Application of Hyper-Fuzzy Logic in Field Oriented Control of Induction Machines

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Abstract: **A comparative study between type-1 and type-2 fuzzy systems, introducing the main differences in membership functions and operations done on these fuzzy sets, as well as defuzzification/ type-reduction, is introduced in this paper. Fuzzy sets with view of membership functions of type-1 and type-2 are illustrated along with the foot print of uncertainty (FOU). A hyper-fuzzy controller is proposed which regulates the speed with minimum steady-state error for a field-oriented PWM inverter of induction motor. It showed better response than conventional PI controller response to variations in load as well as speed reference. In this paper robustness of proposed controller to machine parameter variations is shown.**
Keywords: Fuzzy Logic, Membership function, IT2FLS, FOU, FLC, field oriented control scheme.

1. Introduction

Fuzzy logic has obtained attention of researchers for last couple of decades. It has displaced conventional technologies in different scientific and system engineering applications, especially in pattern recognition, signal processing communication, integrated circuit manufacturing, biomedical systems, and mostly overall control systems.

Same fuzzy technology, in approximation reasoning form, is resurging in the information technology, giving support to decision-making, and expert systems with powerful reasoning capacity and a limited quantity of rules [1-3]. Fuzzy sets were presented by Zadeh in 1965 to process / manipulate data and information affected by unprobabilistic uncertainty/imprecision [2]. These sets were designed to mathematically represent the vagueness and uncertainty of linguistic problems; thereby obtaining formal tools to work with intrinsic imprecision in different type of problems; it is considered a generalization of the classic set theory. Intelligent systems based on fuzzy logic are fundamental tools for nonlinear complex system modeling. Fuzzy sets and fuzzy logic are the base for fuzzy systems, where their objective has been to model how brain manipulates inexact information.

In 1975, Zadeh presented a new type of fuzzy logic as an extension to the ordinary type-1 fuzzy. This new type of fuzzy logic is essentially "fuzzy fuzzy" sets where the fuzzy degree of membership is a type-1 fuzzy set [2,4].

Ordinary fuzzy systems or in other words type-1 fuzzy logic systems are deterministic in the sense that for the same inputs the outputs are always the same. However, human experts exhibit a nondeterministic behavior in decision making. Variation may occur among the decisions of a panel of human experts as well as in the decisions of an individual expert for the same inputs [2,3].

Understanding the dynamics of the variation in human decision making could allow creating truly intelligent systems that cannot be differentiated from their human counterparts. Moreover, in application areas, where having an expert constantly available is not possible, such systems can produce a span of decisions that may be arrived at by a panel of experts [4,5]. This paper presents a comparison between type-1 fuzzy logic systems (T1FLS) and type-2 fuzzy logic systems (T2FLS) in the sense of membership functions (MFs), operations, and defuzzification criteria on both T1FLS and T2FLS. This paper also presents an application of T1FLS on Speed control of induction machine using field oriented PWM inverter.

2. Type-1 Fuzzy Logic System

After Zadeh presented the fuzzy sets, the concepts of fuzzy algorithms, fuzzy decision making, and fuzzy ordering had been proposed. In 1973, Zadeh published another paper which established the foundation for fuzzy control. In that paper he introduced the concept of linguistic variables and proposed the IF-THEN rules to formulate human knowledge [1,4,6].

The term fuzzy logic has been used in two different senses [7]. In a narrow sense, fuzzy logic refers to a logic system that generalizes classical two-valued logic for reasoning under uncertainty. In a broad sense, fuzzy logic refers to all of the theories and technologies that employ fuzzy sets, which are classes with non-sharp boundaries [1,7].

A definition of fuzzy sets can be given as:
Fuzzy set is a set consists of a universe of discourse X and $\mu(x)$, which maps every element in the discourse, to a membership value between 0 and 1. This can be represented as:
Let X is the universe set, and then a fuzzy set A in X can be defined as a set of ordered pairs [1,4,6,7]: