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Genetic algorithm for damping of power system oscillations

Abstract. **Abstract** – *In this paper, Genetic algorithm (GA) optimization method is presented for optimal design of power system stabilizer (PSS). The design problem of the PSS parameters is formulated as an optimization problem and GA optimization method is used to search for optimal PSS parameters. The 2-area-4-machine power system, under a wide range of system configurations and operation conditions is investigated to illustrate the performance of the GA. The performance of the optimization method is compared with the conventional power system stabilizer. The eigenvalue analysis and non-linear simulation results are presented and compared to show the effectiveness of the GA optimization method in optimal tuning of PSS, to enhance power system stability.*

Streszczenie. *W artykule zaprezentowano metodę optymalizacji algorytmu stabilizacji systemu zasilania, z wykorzystaniem algorytmu genetycznego. Opracowana metoda została porównana w działaniu z konwencjonalnym stabilizatorem sieci. Przedstawiono wyniki przeprowadzonych symulacji nieliniowych i analizy wartości własnych. (**Algorytm genetyczny w tłumieniu oscylacji w systemie elektroenergetycznym**).*

Keywords: Genetic Algorithm, Power System Stabilzer, Design, Low Frequancy Oscillation
Słowa kluczowe: algorytm genetyczny, stabilizator systemu elektroenergetycznego, projektowanie, oscylacje niskiej częstotliwości.

Introduction

Constantly increasing intricacy of electric power systems has enhanced interests in developing superior methodologies for power system stabilizers (PSSs). Low frequency oscillation modes have been observed when power systems are interconnected by weak tie-lines [1]. PSSs are the most efficient devices for damping both local mode, and inter-area mode. The generators are equipped with PSS, which provides supplementary feedback and stabilizes the signal in the excitation system [2, 3]. The problem of PSS design is to tune the parameters of the stabilizer so that the damping of the system's electromechanical oscillation modes is increased. This must be done without adverse effects on other oscillatory modes, such as those associated with the exciters or the shaft torsional oscillations. The stabilizer must also be so designed that it has no adverse effects on a system's recovery from a severe fault. The concept and parameters of PSS have been considered in various studies [4-8]. The PSS has been usually used for mitigating the influences of Low frequency oscillation modes [9]. Currently, many generating plants prefer to use conventional lead-lag structure of PSS (CPSS), due to the ease of online tuning and reliability [10]. CPSSs are greatly being used in the power systems and this may be pursuant to some problems behind utilizing the new methods.

Intelligent optimization based methods have been initiated to solve the problems of PSS design [9-14]. Many random investigating techniques, for instance, simulated annealing [15], Tabu search [16], evolutionary programming [17] and gravitational search algorithm [18, 19] have recently gained acceptance due to their effectiveness and the ability to investigate the near-global optimal results in problem space. Recently, genetic algorithm (GA) and particle swarm optimization (PSO) methods appeared as promising algorithms for handling the optimization problems. These methods are finding popularity within research community as design tools and problem solvers because of their versatility and ability to optimize in complex multimodal search spaces applied to non-differentiable cost functions.

GA can be viewed as a general-purpose search method, an optimization method, or a learning mechanism, based loosely on Darwinian principles of biological evolution, reproduction and "the survival of the fittest"[20]. GA maintains a set of candidate solutions called population and repeatedly modifies them. At each step, the GA selects individuals from the current population to be parents and uses them produce the children for the next generation. Over successive generations, the population evolves toward an optimal solution and remains in the genome composition of the population over traits with weaker undesirable characteristics. In this study, the application and performance of Genetic algorithm, for power system stabilizer design is presented. The design problem of the PSS parameters is formulated as an optimization problem and GA optimization method is used to search for optimal PSS parameters. The two-area multi-machine power system, under a wide range of system configurations and operation conditions is investigated to illustrate the performance of the GA. The performance of the optimization method is compared with the conventional power system stabilizer. The eigenvalue analysis and non-linear simulation results are presented and compared to show the effectiveness of the GA optimization method in optimal tuning of PSS, to enhance power system stability.

