Fuzzy Scaled Power System Stabilizer in Multi Machine Power System

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Abstract: Power System Stabilizers (PSS) are used to generate supplementary damping control signals for the excitation system in order to damp the Low Frequency Oscillations (LFO) of the electric power system. The PSS is usually designed based on classical control approaches but this Conventional PSS (CPSS) has some problems. In order to overcome the drawbacks of CPSS, numerous techniques have been proposed in literatures. In this paper a new Fuzzy type PSS is considered for damping electric power system oscillations. In this Fuzzy approach, the upper and lower bounds of the Fuzzy membership functions are obtained using Genetic Algorithms (GA) optimization method. The proposed Fuzzy-Genetics PSS (FGPSS) is evaluated on a multi machine power system. The simulation results clearly indicate the effectiveness and validity of the proposed method.
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1. Introduction

Large electric power systems are complex nonlinear systems and often exhibit low frequency electromechanical oscillations due to insufficient damping caused by adverse operating. These oscillations with small magnitude and low frequency often persist for long periods of time and in some cases they even present limitations on power transfer capability. In analyzing and controlling the power system's stability, two distinct types of system oscillations are recognized. One is associated with generators at a generating station swinging with respect to the rest of the power system. Such oscillations are referred to as "intra-area mode" oscillations. The second type is associated with swinging of many machines in an area of the system against machines in other areas. This is referred to as "inter-area mode" oscillations. Power System Stabilizers (PSS) are used to generate supplementary control signals for the excitation system in order to damp both types of oscillations. The widely used Conventional Power System Stabilizers (CPSS) are designed using the theory of phase compensation in the frequency domain and are introduced as a lead-lag compensator. The parameters of CPSS are determined based on the linearized model of the electric power system. Providing good damping over a wide operating range, the CPSS parameters should be fine tuned in response to both types of oscillations. Since power systems are highly nonlinear systems, with configurations and parameters which alter through time, the CPSS design based on the linearized model of the power system cannot guarantee its performance in a practical operating environment. Therefore, an adaptive PSS which considers the nonlinear nature of the plant and adapts to the changes in the environment is required for the power system. In order to improve the performance of CPSSs, numerous techniques have been proposed for designing them, such as intelligent optimization methods [1-4] and Fuzzy logic method [5-9]. Also many other different techniques such as robust control methods have been reported in [10-14].

This paper deals with a design method for the stability enhancement of a multi machine power system using a new Fuzzy type PSS whose membership functions boundaries are tuned by genetic algorithms.

2. System under study

In this paper IEEE 14 bus test system is considered to evaluate the proposed method. The system data can be found in [15]. Figure 1 shows the proposed test system.

2.1. Dynamic model of the system

The nonlinear dynamic model of the system is given as follows:

$$\begin{cases} \dot{\omega}_i = \dfrac{(P_m - P_e - D\omega)}{M} \\ \dot{\delta}_i = \omega_0(\omega - 1) \\ \dot{E}'_{qi} = \dfrac{(-E_q + E_{fd})}{T'_{do}} \\ \dot{E}_{fdi} = \dfrac{-E_{fd} + K_a(V_{ref} - V_t)}{T_a} \end{cases} \tag{1}$$

where i=1, 2, 3, 4,5 (the generators: 1 to 4); δ, rotor angle; ω, rotor speed; P_m, mechanical input power; P_e, electrical output power; E'_q, internal voltage behind x'_d; E_{fd}, equivalent excitation voltage; Te, electric torque; T'_{do}, time constant of excitation circuit; K_a, regulator gain; T_a, regulator time constant; V_{ref}, reference voltage; V_t, terminal voltage.

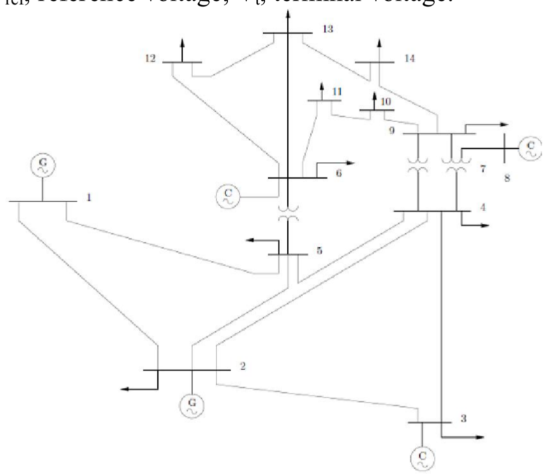

Figure 1: IEEE 14 bus test system

3. Power System Stabilizer

As mentioned before, in large interconnected power systems, the damping torque of system is reduced and system need to PSS for stability. The basic function of PSS is to add damping torque to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal. To provide damping, the stabilizer must produce a component of electrical torque in phase with the rotor speed deviations. The PSS configuration is given in as (2). where, Δω is the speed deviation in p.u. This type of PSS consists of a washout filter, a dynamic compensator. The output signal is fed as a supplementary input signal to the excitation of generator. The washout filter, which is a high pass filter, is used to reset the steady state offset in the PSS output. In this paper the value of the time constant (Tw) is fixed to 10 s. The dynamic compensator is made up to two lead–lag stages with time constants, T1–T4 and an additional gain K_{DC} [16].

