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Optimal PSS Tuning by using Artificial Bee Colony

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ABSTRACT: This paper addresses a new optimization technique namely artificial bee colony (ABC) algorithm for power system stabilizer (PSS) design. In the proposed methodology, PSS is considered with a conventional structure and its parameters are tuned by using ABC algorithm. A two areas power system containing uncertainties is considered as case study to evaluate the proposed method. Besides, non linear simulations are carried out to show the accuracy of results. Time domain simulation results clearly verify that the proposed technique enhances the dynamic stability of the system considering uncertainties.

Keywords: Artificial Bee Colony; Dynamic Stability; Non Linear Simulations; Power System Stabilizer.

INTRODUCTION

Power system stabilizers (PSS) have been widely used in power systems as a cost-effective supplementary controller for stability enhancement. Due to their effectiveness and ability in damping low frequency oscillations and stability enhancement; PSSs have been investigated from different views and aspects; different control methods have been applied to design PSSs and also many investigations have been carried out to find optimal number and location of PSSs. some of these researches are briefly reviewed in the following; paper (Radaideh et al., 2012) presents a two level power system stabilizer based on the conventional method, fuzzy inference system (FIS) and adaptive neuro-fuzzy inference system (ANFIS). Where, the main function of the conventional level is to stabilize unstable or poorly stable systems, while the second – which is designed using (FIS) or (ANFIS) – improves the total response in order to achieve required results. The paper shows that adaptive neuro-fuzzy inference system (ANFIS) damps out the low frequency oscillations in the better manner than fuzzy inference system (FIS).

Paper (Khodabakhshian and Hemmati, 2013) addresses a new technique namely cultural algorithms (CA) to tune the PSS parameters. This technique is robust and computationally efficient as compared with other meta-heuristic algorithms. The paper clearly verifies that the proposed method improves the dynamic stability of the system considering uncertainties.

In paper (Mostafa et al., 2012), particle swarm optimization (PSO) is used to design power system stabilizers (PSSs). This paper considers a test system consisting of 3 power systems. System I represents the Egyptian power system, system II represents the Jordan and Syrian power systems, and system III for the Libyan power system, which are originally self standing and completely independent systems. As a matter of fact each of them should be equipped with its own PSS. For this reason this paper is started by designing an optimum power stabilizer for each of them standing alone. After which, the developed PSSs are firstly installed one at a time. Then the three PSSs are installed together in the interconnected power system and their effect on its dynamic performance is studied. The obtained results show an improvement in the power pool performance accompanied with an improvement in the inter-area oscillation.

A robust fuzzy logic power system stabilizer (FLPSS) based on evolution and learning is proposed in paper (Bhati and Gupta, 2013). A hybrid algorithm that combines learning and evolution is developed whereby each one complements other’s strength. Parameters of FLPSS are encoded in chromosome (individual) of genetic algorithm

(GA) population. Population of FLPSS in GA learns to stabilize electromechanical oscillations in power system at an operating point, as the best fitness becomes large steady value during successive generations. Operating region of FLPSS is enlarged by learning more operating points over the operating domain. Best FLPSS drawn from last generation is saved as designed FLPSS. Effectiveness of the proposed method is validated on a single machine infinite bus (SMIB) power system. Promising optimal stabilizing performance with designed FLPSS for considered power system is obtained at wide range of operating points.

In paper (He et al., 2013) power system stabilizers (PSSs) are extensively applied for damping low frequency power oscillations through modulating the excitation supplied to synchronous machines. This paper examines four different PSS models and investigates their performances on damping power system dynamics using both small-signal Eigen-value analysis and large-signal dynamic simulations. The four kinds of PSSs examined include the Conventional PSS (CPSS), Single Neuron based PSS (SNPSS), Adaptive PSS (APSS) and Multi-band PSS (MBPSS).

Paper (Khodabakhshian et al., 2013) develops a new design for multi band-PSS in which the parameters are tuned by using a new Meta-heuristic optimization algorithm based on the combination of culture algorithm, particle swarm optimization (PSO) and co-evolutionary algorithms. The proposed MB-PSS is tested on a multi-machine power system and results are compared with PSO-based MB-PSS (PSO-MB-PSS) and conventional MB-PSS (C-MB-PSS). Simulation results confirm the effectiveness of the proposed optimization tuning method for improving the power system dynamic stability.

