Adaptive PID-Fuzzy Logic Controller for Brushless DC Motor

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Abstract - **Variable speed drives are increasingly being used in a variety of areas, including the automotive, medical, and household markets. The need for brushless DC motors (BLDCM) has also surged because of this rise in demand. Compared to typical DC motors, BLDC motors provide several advantages, such as increased efficiency, better speed-torque characteristics, less noise, and lower maintenance because there are no brushes to wear out or ignite. An adaptive PID-fuzzy controller has been created to improve precision and resilience in speed regulation, although many BLDC motors now use a PI controller with PWM scheme. When necessary, this controller offers precise control of dynamic speed changes.**

Keywords—* PID *Controller, Fuzzy logic controller, Hall Effect Sensor.

INTRODUCTION:

The use of brushless DC motors (BLDCMs) in a variety of industries, including the automotive, medical, and domestic sectors, has grown significantly. The numerous benefits that BLDCMs have over conventional DC motors, such as increased efficiency, enhanced speed-torque characteristics, decreased noise, and lower maintenance needs, are to blame for this rising demand. However, improved control approaches are needed to properly utilise BLDCMs' potential and ensure accurate and reliable speed control.

The Proportional-Integral-Derivative (PID) controller in conjunction with a Pulse Width Modulation (PWM) scheme is the traditional method for speed control in BLDCMs. Due to its ease of use and ability to sustain set motor speeds, this approach has achieved widespread appeal. However, it could not deliver the best control performance when faced with dynamic operating circumstances or fluctuating loads.

Researchers have focused their efforts on creating adaptive control systems, notably merging fuzzy logic with the PID control framework, to get around the drawbacks of traditional PID control. Fuzzy logic can be used to improve control accuracy and resilience because it offers a flexible framework for dealing with the uncertainties and nonlinearities that are present in BLDCMs.

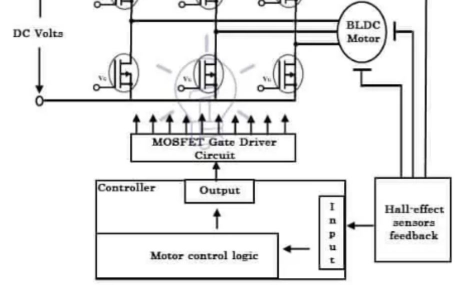
In order to improve accuracy and efficiency in speed regulation, this research proposes an adaptive PID-fuzzy logic controller for BLDCMs that incorporates the benefits of both PID control and fuzzy logic. The controller's ability to adjust and optimise control parameters in real-time enables it to provide the best performance under a variety of operating scenarios.

The primary objectives of this research are as follows:

1. Develop an extensive understanding of the dynamics and traits of BLDCMs, including the mathematical models and control specifications that underlie them.
2. Examine the drawbacks of traditional PID control and the possibility of using fuzzy logic to address these issues.
3. Design an adaptive PID-fuzzy logic controller with improved precision and robustness that can successfully control the speed of BLDCMs.
4. To assess the performance of the suggested controller under various operating settings and load fluctuations, run simulations and experimental experiments.
5. To demonstrate the adaptive PID-fuzzy logic controller's advantage over traditional PID control methods in terms of precision, stability, and dynamic response, compare its performance to that of the latter.

This research intends to expand the control methods for these motors, supporting their wider application across various industries, by creating an adaptive PID-fuzzy logic controller for BLDCMs. The results of this study will help researchers, engineers, and practitioners involved in the design and optimisation of BLDCM control systems by revealing important insights that will ultimately result in more dependable and efficient motor operation.

TRANSFER FUNCTION OF BLDC MOTOR:



Open loop control of BLDC motor

Transfer function without load torque is,

$$G_V(s) = \frac{\omega(s)}{V_d(s)} = \frac{K_T}{L_aJs^2 + (r_aJ + L_aB)s + (r_aB + K_eK_T)}$$

Transfer function between speed and load torque is,

$$G_L(s) = \frac{\omega(s)}{T_L(s)} = -\frac{r_a + L_as}{L_aJs^2 + (r_aJ + L_aB)s + (r_aB + K_eK_T)}$$

Speed response of BLDC motor is given by,

$$\omega(s) = \frac{K_TV_d(s)}{L_aJs^2+(r_aJ+L_aB)s+(r_aB+K_eK_T)} - \frac{r_a+L_as}{L_aJs^2+(r_aJ+L_aB)s+(r_aB+K_eK_T)}$$

CONTROLLERS

Based on where the rotor magnet's north pole is located, a Hall effect sensor output can be either high or low. The stator windings must be powered in line with the position of the rotor, which calls for a controller. Because of this, it is necessary to implement well-designed control logic to make use of the Hall effect sensor output and produce appropriate gate signals for the inverter, assuring the proper order of stator winding energization for motor rotation. The current that passes through the stator is controlled by this controller. An extra feedback system is required to regulate the motor's speed further. Here, PID and fuzzy logic controllers are both used.

