Prosiding Konf Internasional ICEE Motor DC

by Alimuddin Alimuddin

DC Motor Speed Control Based on Fuzzy Adaptive with Fuzzy Model Reference Learning Control (FMRLC) Algorithm

Masjudin
Department of Electrical Engineering
University of Sultan Ageng Tirtayasa
Cilegon, Indonesia
masjudin@untirta.ac.id

Alimuddin
Department of Electrical Engineering
University of Sultan Ageng Tirtayasa
Cilegon, Indonesia
alimuddineeuntirta@yahoo.com

Siti Nur Aisah
Department of Electrical Engineering
University of Sultan Ageng Tirtayasa
Cilegon, Indonesia
sn.aisah@gmail.com

Romi Wiryadinata
Department of Electrical Engineering
University of Sultan Ageng Tirtayasa
Cilegon, Indonesia
wiryadinata@untirta.ac.id

***Abstract*—Fuzzy Model Reference Learning Control (FMRLC) is a control technique developed by extending several self-organizing linguistic control concepts and utilizing ideas from the conventional Model Reference Adaptive Control (MRAC) method. FMRLC in this study is used to control the speed of a DC motor. FMRLC testing is performed on the step response, set point with a constant value, tracking setpoint, and torque load. The test results show the adaptive fuzzy control system with the FMRLC algorithm to control a DC motor's rotation speed can be well designed, proven by simulating the FMRLC control system using MATLAB. The performance of the FMRLC control system that has a design to control the rotation speed of a DC motor at a set point of 3000 rpm without load includes: delay time = 0.0681 seconds, rise time = 0.2279 seconds, setting time = 0.3863 seconds. For DC motors at 3000 rpm, setpoint load ½ torque raises a steady-state error of 0.0207%, with a max torque load resulting in a steady-state error of 0.0413% and when given a load of 2x maximum torque produces a steady-state error of 0.0818%, with each of the following sequential recovery times 0.6457 seconds 0.7939 seconds and 0.7532 seconds.**

***Index Terms*—FMRLC, speed, DC motor, MATLAB**

I. Introduction

Controlling the speed of a DC motor becomes essential to optimize the performance of the actuator. Motor speed parameters can control well indicated by a transient response that lasts briefly, and the steady-state error is getting smaller.

Fuzzy Model Reference Learning Control (FMRLC) is a combination of the Fuzzy Logic Control (FLC) method and the Model Reference Adaptive Control (MRAC) / Model Reference Adaptive System (MRAS). The advantages of FMRLC include an increase in convergence, more efficient control energy, increasing the nature of interference rejection, and reducing dependence on mathematical models [1].

FMRLC has three main parts: fuzzy controllers, reference models, and learning mechanisms (adaptation mechanisms) [2] The fuzzy controller will produce a control signal based on the difference between the reference model's output and the plant output as a measure of performance for the whole process.

II. Research Method

A. FMRLC For DC Motors

The design of DC motor speed control uses Simulink with an input in the form of speed (rpm) and produces an output in a control signal format [3]. Two inputs enter the fuzzy controller, namely, error and error change. The output variable generated from the fuzzy controller is the consequent linguistic value associated with the rules set for Fuzzy Logic Control (FLC) and the Fuzzy Inverse Model (FIM). The formation of the FMRLC algorithm is carried out through several stages, as shown in Fig. 1.

B. Plant Identification

The plant used in this study is a permanent magnet DC motor with the brand Maxon A-max 32 Series type 118740. Based on the datasheet, the values obtained are as shown in Table I [4].

TABLE I
DC Motor Specifications

Machine Data	Value
Resistance in the terminal (Ra)	0.261 ohm
Inductance in the terminal (la)	0.0275 mH
Moment of motor inertia (J)	11.6 gcm2
Torque constant (Ka)	8.00 mNm/A
Speed/gradient torque(f)	39.0 rpm/mNm

Plant identification is obtained based on DC motor modeling; the motor specification data enters into the DC motor

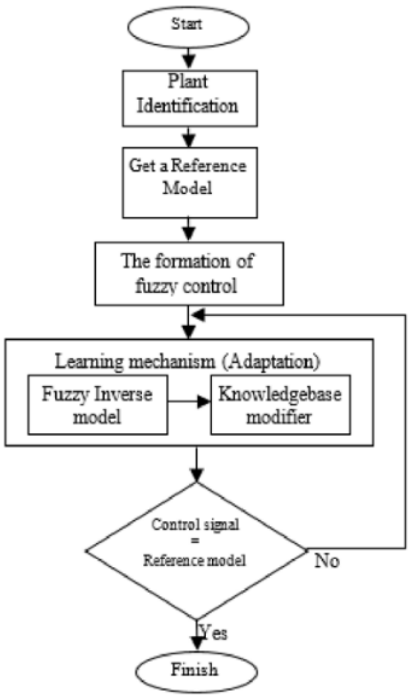

Fig. 1. Flow Chart Formation of the FMRLC Algorithm.

mathematical model equation (1). The mathematical model values were received to use as plant transfer functions for each test performed.

$$G(s) = \frac{\omega(s)}{E_a} = \frac{K_a}{(L_a.J)s^2+(L_a.f+R_a J)s+R_a.f+K_a+K_b} \quad (1)$$

C. Reference models

The system reference model is designed using a time response approach, where motor modeling is done using first-order system identification. The approaching model or system reduction model can be stated in equation (2). There is a situation where the steady-state response does not reach its reference value in the first-order system response. Based on the steady-state error equation, if the input is a step voltage, the steady-state error is shown in equation (3). For zero steady-state errors, the value of b is equal to a; then, this criterion is used in determining the reference model. The steps were taken by researchers to get the value of the reference model to follow the way done by Ilman [5].

$$\frac{C(s)}{R(s)} = \frac{1}{\tau_s + 1} \quad (2)$$

$$ess = 1 - \frac{b}{a} \quad (3)$$

D. Fuzzy Logic Control

The fuzzy logic design in this study uses the MAMDANI method, which is often referred to as the min-max method, namely, the process of implication is selected as the minimum method, and the aggregation process is chosen as the maximum method [6]. The defuzzification process uses the centroid method.

III. RESEARCH RESULT

A. Fuzzy Inference System Results in FMRLC control

Fuzzy Inference System (FIS) is knowledge of the system's workings that is transferred into the software (MATLAB) to then map an input into an output based on the given IF-THEN rule [7]. In the system built in this study, there are 2 FIS, including the FIS basic rules of the Fuzzy Logic Control (FLC) controller shown in Fig. 2 and FIS for the Fuzzy Inverse Model (FIM) shown in Fig. 3 [8].

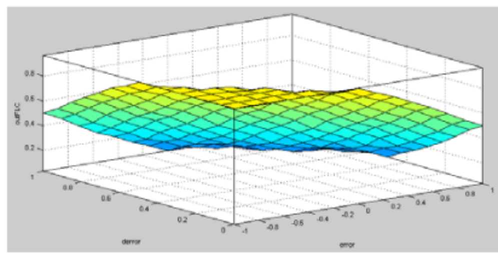

Fig. 2. FIS for Fuzzy Logic Control.

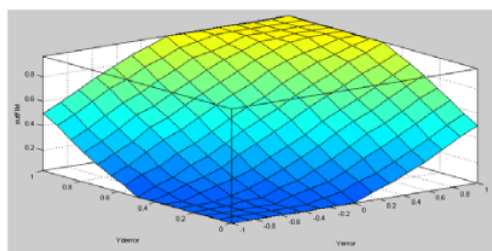

Fig. 3. FIS for Fuzzy Inverse Model.

B. Results of FMRLC Design

The Fuzzy Model Reference Learning Control algorithm's design is based on the control principle that the input signal is the same as the output signal. It starts by identifying the object to be studied in the form of a DC motor, which is then referred to as a plant, then makes a reference model for the plant followed by making a fuzzy logic control and finally forming a learning mechanism by building a fuzzy inverse model and modifying the knowledge base. The results of FMRLC without load design are shown in Fig. 4.

For the design of FMRLC with the addition of loads can be seen in Fig. 5. The design of FMRLC with this load was

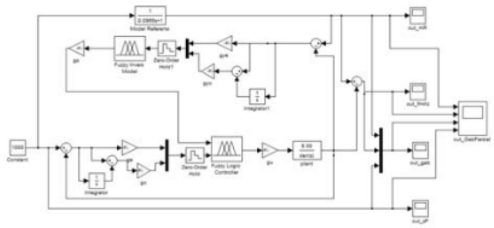

Fig. 4. FMRLC Design Results with No Load.

made to determine the presence of controls designed on the system. The addition to the load is based on the DC motor torque load.

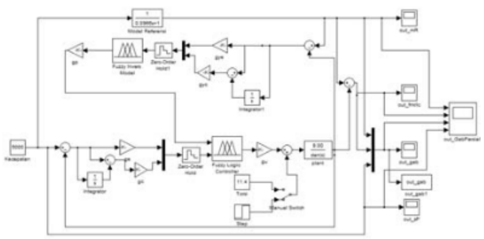

Fig. 5. FMRLC Design Results with Load.

C. Test result

The design of the Fuzzy Model Reference Learning Control (FMRLC) that has been generated in the form of Simulink is then performed several tests, including testing of the step signal, testing of the setpoint, testing of the tracking setpoint, and testing of the load. Here are a few examples.

Fig. 6 shows the results of testing the 3000 rpm setpoint without a load. By observing the output of the set point 3000 test results, it is found that the fixing time (ts) = 0.3863 seconds, rising time (tr) = 0.2279 seconds, and delay time (td) = 0.0681 seconds for the reference model output and the output FMRLC produces the same transient response that is the time of determination = 0.3863 seconds, the rise time = 0.2279 seconds and the delay time = 0.0681 seconds.

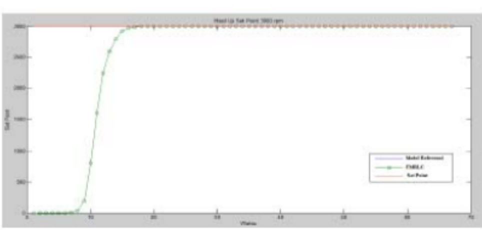

Fig. 6. 3000 rpm SetPoint Test Results with No Load.

The next test is testing the load at a set point of 3000 rpm with half load maximum torque load testing, maximum torque, and 2 times maximum torque with each of the magnitude of 5.7 mNm, 11.4 mNm, and 22.8 mNm. Fig. 7 shows that giving ½ maximum torque load from second to second to 15.905 affects the setpoint achievement before a steady-state load occurs at a speed of 3000 rpm, whereas after a load is given, the steady-state achievement at a speed of 2999,3771 rpm. Based on these differences, it can be seen the magnitude of the steady-state error is 0.02076333%.

Fig. 7. Load Test Results ½ Maximum Torque with SetPoint of 3000 rpm.

If Fig. 7 is enlarged, you can clearly see the recovery process from the burden condition. Recovery time occurs from 15.2593 seconds to 15.905 seconds; this means that the recovery time is 0.6457 seconds. This recovery process is shown in Fig. 8.

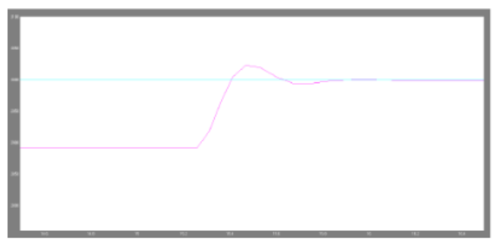

Fig. 8. Load Recovery ½ Max Torque At SetPoint 3000.

The results of testing the load with maximum torque at the set point of 3000 rpm are shown in Fig. 9. The load is given during steady-state until the second to 22.7939. Achievement of the steady-state set point changed from a speed of 3000 rpm to 2998.76 rpm. Based on these changes, the steady-state error can be calculated, amounting to 0.041333333%.

Based on Fig. 10, it can be seen that the maximum torque load recovery at the set point of 3000 rpm occurs in the 22nd second to the 22.7939 seconds. This means that the time needed for recovery is 0.7939 seconds.

Testing the load at the 3000 rpm set point, the last one is giving a maximum load of 2 x torque that is equal to 22.8 mNm. The test results are shown in Fig. 11. Based on Fig. 12, it can be seen that the setpoint reduction decreased from 3000 rpm to 2997,547 rpm, so the steady-state difference is 0.081766667%.

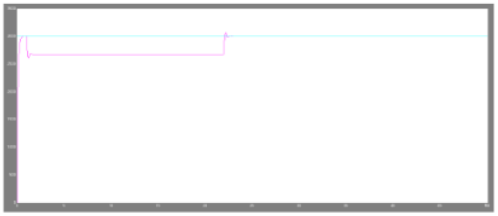

Fig. 9. Maximum Torque Load Test Results At 3000 rpm SetPoint.

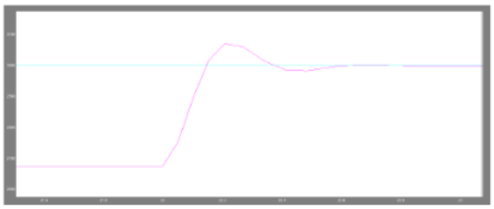

Fig. 10. Maximum Torque Load Recovery at a Set Point of 3000 rpm.

