Design and optimization of fuzzy controllers based on the operator's knowledge

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Abstract:
This makes it a necessity to employ a method to effectively control the speed of a separately excited DC motor. Many methods are available to regulate the speed of a separately excited DC motor such as PID control, Fuzzy Logic Control, Neural Network Method. The Fuzzy method gives a human like intuition to the control strategy and is self-tolerant to inputs which are no so precise. The Fuzzy Logic Controller contains different components like Fuzzification, Defuzzification and Fuzzy Rule inference. The Objective is to understand the Fuzzy Rule base and inference methods and employ them in controlling the speed of the motor. It is very efficient where the precision required is not too high. It is a robust, easily controllable strategy.

1. Introduction:

A DC motor is an electrical machine which coverts direct current electrical power into mechanical power. We use DC motors in almost every aspect of our daily life like in Toys, Fans, Automobile drives. Small DC motors are used in toys, tools and appliances. Larger DC motors are used in electrical automobiles, propulsion systems and elevators. Industrially a good performing DC motor is required of high speed controllability, steady and transient state stability and good Torque-Speed characteristics. The speed of a DC motor is very easily controlled compared to AC motors. The making of highly controlled motors is critical for Industrial purposes. For a satisfactory operation, a DC motor must have an excellent speed tracing and regulation of load. DC motors are easily constructed when compared to the AC motors which are bulky. DC motors are very economical when the requirement of horse power is high. An estimation states that more than 95% of controllers used for controlling speed of a DC motor are PID controllers. But they performance degrades in case of the non-linearity in characteristics.

Approaches to Speed control

Speed control of the DC motor is realised by following methods:
- In constant torque region, we can vary the armature voltage to achieve speeds below the rated speed.
- In constant power region, we can increase the field flux to obtain speeds beyond the rated speed.

Here field control is not generally used because the machine core will be rendered under- utilized. In armature control, the range of speed control is more but the ohmic losses will increase considerably.

Methods of control:

Following methods are the most generally used methods for controlling speed of a separately excited DC motor. They are:
- In low power DC motors, we can use the Armature rheostat control method.
- P or PI or PID control depending upon the requirement of the application.
- Neural Network Controllers are used where continuous control of speed is required.
- Adaptive method in Field weakening to achieve speeds above rated speed.
- PWM inverter method for variable armature voltage control.
- Fuzzy Logic Control method.
- Neuro - Fuzzy Logic controller inherits advantages of both Neural Network Controller and Fuzzy Logic Controller.

Aforementioned control methods have certain dis-advantages. Here we discuss mainly the Fuzzy Logic Control. There has been very productive research in this region of. Fuzzy Logic Controller [3].We face some difficulties in speed these methods like:
- Different indefinite inputs,
- Unpredictable Load dynamics,
- Unidentified parameters,
- Undesired Noise,
- Non-linearity in motor characteristics.

1.2 Steady State Operation:

normally the armature resistance in the circuit is negligible. So, the voltage drop across the armature resistance will be very small and can neglected. Since in steady state the field supply and Load torque are constant the speed finally depends on the Supply voltage for the armature. As shown the speed can be varied using Armature Voltage and Rheostat control. Here, we use the armature voltage control.

As the change in speed during steady state is zero.

$$T_m = B_m\omega + T_L$$

1.3 Variation of Speed:

Using Fuzzy Logic Controller, the armature voltage is varied which gives rise to a change in speed. The range of speed variation can be very small as the range of armature voltage control is generally very limited and also the armature resistance is assumed to be very small.

$$\omega = \frac{(V_f - I_a R_a)}{KF}$$

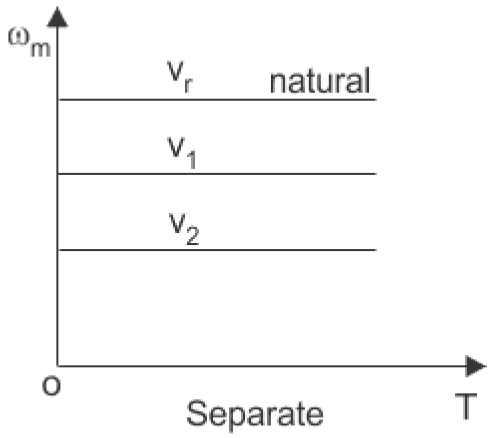

Figure 1 Speed vs. Torque Characteristic for Armature voltage control

Here $V_r > V_1 > V_2$.

