference model speed of the system, decrease of noises under load changes and disturbances and increase of system stability. Thus, model reference adaptive control is applied instead of non-adaptive or conventional control, and also fuzzy controller is used in place of classic controllers like PI.

The operation of non-adaptive 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 securing of the entire system stability. Simulation is done with constant and variable loads, and the obtained results demonstrate that, the adaptive control is highly favorite, in compare with non-adaptive control, and also fuzzy adaptive control is more satisfactory than conventional adaptive control. The simulations are carried out by using MATLAB-SIMULINK.

Key words: Speed Adjustment, Model Reference Adaptive Control, PI Controller, Fuzzy Logic Controller, DC Motor

1. Introduction

Dc motors are one of the most applying parts of industrial systems, which are used for applications such as product line, robot control and etc. thus a large tendency and effort exist to develop the control tool of it. In industrial drives and DC motor control, three methods are common: 1) A classic method is employment of PI and PID controllers which is not flexible for system parameters change. So it provides many limits and problems, Montiela et al (2007) used fuzzy logic to adjust controller parameters of PID that reduces the problems of classic controllers. 2) A method which is more modern than classic one is adaptive control. Commonly, sudden disturbance and changes in driving motor exist that cause we couldn't get a complete and stable design for system. One of control methods for these systems is adaptive control. Seung at el (1997) presents a classic adaptive control for DC motor control. 3) Smart methods operate better than the presented previous methods toward disturbance and changes, like fuzzy controllers and neural network. Parrazales et al (1995) applies fuzzy logic to control DC motor place.

It is possible to coincidently 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 a desired speed that we expect from system. Incorrect choice of reference model makes the system instable, and controller would be unable to control the design. Adaptive controller aim would be an output which cause motor output speed (ω_r) follows desired speed (which is made by reference model (ω_m)), and error between output and reference model (e_d) limits to zero.

In this paper, we proposed to simultaneously use fuzzy and adaptive controller method. "Reference model fuzzy adaptive control" operates much better in stability and reduction of noises for systems which has unknown designs, than the presented methods.

2.Description of conventional MRAC and mathematical model of motor

The entire MRAC scheme is shown in Fig. 1. A separately excited dc motor which is supplied through a convertor is shown in the figure. The motor fed through a controller whose gain is K_c.

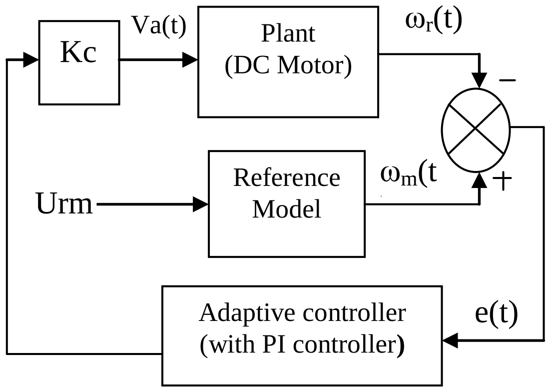


Fig 1. The entire MRAC scheme of DC drive

The DC motor that used, is shown in Fig. 2. The excited part is used in model as constant quality and some coefficients.

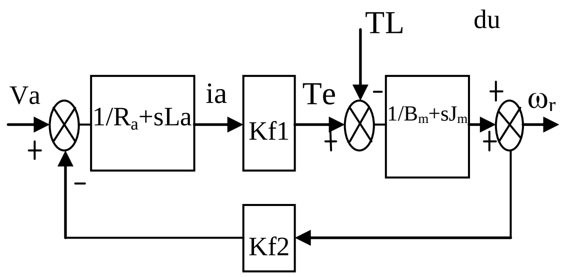


Fig 2. The entire DC Motor scheme

There are three inputs in the shown scheme in Fig. 1, namely, the input signal to the plant or adaptive controller output V_a, load torque T_L, and output disturbances due to uncertainties d_u.

