Design of Fuzzy Logic Controller for the Speed Control of Separately Excited DC Motor

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Abstract— The speed control of a DC motor is an important in operating Direct Control Motor. The DC motor of varying capacities is used in a number of applications with operating values ranging from a few 100 rpm to large industrial motors. The DC Motor is a widely present equipment in many industrial applications requiring variable speed and load characteristics due to its ease of controllability. In this paper, the modelling of DC Motor has been done in Simulink and the speed control of DC motor has been done using the Fuzzy Logic Controller. A comparison with the PID controller has been shown further. The results show better control of speed using Fuzzy Logic Controller as compared to the PID Controller.

Key words: Speed Control, DC Motor, Fuzzy Logic Controller, PID Control

I. INTRODUCTION

The speed of Direct Current (DC) motors can be adjusted within a wide range. This provides easy controllability and high performance. DC motors are used in many applications such as still rolling mills, electric trains, electric vehicles, electric cranes and robotic manipulators etc. Many of these applications require speed control to smoothly perform their tasks. DC motor systems are indispensable in modern industries. DC motors are used in a variety of applications in industrial electronics and robotics that includes precision positioning as well as speed control. DC motors use feedback controller to control the speed or the position, or both. Today most famous and most frequently used type of controller in industry is PID controller, but PID controllers don’t offer satisfactory results when adaptive algorithm are required. The nonlinear characteristics of a DC motor like saturation and friction could degrade the performance of conventional controllers. Many advanced model based control methods such as variable structure control and model reference adaptive control have been developed to reduce these effects. However, the performance of these methods depends on the accuracy of the system models and parameters. Generally, an accurate non-linear model of an actual DC motor is difficult to find, and parameter values obtained from system identification may be only approximated values. Control system that could be able to give a fast response in order to maintain the speed of the DC motor at the desired value with a minimum overshoot, minimum steady state error, minimum settling time and fast rising time are very important and crucial in industrial application. Conventional control has proved to be good enough to handle control tasks on system control, however this implementation relies on an exact mathematical model of the plant to be controlled and not a simple mathematical operations.

Fuzzy Logic Controller offers some solutions. Basic advantages of Fuzzy Logic Controller is that it does not require knowing complete mathematical model of system [3,4]. Popularity of FLC is explained with fact that it puts clear and simple implementation of human thinking into controlling algorithm [5]. Fuzzy controllers are robust regarding dynamic changes and have wide stability range [6]. FLC only based on approximate and linguistic information [7]. The basic continuous feedback controller is PID controller which possesses good performance. However is adaptive enough only with flexible tuning. Although many advanced control techniques such as self-tuning control, model reference adaptive control, sliding mode control and fuzzy logic control have been proposed to improve system performances. In this paper, Fuzzy Logic Controller has been proposed for improvement and analysis of the system performance.

II. MATHEMATICAL MODELLING OF DC MOTOR

A basic model of a DC motor is as shown below:

![DC Motor Model](image)

Fig. 1: DC Motor Model

The equations which govern the operation of the DC motor are as given below :

The motor torque, \( T \), is related to the armature current, \( i \), by a constant factor \( K \):

\[
T = Ki
\]  

(1)

The back electromotive force (emf), \( V_b \), is related to the angular velocity by:

\[
V_b = K\omega = K\frac{d\theta}{dt}
\]  

(2)

From Figure 1, the following equations based on the Newton’s Law combined with the Kirchhoff’s Law can be written as:

\[
\frac{d^2\theta}{dt^2} + b\frac{d\theta}{dt} = Ki
\]  

(3)

\[
I = \frac{V(s) - Ks \theta(s)}{L(s) + R}
\]  

(4)

Using the Laplace transform, equations (3) and (4) can be written as:

\[
J_s \theta(s) + b\theta(s) = K_i(s)
\]  

(5)

\[
L(s)I(s) + R I(s) = V(s) - K \theta(s)
\]  

(6)

Where \( s \) denotes the Laplace operator. From (6) we can express \( I(s) \):

\[
I(s) = \frac{V(s) - K \theta(s)}{L(s) + R}
\]  

