CHAPTER 4

BLDC MOTOR FOR POSITION CONTROL USING FUZZY BASED PID CONTROLLER

4.1 INTRODUCTION

In the last chapter the BLDC motor speed controlling scheme using the PID controller has been discussed. The primary focus of the chapter 4 encompasses on the controlling scheme performance improvisation in along with fuzzy logic application.

Fuzzy logic control or FLC as such been researched extensively for theories in automation and control that pertain to problems associated with controlling systems that cannot be modeled easily.

FLC concept uses the system’s qualitative aspects for designing the practical controller. The fuzzy control algorithm in the process control reflects a researcher and designer’s capabilities both intuitively and experience wise in an operative way. As such it is required for control to resemble or be an exact mathematical model of the plant, hence it fits processes wherein either the model is not known or is not defined with exact parameters in particular to those systems that have elements of uncertainty or possess multifaceted dynamics. Inadvertently the fuzzy control algorithm may be refined through the process of adaptation that is based on the learning and fuzzy model that has been previously presented.
Even for non-linear multi-dimensional systems the fuzzy control functions well and for systems where the parameter has varying problems or in those systems wherein sensor signals have not been specified. As such the fuzzy control has capabilities of being able to easily adapt and nonlinear, and in terms of performance it is sturdy and robust under varying parameters and load disturbance effects.

FLC may be regarded as a control technology that is smart and one which offers a method that systematically incorporates individual experiences and also facilitates implementation of nonlinear algorithms in the controller and features a series of linguistic statements. Generally the fuzzy control algorithm is made up of heuristic decision rules and may be considered as being one which is adaptive, additionally the nonmathematical control algorithm which is starkly opposite to conventional feedback control algorithm is supported by it being a linguistic process. Control implementation like this comprises of input variable translation to a language as: positive big, zero, negative small and others that facilitating establishing control regulatory actions thus allowing ascertaining of control rules that enable decision process to generate suitable outputs. Fuzzy control (FC) that deploys linguistic information has many advantages including strength, robustness, being model-free, applicability of the universal approximation theorem as well as the rules-based algorithm that have been explicitly studied and presented by Kim & Bien (2000); Lee (1990); Timothy (1995).

Literature studies carried out previously searched potential aspects of the fuzzy control suitable for machine drive application that have been presented by Tang & Xu (1994), Heber et al (1995). There is evidence that indicates that a well designed direct fuzzy controller has the capability in terms of outperforming the conventional and usual proportional integral derivative (PID) controllers as shown in Heber et al (1995). Therefore,
chapter 4 deploys the Fuzzy Logic Controller for the purpose of BLDC speed control.

4.1.1 Importance of Fuzzy Logic Operation

Fuzzy logic controller has the ability to form systems that are nonlinear in nature. Designing process of conventional control system has its foundation precepts based on the plant’s mathematical model. Considering a mathematical model that is accurate and available and one which has distinctly identifiable parameters in that condition analysis of the same can be carried out. For instance using bode plots or nyquist plot, controller designing can take place to execute definitive performances. However such processes may take up a significant amount of time spent.

Fuzzy logic controller is characterized mainly by it capability to be adaptive in nature. Such adaptive characteristics can help in pushing the system to generate a robust performance with variation in parameters that are uncertain parameters and other disturbances in the load.

4.1.2 Fuzzy Logic Control Components

Fuzzy logic controller components characteristics and functionalities have been distinctly stated and presented in this section. Figure 4.1 below shows that when input data is received by the fuzzy controller, it automatically translates the same as a fuzzy form and the entire process is referred to as Fuzzification. Thereafter which fuzzy processing is carried out by the controller, entailing input information evaluation in line with the IF…THEN rules which are user generated through programming of the fuzzy control system’s programming and stages of the designing process. After the fuzzy controller completes the stage of rule-processing stage and then reaches at the point of an outcome conclusion, DeFuzzification process is started.
During the final step, output inferences are converted by the fuzzy controller converts as “real” output data (e.g., analog counts). Thereafter, which data is using an output module interface for the purpose of processing.

![Figure 4.1 Fuzzy logic controller operations](image)

Fuzzy logic operational laws have been presented using linguistics terms as opposed to mathematical equations. Various systems are either too difficult to create an accurate, even using mathematical equations that are complicated in terms of application; thus it becomes almost practically impossible to use traditional methods for such systems. Nevertheless fuzzy logics linguistic terms present definitive methods that are feasible and may be used to enhance system operational characteristics.