$$U = K_{DC}\frac{ST_W}{1+ST_W}\frac{1+ST_1}{1+ST_2}\frac{1+ST_3}{1+ST_4}\Delta\omega \qquad (2)$$

4. Design methodology

As mentioned before, in this paper a new Fuzzy type PSS in considered for damping power system oscillations. Fuzzy method has three major sections as membership functions, rule bases and defuzzification. In classical Fuzzy methods, the boundaries of membership functions are adjusted based on expert person experiences that may be with trial and error and does not guarantee performance of the system. For solve this problem, in this paper the boundaries of the membership functions are tuned by an optimal search for achieving the best boundaries. Therefore the boundaries of input and output membership functions are considered as uncertain and then the optimal boundaries are obtained by genetic algorithms [17]. Here the proposed Fuzzy controller block diagram is given in Figure 2. In fact, it is a nonlinear PI-type Fuzzy logic controller with two inputs and one output. In this paper ΔV_{ref} is modulated in order to output of PSS and the speed deviation Δω and its rate d(Δω)/dt are considered as the inputs to the PSS. The inputs are filtered by washout block to eliminate the DC components. Also there are three parameters denoted by K_{in1}, K_{in2} and K_{out} which are defined over an uncertain range and then obtained by genetic algorithms optimization method. Therefore the boundaries of inputs and output signals are tuned on an optimal value.

Though the Fuzzy controller accepts these inputs, it has to convert them into fuzzified inputs before the rules can be evaluated. To accomplish this, one of the most important and critical blocks in the whole Fuzzy controllers should be built and it is The Knowledge Base. It consists of two more blocks namely the Data Base and the Rule Base [17].

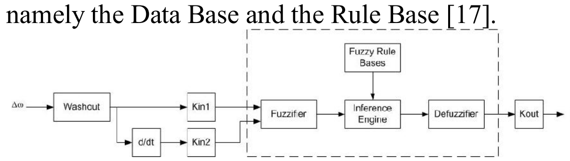

Figure 2: Fuzzy PSS

4.1. Data base

Data base consists of the membership function for input variables Δω and d(Δω)/dt and output variable described by linguistic variables shown in Tables 1-3 [17].

Table 1: The linguistic variables for Δω

Big Positive (BP)	Medium Positive (MP)	Small Positive (SP)
Big Negative (BN)	Medium Negative (MN)	Small Negative (SN)
Zero (ZE)		

Table 2: The linguistic variables for d(Δω)/dt

Positive (P)	Negative	Zero (ZE)

Table 3: The linguistic variables for output

Big Positive (BP)	Medium Positive (MP)	Small Positive (SP)
Big Negative (BN)	Medium Negative (MN)	Small Negative (SN)
Zero (ZE)	Very Big Positive (VBP)	Very Big Negative (VBN)

The "triangular membership functions" are used as membership functions for the input and output variables. The Figures 3-5 illustrate these in detail indicating the range of all the variables. These ranges are defined as default and then tuned via cascade K parameters (K_{in1}, K_{in2} and K_{out}) and adjusted on the optimal values.

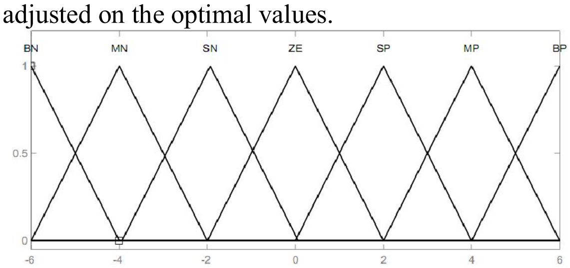

Figure 3: Membership function of input 1 (Δω)

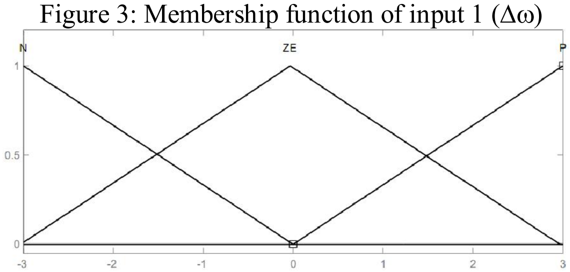

Figure 4: Membership function of input 2 (d(Δω)/dt)

