ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 9, Issue 2, February 2020

Implementation of Fuzzy Logic System for BLDC Motor Speed Control Based on LabVIEW

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ABSTRACT: This work suggested two fuzzy logic schemes implementation for speed controlled brushes DC motor. The first FL controller is Type 1 FL controller, while the other controller is interval Type 2 FL Controller. A comparison study between the two suggested controllers has been made in terms of system dynamics and performance. For fair comparison, the same type, numbers of membership functions are used for both controllers. The effectiveness of both structures of FL controllers has been implemented using within LabVIEW environment. The Practical results showed that Interval type 2 FL controllers have better performance than type 1 FL controller.

KEYWORDS: Fuzzy Logic Type1, Interval Type2Fuzzy Logic, BLDC motor, speed control.

I.INTRODUCTION

Permanent-magnet synchronous motor DC motors (brushless DC motor) can be used in many areas and applications such as industry automated electric car and aerospace computer. Brushless DC motors have several advantages over brushes DC motor. It is characterized by low maintenance and a long service life due to the disposal of the commutator. No friction, no electrical loss and high power density [1, 2].Brushes DC motor have no brushes. Extend the life of the engine and avoid maintenance work. This engine tooit is characterized by a high electromagnetic torque-to-weight ratio and is suitable for most applications[2, 3].Compared to brush DC motors and induction machines are brushes DC motorsActivate a fast dynamic response to reference commands. Besides, she Permanent magnets that can be operated with practically no rotor loss [3-5].Brush DC motors are complex and non-linear models. To overcome the control problem, a non-linear fuzzy logic controller (FLC) is used to control the speed of the brushes DC motor. This intelligent control has a simple structure and is relatively easy to implement due to the correct fuzzy rules in the rule base [6, 7].The intelligent control of brush DC motor has recently caught the attention of many researchers. This white paper provides an overview of the most important studies. R. Arulmozhiyal and R. Kandiban compared traditional PID (Proportional Integration Derivative) controllers with fuzzy PID controllers for speed control of brush DC motor. The results were obtained experimentally using MATLAB/SIMULINK and experimentally verified, and the result actually simulated is fuzzy PID. Kai Sheng Kan and Ying-Yu Tzou proposed an adaptive wide range angle control technique with flexible modulation waveform to get wider range of speed control with efficiency optimization. The proposed technique is based on regulated modulation waveform with wide range of angles of conduction period (120o-180o). The phase current with quasi-sinusoidal waveform to decrease the pulsation torque due to commutation operations. The simulation and experimental tests have been made to check the performance of the proposed control strategy [8].

Jia-Yush Yen, et al. had proposed a variable sampling frequency observer (VSFO) for the velocity estimation. They presented a conservative controller design procedure to guarantee system stability as well. A mathematical model for the model is made and the system is implemented experimentally. The observer selects variable sampling rate for measurements and made the observed output available all the time. The VSFO gave an access to accurate speed measurement. It offered additional freedom in the control design as well [9].Chang-Liang Xia and Wei Chen presented

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Vol. 9, Issue 2, February 2020

a sensor-less control method for BLDC motors. The method is based on zero crossing of line back EMF. It has been demonstrated corresponding with the alteration points and has more reliability at low speeds. The artificial neural network feed forward has been employed and it has been trained in both off-line and on-line cases. The weights of neural networks are updated according the back propagation (BP) technique [10].Jung-Sheng Wen et al.has presented a fuzzy logic controller (FLC) for sensor-less BLDC motor. The proposed FLC is based on the voltage measurement. There were two modules used in speed control design of BLDC motor, which are command and regulating modules. Command module is to locate commutation period and PWM duty cycle at desired speed of the BLDC motor. The regulating module is designed by applying a FLC-based sensor-less technology and it is made to control the speed of BLDC motor under different disturbances such as loading condition. The microcontroller C8051F330 is used to regulate the speed of the motor experimentally. There are two resistances are used to determine the back-EMF voltage on the unexcited phase to detect rotor position [11].