PID Controller:

The PID controller is a conventional controller that operates by manipulating the error signal and generating an output based on the following relationship:

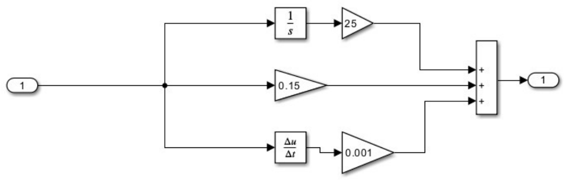
$$y(t) = k_p\, e(t) + k_i \int e(t) + k_d\, (\mathrm{de(t)/dt})$$

Here, K_p is known as the proportional constant, which considers the present value of the error. The proportional mode responds to the immediate error value.

K_d represents the derivative constant, and the derivative mode considers the current rate of change of the error signal, allowing it to anticipate future error values.

K_i is the integral constant, and the integral mode takes into consideration the cumulative effect of past error values.

In summary, the PID controller utilizes these three components to compute the output by combining the proportional, integral, and derivative actions to achieve effective control.

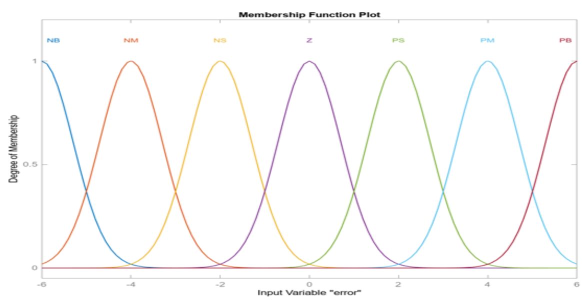


Fuzzy Logic Controller:

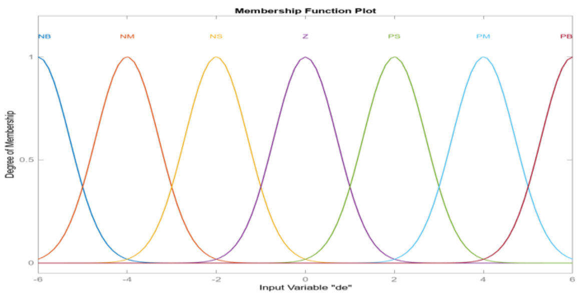
The Fuzzy Logic Toolbox in MATLAB provides a convenient way to design fuzzy logic controllers. The fuzzy logic controller consists of:

Fuzzification: process of transforming inputs also called as crisp values into the linguistic values.
Rule Base: *F*ull collection of control rules which are needed to get the desired output.
Inference Engine: *P*rocesses which performs fuzzy operations and produce the output according to input and knowledge base.
Defuzzificatio**n:** Dual of Fuzzification It transform the result of fuzzy reasoning mechanism again into the crisp value.

To utilize this toolbox, the first step is to create a .fis file. The Mamdani rule structure is commonly employed to define membership functions in the .fis file. In this case, a fuzzy logic controller with one output and two inputs is utilized. The inputs are the error (e) and the rate of change of error (de), while the controlled output is denoted as y. The fuzzy control rules are defined in the form: IF e = A and de = B, then y = C. The membership functions for the variables are shown below, with seven linguistic variables classified as NB, PB, NM, PM, NS, PS, and Z. The range for all inputs and output is set between -3 and 3. Gaussian membership functions are employed in the design of the fuzzy logic controller. The linguistic labels used are Negative Big (NB), Positive Big (PB), Negative Medium (NM), Positive Medium (PM), Negative Small (NS), Zero (Z), and Positive Small (PS). A table is provided to assign the set of rules for obtaining the controlled output. A total of 49 rules are assigned based on these conditions, resulting in the creation of a .fis file that will be utilized in conjunction with the fuzzy toolbox. The accompanying figure displays the Simulink model for the speed control of a brushless DC motor using a fuzzy logic controller.