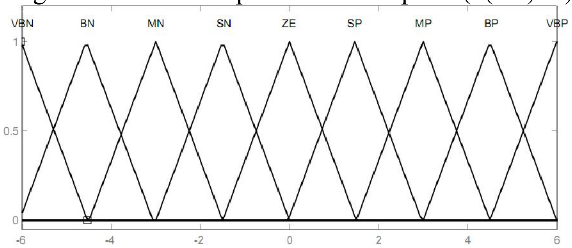

Figure 5: Membership function of output

4.2. Rule base

The other half of the knowledge base is the Rule Base which consists of all the rules formulated by the experts. It also consists of weights which indicate the relative importance of the rules among themselves and indicates the influence of a particular rule over the net fuzzified output. The Fuzzy rules which are used in this scheme are shown in Table 4.

Table 4: Fuzzy Rule Bases

Δω / d(Δω)/dt	BN	MN	SN	ZE	SP	MP	BP
N	VBN	BN	MN	SN	ZE	MP	BP
ZE	BN	MN	SN	ZE	SP	MP	BP
P	BN	MN	ZE	SP	MP	BP	VBP

The next section specifies the method adopted by the Inference Engine especially the way it uses the Knowledge Base consisting of the described Data Base and Rules Base.

4. 3. Methodologies adopted in fuzzy inference engine

Though many methodologies have been mentioned in evaluating the various expressions like Fuzzy union (OR operation), Fuzzy intersection (AND operation) and etc with varying degree of complexity. Here in Fuzzy scheme the most widely used methods for evaluating such expressions are used. The function used for evaluating OR is "MAX", which is the maximum of the two operands and similarly the AND is evaluated using "MIN" function which is defined as the minimum of the two operands. It should be note that in the present research paper, the equal importance is assigned to all the rules in the Rules Base and all the weights are equal [17].

4.4. Defuzzification method

The Defuzzification method followed in this study is the "Center of Area Method" or "Gravity method". This method is discussed in [17]. As mentioned before, in this paper the boundaries of the membership functions are adjusted by genetic algorithms. In the next section a brief introduction about genetic algorithms is presented.

4.5. Genetic Algorithms

Genetic Algorithms (GA) are global search techniques, based on the operations observed in natural selection and genetics. They operate on a population of current approximations-the individuals-initially drawn at random, from which improvement is sought. Individuals are encoded as strings (Chromosomes) constructed over some particular alphabet, e.g., the binary alphabet {0.1}, so that chromosomes values are uniquely mapped onto the decision variable domain. Once the decision variable domain representation of the current population is calculated, individual performance is assumed according to the objective function which characterizes the problem to be solved. It is also possible to use the variable parameters directly to represent the chromosomes in the GA solution. At the reproduction stage, a fitness value is derived from the raw individual performance measure given by the objective function and used to bias the selection process. Highly fit individuals will have increasing opportunities to pass on genetically important material to successive generations. In this way, the genetic algorithms search from many points in the search space at once and yet continually narrow the focus of the search to the areas of the observed best performance. The selected individuals are then modified through the application of genetic operators. In order to obtain the next generation Genetic operators manipulate the characters (genes) that constitute the chromosomes directly, following the assumption that certain genes code, on average, for fitter individuals than other genes. Genetic operators can be divided into three main categories: Reproduction, crossover and mutation [18].

- Reproduction: selects the fittest individuals in the current population to be used in generating the next population.
- Cross-over: Causes pairs, or larger groups of individuals to exchange genetic information with one another
- Mutation: causes individual genetic representations to be changed according to some probabilistic rule.

5. Fuzzy controller tuning using Genetic Algorithms

In this section the membership functions of the proposed FGPSS are tuned by K parameters (K_{in1}, K_{in2} and K_{out}). Only one PSS is installed on generator 1. These K parameters are obtained based on genetic algorithms optimization method. The parameter ΔE_{ref} is modulated to output of FGPSS and speed deviation $\Delta\omega$ and its rate are considered as input to FGPSS. The optimum values of K_{in1}, K_{in2} and K_{out} which minimize an array of different performance indexes are accurately computed using genetic algorithms. In this study the performance index is considered as (3). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (*ITAE*).

$$\mathrm{ITAE} = \int_0^t t\left|\Delta\omega\right|dt \qquad (3)$$

To compute the optimum parameter values, a three phase short circuit in bus 3 is assumed and the performance index is minimized using genetic algorithms. The optimum values of the parameters K_{in1}, K_{in2} and K_{out} are obtained using genetic algorithms and summarized in the Table 5.

Table 5: Obtained parameters using GA

Parameters	K_{in1}	K_{in2}	K_{out}
Obtained Value	55.3	24.7	0.39

6. Simulation results

Simulations are carried out on the test system. To evaluate the system performance under disturbances, a 6-cycle three-phase short circuit in bus 4 is considered as fault.

