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Comparison of Two Power System Stabilizers for the Power System Stability

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Abstract: In this study, the structure of an adaptive networks based fuzzy controlled power system stabilizer, conventional power system stabilizer and dual input stabilizer is presented. With constraints on data availability and for study of power system stability, it is adequate to model the synchronous generator with field circuit and excitation system, connected to a infinite bus. Then power system stabilizers are designed and applied on the single machine infinite bus system. A systematic approach for optimizing the parameters of the dual input power system stabilizer (PSS3B and PSS4B) using ISE technique has been presented and there dynamic response are checked on wide variation in loading condition. A comparative study is also done in between all power system stabilizers.

Key words: Power system stabilier, small signal stability, single machine infinte bus system, Matlab/Simulation, delta-omega, universe of discourse, adaptive networks based fuzzy inference system stabilizer, India

INTRODUCTION

For study the behavior of a power system with various loading condition, it is necessary to use accurate transfer function model of that system. The desired models must be suitable for representing the actual excitation equipment performance for large, severe distribution as well as for small perturbation (Demello and Corcordia, 1969).

Power systems experience low-frequency oscillations due to disturbances. These low frequency oscillations are related to the small signal stability of a power system. The phenomenon of stability of synchronous machine under small perturbations is explored by examining the case of a single machine connected to an infinite bus system (SMIB) (Dandeno, 1980). The analysis of SMIB gives physical insight into the problem of low frequency oscillations. These low frequency oscillations are classified into local mode, inter area mode and tensional mode of oscillations (Kilgore).

The SMIB system is predominant in local mode low frequency oscillations. These oscillations may sustain and grow to cause system separation if no adequate damping is available. In recent years, modern control theories have been applied to Power System Stabilizer (PSS) design problems. These include optimal control, adaptive control, variable structure control and intelligent control. The conventional power system stabilizer is widely used in existing power systems and has contributed to the enhancement of the dynamic stability of power systems. The parameters of CPSS (Conventional Power System Stabilizer) are determined based on a linearized model of the power system around a nominal operating point where they can provided good performance (Kundur, 1999).

Because power systems are highly nonlinear systems with configurations and parameters that change with time, the CPSS design based on the linearized model of the power systems cannot guarantee its performance in a practical operating environment (Larsen and Swann, 1981). In recent years, adaptive network based fuzzy logic control has emerged as a powerful tool and is starting to be used in various power system applications.

This study presents a new power system stabilizer with an adaptive network based fuzzy controller for different operating conditions of the power system. Various simulations have been performed in order to subject it to several types of large disturbances using a SMIB power system.

Now a day, Dual input stabilizer is also used for power system stability which is called delta-p-omega stabilizer (Kundur *et al*., 1989).

CONVENTIONAL POWER SYSTEM STABILIZER

The PSS shown in the Fig. 1 is a conventional delta-omega PSS, consist of three blocks; a phase compensation block, a signal washout block and a gain block. Where, stabilizer gain, washout time constant, time constants of the lag lead networks are shown in Fig. 1. The step by step procedure for optimizing PSS parameter is as follows:

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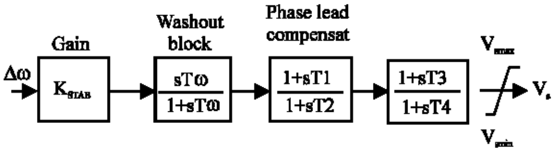

Fig. 1: Power system stabilizer transfer function model

- For any given operating condition, compute-constant of the SMIB system model
- Compute the natural frequency of oscillation (ω_n) from mechanical loop