(7)

This results into:

\[
J_s \theta(s) + b\theta(s) = \frac{V(s) - K \theta(s)}{L(s) + R}
\]  

(8)
From equation (3.8), the transfer function from the input voltage, \( V(s) \), to the output angle \( \theta \), directly follows:
\[
G_v(s) = \frac{\theta(s)}{V(s)} = \frac{K}{s[R + L(s) + J(s) + b + K2]}
\]

(9)

From the block diagram in Figure 2, it is easy to see that the transfer function from the input voltage, \( V(s) \), to the angular velocity, \( \omega \), is:
\[
G_v(s) = \frac{\omega(s)}{V(s)} = \frac{K}{(R + L)s + J + b + K2}
\]

(10)

### III. DC MOTOR CONTROL

DC motor control system that could be able to give a fast response in order to maintain the speed of the DC motor at the desired value with a minimum overshoot, minimum steady state error, minimum settling time and fast rising time are very important and crucial in industrial application.

#### A. PID Control

PID controllers are one of the best known controllers used in many industrial processes. Their important and impressive properties such as fast and efficient control action, simple but functional structure, ease of application and robust performance are among the reasons for their preferences.

During the design phase of a PID controllers, there is a crucial and challenging task, in that, three controller parameter \( K_p \), \( K_i \) and \( K_d \) which have a significant controller success, should be determined properly. Practically, this determination or say ‘tuning process’ is performed by an experienced operator based on trial and error method through the some practical rules. It is apparent that this method is time consuming and accordingly needs for relatively more time. Besides, once tuned, the controller performance may later deteriorate because of nonlinear or time varying characteristics of the process under control. In others word, a PID controller with fixed parameter set cannot provide a moderate performance over wide a range of operating condition.

The PID controller calculation involves three separate parameters; the proportional, the integral and the derivative values. The proportional, integral and derivative term is given by:

- Proportional: \( P = K_p e(t) \)
- Integral: \( I = K_i \int_0^t e(\tau)d\tau \)
- Derivative: \( D = K_d \frac{de(t)}{dt} \)

Therefore,
\[
\text{PID} = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt}
\]

(14)

### IV. PROPOSED METHOD: FLC

Fuzzy Logic is a type of logical reasoning that can be incorporated into automation systems typically enacting human reasoning schemes. Fuzzy theory was first proposed and investigated by Prof Zadeh in 1965. One of the main features of fuzzy logic is its ability to operate with vague or ambiguous concepts typical of qualitative reasoning, based on a mathematical support quantitative conclusion can be drawn from a set of observations and qualitative rules. Fuzzy logic control is the application of fuzzy inference process automation. A typical fuzzy controller infers the consequent of more or less large simple rules, this process of reasoning can be performed in parallel, yielding the result with a simple logical sum. This parallel processing capability allows even relatively complex controllers to perform the fuzzy inference in a minimum computation time.

In a fuzzy logic system, the inference mechanism decides what rules to apply for the corresponding inputs by matching the fuzzified inputs to the premises of the rules in the rule base. The inference mechanism provides a fuzzy set that indicates the certainty that the plant input should take the various values. The de-fuzzification is used to convert the fuzzy set produced by the inference mechanism into a crisp output to be used by the plant.

![PID Controller](image_url)

**Fig. 3: PID Controller**

The PID controller calculation involves three separate parameters; the proportional, the integral and the derivative values. The proportional, integral and derivative term is given by:

\[
P = K_p e(t) \quad (11)
\]

\[
I = K_i \int_0^t e(\tau)d\tau \quad (12)
\]

\[
D = K_d \frac{de(t)}{dt} \quad (13)
\]

Therefore,
\[
\text{PID} = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \quad (14)
\]
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a single non-fuzzy output signal which is the control signal of the system. The output levels are depending on the rules that the systems have and the positions depending on the non-linearities existing to the systems.

To achieve the result, the control curve of the system representing the Input-output relation of the systems is developed and it is based on the information, defining the output degree of the membership function with the aim to minimize the effect of the non-linearity.