The resultant or ultimate speed of the motor is defined as:

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

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

The dynamics of a separately excited DC motor with negligible load torque and disturbances due to uncertainties is governed by:

$$\frac{d\omega_0(t)}{dt} = \dot{\omega}_0(t) = -\frac{B_m}{J_m}\omega_0(t) + \frac{K_{f1}}{J_m}i_a(t) \tag{3}$$

$$T_e = K_{f1}i_a(t) \tag{4}$$

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

$$\frac{di_a(t)}{dt} = \dot{i}_a(t) = -\frac{K_{f2}}{L_a}\omega_0(t) - \frac{R_a}{L_a}i_a + \frac{K_c V_a(t)}{L_a} \tag{5}$$

The transfer function of the plant with no load torque and uncertainties (Va≠0,d1≡0,du≡0) is obtained from Eq. 3, 4 and 5 as:

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

$$\left.\begin{aligned} a_1 &= \frac{B_m}{J_m} + \frac{R_a}{L_a} \\ a_0 &= \frac{B_m R_a + K_{f2}K_{f1}}{J_m L_a} \\ K_T &= \frac{K_{f1}K_c}{J_m L_a} \end{aligned}\right\} \tag{7}$$

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

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

Where

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

Similarly when load torque and uncertainties in the input supply are present, the resultant speed is obtained from Eq. 1, 6 and 8:

$$\omega_r(s) = \frac{Va(s) - T_L(s)(R_{at} + sL_{at})}{s^2 + a_1 s + a_0} + d_u(s) \tag{10}$$

A reference model is chosen whose pole position decides the 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 transfer function at x_1 and x_2 are placed on the left hand of the s-plane.

The transfer function $G_m(s)$ of the reference model is defined as:

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

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:

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

$e_r(t)$ and $e_0(t)$ is defined as error when the disturbance is present and when the disturbances are absent. That is:

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

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

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

Incorporating Eq. 13 and 14 becomes:

$$\begin{aligned} &e_r(t) = \omega_0(t) + d(t) - \omega_m(t) \;\Rightarrow \\ &\Rightarrow e_r(t) = e_0(t) + d(t) \end{aligned} \tag{15}$$

The adaption process can be explained on the basis of the control laws explained above, 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. The adaption process of output speed of motor ω_r can actually verges to the reference speed ω_m those they exactly approaches to a same value.

If disturbances or changes in torque and load, input to the model that make ω_r and ω_m different from each other, the adaption process works again till error between ω_r and ω_m converges to zero.

3. Description of Model Reference Fuzzy Adaptive Control(MRFAC) and fuzzy logic

A schematic representation of MRFAC was shown in Fig. 3.

In fuzzy implementation of model reference adaptive control can also use a reference model for increasing function of control process. In this method, the reference model approaches desired speed and direction. The error between the output of the reference model and the plant is used to drive the fuzzy controller. Reference model is designed based on desired speed, control specifications and the speed controller, that appropriate selection of reference model leads to stable the entire system.

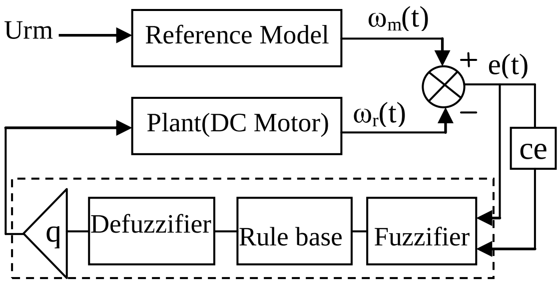


Fig 3. Basic control diagram for model reference fuzzy adaptive control scheme.

To design the fuzzy adaptive controller, we can use motor behavior and reference model output. The motor behavior follows input of reference with a primary error as shown in Fig. 4. According to the fuzzy implementation of adaptive process, the error approaches zero by laps of time .the error (e) and the error change (ce) are defined as:

