SPEED CONTROL OF SEPERATELY EXCITED DC MOTOR USING ADAPTIVE PID CONTROLLER

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ABSTRACT

This paper deals with the idea to find perfection for Model Reference adaptive PID Control (MRAPIDC) by providing smooth control to the separately excited DC Motor. The PID controller is integrated with the adaptive observer to simplify the implementations. The output of the system is compared to a desired response from a reference model. The control parameters are updated based on this error. The goal is for the parameters to converge the ideal values to match the response of the reference model.

Keywords----*Separately Excited DC Motor (SEDM), Model Reference Adaptive Control (MRAC), Model Reference Adaptive PID Control (MRAPIDC).*

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I. INTRODUCTION

Direct Current (DC) Motors have been dominating the field of adjustable speed drives for over a century. It is due to their excellent operational properties and control characteristics; hence are used extensibly in variable-speed drives. DC motor can provide a high starting torque and is used to obtain speed control over a wide range.One of the aims of this paper is to present a way of designing an adaptive observer for separately excited DC motor.

II. MODELING OF DC MOTOR

A separately excited Dc motor could be characterized by the following mathematical model[2]:

$$\omega_d = \omega + d_L + d_U \quad (1)$$

$$v_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + e_b(t) \quad (2)$$

$$e_b(t) = K_b \omega(t) i_f(t) \quad (3)$$

$$K_m + I_a(t) = J\frac{d\omega(t)}{dt} + B\omega(t) + T_L \quad (4)$$

$$v_f(t) = R_f\, i_f(t) + L_f \frac{di_f(t)}{dt} \quad (5)$$

Where, $v_a(t)$ is the armature supply voltage (V); $i_a(t)$, the armature current (A); $e_b(t)$, theback emf (V);$v_f(t)$, the field supply voltage (V);$i_f(t)$, the field current (A);R_a , the armature resistance (Ω); L_a, the armature inductance (H); R_f, the field resistance (Ω); L_f, the field inductance (H); T_d(t), the developed torque (Nm); ω(t), the motor speed (rad./s); T_L, the load torque (N-m); J, inertia of the system (kg-m^2); B_m,viscous friction coefficient (Nms); K_b, motor constant. The Simulink Model of DC Motor is shown in figure 1.

On taking Laplace transform of the system differential equations (2)–(5) with zero initialconditions, we may write,

$$I_a(s) = \frac{V_a(s) - E_b(s)}{R_a + sL_a} \quad (6)$$

$$E_b(s) = K_b I_f(s)\omega(s) \quad (7)$$

$$\omega_m(s) = \frac{K_m + I_a(s) - T_L}{B + sJ} \quad (8)$$

$$I_f = \frac{V_f(s)}{R_f + sL_f} \quad (9)$$

From equations (6) and (8) the transfer function of the DC motor with no load torque and uncertainties (d = 0) is obtained from let T_L = 0:

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

First considering the case with only load disturbances $T_L \neq 0$

$$d_L = \frac{-T_L(\frac{R_a}{JL_a}+s(\frac{1}{J}))}{[s^2+\frac{(JR_a+BL_a)}{JL_a}s+\frac{(BR_a+K_mK_b)}{JL_a}]} \quad (10)$$

