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COMPARISON OF DAMPING PERFORMANCE OF CONVENTIONAL AND NEURO–FUZZY BASED POWER SYSTEM STABILIZERS APPLIED IN MULTI–MACHINE POWER SYSTEMS

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The objective of this paper is to investigate the power system damping enhancement via power system stabilizers (PSSs). However, the conventional power system stabilizers (CPSSs) have certain drawbacks. There are many techniques proposed in the literature for damping improvement of low frequency power system oscillations. In this paper, adaptive neuro-fuzzy inference system (ANFIS) technology has been proposed to coordinate the CPSSs in a multi-machine power system. The time-domain simulations are carried out in Matlab/Simulink environment to validate the effectiveness of the proposed control scheme under different operating conditions.

K e y w o r d s: ANFIS, CPSS, damping enhancement, low frequency oscillations, multi-machine power system, time-domain simulation

1 INTRODUCTION

Since the development of large interconnected power systems, there have been spontaneous system oscillations at very low frequencies in the order of 0.2-3 Hz. Once started, the oscillation would continue for a while and then disappear, or continue to grow, causing system separation [1]. Two electromechanical modes of oscillations are reported [2]: (i) local mode, with a frequency 0.8-3 Hz, which is related to oscillation in a single generator or a group of generators in the same area oscillate against each other, and (ii) inter-area mode, with frequency 0.2-0.8 Hz, in which the generator units in one area oscillate against those in other area.

In order to damp these power system oscillations and increase system oscillations stability, the installation of Power System Stabilizer (PSS) is both economical and effective. PSSs have been used for many years to add damping to electromechanical oscillations. To date, most major electric power system plants in many countries are equipped with PSS [3].

Klein *et al* [4, 5] presented the simulation studies into the effects of stabilizers on inter-area and local modes of oscillations in interconnected power systems. It was shown that the PSS location and the voltage characteristics of the system loads are significant factor in the ability of a PSS to increase the damping of inter-area oscillations.

Nowadays, the conventional lead-lag power system stabilizer (CPSS) is widely used by the power system utility [6]. Other types of PSS such as proportional-integral power system stabilizer (PI-PSS) and proportional-integral-derivative power system stabilizer (PID-PSS) have also been proposed [7, 8]. However, CPSSs are not able to provide satisfactory results over wider ranges of operating conditions [9].

To overcome this problem, Fuzzy logic based technique is used for designing of PSSs. Fuzzy logic controllers (FLCs) are very useful in the case a good mathematical model for the plant is not available, however, experienced human operators are available for providing qualitative rules to control the system [9]. Also Hybrid PSSs using fuzzy logic and/or neural networks or Genetic Algorithms have been reported in some literature to improve the performance of Fuzzy logic based PSSs [10,11].

This paper describes the design of neuro-fuzzy adaptive stabilizers, which have a fuzzy logic design base and use neural network to adjust the fuzzy logic parameters. The ANFIS based PSS uses a first-order Sugeno-type fuzzy logic controller whose membership functions (MFs) and consequences are tuned by back-propagation method.

The proposed technique is illustrated on a 9-bus, 3-machine power system. MATLAB/SIMULINK and fuzzy logic toolbox have been used for system simulation. The results demonstrate that the proposed ANFIS based PSS improved the damping of power system oscillations over a conventional PSS.

2 MODEL OF POWER SYSTEM UNDER STUDY

Inter-area oscillation control problem is examined by considering a 3-machine 9-bus power system model, whose single line diagram representation is shown in Fig. 1 where all impedance values are marked in per unit on 100 MVA base [12]. The system frequency is 50 Hz. In Fig. 1, the bus 1, to which generator G1 is connected, is considered as reference bus. The details of generators data [13, 14] are given in Appendix. There are two sets of conventional lead-lag PSS used in the system; one PSS connected in Area 1 (G2) and another one in Area 2 (G3).

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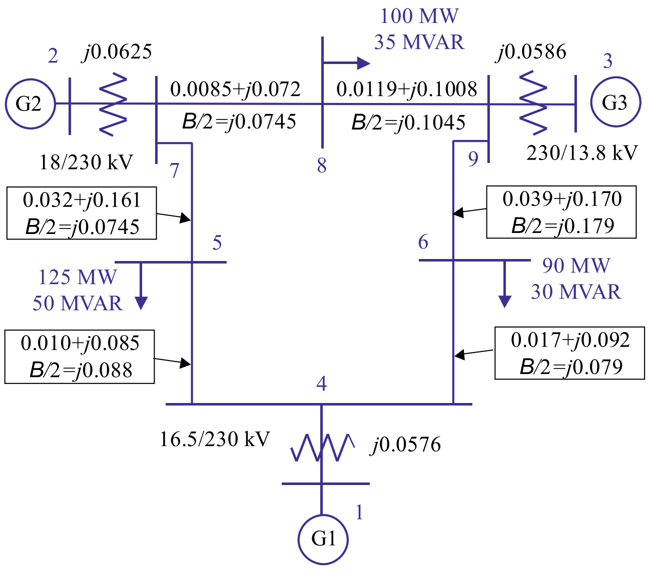

