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Different Types of Inference Method for Fuzzy Power System Stabilizer Analysis

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Abstract: In this paper, fuzzy power system stabilizer (FPSS) is being analyzed. Power system stabilizer (PSS) is acknowledged in stability performance in power system by providing a damping signal for low-frequency oscillation. The application of fuzzy logic controller into power system stabilizer is being presented in the simulation of 2 machines 3 buses environment. The rules of fuzzy is constructed and the performance is being tested for different types of inference method applied to the FPSS. A type of contingency, single phase fault is being tested to validate the ability of the FPSS to overcome the oscillation and improve the stability of the system. The changes in rotor angles as well as the speed of each machine are being measured as the output responses of the FPSS. The simulation of the system is performed in MATLAB/SIMULINK environment. The superior responses for FPSS for both inference methods prove the capability of fuzzy controller to improve the stability of the system.

Keywords: Power system stabilizer, low-frequency oscillation, fuzzy controller, 2 machines 3 buses system, Matlab/Simulink

1. INTRODUCTION

As in power system, since the last 4 decades, most of the new generating units added to electric utility systems were equipped with continuously acting voltage regulators. As these unit came to constitute a large percentage of generating capacity, it became apparent that the voltage regulator action had a detrimental impact upon the steady state stability of the power system [1], [2]. Oscillation of small magnitude and low frequency often persists for long periods of time and in some cases can hinder power transfer capability [1]-[4]. Thus, power system stabilizer (PSS) is being introduced as it can add damping to the system oscillation to improve the performance [1]-[12]. PSS will act by adding sufficient damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal and produce a component of electrical torque in phase with the rotor speed deviations [1], [4]. The most used PSS in power system is known as conventional PSS (CPSS), which uses lead-lag compensation. CPSS features with the gain settings are designed for specific conditions and being determined based on a linearized model of power system [1], [2], [13]-[14].

CPSS only can provide good performance under nominal operating point but resulting to turn poor performance under real power system which is highly nonlinear systems [5], [13]. Consequently, to improve the performance of CPSS, numerous methods such as intelligent optimization methods which include fuzzy logic control need to be design and implemented as to overcome the lack in CPSS output.

The application of fuzzy logic control techniques become a most suitable for a well-defined control objective that cannot specified, the complex controlling of the system, and the system that not available with the exact mathematical model [1]-[3], [5]. It proved that fuzzy logic technique is one of the intelligence methods in designing the controller.

Recent research has been made using the fuzzy logic approach for designing PSS. Neeraj and Sanjay [2] use the fuzzy logic controller with different membership function in comparative the enhancement in performance. PID controller design for PSS is being used by [5] with the fuzzy logic controller based with empirical control rules. Lokman et. al [3] used Takagi-Sugeno fuzzy logic with auto-tuned PI stabilizer to perform in large and complex multi machines test system. Rajeev et. al [1] uses fuzzy logic based PSS with different defuzzification method to valid the performance of the controller in the system. All the research proved that fuzzy logic controller can be implemented in PSS as to enhance the system stability.

In this paper, the performance of 3 buses system is being analyzed with the fuzzy power system stabilizer using different typed of inference method. The analysis is being conducted with both types of inference which are Mamdani and Sugeno. Various simulations have been made with the typical fuzzy rules to compare the ability for each inference method in enhancing the system's stability. The simulation response clearly demonstrates the ability of each inference method of FPSS.

2. TEST SYSTEM MODELLING

The 2 machines 3 buses system is being used as the test system for the FPSS performances. Two FPSS is being introduced and each FPSS is installed in each machine in the system. The 3 buses system is a 500kV transmission system that consists of hydraulic generation plant with 1000 MW rated for Machine 1. The transmission system is 700 km long with 5000 MW resistive load center. The load is fed from both remote 1000 MVA plant and a local generation of 5000 MVA for Machine 2. The below diagram of Figure 1 shows the single line diagram that represent the system.

