

Multi Input Power System Stabilizer Design Based on Genetic Algorithms

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Abstract: This study presents a new generator's PSS (Power System Stabilizer) design methodology. A multi input PSS is utilized to achieve a better performance over a wide range of operating conditions instead of a conventional single input PSS. The parameters of the proposed PSS are obtained by minimizing a time domain performance index. The proposed PSS is evaluated against the Conventional Power System Stabilizer (CPSS) at a multi area power system considering system parametric uncertainties. Simulation results show that the proposed PSS provides a better performance than the conventional PSS.

Key words: Multi input power system stabilizer, low frequency oscillations, genetic algorithms, time domain, Iran

INTRODUCTION

Due to recent increase in electric power demand, power systems are becoming large in scale. Furthermore, wide area power interchanges lead to large and complex power system. Under such conditions, poor damping Low Frequency Oscillations (LFO) between 0.3-0.5 Hz might occur to influence the whole system.

One of several methods to stabilize power system oscillation is to use a single input PSS that is equipped with generator excitation system. In real world practical applications, the PSS has been a very effective device for improving generator's oscillation. However, the conventional single input PSS has a weak point in that it cannot be applied to the above mentioned wide range of swing frequency that is the so called inter-area mode. The reason is that the conventional PSS is designed using one generator connected to infinite bus system in general and it is tuned for the local mode which frequency is around 1.0-2.0 Hz. Moreover when designing the PSS only one operating condition is considered. The inter-area mode is a complex phenomenon which arises from all of generator dynamics. Therefore, the conventional PSS must be improved to be more a robust controller (Liu *et al.*, 2005). In order to improve the performance of CPSSs, numerous techniques have been proposed for designing them such as Intelligent Optimization Methods (Linda and Nair, 2010; Sumathi *et al.*, 2007; Yassami *et al.*, 2010; Sudha *et al.*, 2009; Jiang and Yan, 2008) and Fuzzy Logic Method (Hwang *et al.*, 2008; Dubey, 2007). Also many other different techniques have been reported in (Chatterjee *et al.*, 2009; Nambu and Ohsawa, 1996) and the

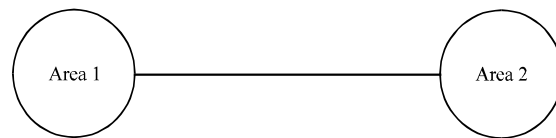


Fig. 1: Two area power system

application of robust control methods for designing PSS has been presented in (Bouhamida *et al.*, 2005; Gupta *et al.*, 2005; Mocwane and Folly, 2007; Sil *et al.*, 2009).

This study deals with a design method for the stability enhancement of a multi machine power system using Multi-Input PSS (MI-PSS) which its parameters are tuned using GA. To show effectiveness of the new MI-PSS, this PSS is compared with the CPSS. Simulation results show that the proposed PSS guarantees robust performance under a wide range of operating conditions.

System under study: Figure 1 shows a two area power system (Kundur, 1993). In this system, the first area is a single generator and the second area is aggregation of a large number of generators. The second area performs like an infinite bus. The system data are completely presented in Kundur, 1993. In the simulation process, the second area is simulated as a single generator with inertia $M = 1000$ Mj/MVA.

DYNAMIC MODEL OF THE SYSTEM

Non-Linear Dynamic Model: A Non-Linear Dynamic Model of the system is derived by disregarding the

resistances and the transients of generator, transformers and transmission lines (Kundur, 1993). The Nonlinear Dynamic Model of the system is given as in Eq. 1:

$$\begin{cases} \dot{\omega} = \frac{(P_m - P_e - D\Delta\omega)}{M} \\ \dot{\delta} = \omega_0(\omega - 1) \\ \dot{E}'_q = \frac{(-E_q + E_{fd})}{T'_{do}} \\ \dot{E}_{fd} = \frac{-E_{fd} + K_a(V_{ref} - V_t)}{T_a} \end{cases} \quad (1)$$

Linear Dynamic Model: A Linear Dynamic Model of the system is obtained by linearizing the Non-Linear Dynamic Model around the nominal operating condition. The linearized model of the system is obtained as in Eq. 2. Besides, the dynamic model of the system in the state-space form is obtained as in Eq. 3 (Kundur, 1993):

$$\begin{cases} \Delta\dot{\delta} = \omega_0\Delta\omega \\ \Delta\dot{\omega} = \frac{-\Delta P_e - D\Delta\omega}{M} \\ \Delta\dot{E}'_q = (-\Delta E_q + \Delta E_{fd})/T'_{do} \\ \Delta\dot{E}_{fd} = -\left(\frac{1}{T_A}\right)\Delta E_{fd} - \left(\frac{K_A}{T_A}\right)\Delta V \end{cases} \quad (2)$$

