A new optimization method for PSS design in New-England Power system

Mehdi Nikzad[1], Shoorangiz Shams Shamsabad Farahani[2], Mohammad Bigdeli Tabar[3], Hossein Tourang[4], Behrang Yousefpour[5]

[1, 2, 3, 4, 5] Department of Electrical Engineering, Islamshahr Branch, Islamic Azad University, Tehran, Iran
mehdinikzad28@yahoo.com

Abstract: Power system stabilizer (PSS) design in large scale power systems is a critical issue and has always been investigated by researchers. In this paper a new strong optimization method named memetic algorithms is used to design PSS in a large scale power system. New-England power system is considered as case study to show effectiveness of the proposed method.

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1. Introduction

With 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 to 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 1.0-2.0Hz. 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, conventional PSS must be improved to be more a robust controller. 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].

In this paper a new optimization method is used to design PSS at a large scale power system with 10 generators. The results show the ability of the proposed optimization method in finding optimal solution.

2. System under study

A large scale power system with ten generators and 39 buses is considered as case study. Figure 1 shows the proposed test system which is known as New-England power system. Generator 1 is equivalent of a large number of generators and is not installed with PSS; the other generators are equipped with PSS. The system data are given in [15].

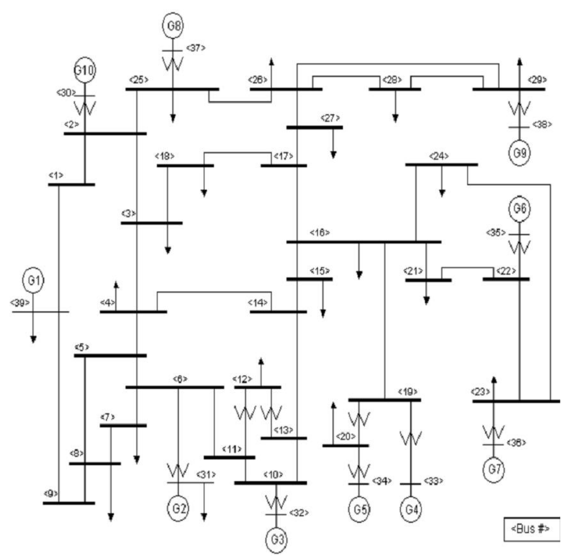

Figure 1: 10-machine 39-bus power system

3. Dynamic model of the system

A non-linear dynamic model of the system is derived by disregarding the resistances and the transients of generator, transformers and transmission lines [15]. The nonlinear dynamic model of the system is given as (1).

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

3.1. Analysis

The Eigen values of the system are obtained and listed in Table 1. It is clearly seen that the system has one pole at zero and therefore the system is unstable and needs to Power System Stabilizer (PSS) for stability.

Table 1: The Eigen values of power system

-8358.4+39301i
-8358.4-39301i
-4945.2+70702i
-4945.2-70702i
-5017.8+70208i
-5017.8-70208i
-5320.2+67975i
-5320.2-67975i
-6393.3+59586i
-6393.3-59586i
-5642.1+65561i
-5642.1-65561i
-5786.1+64437i
-5786.1-64437i
-6147.2+61294i
-6147.2-61294i
-6018.8+62463i
-6018.8-62463i
-0.01398+6.0244i
-0.01398-6.0244i
-0.01702+5.085i
-0.01702-5.085i
-0.01813+4.2203i
-0.01813-4.2203i
-0.0178+3.9941i
-0.0178-3.9941i
-0.01431+3.5683i
-0.01431-3.5683i
-0.01512+3.1525i
-0.01512-3.1525i
-0.01509+2.5403i
-0.01509-2.5403i
-0.01473+1.695i
-0.01473-1.695i
-0.00596+0.69955i
-0.00596-0.69955i
-0.02614
0
-0.97421
-0.99417
-0.99579
-0.99651
-0.99735
-0.99794
-1.0003
-0.99911
-0.99994

-0.1,-0.1,-0.1, -0.1,-0.1,-0.1, -0.1,-0.1,-0.1
-10,-10,-10, -10,-10,-10, -10,-10,-10
-20,-20,-20, -20,-20,-20, -20,-20,-20

4. 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 [16].

