Speed Control of BLDC Motors Using MRAC

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Abstract— *BLDC motors are widely used in various industrial and household applications due to its higher efficiency, reliability and better performance compared to Brushed motor. A speed estimation algorithm based on model reference adaptive control (MRAC) was proposed to correct the speed error. When the parameter of the plant changes with respect to time then the constant gain PI controller action is not effective. In case of MRAC based design the adjustable PI gain parameters corresponding to changes in the plant will be determined by referring to reference model specifying the property of desired control system. This paper presents the method to design MRAC based PI controller for speed control of BLDC motor using Matlab.*

Key words- *MRAC, Adaptive Control, BLDC motor, PI, Matlab.*

1.INTRODUCTION

Brushless dc (BLDC) motors are preferred as small horsepower control motors due to their high efficiency, silent operation, compact form, reliability, and low maintenance. They are also known as electronically commutated motors and are synchronous motors that are powered by a DC electric source via an integrated inverter/switching power supply, which produces an AC electric signal to drive the motor[6]. Adjustable speed drivers control schemes and permanent-magnet brushless electric motor productions have been combined to enable reliable, cost-effective solution for a broad range of adjustable speed applications.

Brushless dc motors usually contain three or more Hall sensors to obtain rotor position and speed measurement. To obtain reliable speed measurement it would be necessary to inverse the time difference between two successive Hall sensor signals. There are only a few sensor signals available to the motor at low speeds. Depend on the number of poles there may be 12 or 24 sensor pulses per round. The sampling time, thus, becomes a variable according to the motor speed. These systems have uncertainty in a discrete time model and have a lot of difficulties to design speed regulators. also, at low speeds the sampling time is too long for speed regulations.[1]

To achieve desired level of performance the motor requires suitable speed controllers. In case of permanent magnet motors, usually speed control is achieved by using proportional integral (PI) controller. Due to their simple control structure and ease of implementation conventional PI controllers are widely used in the industry, these controllers pose difficulties where there are some control complexity such as nonlinearity, load disturbances and parametric variations. In such case the constant gain PI controller cannot satisfy the performance specification. Also PI controllers require precise linear mathematical models. As the PMBLDC machine has nonlinear model, the linear PI may no longer be suitable. In such MRAC (Model Reference Adaptive Control) is a good choice[3].

In the MRAC system the desired performance are given in terms of a reference model and each time an error is generated by comparing actual and desired output and by considering this error , using suitable algorithm the gain expressions of the controller is obtained[3].The MRAS based controller has been designed and tested through various software tool.In this paper an attempt has been made to design and implement the adaptive controller using Matlab.The key problem in MRAC is to determine the adjustment mechanism. There are various adjustment mechanism of MRAC system like MIT rule, Lyapunov theory, passivity theory etc. Here the MIT rule adaption mechanism is used to tune the controller parameter.

2.MODELLING OF BLDC MOTOR

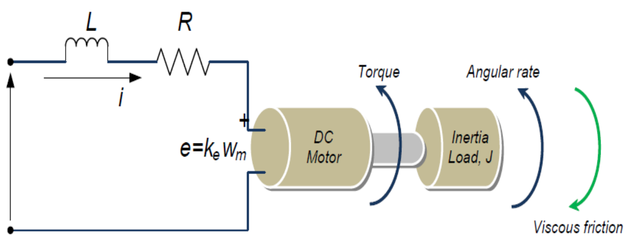

Fig-1.A typical dc motor schematic diagram

Using KVL,

$$V_s = Ri + L\frac{di}{dt} + e \quad (1)$$

$$e = -Ri - L\frac{di}{dt} + Vs \quad (2)$$

Electromagnetic torque,

$$T_e = K_f \omega_m + J\frac{d\omega_m}{dt} + T_L \quad (3)$$

Put $T_e = k_t \omega_m$ and $e = k_e \omega_m$

$$\frac{di}{dt} = -i\frac{R}{L} - \frac{ke}{L}\omega_m + \frac{1}{L}V_s \quad (4)$$

$$\frac{d\omega_m}{dt} = i\frac{k_t}{J} - \frac{k_f}{J}\omega + \frac{1}{J}T_L \quad (5)$$