In paper (Alkhatib and Duveau, 2013), a novel optimization approach based on genetic algorithms (GA) is addressed. It consists in moving the search space range during the optimization process toward promising areas that may contain the global optimum. This dynamic search space allows the GA to diversify its population with new solutions that are not available with fixed search space. The proposed approach is applied to optimal design of multi-machine power system stabilizers. The obtained results demonstrate the effectiveness of the proposed approach in damping the electromechanical oscillations and enhancing the system dynamic stability.

A new robust power system stabilizer (PSS) design using Quantitative Feedback Theory (QFT) for damping electromechanical modes of oscillations and enhancing power system stability is proposed in paper (Khodabakhshian and Hemmati, 2012). The design procedure is carried out on a multi-input–multi-output (MIMO), non-minimum phase and unstable plant. A multi-machine electric power system with system parametric uncertainties is considered as a case study. To show the effectiveness of the QFT technique, the proposed method is compared with a conventional PSS (CPSS) whose parameters are tuned using the classical lead-lag compensation and genetic algorithms. Several nonlinear time-domain simulation tests indicate that the suggested control scheme is robust to the changes in the system parameters and also to successfully reject the disturbances. The results also show that the performance of the QFT method given in this paper is more desirable than CPSS and genetic algorithm (GA).

This paper presents a new optimization technique namely artificial bee colony (ABC) algorithm for tuning power system stabilizer. A single machine power system is considered as case study and embedded with PSS. The parameters of the proposed PSS are tuned by using the proposed algorithms. Simulation results demonstrate the ability and effectiveness of the proposed method in stability improvement.

Power system stability

The stability of a power system is understood as its ability to return to the equilibrium state following a physical disturbance. Important variables at power system equilibrium are rotor (power) angles, nodal voltages and frequency. Hence power system stability can be divided into: (i) rotor (power) angle stability, (ii) voltage stability and (iii) frequency stability. The rotor (power) angle stability of a power system can be enhanced, and its dynamic response improved, by correct system design and operation. For example, the following features help to improve stability (Machowski et al., 2011):

- the use of protective equipment and circuit-breakers that ensure the fastest possible fault clearing;
- the use of single-pole circuit-breakers so that during single-phase faults only the faulted phase is cleared and the un-faulted phases remain intact;
- the use of a system configuration that is suitable for the particular operating conditions (e.g. avoiding long, heavily loaded transmission links);
- ensuring an appropriate reserve in transmission capability;
- avoiding operation of the system at low frequency and/or voltage;
- avoiding weakening the network by the simultaneous outage of a large number of lines and transformers.

In practice, financial considerations determine the extent to which any of these features can be implemented and there must always be a compromise between operating a system near to its stability limit and operating a system with an excessive reserve of generation and transmission. The risk of losing stability can be reduced by using additional elements inserted into the system to help smooth the system dynamic response. This is commonly referred to as stability enhancement and is the subject of this paper.

Power system stabilizer

A power system stabilizer (PSS) is a device which provides additional supplementary control loops to the automatic voltage regulator (AVR) system and/or the turbine-governing system of a generating unit. A PSS is also one of the most cost-effective methods of enhancing power system stability. Adding supplementary control loops to the generator AVR is one of the most common ways of enhancing both small-signal (steady-state) stability and large-signal (transient) stability. Adding such additional control loops must be done with great care; it is known that an AVR (without supplementary control loops) can weaken the damping provided by the damper and field windings. This reduction in the damping torque is primarily due to the voltage regulation effects inducing additional currents in the rotor circuits that oppose the currents induced by the rotor speed deviation $\Delta\omega$ (Machowski et al., 2011).

