

Estimation of Power System Stabilizer Parameters Using Swarm Intelligence Techniques to Improve Small Signal Stability of Power System

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ABSTRACT

Interconnection of the power system utilities and grids offers a formidable dispute in front of design engineers. With the interconnections, power system has emerged as a more intricate and nonlinear system. Recent years small signal stability problems have achieved much significance along with the conventional transient constancy problems. Transient stability of the power system can be attained with high gain and fast acting Automatic Voltage Regulators (AVRs). Yet, AVRs establish negative damping in the system. Propagation of small signals is hazardous for system's health and offers a potential threat to system's oscillatory stability. These small signals have magnitude of 0.2 to 2 Hz. The professional control tactic to develop system damping is Power System Stabilizer (PSS). This paper presents application of swarm intelligence for PSS parameter estimation issue on standard IEEE 10 Generator 39 Bus power network (New England). Realization of the objective function is done with the help of interpolation investigation using MATLAB. The system performance is compared with the conventional optimization algorithms like Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) based PSS controller. The strength of proposed controller is tested by examining various operating conditions. An Eigen property analysis is done on this system i.e. before installing PSS, and after the employment of GA and PSO tuned PSSs. A significant comparison is carried out with GA and PSO on the basis of convergence uniqueness and dynamic response of speed deviation curves of various generators.

1. Introduction

Recent years, power system stability and reliability have been taken into account as very important issues in the context of modern power system [1]. Stressed operating conditions and competitive business environments have been showing threats to power engineers for an efficient design and optimal utilization of the electrical utilities. In earlier days system stability issues were classified as the problem related with transient stability, but, the small oscillations of magnitude 0.2-2 Hz were not a major consideration. To ensure transient stability fast acting Automatic Voltage Regulators (AVRs) were employed with generators.

However, later in 1960 Concordia et al., discovered that these high gain regulators are the main culprit for introducing the negative damping in the system [2].

The underdamped system has an oscillatory response; hence it inculcates oscillatory instability in the power system. The oscillations of small magnitude are harmful for the stability of a power system. These oscillations can cause system collapse if not handled accurately [3]. To find a potential and cost-effective solution to this issue, initial work on Power System Stabilizer (PSS) was proposed by E. V. Larsen et al. The AVR and PSS are dynamically interlinked instruments; one increases transient stability and the other complements the small signal stability. To augment the system stability, design engineers should keep a bird

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eye’s view on electromagnetic torque of the generator [4]. It has two elements; synchronizing torque, it is in phase with the variation in angle δ (load angle) and other is damping torque, which is in phase with speed deviation [5].

Design of damping controller for a poorly damped system is a formidable problem for power engineers. The damping controller is not only a potential answer for the oscillatory instability but also provides a good damping over the variety of operating conditions. The design of PSS has an ample significance to ensure the oscillatory stability. The Conventional Power System Stabilizer (CPSS) is a lead lag compensator [6]. For designing the damping controller, a designer has to find an accurate set of parameters (Gain & time constant). Proper tuning of the Lead Lag loop presents an adequate amount of damping to the system which helps the system to overcome with oscillatory instability [7].

Over the last decade many techniques were reported by the scientists to solve the PSS factor estimation problem. Some of these researches introduced techniques, to gain the robust conventional design through optimization, adaptive design with the help of expert systems (Neural Network, Fuzzy and Hybrid system), Linear Matrix Inequalities (LMI), Pole Placement and many others [8].

Recent years the enhancement in the field of damping controller design is revolutionized by the Evolutionary Algorithms. Evolutionary computations came in the picture in early 80’s. Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Biography Based Optimization (BBO), Bacterial Foraging Algorithm (BFA) and many more were proposed. These procedures are mathematical adaption of nature. They use nature rules to find the global optimum answer. PSS parameter estimation is a complex optimization issue [9].