Take laplace transform,

$$Si = -i\frac{R}{L} - \frac{K_e}{L}\omega_m + \frac{1}{L}V_s \quad (6)$$

$$S\omega_m = i\frac{k_t}{J} - \frac{k_f}{J}\omega + \frac{1}{J}T_L \quad (7)$$

At no load, $T_L = 0$

$$S\omega_m = i\frac{k_t}{J} - \frac{k_f}{J}\omega_m \quad (8)$$

$$i = \frac{S\omega_m + \frac{k_f}{J}\omega_m}{\frac{k_t}{J}} \quad (9)$$

Put eqn.(9) in eqn. (6) we get,

$$\left(\frac{S\omega_m + \frac{k_f}{J}\omega_m}{\frac{k_t}{J}}\right)\left(S + \frac{R}{L}\right) = -\frac{K_e}{L}\omega_m + \frac{1}{L}V_s \quad (10)$$

$$\left(\frac{S^2 J}{K_t} + SK_f + \frac{SRJ}{K_t L} + \frac{K_f R}{K_t L} + \frac{K_e}{L}\right)\omega_m = \frac{1}{L}V_s \quad (11)$$

$$Vs = \left(\frac{S^2 JL + SK_f L + SRJ + K_f R + K_e K_t}{K_t}\right)\omega_m \quad (12)$$

Therefore,

$$T.F = \frac{\omega_m}{V_s} = \frac{K_t}{S^2 JL + (RJ + K_f L)S + K_f R + K_e K_t} \quad (13)$$

By applying some assumptions,

1. K_f tends to zero
2. $RJ >> K_f L_s$
3. $K_e K_t >> RK_f$

T.F will become,

$$G(s) = \frac{\omega_m}{v_s} = \frac{K_t}{s^2 JL + RJS + K_e K_t} \quad (14)$$

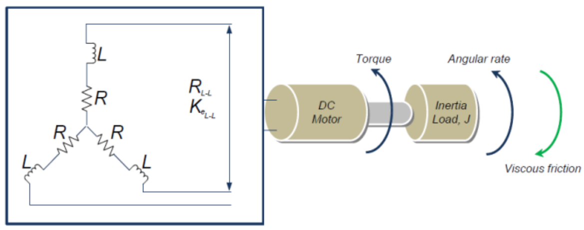

Fig.-2 BLDC motor schematic diagram

Mechanical time constant

$$\tau_m = \frac{3RJ}{K_e K_t} \quad (15)$$

Electrical time constant,

$$\tau_e = \frac{L}{3R} \quad (16)$$

Therefore Transfer function of bldc motor is,

$$G(s) = \frac{1/K_e}{\tau_m \tau_e S^2 + \tau_m S + 1} \quad (17)$$

3. MODEL REFERENCE ADAPTIVE CONTROL

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. The adaptive control theory provides an approach to design of uncertain systems. Adaptive controller adjusts their behavior on-line to the changing property of the controlled processes. MRAC regarded as an adaptive 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. 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 adjustment mechanism uses the adjustable parameter known as control parameter ɵ to adjust the controller parameters[5].

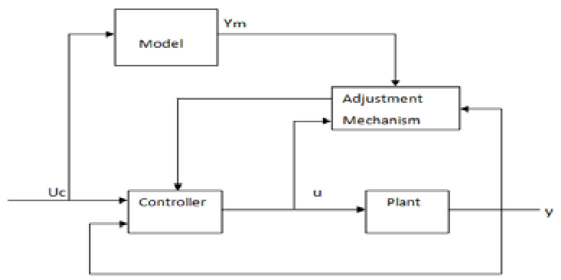

Fig-3 MRAS basic block diagram

The system has an ordinary feedback loop composed of plant and the controller (inner loop) and another feedback loop that changes the controller parameters (outer loop).The parameters are changed on the basis of feedback from error which is the difference between the output of the system and the output of the reference model. The tracking error and the adaptation law for the controller parameters were determined by MIT Rule[3].

3.1 The MIT Rule

The time rate of change of controller parameter vector θ is proportional to negative gradient of J. The MIT rule approach aims to minimize the squared model cost function. Because as the error function becomes minimum there will be perfect tracking between actual plant output (y) and reference model output (y_m). In MRAC it is assumed that the structure of the plant is known although the parameters are not known i.e. the number of poles and zeros are assumed to be known but there locations are not known[4].

