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Design and Implementation of Fuzzy Logic Based Power System Stabilizers

S. Ramamoorthy

Bharath University,
Chennai-73, India

Abstract: Fuzzy logic has emerged as a promising tool for several power system applications. A large body of the literature in this area is concerned with the stability of the electric power system and considerable effort has been directed to the development of a fuzzy logic based power system stabilizer (FLPSS). The purpose of this paper is to present an overview of the FLPSS, based on published literature from 1989 to the present.

Key words: Fuzzy logic % Power system stabilizer % Power system stability

INTRODUCTION

Fuzzy logic has emerged as a promising tool for solving complicated problems involving the control of nonlinear systems and systems with complex behavior. Several power system applications fall into this category. Although the first such application, solving power system long-range decision-making problems, was investigated during the late 1970s, substantial interest in fuzzy logic based power system applications is fairly recent. The majority of these applications can be found in the area of excitation control, especially power system stabilizers [1-7]. Fuzzy logic power system stabilizers show promise as being less computationally burdensome and more robust than conventional power system stabilizers.

The purpose of this paper is to present an overview of FLPSSs, based on published literature from 1989 to the present. The overview of this paper is organized as follows: Sec. II presents some basic definitions and mathematical operations of fuzzy sets; Sec. III reviews the benefits and drawbacks of conventional (i.e. non-fuzzy) power system stabilizers, first proposed in the 1950s; Sec. IV introduces the major parts of a FLPSS; Sec. V briefly discusses how a FLPSS is made adaptive; and Sec. VI mentions the robustness feature of a FLPSS.

Rudiments of Fuzzy Set Theory: First, some basic definitions and mathematical operations of fuzzy sets, taken from [5], are presented.

Fuzzy Set: Let X be a collection of objects. (X is the universal set.) A fuzzy set A in X is defined [5] to be a set of ordered pairs [5].

$$A = \{(x, \mu_A(x)) \mid x \in X\}, \quad (1)$$

where $\mu_A(x)$ is called the membership function of x in A. Note that the membership function $\mu_A(x)$ denotes the degree to which x belongs to A and is normally limited to values between 0 and 1. A high value of $\mu_A(x)$ implies that it is very likely for x to be in A. Elements with a zero degree of membership are normally not listed. If we limit the values of the membership function to be either 0 or 1, then A becomes a crisp (non-fuzzy) set [8, 9].

And Operation of Fuzzy Sets: Let A and B be two fuzzy sets with membership functions $\mu_A(x)$ and $\mu_B(x)$, respectively. The membership function of the intersection $C=A \wedge B$, denoted $\mu_C(x)$, is defined [5] by

$$\mu_C(x) = \min(\mu_A(x), \mu_B(x)) \quad (2)$$

Or Operation of Fuzzy Sets: Let A and B be two fuzzy sets with membership functions $\mu_A(x)$ and $\mu_B(x)$, respectively. The membership function of the union $D=A \wedge B$, denoted $\mu_D(x)$, is defined [5] by

$$\mu_D(x) = \max(\mu_A(x), \mu_B(x)) \quad (3)$$

Not Operation of Fuzzy Set: Let A be a fuzzy set with membership function $\mu_A(x)$. Let A' denote the complement of A. The membership function for A', denoted $\mu_{A'}(x)$, is defined [5] by

$$\mu_{A'}(x) = 1 - \mu_A(x) \quad (4)$$

Fuzzy Relation: Let A and B be two fuzzy sets with membership functions $\mu_A(x)$ and $\mu_B(x)$, respectively.

Corresponding Author: S. Ramamoorthy, Bharath University,Chennai-73, India

A fuzzy relation R from A to B can be visualized [5] as a fuzzy graph and can be characterized by a membership function $\mu_R(x,y)$ satisfying the following composition rule:

$$\mu_B(x) = \max|_x(\mu_R(x,y), \mu_A(x)) \qquad (5)$$

Conventional Power System Stabilizers: The most commonly used PSS, referred to as the Conventional PSS (CPSS), is a fixed parameter analog type device. The CPSS, first proposed in the 1950's, is based on a transfer function designed using classical control theory [10]. It contains a phase compensation network for the phase difference from the excitation controller input to the damping torque output. By appropriately tuning the phase and gain characteristics of the compensation network, it is possible to set the desired damping ratio [11-15].

CPSSs are widely employed in present-day power systems to improve power system dynamic stability. According to Ref. 7, the CPSS has inherent drawbacks. It is designed for a particular operating condition around which a linearized transfer function model is obtained. The high nonlinearity, very wide operating conditions and unpredictability of perturbations of the power system cause the following problems to the CPSS: accuracy of linear model of power system and effective tuning of CPSS parameters. Numerous tuning techniques have been introduced to effectively tune the CPSS parameters.

