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Power System Stability and Optimization Techniques: An Overview

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ABSTRACT
Low frequency oscillation problems are very difficult to solve because power systems are very large, complex and geographically distributed. Therefore, it is necessary to utilize most efficient optimization methods to take full advantages in simplifying the problem and its implementation. From this perspective, many successful and powerful optimization methods and algorithms have been employed in formulating and solving this problem. This paper reviews new approaches in modern research using optimization techniques such as Tabu Search (TS), Simulated Annealing (SA), Ant Colony Optimization (ACO), Evolutionary Programming (EP), Bacteria Foraging Optimization (BFO), Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Artificial Bee Colony (ABC) to develop Power System Stabilizer (PSS). Research showed controllers designed based on a conventional control theory, modern and adaptive control theories, suffer from some limitations. However, optimization techniques proved to be able to overcome these limits. Hence, more researchers preferred to utilize these approaches for the power systems. The review efforts geared towards PSS developed based on optimization techniques, which effectively enhance both small signal stability, transient stability and equally provide superior performances. In this paper, an effort is made to present a comprehensive analysis of optimization techniques for designing PSSs as proposed by various researchers.
Keywords: Artificial Bee Colony (ABC), Bacteria Foraging Optimization (BFO), Low frequency oscillation, Optimization, Power System Stabilizer.

I. Introduction

Large electric power systems are complex nonlinear systems and often exhibit low frequency electromechanical oscillations due to insufficient damping caused by adverse operating. These oscillations with small magnitude and low frequency often persist for long periods of time and in some cases they even present limitations on power transfer capability [1]. In analyzing and controlling the power system's stability, two distinct types of system oscillations are recognized. One is associated with generators at a generating station swinging with respect to the rest of the power system and such oscillations are referred as "Local mode" oscillations. Local modes normally have frequencies in the range 0.7 to 2 Hz. The second type is associated with swinging of many machines in an area of the system against machines in other areas and these are referred as "inter-area mode" oscillations. Inter-area modes have frequencies in the range of 0.1 to 0.8 Hz. Power System Stabilizers (PSS) are used to generate supplementary control signals for the excitation system in order to damp both types of oscillations [2]. It is important that these disturbances do not drive the system to an unstable condition. Stability in power systems is commonly referenced as the ability of generating units to maintain synchronous operation [3] [4]. It is common to divide stability into the following types:

- **Transient stability:** It is the ability to maintain synchronism when the system is subjected to a large disturbance. In the resulting system response, the changes in the dynamic variables are large and the nonlinear behavior of the system is important.
- **Small Signal Stability**: It is the ability of the system to maintain stability under small disturbance. Such disturbances occur continuously in the normal operation of a power system due to small variations in load and generation. Electro-mechanical oscillations between interconnected synchronous generators are phenomena inherent to power systems. In an N-machine power system, there are (N-1) natural electromechanical modes

of oscillations. The stability of these oscillations is of vital concern, and is a prerequisite for secure system operation.

II. POWER SYSTEM STABILIZER (PSS)

PSSs have been used widely to add damping to electromechanical oscillations. Traditionally, the excitation system regulates the generated voltage and there by helps to control the system voltage. The automatic voltage regulators (AVR) are found extremely suitable for the regulation of generated voltage through excitation control. But extensive use of AVR has detrimental effect on the dynamic stability or steady state stability of the power system as oscillations of low frequencies (typically in the range of 0.2 to 3 Hz) persist in the power system for a long period and sometimes affect the power transfer capabilities of the system [1]. PSS were developed to aid in damping these oscillations by modulation of excitation system and by this supplement stability to the system [2]. The basic operation of PSS is to apply a signal to the excitation system that creates damping torque which is in phase with the rotor oscillations. The commonly used structure of the PSS is shown in Fig. 1.

