A Dynamic Input Membership Scheme for A Fuzzy Logic DC Motor Controller

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Abstract- **Conventional fuzzy logic controller uses input membership functions that consist of identical triangular input membership functions (MF) for all the subsets that are not located at the two ends of the universal set (center width constant or CWC). Some researchers in the field of motor controllers have started using narrower base triangular membership functions for the input subsets that are located at the center of the universal set and wider base triangles towards the two ends of the universal set (center width narrow or CWN). This new approach has proved to enhance the performance of the controller. This paper proposed a dynamic input membership function scheme which combines the center width narrow and the center width constant scheme together with a new scheme where the center triangular input membership functions has a wider width than those that are located more towards the two ends of the input universal set (center width wide or CWW). The dynamic input membership scheme (DIMS) applies CWN, CWC and CWW at different stages of the transient states of the controller step response to achieve a superior step response for a DC motor controller as compared to applications of only one type of input membership functions throughout the controller operation. Matlab simulation studies have been done to confirm the improved performance of the dynamic input membership functions as compared to the other schemes commonly employed.**

I. INTRODUCTION

Ever since the introduction of fuzzy logic concepts by Lofti Zadeh in 1965 [1,2] and E.H.Mamdani introduced the application of fuzzy algorithms for developing Fuzzy Logic controllers (FLC) [3,4]; Fuzzy Logic has emerged as one of the most active topics of research in the area of dc motor drives application.

Fuzzy Logic controllers have some advantages compared to classical controllers such as the simplicity of control, complexity of non-linear system and ability to design without the accurate and precise mathematical model [5,6]. A lot of sophisticated adaptive Fuzzy Logic Controllers such as self-tuning and self-organizing Fuzzy-PI and Fuzzy PD controllers have been developed and implemented for various applications. Motor speed error and armature current error are often taken together with the change of errors as the fuzzy input to determine the suitable gains (PI or PD) in order to achieve fast speed regulation (with minimum overshoot, fast rise and settling time) while maintaining inrush current at a preferring level. [7-13]. Most of the conventional FLC uses input membership functions that consist of identical triangular input membership functions. Some other researchers use triangular with narrow width near the origin to provide increased sensitivity around the steady state condition. On the other hand, the wider width triangular at the two ends of the universal set plays the role of containing the starting inrush current of the DC motor [14].

This paper includes a new scheme called "dynamic input membership scheme (DIMS)" for not only fast speed and current regulation, but also minimizing the chattering around the set point.

II. DC MOTOR DRIVE SYSTEM

The converter used is the most common single switch (GTO), single diode type electronic controller for DC motor as shown in Fig.1.

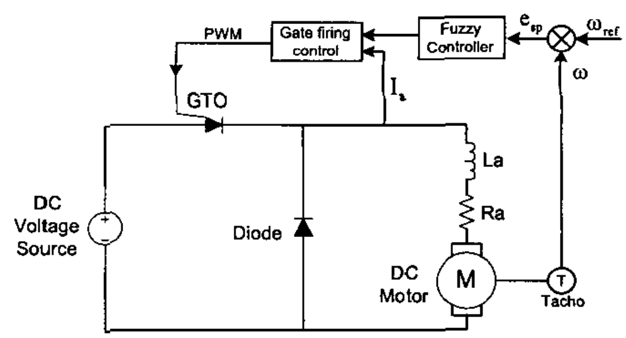


Fig.1

The switch is turning on and off thus producing a chopped voltage across the dc motor. In continuous conduction, the armature circuit equations can be given as follows:

$$V_a = \frac{t_{on}}{T} V_t \quad (1)$$

$$I_a = \frac{V_a - E_c}{R_a} \quad (2)$$

$$\omega = \frac{1}{K_E}\left(V_t - \frac{R_a}{K_T} T_{em}\right) \quad (3)$$

where,

V_a= armature voltage R_a = armature resistance
t_{on}= duration of pulses E_c= back EMF
T = period K_E=Voltage constant
V_T = dc voltage source I_a = armature current
T_{em}= Electromagnetic torque

III. DESIGN OF FUZZY LOGIC CONTROLLER

Fuzzy Logic, the logic of approximate reasoning, is an innovative technology that enables users to describe a desired system behavior using everyday spoken language. In general, a FLC consists of a set of linguistic statements which define a set of control protocol relating the control conditions to control actions by "If –then" rules. It uses membership functions to define the degree to which crisp physical values belong to terms in a linguistic variable set.