Fuzzy Logic Based PSS: Fuzzy control systems are rule-based systems in which a set of fuzzy rules represents a control decision mechanism to adjust the effects of certain causes coming from the system.

A fuzzy logic power system stabilizer is basically a fuzzy logic controller. According to Ref. 8, the following are some of the major features of fuzzy logic control: model-free, in that this approach doesn't require the exact mathematical model of the system and robustness, offering simple solutions encompassing a wide range of system parameters and significant disturbances [16-20].

The basic configuration of a FLPSS can be represented in four parts: fuzzifier, knowledge base, inference engine and defuzzifier. "The fuzzifier maps the FLPSS input crisp values into fuzzy variables using normalized membership functions and input gains. The fuzzy logic inference engine then infers the proper control action based on the available fuzzy rule base. In turn, the fuzzy control action is translated to the proper crisp value through the defuzzifier using normalized membership functions and output gains." [8] Given the model of the FLPSS controller, we next consider the I/O to it, according to Ref. 8. For power system stabilization, speed deviation,)T and active power deviation,)P, or derivative of speed deviation of the synchronous machine are chosen as the FLPSS inputs. The output control signal (U_{pss}) is the input to the automatic voltage regulator (AVR). Each of the FLPSS input and output variables, (X_j={)T,)P,U_{pss}}), are scaled through input gains and interpreted into seven linguistic fuzzy subsets varying from Negative Big (NB) to Positive Big (PB). Each subset is associated with a triangular membership function to form a set of seven normalized and symmetrical triangular membership functions for each fuzzy variable. A symmetrical fuzzy rule set is used to describe the FLPSS behavior. Each entity in the table represents a rule in the form "if antecedent then consequence" (e.g. "if)T is NM and)P is PB then U_{pss} is PS").

Table 1 from Ref. 8 shows a sample of a rule base. Using the correlation product inference and the center of gravity defuzzification method, the appropriate crisp control is then generated.

Adaptive Fuzzy Logic Based PSS: An adaptive fuzzy system is implemented in the framework of an adaptive network architecture and equipped with a training (adaptation) algorithm using an Artificial Neural Network (ANN) [21]. Training input data are presented to the network and the network computes its output. The error between the system's output and the desired output is calculated and then the error is back-propagated through the whole network to adjust the network parameters to reduce the output error at each step.

Table 1: Sample of Rule Base

	Accelerating Power)P or Speed Deviation)ñ					
)T	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NM	NS	Z	PS	PM
Z	NM	NM	NS	Z	PS	PM	ΩM
PS	NM	NS	Z	PS	PM	PM	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

An example of this approach from Ref. 21, involves a fuzzy PSS with learning ability constructed and trained directly from the input and output data of the generating unit. Because the Artificial Network Fuzzy (ANF) system has the property of learning, fuzzy rules and membership functions of the controller can be tuned automatically by the learning algorithm. Learning is based on the error evaluated by comparing the output of the ANF controller and a desired controller.

Hariri and Malik in Ref. 21 reduce the initial startup error in training the ANF PSS by employing a priori knowledge in the form of untuned fuzzy if-then rules. In a conventional FLPSS, parameters (i.e. membership functions and rules) are specified by an expert who is familiar with the system. In the ANF based PSS, however, it is assumed that no expert is available; the initial values of membership functions parameters are equally distributed along the universe of discourse and all consequent parts of the rule table are set to zero. In this manner, the ANF PSS starts from zero output and during the training process it gradually learns to function as close to the desired controller as possible.

Robustness of Fuzzy Logic Based Pss: In general, a robust model has the following properties [20]:

- Continuous Behavior
- Shows a satisfactory generalization capability when extended to a set of data that has not been used in the model construction.

Fuzzy-logic models shown in the domain in which the actual system is continuous for small variations in the input are expected to generate small changes in the output whether or not the values of the deviated input have been used in the training procedure. Also, fuzzy-logic models can be extended from the training data set to a new data set that has not been used in the model construction when combined with ANN. With this arrangement it can achieve a larger system operating range while guaranteeing performance, not only for slowly changing parameters but also for arbitrarily fast changing parameters [20].

Compared with classical control design, not only does it eliminate the strict limitations on the changing rates of variables, but also shows guarantees for performance. In addition, it has been proven useful in simplifying the interpolations and realization problems associated with classical control.

CONCLUSION

This paper has presented an overview of fuzzy logic based power system stabilizers, based on published literature from 1989 to the present. Based on the efforts of these researchers, fuzzy logic power system stabilizers show promise as being less computationally burdensome and more robust than conventional power system stabilizers.

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