$$\begin{bmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{E}'_q \\ \Delta\dot{E}_{fd} \end{bmatrix} = \begin{bmatrix} 0 & \omega_0 & 0 & 0 \\ -\frac{K_1}{M} & 0 & -\frac{K_2}{M} & 0 \\ -\frac{K_4}{T'_{do}} & 0 & -\frac{K_3}{T'_{do}} & \frac{1}{T'_{do}} \\ -\frac{K_A K_5}{T_A} & 0 & -\frac{K_A K_6}{T_A} & -\frac{1}{T_A} \end{bmatrix} \times \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta E'_q \\ \Delta E_{fd} \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ \frac{1}{M} & 0 \\ 0 & 0 \\ 0 & \frac{K_A}{T_A} \end{bmatrix} \times \begin{bmatrix} \Delta T_m \\ \Delta V_{ref} \end{bmatrix} \quad (3)$$

Analysis: In the nominal operating condition, the eigen values of the system are obtained using analysis the State-Space Model of the system presented in Eq. 3 and these eigen values of the closed loop system are: -4.2797, -46.3666, 0.1009 + j4.758, 0.1009 - j4.758. It is clearly seen that the system has two unstable poles at the right half plane and therefore the system is unstable and needs to Power System Stabilizer (PSS) for stability.

Power system stabilizer: A Power System Stabilizer (PSS) is provided to improve the damping of power system oscillations. Power system stabilizer provides an electrical damping torque (ΔT_m) in phase with the speed deviation ($\Delta\omega$) in order to improve damping of power system oscillations (Kundur, 1993). In this study, MI-PSS and CPSS are developed. In the study, the proposed methods are introduced.

Conventional power system stabilizer: The Conventional Power System Stabilizer (CPSS) block can be used to add damping to the rotor oscillations of the synchronous machine by controlling its excitation. The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators. These oscillations also called power swings must be effectively damped to maintain the system stability. The output signal of the PSS is used as an additional input (v_{stab}) to the Excitation System. The PSS input signal can be either the machine speed deviation, $\Delta\omega$ or its acceleration power. The CPSS is modeled by the following nonlinear system (Fig. 2).

The model consists of a low-pass filter, a general gain, a washout high-pass filter, a phase-compensation system and an output limiter. The general gain K determines the amount of damping produced by the stabilizer. The washout high-pass filter eliminates low frequencies that are present in the dw signal and allows the PSS to respond only to speed changes. The phase-compensation system is represented by a cascade of two first-order lead-lag transfer functions used to compensate the phase lag between the excitation voltage and the electrical torque of the synchronous machine.

Multi input power system stabilizer: The P + ω input PSS is shown in Fig. 3. P and ω are generator's local signals which are selected as the PSS input. The P input PSS and the ω input PSS work mainly for local and inter-area oscillation mode, respectively. If P input PSS and ω input PSS are optimized independently and are combined for use as P + ω input PSS, an unexpected unstable oscillation

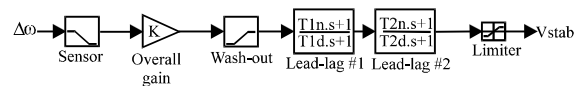


Fig. 2: Conventional power system stabilizer

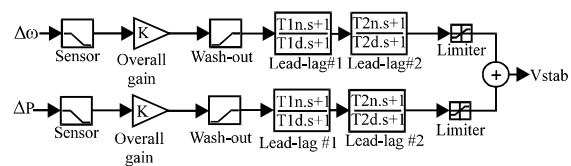


Fig. 3: Multi input power system stabilizer

mode may occur. In the proposed method, the parameters of the P + ω input PSS are optimized all together.

GENETIC ALGORITHMS

In this study, GA Method is considered for tuning the proposed PSSs. 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 (Randy and Sue, 2004).

DESIGN METHODOLOGY

In this study, the proposed PSSs are tuned based on the GA. In this study, the performance index is considered as in Eq. 4. In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (ITAE):

Table 1: Obtained parameters of CPSS and MI-PSS

Parameters	K	T _{1n}	T _{1d}	T _{2n}	T _{2d}
CPSS	21.74	0.055	0.023	3.990	6.110
MI-PSS (Δω input)	17.22	17.320	6.110	0.022	0.039
MI-PSS (ΔP input)	2.71	0.120	0.050	0.800	0.050

Table 2: The calculated ITAE

Operating conditions	MI-PSS	CPSS
Nominal	3.00×10 ⁻⁴	3.98×10 ⁻⁴
Heavy	3.10×10 ⁻⁴	4.73×10 ⁻⁴
Very heavy	3.37×10 ⁻⁴	6.31×10 ⁻⁴

$$ITAE = \int_0^t t |\Delta\omega| dt \quad (4)$$

To compute the optimum parameter values, a 0.1 step change in the reference mechanical torque (ΔT_m) is assumed and the performance index is minimized using GA. It should be noted that GA algorithm is run several times and then optimal set of PSS parameters is selected. The optimum values of the parameters are listed in the Table 1.