The FLC consists of mainly three basic components, namely the Fuzzification, Fuzzy Engine (rule base) and Defuzzification. The Fuzzification transforms the analog input signal into linguistic fuzzy variable in between 0 and 1. The fuzzy engine handles rule inference where the variables are articulated in the "If-then" rules. The Defuzzification transform the fuzzy control actions to continuous signal that can be apply to the system. Motor speed is picked up and the speed error (e_{sp}) is determined by subtracting the motor speed from its reference speed (ω_{ref}).

$$e_{sp} = \omega_{ref} - \omega \qquad (4)$$

The error of the speed are properly scaled and then converted into linguistic variables. The degree to which the crisp value belongs to a linguistic variable set (fuzzy set), or the degree to which a linguistic variable is true. The scale of 0 to 1 represents the degree of membership. 0 being totally untrue and 1 being totally true. The following linguistic variables are used for the input variable:

PB = Positive Big   NB = Negative Big   Z = zero
PS = Positive Small   NS = Negative Small

The universe of discourse for the input membership functions is shown in Fig 2,3 and 4. The output data of the fuzzy controller is the dc reference voltage that is used to generate the PWM and its duty cycle. The derivation of the fuzzy control rules is based on the following criteria:

1) If the output is far from the set point, duty cycle change must be large to bring the output to the set point.
2) If the output is approaching the set point, the change is rather small.
3) If the set point is reached and output is steady, the duty cycle remains unchanged.

The defuzzification method used is the Center of Gravity (Centroid) method. It is one of the most commonly used defuzzification strategies in the design of FLCs. The inferred value of the control action is given by

$$u = \frac{\sum m_i T_i}{\sum T_i} \qquad (5)$$

where m_i are the singletons and T_i are the corresponding degree of fulfillment.

In this paper, three types of membership functions are used in the DIMS. CWN membership function with the width narrow near the origin is used for the purpose of having minimum current overshoot. In the initial start-up duration, the inrush current is tend to be high due to the natural high torque characteristic of DC motor (especially series motor). The degree of validity is located near the end of the universal set and the change of validity is rather small hence the inrush current can be maintained in a desire level.

The center-width constant (CWC) membership function is use when the step response is getting close in reaching the set point for the optimum regulation for both speed and current. The PWM duty cycle is almost in the 50% region and the armature current is rapidly decline to its steady state condition.

The center-width wide membership function (CWW) is used when the response is reaching steady state mainly for minimizing the oscillation occurs. The degree of validity is near the origin and the wide width function ensures small change of validity and hence reduces the chattering around the set point.

The DIMS applies CWN, CWC and CWW one at a time at different stages of the transient states of the controller step response to achieve a superior step response for a DC motor controller.

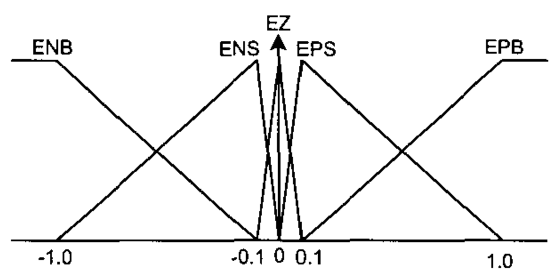


Fig.2 Center width narrow (CWN) MF

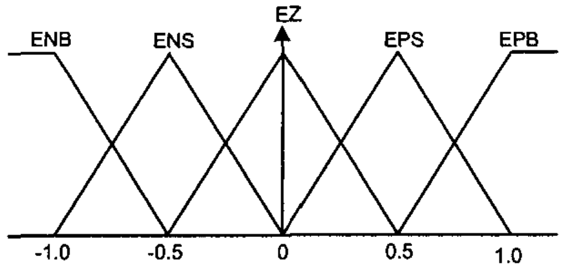


Fig.3 Center-width constant (CWC) MF.

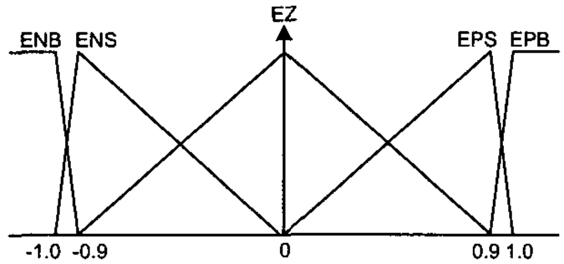


Fig.4 Center-width wide (CWW) MF.

IV SIMULATION AND RESULTS

The FLCs with different membership function schemes are simulated with the input taken for the fuzzy sets is just the speed error only (excluding the acceleration or change of error) and the current controller is excluded also. With the absence of current controller, a suitable scaling factor is preset for all the FLCs to hold the current (with its own response) below the rated current. The reason to do so is to monitor the natural response of the FLCs under the simplest condition allowed without any extra influences. With the reference speed set at 100rad/s, simulations are carried out for 1 second.

Table I
Tabulation of results.

	DIMS	CWW	CWC	CWN
Maximum speed (rad/s)	98.29	94.15	96.55	98.28
Speed settling time (s)	0.26	0.96	0.71	0.31
Oscillation (s)	4.5e-3	4e-3	5e-3	5e-3
Current settling time (s)	0.33	0.69	0.58	0.35
Peak inrush current (A)	35	45	42	35

The simulation results of speed and current response are shown in Fig5 to Fig.7 and data tabulation is available in Table I. From the table, DIMS FLC outperform the others except on steady state oscillation in which CWW FLC has the best performance over the rest. Simulation studies have confirmed the improved performance of the dynamic input membership functions as compared to the other schemes commonly employed.

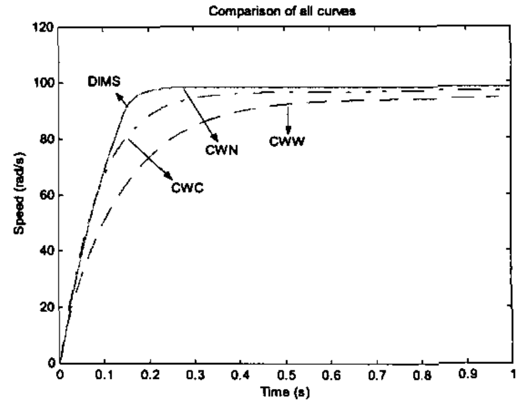


Fig.5 Transient response of all MF schemes.

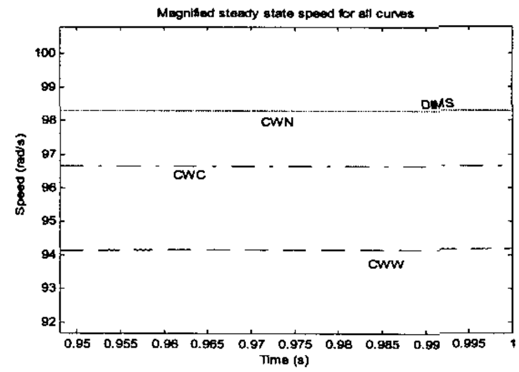
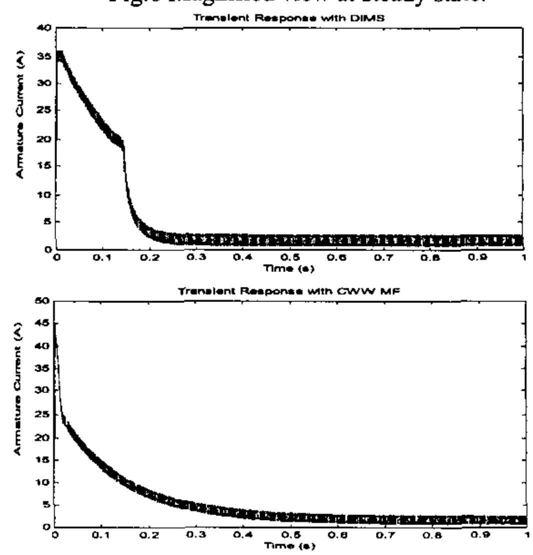


Fig.6 Magnified view at steady state.



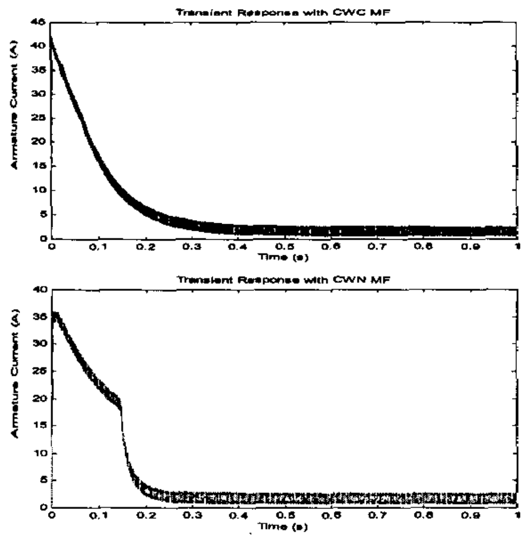


Fig.7 Transient response of armature current.
(From top to bottom DIMS, CWW, CWC, CWN.)

V CONCLUSION

A dynamic membership function scheme has been proposed and proved with improved performance for fuzzy logic dc motor controller. The simulation results shown in this paper can be further improved by applying proper tuning methodology to the FLC.

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