4.1. 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 as shown by Figure 2 [16].

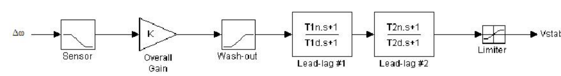

Figure 2: Conventional Power System Stabilizer

This 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 $\Delta\omega$ 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 [16].

5. Memetic algorithms

Evolutionary algorithms (EA) propagate effective neuron structures by varying the sample distribution in the solution space, depending upon the evaluation of the objective (fitness) function. This selection biases the search towards regions of the solution space where near optimal solutions have been discovered. Local refinements to these near optimal solutions could significantly accelerate arriving at an optimal solution. However, EA's are not suited to focusing local refinements in large combinatorial tasks. Genetic Evolution may be augmented to facilitate local (neighborhood) search via cultural evolution [17]. Analogous to genetic propagation, cultural transmission (i.e., bird song) is the evolutionary flow of information. However, there are significant differences between cultural and genetic evolution. In cultural evolution, improvements are seldom a result of copying errors or the exchange of co-adapted units of information. Clear-cut combination of exact ideas does not generally lead to innovation. An idea is rather blended with other similar ideas based upon perception and understanding. This blending process is the driving force towards innovation. Genetic evolution does not incorporate an innovative component, as experimentation (reproduction) with new information is governed by biased selection. A gene is not changed based on the quality of other similar genes. The individuals in cultural evolution are conscious entities that use one another's ideas in the search process, subject to cooperation and competition. Genetic evolution has no concern for individual genes, but focuses on improving the population by propagating effective gene combinations.

Memetic algorithms (MA) are evolutionary algorithms that use cultural evolution for local search (LS). The local search is applied to solutions in each generation of the EA, creating a process of lifetime learning. The EA searches globally for regions containing significant optima, while the LS search these regions for the local optimum. The EA is thus responsible for exploration, whilst the LS govern exploitation. A balance between exploration and exploitation ensures that the minimum number of evaluations is employed in finding the global optimum. This balance is dependent on the synergy between lifetime learning and evolution. LS aid the evolutionary process by smoothing the fitness landscape. LS exploit the local fitness landscape, which absolves the EA from devoting resources to searching in areas of local complexity on the fitness surface. This smoothing essentially involves discretion of the fitness landscape. Consider the optimization of the fitness landscape in Figure 3.

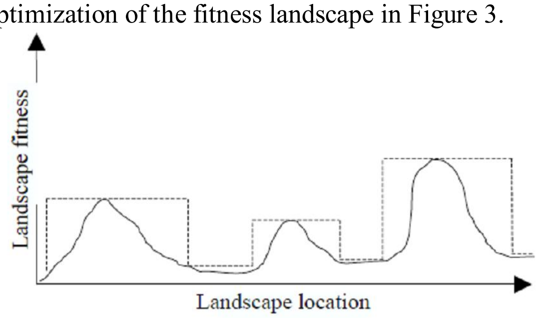

Figure 3: Smoothing of the fitness landscape by local search

Assume that any EA solution, located on one of the slopes on the three peaks, is able to locate the local maximum through LS. The EA's task is simplified considerably, in that it only needs to locate three regions of the search space. The dashed lines in Figure 3 indicate these three discrete regions. With the added local search capability, the complexity of the EA's solution space is reduced significantly. The plasticity afforded by lifetime learning makes it easier for the EA to climb to peaks in the fitness landscape [17].