Guan-Yan Chen et al. have used Particle Swarm Optimization (PSO) for optimal tuning of PID controller's gains to regulate the speed of BLDC motor. The PID controller based on PSO algorithm has been coded inside DSP TMS320F2812 to enhance the time response of real time implementation. The results show that an optimal control gain can be achieved, which improves the step response of the speed controller [12].A major problem with BLDC motor control is how to design controls so that high performance is achieved.Dealing with dynamic performance and system uncertainty as well as load failures.Existing controllerLack of ability to respond satisfactorily to parameter variations and load application. So isFL controls have been proposed to replace existing controls to address system degradation.System parameter uncertainty. This study compares type 1 FLC (T1FLC) and interval type.2 FLC (IT2FLC) for speed control of the BLDC motor.The performance of every controllerTerminology of transient and stationary properties.This performance will be assessed in MATLAB.

II.DYNAMIC MODEL OF A BLDC MOTOR

The BLDC motor is a three phase, star connected, four pole, trapezoidal back-EMF type with three phaseinverter fig 1, shows the basic block diagram of speed control for BLDC motor.

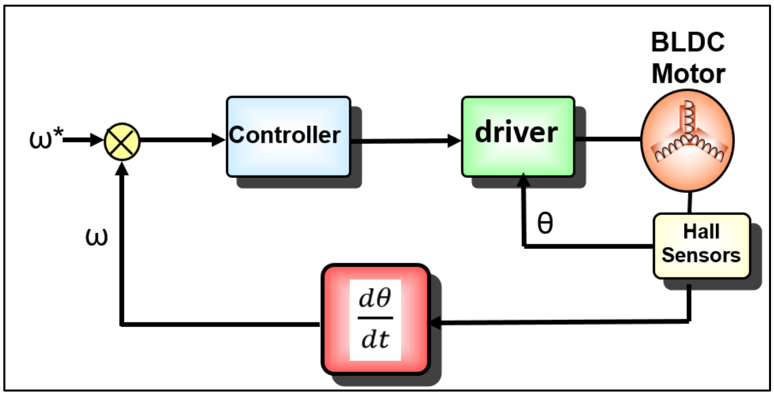

Fig. 1 Basic Block diagram of Sensor-less drive of BLDC Motor

The voltage equations of the BLDC motor can be described by the following set of equations [13]:

$$v_a = R_{as}i_a + L_{aa}\frac{d}{dt}(i_a) + L_{ab}\frac{d}{dt}(i_b) + L_{ac}\frac{d}{dt}(i_c) + e_{as} \quad (1)$$

$$v_b = R_{bs}i_b + L_{ba}\frac{d}{dt}(i_a) + L_{bb}\frac{d}{dt}(i_b) + L_{bc}\frac{d}{dt}(i_c) + e_{bs} \quad (2)$$

$$v_c = R_{cs}i_b + L_{ca}\frac{d}{dt}(i_a) + L_{cb}\frac{d}{dt}(i_b) + L_{cc}\frac{d}{dt}(i_c) + e_{bs} \quad (3)$$

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where v_a, v_b, v_c are the stator phase voltages, R_a, R_b,$R_c$are the phases resistances of stator,i_a, i_b, i_c are the currents of stator phases, L_{aa},L_{bb}, L_{cc} are the self-inductances of stator windings, L_{ab},L_{bc}, L_{ba}, L_{ac}, L_{ca}, $L_{ca}$are the mutual inductance among the statorswinding, E_a, E_b, E_c arethe back electromotive force (e.m.f) of the threephase stator [13].
Due to the symmetric structure of three stator winging and since the resistances of stator windingsare equal, then one can write:

$$L_{aa} = L_{bb} = L_{cc} = L (4)$$

$$L_{ac} = L_{ab} = L_{ba} = L_{bc} = L_{ca} = L_{cb} = M \quad (5)$$

where, $L$is the self-inductances of stator and $M$is the mutual inductances, which are independent of the rotor position. The three-phase star winding motor, the following

$$i_a + i_b + i_c = 0 \qquad (6)$$

$$Mi_a + Mi_b + Mi_c = 0 \qquad (7)$$

The instantaneousinduced e.m.fs can be described by:

$$e_{ats} = f_{as}(\theta_r)\lambda_p\omega_m (8)$$

$$e_{bts} = f_{bs}(\theta_r)\lambda_p\omega_m \qquad (9)$$

$$e_{bts} = f_{bs}(\theta_r)\lambda_p\omega_m (10)$$

where$\omega_m$is rotor angular speedandθ_r is the rotor position.
Using Eq. (1), Eq. (2) and Eq. (3), the complete model of BLDC motor can be written in matrix form [13]:

$$\begin{pmatrix} v_a \\ v_b \\ v_c \end{pmatrix} = \begin{pmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} + \begin{pmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{pmatrix} \frac{d}{dt} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} + \begin{pmatrix} e_{as} \\ e_{bs} \\ e_{cs} \end{pmatrix} (11)$$

Since a balanced three phase motor has been considered, all phase resistances are equal and can be designated by (R). Therefore, Eq. (11) can be written as follows:

$$\begin{pmatrix} v_a \\ v_b \\ v_c \end{pmatrix} = \begin{pmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} + \begin{pmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{pmatrix} \frac{d}{dt} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} + \begin{pmatrix} e_a \\ e_b \\ e_c \end{pmatrix} (12)$$

where the functions $f_{as}(\theta_r)$, $f_{bs}(\theta_r)$ and $f_{cs}(\theta_r)$ have the same shape as e_{ats} , e_{bts} and $e_{cts}$with ±1 maximum magnitude. Also, the induced emfs have rounded edges than sharp corners as found in trapezoidal functions; this is due to the time derivative of flux linkages. Also, since the flux linkages are fringing and continuous functions, which makes the flux density functions smooth without sudden edges. The expression of electromagnetic torque can be written as:

$$T_e = (e_a i_a + e_b i_b + e_c i_c)/\omega \qquad (13)$$

$$E_p = \lambda_p\omega_m (14)$$

The developed torque is used to overcome the mechanical rotation and load torque as given by:

$$T_e = J\frac{d\omega}{dt} + B_f\omega_m + T_L (15)$$

III.TYPE-1 FLC AND TYPE-2FLC (T1FLC, T2FLC)

The design of a fuzzy logic controller requires the choice of membership functions. The membership functions should be chosen such that they cover the whole universe of discourse. It should be taken care that the membership functions overlap each other. This is done in order to avoid any kind of discontinuity with respect to the minor changes in the inputs [14]. T2FLC consists of a set of membership functions (MFs) that operate with 3D uncertainties, whereas the MFs of type 1 fuzzy sets operate with only two dimensions. The fuzzy sets of MFs are shown in fig2, These fuzzy sets are capable of modelling and handling uncertainties, nonlinearities and linguistic variables related to the input and output of FLCs by modelling them and reducing their effectiveness. T1FLC fuzzy sets supplement classical fuzzy sets, thereby clearly indicating the preferences of IT2FLC [15].

