A Thyristor Based Speed Control Of Dc Motor: A Comparative Analysis

Using Pi-Fuzzy

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ABSTRACT-

The best control characteristics of DC motor have used in industries for different range of loading condition. Speed of DC machine can be controlled by the armature voltage. Armature voltage is controlled using AC-DC converter. With the increasing use of power semiconductor units, the speed control of DC motor is increasingly getting sophisticated and precise. Half converter, semi converter, full converter and dual converter are some of the thyristor based circuits which are used for speed control of DC motor. This paper describes the speed control scheme of DC motor by thyristor with its firing angles, at variable load condition and a comparative analysis of speed control technique is made in between PI and fuzzy logic on the controlling action.

The fuzzy logic controller enhances the robustness of the motor control system, which can handle abrupt load variation and exhibit good disturbance behavior. With this we implemented the PI (proportional integral) control on the system, which is the older technique to control the speed of DC motor and made a comparative analysis among both the technique. And it is watched out that fuzzy logic control technique is the best way to control the speed of DC motor at variable load condition.

Keywords: - DC motor control, fuzzy-logic controller, PI controller, Parameter tuning.
INTRODUCTION
DC motors are widely used in industry because of its low cost, less complex control structure and wide range of speed and torque. There are many methods of speed control of DC drives namely field control, armature voltage control and armature resistance control methods [1]. DC motors provide high starting torque which is required for traction applications. In DC motor control over a large speed range, both below and above the rated speed can be achieved quite easily. DC motors have inherent disadvantages that it needs regular maintenance and it is bulky in size. DC motors are tailor made, so it is very difficult to replace them. In general, armature voltage control method is widely used to control the DC drives. In this method, a controlled rectifier, or chopper is used but due involvement of power electronics elements, nonlinear torque speed characteristics are observed which are undesirable for control performance [2].

Nowadays state of art speed control techniques of DC motor are available. Thyristor based DC drives with analog and digital feedback control schemes are used. Phase locked loop control technique is also used for precise speed control and zero speed regulation. In past, many researchers presented various new converter topologies of DC motor control for different applications of industry [3], but at the basic level in all of them thyristor based AC-DC converter are used. MATLAB with its toolboxes like Simulink and SimPower System are used for simulation [4,5].

With this the application of fuzzy logic is an effective alternative for any problem where logical inferences can be derived on the basis of causal relationships. As a mathematical method which encompasses the ideas of vagueness, fuzzy logic attempts to quantify linguistic terms so the variables thus described can be treated as continuous, allowing the system’s characteristics and response to be described without the need for exact mathematical formulations [6]. In this paper, the application of fuzzy-logic concepts with PI on thyristor based AC/DC, to the speed control of a simple dc motor is illustrated.

The device model is straightforward and the physical implications of speed control are readily perceived. The objective of my paper provides a comparative study of thyristor based speed control techniques using PI and fuzzy logic. With these two technique I am controlling the firing angle of thyristor which will regulate the armature voltage.

MATHEMATICAL ANALYSIS OF DC MOTOR

![Fig.1. Equivalent circuit of separately excited DC motor](image)

*Fig.1. Equivalent circuit of separately excited DC motor*
The dynamic and steady-state model of separately excited DC motor is needed to analyze the torque speed characteristics. The schematic representation of the model of a separately excited DC motor is shown below in figure 1 in which $e_a$ is the terminal voltage applied to the motor, $R_a$ and $L_a$ are the resistance, and inductance of the armature circuit respectively, $R_f$ and $L_f$ are the resistance, and inductance of the field circuit respectively, $e_b$ is generated back emf and $T_m$ is the electromagnetic torque developed by the motor.

The torque is produced as a result of interaction of field flux with current in armature conductors and is given by Eq. (1)

$$T_m = K_f \Phi i_a$$  \hfill (1)

Here, $K_f$ is a constant depending on motor windings and geometry and $\Phi$ is the flux per pole due to the field winding.