Therefore, the EA of a memetic algorithm should not generate multiple solutions in the neighbourhood of a single optimum, but should maintain a diverse (wider) search in the solution space. Thereby, the EA aids the LS by bordering regions (sub-spaces) of the fitness landscape that contain significant optima. Such regions become prime candidates for exploitation by local search algorithms. A synergetic effect, which accelerates evolution, thus exists in an evolving population of individuals, where the individuals are also exposed to learning during their lifetime. A key element to maintaining such synergy is a diversification mechanism in the EA. Genetic diversity is required to continue a global search. Global reliability, which promises convergence to the global optimum, is required to ensure that every region of the solution space is effectively explored [17].

6. Design methodology

In this section the proposed PSSs are tuned based on the MA. In this study the performance index is considered as (2). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (*ITAE*).

$$\mathrm{ITAE} = \int_0^t \sum_{i=1}^{n} t\left|\Delta\omega_i\right| dt \qquad (2)$$

To compute the optimum parameter values, different three phase short circuits are assumed and the performance index is minimized using MA. It should be noted that MA 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 2. T_{1d} and T_{2d} are fixed on 0.01.

Table 2: PSS parameters using GA

	K	T_{1n}	T_{2n}
G_2	7.77	0.034	0.122
G_3	142.9	0.037	0.054
G_4	166.8	0.041	0.041
G_5	155.1	0.023	0.058
G_6	136.1	0.01	0.030
G_7	175.5	0.01	0.051
G_8	179.9	0.02	0.011
G_9	176.3	0.02	0.019
G_{10}	123.9	0.011	0.13

7. Simulation results

The simulation results are depicted in Figures 4-13. The figures show speed of all ten generators following a 5 cycle three phase short circuit in bus 14. Each figure contains two plots which as system with PSS (solid line) and system without PSS (dashed line). It is clear to see that the system without PSS is unstable and in this system the oscillations are cannot be damped out. But, the system with PSS is stable and oscillations are damped out by using PSS.

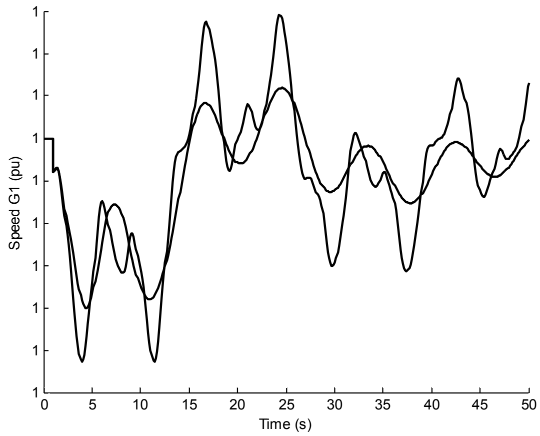

Figure 4: speed G_1 following three phase short circuit in bus 1 (Solid: with PSS; dashed: without PSS)

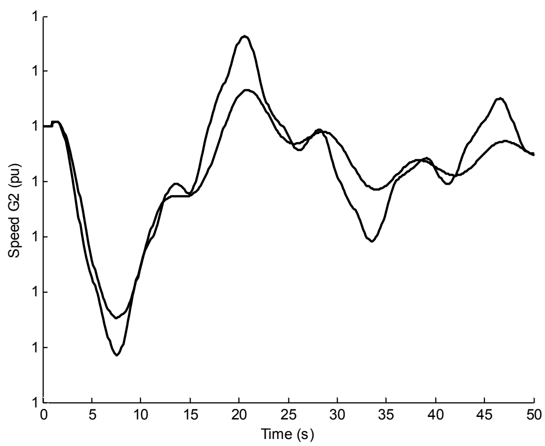

Figure 5: speed G_2 following three phase short circuit in bus 1 (Solid: with PSS; dashed: without PSS)