3.2 Steps for designing MRAC

First include PI/PID controller in our design so that design becomes MRAPIC/MRAPIDC to kill the oscillations as possible. Define the adaptation error as in,

$$\varepsilon = y_p(t) - y_m(t) \tag{18}$$

where,
y_p is the output of the plant and y_m is the output of the model.
Define the cost function J which will be minimized according to the adaption error,

$$J = \frac{1}{2}\varepsilon^2(t) \tag{19}$$

Define MIT rule which is the time rate of change of that is proportional to the negative gradient of the cost function (J),

$$\frac{d\theta}{dt} = -\gamma\frac{dJ}{dt} = -\gamma\varepsilon\frac{\partial\varepsilon}{\partial\theta} \tag{20}$$

For our design choose the second order transfer function as reference model ie,

$$G_m(s) = \frac{b_{m1}s + b_{m0}}{s^2 + a_{m1}s + a_{m0}} \tag{21}$$

Define the tracking error e for the system as,

$$e = r - y_p \tag{22}$$

So,

$$\frac{de}{dt} = -\frac{dy_p}{dt} \tag{23}$$

Define the control law for the system according to PI controller as,

$$u(t) = k_p e(t) + k_i \int e(t)dt \tag{24}$$

By taking the laplace transform for control law,

$$U(s) = K_p E(s) + \frac{K_i}{s}E(s) \tag{25}$$

After applying this control law to this system the closed loop T.F is,

$$y_p = \frac{G_p K_p r + \frac{G_p k_i r}{s}}{1 + G_p k_p + \frac{G_p k_i}{s}} \tag{26}$$

Solving for y_p in terms of r and substituting in equation (18) the adaptation error become,

$$\varepsilon = \frac{(G_p K_p s + G_p K_i)r}{s(1+G_p K_p) + G_p k_i} - y_m \quad (27)$$

Make extraction of the adaption error ε regarding to the MIT rule for getting kp, and ki.

$$\frac{d\varepsilon}{dk_p k_i} = \frac{dy_p}{dk_p k_i} \quad (28)$$

We can rewrite ε as,

$$\varepsilon = \frac{G_p K_p r + \frac{G_p k_i r}{s}}{1 + G_p k_p + \frac{G_p k_i}{s}} \quad (29)$$

$$\varepsilon = \left(G_p K_p r + \frac{G_p k_i r}{s}\right)\left(1 + G_p K_p r + \frac{G_p k_i}{s}\right)^{-1} \quad (30)$$

Applying MIT rule for obtaining kp,

$$\frac{d\varepsilon}{dk_p} = \frac{G_p r}{1 + G_p k_p + \frac{G_p k_i}{s}} - \frac{G_p\left(G_p K_p r + \frac{G_p k_i r}{s}\right)}{\left(1 + G_p k_p + \frac{G_p k_i}{s}\right)^2} \quad (31)$$

We can Substituting eqn.(26) in eqn. (31), we got,

$$\frac{d\varepsilon}{dk_p} = \frac{G_p r}{1 + G_p k_p + \frac{G_p k_i}{s}} - \frac{G_p y_p}{\left(1 + G_p k_p + \frac{G_p k_i}{s}\right)} \quad (32)$$

After making some arrangements we get,

$$\frac{d\varepsilon}{dk_p} = \frac{G_p E}{1 + G_p k_p + \frac{G_p k_i}{s}} \quad (33)$$

Applying MIT rule for obtaining ki,

$$\frac{d\varepsilon}{dk_i} = \frac{\frac{G_p}{s} r}{1 + G_p k_p + \frac{G_p k_i}{s}} - \frac{\frac{G_p}{s}\left(G_p K_p r + \frac{G_p k_i r}{s}\right)}{\left(1 + G_p k_p + \frac{G_p k_i}{s}\right)^2} \quad (34)$$

We can substitute eqn. (26) in above equation we get,

$$\frac{d\varepsilon}{dk_i} = \frac{\frac{G_p}{s} r}{1 + G_p k_p + \frac{G_p k_i}{s}} - \frac{\frac{G_p}{s} y_p}{\left(1 + G_p k_p + \frac{G_p k_i}{s}\right)} \quad (35)$$

After making some arrangements,

$$\frac{d\varepsilon}{dk_i} = \frac{\frac{G_p}{s} E}{1 + G_p k_p + \frac{G_p k_i}{s}} \quad (36)$$

Because of the exact formula cannot be used so we need valid approximations such that parameters are closed to ideal value as follows,

Denominator of the plant = denominator of model reference

$$den\left(\frac{G_p}{1 + G_p k_p + \frac{G_p k_i}{s}}\right) = s^2 + a_{m1} s + a_{m0} \quad (37)$$