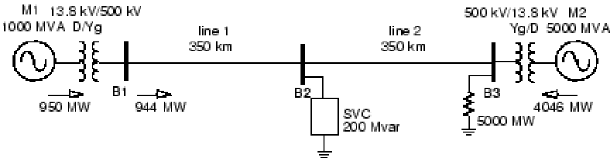

Figure 1. Single line diagram of 3 buses system

2.1 Power Flow Description

Machine 1 (M1) is being setted as a PV generation bus rated with 13800 V while Machine 2 as a swing bus with the same voltage rated. Machine 1 (M1) generating 950 MW so that Machine 2 (M2) produces 4046 MW for load flow performance on this system. The line carries 944 MW which is around its surge impedance loading (SIL) where in this case, the SIL value is 977 MW. Both machines are equipped with a hydraulic turbine and governor (HTG), excitation system, as well as power system stabilizer (PSS).

A fault breaker block is being connected at bus B2 and several types of faults are being tested on the 500kV system so that the ability of FPSS can be determined.

2.2 Power System Stabilizer

Power system stabilizer is being used in this test system as to improve the damping of the electromechanical oscillations. To provide damping into the system, the PSS must produce a component of electrical torque to be in phase with the rotor speed deviations [1], [4], [11]. The PSS uses phase compensation by adjusting the timing of correction signal opposing the rotor oscillation. Thus, the damping coefficient can be increased. As shown in Figure 2, PSS consists of three components: a phase compensation block, a signal washout block and a gain block [3], [11].

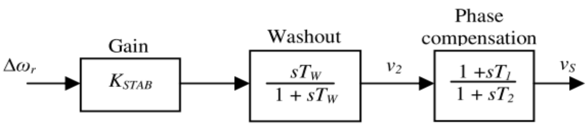

Figure 2. Conventional lead-lag PSS

A gain block that consist parameter K_{STAB} will functions as the amount of damping introduced by PSS. The signal washout block act as a high-pass filter, with the time constant TW high enough to allow signals associated with oscillations in ω_r to pass unchanged. Steady state changes in speed would modify the terminal voltage if the washout block did not exist [11].

The phase compensation block provides the sufficient phase-lead characteristic to compensate for the phase lag between the exciter input and the generator electrical torque. TW is known as the washout filter time constant [3], [11].

3. FUZZY LOGIC CONTROLLER

By using fuzzy logic approached in designing the PSS controller, a mathematical model is not required to describe the system under study.

3.1 Control System

Figure 3 shows the principle design of the fuzzy controller, which comprises of four stages: fuzzification, a knowledge base, decision making and defuzzification.

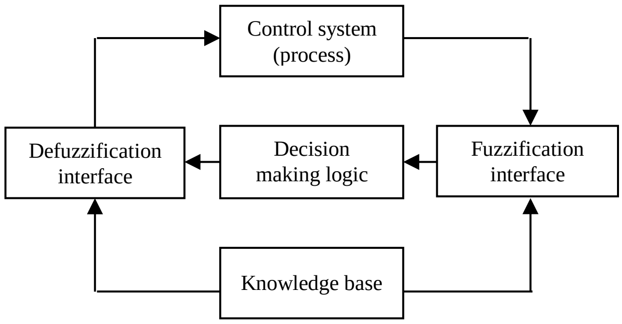

Figure 3. Fuzzy logic controller design structure

The fuzzification interface will converts the input data into the suitable linguistic value that can be viewed as label fuzzy sets [3]. The knowledge base includes the definitions of the fuzzy membership functions that defined for each control variables and the necessary rules that specify the control goals using linguistic variables [3], [6]. The decision making is the aggregation of output of various control rules that simulate the capability of human decision making. The defuzzification inference converts the inferred decision from the linguistic variable into corresponding universe of discourse [3]. The fuzzy logic controller itself is normally a two-input with a single-output component.

Fuzzy inference system (FIS) is best described as a system that uses fuzzy set theory for input/output mapping. A fuzzy set is an extension of classical set. If X is the universe of discourse while its elements are denoted by x, then a fuzzy set A in X is defined as a set of ordered pairs. Thus;

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

where; $\mu A(x)$ is a membership function of x in A. The membership function maps each element of X to a membership value between 0 and 1.

The simplest membership functions are formed using straight lines. Thus, the simplest membership function is the triangular-shaped. The other form of membership function in fuzzy logic are includes Gaussian combination;

generalized bell-shaped, pi-shaped, trapezoidal shaped and others.

