"Design of Interval Type-2 Fuzzy Logic PSS for a Multi-Machine Power System Control using GA Search Engine"

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Abstract - we introduce a novel interval type-2 Fuzzy Logic Power System (IT2FPSS). Interval type-2 FLS is used to improve the disturbance rejection of Power system which can be caused by variable nature of input parameters (electro-mechanical oscillations). The performance of interval type-2 fuzzy-logic power system stabilizer (IT2FPSS), which is tuned automatically as the operating conditions of power system change, is investigated by applying it to a multi-machine power system. IT2FPSS is developed using speed deviation ($\Delta\omega$) and the derivative of speed deviation ($d\Delta\omega$) as the controller inputs variables. Two scaling parameters are introduced to tune the IT2FPSS. These scaling parameters are the output of GA search engine, whose input is the ISE of the rotor speed deviation. The proposed scheme is referred to as the self-tuning interval type-2 fuzzy power system stabilizer (IT2FPSS). In this paper, the GA-based strategy that was employed to tune the parameters of IT2FPSS is described. Four IT2FPSSs (IT2FPSS1, IT2FPSS 2, IT2FPSS3, and IT2FPSS4) are evolved and tested on a power system.

Key Words: Conventional PID Power System Stabilizer (PIDPSS), Multi-machine system, Interval Type-2 fuzzy logic; Genetic Algorithms, Interval type-2 Fuzzy logic Power System Stabilizer (IT2FPSS)

1.INTRODUCTION

The fuzzy logic implementation of power system stabilizer (PSS) has been reported in a number of publications. As with conventional power system stabilizer (CPSSs), the performance of FPSSs depends on the operating conditions of the system however, they are less sensitive to changing operating conditions than CPSSs. Further improvement can be achieved by the IT2FPSS as the operating conditions of the power system changed.

In this paper a rule-based IT2FPSS is designed. Its parameters are tuned by another fuzzy logic system, making it adaptable to changes in operating conditions. It is then used to stabilize a synchronous machine, which is part of a multi-machine power system (Goldberg D. E. 1989). The power system stabilizers (PSSs) are implementation at each machine. Response of the machines subjected to three-phase to ground fault are studied. System responses with tuned interval type-2 fuzzy-logic power system stabilizer (IT2FPSS) for different operating conditions are then compared with a CPSS and fixed parameter FPSS.

Interval Type-2 fuzzy sets, characterized by membership grades that are themselves fuzzy, were introduced by Zadeh in 1975 to better handle uncertainties. As illustrated in Fig.1, the membership function (MF) of a type-2 set has a footprint of uncertainty (FOU), which represents the uncertainties in the shape and position of the type-1 fuzzy set. The FOU is bounded by an upper MF and a lower MF, both of which are type-1 MFs. Fuzzy logic systems constructed using rule bases that utilize at least one interval type-2 fuzzy sets are called interval type-2 FLSs. Since the FOU of a type-2 fuzzy set provides an extra mathematical dimension, type-2 FLSs can better handle system uncertainties and have the potential to outperform their type-1 counterparts.

2. Body of Paper

Interval Type2 Fuzzy Logic Systems (IT2FLS)

Fuzzy Logic Systems (FLS) are known as the universal approximators and have various applications in identification and control designs. A type-1 fuzzy system consists of four major parts: fuzzifier, rule base, inference engine and defuzzifier. A type-2 fuzzy system has a similar structure, but one of the major differences can be seen in the rule base part, where a type-2 rule base has antecedents and consequents using Type-2 Fuzzy Sets (T2FS). In a T2FS, we consider a Gaussian function with a known standard deviation, while the mean (m) varies between m1 and m2. Therefore, a uniform weighting is assumed to represent a footprint of uncertainty as shaded in Fig.1. Because of using such a uniform weighting, we name the T2FS as an Interval Type-2 Fuzzy Set (IT2FS). Utilizing a rule base which consists of IT2FSs, the output of the inference engine will also be a T2FS and hence we need a type-reducer to convert it to a type-1 fuzzy set before defuzzification can be carried out. Fig.1 shows the main structure of type-2 FLS.