The recovery of maximum torque load at set point 3000 rpm is shown in Fig. 12. Based on this picture, it can be seen that recovery occurs in the range of seconds from 14.5022 to 15 seconds, 2554, so that it can be seen that the time needed to restore stability is 0, 7532 seconds.

With the trial and error method and the PID controller approach [2] for the best results, the values are:

ge = 0,1375

gc = 0,0286802889

gu = 0,02704250948

gye = 0,1375

gyc = 301,3

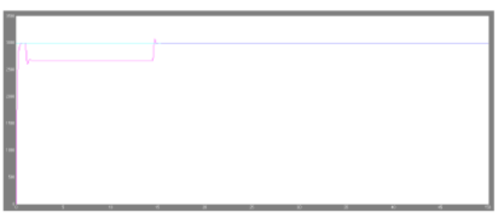

Fig. 11. Load Test Results 2x Maximum Torque At 3000 rpm SetPoint.

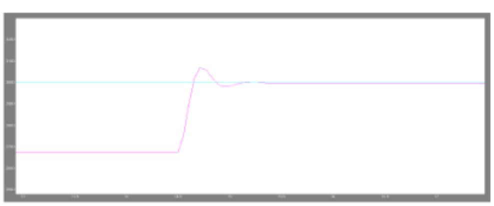

Fig. 12. Maximum Load Recovery 2x Torque At 3000 rpm SetPoint.

gp = 0,02704250948

Table II. is the result of the no-load test. Based on this table, it can be seen that the performance of FMRLC as a control algorithm used in the research has been successfully applied. The results obtained from testing in the form of settling time Ts, rise time Tr, delay time Td, and the amount of error or the difference between the output of the reference model with the output of Fuzzy Model Reference Learning Control (FMRLC), which is seen from the achievement of the setpoint when conditions are steady-state. From this table, it can be seen that there is no difference in error between the reference model and the FMRLC control. For the reading of the determination time (ts), the rise time (tr) and the delay time (td) are done on a unit scale of seconds.

TABLE II
PERFORMANCE TEST RESULT WITH NO-LOAD

Type of test		Reference Model			FMRLC			% error
		Ts	Tr	Td	Ts	Tr	Td	
Step		1.3	1.23	1.06	1.3	1.23	1.06	0%
Setpoint is speed (rpm)	1000	0.3852	0.2247	0.0696	0.3852	0.2247	0.0696	0%
	3000	0.3863	0.2279	0.0681	0.3863	0.2279	0.0681	0%
	5000	0.3852	0.2247	0.0696	0.3852	0.2247	0.0696	0%
	7000	0.3826	0.2248	0.0702	0.3826	0.2248	0.0702	0%
	9000	0.3850	0.2270	0.0698	0.3850	0.2270	0.0698	0%

Table III. summarizes the test results with the load is seen based on the value of the Simulink design performance shown in table III. Based on the table, it can be seen that the value of the load given is proportional to the magnitude of the error generated. The greater the load is given, the greater the steady-state error. With the condition of increasing the load, FMRLC is still able to follow the reference model even though there is a set point error. The smaller the load is given, the resulting difference is even smaller, and for large loads, the difference is also large, so the magnitude of the load given is proportional to the magnitude of the error produced. The results of this test prove that the learning system built-in FMRLC has been successfully implemented.

Based on the testing of disturbance in stable conditions, it can be analyzed that FMRLC control is able to adapt to the disturbance that occurs. Although there is a decrease in speed, but these conditions can be immediately returned to stable conditions to a steady-state with a relatively short recovery time that is in the range of 0.6-0.84 seconds.

CONCLUSION

Based on the results of simulation and analysis, it can be concluded that:

1. Adaptive fuzzy control system with FMRLC algorithm to control the rotation speed of DC motors can be well designed proven by simulations in the MATLAB software that FMRLC output can follow the reference model output very well.

2. FMRLC control is the best control compared to MRAS or Fuzzy PID, this is evidenced by the FMRLC transient response which is faster than the other two methods and FMRLC is able to adapt to the disturbance.

