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Adaptive PID Controller for Dc Motor Speed Control

A.Taifour Ali[1], Eisa Bashier M. Tayeb[2] and Omar Busati alzain Mohd[3]
[1,2]*School of Electrical and Nuclear Engineering; College of Engineering; Sudan University of Science &Technology; SUDAN*
[3]*M.Sc. at School of Electrical and Nuclear Engineering*

Abstract—This investigation is concerned with the model reference adaptive PID control (MRAPIDC). Incorporating separately excited DC motors, subjected to uncertainties including parameter variations and ensuring optimum efficiency. The idea is to find further perfection for MRAC method and to provide an even more smooth control to the DC motor and to minimize deficiencies of the traditional MRAC method. This is examined when combining the MRAC method with the PID control. The performance of the drive system obtained, formed a set of test conditions with MRAPIDC. To achieve these objectives the simulation environment is provided in the MATLAB Simulink.

Keywords—Adaptive PID, Model Reference Adaptive Control (MRAC), Model Reference Adaptive PID Control (MRAPIDC), DC Motor Speed Control.

I. INTRODUCTION

The Direct Current (DC) motors have variable characteristics and are used extensively in variable-speed drives. DC motor can provide a high starting torque and it is also possible to obtain speed control over a wide range. There are many adaptive control techniques, among them is the MRAC. It is regarded as an adaptive servo system in which the desired performance is expressed in terms of reference model. Model Reference Adaptive Control method attracting most of the interest due to its simple computation and no extra transducers is required [1-4]. The PID controller has several important functions; it provides feedback, has the ability to eliminate steady state offsets through integral action, and it can anticipate the future through derivative action. PID controllers are the largest number of controllers found in industries sufficient for solving many control problems [5]. Many approaches have been developed for tuning PID controller and getting its parameters for single input single output (SISO) systems. Among the well-known approaches are the Ziegler-Nichols (Z-N) method, the Cohen-Coon (C-C) method, integral of squared time weighted error rule (ISTE), integral of absolute error criteria (IAE), internal-model-control (IMC) based method, gain-phase margin method [6-14]. Adaptive control use to change the control algorithm coefficients in real time to compensate for variations in environment or in the system itself. This paper deals with the model reference adaptive control approach MRAC [15-18]. In which the output response is forced to track the response of a reference model irrespective of plant parameter variations.

II. SYSTEM DESCRIPTION AND MODELING

When the plant parameters and the disturbance are varying slowly or slower than the dynamic behavior of the plant, then a MRAC control can be used. The model reference adaptive control scheme is shown in figure 1. The adjustment mechanism uses the adjustable parameter known as control parameter θ to adjust the controller parameters [4]. The tracking error and the adaptation law for the controller parameters were determined by MIT Rule [19].

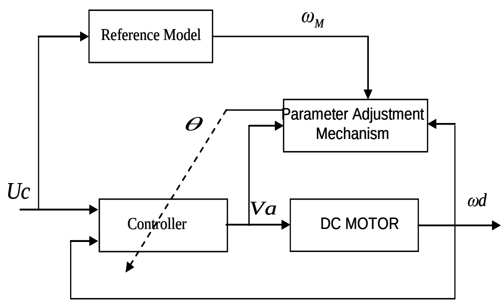

Fig. 1: Structure of Model Reference Adaptive Control

MIT (Massachusetts Institute of Technology) Rule is that the time rate of change of θ is proportional to negative gradient of the cost function (J), that is:

$$\frac{d\theta}{dt} = -\gamma \frac{\partial J}{\partial \theta} = -\gamma \varepsilon \frac{\partial \varepsilon}{\partial \theta} \qquad (1)$$

The adaptation error $\varepsilon = y_p(t) - y_M(t)$. The components of $d\varepsilon/d\theta$ are the sensitivity derivatives of the error with respect to the adjustable parameter vector θ. The parameter γ is known as the adaptation gain. The MIT rule is a gradient scheme that aims to minimize the squared model error ε^2 from cost function [20]:

$$J(\theta) = \tfrac{1}{2}\varepsilon^2(t) \qquad (2)$$

A. *Modeling of DC Motor:* The plant used in simulation is seperatly excited dc motor with dynamic equations as [21]:

$$\omega_d = \omega + d_L + d_U \qquad (3)$$

$$V(t) = I_a(t)R_a + L_a\tfrac{di}{dt} + K_b\omega(t) \qquad (4)$$

$$(5) \quad K_m + I_a(t) = B\omega(t) + J\tfrac{d}{dt}\omega(t) + T_L$$

Taking Laplace transform of equations (4) and (5), the transfer function of the DC motor with no load torque and uncertainties ($d = 0$) is obtained from let T_L= 0:

$$(6) \quad \frac{\omega(s)}{V(s)} = \frac{\frac{K_m}{JL_a}}{[s^2 + \frac{(JR_a + BL_a)}{JL_a}s + \frac{(BR_a + K_mK_b)}{JL_a}]}$$