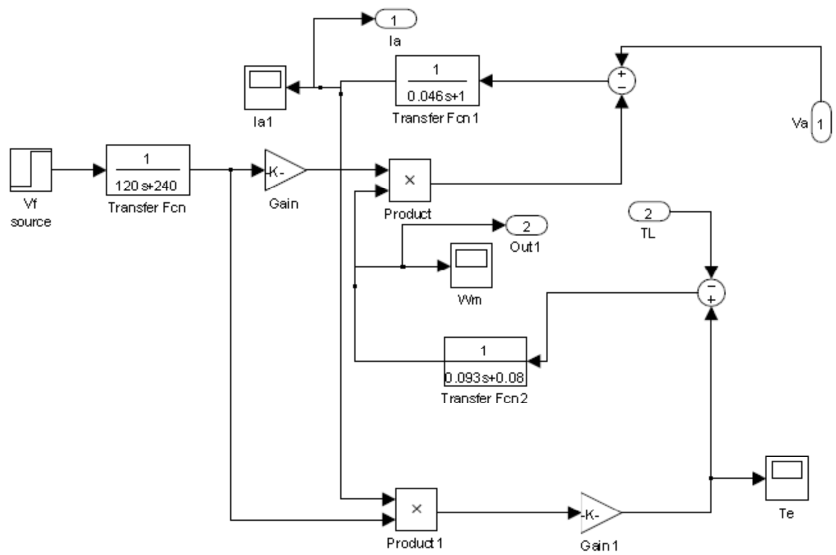

Figure 1: Simulink Model of Separately Excited DC Motor

III. MODEL REFERENCE ADAPTIVE PID CONTROL (MRAPIDC):

The idea behind Model Reference Adaptive Control is to create a closed loop controller with parameters that can be updated to change the response of the system to match a desired model. In Model Reference Control (MRC), a good understanding of the plant and performance requirements it has to meet allow the designer to come up with a model, referred to as the Reference Model, that describes the desired I/O properties of the closed loop plant.

When the plant parameters and the disturbances are slowly or slower than the dynamic behaviour of the plant, then a MARC control is used. The model reference adaptive control scheme is shown in figure 2. The adjustment mechanism uses the adjustment parameter known as control parameter *Θ* to adjust the controller parameters. The tracking error and the adaption law for the controller parameters were determined by MIT Rule [6].

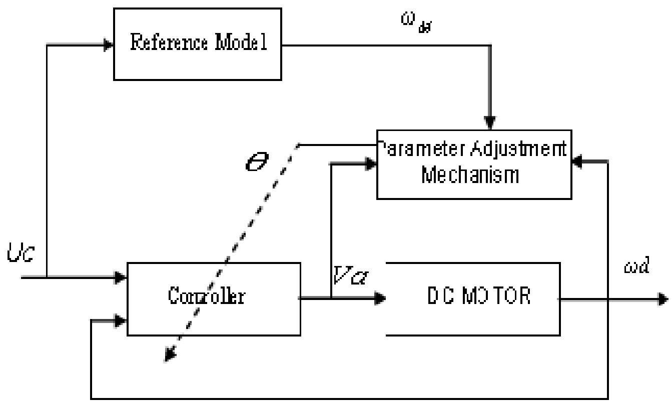

Figure 2: Structure of Model Reference Adaptive Control

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:

$$\frac{d\theta}{dt} = -\gamma\frac{dJ}{d\theta} = -\gamma\varepsilon\frac{d\varepsilon}{d\theta} \quad (11)$$

The adaption error, $\varepsilon = y_p(t) - y_M(t)$. The component of $d\varepsilon/d\theta$ are the sensitivity derivatives of the error with respect to adjustable parameters vector Θ. The parameter γ is known as the adaption gain. The MIT rule is a gradient scheme that aims to minimize the squared model error ε^2 from cost function [1]:

$$J(\theta) = \frac{1}{2}\varepsilon^2(t) \quad (12)$$

The aim is to develop parameter adaption laws for a PID control algorithm using MIT rule.

The reference model for the MRAPIDC 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:

$$H_M(s) = \frac{b_M}{s^2 + a_{M1}s + a_{M0}} (13)$$

Considering the adaption law of MRAPIDC structure as [5]:

$$u(t) = (K_p e(t) + K_i \int e(t)dt - K_d e^*(t) y_p) \quad (14)$$

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. Taking Laplace transform of equation (14) we get:

$$U = (K_p E + \frac{K_i}{s}E - sK_d y_p) \quad (15)$$

After applying this control law to the system it is possible to give the following closed loop transfer function:

$$Y_p = G_p(\left(K_p + \frac{K_i}{s}\right)\left(u_c - y_p\right) - sK_d y_p) \quad (16)$$