By using singleton fuzzification, the singleton inputs are fed into the inference engine. Combining the fuzzy if-then rules, the inference engine maps the singleton input x = [x_1, x_2,…x_3] into a type-2 fuzzy set as the output. A typical form of an if-then rule can be written as:

$$R_i = \textit{if } x_1 \textit{ is } \tilde{F}_1^i \textit{ and } x_2 \textit{ is } \tilde{F}_2^i \textit{ and } \ldots\ldots \textit{and } x_k \textit{ is } \tilde{F}_k^i \textit{ then } \tilde{G}^i \quad (1)$$

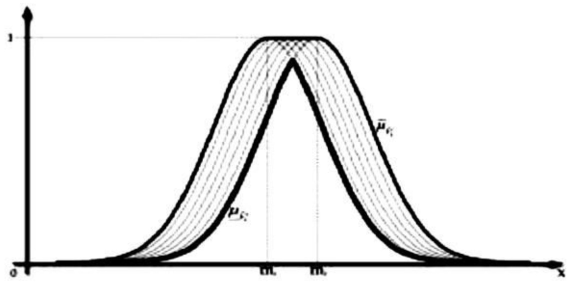


Fig.1: Interval type 2 fuzzy set (IT2FS)

Where F_k are the antecedents (k = 1,2,…,n) and G^i is the consequent of the i^{th} rule. We use sup-star method as one of the various inference methods. The first step is to evaluate the firing set for i^{th} rule as following:

$$F^i(\underline{x}) = \prod_{i=1}^{n} \mu_{\widetilde{F_1}}(x_1) \quad (2)$$

As all of the F_k^s are IT2FSs, so $F^i(\underline{x})$ can be written as $F^i(\underline{x}) = \left[\underline{f}^i(\underline{x})\, \overline{f}^i(\underline{x})\right]$

Where:

$$\underline{f}^i(\underline{x}) = \prod_{i=1}^{n} \underline{\mu}_{\tilde{F}_i}(x_i) \quad (3)$$

$$\overline{f}^i(\underline{x}) = \prod_{i=1}^{n} \overline{\mu}_{\tilde{F}_i}(x_i) \quad (4)$$

The terms $\underline{\mu}_{\tilde{F}_i}$ and $\overline{\mu}_{\tilde{F}_i}$ are the lower and upper membership functions, respectively (Fig.2). In the next step, the firing set $F_i(x)$ is combined with the i^{th} consequent using the product t-norm to produce the type-2 output fuzzy set. The type-2 output fuzzy sets are then fed into the type reduction part. The structure of type reducing part is combined with the defuzzification procedure, which uses Center of Sets (COS) method. First, the left and right centroids of each rule consequent are computed using Karnik-Mendel (KM) algorithm. Let's call them y_l and y_r respectively.

The firing sets $F^i(\underline{x}) = \left[\underline{f}^i(\underline{x})\, \overline{f}^i(\underline{x})\right]$ computed in the inference engine are combined with the left and right centroid of consequents and then the defuzzified output is evaluated by finding the solutions of following optimization problems:

$$y_l(\underline{x}) = \min_{\forall f^k \in \{\underline{f}^k, \overline{f}^k\}} \left(\sum_{i=1}^{M} y_l^i f^i(\underline{x}) \Big/ \sum_{i=1}^{M} f^i(\underline{x})\right) \quad (5)$$

$$y_r(\underline{x}) = \max_{\forall f^k \in \{\underline{f}^k, \overline{f}^k\}} \left(\sum_{i=1}^{M} y_r^i f^i(\underline{x}) \Big/ \sum_{i=1}^{M} f^i(\underline{x})\right) \quad (6)$$

Power System Stabilizer Design

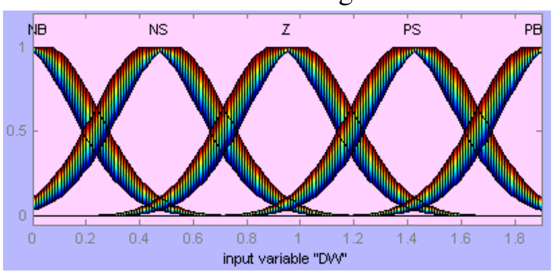
First to design an Interval Type-2 Fuzzy power system stabilizer (IT2FPSS), for power system control, two crisp inputs i.e. speed deviation Δω, derivative of speed deviation (dΔω), stabilizing factor K_{STAB} and one output of IT2FPSS 'u' will be introduced. The working procedure of proposed IT2FPSS is as following:

(a) In the fuzzification stage the crisp inputs are transformed to interval type-2 fuzzy sets.

(b) These sets are processed by inference machine in relation with interval type-2 rule base. Result of this procedure is a group of interval type-2 fuzzy output sets.

(c) Difuzzifacation stage integrated with type reducer block convert interval type-2 fuzzy output sets to crisp output values that are fed into control system.

This procedure is illustrated in block diagram of Fig.3. As mentioned before in power system we have four variables, Membership Functions (MFs) of these variables are chosen as interval type-2 Gaussian functions. These MFs are shown in Fig.2.