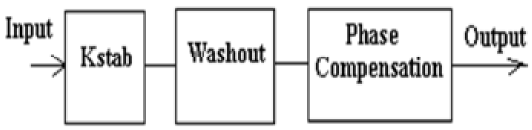

Figure 1: Block diagram of PSS

III. DIFFERENT TECHNIQUES IN PSS

3.1 Artificial Intelligence Techniques

In the field of power system operations and planning, very sophisticated computer programs are required and designed in such a way that they could be executed and modified frequently according to any variations. Artificial intelligence (AI) is a powerful knowledge-based approach that has the ability to deal with the high non-linearity of practical systems [5]. AI has a benefit to decrease the mathematical complexity beside the rapid response which can be utilized for transient analysis. AI techniques, which promise almost a global optimum, such as Artificial Neural Networks (ANN), Fuzzy Logic (FL) and Evolutionary Computation (EC), have appeared in recent years in power systems applications as efficient tools to mathematical approaches. Recently, many researchers are concerned with various types of AI techniques to develop efficient PSSs. This section presents a survey of AI techniques (e.g. ANN, FL, EC, etc.) which are used in power system stabilizer optimization problems.

3.1.1 Artificial Neural Network (ANN)

In [6], authors presented the training algorithm and verified how a network of neurons could exhibit learning behavior. This was the starting point of the ANN. An ANN is a computational model or mathematical model on the basis of biological neural networks and is an information processing paradigm that is inspired by the way biological nervous systems such as the brain processes the information. The novel structure of the information processing system is the main component of this paradigm. It is composed of a great number of highly interconnected processing components (neurons) working in unison to overcome the special problems. Like people, ANNs learn by example. The most important advantages of the ANN are: (i) learning ability; (ii) appropriateness and control; (iii) adaptation to the data; (iv) robustness; (v) rapidity. Despite the advantages, some disadvantages of the ANN are: (i) large dimensionality; (ii) choice of the optimal configuration; (iii) selection of training method; (iv) the 'black-box' representation of the ANN and (v) the generation output even if the input data are unreasonable.

The ANN, when sufficiently trained, may be used as a controller instead of the conventional lead-lag power system stabilizer (CPSS). To achieve best performance, the ANN must be trained for different operating conditions to tune the CPSS parameters [7]. The learning procedures cause interference by the conventional back propagation network under various conditions. To develop a neural adaptive PSS, a feed-forward neural network with a single hidden layer is investigated in [8][9] [10].

3.1.2 Fuzzy Logic (FL)

L. Zadeh [12] developed FL to address inaccuracy and uncertainty which usually exist in engineering problems. Fuzzy set theory can be considered as a generalization of the classical set theory. In classical set theory, an element of the universe either belongs to or does not belong to the set. Therefore, the degree of association of an element is crisp. Membership function is the measure of degree of similarity of any element in the universe of discourse to a fuzzy subset [11] [13].

To design traditional controllers, it is essential to linearize non-linear systems. Fuzzy Logic Controllers (FLCs) are nonlinear. Moreover, FLCs do not need a controlled plant model, and are not sensitive to plant parameter variations [17]. The human experience and knowledge can be applied to design of the controller by using FL. FLCs are rule-based and the rules of the system are written in natural language and translated into FL [14]. A FLC based on a state feedback control system is developed for damping electro-mechanical modes of oscillations and enhancing power system stability [15]. A design process for a fuzzy logic based PSS (FLPSS) is proposed and investigated for a multi-machine power system [16].

3.2. Evolutionary Computing (EC) methods

Different types of intelligent optimization techniques are used to search for optimal or near optimum solutions for many power system problems, especially for PSSs. These techniques are TS, SA, ACO, HS, BFO, GA and PSO etc.

3.2.1 Tabu Search (TS)

TS is a mathematical optimization method belonging to the class of local search techniques. TS enhances the performance of a local search method by using memory structures. Once a potential solution has been determined, it is marked as "taboo" ("tabu" being a different spelling of the same word) so that the algorithm does not visit that possibility repeatedly. TS is an iterative improvement procedure that can start from any initial feasible solution (searched parameters) and attempt to determine a better solution. As a meta-heuristic method, TS is based on a local search technique with the ability to escape from being trapped in local optima [18][19]. Abido [20] presented the TS algorithm to search the optimal parameters of the conventional lead-lag power system stabilizer (CPSS). This approach provided a good performance when tested on a single-machine-infinite bus (SMIB) and multi-machine power systems with different operating conditions. In addition, application of the TS optimization technique to multi-machine PSS design are presented in [21][22][23]. Incorporation of a TS algorithm in a PSS design significantly reduced the computational burden.