- Fuzzy Output: The output is output gain that can be tuned and also become as an integrator. The output crisp value can be calculated by the centre of gravity or the weighted average.

In order to develop the Fuzzy Logic Controller, FLC toolbox in Simulink has been used. Below are general setting parameter and method has been used for FLC controller.

- Fuzzy Input
  1) Error
  2) Change in error

- Fuzzy Output:
  1) Control output

- Fuzzy Inference System: Mamdani

- Defuzzification Method: Centroid

- Rules Base

V. SIMULATION AND RESULTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armature Resistance (Ra)</td>
<td>1 Ohm</td>
</tr>
<tr>
<td>Armature Inductance (La)</td>
<td>0.5 H</td>
</tr>
<tr>
<td>Inertia, J</td>
<td>0.01</td>
</tr>
<tr>
<td>Damping, b</td>
<td>0.1</td>
</tr>
<tr>
<td>Kp</td>
<td>17.93</td>
</tr>
<tr>
<td>Ki</td>
<td>43.54</td>
</tr>
<tr>
<td>K</td>
<td>-0.77</td>
</tr>
<tr>
<td>Filter Co-efficient(N)</td>
<td>4.22</td>
</tr>
</tbody>
</table>

Table 1: Simulation Parameters

The DC Motor Model used in this work is as shown below:

Fig. 5: Proposed Model of Fuzzy Logic Controller

The PID controller simulink model used in this research work is as shown below:

Fig. 7: PID Control DC Motor Simulink Model

The comparison plot of PID control and Fuzzy Logic Control is as shown below:

Fig. 9: Comparison of PID and Fuzzy Logic Controller

The Fuzzy Inference System is shown in figure 8. The two inputs are ERROR and Change in ERROR values. The CONTROL variable is taken as the output.

The following rule base has been used for implementing the fuzzy logic.

1) If (ERROR is VERY_LOW) then (CONTROL is INCREASES_MUCH)
2) If (ERROR is VERY_HIGH) then (CONTROL is DECREASES_MUCH)
3) If (ERROR is CONSTANT) and (CHANGE is ERROR_HIGH_NEGATIVE) then (CONTROL is DECREASES_LITTLE)
4) If (ERROR is CONSTANT) and (CHANGE is ERROR_HIGH_POSITIVE) then (CONTROL is INCREASES_LITTLE)
5) If (ERROR is MED_HIGH) then (CONTROL is DECREASES_LITTLE)
6) If (ERROR is MED_LOW) then (CONTROL is INCREASES_LITTLE)
7) If (ERROR is CONSTANT) then (CONTROL is HOLD)

Fig. 8: FIS Editor

The comparison plot of PID control and Fuzzy Logic Control is as shown below:
The graph shows the effectiveness of Fuzzy Logic Controller in mitigating the effects of non-linearity in the DC motor characteristics. The comparison graph shown in figure 9, clearly shows that fuzzy logic controller quickly latches on the steady state level as compared to the PID controller.

<table>
<thead>
<tr>
<th>Controller</th>
<th>Peak Overshoot (%)</th>
<th>Rise Time (s)</th>
<th>Settling Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuzzy</td>
<td>.31</td>
<td>0.3</td>
<td>.73</td>
</tr>
<tr>
<td>PID</td>
<td>9.227</td>
<td>0.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Table 2: Characteristics

Table 2 shows the performance characteristics of the two controllers. The fuzzy logic controller takes less setting time and has almost negligible peak overshoot. A load is applied at around 7secs to both the models, as can be seen, the fuzzy logic controller a slightly lesser time to recover. Thus, fuzzy logic controller have found to be effective in control of DC motor.

VI. CONCLUSION

Fuzzy Logic Controller for controlling speed characteristics of DC Motor has been modelled and simulated in this research work. The PID controller has also been implemented. The results shown as a comparison between PID controller and Fuzzy logic Controller which proves that under similar parameters the Fuzzy logic Controller has better results in terms of settling time and lesser peak overshoot values. A fuzzy logic controller takes lesser time in restoring to normalcy in wake of some changes in the characteristics.

REFERENCES