Neglecting the effect of damping ($k_D = 0$), the characteristic equation of the mechanical loop is written as:

$$2HS^2 + \omega_0 K_1 = 0 \qquad (1)$$

The roots of above equation are:

$$S_1 S_2 = \pm j\sqrt{\frac{k_1\omega_0}{2H}} \qquad (2)$$

Thus, the natural frequency of oscillation is:

$$\omega_n = \sqrt{\frac{k_1\omega_0}{2H}} \qquad (3)$$

- Computation of angle of GEP (phase lag between stabilizing signal v_s and $\Delta\Psi_{fd}$ including the feedback effect of k_6 and setting $\Delta\delta = 0$:

$$GEP(S) = \frac{K_A K_3}{(1+sT_A)(1+sT_B)} \qquad (4)$$

Where:

$$k_A = {}^{T_B}\!/_{T_C} * K_{AVR} \qquad (5)$$

Time constant is very small and hence, neglected. Let γ be the phase angle of GEP:

$$\begin{aligned}\gamma &= \angle GEP(S) ats = j\omega_n \\ &= -\tan^{-1}\left(\frac{(T_A + T_{S)\omega_n}}{1 + K_A K_S K_6 - T_A T_S \omega_n^2}\right)\end{aligned} \qquad (6)$$

Design of phase lead-lag compensator: The phase lead-lag compensator is design to provide required degree of phase compensation. For 100% phase compensation:

$$\angle G_C(j\omega_n) + \angle GEP(j\omega_n) = 0 \qquad (7)$$

Assuming two identical cascaded connected lead lag networks $T_1 = T_3$ and $T_2 = T_4$ and $T_1 = aT_2$, the transfer function of the phase compensator G_c become:

$$G_C = \left[\frac{1+ST_1}{1+ST_2}\right]^2 \qquad (8)$$

Since, the phase compensation by both the lead-lag networks is equal, i.e., $-\gamma/2$. The parameter a and T_2 are computed, using following relation:

$$a = \frac{1+\sin(\frac{\gamma}{2})}{1-\sin(\frac{\gamma}{2})} \qquad (9)$$

$$T_2 = \frac{1}{\omega_n\sqrt{a}} \qquad (10)$$

$$T_1 = aT_2 \qquad (11)$$

Computation of optimum gain K_{STAB} for PSS: The required gain setting K_{STAB} for a desire value of ξ is obtained from:

$$K_{STAB} = \frac{2\delta\omega_n(2H)}{K_Z|G_C||GEP(S)|} \qquad (12)$$

Where, $|G_c|$ and $|GEP\ (S)|$ are evaluated for $S = j\omega_n$.

ADAPTIVE NETWORK BASED FUZZY LOGIC POWER SYSTEM STABILIZATION

In this research, an adaptive network based fuzzy structure is employed to design a Fuzzy logic Power System Stabilizer (FPSS). The FPSS considered have two inputs that are components of the speed and its deviation. In this method, input parameters change to linguistic variable and suitable Membership Functions (MFs) should be chosen for them.

Moreover, the rule base contains the fuzzy if then rules of Takagi and Sugeno type in which the output of each rule is a linear combination of input variables added by a constant term (You *et al*., 2002) structure of ANFIS. In this part, the structure of ANFIS for tuning parameter of a fuzzy inference system with two inputs and one output is explained. The structure of ANFIS which is shown in Fig. 1 consists of five layers:

Layer 1: Each node in this layer is an adaptive node with a node function shown in the following Eq. 13 and performs a Membership Function (MF):

$$\text{ɋ} = \mu_{Ai}(X) \tag{13}$$

Where:

ɋ = Membership function of $\mu_{Ai}(X)$
A = The linguistic label associated with this node

In this layer, parameter of each MF are adjusted. In this study, MFs of these nodes are bell-shaped function.

Layer 2:

$$w_i = \mu_{Ai}(X) * \mu_{Bi}(y) \tag{14}$$

In this layer, the output of each node represents the firing strength of each rule. Hence, the nodes perform the fuzzy AND operation that its output is multiple of inputs as shown in Eq. 14:

Layer 3: As shown in Eq. 15, the nodes of this layer determine the normalized firing strength of each rule:

$$\bar{\omega}_i = \frac{\omega_i}{\sum_{i=1}^{n} \omega_i} \tag{15}$$

Layer 4: Each node in this layer is an adaptive node and in this layer parameters of output are adjusted. This output usually is a linear function of input.