TABLE III
LOAD TEST RESULT

Type of test		Steady-State error percentage (%)	Recovery time (second)
Setpoint 1000 rpm	½ maximum torque	0.062109999	0.0696
	Maximum torque	0.121289999	0.68
	2x maximum torque	0.24356	0.6886
Setpoint 3000 rpm	½ maximum torque	0.02076333	0.6457
	Maximum torque	0.041333333	0.7939
	2x maximum torque	0.08176666	0.7532
Setpoint 5000 rpm	½ maximum torque	0.0116	0.8405
	Maximum torque	0.0246	0.6273
	2x maximum torque	0.05	0.8222

REFERENCES

[1] R. Jeffery and Kevin M. Passino, "Fuzzy Model Reference Learning Control for Cargo Ship Steering", IEEE Control System Magazine, Vol.13, No. 6, pp.23–34.
[2] Aly, Ayman and Ohuchi, Hidetoshi and Abo–Ismail, Ahmed, "Fuzzy Model Reference Learning Control for Positioning An Electro-Hydraulic Servo System", Transactions of The Japan Fluid Power System Society. Vol. 34, pp. 66–71, doi. 10.5739/jfps.34.66.
[3] Raju MMSSN Penimosowa, K. Chandra Sekhar, "Model Reference Adaptive Control for DC Motor and Induction Motor Drive", International Journal and Magazine of Engineering, Technology, Management, and Research. Vol. 5, Issue No. 9, page. 52–60.
[4] A. Maxon Datasheet, https://www.maxongroup.com/maxon/view/product/118740.
[5] Ilman, Bahri. 2012. DC Motor Speed Controller Analysis Using Model Reference Adaptive System (MRAS). Cilegon. UNTIRTA
[6] Kusumadewi, Sri., ect. 2006. Fuzzy Multi–Attribute Decision Making (Fuzzy MADM). Yogyakarta: Graha Ilmu.
[7] Agus Naba. Learn Fuzzy Logic Fast Using Matlab. Yogyakarta : Andi
[8] J.-S.R Jang, C.–T Sun dan E. Mizutani. 1997. Neuro-Fuzzy and Soft Computing. USA: Prentice Hall International, Inc.

Prosiding Konf Internasional ICEE Motor DC

ORIGINALITY REPORT

11%	6%	9%	3%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	idus.us.es Internet Source	3%
2	ijeee.edu.iq Internet Source	1%
3	mafiadoc.com Internet Source	1%
4	Bahareh Ahkami, Kirstin Ahmed, Alexander Thesleff, Levi Hargrove, Max Ortiz-Catalan. "Electromyography-based control of lower limb prostheses: a systematic review", Institute of Electrical and Electronics Engineers (IEEE), 2022 Publication	1%
5	sami muhaidat. "Intelligent Reflecting Surfaces Assisted UAV Communications for IoT Networks: Performance Analysis", Institute of Electrical and Electronics Engineers (IEEE), 2021 Publication	1%
6	1451-4869, 2008 Publication	1%

7	J.R. Layne, K.M. Passino, S. Yurkovich. "Fuzzy learning control for antiskid braking systems", IEEE Transactions on Control Systems Technology, 1993 Publication	1 %
8	Ali Mohamed Elmelhi. "Fuzzy sliding adaptive control", 2010 International Conference On Computer Design and Applications, 2010 Publication	<1 %
9	Daijian Ling. "Fuzzy Model Reference Learning Control for a Nonlinear Model of Hydrogenerator Unit", 2009 International Workshop on Intelligent Systems and Applications, 05/2009 Publication	<1 %
10	L. Zhen, L. Xu. "Fuzzy learning enhanced speed control of an indirect field-oriented induction machine drive", IEEE Transactions on Control Systems Technology, 2000 Publication	<1 %
11	Rusdhianto Effendie, Eka Iskandar, Mochammad Rameli, Irfan Syuhudi. "Study and Design of Self-Adaptive Pid-Fuzzy Control on Multistage Steam Turbine Rotation Setting", 2018 International Seminar on Intelligent Technology and Its Applications (ISITIA), 2018 Publication	<1 %

12	www.jstage.jst.go.jp Internet Source	<1 %
13	www.scirp.org Internet Source	<1 %
14	Kovacic, . "Self-Organizing Fuzzy Controllers", Automation and Control Engineering, 2005. Publication	<1 %
15	Lecture Notes in Computer Science, 2009. Publication	<1 %
16	W.A. Kwong. "Dynamically focused fuzzy learning control", IEEE Transactions on Systems Man and Cybernetics Part B (Cybernetics), 1996 Publication	<1 %

Exclude quotes	On	Exclude matches	< 5 words
Exclude bibliography	On		