The main idea of power system stabilization is to recognize that in the steady state, that is when the speed deviation is zero or nearly zero, the voltage controller should be driven by the voltage error ΔV only. However, in the transient state the generator speed is not constant, the rotor swings and ΔV undergoes oscillations caused by the change in rotor angle. The task of the PSS is to add an additional signal which compensates for the ΔV oscillations and provides a damping component that is in phase with $\Delta\omega$. This is illustrated in Figure 1; where the signal V_{PSS} is added to the main voltage error signal ΔV. In the steady state V_{PSS} must be equal to zero so that it does not distort the voltage regulation process. The general structure of the PSS is shown in Figure 2; where the PSS signal V_{PSS} can be provided from a number of different input signals measured at the generator terminals. The measured quantity (or quantities) is passed through low- and high-pass filters. The filtered signal is then passed through a lead and/or lag element in order to obtain the required phase shift and, finally, the signal is amplified and passed to a limiter. When designing the phase compensation it is necessary to take into account the phase shift of the input signal itself and that introduced by the low- and high- pass filters. Typically the measured quantities used as input signals to the PSS are the rotor speed deviation, the generator active power or the frequency of the generator terminal voltage. There are a number of possible ways of constructing a PSS depending on the signal chosen (Machowski et al., 2011).

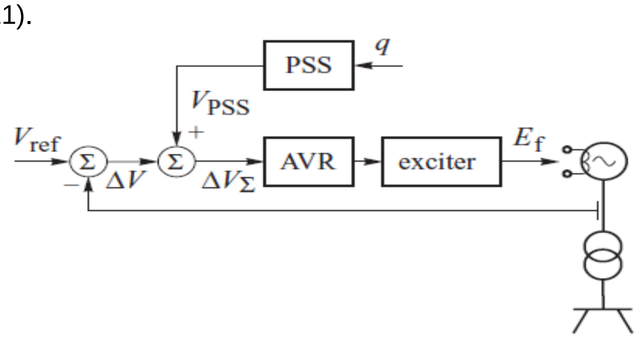

Figure 1. block diagram of supplementary control loop for the AVR system (Machowski et al., 2011)

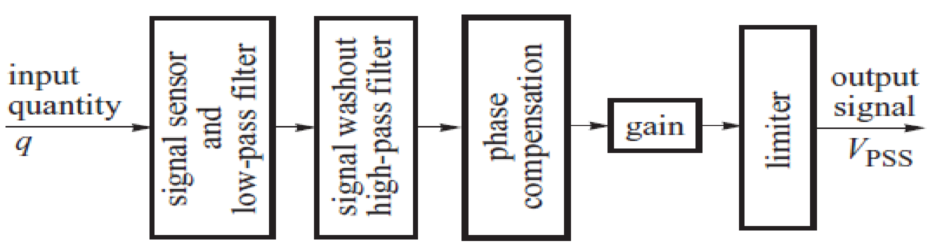

Figure 2. The major elements of a PSS (Machowski et al., 2011)

Artifital bee colony alghorithm

The ABC algorithm was first proposed by Karaboga (Karaboga, 2005) in 2005. Similar to other intelligent swarm algorithms, it simulates the foraging behavior of honeybees. There are three groups of honeybees in the ABC algorithm, employed bees, onlooker bees, and scout bee. Employed bees take the responsibility of searching new food sources. After the process completed, they fly back to the hive and share the position and nectar amount information with onlooker bees in the dancing area. By observe the dance of employed bees, onlooker bees decide the food sources which they want. Scout bees carry out the random search while the food source is exhausted. In the original ABC algorithm (Karaboga and Basturk, 2007), the number of food sources is equal to the number of employed bees. The number of employed bees is equal to the number of onlooker bees simultaneously. In other words, a half of the colony size is employed bees. The process of the artificial bee colony algorithm is shown as below (Liao et al., 2013):

Step 1: Initialize the population.
Step 2: Send the employed bees to the food sources.
Step 3: Memory the best food source in employed bees by fitness evaluation.
Step 4: Employed bees come back to hive and share information of food sources with onlooker bees, then onlooker bees fly to the food sources which they have chosen.
Step 5: Memory the best food source in onlooker bees by fitness evaluation.
Step 6: The scout bees fly to the search area and look for new food sources.
Step 7: While the terminal condition is met or maximum cycle number is reached, Algorithm stop; otherwise, go back to step 2.

Simulated to other swarm evolution algorithms, the ABC algorithm has its own operators such as employed bee phase, onlooker bee phase and scout bee phase.