Fig. 1. Single line diagram of a 3-machine 9-bus power system

The reduced Y_{BUS} matrix for the above system is

$$Y_{BUS} = \begin{bmatrix} 0.846 - j2.988 & 0.287 + j1.513 & 0.210 + j1.226 \\ 0.287 + j1.513 & 0.420 - j2.724 & 0.213 + j1.088 \\ 0.210 + j1.226 & 0.213 + j1.088 & 0.277 - j2.368 \end{bmatrix}.$$

3 CONVENTIONAL POWER SYSTEM STABILIZER (CPSS)

Without PSS, the system has more oscillations, in power angle and speed deviation, with increased amplitudes and settling times. Hence, PSSs are introduced in the system to provide damping to electromechanical oscillations by increasing the generators damping coefficient. The structure of a conventional lead-lag PSS (CPSS) shown in Fig. 2 has three components; gain block, washout block, and the phase compensation block. The stabilizer gain K determines the amount of damping introduced by PSS. Here, in our work, $K = 400$. The signal washout block serving as high pass filter has such a high value of time constant T_w that the signals associated with oscillations in ω are passed without any change. The value of T_w used here is 3 s. The phase compensation block is used to provide compensation for the phase lag between exciter input and generator electrical torque. Here, $T_1 = 0.1537$ s and $T_2 = 0.1$ s. For the conventional lead-lag PSS, the following transfer function is used

$$\frac{\Delta U_{PSS}}{\Delta\omega} = \frac{KsT_w(1+sT_1)}{(1+sT_w)(1+sT_2)}. \qquad (1)$$

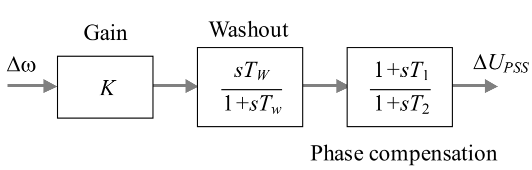

Fig. 2. Structure of Conventional lead-lag PSS (CPSS)

4 NEURO–FUZZY BASED POWER SYSTEM STABILIZER

In this paper, adaptive neuro-fuzzy inference system (ANFIS) technology has been used to coordinate the CPSSs in 3-machine 9-bus power system model shown in Fig. 1. The proposed ANFIS controller uses seven linguistic variables such as: Positive Big (PB), Positive Medium (PM), Positive Small (PS), Zero (ZE), Negative Small (NS), Negative Medium (NM) and Negative Big (NB). The Gaussian membership functions are chosen. The defuzzification process is tested by using the weighted average method.

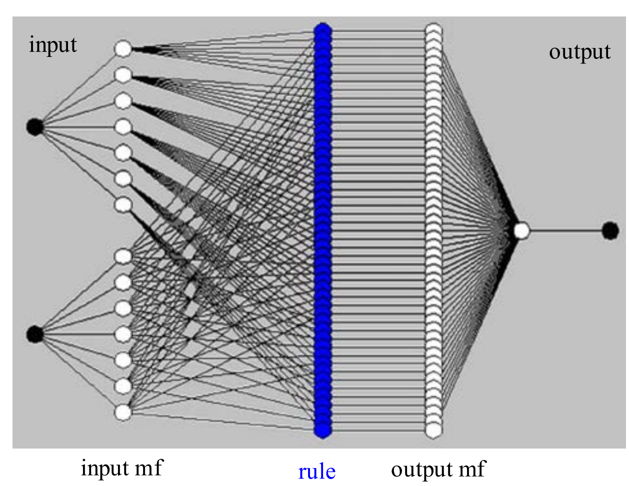

Fig. 3. Structure of proposed ANFPSS for the power system under study

In MATLAB, the ANFIS editor graphics user interface is available in Fuzzy Logic Toolbox [15]. In the ANFIS Editor, the fuzzy inference is generated using grid partitioning method. For grid partitioning, it uses the Fuzzy C-means clustering (FCM) data clustering technique. FCM is a data clustering algorithm in which each