Membership function for error

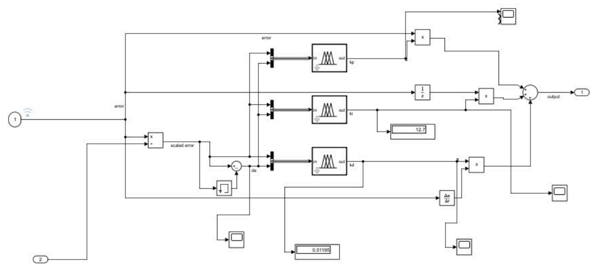


Membership function for de

e\de	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	Z	Z
NM	PB	PB	PM	PS	PS	Z	NS
NS	PM	PM	PM	PS	Z	NS	NS
Z	PM	PM	PS	Z	NS	NM	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NM	NM	NM	NB
PB	Z	Z	NM	NM	NM	NB	NB

Fuzzy Controller Rule Sets

All the results obtained indicate a clear eye diagram, however, there is a variation in ER (extinction ratio) among them. This implies that there is a positive correlation between wavelength and extinction ratio, meaning that as the wavelength increases, the extinction ratio also increases.



Simulink model of speed control of BLDC motor using fuzzy controller

Adaptive PID Fuzzy Controller:

The given diagram illustrates the block diagram of an adaptive PID fuzzy controller. The controller is designed to have two inputs, namely the error (e) and the rate of change of error (de), as well as three outputs: proportional gain (K_p), integral gain (K_i), and derivative gain (K_d). The fuzzy logic controller generates the values of K_p, K_i, and K_d based on the linguistic variables of the inputs, which include Negative Big (NB), Negative Medium (NM), Negative Small (NA), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB). Similarly, the linguistic variables for the outputs are Zero (Z), Very Low (VL), Very High (VH), Low (L), Medium (M), High (H), and Very Very High (VVH) for K_p, K_i, and K_d, respectively. The range for K_p is defined between 0 and 0.5, for K_i between 0 and 20, and for K_d between 0 and 0.005. The membership functions for K_p, K_i, and K_d are depicted in the accompanying figures. Additionally, a set of fuzzy logic rules is formulated to guide the controller in achieving the desired control output. Gaussian membership functions are utilized throughout the controller design.

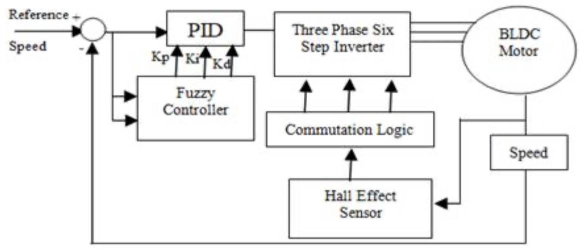
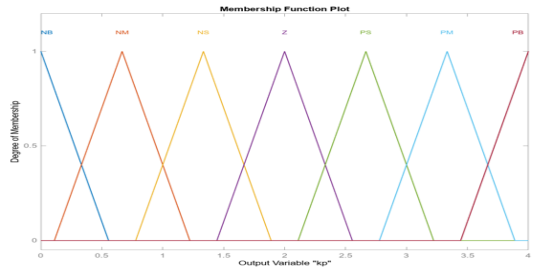
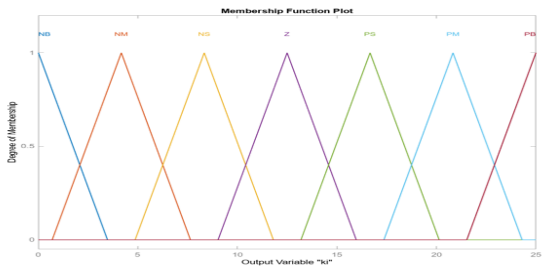


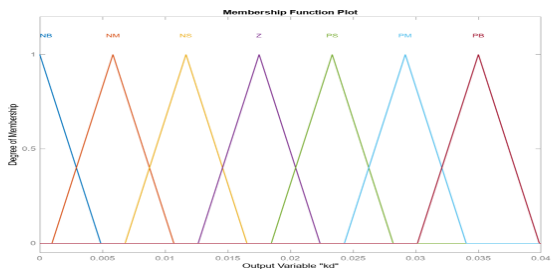
Fig 7 Block diagram of Adaptive fuzzy PID controlled Brushless DC Motor