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

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

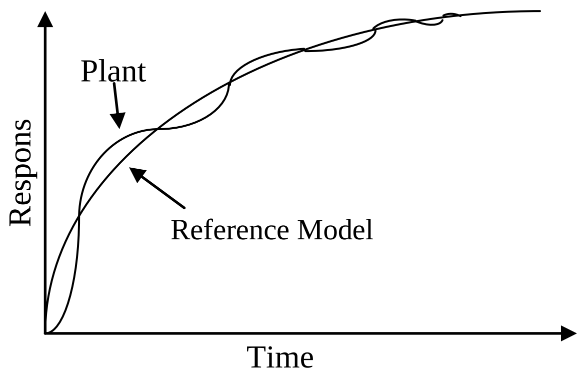


Fig 4. The motor behavior and reference model

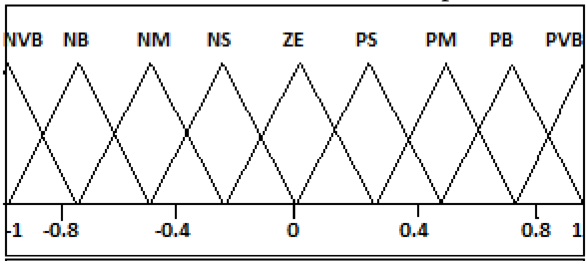
The fuzzy if-then rules are provided according to the following table:

ce \ e	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

Table 1. The linguistic rule table

The fuzzy controller input is selected as error (e) (between the output speed of motor DC and the reference model speed) and change of error (ce). The membership functions are used chosen triangular for simplicity. The membership functions are used for two inputs of controller in Fig. 5 and for output in Fig. 6.

Middle of maximums method (mom) is used as defuzzification method in drive, which gets the best result in all defuzzification methods. For more exact results, it is used 9 language terms which totally result 81 rules, and appropriate scale factors are demonstrated to define desired output.



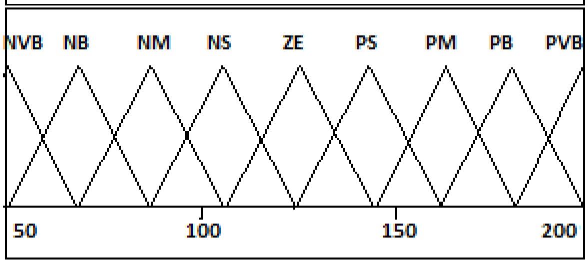


Fig 5. Input membership functions (e & ce)

Fig 6. Output membership functions

We can see output graphical shape by attention to changes of e (error value) or ce (changes of error).

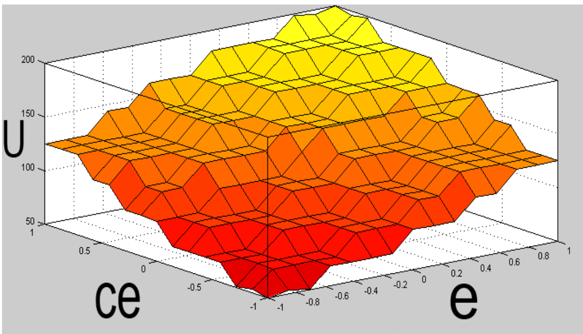


Fig 7. Output graphical shape

5. Nonadaptive control

Nonadaptive control means the classic control methods that which uses a constant quantity as the reference quantity instead of using a function as the reference model. In nonadaptive control, controller parameters are constant during process, against adaptive control. At motor drive time by this method, the error is so big, then vibrations amortized and the motor output approaches reference quantity.

6. Simulation

The simulations have been performed with the help of simulink software. In this simulation, all the blocks are considered according to the formulas and Dc motor model according to the Fig. 2. And K_{f1} and K_{f2} are two constant qualities for exciter DC motor. The two constant and variable loads are considered for testing implementation of fuzzy controller. The reference model is defined by the previous formulas. The U_{rm} which drives reference model can be a constant quantity or a step function with desired start time, which the amplitude of reference model is defined by desired reference speed quantity. Scale factors quantities are defined as getting desired result. Fuzzy controller is loaded by defined rules. A PI controller is used in simulation of conventional model reference adaptive control, instead of fuzzy controller.

In this study, a 3hp, 2400v, 1500 rpm, separately excited DC motor is considered. The different parameters of the system are:

K_c=10 , k_{f1}=k_{f2}=0.55, R_a=1 , L_a=0.046 , J_m=0.093 kg-m ^{2} ,B_m=0.08 Nm/s/rad

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

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

The PI controller specifications are integral gain ki=3, proportional gain kp=16.

A 1500 constant quantity is used to get the desired speed in simulation of nonadaptive control results. Two constant and variable loads are used for comparing. Variable load affects to the system at 3.5 and 6.5 seconds.

7. Simulation Results

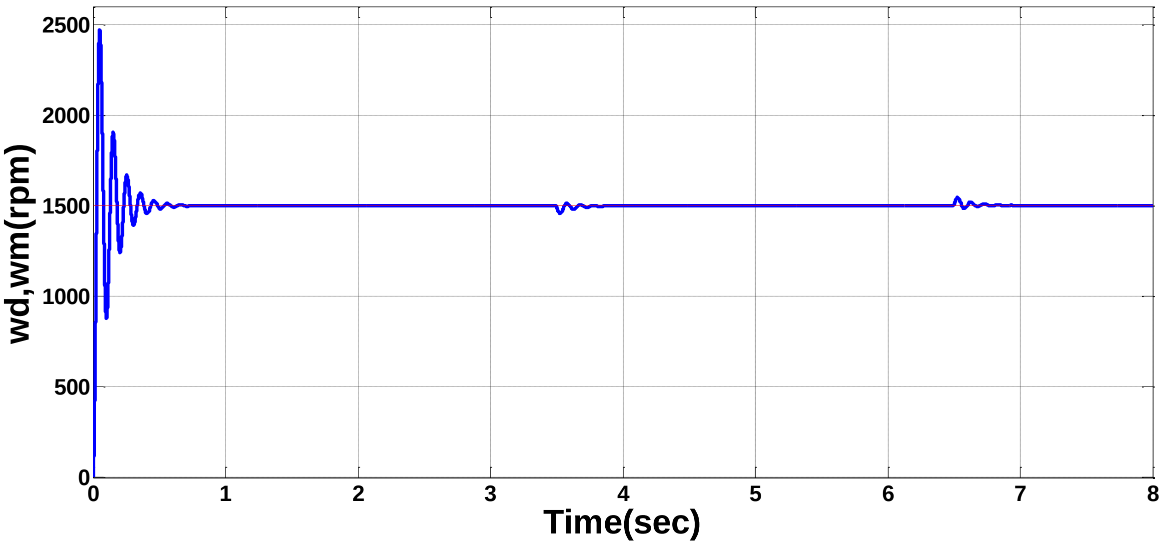


Fig 8. Diagram of output speed and nonadaptive reference control.

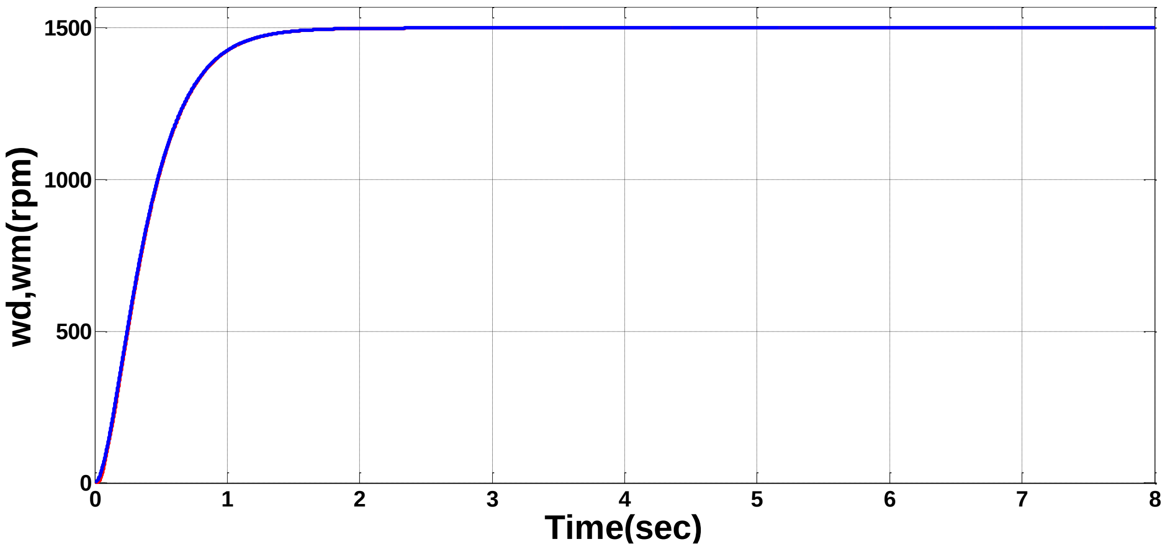


Fig 9. Diagram of output speed and constant load using conventional MRAC.

