Interval Type-2 Fuzzy Logic Controller for Speed Control of DC Motor in an Intelligent Manner

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Abstract:
The method of variable speed control use in direct current motors adopting a fuzzy logic controller is fast replacing as compare some of the earlier conventional methods. In Electrical drive system a dc motor is fed from a fully controlled single phase convertor but the control is fails in the uncertain condition. This type of problem makes a critical issue in power plant where lots of motor are working. So there is need to control dc motor in such uncertain condition. This work give a design based on simulation of intelligent control by Interval Type-2 Fuzzy Logic Controller (IT2FLC). The designed fuzzy controller is effective in control performance in abnormal or uncertain conditions. The simulation study has been carried out and result are compared with type-1 FLC. The Result clearly demonstrate the superiority of the IT2FLC and compare to other methods proposed system is capable to control dc motors and performed better in both steady-state and cyclic conditions with more reliability.

Keywords: Type 2 fuzzy logic, DC motor, uncertainty, membership function

1. Introduction

DC motor system in industries is widely use due to its special performance characteristics such as high starting torque and relatively small change in current due to low change in current in unbalance load[1],[2]. DC motors are favored for high-performance, variable-speed drives due to their low maintenance requirements, minimum inertia, high power- and volume ratio, minimal friction, and reduced noise levels. The controller for a DC motor is more complex than that of a conventional motor. Additionally, to ensure proper operation of a DC motor, a good armature current response is essential. [3],[4],[5]. Numerous control techniques exist, dead-beat control including vector control, predictive control,and direct torque control, each with its own set of advantages and limitations. Traditional controllers often face challenges due to variations in electrical machine parameters, like armature resistance. Intelligent fuzzy logic (FL) has frequently been utilized in controller design. The benefit of fuzzy control methods is that they do not require the high precision that is difficult to achieve in a dynamic model. [6],[7],[8],[9].

There is considerable interest in exploring and advancing fuzzy systems, especially those utilizing type-2 fuzzy logic, because of their capability to manage uncertainty effectively. These systems hold great potential for use in control systems, as they can potentially compensate for errors from instrumentation systems and other sources. However, they require substantial computing resources, posing challenges for implementation on personal computers. Consequently, exploring alternative implementation methods, such as using programmable logic devices for fuzzy control, is an active area of research. Some studies focus on optimizing fuzzy inference systems for specific problems. In [10], This review examines different approaches for designing interval type-2 fuzzy controllers, highlighting the main reasons for optimizing these controllers in various application domains. It addresses the application of genetic algorithms, particle swarm optimization, and ant colony optimization as three unique paradigms that aid in developing optimal type-2 fuzzy controllers. In [11] They present a hybrid architecture that combines type-1 or type-2 fuzzy logic systems with genetic algorithms to fine-tune the parameters of membership functions, tackling the output regulation issue in a servomechanism with nonlinear backlash. Simulation results highlight the success of the optimized closed-loop system.

In the real world, imprecision is inevitable because of unexpected situations. Fuzziness is frequently used to describe imprecision and uncertainty. Zadeh [12] developed the fuzzy sets concept to manage the uncertainty of information in real-world scenarios.. Chang and Zadeh [4] identified the fundamental fuzzy sets concept and associated it with numbers, where a fuzzy number is utilized to numerically represent an imprecise or vague concept.. To deal with different problems involving uncertainty, imprecision and vagueness, the fuzzy sets concept was extended to various other concepts, especially interval-valued fuzzy set , intuitionistic fuzzy sets by Attanassov [13] and interval type-2 fuzzy sets by Mendel et al. [20]. Type-2 fuzzy sets proposed by Zadeh as an extension the idea of an ordinary fuzzy set, or a type-1 fuzzy set. The number of α-planes that approximate the generalized type-2 fuzzy sets is reduced with the implementation of high-order α-planes integration [23]. Due to the computational difficulty of applying a generic type-2 fuzzy set, Liang and Mendel[10] defined an interval type-2 fuzzy set as a specific instance of a mathematical formulation for the type-2 fuzzy set concept when the secondary membership degree equals one. A comparison between interval type-2 fuzzy systems and general type-2 fuzzy systems is described by Ontiveros et al. [14]for a set of diagnosis problems. In short, different types of fuzzy sets are defined to clarify their vagueness and uncertainty. The fuzzy numbers concept is an extension of the real numbers concept. In previous studies [9], there were several types of fuzzy numbers that were developed with the membership function concept, including triangular, trapezoidal and pentagonal fuzzy numbers. In the present approach the fuzzy rules results from a basic combination of the basic principles and expert working in control of dc motor. The guideline is illustrate in[15].

The structure of this paper is as follows: Section 2 elaborates on Preliminaries in which several definitions related to the objective of this study and presents some interval type-2 Fuzzy Logic Controller concepts. Section 3 demonstrate Modelling and Design of IT2FLC System . Section 4 provides Simulation and Results, and lastly, Section 5 presents the

1.1 Research Gap

In traditional techniques, achieving the desired control performance necessitates adjusting the controller parameters appropriately. In practice, this reflects numerous scenarios where it is challenging to decisively determine if something belongs to a specific category. Fuzzy expert systems can be applied in FLC to make effective control decisions. The knowledge used to create these fuzzy rules is often uncertain, resulting in rules with uncertain antecedents or consequents, which, in turn, leads to uncertain membership functions for those antecedents or consequents.

2. Preliminaries

This section introduces the concepts of fuzzy interval type-2 in term of fuzzy sets and numbers, pentagonal fuzzy numbers, and interval Type-2 pentagonal fuzzy numbers (IT2PFN). It also covers key concepts related to IT2PFN, such as fuzzy center value, area, and centroid. Type-2 fuzzy logic extends conventional type-1 fuzzy logic by incorporating uncertainty not only in linguistic variables as well as in the formulation of the membership function. Introduced by Zadeh in 1975, type-2 fuzzy sets extend ordinary fuzzy sets (type-1) by using a fuzzy membership function where the membership grade for each element is itself a fuzzy set within [0,1], as opposed to type-1 sets where the membership grade is a crisp number in the same interval. These sets are useful membership grades uncertainty, such as ambiguity in the membership function's shape or its parameters. Just as we apply here type-1 fuzzy sets when membership cannot be clearly defined as 0 or 1, type-2 fuzzy sets come into play when the membership grade itself is too uncertain to be represented as a crisp number. For instance, a type-1 membership function can be blurred to the left and right to create a type-2 membership function, as illustrated in the provided figures 2.

If we take a type-1 membership function, as depicted in Fig. 1, and extend it both to the left and right, as shown in Fig. 2, we obtain a type-2 membership function. The type-2 fuzzy membership function is illustrated in Fig. 3.

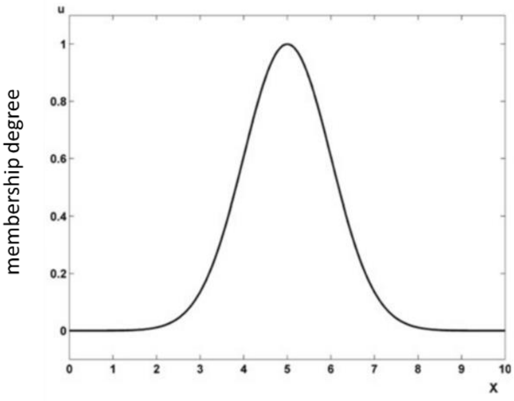

Fig. 1 Type-1 Membership function

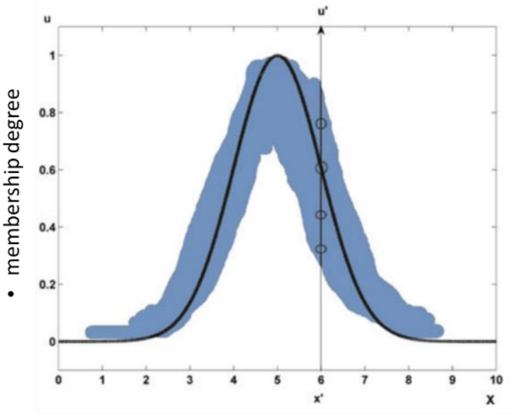

Fig 2. Blurred type-1 membership function

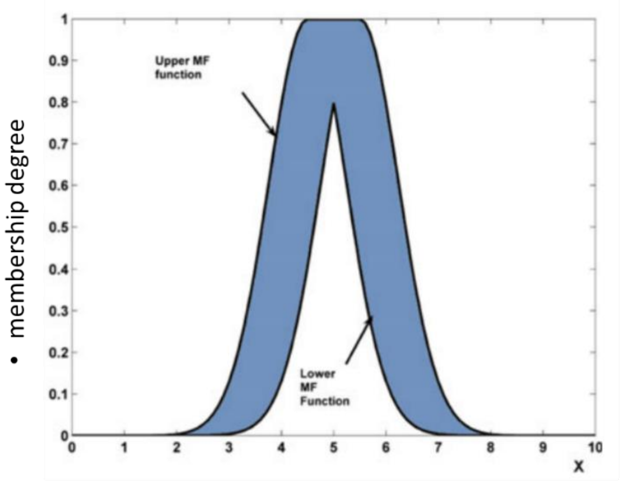

Fig. 3 Interval type-2 membership function

Definition .1. (Type-2 fuzzy sets): A type-2 fuzzy sets AT2F S is characterized by a type-2 membership function, A type-2 fuzzy sets, µAT 2F S (x, u) where x ∈ X and u ∈ JX, ⊆ [0, 1]. It is defined as: AT2F S = {((x, u), µAT 2F S (x, u)) /∀x ∈ X, ∀u ∈ JX ⊆ [0, 1]}, where Jx is the primary membership function in (0, 1) and u is the primary membership values in 0 ≤ µAT 2F S ≤ 1. It can also be expressed as follows: AT2F S = Z x∈X Z u∈JX µAT 2F S (x, u)/(x, u); JX ⊆ [0, 1], (2) where R R denotes union ovel all admissible x and u

Definition 2.2. (Interval type-2 fuzzy sets): An interval type-2 fuzzy set, AT2F S is a type-2 fuzzy set when all secondary membership function is unity defined as: AT2F S = Z x∈X Z u∈JX 1/(x, u); JX ⊆ [0, 1].

Definition 2.3. (Interval type-2 fuzzy numbers : An interval type-2 fuzzy set defined on real line R is called an interval type-2 fuzzy number AIT2F N . It is defined as: AIT2F N = [A U , AL], (4) where AU and AL are upper and lower membership functions, respectively, such that AU ⊆ AL

A fuzzy logic system (FLS) that exclusively uses type-1 fuzzy sets is called a type-1 fuzzy logic system (type-1 FLS).It consists of a knowledge base, which contains linguistic control rules provided by the process operator; a fuzzification interface that converts crisp data into fuzzy sets; an inference system that combines these fuzzy sets with the knowledge base to draw conclusions using a reasoning approach; and a defuzzification interface that translates the resulting fuzzy control action into a specific control action through a defuzzification process

In both engineering and scientific fields, there is growing interest in employing type-2 fuzzy logic controllers (FLCs). Type-2 FLCs are well-documented for their effectiveness in managing uncertainty, a common feature of real systems. As uncertainty and real-world systems are inherently linked, research into innovative methods for handling incomplete or unreliable information remains highly relevant (Mendel, 2001). Recently, type-2 fuzzy sets have been applied in various fuzzy logic systems across different fields. These applications span fuzzy logic systems, neural networks, and genetic algorithms, with some studies focusing on the implementation of type-2 FLS and others demonstrating how type-2 fuzzy sets can model and mitigate the effects of uncertainties in rule-based FLS[16]. Additionally, a paper presents mathematical formulas and computational flowcharts for calculating the derivatives required to apply steepest-descent parameter tuning algorithms to type-2 fuzzy logic systems. Fuzzy logic controllers can handle imprecise information and model nonlinear functions of any complexity. They have been effectively utilized in a wide range of applications.