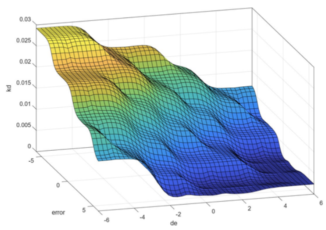
Membership function for K_p

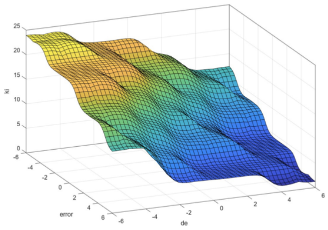


Membership function for K_i

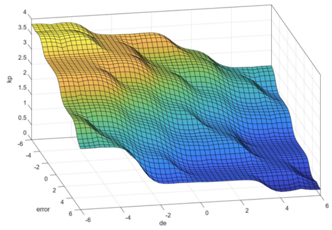


Membership function for K_d

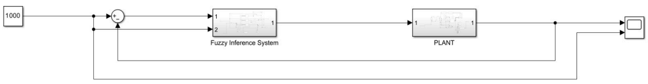




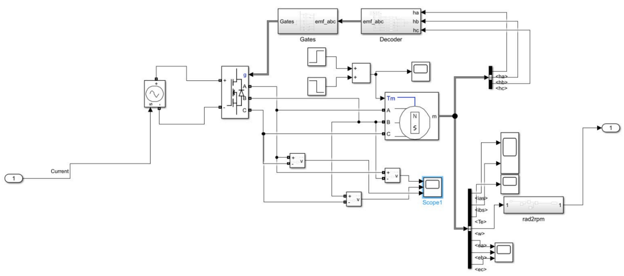
Control Surface of K_p *Control Surface of K_i*



Control Surface of K_d



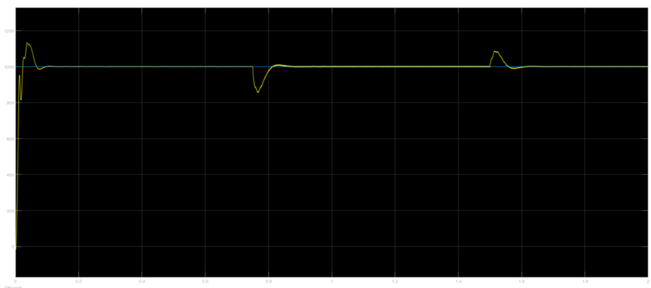
Simulink model of speed control of BLDC motor using adaptive PID- fuzzy controller



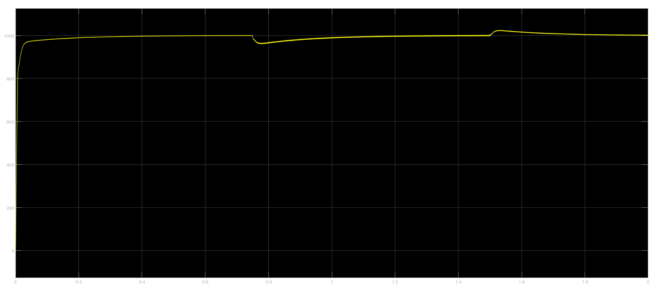
Simulink model of model / plant

SIMULATION RESULTS

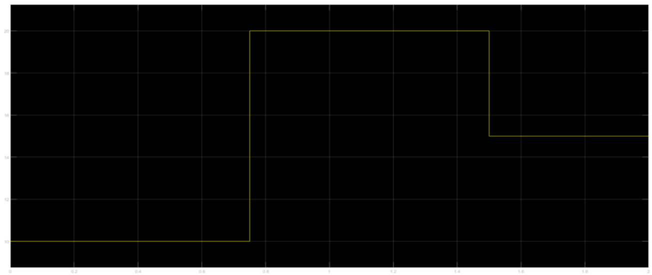
Specifications		
Parameters	Range	SI Units
L, R	0.0085, 2.875	Henry, Ohm
P	4	-
K_e	1.3	V/radian/second
K_T	1.4	Nm/A
J	0.08	Kgm^2
B	0.045	Nms/rad



Speed response using PID controller



Speed response using adaptive PID fuzzy controller



Load Torque

CONCLUSION

In this paper, we have derived the transfer function of a three-phase BLDC motor. This transfer function can be used for further analysis, controlling, or stability check of brushless DC motors. We have also proposed an adaptive fuzzy logic PID controller that can perform adaptively irrespective of any dynamic change in the speed. The proposed controller has been tested on a three-phase BLDC motor and the results show that it can effectively control the speed of the motor even under dynamic conditions.

The conclusion of this paper is that the proposed adaptive fuzzy logic PID controller is a promising approach for controlling three-phase BLDC motors. The controller can effectively control the speed of the motor even under dynamic conditions, which makes it a suitable choice for a wide range of applications.

Here are some additional details about the proposed controller:

- The controller is based on a fuzzy logic system that can adapt to changes in the motor's speed.
- The controller uses a PID controller as its core, but it is enhanced with fuzzy logic to make it more adaptive.
- The controller has been tested on a three-phase BLDC motor and the results show that it can effectively control the speed of the motor even under dynamic conditions.

The proposed controller is a promising approach for controlling three-phase BLDC motors. It can effectively control the speed of the motor even under dynamic conditions, which makes it a suitable choice for a wide range of applications.

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