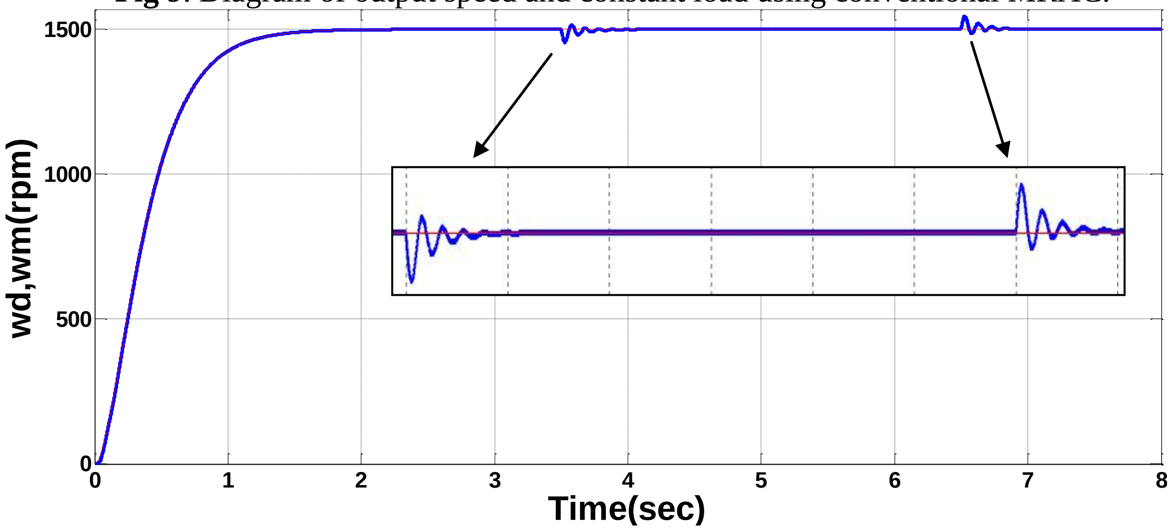


Fig 10. Diagram of output speed and variable load using conventional MRAC.