1.4 Ranges of Speed variation:

Base Speed:

Base Speed is the speed of the motor at the rated armature voltage, rated armature current and rated field current.

Constant Torque Region:

This is the region where speed of the motor is below the rated speed and armature voltage is controlled to change the speed with Ia and If is fixed to generate constant torque.

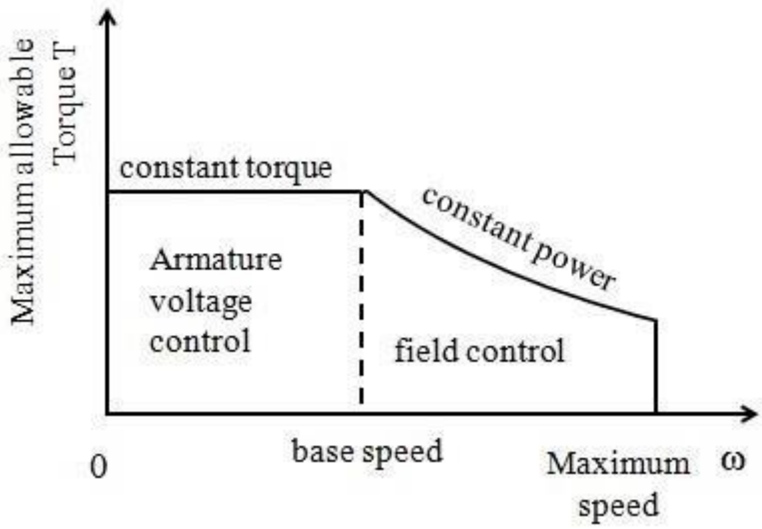

Figure 3 Torque vs. Speed Characteristics

Constant Power Region:
Here the speed is increased beyond the rated speed but armature voltage is kept constant. The field current is varied to increase the speed by weakening the field.

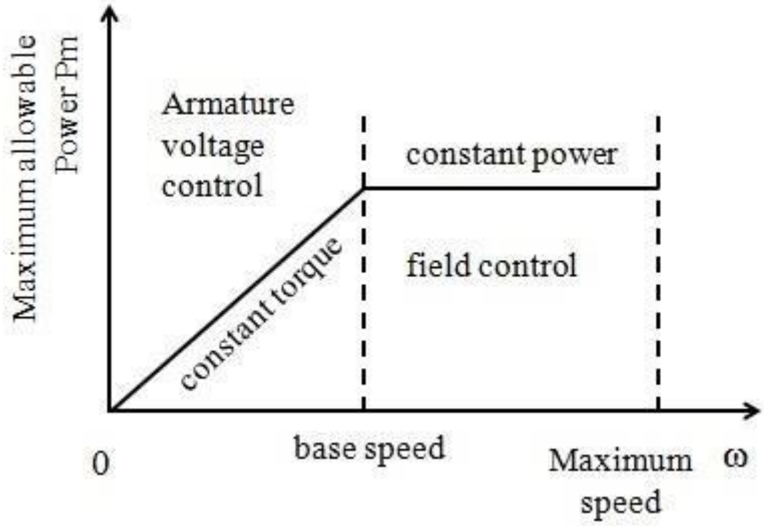

Figure 4 Power vs. Speed Characteristics

4 Fuzzy Control Method:

4.1 Basic Components in Fuzzy control:

Fuzzy logic control mainly depends upon the rules formed by the Linguistic variables. Fuzzy logic control is free of complex numerical calculations, unlike other methods. It only uses simple mathematical calculations to control the model. Despite relying on basic mathematical analysis it provides good performance in a control system. Hence, this method is one of the best methods available and also easier one to control a plant.
Fuzzy logic control is based on the Fuzzy set theory. In fuzzy set theory, each element has a degree of membership with which it belongs to any particular set. We can say that fuzzy sets are like classical sets without much sharper boundaries. Fuzzy Logic Controller (FLC) is more used when the precision required is moderate and the plant is to be devoid of complex mathematical analysis. Other advantages are:

- It does not require highly precise Inputs.
- It does not require fast microprocessors to bring about an efficient response.
- It needs very fewer data comparatively which is mainly rules and membership functions.
- It is more efficient and can perform better even in non-linear models.