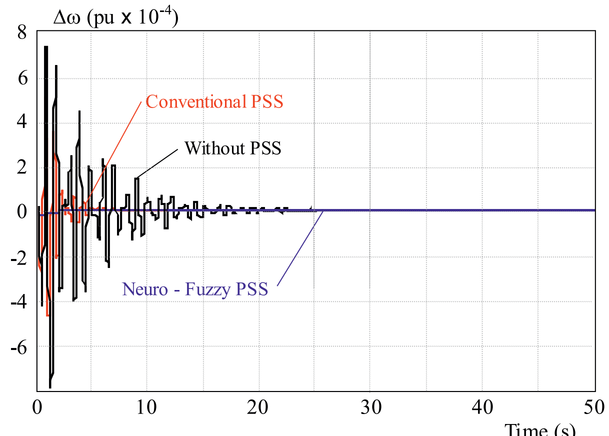

Fig. 4. Dynamic response — angular speed deviation $\Delta\omega$, Area 1, for P=0.8 pu, Q=0.9 pu, step torque disturbance = 0.005 pu

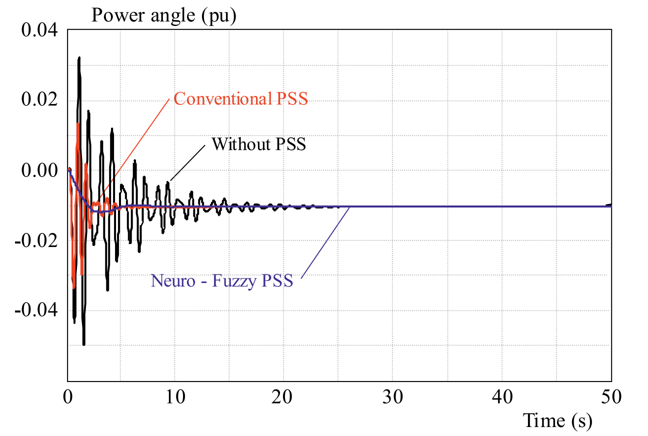

Fig. 5. Dynamic response — power angle, Area 1, for P=0.8 pu, Q=0.9 pu, step torque disturbance = 0.005 pu

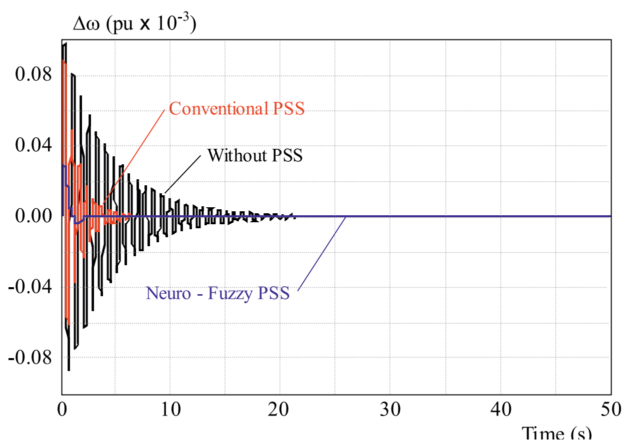

Fig. 6. Dynamic response — angular speed deviation $\Delta\omega$, Area 2, for P=0.8 pu, Q=0.9 pu, step torque disturbance = 0.005 pu

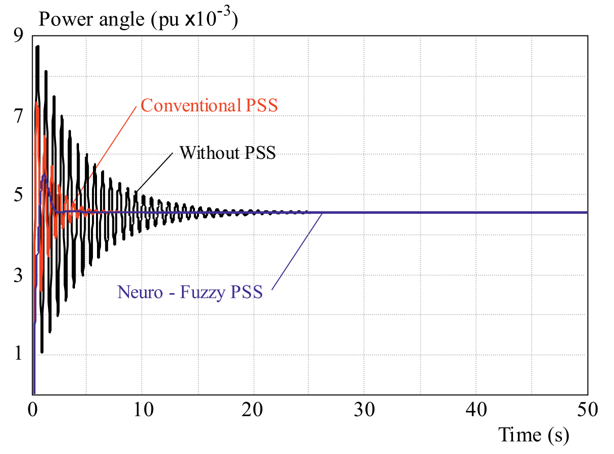

Fig. 7. Dynamic response — power angle, Area 2, for P=0.8 pu, Q=0.9 pu, step torque disturbance = 0.005 pu