3 Modelling and Design of IT2FLC System

This section outlines the framework for interval type-2 (IT2) direct reasoning with IT2 fuzzy inputs. A Fuzzy Inference System (FIS) is a rule-based system that employs fuzzy logic rather than Boolean logic. Its fundamental structure consists of four components (as illustrated in Figure 4).[17][18],[15]]. This knowledge base is utilized by an inference mechanism, along with information about the process states (such as measured response variables), to determine the appropriate control actions. The key advantages of fuzzy logic controllers (FLCs) include:

(a) A precise mathematical model of the system is not required.
(b) They can manage nonlinearities of any complexity
(c) They rely based on linguistic rules with an if-then format, mirroring human logical reasoning

Standard Fuzzy Logic Controllers (FLCs) struggle to adapt to changes in operating conditions. They require additional information to address nonlinearities when conditions vary. Increasing the number of fuzzy logic inputs also enlarges the rule base, making its maintenance more time-consuming. Furthermore, FLCs lack systematic, effective design methods and adequate analysis tools that can leverage a priori knowledge of plant dynamics. Additionally, the implementation of FLCs has encountered challenges during hardware and software integration due to their high computational demands. Previous studies on fuzzy-logic applications in motor drives have mostly been theoretical or based on simulations and experimental results at low-speed conditions. Type-2 fuzzy systems involve four stages: fuzzification, inference, type reduction, and defuzzification, which are described below.

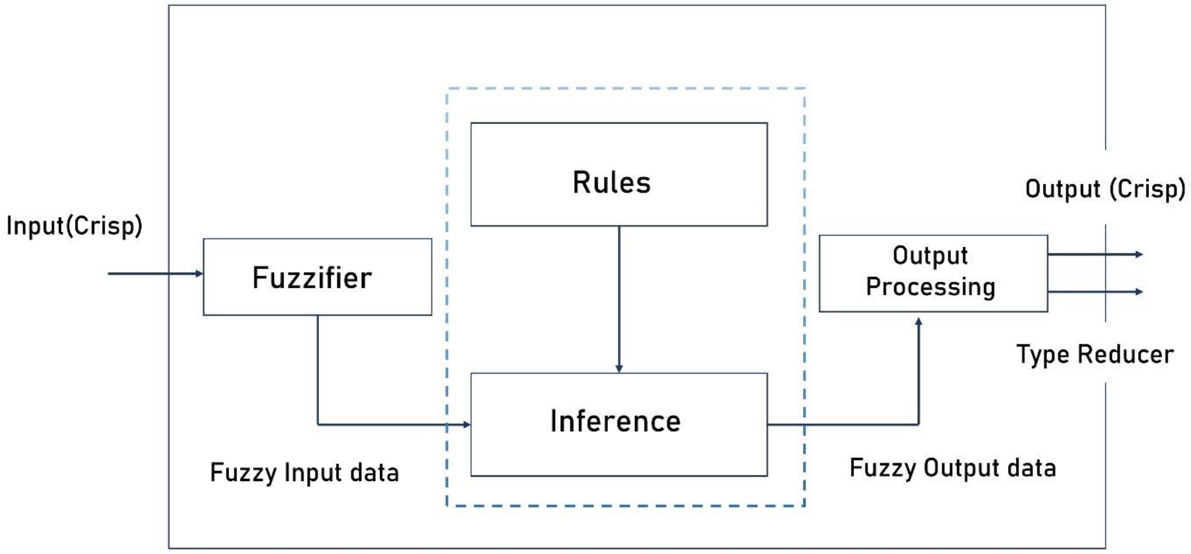

Fig.4 Architecture of Type-2 FLC

Fuzzifier

A numeric vector $x = (x_1,..., x_p)^T \in X_1 x X_2 x \dots x X_p \equiv X$ is mapped by the fuzzifier into a type-2 fuzzy set $\widetilde{A}_x$ in X, which is in this case an interval type-2 fuzzy set. We employ a type-2 singleton fuzzifier for the system shown in Fig. 4. In singleton fuzzification, there is only one point on the input fuzzy set that is not zero. If $\mu \widetilde{A}_x (x) = \frac{1}{1}$ for x = x` and $\mu \widetilde{A}_x (x) = \frac{1}{0}$ for all other X=X` then $\widetilde{A}_x$ is a type-2 fuzzy singleton.

Interval type-2

When every point in the domain has a crisp set membership grade and its domain is an interval inside [0,1], this is referred to as an interval type-2 fuzzy set. The characteristics of a fuzzy set with a Gaussian membership function are a variable standard deviation [σ1,σ2].and a mean (m).

Fuzzification

The motor variables requiring control are speed (ω) and armature current (ia). In the proposed PI fuzzy speed controller, the input variables are defined as the motor speed error es(k) and the rate of change of the speed error Δes(k).