First let us consider the case with only load disturbances $T_L \neq 0$

$$d_L = \frac{-T_L\left(\frac{R_a}{JL_a} + s\left(\frac{1}{J}\right)\right)}{[s^2 + \frac{(JR_a + BL_a)}{JL_a}s + \frac{(B\,R_a + K_m\,K_b)}{JL_a}]} \qquad (7)$$

B. *Model Reference Adaptive PID Control:* The goal of this section is to develop parameter adaptation laws for a PID control algorithm using MIT rule.
The reference model for the MRAC generates the desired trajectory y_M, which the DC motor speed y_P has to follow.
Standard second order differential equation was chosen as the reference model given by:

$$H_M(s) = \frac{b_M}{s^2 + a_{M1}s + a_{M0}} \qquad (8)$$

Consider also the adaptive law of MRAC structure taken as the following form [22]:

$$u(t) = \left(K_P\,e(t) + K_i\int e(t)dt - K_d\,e^*(t)y_P\right) \qquad (9)$$

Where; $e(t) = u_c - y_p$, K_p is proportional gain, K_i is integral gain, K_d is derivative gain and u_c is a unit step input. In the Laplace domain, equation (9) can be transformed to:

$$U = \left(K_P E + \frac{K_i}{s}E - sK_d y_P\right) \qquad (10)$$

It is possible to show that applying this control law to the system gives the following closed loop transfer function:

$$Y_P = G_P\left(\left(K_P + \frac{K_i}{s}\right)(u_C - y_P) - sK_d y_P\right) \qquad (11)$$

Apply MIT gradient rules for determining the value of PID controller parameters ($\overset{*}{K}_{P,}\ \overset{*}{K}_i\ and\ \overset{*}{K}_d$). The tracking error equation (8) satisfies:

$$\varepsilon = \frac{\left(G_P K_P s + G_P K_i\right)U_C}{\left(s(1 + G_P K_P) + G_P K_i + s^2 G_P K_d\right)} - Y_M \qquad (12)$$

The exact formulas that are derived using the MIT rule can not be used. Instead some approximations are required. An approximation made which valid when parameters are closed to ideal value is as follows [23]:
Denominator of plant $\approx$ Denominator model reference then, from gradient method.

$$\frac{dK}{dt} = -\gamma\,\frac{\partial J}{\partial K_i} = -\gamma\left(\frac{\partial J}{\partial \varepsilon}\right)\left(\frac{\partial \varepsilon}{\partial Y}\right)\left(\frac{\partial Y}{\partial K}\right) \qquad (13)$$

Where ; $\frac{\partial J}{\partial \varepsilon} = \varepsilon, \quad \frac{\partial \varepsilon}{\partial Y} = 1$

Then the approximate parameter adaptation laws are as follows:

$$\overset{*}{K}_p = \left(\frac{-\gamma_p}{s}\right)\ \varepsilon \left(\frac{s}{a_0 s^2 + a_{m1}s + a_{m2}}\right) e \qquad (14)$$

$$\overset{*}{K}_i = \left(\frac{-\gamma_i}{s}\right)\ \varepsilon \left(\frac{1}{a_0 s^2 + a_{m1}s + a_{m2}}\right) e \qquad (15)$$

$$\overset{*}{K}_d = \left(\frac{\gamma_d}{s}\right)\ \varepsilon \left(\frac{s^2}{a_0 s^2 + a_{m1}s + a_{m2}}\right) Y_P \qquad (16)$$

III. SIMULATION RESULTS

In this section, some simulation carried out for MRAC Separately Excited DC motor controller. Matlab software was used for the simulation of control systems. Fig 2 shows Simulik models for both MRAC along with the motor under control. While Fig.3 shows implementation of MIT rule to obtain adaptation gains. The parameters of separately excited DC motor are considered as:

$K_m = K_b = 0.55$; $R_a = 1\Omega$; $L_a = 0.046H$ $J = 0.093Kg.m^2$; $B = 0.08Nm/s/rad$.

Also, the second order transfer function of the Model Reference as follows:

$$H_M = \frac{16}{s^2 + 4s + 16}$$

This reference model has 16% maximum overshoot, settling time of more than two seconds and rise time of about 0.45 seconds. In simulation, the constants gammas were grouped in five sets as in table 1:

Table 1: Groups of Gammas

set	1	2	3	4	5
γ_p	0.2	0.4	0.6	0.8	1.0
γ_i	0.8	1.6	2.4	3.2	4.0
γ_d	0.48	0.96	1.44	1.92	2.4