Table 1. Fuzzy Inference System obtained from the CPSS

Deviation of angular speed $\Delta\omega$	Deviation of angular acceleration $\Delta\dot{\omega}$						
	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	ZE	PM	PM
PS	NM	NS	ZE	ZE	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	ZE	PM	PS	PB	PB	PB

data point belongs to a cluster with a degree specified by a membership grade. After generating the fuzzy inference system as shown in Table 1, the generated information describing the model structure and parameters of both the input and output variables are used in the ANFIS training phase. This information will be fine-tuned by applying the hybrid learning or the backpropagation scheme. The generated model is of a first-order Sugeno's form and the generated rules are as follows

$$U_{PSS} = p_i\Delta\omega + q_i\Delta\dot{\omega} + r_i \tag{2}$$

where, $i = \{1, n \times m\}$ refers to the rule numbers, $j = \{1, n\}$ refers to the angular speed deviation error terms in the fuzzy set, n, m refers to the number of terms generated, $k = \{1, m\}$ refers to the acceleration terms in the fuzzy set, $\{p_i, q_i, r_i\}$ are the i-th consequent (PSS output) parameters. The input signals to the ANFIS controller for the PSS are $\Delta\omega$ (deviation of the angular speed) and $\Delta\dot{\omega}$ (deviation of the angular acceleration).

The scheme of proposed ANFPSS and its application in the power system under study is shown in Fig. 3, where the inputs are $\Delta\omega$ and $\Delta\dot{\omega}$ and the output is ΔU_{PSS}.

5 SIMULATION RESULTS AND DISCUSSION

Initially, the 3-machine 9-bus power system shown in Fig. 1 is installed with two conventional power system

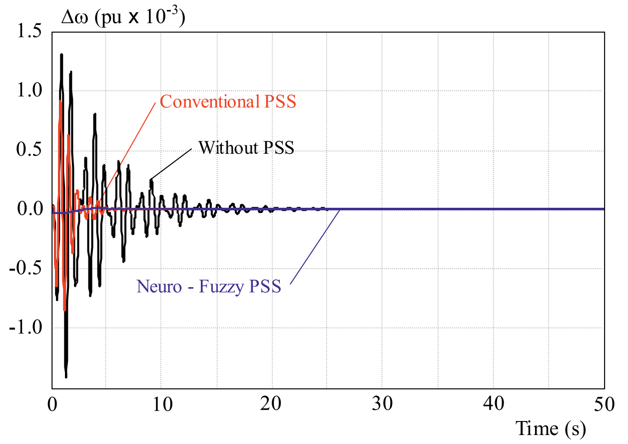

Fig. 8. Effect of increased torque disturbance on angular speed deviation $\Delta\omega$, Area 1, for $P=0.8$ pu, $Q=0.9$ pu, step torque disturbance = 0.009 pu

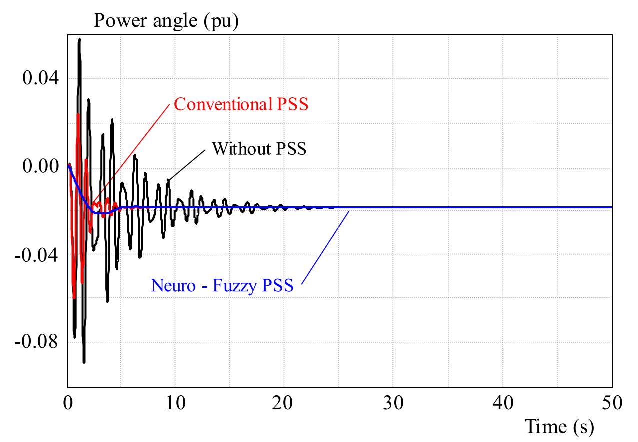

Fig. 9. Effect of increased torque disturbance on power angle, Area 1, for $P=0.8$ pu, $Q=0.9$ pu, step torque disturbance = 0.009 pu

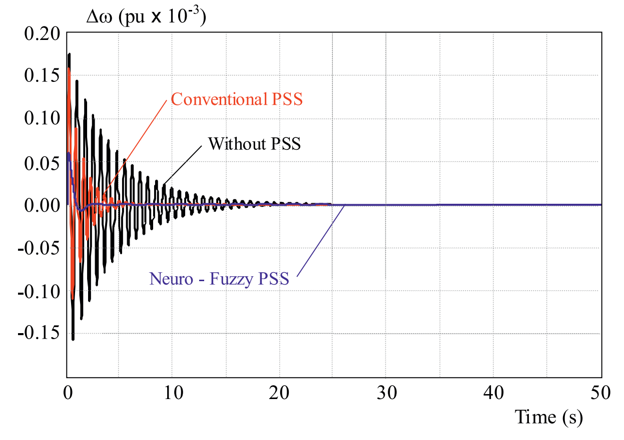

Fig. 10. Effect of increased torque disturbance on angular speed deviation $\Delta\omega$, Area 2, for $P=0.8$ pu, $Q=0.9$ pu, step torque disturbance = 0.009 pu