Layer 5: This layer has only one node and calculates the overall output as a summation of all input signals:

$$f = \sum_{i=1}^{n} f_i \tag{16}$$

Hence, an adaptive network has been constructed which is functionally equivalent to a fuzzy logic fault locator. This structure can update the MFs and rule base parameters. The ANFPSS is initially trained off-line. For this, typically disturbances under various operation conditions were applied to simulated Multi-machine power system.

The main effective characteristic and condition of the power system by which the PSS operations could be distorted are assumed to be one of the fault positions, level of system load and clearing time of protection devices. In other words, a useful PSS should be able to generate proper so an effective PSS must be able to generate suitable damping signals under various position of fault and different levels of load. Furthermore, if the protection system has not a proper operation and failed to clear fault in the shortest time, the backup protection would be activated after a determined time delay so the PSS should be enable to send proper damping signal under this conditions. For this further to normal operation of power system, we simulated other critical conditions and used the obtained data in training process of ANFPSS therefore, the proposed PSS is able to damp oscillations under normal condition of power system and also conditions described as:

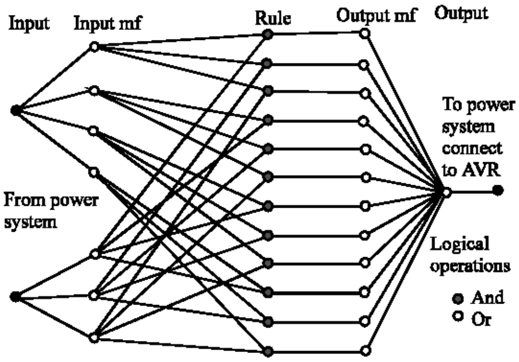

Fig. 2: Proposed ANFPSS for power system

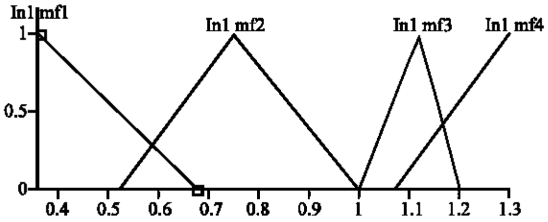

Fig. 3: MFs of two inputs of controller in proposed technique

Various position of fault on power system: The ANFPSS can damp oscillation due to fault on different bus or along each line of power system.

Fault clearing time: The ANFPSS has good performance even if the main protection system failed and fault clearing time increases until backup protection operates with a determined time delay.

Level of load: The proposed ANFPSS has a nice operation when power system faces with a maximum 20% overload. Initial parameters of MFs and if-then rules are selected in a random manner and after training process the obtained MFs and rules are applied to power system as an ANFPSS.

ANFPSS scheme: Figure 2 shows the scheme of proposed ANFPSS and its application in a Multi-machine power system. A zero order Sugeno fuzzy controller with eighteen rules is used for ANFPSS. The controller rules are of the form: If Δω is Ai and P is Bi then u = Ki. The MFs of two inputs of controller represent the triangle membership functions for each linguistic set and each input. These Mfs after training process are shown in Fig. 3.

DELTA-P-OMEGA STABILIZER

The principle of this stabilizer is illustrated by the following equation that shows how a signal proportional to rotor speed deviation can be derived from the accelerating power:

$$\Delta\omega_{eq} = \frac{1}{2H}\int(\Delta P_m - \Delta P_e)dt \qquad (17)$$

The objective is to derive $\Delta\omega_{eq}$ so that it does not contain torsional modes. Torsional components are inherently attenuated in the integral of ΔP_e signal. The problem is to measure the integral of ΔP_m free of torsional modes. In many applications, the component ΔP_m is neglected. This is satisfactory, except when changing loads on the unit and other systems conditions when the mechanical power changes. Under such conditions, a spurious stabilizer output is produced if ΔP_e, alone is used as the stabilizing signal. This in turn results in transient oscillations in voltage and reactive power. The integral of mechanical power is related to shaft speed and electrical power as follows:

$$\int \Delta P_m dt = M\Delta\omega + \int \Delta P_l \qquad (18)$$

The delta-p-omega stabilizer makes use of the above relationship to simulate a signal proportional to the integral of mechanical power change by adding signals proportional to shaft-speed change and integral of electrical power change.