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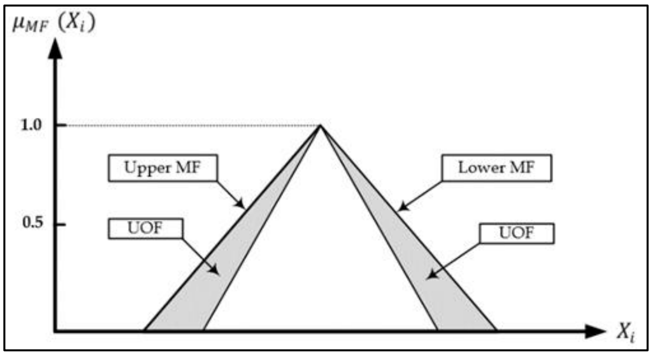

Fig. 2 Interval type 2fuzzy MF structure

The mathematical equation for a system is required to control practical systems based on the traditional control design. Most system equations that describe system dynamics are differential equations associated with either continuous or discrete time systems. In reality, most physical systems are complex and nonlinear. An accurate nonlinear model is difficult to develop for most systems. Although a relatively exact model can be derived, designing a controller that can achieve the required dynamics is too complex, particularly for traditional control designs that impose certain assumptions on a system (e.g. system linearity). The advantages of T2FLCs over T1FLCs can be summarized as follows [16-18]:

- T2FLCs are more robust than T1FLCs because they can work under a wider range of operating conditions than T1FLCs. In addition, T2FLCs can deal with noise and load changes in a plant.
- The fuzzy sets and MFs of T2FLCs are fuzzy. Moreover, the uncertainty can handle and model numerical uncertainties, nonlinearities and linguistic variables that are accompanied by the inputs and output of the universe of discourse (UOD) for FLCs.
- The uncertainty of type 2 fuzzy sets can adopt the same UOD as that of type 1 fuzzy sets but with a smaller number of labels.

The following definitions describe the basic mathematical concepts for T2FLCs [17].

Definition 1. If $\tilde{A}$ denotes type 2 fuzzy sets, which is characterised by MF $u_{\tilde{A}}(x.u)$, where $x \subset X$, X is the UOD and $u \in J_x \subseteq [0.1]$; then

$$\tilde{A} = \{((x.u).\mu_{\tilde{A}}(x.u))|x \in X\,.u \in\, J_x \subseteq [0.1] \qquad (16)$$

where $0 \leq u_{\tilde{A}}(x.u) \leq 1$. The equation can be expressed as

$$\tilde{A} = \int_{x\in X}\int_{u\in\, J_x}\frac{\mu_{\tilde{A}}(x.u)}{(x.u)}J_x \subseteq [0.1](17)$$

where $\int\int$ represents the union over all admissible u and$x$.

Definition 2. A 2D system with axes u and $u_{\tilde{A}}(x.u)$ is known as the vertical slice of$u_{\tilde{A}}(x.u)$, which is represented as

$$\mu_{\tilde{A}}(x = x_1.u) = \mu_{\tilde{A}} = \int_{u\in\, J_x}\frac{\mu_{\tilde{A}}(x.u)}{(x.u)}J_{x1} \subseteq [0.1], \qquad (18)$$

where $0 \leq f_{x1}(u) \leq 1$ and $\mu_{\tilde{A}}(x)$is defined as the secondary MF and secondary set, respectively. The primary MF of x_1 is designated by J_{x1} and is the domain of the secondary membership, where $J_{x1} \subseteq [0.1]$ for all x_1 in X.

Definition 3. The amplitude of the secondary MF is defined as the second degree, which is referred to as the secondary grade.

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Definition 4. The bounded area of uncertainty for type 2 fuzzy set $\tilde{A}$ is called the footprint of uncertainty (FOU). FOU defines the union of all primary MFs, which can be described as

$$FOU(\tilde{A}) = U_{x \in X} J_x. \quad (19)$$

Definition 5. The upper and lower MFs of $\tilde{A}$ are two type 1 fuzzy sets, where the boundaries of $FOU(\tilde{A})$ for type 2 fuzzy sets $\tilde{A}$ are the lower and upper bounds of type 1 fuzzy sets. The lower MF is described as $\underline{\tilde{\mu}_{\tilde{A}}}(x) x \in X$ and the upper MF is defined as $\overline{\tilde{\mu}_{\tilde{A}}}(x) x \in X$, which indicate that

$$\overline{\tilde{\mu}_{\tilde{A}}}(x) = \overline{FOU(\tilde{A})}, \quad (20)$$

$$\underline{\tilde{\mu}_{\tilde{A}}}(x) = \underline{FOU(\tilde{A})}. \quad (21)$$