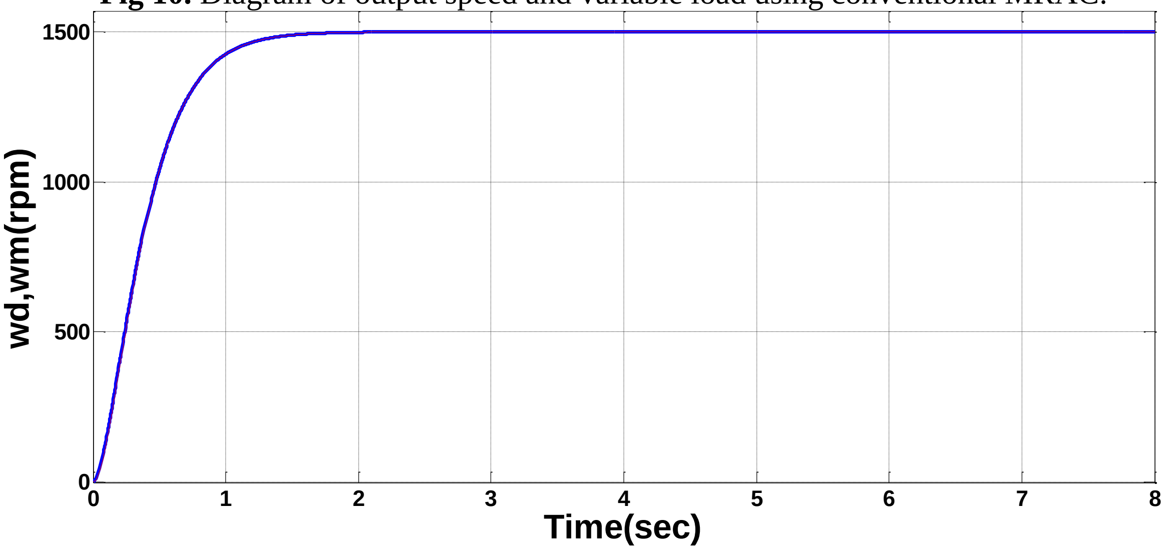


Fig 11. Diagram of output speed and constant load using MRFAC

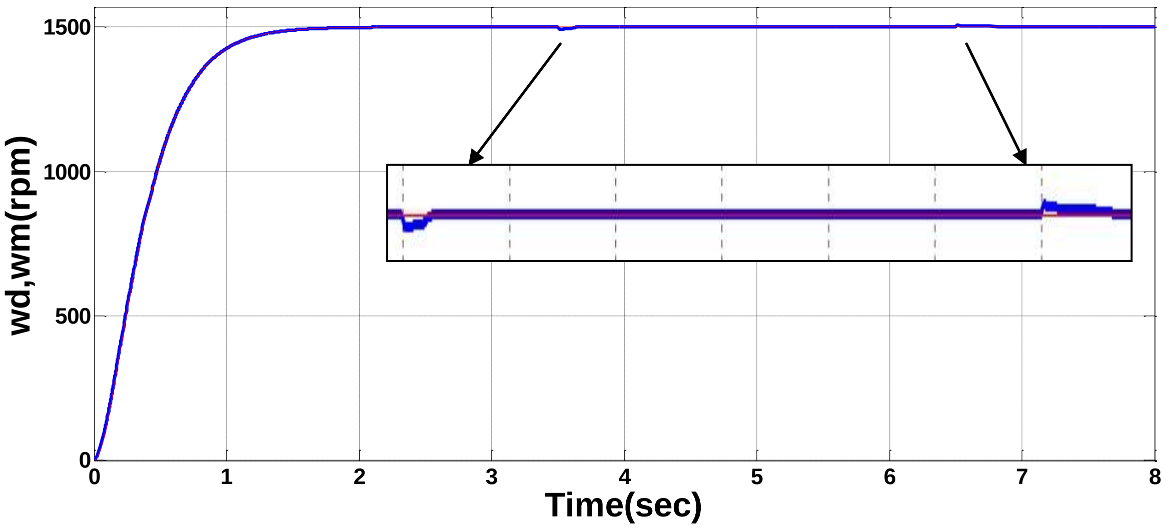


Fig 12. Diagram of output speed and variable load using MRFAC

8. Comparisons

8-1. Adaptive and Nonadaptive

driving a system with nonadaptive control was shown in Fig. 8. The results show at driving time, motor's speed is 1000 rpm higher than reference quantity. But conventional and fuzzy adaptive control in Fig. 9 until Fig. 12, shows at driving time that, motor speed is exactly the same as reference speed.

8-2. Fuzzy and Conventional Adaptive

In these two methods, the motor speed is exactly equal to the reference speed at driving time and constant load. But when variable load increases from 7 N.M to 30N.M, conventional adaptive controller has a deviation speed about 20 rpm, and when fuzzy adaptive controller has a deviation speed about 3 rpm.

9. Conclusion

This paper basically explains advantage of model reference adaptive control over nanadaptive control and especially model reference fuzzy adaptive control (MRFAC). In the simulation results, dc motor drive by fuzzy adaptive controller results an optimizer and more economical solution. Furthermore MRFAC enhances the performance of driving system because results show, adaptive control is optimizer and safer than nonadaptive control and follows reference quantity without being upper or downer. The work can also be effectively applied higher order systems without any complications. The simulation results show that, whenever a load disturbance or sudden load variation exists, adaptive control works better than nonadaptive control, and fuzzy adaptive control works better than conventional adaptive control and error tends to zero.

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