This signal will contain torsional oscillations unless a filter is used. Because mechanical power changes are relatively slow even for fast valve movements, the derived integral of the mechanical power signal can be conditioned with a simple low-pass filter to remove torsional frequencies.

The overall transfer function for deriving the equivalent rotor speed deviation signal from shaft speed and electrical power measurements is given by:

$$\Delta\omega_{eq}(s) = -\frac{\Delta P_e(s)}{2Hs} + G(s)\left[\frac{\Delta P_e(s)}{2Hs} + \Delta\omega(\Delta\omega(s))\right] \qquad (19)$$

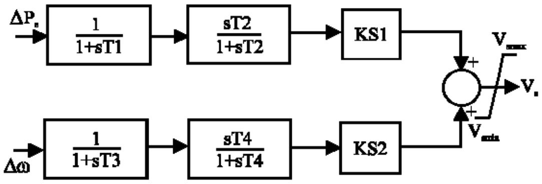

Fig. 4: IEEE type PSS3B dual input power system stabilizer

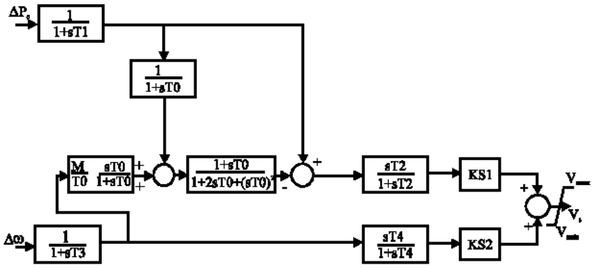

Fig. 5: IEEE type PSS4B dual input power system stabilizer

where, G (s) is the transfer function of the torsional filter. The delta-p-omega PSS has two major advantages over the delta-omega PSS.

The ΔP_e signal has a high degree of torsional attenuation and hence, there is generally no need for a torsional filter in the main stabilizing path. This eliminates the exciter mode stability problem, thereby permitting higher stabilizer gain which results in better damping of system oscillations.

An end-of-shaft speed sensing arrangement can be used. This allows the use of a standard design for all units irrespective of their torsional characteristics. There are two type of dual input stabilizers PSS3B and PSS4B (Fig. 4 and 5).

DYNAMIC PERFORMANCE OF THE SYSTEM

After the application of CPSS, ANFLPSS and dual input stabilizer (one by one) on SMIB system, the performance of system is investigated. To study the behavior of the system after the change in the mechanical power input, the speed variation has observed. Then a power system stabilizer has been applied on the system and again the behavior of the system was observed as in Fig. 6 and 7.

Change in Rotor angle is also observed in all cases shown in Fig. 8 and 9. After the observation for individual stabilizer, a comparative study is also carried