The direction of the torque produced depends on the direction of armature current. When armature rotates, the flux linking the armature winding will vary with time and therefore according to Faraday’s law, an emf will be induced across the winding. This generated emf, known as the back emf, depends on speed of rotation as well as on the flux produced by the field and given by Eq. (2)

$$e_b = K_f \Phi \omega$$  \hfill (2)

By applying KVL at input side of in figure 1,

$$e_a = i_a R_a + L_a di_a/dt + e_b$$  \hfill (3)

In steady state condition,

$$E_a = I_a R_a + E_b$$  \hfill (4)

In terms of torque and speed, the steady state equation will be given by Eq. (5)

$$E_a = (T_m/K_f \Phi)R_a + K_f \Phi \omega$$  \hfill (5)

So,

$$\omega = E_a / K_f \Phi - [T_m/(K_f \Phi)^2]R_a$$  \hfill (6)
Thus from the above equation it is clear that speed can be controlled by varying there parameters, namely $E_a$, $R_a$, and $\Phi$.

The three methods of speed control are as following:
Armature voltage controlled ($E_a$).
Armature resistance controlled ($R_a$).
Flux controlled ($\Phi$).

Speed control using armature resistance by adding external resistor $R_{ext}$ is not used very widely because of the large energy losses due to the $R_{ext}$. Armature voltage control is normally used for speed up to rated speed (base speed). Flux control is used for speed beyond rated speed but at the same time the maximum torque capability of the motor is reduced since for a given maximum armature current, the flux is less than the rated value and so as the maximum torque produced is less than the maximum rated torque. Here the main attention is given to the armature voltage control method. In the armature voltage control method, the voltage applied across the armature $e_a$ is varied keeping field voltage constant. As equation (6) indicates, the torque-speed characteristic is represented by a straight line with a negative slope when the applied armature voltage is ideal, that ideal torque speed characteristic is illustrated in figure 2

![Fig.2. Torque speed characteristics of the separately excited DC motor at different armature voltage](image)

**THYRISTOR BASED TECHNIQUES OF DC MOTOR SPEED CONTROL**

A separately excited DC motor fed through three phase full wave converter is shown in fig.3. Three phase full wave converter feeding a DC motor offers the armature voltage to the DC motor. It offers two quadrant drive and is used up to about 1500 kW drives.

For three phase full wave converter, average output voltage of converter can be calculated, given as in Eq. (7)

$$V_0 = \frac{V_t}{\pi} = \frac{3V_m}{\pi} \cdot \cos \alpha \quad \text{for } 0 \leq \alpha \leq \pi \quad (7)$$
Hence with adjusting the value of alpha ($\alpha$) we can control the voltage at the output of the rectifier end which act as the armature voltage to the Dc motor and hence it speed can also be controlled with this.

![Fig.3. Thyristor based speed control of separately excited dc motor](image)

**FUZZY LOGIC FUNDAMENTALS**

Fuzzy logic is a mathematical theory which encompasses the idea of vagueness when defining a concept or a meaning. For example, there is uncertainty or “fuzziness” in expressions like “large” or “small,” since these expressions are imprecise and are relative to one another. Variables considered thus are termed “fuzzy,” as opposed to “crisp.” Fuzziness is simply one means of describing uncertainty [7]. The following definitions and principles [8] are relevant here:

**Definition 1. Fuzzy Set:**

Let $X = \{x\}$ signify a classical set whose elements are signified by $x$.

Then a fuzzy set $A$ in $x$ represents a set of ordered pairs

$$A = \{x, \mu_A(x), x \in X\}$$

Where $\mu_A(x)$ is designated as the degree of membership of $x$ in and is limited to values between 0 and 1, with 0 signifying the lowest degree and 1 the highest degree of membership. (This is in contrast to classical, discrete set theory, where $\mu_A(x) = 0$ or 1, where 0 signifies that $x$ does not belong to $A$ and 1 denotes that belongs to $A$.)