Applying MIT rule for determining adjustment parameters θ_1, θ_2 and they are equal to kp and ki respectively .so regarding the equation (20) , the adjustment parameters are,

$$\frac{d\theta_1}{dt} = \frac{dk_p}{dt} = -\gamma\varepsilon\frac{d\varepsilon}{dk_p} = -\left(\frac{\gamma_p}{s}\right)\varepsilon\left(\frac{s}{a_0 s^2 + a_{m1} s + a_{m2}}\right)e \quad (38)$$

$$\frac{d\theta_2}{dt} = \frac{dk_i}{dt} = -\gamma\varepsilon\frac{d\varepsilon}{dk_i} = -\left(\frac{\gamma_i}{s}\right)\varepsilon\left(\frac{1}{a_0 s^2 + a_{m1} s + a_{m2}}\right)e \quad (39)$$

The parameters of separately excited DC motor are considered as, P=4; Vdc=12v; Km=kb=0.55; Ra=1Ω ; La=0.046H; J=0.093Kgm2; B=0.08Nm/s/rad .

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

$$H_M(S) = \frac{16}{S^2 + 4S + 16} \tag{40}$$

This reference model has 16% maximum overshoot, settling time of more than two seconds and rise time of about 0.75 seconds.

4.SIMULATION USING MRAC

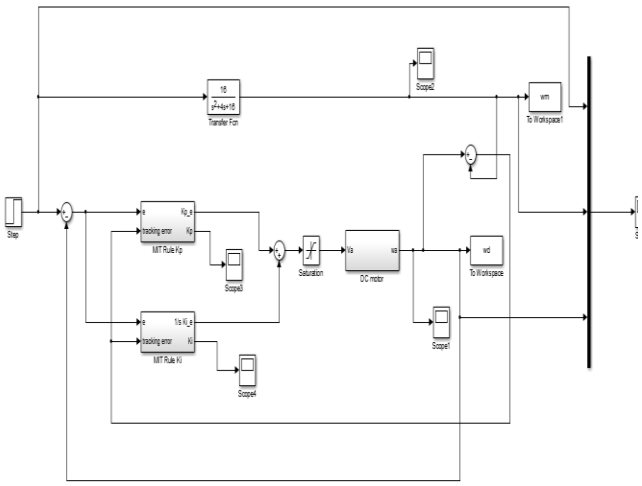

Fig-4 Simulink diagram for BLDC motor used MRAC

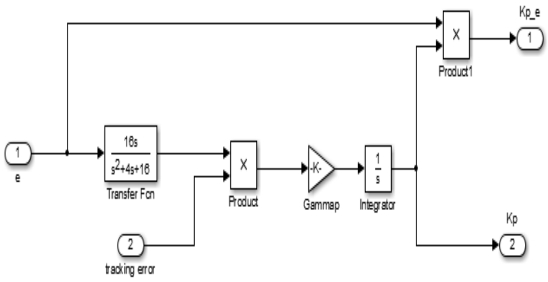

Fig-5 MIT rule for obtaining kp

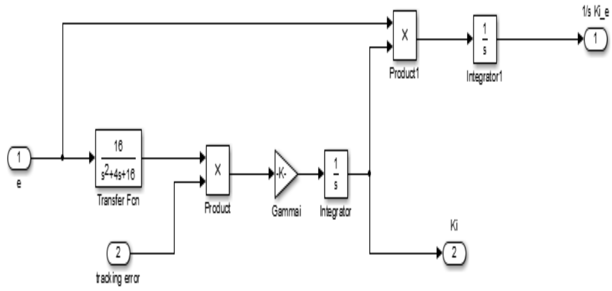

Fig-6 MIT rule for obtaining ki

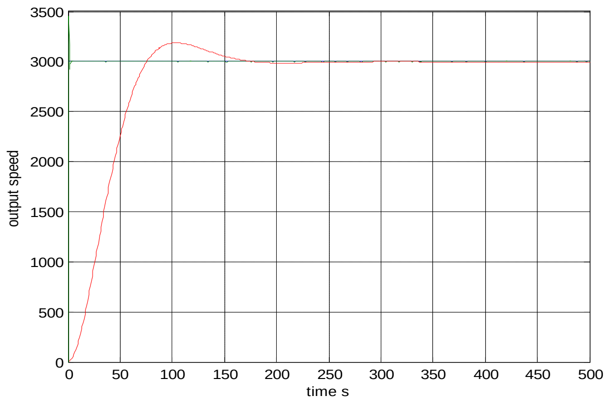

Fig-7 output waveform for a particular γ_1 , γ_2 values

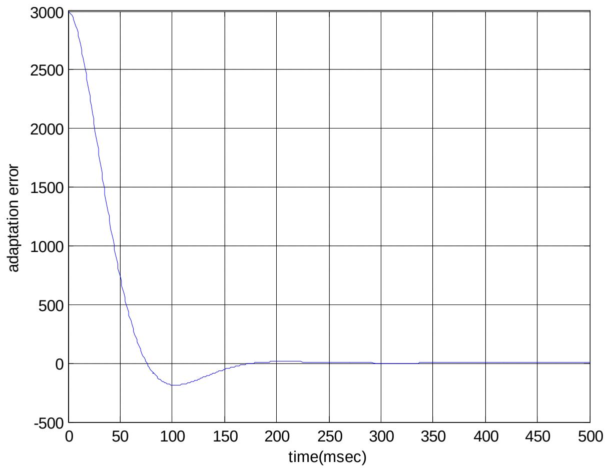

Fig-8 Adaptation error for a particular γ_1 ,γ_2 values

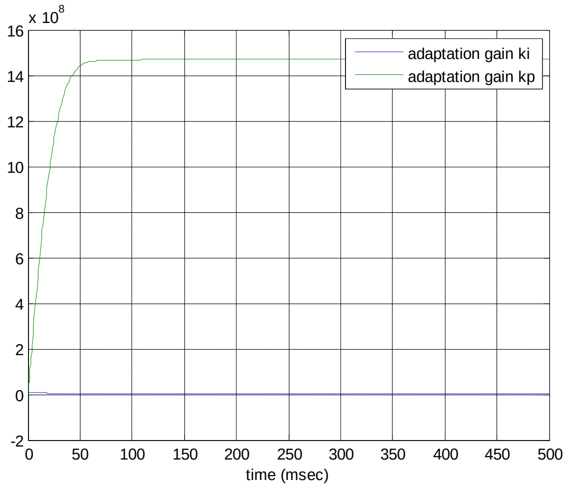

Fig-9 Adaptation gains

Table-1 Output responses for set of γ values

Γ_1	Γ_2	Settling time(s)	% over shoot	Rise time (s)
0.1	0.5	1.785	6.23	0.77
0.5	1	1.78	6.2	0.762
0.8	3.2	1.782	6.3	0.763
1.8	6.4	1.775	6.2	0.76
2	**8**	**1.77**	**6.23**	**0.759**
5	10	1.772	6.24	0.76

5. CONCLUSION