IV.RESULT AND DISCUSSION

In The effectiveness of T1FLC and T2FLC for the speed control of BLDC motors is verified through simulation in MATLAB/SIMULINK (R2017b) environment. The SIMULINK modelling of FLC-based speed control is shown in fig.3, The BLDC motor parameters used throughout the simulation are listed in Table 1.

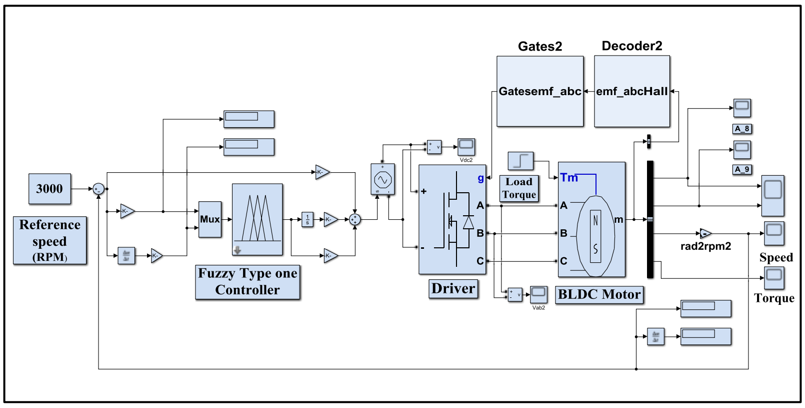

Fig. 3 BLDC motor with T1FLC

Table 1: Parameters of BLDC Motor

Motor Parameters	Values
Number of poles	8
Number of phases	3
Stator Resistance	0.7 Ω
Stator Inductance	0.5×10^{-3} H
Rated power of motor	92 Watt
Rated speed of motor	3000 RPM
Rated torque of motor	0.22 N.m
Rotor inertia of motor	0.0075×10^{-3} Kg.m^2

The MFs of T1FLC for error and change of error is shown in fig. 4 and the MF of FL output is depicted in fig. 5fig. 6,presents the speed response due to T1FL and IT2FL controllers. The performance evaluation of T1FLC and T2FLC is performed in terms of the dynamic response and steady-state characteristics of the controlled motor. The best controller is the one that provides the minimum peak overshoot M_p, minimum rise time $T_r$and minimum steady-state errore_{ss}. It is

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clear in the figure that IT2FL controller shows better transient characteristics than T1FL controller. Table 2 lists the numerical evaluation of transient parameters for both controllers. It evident from the zoomed figure that the response suffers no change in case of IT2FL controller, while a dip of maximum 60 RPM has been observed in case of T1FL controller. This indicates that IT2FL controller has better load rejection capability than T1FL controller. Another simulation is performed for the operation of BLDC using IT2FLC, as shown in fig. 7, An M-file code is written and inserted into the simulation rather than utilising the FLC tool box for T1FLC.