The procedure towards the designing of CPSS contains following steps [10]:

1. Stability of any system depends on its initial operating conditions. In order to obtain the robust design hard operating conditions should be studied.
2. The design of the PSS should be investigated over various types of perturbations, fault locations and dissimilar system configurations. These contingencies help to ensure that design gained from the approach is robust enough [11].
3. Eigen Property analysis should be done to validate the efficacy of the design.

2. Small Signal Stability

Stability problems have already acquired prominence with every passing day. The need of the hour is to develop a robust system, which is not likely to give up in the wake of blackouts and various contingencies. IEEE/CIGRE Joint Task Force committee introduce the power system stability as follows “Small-disturbance (or small-signal) rotor angle stability is concerned with the ability of the power system to maintain synchronism under small disturbances. The disturbances are considered to be sufficiently

small that linearization of system equations is permissible for purposes of analysis” [12].

Power system utilities still prefer the conventional lead-lag power system stabilizer structure. Since the PSS has engrossed the interest of researchers, extensive research has been conducted in the following fields:

- Effect of PSS on system stability
- PSS tuning methods
- Practical experience in design, installation & operation of PSS.

Figure 1 shows the conventional Delta-Omega PSS. A stabilizer is designed by suitable selection of time constants $T_\omega, T_1, T_2, T_3, T_4$ and stabilizer gain K_{STAB} . In practical situation, a torsional filter is used for attenuating the stabilizer gain at turbine generator shaft torsional frequencies and may be neglected while designing PSS [13].

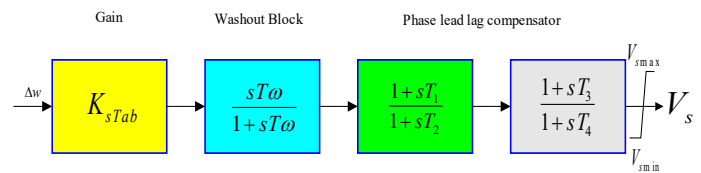


Figure 1. Power System Stabilizer transfer function model

$$\frac{V_s(s)}{\Delta\omega(s)} = K_s \left[\frac{sT_\omega}{1+sT_\omega} \right] \left[\frac{1+sT_1}{1+sT_2} \right] \left[\frac{1+sT_3}{1+sT_4} \right] \quad (1)$$

Where K_s is Stabilizer gain, T_ω is Washout time constant and T_1, T_2, T_3, T_4 are time constants of the lag lead networks [14].

The problem first encountered in the year 1969 reported by Concordia *et al.* was negative damping injection by turbine’s speed governor loop. It could be resolved by fitting the generators with a feedback controller. This controller sensed the change in terminal power of the generator and fed it back at the AVR reference input with proper phase lead and magnitude. This generated an additional damping torque on the rotor. Hence this fact advocates the acute requirement of PSS for adequate damping in the modern power networks. Larsen and Swann [15] in 1981 discussed the chronological development of damping controllers in their three-part paper. They recommended that the objective of the most appropriate stabilizer tuning criterion is to provide an adequate amount of damping to local mode of oscillations and inter area modes of oscillations. Michael J. Basler *et al.* [16] discussed power system instability and the importance of fast disturbance clearing performance. Explanation is provided regarding small signal stability, high impedance transmission lines, line loading, and high gain, fast acting excitation systems [17].

3. The Swarm Intelligent Techniques Algorithm

Swarm intelligence is a research field that models the communal behavior in swarms of insects or animals. Several algorithms ascending from these models have been anticipated to solve an extensive range of complex optimization problems. In this

work, comparative study of novel swarm algorithms like Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) will be considered to estimate the parameters of PSS [18].

3.1. Particle Swarm Optimization

The particle swarm optimization (PSO) technique is a population based optimization technique first proposed by Kennedy and Eberhart in 1995 inspired by social behavior of bird flocking or fish schooling [19]. PSO as an optimization tool provides a population based search procedure in which individuals called *particles* change their position (*state*) with time [14]. In a PSO system particles fly around in a multidimensional search space; during their flight, each particle adjusts its position according to its own experience (*pbest*) and according to its neighbor's experience (*gbest*), making use of the best position encountered by itself and its neighbors.