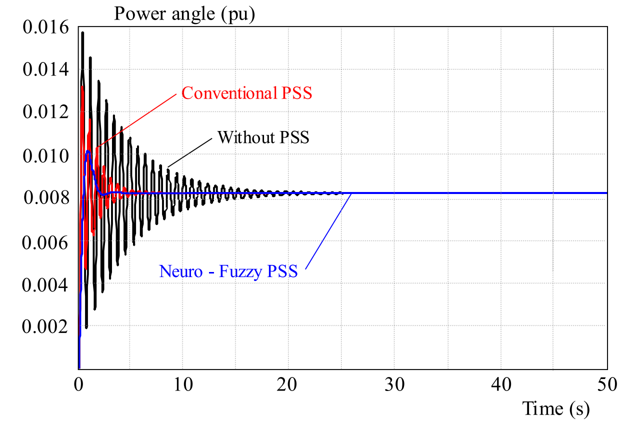

Fig. 11. Effect of increased torque disturbance on power angle, Area 2, for $P=0.8$ pu, $Q=0.9$ pu, step torque disturbance = 0.009 pu

stabilizers (CPSSs); one in Area 1 (G2) and another one in Area 2 (G3) respectively. The system is simulated in Matlab/Simulink environment with different operating conditions. Here, for illustration, the following two sets of operating conditions are considered in order to test the effectiveness of CPSSs.

(i) Total real power of load $P = 0.8$ pu, total reactive power of load $Q = 0.9$ pu, terminal voltage $V_t = 1.05$ pu, step torque disturbance $\Delta T_m = 0.005$ pu, and disturbance clearing time is 50 s.

(ii) Total real power of load $P = 0.8$ pu, total reactive power of load $Q = 0.9$ pu, terminal voltage $V_t = 1.05$ pu, Step torque disturbance $\Delta T_m = 0.009$ pu, and disturbance clearing time is 50 s.

From the simulation results shown in Figs. 4-7, it is inferred that the amplitudes and settling times of speed deviation and power angle oscillations for Area 1 and Area 2 are very high in the absence of PSSs. But after the introduction of CPSSs in the system, the amplitudes and settling times of oscillations are reduced.

To have further improvement in the damping performance of the system, the CPSSs are coordinated using ANFIS control scheme. The system is again simulated in Matlab/Simulink environment with same set of operating points in order to validate the efficiency of the proposed ANFIS control scheme. The simulation results are compared with that of CPSSs. The results shown in Figs. 4-7 reveal that the proposed simple and robust ANFIS control scheme has improved the damping performance of the system in terms of very much reduced amplitudes and settling times of oscillations.

When the torque disturbance is increased to 0.009 pu, the system shows somewhat increased amplitude of oscillations in both speed deviation and power angle for Area 1 and Area 2 with almost no change in settling times as shown in Figs. 8-11.

6 CONCLUSIONS

The conventional power system stabilizers (CPSSs) suffer from the drawback that they are not able to provide good damping performance over wide range of operating conditions. To overcome this drawback, ANFIS technology has been proposed in this paper to coordinate the CPSSs. The proposed method is evaluated on a 3-machine 9-bus power system model. The time domain simulation results demonstrate that the ANFIS coordinated CPSSs can provide a very good damping performance over a wide range of operating conditions and improve stability margin as well, compared to CPSSs. The effects of increased torque disturbance are also analyzed. Thus, the ANFIS based PSSs are able to yield better and fast damping characteristics under small and large disturbances even with changes in system operating conditions.

Appendix

Data for Generators G2 and G3 in 3-machine 9-bus power system:

Generator G2: Rated 192 MVA, Rated voltage = 18 kV, $H(s) = 6.4$, $T'_{d0} = 6$ s, $T'_{q0} = 0.535$ s, $x_d = 0.858$, $x'_d = 0.1198$, $x_q = 0.8645$, $x'_q = 0.1969$

Generator G3: Rated 128 MVA, Rated voltage = 13.8 kV, $H(s) = 3.01$, $T'_{d0} = 5.89$ s, $T'_{q0} = 0.6$ s, $x_d = 1.3125$, $x'_d = 0.1813$, $x_q = 1.2578$, $x'_q = 0.25$.

Reactance values are in pu on a 100 MVA base.

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