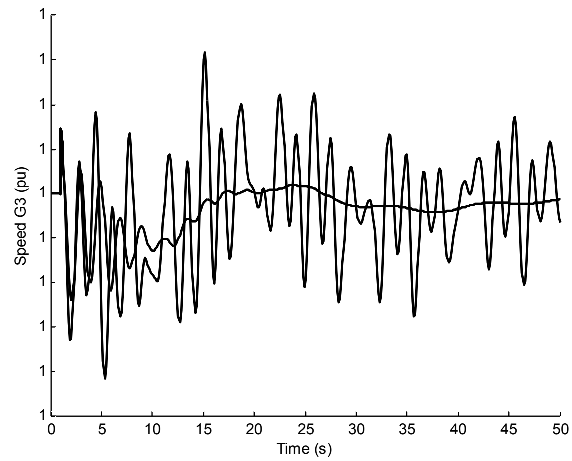

Figure 6: speed G_3 following three phase short circuit in bus 1 (Solid: with PSS; dashed: without PSS)

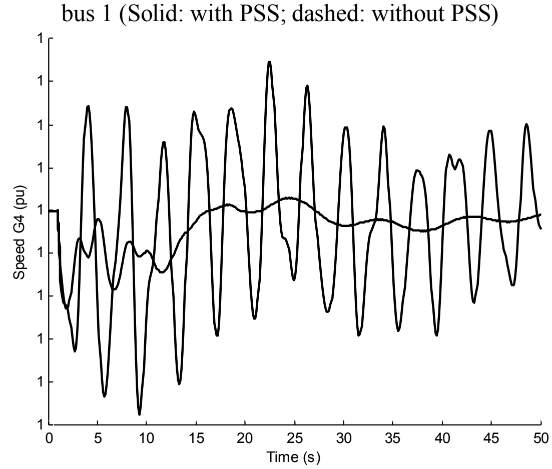

Figure 7: speed G_4 following three phase short circuit in bus 1 (Solid: with PSS; dashed: without PSS)

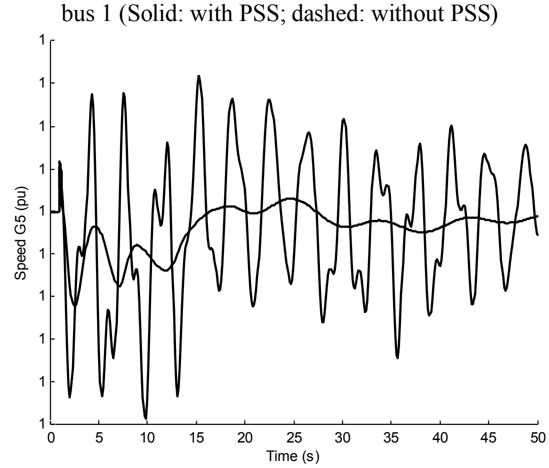

Figure 8: speed G_5 following three phase short circuit in bus 1 (Solid: with PSS; dashed: without PSS)

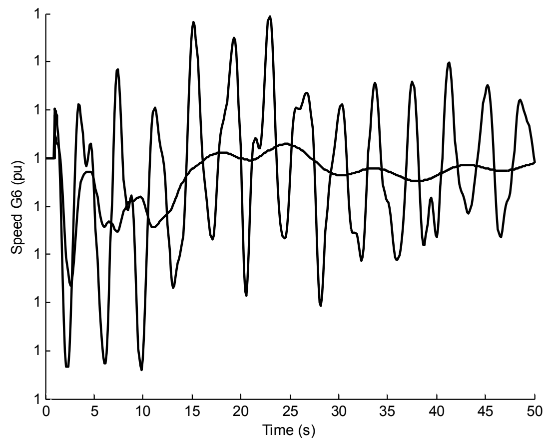

Figure 9: speed G_6 following three phase short circuit in bus 1 (Solid: with PSS; dashed: without PSS)

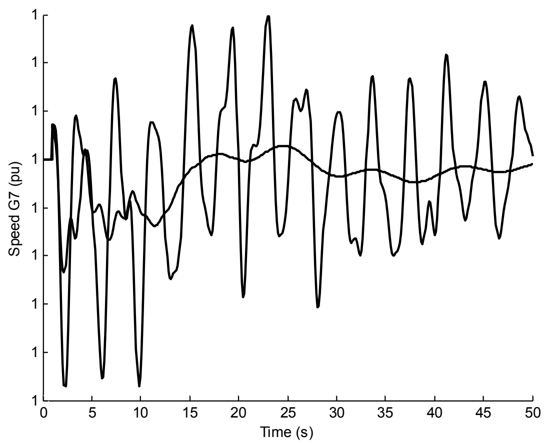

Figure 10: speed G_7 following three phase short circuit in bus 1 (Solid: with PSS; dashed: without PSS)