The Fuzzy logic controller may be regarded as the symbolic controller that belongs to a special class. Figure 4.2 shows fuzzy logic controller configuration.
Figure 4.2 Structure of fuzzy logic controller

The fuzzy logic controller carries out three operative functions as below:

- Fuzzification
- Fuzzy processing
- DeFuzzification

Fuzzification

1. Various measured crisp inputs need to be mapped initially into the fuzzy membership function and this is referred to as Fuzzification.
2. Scale mapping carried out permits transfer of input variable values into related discourse universes.
3. It carries out Fuzzification which enables input conversion into linguistic values that are suitable which can be considered as fuzzy sets labels.

Almost quite frequently fuzzy logic linguistic terms are presented as logical implication forms like if-then rules. If-then rules classify a value range which is referred to as the fuzzy membership functions. Fuzzy membership function as such can be either triangular, trapezoidal or like a bell or in any other form.

Figure 4.1 defines triangle membership function wherein the limits have been defined by \( M_{Tl1} , M_{Tl2} \) and \( M_{Tl3} \).

\[
\mu(x_i) = \begin{cases} 
\frac{x_i - M_{Tl1}}{M_{Tl2} - M_{Tl1}}, & M_{Tl1} \leq x_i \leq M_{Tl2} \\
\frac{M_{Tl3} - x_i}{M_{Tl3} - M_{Tl2}}, & M_{Tl2} \leq x_i \leq M_{Tl3} \\
0, & Otherwise 
\end{cases}
\]  

(a) Triangle membership function

(4.3 (a)) shows trapezoid membership function where the limits are defined as \( M_{TP1} , M_{TP2} , M_{TP3} \) and \( M_{TP4} \).
\[
\mu(x_i) = \begin{cases} 
\frac{x_i - M_{Tp1}}{M_{Tp2} - M_{Tp1}}, & M_{Tp1} \leq x_i \leq M_{Tp2} \\
1, & M_{Tp2} \leq x_i \leq M_{Tp3} \\
\frac{M_{Tp3} - x_i}{M_{Tp3} - M_{Tp2}}, & M_{Tp3} \leq x_i \leq M_{Tp2} \\
0, & Otherwise 
\end{cases}
\]  

(b) Trapezoid membership function

The bell membership functions are defined by parameters \( M_b, w_d \)

and \( m \) as follows

\[
\mu(x_i) = \frac{1}{1 + \left(\frac{|x_i - M_b|}{\omega}\right)^{2m}} \quad (4.3)
\]

Where, \( M_b \) the midpoint and \( w_d \) is the width of bell function. \( m \geq 1 \), which shows the convexity of the bell function.
Fuzzy controller inputs have been expressed using varying linguist levels. Figure 4.4 shows the levels that include Positive High or PH, Positive medium or PM, Positive Low or PL or Negative Low or NL, Negative medium or NM, Negative High or NH or others. A fuzzy set expresses each level.

Figure 4.3 Fuzzy logic membership functions

Figure 4.4 Several linguist levels of fuzzy controller with triangular membership function
Fuzzy inference

Fuzzy inference involves formulation of mapping output from a given input using fuzzy logic. The process of mapping as a result presents a basis which enables decision making or the purposes of pattern discernment. In the Fuzzy Logic Toolbox two kinds of fuzzy inference systems can be possibly implemented. The first is the Mamdani and the second is the Sugeno-type. Both types have different characteristics specifically in terms of determination of output. Fuzzy inference systems application has been successful in many areas like computer vision, automatic control, decision analysis, data classification and expert systems. These systems possess a multidisciplinary nature and are referred to with various names for example; fuzzy-rule-based systems, fuzzy modeling, fuzzy expert systems, fuzzy logic controllers, fuzzy associative memory and simply (and ambiguously) fuzzy Mamdani’s fuzzy inference method which is among the most popular fuzzy methodology.

Mamdani’s method is considered as being amongst the first control systems that was made by deploying the fuzzy set theory. These were efforts taken consciously and directed to control both the steam engine as well as boiler combination by fusing linguistic control rules acquired human operators that were familiar and had prior experience in the same. Mamdani’s research was founded on fuzzy algorithms deployed for systems that were complex and other processes that required decision making.

In the fuzzy logic controller’s second phase it is in the fuzzy inference wherein both knowledge base and decision making logic exist. Both rule and data base are from the knowledge base. Data base includes input as well as output variables description. Decision making logic analyses control
rules. Control-rule base may be further developed to facilitate relationship between output action and inputs obtained in the controller.