3.2 Fuzzy Inference System

Fuzzy inference is known as the process of formulating to map a given input to an output using fuzzy logic. The mapping then provides a basis to develop decisions, or patterns discerned [14]. Fuzzy inference systems have been widely applied with success in fields such as automatic control, classification of data, decision analysis, expert systems, and computer vision. Due to its multidisciplinary nature, fuzzy inference systems are attributed with numerous names, such as fuzzy-rule-based systems, fuzzy expert systems, fuzzy modeling, fuzzy associative memory, fuzzy logic controllers, and simply (and ambiguously) fuzzy systems.

3.3 Mamdani-type Inference

Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory.

Fuzzy set is expected as an output membership function of this Mamdani-type inference. After the aggregation process, each output variable which is consists of fuzzy set are needs defuzzification process. A single spike of output membership function is much more efficient whereas it is applicable in many cases, rather than an output of distributed fuzzy set. This single spike is sometimes known as a *singleton* output membership function, and it can be assumed as a pre-defuzzified fuzzy set. It improves the efficiency of the defuzzification process because it significantly simplifies the computation required, which finds the centroid of a two-dimensional function for commonly more general Mamdani method [15]. The fuzzy inference process is illustrated in the Figure 4 below as taken a simple example for further explanation.

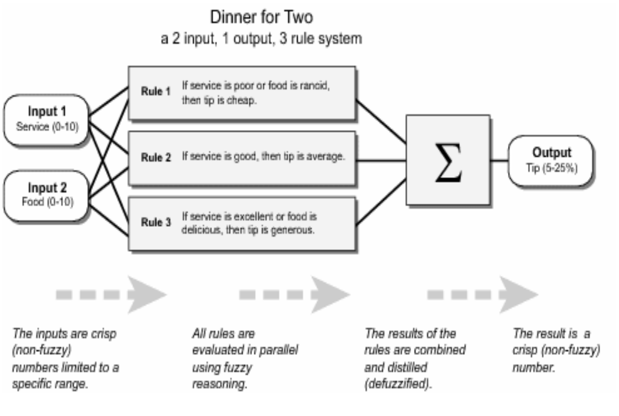

Figure 4. The Mamdani-type Inference method process between input and output

3.4 Sugeno-type Inference

Sugeno-type inference, as compared to Mamdani, uses the weighted average of a few data points rather than integrating across the two-dimensional function to find the centroid, it should. In general, Sugeno-type systems is mostly used to model any inference system with linear or constant of output membership function. Introduced in 1985 [16], it is much more alike the Mamdani method in many respects. The core difference between both Mamdani and Sugeno is that the Sugeno output membership functions are either linear or constant.

A typical rule in a Sugeno fuzzy model has the form

If Input 1 =x and Input 2 = y, then;
Output is $z = ax + by + z$

For a zero-order Sugeno model, the output level z is a constant (a=b=0). The output level z_i of each rule is weighted by the firing strength w_i of the rule. For example, for an AND rule with Input 1 = x and Input 2 = y, the firing strength is

$$w_i = AndMethod(F_1(x), F_2(y))$$

where F1,2 (.) are the membership functions for Inputs 1 and 2.

The final output of the system is the weighted average of all rule outputs, computed as

$$\text{Final Output} = \frac{\sum_{i=1}^{N} w_i z_i}{\sum_{i=1}^{N} w_i}$$

where N is the number of rules. The operation for Sugeno-type inference method is described in the figure shown below.

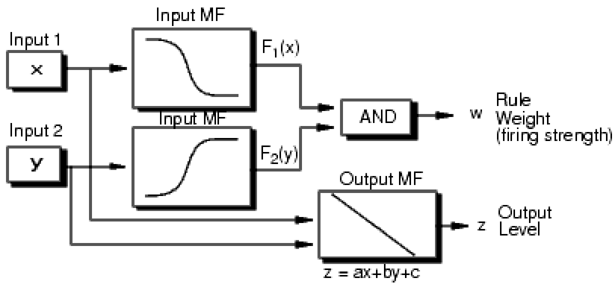

Figure 5. The Sugeno-type Inference method process between input and output

3. FUZZY RULES

As for system dynamics, which are unknown or highly nonlinear, there is a need to use trial-an-error and experience procedure as to define the fuzzy rules. The most common typical rules [3] are;

Rule 1: If angular speed deviation, $\Delta\omega_r$ is NM AND acceleration, $\Delta\omega$ is PS, then the output (voltage) is NS.

Rule 2: If angular speed deviation, $\Delta\omega_r$ is NB AND acceleration, $\Delta\omega$ is NB, then the output (voltage) is NB.