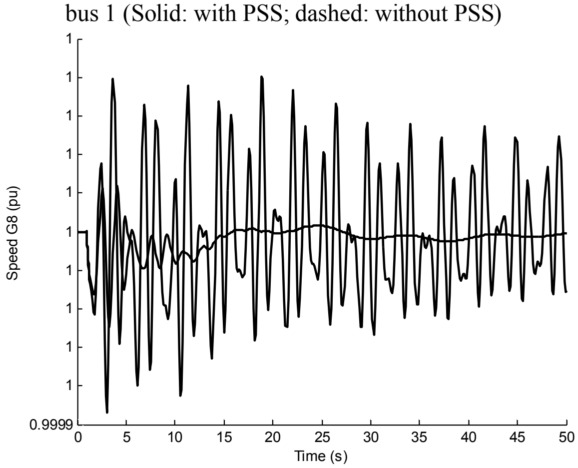

Figure 11: speed G_8 following three phase short circuit in bus 1 (Solid: with PSS; dashed: without PSS)

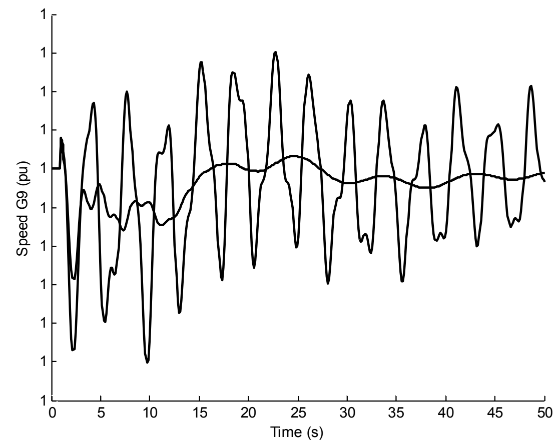

Figure 12: speed G_9 following three phase short circuit in bus 1 (Solid: with PSS; dashed: without PSS)

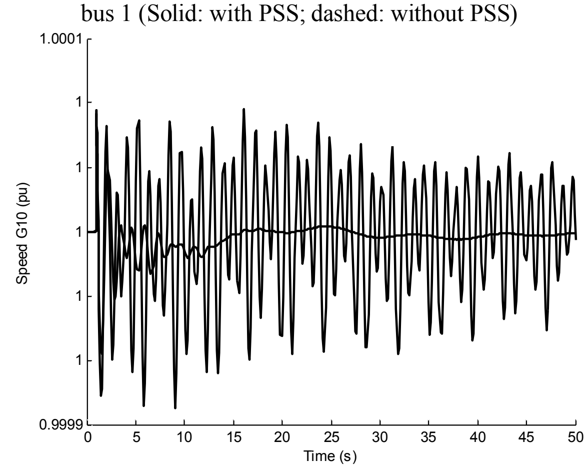

Figure 13: speed G_{10} following three phase short circuit in bus 1 (Solid: with PSS; dashed: without PSS)

8. Conclusions

Tuning a large number of PSSs was successfully carried out in this paper. A large scale power system installed with nine PSSs was considered as case study. The proposed PSSs were successfully tuned at the same time by using memetic algorithms. It was showed that the system with proposed PSSs is stable and robust under large signal disturbances such as three phase fault. The effectiveness of the designed PSSs was tested by nonlinear simulations.

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Corresponding Author
Mehdi Nikzad,
Department of Electrical Engineering, Islamshahr Branch, Islamic Azad University, Tehran, Iran.
Email: mehdinikzad28@yahoo.com

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