Applying MIT gradient rules for determining the value of PID controller parameters ($\dot{K}_p, \dot{K}_i$ and $\dot{K}_d$). The tracking error equation (13) satisfies:

$$\varepsilon = \frac{(G_p K_p s + G_p K_i)U_c}{(s(1+G_p K_p) + G_p K_i + s^2 G_p K_d)} - Y_M \quad (17)$$

Since exact formulas cannot be used instead some approximations are required. An approximation is made valid when parameters are closed to ideal value as follows [8]:

Denominator of plant ≈ Denominator model reference, then gradient method.

$$\frac{dK}{dt} = -\gamma \frac{\partial J}{\partial K_i} = -\gamma (\frac{\partial J}{\partial \varepsilon})(\frac{\partial \varepsilon}{\partial Y})(\frac{\partial Y}{\partial K}) \quad (18)$$

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

Then the approximate parameter adaption laws are as follows:

$$\dot{K}_p = (-\frac{\gamma_p}{s})\varepsilon(\frac{s}{a_0 s^2 + a_{m1} s + a_{m2}})e \quad (19)$$

$$\dot{K}_i = \left(-\frac{\gamma_i}{s}\right)\varepsilon\left(\frac{1}{a_0 s^2 + a_{m1} s + a_{m2}}\right)e \quad (20)$$

$$\dot{K}_d = (\frac{\gamma_d}{s})\varepsilon(\frac{s^2}{a_0 s^2 + a_{m1} s + a_{m2}})Y_p \quad (21)$$

IV. SIMULATION RESULTS:

In this part, some simulation is carried out for MRAPIDC separately excited DC motor controller. Matlab software is used for the simulation of control systems. Figure 3 shows the Simulink models for both MRAPIDC along with the motor under control. The parameters of separately excited DC motor are considered as:

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

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

$$H_M = \frac{16}{s^2 + 8s + 16}$$

This reference model has 16% maximum overshoot, settling time of more than 2 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