The three main components of a Fuzzy Logic controller are

1. Fuzzification,
2. Fuzzy Rule base and Interfacing engine,
3. Defuzzification.

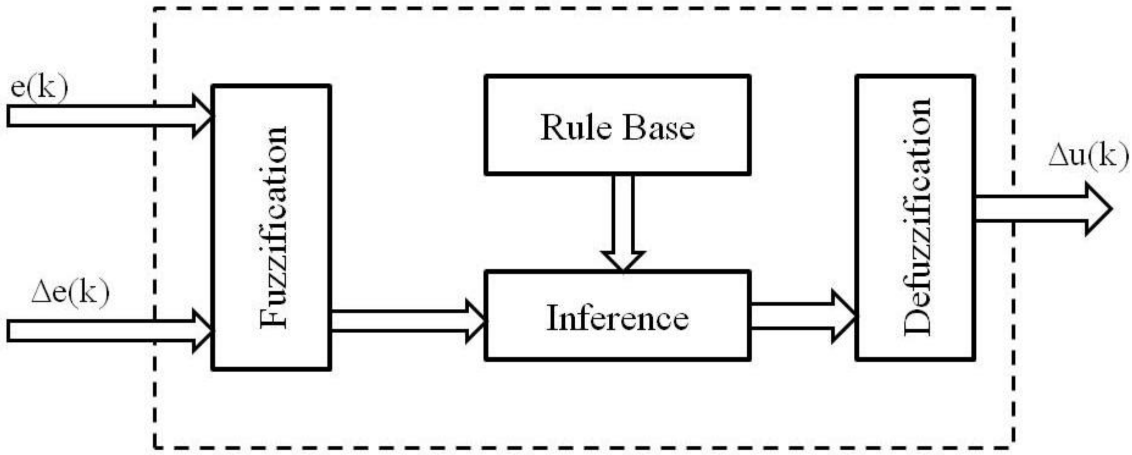

Figure 6 Fuzzy Control Internal Block diagram

4.2 Fuzzification module:

The most important step in formulating a design for the fuzzy controller is to identify the state variables which efficiently control the plant. After figuring out the state variables, they are to be passed through the fuzzification block to fuzzzify the inputs as the FLC works with only the Fuzzy inputs. As the Fuzzy Rule base employs rules on only linguistic variables, the numerical inputs have to be converted to fuzzy linguistic variables first. This process of converting a numerical state variable into a fuzzy input linguistic variable is called Fuzzification process. The variables generally used comprise of state error, the rate of change of state error (derivative of state error), or the area of a state error (integral of state error). The membership function is the graphical representation of the degree of belonging of an element to the fuzzy set. We can use different membership functions for an input and output depending upon the requirement of the precision to be provided. Generally used membership functions are triangular and trapezoidal membership functions. Gaussian and Bell shaped are some other available membership functions. For number of membership functions, the accuracy of control increases and the control works effectively. Complexity and time delay due to calculations increase with the number of membership functions taken for a linguistic variable. Hence, the number of membership functions to be used is a judgement that has to be made considering the quickness and efficiency of control to be delivered. In this model five membership functions for the Error and 2 membership functions for the Rate of change of error have been considered and the output has been given five membership functions.

4.3 Fuzzy Rule Inference:

Fuzzy inference is of two methods. They are Mamdani and Sugeno [6]. They are explained as below:

Mamdani Method:

Mamdani's methods of the Fuzzy interface is the most commonly used method. It was among the first control systems built using fuzzy set theory. It was first put forward by Ebrahim Mamdani as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. This inference method expects the output variable to be fuzzy sets. It is possible and also efficient to use a single spike in the output as membership function rather than a distributed fuzzy set. This is known as singleton output membership function. It enhances the Defuzzification process because it greatly simplifies the computation required by the more general Mamdani method which finds the centroid of the two dimensional function. But in the Sugeno type of inference can be used to model any inference system in which the output membership function is either linear or constant.

4.4 Defuzzification:

General methods adopted for Defuzzifying are:

1. Centre of Gravity Method,
2. Bisector of Area Method,
3. Mean of minimum Method.

The converse of Fuzzification is called Defuzzification. The Fuzzy Logic Controller (FLC) produces output in a linguistic variable (fuzzy number). As indicated by true prerequisites, the linguistic variables must be changed to crisp output. Centre of gravity strategy is the best understood Defuzzification system and utilized as a part of this exploration work. It acquires the centre of gravity of a region involved in the fuzzy set.

Defuzzification is the methodology of delivering a quantifiable result in the fuzzy form. A fuzzy control system has certain rules that change various variables into a "fuzzy" form, that is, the outcome is shown as membership functions and their degree of membership in fuzzy sets. The easiest but not much useful technique is to select the fuzzy set with the highest membership belonging, for this situation. The disadvantage of this methodology is that some data gets lost in this process. The rules that performed "Reduce Pressure" might as well have been absent with this process.

A helpful Defuzzification procedure should first include the outcomes of the results together somehow. The most average fuzzy set enrolment capacity has the shape of a triangle. Suppose, if this triangle were to be cut in a straight level line some place between the top and the base, and the top segment were to be removed, the remaining figure is in the shape of a trapezoid. This procedure removes parts of the figures to give trapezoids if the membership function used earlier was triangular (or different shapes if the initial shapes were not triangles). Generally these trapezoids are superimposed one upon another, giving a single shape. Finally, the centroid of this is computed. The abscissa of the centroid gives the defuzzified output.

5 Different Fuzzy Control Methods:

5.1 Types of Fuzzy Control Methods:

Fuzzy interface systems can be designed using two different methodologies. They are:

- Mamdani,
- Sugeno.

The outputs of these two methods vary somewhat in these two methods.

5.2 Mamdani Method:

Mamdani's methods of the Fuzzy interface is the most commonly used method. It was among the first control systems built using fuzzy set theory. This inference method expects the output variable to be fuzzy sets. It is more advantageous to use a single membership function of a linguistic variable instead of number of fuzzy sets which can be tedious in some cases. This method of using a single linguistic variable in output is called as Singleton output mechanism. It enhances the Defuzzification process because it greatly simplifies the computation required by the more general Mamdani method which finds the centroid of the two dimensional function. But in the Sugeno type of inference can be used to model any inference system in which the output membership function is either linear or constant.

5.3 Sugeno Method:

The first two parts namely, fuzzifying the inputs and applying the fuzzy operator, of the Sugeno method are similar to the Mamdani method. [8]

If the first input is x and the second input is y, then the Output is of the linear form

$$O = Kx + Ly + M$$

For a zero-order Sugeno model, the output O will be a constant (K = L = M).
The output level Oi of each rule is only weighted by the weightage Wi of the rule.

Comparison: When the performances of Mamdani and Sugeno models are compared with each other, the superlative outcome is obtained from the Sugeno mode. [7]

Mamdani Advantages:

- It is instinctual. Can be trained in human intuition.
- More generally acknowledged.
- It is more effective to human input.

Sugeno Advantages:

- It is very effective in calculations and controlling.
- It is generally used to enhance the linear techniques.
- It is used to optimize the parameters and works adaptively.

Conclusion

The inputs are Error is speed and Change in Error. We have studied above the Fuzzy rule base and formed the rules for 5, 2 linguistic variables of the inputs and 5 linguistic variables of the output using Fuzzy tool box. The membership functions used are
Error Signal – 2 trapezoidal and 3 triangular. Change in Error signal – 2 triangular.
Control signal – 5 triangular.

We have modelled the Fuzzy control scheme using SIMULINK and plotted various waveforms. From the Speed response waveform we can see that the rise time is 0.3318 sec, the peak time is 0.36 sec and the peak overshoot is 20 rad/sec (1.3% of the reference speed). Thus, we have controlled the speed of the DC motor using the Fuzzy control logic.

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