3.2.2 Genetic Algorithm (GA)

GA is an evolutionary based stochastic optimization algorithm with a global search potential [24]. GAs are among the most successful class of algorithms under EAs which are inspired by the evolutionary ideas of natural selection. GA is useful and efficient when:

- The search space is large complex or poorly known.
- No mathematical analysis is available.
- Domain knowledge is scarce to encode to narrow the search space.
- For complex or loosely defined problems since it works by its own internal rules.
- Traditional search method fails.

Even though GAs can rapidly locate good solutions, for difficult search spaces, it has some disadvantages:
(i) GA may have a tendency to converge towards local optima rather than the global optimum of the problem if the fitness function is not defined properly; (ii) Operating on dynamic data sets is difficult; (iii) For specific optimization problems, and given the same amount of computation time, simpler optimization algorithms may find better solutions than GA; (iv) GAs are not directly suitable for solving constraint optimization problems.

The GA has been applied by many authors for tuning PSS parameters. A method to simultaneously tune PSSs in a multi-machine power system is presented using hierarchical GA and parallel micro GA based on a multi-objective function [24].
A digital simulation of a linearized model of a single-machine infinite bus power system at some operating point is used in conjunction with the GA optimization process [25].
Optimal multi-objective design of robust multi-machine PSSs using GA are presented [26].

3.2.3 Differential Evolution

Another paradigm in EA family is differential evolution (DE) proposed by Storn and Price [27]. DE is similar to GA since populations of individuals are used to search for an optimal solution. The main difference between GA and DE is that, in GA, mutation is the result of small perturbations to the genes of an individual while in DE mutation is the result of arithmetic combinations of individuals.

- DE is easy to implement, requires little parameter tuning.
- Exhibits fast convergence
- It is generally considered as a reliable, accurate, robust and fast optimization technique.

Limitations:
(i)Noise may adversely affect the performance of DE due to its greedy nature.
(ii) Also the user has to find the best values for the problem-dependent control parameters used in DE and this is a time consuming task.

3.2.4 Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is a computational intelligence oriented, stochastic, population-based global optimization technique proposed by Kennedy and Eberhart [28]. It is inspired by the social behavior of bird flocking searching for food. PSO has been extensively applied to many engineering optimization areas due to its unique searching mechanism, simple concept, computational efficiency, and easy implementation.

Advantages over Genetic Algorithm: (a) PSO is easier to implement and there are fewer parameters to adjust. (b) PSO has a more effective memory capability than GA. (c) PSO is more efficient in maintaining the diversity of the swarm, since all the particles use the information related to the most successful particle in order to improve themselves, whereas in Genetic algorithm, the worse solutions are discarded and only the new ones are saved; i.e. in GA the population evolve around a subset of the best individuals. A PSO technique for tuning parameters of the brushless exciter and lead-lag power system stabilizer is proposed [29] [30]. A novel evolutionary algorithm-based approach to optimal design of multi machine PSSs is proposed [31][32].

3.2.5 Ant Colony Optimization (ACO)

ACO is among the most successful swarm based algorithms proposed by Dorigo & Di Caro [33]. It is a meta heuristic inspired by the foraging behavior of ants in the wild, and moreover, the phenomena known as stigmergy, term introduced by Grasse in 1959. Stigmergy refers to the indirect communication amongst a self-organizing emergent system via individuals modifying their local environment. The first ant algorithm, named Ant System (AS), was developed in the nineties by Dorigo et al. and tested successfully on the well known benchmark Travelling Salesman Problem. The ACO meta heuristic was developed to generalize, the overall method of solving combinatorial problems by approximate solutions based on the generic behavior of natural ants. ACO is applied for tuning of PSS parameters in [33].