**Defuzzification**

Fuzzy output variables are generated from inference mechanism output. Fuzzy logic controller is required to convert the internal fuzzy output variables into values that are crisp values enabling the actual system to use such variables. The process of conversion is referred collectively as DeFuzzification. There are many way to carry out this operation. Among control defuzzification strategies the most common one is the max criterion method or MAX. Max criterion turns out the membership function wherein fuzzy control action attains the maximum value.

### 4.1.3 Tuning of PID Controller using Fuzzy Logic

The fuzzy logic controller that has been presented optimizes both speed and torque parameters. With respect to uncertain and ill-defined nonlinear systems this control methodology has proven to be quite useful as discussed shown in Ji & Li (2008). FLC Control actions have certain linguistic rules that define their characteristics which makes understanding the control algorithm uncomplicated.

The simplest of associated functions which is the triangular membership function has been used here. The implication taken in to consideration here is the Sugeno type wherein singleton membership function has been deployed for the output variable especially during the duty cycle change. Normalization of the error is carried out by dividing both actual error and reference speed. This process is productive and appropriate when the fuzzy controller is used for several speed references.
4.2 PROPOSED FUZZY BASED CONTROLLER IN BLDC MOTOR

The Fuzzy logic controller because of its functionality it has now been adopted as a fitting solution to a number of non-linear problems. PID controller (input/output) response here has been put together manually to generate the knowledge database. Fuzzy logic controller has several membership functions (input/output). The knowledge base input response that has been collected therein is categorized as error ‘e’ and change in error ‘de’ refers to unit delay response of error ‘e’. The single associated function in error ‘d’ is then compared with other change associated functions in error ‘de’ at any given particular time. Hence, fuzzy logic time consumption is comparatively significantly less to the PID controller. Figure 4.5 shows Fuzzy logic controller architecture.

![Figure 4.5 Fuzzy logic controller architecture](image-url)
Figure 4.6 Input output fuzzy membership functions

Figure 4.6 Input Output Fuzzy Membership Functions. Table 4.1 shows the fuzzy rules generated based on the error (e/de).
NL – Negative Large; NM- Negative Medium; NS – Negative Small; Z – Zero; PS - Positive Large; PM – Positive Medium; PL – Positive Large

Table 4.1 Fuzzy rules

<table>
<thead>
<tr>
<th>de</th>
<th>NL</th>
<th>NS</th>
<th>Z</th>
<th>PS</th>
<th>PL</th>
</tr>
</thead>
<tbody>
<tr>
<td>NL</td>
<td>NL</td>
<td>NL</td>
<td>NM</td>
<td>NS</td>
<td>Z</td>
</tr>
<tr>
<td>NS</td>
<td>NL</td>
<td>NM</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
</tr>
<tr>
<td>Z</td>
<td>NM</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
</tr>
<tr>
<td>PS</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
<td>PL</td>
</tr>
<tr>
<td>PL</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
<td>PL</td>
<td>PL</td>
</tr>
</tbody>
</table>

The fuzzy variable “change in speed error” has seven sets: Negative Large (NL), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), Positive Large (PL).

Hence, PID controller which forms the basis of the proposed fuzzy logic aimed at controlling BLDC motor’s speed ‘$\omega_m$’ has been developed. Both fuzzy logic control and error signal have been tuned so that it can then be given to PID controller. Error signals mid values has been tuned by Fuzzy logic as a result, both settling time difference and rise time deviations have been reduced considerably and final signal that has a lesser settling as well as rise time is then handed over to PID controller. Following steps briefly describe Fuzzy based PID controller process when the BLDC motor has been tuned. In chapter 3 steps 1 to 7 have already been discussed. In this particular section fuzzy logic based controlling scheme has been presented in detail.

Step 1: Speed, $\omega_m$ is controller through fuzzy logic control
Step 2: Database collection based on the PID controller response through knowledge base

Step 3: Triangular Membership function evaluation

Step 4: Membership Range is set (−1 to 1) with five membership functions

Step 5: AND operation and the related value thereof are used to generate Fuzzy rules

Step 6: The PID controller is given a tuned error signal that possesses lesser settling as well as rise time which results in the production of a lesser peak overshoot as well as undershoot.

4.3 SUMMARY

Chapter 4 entails PID controller that is based on fuzzy logic for the purpose of BLDC motor speed control. Fuzzy theory and its associated functionalities and operation along with the relevance and role of fuzzy logic in the tuning of the PID controller have been presented in chapter 4.