The simulation results are presented in Figures 6-10. The simulation results show that applying PSS signal greatly enhances the damping of the generator angle oscillations. The results clearly show that in large electric power systems, PSS can successfully increase damping of power system oscillations. Also the responses without PSS clearly show that the system without PSS does not have enough damping torque and the responses go to fluctuate.

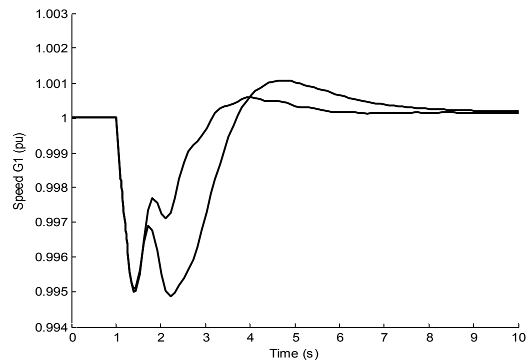

Figure 6: Speed G_1 (Solid (GA-PSS), Dashed (without PSS))

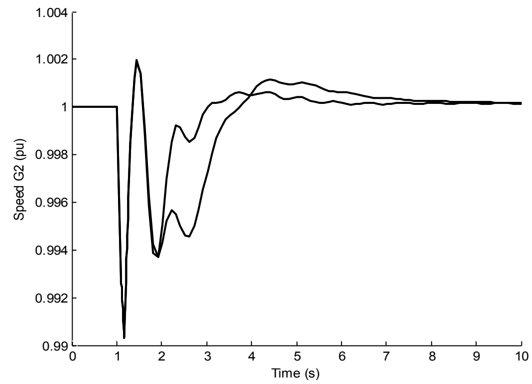

Figure 7: Speed G_2 (Solid (GA-PSS), Dashed (without PSS))

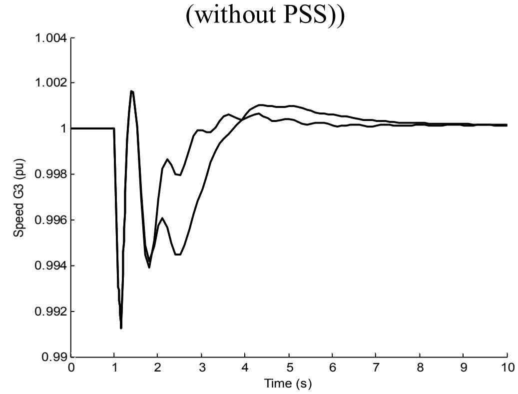

Figure 8: Speed G_3 (Solid (GA-PSS), Dashed (without PSS))

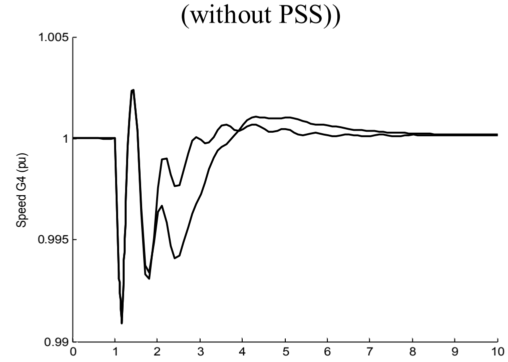

Figure 9: Speed G_4 (Solid (GA-PSS), Dashed (without PSS))

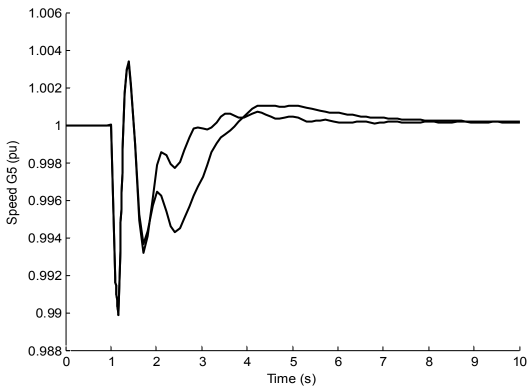

Figure 10: Speed G_5 (Solid (GA-PSS), Dashed (without PSS))

9. Conclusions

In this paper a new Fuzzy PSS based on genetic algorithms optimization method has been successfully proposed. The final designed FGPSS has characteristics of the both optimal and nonlinear controllers. The proposed method was applied to a typical power system. The simulation results demonstrated that the designed optimal FGPSS is capable of guaranteeing the robust stability and robust performance of the power system under a wide range of system uncertainties. These results and the suitability of Fuzzy logic to nonlinear problems, open the door to study the effect of nonlinear constraints on the power system damping oscillations problems.

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