The position of particle in an n dimensional vector can be represented mathematically as [20]:

$$X_m = (x_{m1}, x_{m2}, x_{m3}, \dots, x_{mn}) \quad (2)$$

The modification is made in current position using following equation [21]:

$$S_i^{k+1} = S_i^k + v_i^{k+1}, i = 1, 2, \dots, n \quad (3)$$

Where S^k represents the current position of the particle, S^{k+1} represents the modified position of the particle and v is the velocity of each particle [22].

The velocity of each particle is n-dimensional vector given by the following equation:

$$V_m = v_{m1}, v_{m2}, \dots, v_{mn} \quad (4)$$

The velocity of each particle is updated after every iteration according to the following equation:

$$v_i^{k+1} = w_i v_i^k + c_1 rand * (pbest_i - s_i^k) + c_2 rand * (gbest_i - s_i^k) \quad (5)$$

Where v^k is the current velocity of the particle, v^{k+1} is the modified velocity of the particle, $pbest_i$ is the pbest of particle i , $gbest_i$ is the gbest of particle i , m is the number of members in a particle, w is the weight function for velocity of particle i and c_i is the weighing coefficients for each particle [23].

The objective function will be taken as fitness function for PSO algorithm. The best position related to the lowest value of the objective function for each particle is given as [24]:

$$Pbest_m = (pbest_{m1}, pbest_{m2}, \dots, pbest_{mn}) \quad (6)$$

And global best among all particles or best out of all $pbest$ is represented as:

$$Gbest_m = (gbest_{m1}, gbest_{m2}, \dots, gbest_{mn}) \quad (7)$$

The velocity and position of particles are updated after each iteration [25].

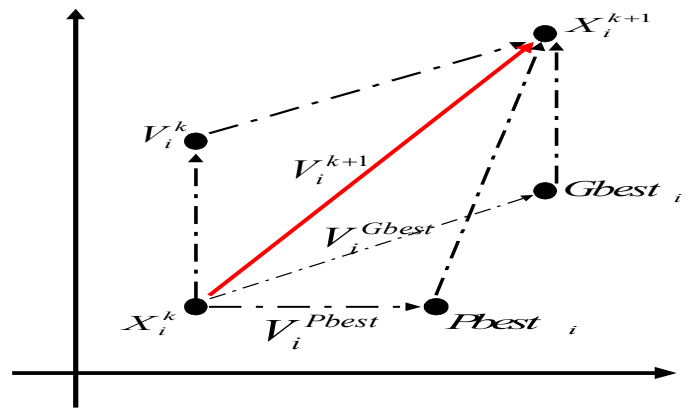


Figure 2. Concept of a searching point by PSO

Where

V_i^k is current velocity of particle i at iteration k .

V_i^{k+1} is modified velocity of particle i .

X_i^k is current position of particle i at iteration k .

X_i^{k+1} is modified position of particle i .

V_i^{Pbest} is velocity based on $Pbest$.

V_i^{Gbest} is velocity based on $Gbest$.