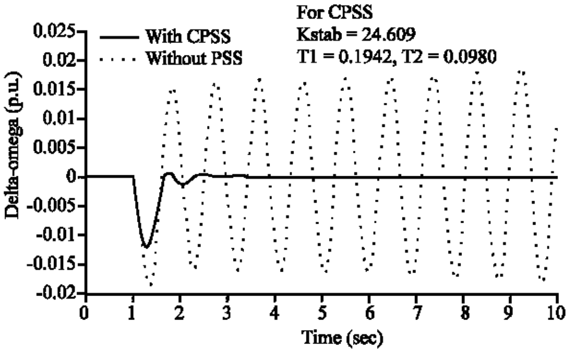

Fig. 6: Dynamic response of the SMIB system for with CPSS and without PSS

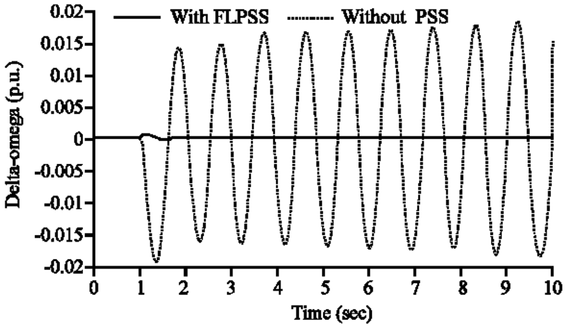

Fig. 7: Dynamic response of the SMIB system for with CPSS and without PSS

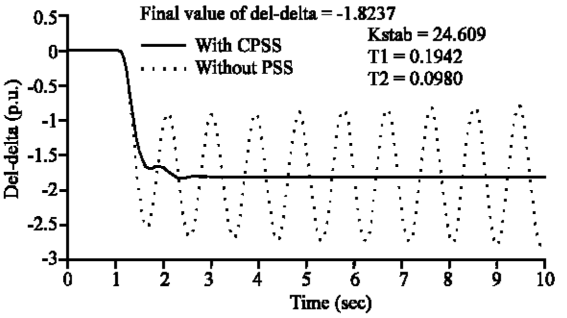

Fig. 8: Dynamic response of the SMIB system for with ANFLPSS and without PSS

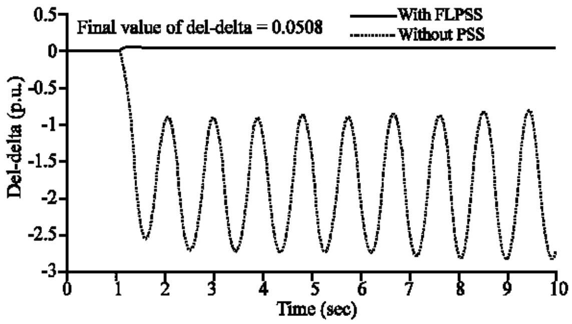

Fig. 9: Dynamic response of the SMIB system for with ANFLPSS and without PSS

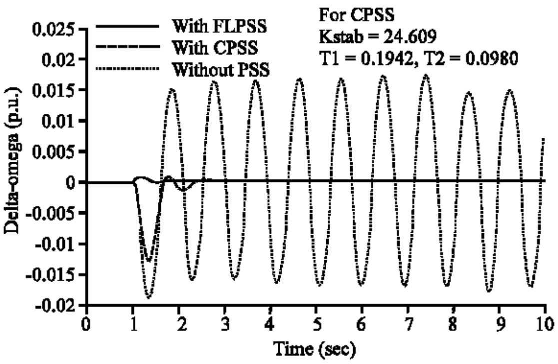

Fig. 10: Comparative study of dynamic response of the SMIB system for with ANFLPSS, CPSS and without PSS

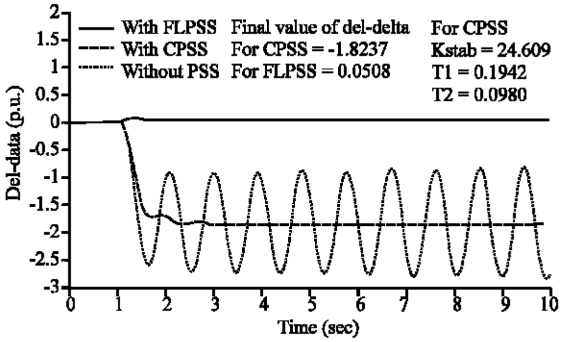

Fig. 11: Comparative study of dynamic response of the SMIB system for with ANFLPSS, CPSS and without PSS

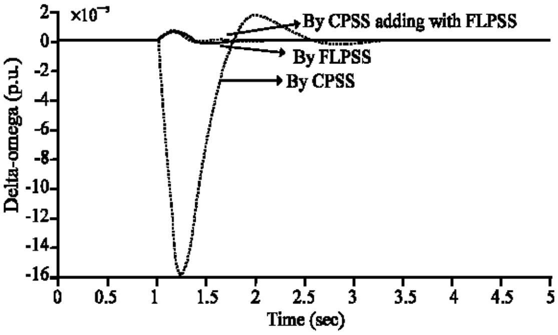

Fig. 12: On adding both ANFLPSS and CPSS compared with individual stabilizer

out to check the improvement in system performance after the application of ANFLPSS over CPSS. Figure 10 shows the comparative study of $\Delta\omega$ on which it can be conclude that the stabilizing time of delta-omega has been reduced. Rotor angle oscillations are also showed in Fig. 11 which show that stabilizing rotor angle is much improved by the application of ANFLPSS over the CPSS.