(a) IT2 Fuzzy MF for First input Speed deviation (Δω)

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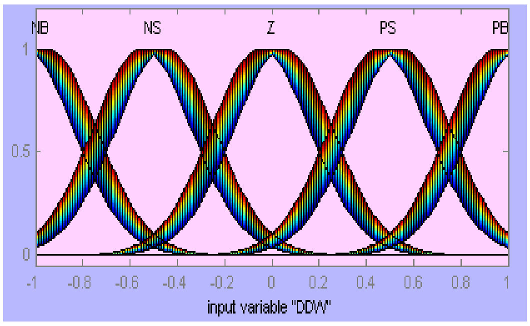
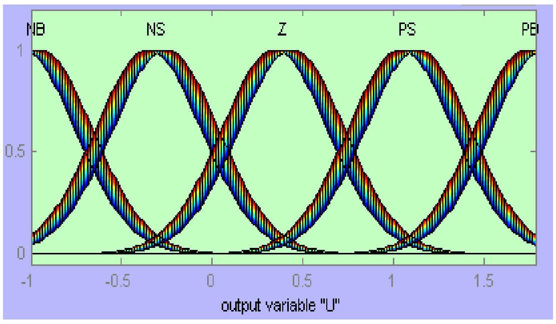


(b) IT2 Fuzzy MF for second input Derivative of speed deviation (dΔω)



(c) MFs of output of IT2FPSS ‘u’

Fig. 2: Input/output membership functions of designed IT2FPSS

The final layout of the developed IT2FPSS is shown in Fig.(3).

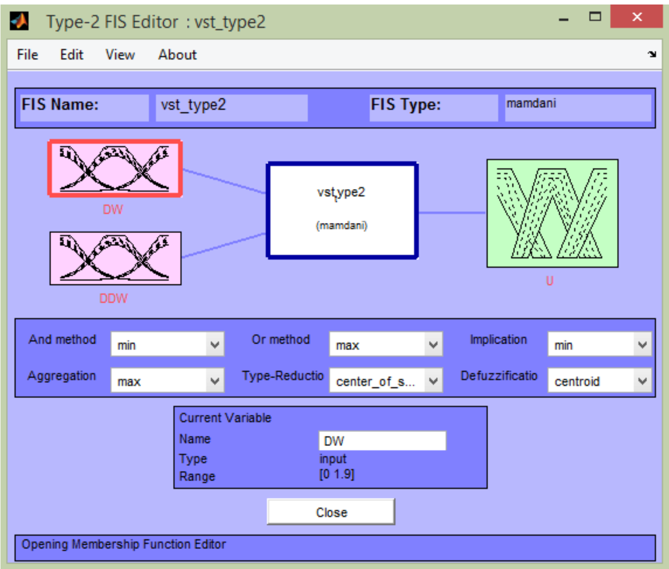


Fig.3. layout of the developed IT2FPSS

Four Machines Two Area System Test System

The test system present in MATLAB 2012(b) consists of two fully symmetrical areas linked together by two tie 230 KV lines of 220 Km length as shown in Fig.4. It was specifically designed to study low frequency electromechanical oscillations in large interconnected power systems. Despite its small size, it mimics very closely the behavior of typical system in actual operation. Each area is equipped with two identical round rotor generators rated 20 KV/900 MVA. The synchronous machines have identical parameters except for the inertias which are H = 6.5s in area 1 and H is = 6.175s in area 2. Thermal plants having identical speed regulators are further assumed at all locations, in addition to fast static exciter with a 200 gain. The load is represented as constant impedance and spilt between the areas.

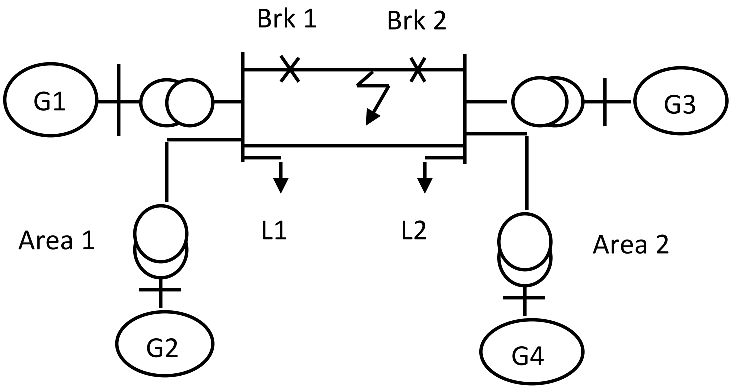


Fig. 4 Two Area Four-Machine power system for Stability study

3. CONCLUSIONS

In this paper, a simplified IT2FPSS that is more suitable for real-time control is proposed. A IT2FPSSs with simplified structure are designed for power system governing control. Experimental results show that the simplified IT2FPSS outperforms the type-1 FPSSs and has similar performance as the traditional IT2FPSS. Analysis also indicates there will be at least 50% reduction in computational cost if the simplified IT2FPSS is used in place of a traditional IT2FPSS. It may, therefore, be concluded that the simplified IT2FPSS is able to bring about computational savings without sacrificing the ability to handle modeling uncertainties.

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