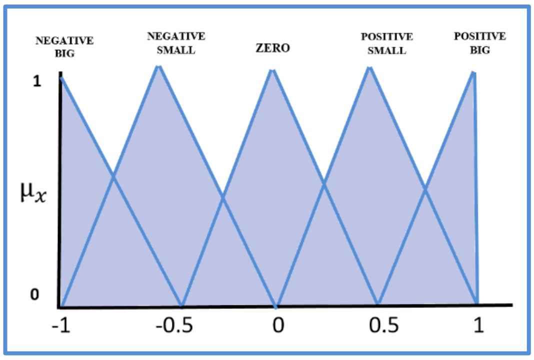

Fig. 4 MFs of the error and change of error of T1FLC

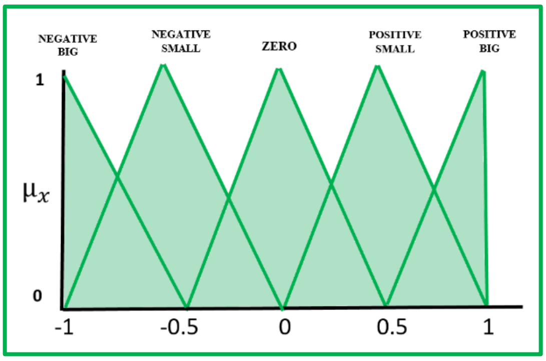

Fig. 5 MFs of the output of T1FLC

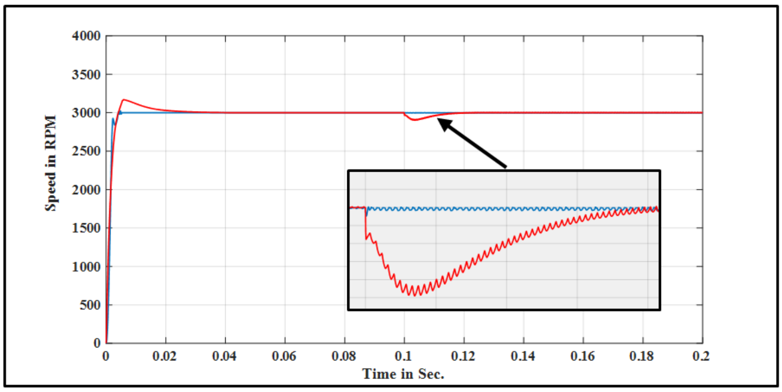

Fig. 6 Dynamic responses due to T1FL and ITFL controllers under disturbance application

Table: 2 Comparison of speed control between different controllers for a BLDC motor

Characteristics of Dynamic Response	Types of Controllers	
	Type-1 FLC	Type-2 FLC
Rising Time (Tr) Sec	3.34×10^{-3}	3.12×10^{-3}
Maximum Overshoot (Mp)	277	11
Steady-state error (Ess) rad/sec.	4.3797	1.6193
Settling Time (Ts) Sec.	12.9×10^{-3}	3.2×10^{-3}

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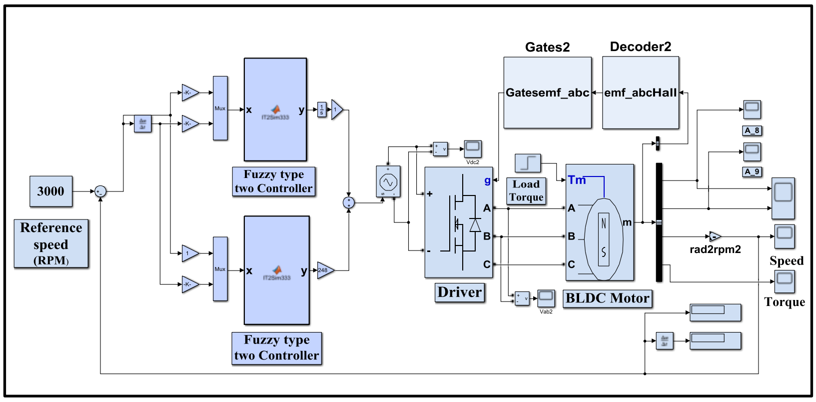

Fig. 7 BLDC motor with T2FLC

V.CONCLUSION

This study compares two types of FL structure, namely, T1FLC and IT2FLC, for controlling the speed of BLDC motors. The performance evaluation is verified through simulation in MATLAB/SIMULINK. The performance of the controllers is based on transient and steady-state characteristics. The simulation results and performance table show that IT2FLC outperforms T1FLC in terms of transient and steady-state parameters.

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