The employed bee phase

In the employed bee-phase, artificial bees update the new food sources by following expression (Liao et al., 2013):

$$m_i^j = x_i^j + \varphi_i^j \left(x_i^j - x_k^j \right) \qquad (1)$$

Where m^i_j and x^j_i represents the new and old solution (food source) in *j*th dimension of the *i*th individual, respectively; φ^i_j is a random real number between {-1, 1} corresponding to x^j_i, it controls the effectiveness of distance between x^j_i and x^j_k, *k* is an index number selected randomly in food sources. Obviously, a new food source is affected by the status of the bee colony distribution. After the new food source updated, original ABC chose the food source by the fitness value of each corresponding employed bee. Greedy selection has been applied in the ABC algorithm in order to determine which food source is better and would be remembered after the employed bee phase.

The onlooker bee phase

In the onlooker bee phase, employed bees go to a dance area share the nectar amount information of a food source, and onlooker bees waiting in the hive chose the employed bees randomly, but probability is related to the nectar amount. In the ABC algorithm, the nectar amount represents the fitness value of food source. Therefore, the food sources which have higher nectar amount information are more likely to be chosen after onlooker bee phase completed (Liao et al., 2013).

Scout bee phase

After onlooker bee phase, a modified bee colony distribution is determined. If one of these food sources cannot be improved in predetermined cycle ‘‘limit’’, it will be replaced by a new one according to following equation (Liao et al., 2013):

$$x_i^j = x_{\min}^j + rand[0,1]\left(x_{\max}^j - x_{\min}^j \right) \qquad (2)$$

Where x^j_{min} and x^j_{max} represent the lower and upper boundary in dimension *j*, respectively; *rand* {0, 1} is the random number between {0, 1}; Scout bee phase in ABC is applied to abandon the solution which cannot be improved (Liao et al., 2013).

Test system

A power system with two areas is considered as case study. Figure 3 shows the proposed test system. The first area is a single generator and the second area is aggregation of a large number of generators. Therefore, the second area can be modeled as an infinite bus and simulated as a single generator with high inertia. The system data can be found in (Kundur, 1994).

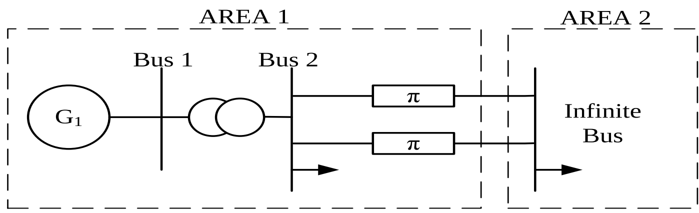

Figure 3. Two areas power system

Design methodology

In this section the PSS parameters are tuned by using ABC algorithm. The PSS configuration is as follows; it comprises two compensators with time constants, T_1–T_4 with an additional gain K.

$$\text{Stabilizer output} = K\frac{ST_W}{1+ST_W}\frac{1+ST_1}{1+ST_2}\frac{1+ST_3}{1+ST_4}\Delta\omega \tag{3}$$

The optimum values of K and T_1–T_4 are accurately computed using ABC Algorithms. Objective function is also considered as following which is the Integral of the Time multiplied Absolute value of the Error (*ITAE*). The optimum values of the parameters are obtained and summarized in the Table 1.

$$ITAE = \int_0^t t|\Delta\omega|dt \tag{4}$$

Table 1. optimal values of PSS parameters

Parameter	K	T_1	T_2	T_3	T_4
Optimal Value	8.12	0.45	0.02	0.38	0.01

Simulatin results

Simulation results are carried out on the given test system. A three phase short circuit at bus 2 is assumed as disturbance and the result are presented following this fault. The fault period is considered as 0.2 seconds. Figure 4 shows the speed of generator following this fault. The figure comprises two diagrams which are system installed with PSS (solid line) and system without PSS (dashed line). The result shows that PSS can mitigate the oscillations and increase power system damping; where the oscillations are damped out faster than system without PSS. The injected signal by PSS is also shown in Figure 5. It is seen that PSS signal is limited from up and down sides and also it becomes stable after almost 10 seconds. In order to show the performance of system under uncertainty, the loads are increased by 100% from the nominal value. The results under these heavy loads are depicted in Figures 6-7. It is clearly seen that PSS can greatly enhance the system stability and damp out the oscillations, while the system without PSS is pendulous.