The two inputs and single output of the fuzzy controller will result in 49 rules as shown in Table 1.

Table 1. Rules for Fuzzy PSS

SPEED DEVIATION	ACCELERATION						
	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NM	NS
NM	NB	NM	NM	NM	NS	NS	Z
NS	NM	NM	NS	NS	Z	Z	PS
Z	NM	NS	NS	Z	PS	PS	PM
PS	NS	Z	Z	PS	PS	PM	PM
PM	Z	PS	PS	PM	PM	PM	PB
PB	PS	PM	PM	PB	PB	PB	PB

For both inputs of FPSS are known as angular speed deviation and its derivative as acceleration and the output parameter of voltage signal.

4. RESULT AND DISCUSSION

The 3 buses system is being tested with different type of PSS which are with no PSS, CPSS, FPSS with Mamdani and FPSS with Sugeno. The simulation of the 3 buses system is carried out in MATLAB/Simulink environment. As to validate the performance for each controller, a 1Ø fault is being tested on the transmission line near the B_1. Fault is set at 5 s and clear after 5.1 s. The rotor angle different between two machines is recorded as well as the speed deviation as the output for system performance.

All different cases with no PSS, CPSS, FPSS with Mamdani and FPSS with Sugeno is being test and compared with each other. The output responses consist of rotor angle different between two machine, speed deviation and additional of output voltage different between two machines respectively are shown in the next Figure 6 to Figure 9.