$e_s(k) = w_r(k) - w(k)$……………………………………………………………..(4)

$\triangle e_s(k) = e_s(k) - e_s(K-1)$ ………………………………………………………(5)

Fuzzy Control Rules

Fuzzy control rules are developed based on intuition and experience rather than relying on a specific system model. A general rule can be described as follows:

If e(k) is W and △e(k)) is Q Then Δu (k) is C

Here, △u (k) represents the change in control input (the output of the fuzzy controller), while W, Q, and C denote the fuzzy subsets defined over the universes of discourse for e, △e, and △u, respectively.

Type Reducer

The type-reducer produces a type-1 fuzzy set output, which is subsequently converted into a crisp value by the defuzzifier. This type-1 fuzzy set is also an interval set; in our fuzzy logic system, we utilized the center of sets (cos) type reduction method.

Defuzzification

Essentially, a defuzzification scheme can be seen as a transformation from a set of fuzzy control actions defined over an output universe of discourse into a set of precise control actions. The goal of a defuzzification strategy is to generate a crisp control action that accurately reflects the possibility distribution of an inferred fuzzy control action. Various strategies for defuzzification are documented in the literature, including the max criterion, the mean of maximum, winner-takes-all, and center-of-gravity methods. The centroid method, based on the Takagi-Sugeno-Kang inference method, is employed for defuzzification.

These systems depend on rules that use linguistic variables, terms, and fuzzy logic. While obtaining these rules can be a complex task for experts, it is essential for the effective functioning of the controller.

From the type reducer, we derive an interval set Ycos. To defuzzify this, we use the average of Yl and Yr, resulting in the defuzzified output for an interval singleton type-2 fuzzy logic system.

$$y(x) = \frac{y_l + y_r}{2}$$

4 Simulation and Results

An interval type-2 fuzzy logic controller (IT2FLC) for a DC motor was modeled and simulated utilizing MATLAB/Simulink Power System Blocksets as illustrated in Fig. 5. Fig. 6 displays the motor current obtained from the simulation runs, demonstrating variable current for different loads on the motor. The Simulink model was employed to predict performance under uncertain conditions. To evaluate the performance of the T2 and

T1 FLC and T1-FLC, speed control simulations were conducted employing a mathematical model of the plant within MATLAB/Simulink. Figure 7 illustrates the T1and T2-FLC used for controlling the speed of a DC motor with the fuzzy incremental control model. Each input and output of the T2-FIS and T1-FIS comprises three linguistic terms. For the linguistic variables 'error' and 'change of error,' the terms are {NB, Z, PB}, with NB representing Negative Big, Z signifying Zero, and PB indicating Positive Big. For the linguistic variable 'control signal,' the terms are {BD, H, BI}, where BD denotes Big Decrement, H stands for Hold, and BI signifies Big Increment.. The rule base employed in this study includes 49 rules with 7 membership functions, generated from expert insights and multiple simulation runs of the FLC. The simulation results indicate that this method of controlling the DC motor outperforms both the conventional controller and the type-1 controller.

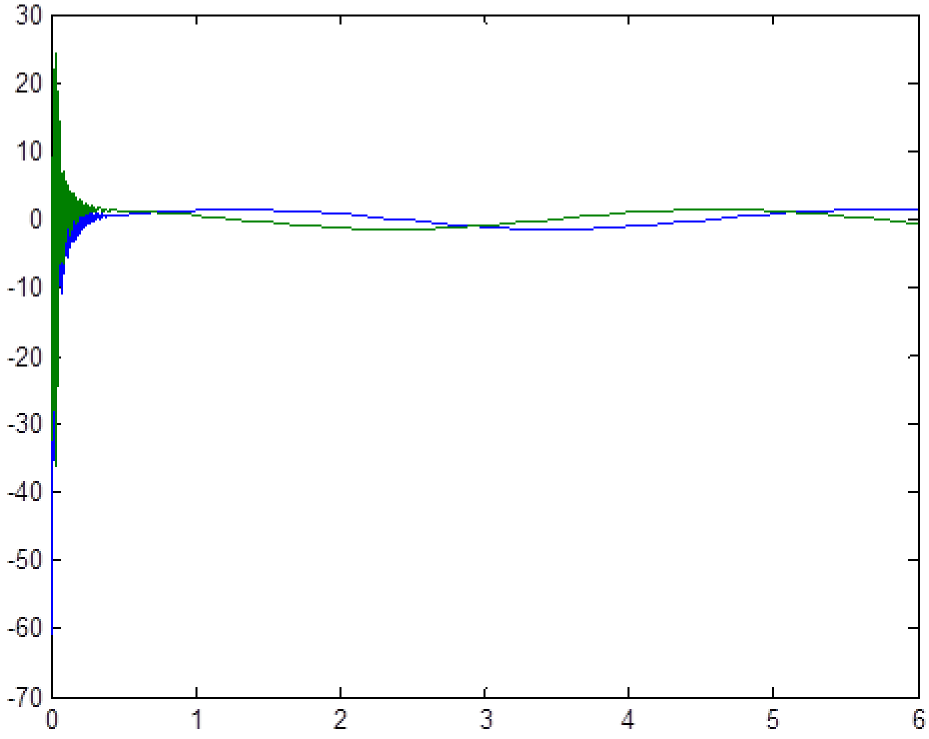

Fig. 6. Motor rotor current at type1 and type 2

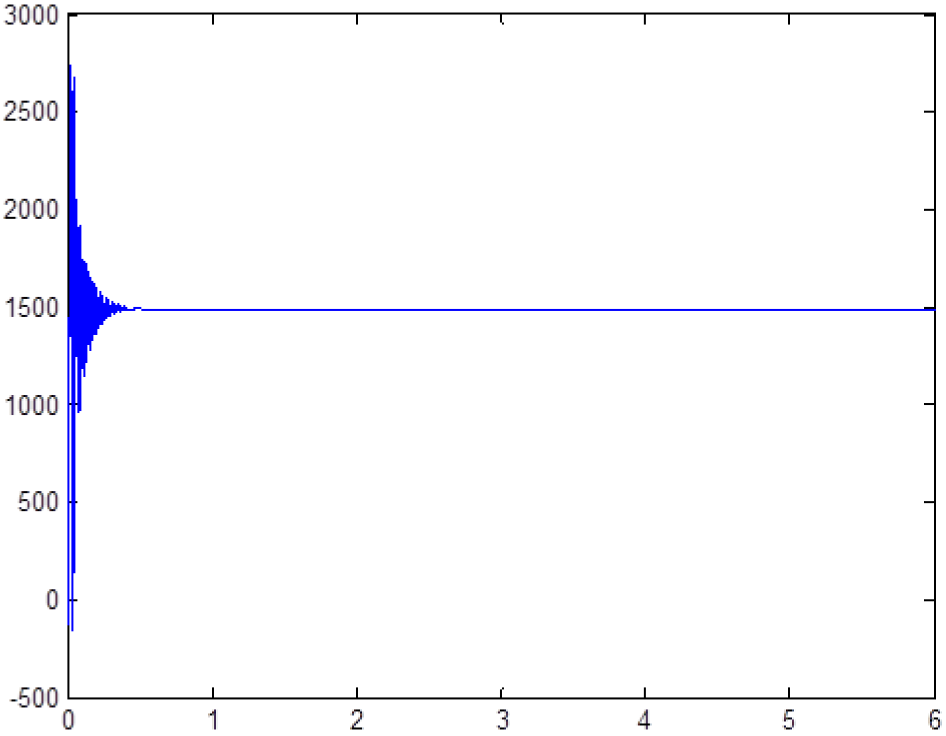

Fig. 7. control speed by type-2

5 Conclusions

Various methods used and available for starting high-inertia loads. When selecting a specific starter for such applications, of ownership must be considered. Regardless of the chosen starting method, it is essential to inform the motor manufacturer to ensure the motor is designed to meet performance expectations.

This study utilizes three defuzzification methods—center of sums, center of gravity, and weighted average—to determine the crisp number for IT2PFN. The soft starter proposed is engineered to fulfill the industrial demands of equipment such as compressors, blowers, fans, pumps, mixers, and crushers., grinders, and various other applications such as machine tools, robotics, and servo drives. Future work includes developing a comprehensive toolbox capable of simulating any machine controller.

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