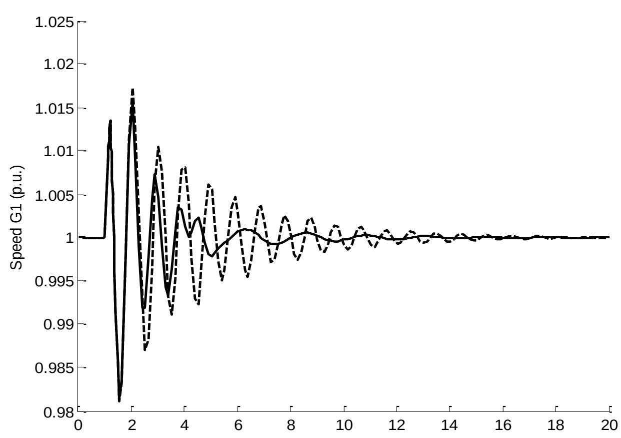

Figure 4. speed of generator in the nominal operating condition
solid: with PSS; dashed: without PSS

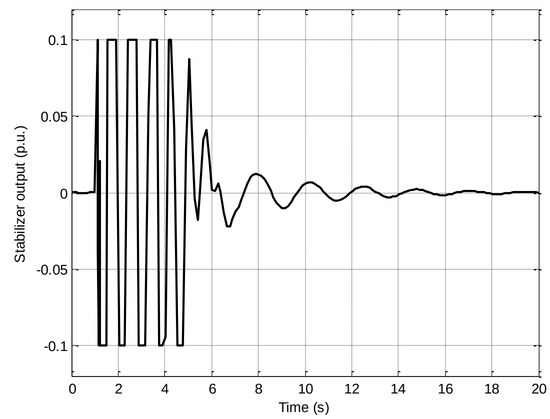

Figure 5. output signal of PSS for results shown in Figure 4

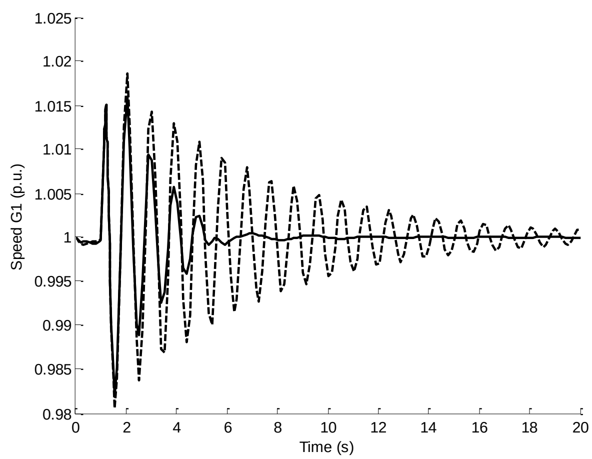

Figure 6. speed of generator in the heavy operating condition
solid: with PSS; dashed: without PSS

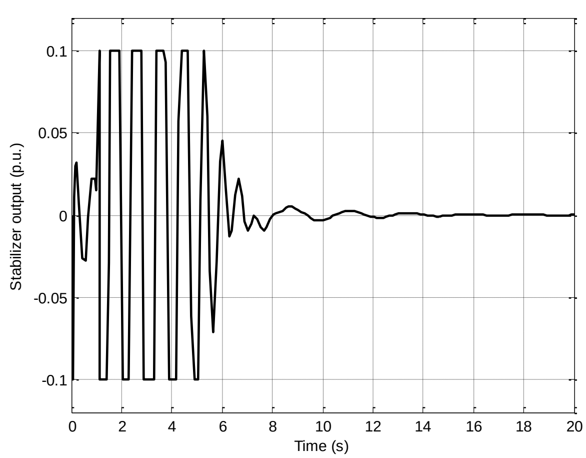

Figure 7. output signal of PSS for results shown in Figure 6

CONCULSION

An optimization technique namely artificial bee colony algorithm was presented to adjust power system stabilizer parameters. The proposed method was simulated on a single machine infinite bus power system comprising uncertainties. Non linear simulation results were carried out to show ability and effectiveness of the proposed technique. It was shown that PSS can greatly enhance power system stability and damp out the low frequency oscillations.

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