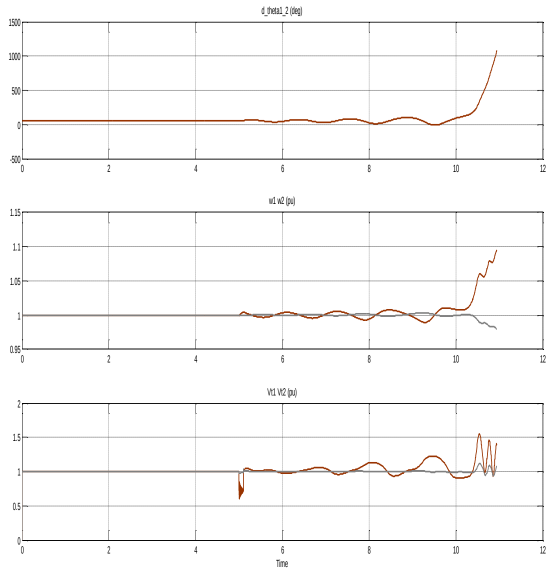

Figure 6. Response with no PSS installed

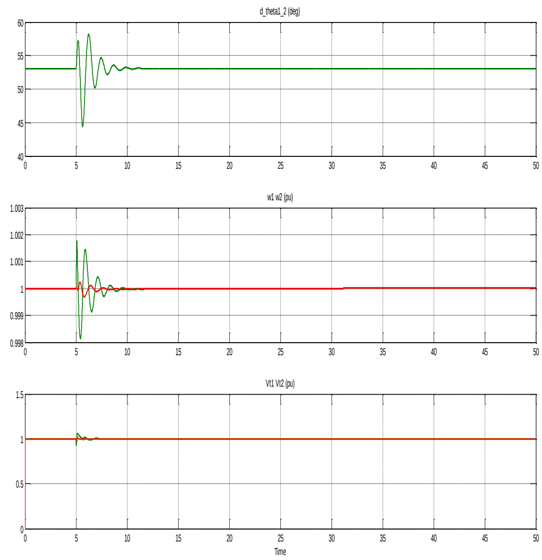

Figure 7. Responses with CPSS

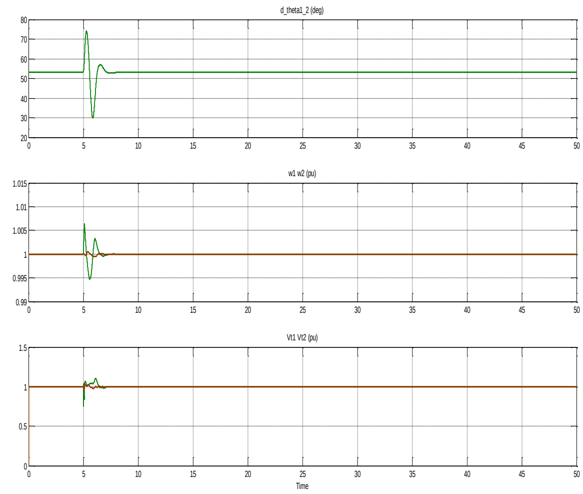

Figure 8. Responses for FPSS with Mamdani inference method

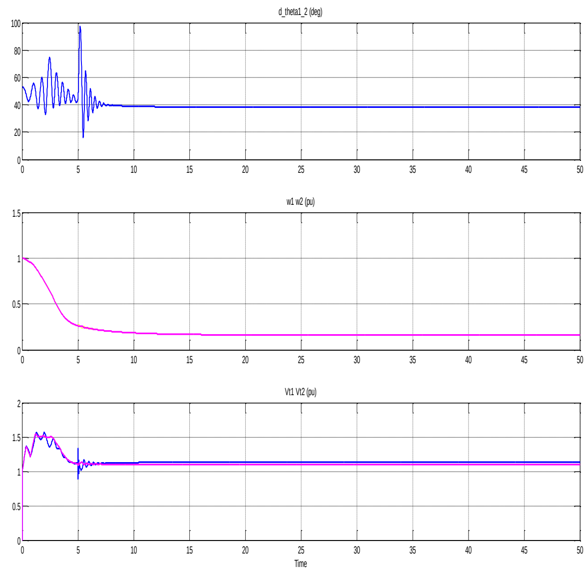

Figure 9. Responses for FPSS with Sugeno inference method

From all the results shown, once the fault is occurred, all types of controller responding in maintaining its stability state. Test system with no PSS is clearly unstable and cannot sustain its stability state when the oscillation keeps remain. Meanwhile, for CPSS, FPSS with Mamdani and FPSS with Sugeno does respond and damp out the oscillation but with different value of overshoot and time settling. The total parameters output for both machine 1 and 2 is being recorded in tables below.

Referring to both Table 2 and Table 3, it shows that CPSS and both FPSS are giving superior respond to damp out the oscillation. For Machine 1, CPSS become stable after 12 s with 1.0 p.u of overshoot in speed deviation and almost the same value for rotor angle different between two machines with 9.43% of overshoot. FPSS with Mamdani recorded a better time settling at 8 s and 1.0 p.u in overshoot for speed deviation as well as rotor angle difference with 30.91% of overshoot. Meanwhile, for FPSS with Sugeno, the speed deviation is stable at 12 s with 0.25 p.u for overshoot and rotor angle different gives time settling value as 8 s with 137.5% overshoot.

Table 2. Parameters output for Machine 1

Method	Parameter	Overshoot	Time Settling
NO PSS	Δω	Keep oscillate	Keep oscillate
	d_theta1_2	Keep oscillate	Keep oscillate
CPSS	Δω	1.002	12s
	d_theta1_2	9.43%	11 s
FPSS – mamdani	Δω	1.005	8 s
	d_theta1_2	30.91%	8 s
FPSS – sugeno	Δω	0.25	12s
	d_theta1_2	137.5%	8 s

Table 3. Parameters output for Machine 2

Method	Parameter	Overshoot	Time Settling
NO PSS	Δω	Keep oscillate	Keep oscillate
	d_theta1_2	Keep oscillate	Keep oscillate
CPSS	Δω	1.0002	11 s
	d_theta1_2	9.43%	12 s
FPSS – mamdani	Δω	1.001	4 s
	d_theta1_2	30.91%	8 s
FPSS – sugeno	Δω	0.25	12 s
	d_theta1_2	137.5%	8 s

As for Machine 2, CPSS still gives the 1.0 p.u overshoot but only become stable after 11 s and 12 s for speed deviations and rotor angle different respectively. FPSS with Mamdani gives lower settling time where the system stable at 4 s and FPSS with Sugeno only stable at 8 s.

5. CONCLUSION

This paper is focusing on analysis of different types of inference method of fuzzy logic in designing a power system stabilizer (SPS). From the result, it can be proved that FPSS with Mamdani inference method gives superior result in stabling the system after fault is occurred. Meanwhile, FPSS with Sugeno also can stable the system after fault but does not gives better performance as compared to FPSS with Mamdani. Results shows that Fuzzy with Mamdani inference method can solve as a better alternative to enhance power system stability.

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