SIMULATION RESULTS

In order to study the PSS performance under system uncertainties (controller robustness), three operating conditions are considered as follow:

- Nominal operating condition
- Heavy operating condition (20% changing parameters from their typical values)
- Very heavy operating condition (50% changing parameters from their typical values)

To demonstrate the robustness performance of the proposed method, the ITAE is calculated following a 10% step change in the reference mechanical torque (ΔT_m) at all operating conditions (nominal, heavy and very heavy) and results are shown in Table 2. It is seen that in all operating conditions the MI-PSS is better than the CPSS.

Also the simulation results are depicted in Fig. 4. Figure 4 shows Δω at nominal, heavy and very heavy operating conditions following 10% step change in the reference mechanical torque (ΔT_m). It is clear to see that under all operating conditions, the MI-PSS has better performance than the other method in damping of oscillations. It is shown that the double input signal PSS under consideration of the multiple load conditions satisfies the robustness requirements in that the damping of oscillations modes are significantly improved over a wide range of the operation conditions.

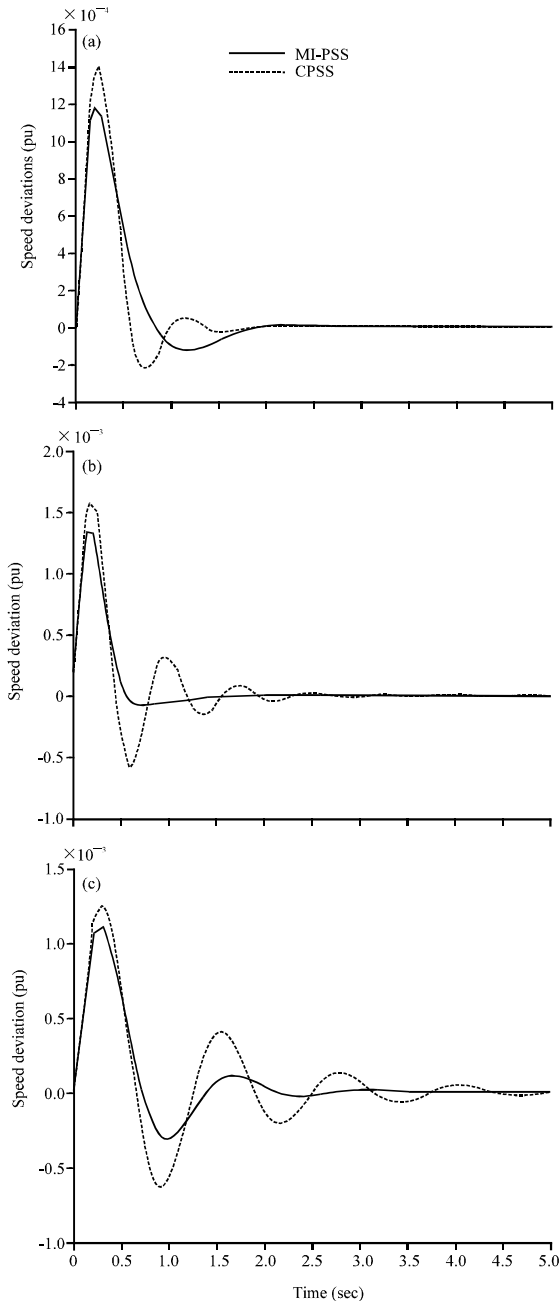


Fig. 4: Dynamic responses $\Delta\omega$ following 0.1 step in the reference mechanical torque (ΔT_m); a) Nominal operating condition; b) Heavy operating condition and c) Very heavy operating condition

CONCLUSION

In this study, a new multi input PSS has been successfully developed. The proposed method was applied to a typical multi area infinite power system containing system parametric uncertainties and various

loads conditions. The simulation results demonstrated that the designed MI-PSS is capable of guaranteeing the robust stability and robust performance of the power system under a wide range of system uncertainties. From these results, it is expected that any of the generators in the system can contribute to stabilize any poor damping oscillation mode by using the appropriate multi signal as PSS input.

NOMENCLATURE

ω	= Synchronous speed
δ	= Synchronous angle
P_m	= Input mechanical power
P_e	= Output electrical power
M	= Inertia
E_q	= q axis voltage
E_{fd}	= Field voltage
E'_q	= Transient voltage of q axis
T'_{dq}	= Transient time constant of q axis
K_a	= Excitation system gain
T_a	= Excitation system time constant
V_t	= Terminals voltage
V_{ref}	= Reference voltage of excitation system
T_m	= Mechanical torque
CPSS	= Conventional Power System Stabilizer
GA	= Genetic Algorithms
ITAE	= Integral of the Time multiplied Absolute value of the Error
LFO	= Low Frequency Oscillations
MI-PSS	= Multi Input-Power System Stabilizer
PSS	= Power System Stabilizer

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