**Definition 2. The Union of Two Fuzzy Sets:**

The union of two fuzzy sets $A$ and $B(A \cup B)$ is the smallest fuzzy set which includes all articles in $A$ or $B$ both $A$ and $B$ from this it can be stated that the union is a logical $OR$ operator. The membership function of $A \cup B$ is shown as follows:

$$\mu_{A\cup B}(x) = \max(\mu_A(x), \mu_B(x)), \quad x \in X$$

Where $\max(a,b) = a$ if $a \geq b$ and $\max(a,b) = b$ if $a < b$. 
Definition 3. The intersection of Two Fuzzy Sets:

The intersection of A and B (A \( \cap \) B) is the largest fuzzy set within both A and B, which indicates that the intersection is a logical \textit{AND} operator. The following is the membership function of A \( \cap \) B:

\[ \mu_{A \cap B}(x) = \min (\mu_A(x), \mu_B(x)), \quad x \in X \]

Where \( \min(a,b) = a \) if \( a \leq b \) and \( \min(a,b) = b \) if \( a > b \).

Once the fuzzy variables are defined, membership functions are assigned to them. This process is called \textit{fuzzification}. There are some rules of thumb which are customarily applied in defining the fuzzy sets. First, the number of fuzzy sets assigned to each variable is usually an odd number. This ensures the availability of a center point, which tends to inhibit numerical oscillation between adjoining values. Second, the number of such fuzzy sets is usually between three and nine. Since linguistic variables are used to describe causal relationships, we must (in a human-logic sense) be able to distinguish one subset from another. This becomes more difficult as the number of subsets becomes large (i.e., it is relatively easy to distinguish between “small,” “medium,” and “large” values of a variable, but much more difficult if many gradations exist). We must be able to make sense of the linguistic definitions of the subsets.

Also, each fuzzy set should overlap its adjoining set(s). This overlap provides a contiguous control surface for the fuzzy controller. A 10–50% overlap between adjoining sets is generally recommended [9].

After defining the fuzzy sets and assigning their membership functions, rules must be written to describe the action to be taken for each combination of control variables. These rules will relate the input variables to the output variable using \textbf{If- Then} statements which allow decisions to be made. The \textbf{If} (condition) is an antecedent to the \textbf{Then} (conclusion) of each rule. Each rule in general can be represented in the following manner:

\textbf{If} (antecedent) \textbf{Then} (consequence)

Finally, a process called \textit{defuzzification} is necessary to convert fuzzy values into crisp numerical results [9]. One of the most common (and easily understood) methods of defuzzification is the centroid (or moments of inertia) method.

In this method, the centroid of the area confined by the membership function curve is assumed to be the most typical crisp value of the fuzzy measure. With reference to fig. 4, the centroid or “center of gravity” CG can be found as
$$CG = \frac{\sum_i \mu_i(y_i) y_i}{\sum_i \mu_i(y_i)}$$

**Fig. 4.** Illustration of center of gravity method.

**SPEED CONTROL USING CLASSICAL PI TUNING METHODS**

The P-I controller has a proportional as well as an integral term in the forward path, the P-I controller for a dc motor drive is shown in Simulink fig. 5.

The integral controller has the property of making the steady state error zero for a step change, although a P-I controller makes the steady-state error zero, it may take a considerable amount of time to accomplish this. Here $K_p$ and $K_i$ values are adjusted as per the desired output. And it is seen the value of $K_p$ and $K_i$ for which we get better response is selected.

**SIMULINK RESULT**

The result of the two models shows that Pi controller has more transient and at variable load it is not able to make steady response of the system.

Whereas in fuzzy controller it is seen that the transient is much less in comparison to PI and at the variable load condition the fuzzy controller shows more steady response than that of PI as shown in the results i.e in fig. 8.

Both the models are designed to provide the proper firing angle to the thyristor so that DC motor armature voltage can be controlled and they are shown in fig. 5 and fig. 7 in simulink model of PI and fuzzy respectively.

**Fig. 5.** Simulink Model of PI controller
CONCLUSION

From simulation results, it was shown that PI controller maintained the steady state accuracy while the fuzzy controller performed well in the case of load change with shorter settling time and better response as shown in simulation result of PI and fuzzy in fig. 6 and fig. 8 respectively. The PI controller will be selected to maintain the high steady-state accuracy. The simulation results obtained on a dc motor speed control system using a fuzzy logic controller and PI controller are presented in the paper. Here we used both the controller technique to adjust the proper firing angle of the thyristor and it was found that fuzzy shows better response than that of PI. The system uses a basic FLC. It is seen that the step response with error interpreter has a smaller rise time and a reduced overshoot with almost no change at variable load in speed.
REFERENCES