From the simulation results, it is found that the MRAPIC achieves satisfactory performance in the output speed response of the DC motor. The designed PI controller using MRAC scheme for motor can faithfully adjust controller parameters corresponding to change in plant parameters. 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.

REFERENCES

[1]Yang Liu, Jin Zhao, Mingzi Xia, and Hui Luo "Model Reference Adaptive Control-Based Speed Control of Brushless DC Motors With Low-Resolution Hall-Effect Sensors" *IEEE Trans. Power Electronics,* vol. 29, no. 3, March 2014.

[2] A.Taifour Ali, Eisa Bashier M. Tayeb and Omar Busati alzain Mohd "Adaptive PID Controller for Dc Motor Speed Control" *International Journal of Engineering Inventions* Volume 1, Issue 5, PP: 26-30,September2012.

[3] Sumit kumar sar, Lillie dewan "MRAC Based PI Controller for Speed Control of D.C. Motor Using Lab View" *WSEAS Transactions on Systems and Control,* E-ISSN: 2224-2856, Volume 9, 2014.

[4]Narendra, K.S. and A.M. Annaswamy; Stable Adaptive System: Dover Publication,2005.

[5] Richa Papdeja , P.Sankala "Modelling and Simulation of Three Phase Brushless DC Motor With Using Model Reference Adaptive Controller" *International Journal of Inventions in Computer Science and Engineering, ISSN (Online): 2348 – 3539,* Volume 1 , Issue 3 ,2014.

[6] Microchip Technology Incorporated 2003, padmaraja Yedamale, "Brushless DC motor fundamentals"

[7]Vinod KR Singh Patel, A.K.Pandey "Modeling and Performance Analysis of PID Controlled BLDC Motor and Different Schemes of PWM Controlled BLDC Motor" *International Journal of Scientific and Research Publications,*
ISSN 2250-3153, Volume 3, Issue 4, April 2013.

[8] Harith Mohan, Remya K P, "Modeling and Control of DC Chopper Fed Brushless DC Motor" *International Research Journal of Engineering and Technology (IRJET),* Volume: 02 Issue: 03 ,June-2015

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