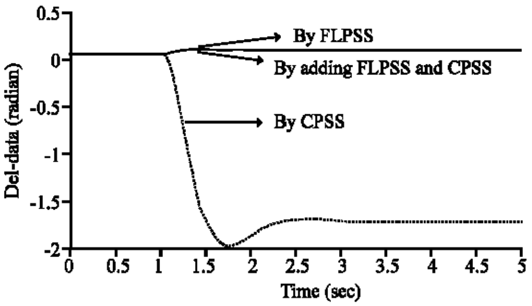

Fig. 13: On adding both ANFLPSS and CPSS compared with individual stabilizer

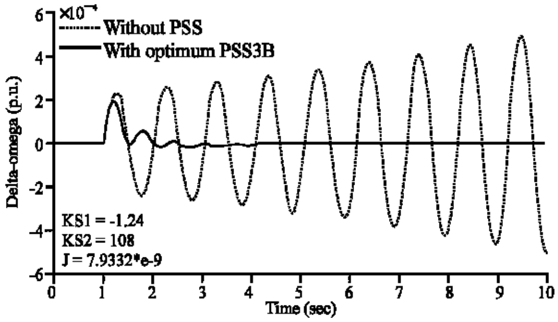

Fig. 14: Dynamic response of the SMIB system with type PSS3B stabilizer for P = 0.95 p.u., Q = 0.321 p.u. (Nominal operating condition)

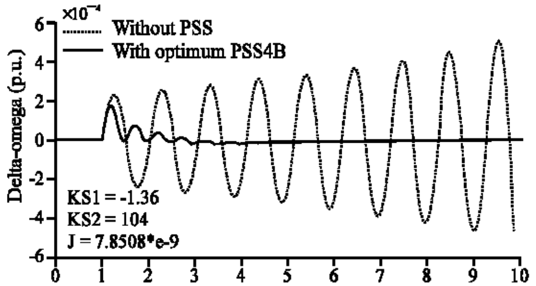

Fig. 15: Dynamic response of the SMIB system with type PSS4B stabilizer for P = 0.95 p.u., Q = 0.321 p.u. (Nominal operating condition)

Now both CPSS and ANFLPSS are applied on a same system and response is observed shown in Fig. 12 and 13. Then after the application of dual input stabilizer the response are again checked whish are shown in Fig. 14 and 15.

CONCLUSION

In this study, a Conventional power system stabilizer, ANFuzzy logic controlled power system stabilizer and dual input stabilizers are designed. The small signal stability is targeted. First a single machine infinite bus system has modeled. Then the input mechanical power was increased to study the behavior of system. Due to sudden increase in mechanical power the system goes unstable it can be observed by observing, in which the oscillations has continuously increases. To get a stable system a power system stabilizer was designed which control the excitation of the generator. The comparison between CPSS and ANFLPSS is also carried out. On the bases of this comparison, it was found that the ANFLC improve the performance of system and stabilizing time also decreases. Then both ANFLPSS and CPSS are applied on the same system to improve the performance more and it was found that the performance of whole system is improved quit well. After this, a dual input power system stabilizer are also designed and there dynamic performance of the system with optimum PSS4B dual input power system stabilizer is quite robust to wide variation in loading condition as compare to the PSS3B dual input power system stabilizer, provided parameters are optimized for a suitable loading condition.

NOMENCLATURE

All quantities are per unit on machine base:

K_A = Exciter gain
T_A = Exciter time constant
T_R = Terminal transducer time constant
X_e = Transmission line Reactance
R_e = Transmission line Resistance
P = Generator real power output
Q = Generator reactive power output
K_1 = Generator terminal voltage
f_0 = Frequency (Hz)
K_1 = Change in T_e for a change in with constant flux linkages in the d axis
K_2 = Change in T_e for a change in d axis flux linkages with constant δ
K_3 = Impedance factor
K_4 = Demagnetising effect of a change in rotor angle
K_5 = Change in V_t with change in rotor angle for constant
K_6 = Change in V_t with change in E_q constant rotor angle

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