Genetic Algorithm (GA)

GAs are inspired by biological systems' improved fitness through evolution. The genetic algorithm is advanced by Holland [21]. It is an optimization approach based on the concepts of genetics and natural reproduction and the evolution of the living creatures, in which an optimum solution evolves through a series of generations. A solution to a given problem is represented in the form of a string, called 'chromosome'/solution vector, consisting of a set of elements, called 'genes', that hold a set of values for the optimization variables. GAs work with a random population of solution vectors (chromosomes). The fitness of each chromosome is determined by evaluating it against an objective function. To simulate the natural "survival of the fittest" process, best chromosomes exchange information (through crossover or mutation) to produce offspring chromosomes. The offspring solution vectors are then evaluated and used to evolve the population if they provide better solution vectors than weak population members. Usually, the process is continued for a large number of generations/iterations to obtain a best-fit (near-optimum) solution vector. More details on the mechanism of GAs can be found in Goldberg [20]. Four main parameters affect the performance of GAs: population size, number of generations, crossover rate, and mutation rate. Larger population size (i.e. hundreds of chromosomes) and large number of generations (thousands) increase the likelihood of obtaining a near-global optimum solution, but substantially increase processing time. Crossover among parent chromosomes is a common natural process and traditionally is given a rate that ranges from 0.6 to 1.0. In crossover, the exchange of parents' information produces an offspring. As opposed to crossover, mutation is a rare process that resembles a sudden change to an offspring. This can be done by randomly selecting one chromosome from the population and then arbitrarily changing some of its information. The benefit of mutation is that it randomly introduces new genetic material to the evolutionary process, perhaps thereby avoiding stagnation around local minima. A small mutation rate less than 0.1 is usually used. A flowchart for the GA algorithm is shown in Fig. 1.

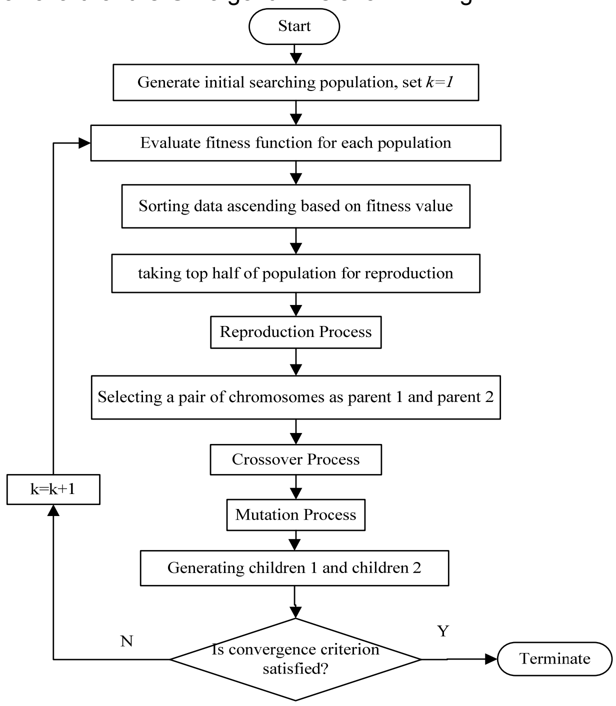

Fig. 1. Algorithm of genetic algorithm

Problem Formulation

In an unstable condition, the declining rate of the power system oscillation is determined by the highest real part of the eigenvalue in the system and the magnitude of each oscillation by its damping ratio. Hence, the objective functions naturally contain the damping ratio and the damping factor in the formulation for the optimal setting of controller parameters.Therefore, for the optimal tuning of PSS parameters, a multi-objective function may be formulated as follows [22]:

(1) Max: $F_1 = min(abs(\sigma_k))$

(2) Max: $F_1 = min(\xi_k)$

(3) Min: $f(x) = (F_1 + \varpi . F_2)^{-1} = \left[min(abs(\sigma_k)) + \varpi . min(\xi_k)\right]^{-1}$