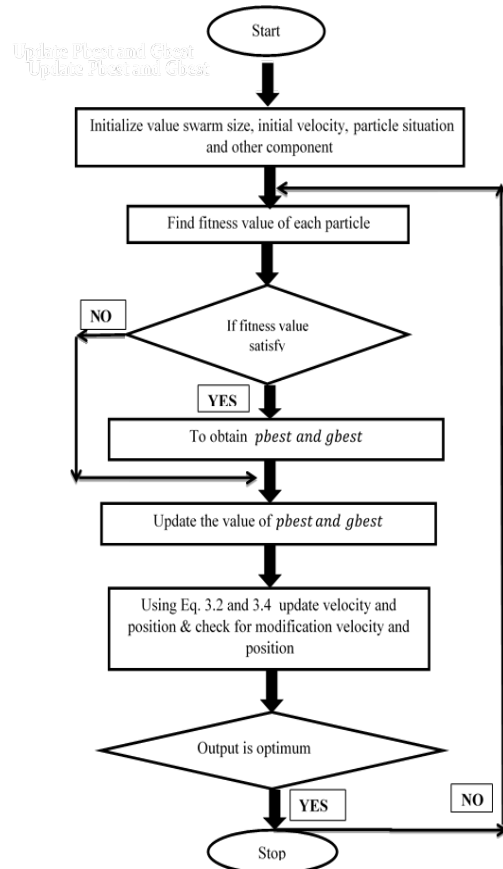


Figure 3. Flow Chart of PSO

Figure 3 shows the flow chart for the optimal allocation of PSO procedure [26].

3.2. Genetic Algorithm

A genetic algorithm (GA) is a search and optimization procedure which acts by mimicking the evolutionary principles and chromosomal processing in natural genetics. A GA begins its search with a random set of solutions usually coded in binary strings. Every solution is assigned a fitness which is directly related to the objective function of the search and optimization issue [27]. Thereafter, the population of solutions is modified to a new population by applying three operators similar to natural genetic operators- reproduction, crossover, and mutation. It works iteratively by successively applying these three operators in each generation till a termination criterion is satisfied. Over the past decade and more, GAs have been successfully applied to a wide range of problems, because of their simplicity, global perspective, and inherent parallel processing [28].

4. Mathematical Recognition of Objective Functions

To realize the polynomial in various orders MATLAB curve fitting tool is employed. Following are mathematical expressions associated with the objective functions [29].

$$f(x) = p_1(x) + p_2 + p_3(x) + p_4 + \dots + p_{59}(x) + p_{60}(8)$$

$$f(x) = p_1(x)^2 + p_2(x) + p_3 + \dots + p_{88}(x)^2 + p_{89}(x) + p_{90}(9)$$

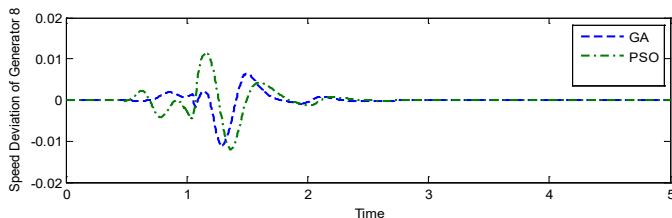
$$f(x) = p_1(x)^3 + p_2(x)^2 + p_3(x) + p_4 + \dots + p_{117}(x)^3 + p_{118}(x)^2 + p_{119}(x) + p_{120}(10)$$

5. Simulation Outcomes and Discussion

Table 1 shows the Eigen characteristic analysis of New England System with and without PSS [30].

It is observed that when PSS is not installed with generators, system shows poor damping. Some of the poorly damped types (swing modes) are shown in the following table. The real part of the Eigen value is positive.

Although the damping controller designed through evolutionary algorithms is quite robust and proved effective in all operating contingencies yet to show the efficacy of the proposed controller extreme conditions are chosen. The performance of the controller is exhibited in terms of hard situations. For this reason, here three phase disturbances are verified and speed responses of those generators are shown which are near by the disturbance locations [31].



It can be observed from the responses of various generators that PSS tuned through GA gives less dynamic response as compared with PSO tuned PSS. Figures 5 to 8 are the speed deviation curves of various generators under dissimilar perturbations and disturbance locations [32].