3.2.6 Artificial Bee Colony Algorithm (ABC)

Based on the behavior of the bees in nature, various swarm intelligence algorithms are available. These algorithms are classified into two; foraging behavior and mating behavior. Examples of algorithms simulating the foraging behavior of the bees include the Artificial Bee Colony (ABC)[34] , the Virtual Bee algorithm proposed by Yang , the Bee Colony Optimization algorithm proposed by Teodorovic and Dell'Orco, the BeeHive algorithm proposed by Wedde et al., the Bee Swarm Optimization algorithm proposed by Drias et al. and the Bees algorithm proposed by Pham et al. An individual entity (e.g., a bee in a bee colony) exhibit a simple set of behavior policies (e.g., migration, replication, death), but a group of entities (e.g., a bee colony) shows complex emergent behavior with useful properties such as scalability and adaptability.

3.2.7 Intelligent Water Drops Algorithm (IWD)

Intelligent Water Drops (IWD) is an innovative population based method proposed by Hamed Shah-hosseini [35]. It is inspired by the processes in natural river systems constituting the actions and reactions that take place between water drops in the river and the changes that happen in the environment that river is flowing. Based on the observation on the behavior of water drops, an artificial water drop is developed which possesses some of the remarkable properties of the natural water drop. IWD has two important properties: (i)The amount of the soil it carries now, Soil (IWD); (ii) The velocity that it is moving now, Velocity (IWD). The environment in which the water flows, depend on the problem under consideration. An IWD moves in discrete finite-length steps. From its current location to its next location, the IWD velocity is increased by the amount nonlinearly proportional to the inverse of the soil between the two locations.

IV. CONCLUSION

This paper presents a survey of literature on the various optimization methods applied to solve the PSS problems. The evolutionary computation in comparison to other techniques has the deep knowledge of the system problem with well-defined models. Swarm intelligence appears to have more potential in power system analysis and they are also the most recent in the field of computational intelligence techniques. A review of the techniques used by researchers in designing the conventional PSS only is presented.

REFERENCES

[1] F.P. Demello and C. Concordia, "Concepts of Synchronous Machine Stability as Effected by Excitation Control", *IEEE Transactions on Power Apparatus and Systems, 88(4),* 1969, 316-329.
[2] E.V. Larsen, and D.A. Swann, "Applying Power System Stabilizers, parts I, II & III", *IEEE Transactions on Power Apparatus and Systems, Vol. 100(6),* 1981, 3025-3033.
[3] P. Kundur, "Power System Stability and Control," *McGraw-Hill Press*, 1994.
[4] P.M. Anderson and A.A. Fouad, "Power System Control and Stability", *IEEE Press*, 1994.
[5] J. McCarthy, "Programs with common sense," *Proc. of the Symposium of the National Physics Laboratory*, 1958, 77-84.
[6] Wasserman P., Meyer-Arendt J., "Neural computing, theory and practice," *Coriolis Group Publication,* 1989.
[7] Pillutla S., Keyhani A., "Power system stabilization based on modular neural network architecture.," *International Journal of Electrical Power Energy System*, *19(6),* 1997, 411-418.

[8] Hosseinzadeh N.,Kalam A., “A hierarchical neural network adaptive power system stabilizer,” *International Journal of Electrical Power Energy System, 19 (1)*, 1999, 28-33.

[9] Shamsollahi P. ,Malik O., “Design of a neural adaptive power system stabilizer using dynamic back-propagation method,” *International Journal of Electrical Power Energy System , 22(1)*, 2000, 29-34.

[10] Shamsollahi P. ,Malik O., “An adaptive power system stabilizer using on-line trained neural networks,” *IEEE Transaction on Energy Conversion, 12 (4)*, 2002, 382-387.

[11] Tsoukalas L.,Uhrig R., “Fuzzy and neural approaches in engineering.,” *John Wiley & Sons*, Inc. NY, USA,1996.

[12] Zadeh L., “Fuzzy sets *,” Information and control, 8 (3),* 1965, 338-353.

[13] Pal S.,Mandal D., “Fuzzy Logic and Approximate Reasoning: An Overview,” *Institution of Electronics and Telecommunication Engineers*, 1991, 548–559.

[14] El-Hawary M., “Electric power applications of fuzzy systems,” *Wiley-IEEE Press*, 1998.

[15] El-Sherbiny M., Sharaf A., El-Saady G., Ibrahim E., “A novel fuzzy state feedback controller for power system stabilization” *Electric Power System Research, 39 (1)*, 1996, 61-65.