Subject to

(4) $$\begin{cases} \sigma_j < 0 \\ \alpha < \omega_k < \beta \quad k = 1,2,3 \\ \zeta_j \geq \zeta_{min} \end{cases} \& \begin{cases} k_{i\,min} \leq k_i \leq K_{i\,max} \\ T_{1i,min} \leq T_i \leq T_{1i,max} \\ T_{2i,min} \leq T_i \leq T_{2i,max} \quad i = 1,2,3,4 \\ T_{3i,min} \leq T_i \leq T_{3i,max} \\ T_{4i,min} \leq T_i \leq T_{4i,max} \end{cases}$$

where $k=1,2,3$ represent the number of electro-mechanical modes of oscillation and $i=1,2,3,...,n$. n is the total number of eigenvalues. σ_k is the real part of the k^{th} electro-mechanical mode and $\xi_k = -\sigma_k / \sqrt{\sigma_k^2 + \omega_k^2}$ is the damping ratio of the k^{th} electro-mechanical mode. ξ_{min} *is* considered experimentally as 0.2. In (4), α and β are empirically considered limits of frequency for the electro-mechanical modes. ϖ is a weight for combining both damping factor and damping ratio.

Simulation Results

To demonstrate the application of GA in tuning PSS, a two-area multi-machine power system is simulated. The single line diagram of the system is shown in Fig. 2. There are three different electromechanical modes of oscillation, which includes two local modes of oscillation corresponding to each area, and one inter-area mode. This system is unstable without PSS and therefore, PSS must be installed with appropriate parameters.

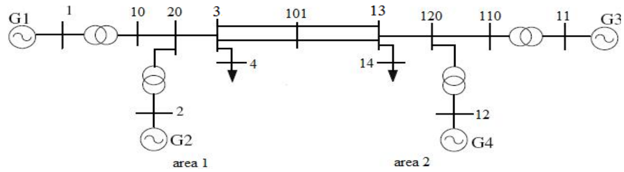

Fig. 2. Single line diagram of a two area system

PSS Design and Eigenvalue Analysis

The goal of the optimization is to find the best value for the four PSSs in the two-area-four-machine system. The ranges of optimized parameters are [1, 100] for K_{PSS} and [0.001, 2] for T_1–T_4. These limits help in reducing the computational times significantly. In this work, the values of α and β are considered as π and 3π, respectively. The weight parameter ϖ is set to be 10, which is derived from the experiences of many experiments conducted on this problem. First, the system is run without PSS for the four cases mentioned before. Then PSSs are connected to all the four generators and GA algorithm is used to find out the optimum parameters for the PSSs. The final values of the optimized parameters with the objective function F by the method (GA) are presented in Table 1. It shows the values of the parameters corresponding to the best fitness achieved by each algorithm after 30 trials. The principal eigenvalues and the damping ratios obtained for all operating conditions with no PSS, CPSS and after application of GA optimization method in the system are given in Table 2. The bolded values represent the greatest damping factor, and the unstable cases are highlighted. For the system without PSS, it can be observed that some of the modes are weekly damped and for some operating conditions the system is unstable. The addition of PSSs improves the damping in the system oscillations. The results from the GA show that the minimum damping ratio and the maximum damping factor under all cases are better than the results obtained by the use of CPSS.

Table 1 Searched parameters of PSSs by GA

	unit	K	T1	T2	T3	T4
GA optimized parameters	G1	11.934	0.051	0.024	0.050	0.056
	G2	17.033	0.190	0.016	0.102	0.034
	G3	26. 308	0.067	0.023	0.073	0.036
	G4	15.099	0.035	0.015	0.071	0.038

Table 2 Eigenvalues and damping ratios with and without psss

	Case1
Without PSSs	**0.044387**±4.0309i, -0.011 -0.55258±7.302i, 0.07546 -0.55317±7.383i, 0.07471
With CPSS	**-0.52484**±3.8483i, 0.1351 -3.2505±8.2795i, 0.36545 -3.248± 8.5995i, 0.35333
With GA	**-0. 9499**±3.5917i, 0.255 -4.0428±5.8045i, 0.5716 -5.5160±5.22030i, 0.710

Nonlinear time-Domain Simulation

A number of time domain simulations have been performed to demonstrate the efficiency of tuning of PSS parameters using the GA method. In these tests, to evaluate the effectiveness of the GA based tuned PSS using the proposed multi-objective function, a 200-ms three-phase fault is applied at bus 3 and a fault between the bus 3 and bus 101 is cleared in 0.05 s at the near end. After a further 0.05 s, remote end circuit breaker at bus 101 is operated for the complete clearance in each case. The speed deviations of all generators under the fault at bus 3 are shown in Figs. 3-6, respectively. The figures illustrate the advantage of the PSOPSS and GAPSS compared to CPSS. These positive results of the proposed PSOPSS can be attributed to its faster response with less overshoot compared to that of CPSS. Further, it is also clear that the both PSOPSS and GAPSS give almost similar responses. The controllers have good damping characteristics to low frequency oscillations and stabilize the system much faster. This extends the power system stability limit and the power transfer capability. These time domain simulations are also in well agreement with the results of eigenvalue analysis. The addition of PSSs improves the damping in the system oscillations.