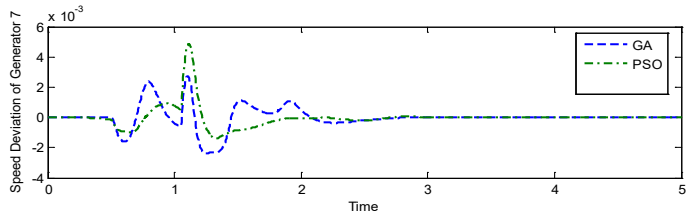
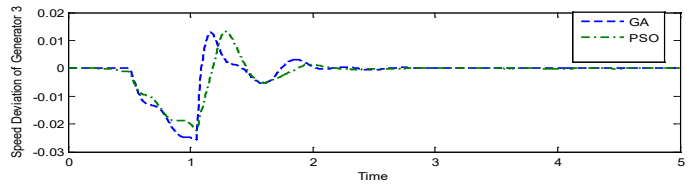
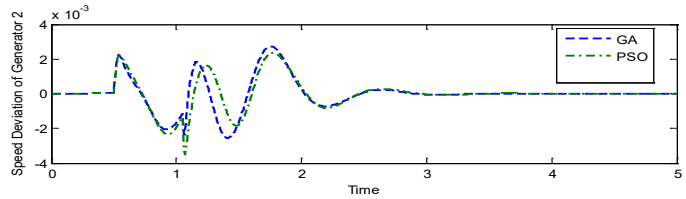
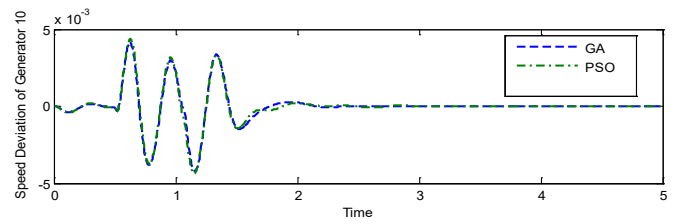


Table 1. Eigen Values and Damping Ratios With and Without PSS

Without PSS		With PSS	
Eigen Values	Damping Ratio	Eigen Values	Damping Ratio
0.0926-i0.2063	-0.0259	-0.1823-i0.3003	0.7595
0.0926+0.2083	-0.0259	-0.1823+i0.3003	0.7595
1.3110-i0.3730	-0.0316	-0.9979-i0.0404	0.3813
1.3110+i0.3730	-0.0316	-0.9979+i0.0404	0.3813
0.2300+i4.0882	-0.0083	-1.0262-i0.7672	0.538
0.2300-i4.0882	-0.0083	-1.0262+i0.7672	0.538
0.0501-i13.863	-0.015	-11.3849-i10.7133	0.5099
0.0501+i13.863	-0.015	-11.3849+i10.7133	0.5099
0.0033-i5.3036	-0.0014	-34.7713-i59.6870	0.4307
0.0033+i5.3036	-0.0014	-34.7713+i59.687	0.4307

The factors of all 10 PSSs gained from solving optimization issue using PSO is shown in Table 2. The convergence

characteristics of various optimization methods for variation of objective function and iteration is shown in Figure 8 [33].

Table 2. PSS factor for 10 Machine 39 Bus Using PSO [34-38]

Generator Number	K_{stab}	T_1	T_3
1	25.31	0.048	0.03
2	29.32	0.067	0.07
3	46.3	0.185	0.03
4	32.09	0.141	0.19
5	25.74	0.1	0.1
6	27.02	0.18	0.04
7	21.31	0.1	0.07
8	26.8	0.15	0.1
9	26.19	0.08	0.05
10	22.85	0.11	0.03

6. Conclusion

In this article endeavor is made to implement GA and PSO for finding the optimal parameters of Power System Stabilizer (PSS) for New England Power system. From this revision following points can be accomplished:

- a. Flourishing realization of conventional speed based objective functions in four dissimilar polynomials is presented in section 4. The qualified analysis of these realizations is shown with the help of dynamic responses of speed deviation curves of the generators. It is observed that linear combination of linear, quadratic and cubic polynomial gives the finest response.
- b. The consequential comparison of application of two optimization methods namely GA and PSO algorithm in PSS design problem.

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