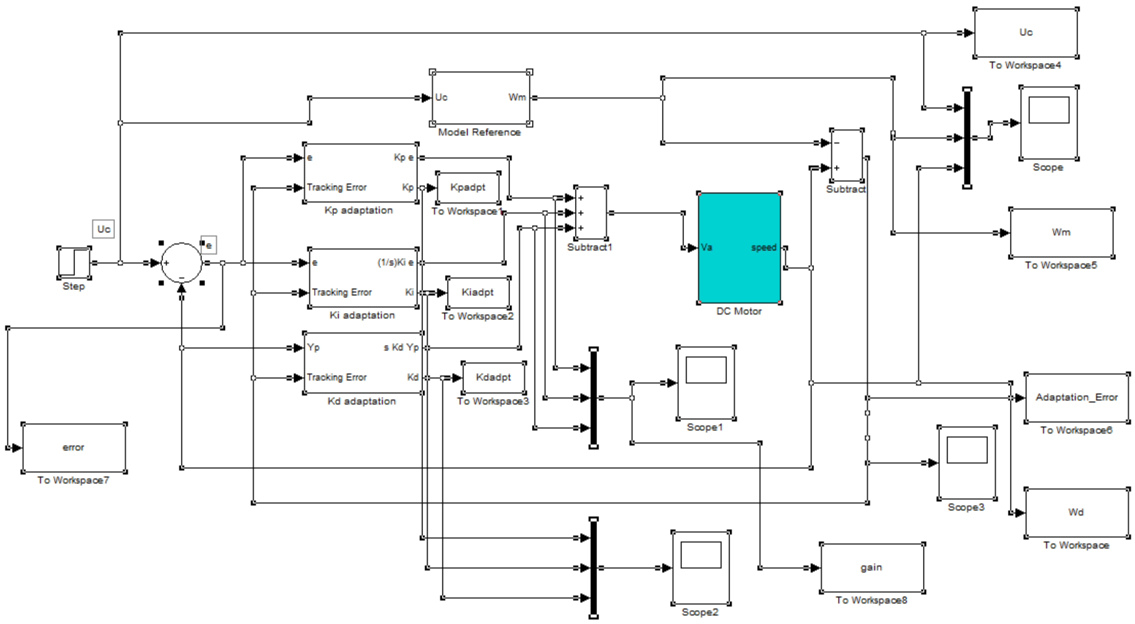

Figure 3: Simulink Model for MRAPIDC

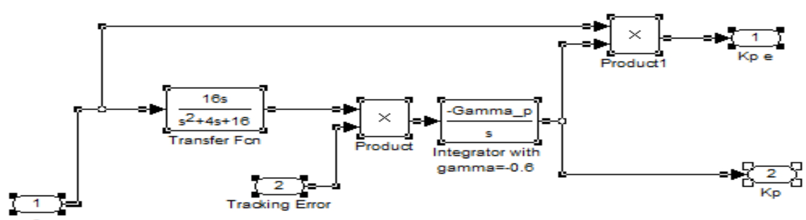

Figure 4: Simulink Model for Proportional Adaption Gain (MIT rule)

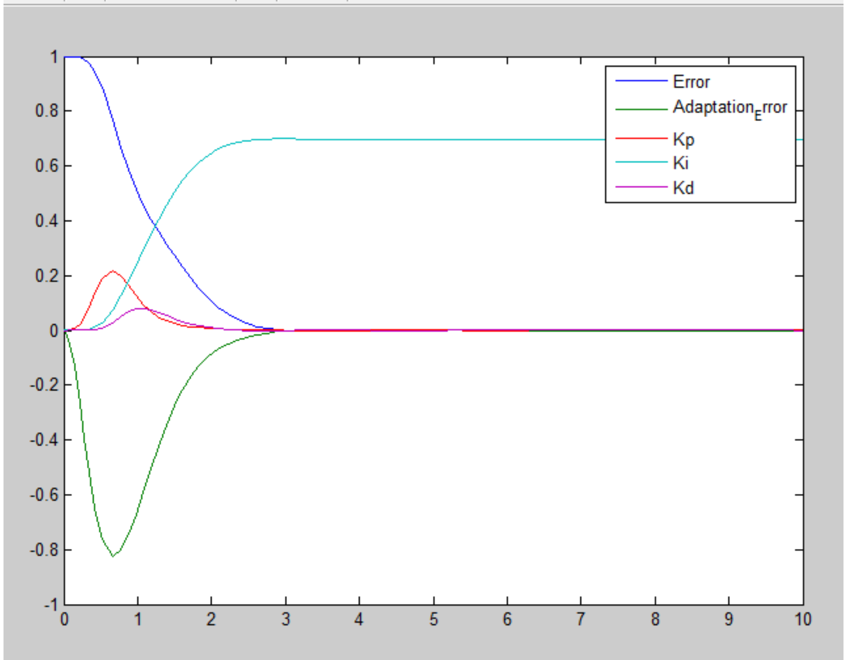

Figure 5: Error, Adaption Error and Adaption PID Gains

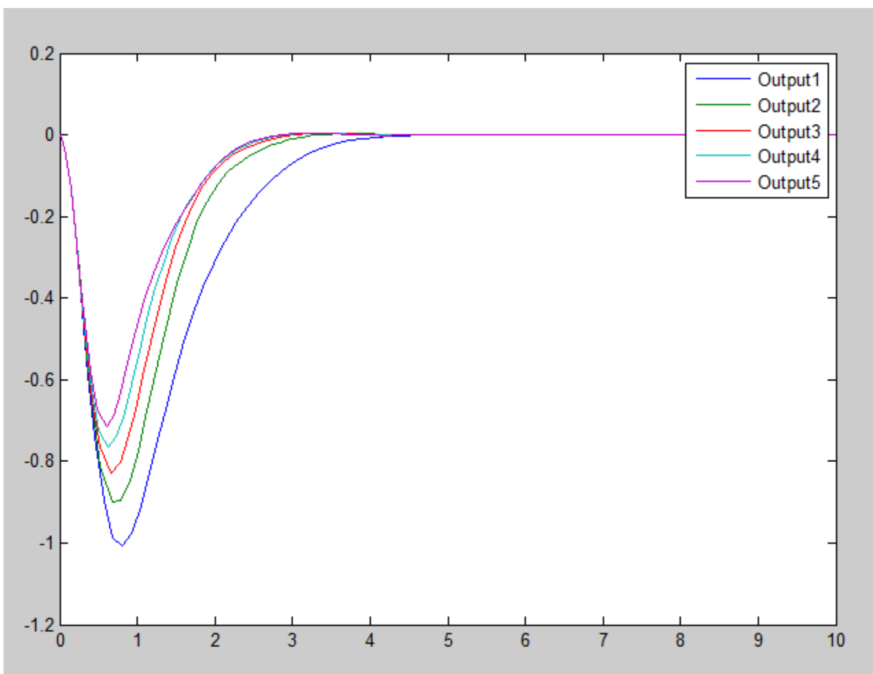

Figure 6: Adaption Error for Different Groups ofγ's

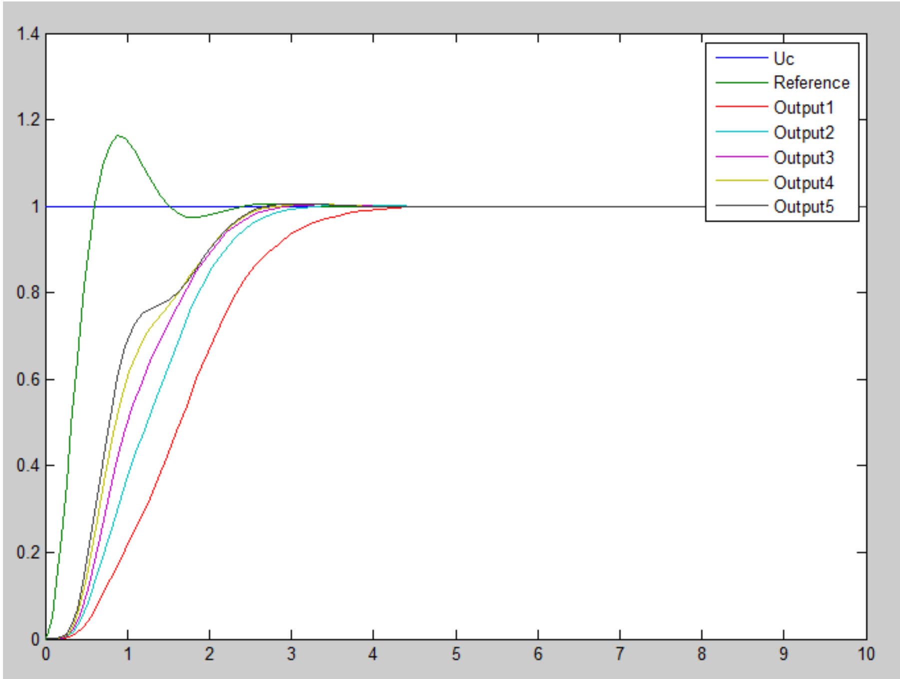

Figure 7: Output Speed for Different Groups of γ's

As shown in figure 7 for low adaption gains, the actual speed has no oscillation but too much delay, so poor performance. Increasing adaption gains the output speed response improved towards matching the desired speed value of model reference. The adaption error is shown in figure 6, while figure 5 shows the error, adaption error and adaption gains for certain groups of gammas. As a result 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	Set 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

V. CONCLUSION:

It is found that the speed control of the separately excited Dc motor is satisfactory by the use of MRAPIDC. MRAPIDC achieves its desired performance and 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

VI. REFERENCES

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