[16] Lakshmi P.,Abdullah Khan M., “Design of a robust power system stabilizer using fuzzy logic for a multi-machine power system,” *Electric Power System Research*, *47 (1).* 1998, 39-46.

[17] Ramirez-Gonzalez M.,Malik O., “Self-tuned Power System Stabilizer Based on a Simple Fuzzy Logic Controller,” *Electric Power Components and Systems, 38 (4)*, 2010, 407-423.

[18] Glover F., Marti R., “Tabu search. Metaheuristic Procedures for Training Neutral Networks,” *Operation Research/Computer Science Interface Series*, 2006, 53-69.

[19] Rayward V., Osman I., Reeves C., Smith G., “Modern heuristic search methods,” John Wiley & Sons, 1996.

[20] Abido M., “A novel approach to conventional power system stabilizer design using tabu search,” *International Journal of Electrical Power Energy System*, 21 (6), 1999, 443-454.

[21] Abido M., Abdel-Magid Y., “Eigen value assignments in multi machine power systems using tabu search algorithm,” *Computers & Electrical Engineering*, *28 (6)*, 2002, 527-545.

[22] Abido M., Abdel-Magid Y., “Robust design of electrical power based stabilizers using tabu search,” *IEEE, Power-Engineering Society Summer Meeting*, 2001, 1573-1578.

[23] Abido M.,Abdel-Magid Y., “Robust design of multimachine power system stabilisers using tabu search algorithm, *IET in Generation, Transmission and Distribution,”* 2000,387- 394.

[24] Talaat H.E.A., Abdennour A., “Al-Sulaiman A.A., Design and experimental investigation of a decentralized GA-optimized neuro-fuzzy power system stabilizer,” *International Journal of Electrical Power Energy System*, 32 (7), 2010, 751-759.

[25] Hongesombut K., Dechanupaprittha S., Mitani Y., Ngamroo , “Robust power system stabilizer tuning based on multiobjective design using hierarchical and parallel micro genetic algorithm,” *Proc. IEEE International Conf. on Power System Technology*, 2005, 402-407.

[26] Abdel-Magid Y.,Dawoud M., “Tuning of power system stabilizers using genetic algorithms,” *Electric Power System Research*, *39 (2)*, 1996, 137-143.

[27] Abido M.,Abdel-Magid Y., “A genetic-based power system stabilizer,” *Electric Power Components and Systems*, 26 (6), 1998, 559-571.

[28] Kennedy, J.; Eberhart, R. ,"Particle Swarm Optimization,*". Proc. International Conf. on Neural Networks*, 1995, 1942–1948.

[29] El-Zonkoly A., “Optimal tuning of power systems stabilizers and AVR gains using particle swarm optimization,” *Expert System Applications*, *31 (3)*, 2006, 551-557.

[30] El-Zonkoly A., Khalil A., Ahmied N., “Optimal tunning of lead-lag and fuzzy logic power system stabilizers using particle swarm optimization,” *Expert System Applications, 36 (2)*, 2009, 2097-2106.

[31] Shayeghi H., Shayanfar H., Safari A., Aghmasheh R., “A robust PSSs design using PSO in a multi-machine environment,” *Energy Conversion and Management, 51 (4)*, 2010, 696-702.

[32] Shayeghi H., Safari A., “Multimachine power system stabilizers design using PSO algorithm,” *International Journal of Electrical Power Energy System*, 1 (4), 2008, 226-233.

[33] Dorigo, M., Maniezzo, V., & Colorni, A. ,” Ant System: Optimization by a colony of cooperating agents,” *IEEE Transactions on Systems, Man, and Cybernetics – Part B, 26 (1), 1996, 29–41.*

[34] D. Karaboga, B. Basturk, “A powerful and efficient algorithm for numerical function optimization: artificial bee colony (ABC) algorithm,” *Journal of Global Optimization*, 39 (1), 2007, 459–471.

[35] Shah_Hosseini, H. Shahid, “Problem solving by intelligent water drops,” *IEEE Congress on Evolutionary Computation*, 2007. 3226-3231.