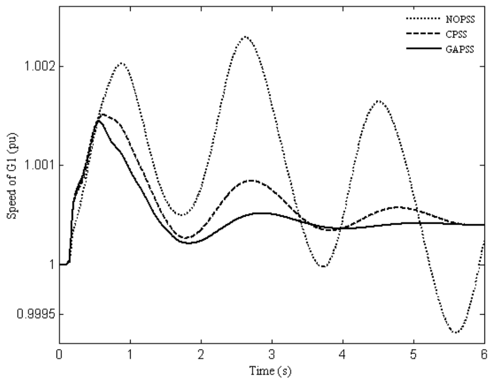

Fig. 3. Speed response of G1

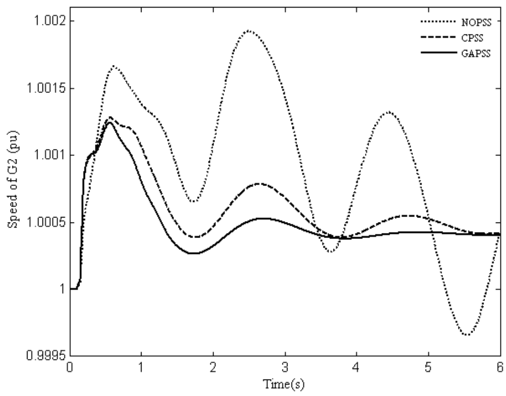

Fig. 4. Speed response of G2

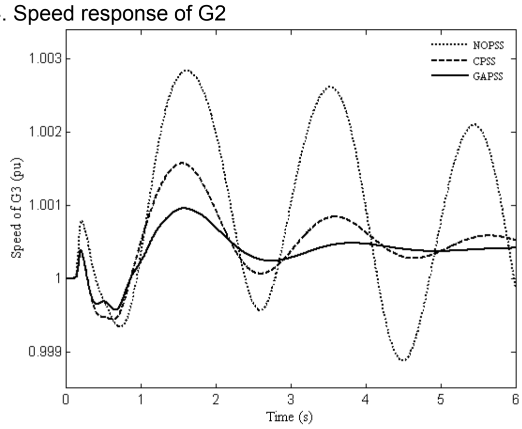

Fig. 5. Speed response of G3

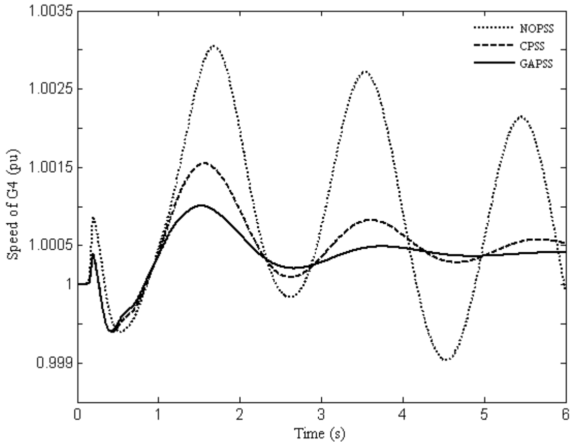

Fig. 6. Speed response of G4

Conclusion

In this paper, GA optimization method is applied for optimal design of PSSs in multi-machine power system. The design problem of the PSS parameters is formulated as an optimization problem and GA optimization method is used to search for optimal PSS parameters. The 2-area-4-machine power system, under a wide range of system configurations and operation conditions is investigated to illustrate the performance of the GA. The performance of the optimization method is compared with the CPSS. The eigenvalue analysis and non-linear simulation results are presented and compared to show the effectiveness of the GA optimization method in optimal tuning of PSS, to enhance power system stability.

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