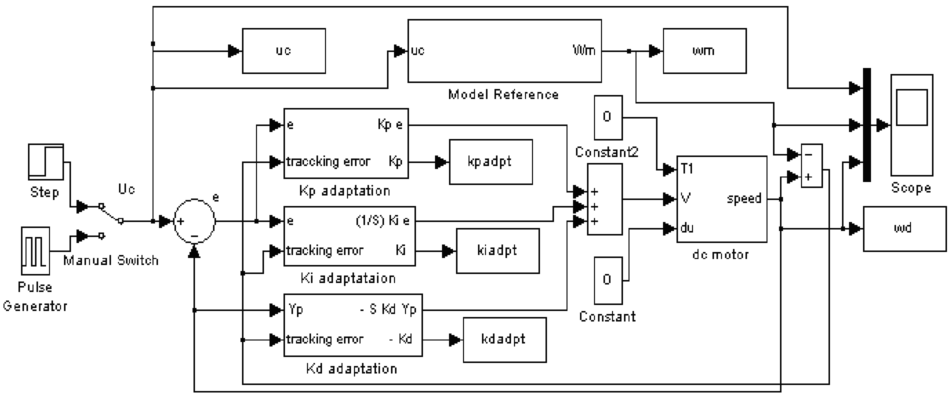

Fig. 2: Simulik Model for MRAC

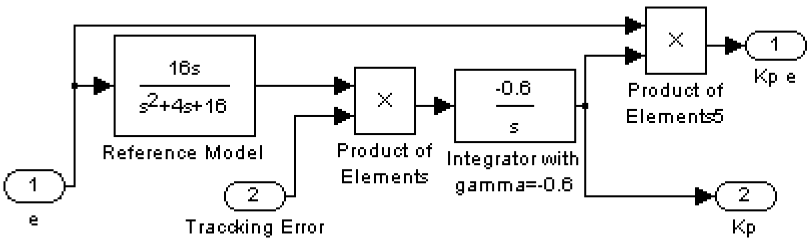

Fig. 3: Simulik Model for Proportional Adaptation Gain (MIT rule)

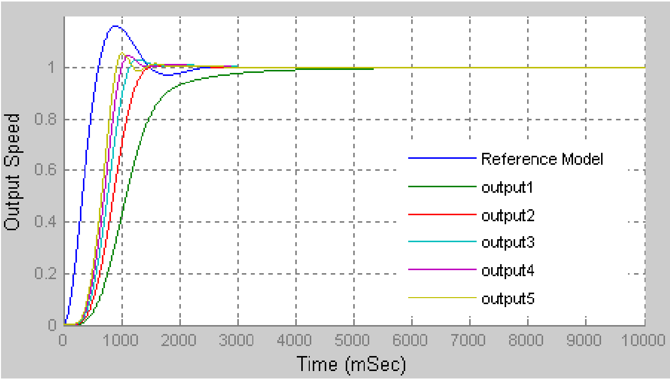

Fig. 4: Output Speed for Different Groups of γ 's

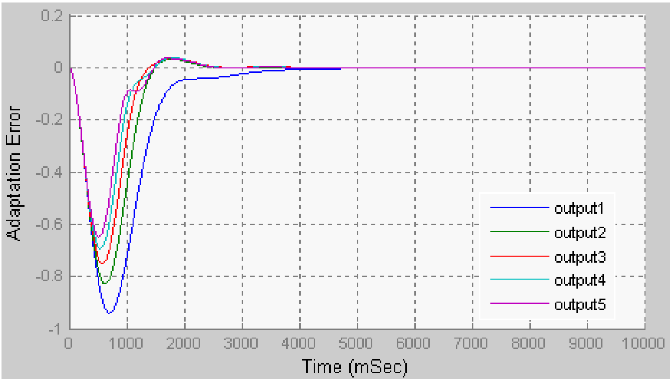

Fig. 5: Adaptation Error for Different Groups of γ 's

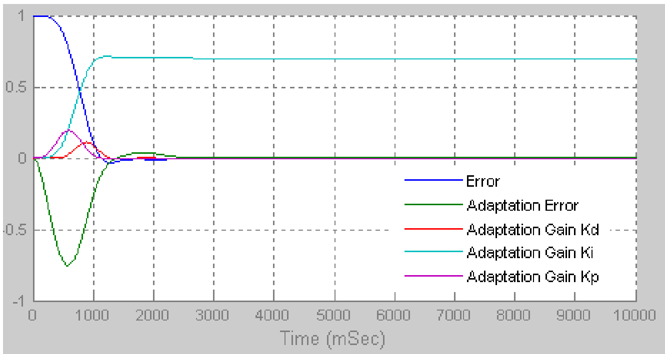

Fig. 6: Error, Adaptation Error and Adaptation PID Gains

As shown in Fig. 4 for low adaptation gains, the actual speed has no oscillation but too much delay, so poor performance. Increasing adaptation gains the output speed response improved towards matching the desired speed value of model reference. The adaptation error is shown in Fig. 5, while Fig. 6 sows the error, adaptation error and adaptation gains for certain group of gammas. As results the MRAPIDC achieves satisfactory performance. The transient performance specifications are shown in table 2. These simulations show that MRAPIDC requires less information of the process at the same time achieves good performances.

Table 2: Characteristic Values for no Load Speed

Specifications	Sets of Gammas				
	1	2	3	4	5
Rise Time (sec)	1.15	0.71	0.54	0.46	0.44
Settling Time (sec)	3.2	1.34	1.46	1.29	1.42
% Max Overshoot	0	1.0	3.8	6.1	8.2

IV. CONCLUSION

From the simulation results, it is found that the MRAPIDC achieves satisfactory performance the output speed response of the DC motor. The adaptation gains are responsible to improve the transient performance of the speed response in terms of rise time, overshoot, settling time and steady-state for step speed response.

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