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Tuning of Power System Stabilizer using Bat Algorithm

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ABSTRACT

Background: A power system stabilizer is used to add a modulation signal to a generator's automatic voltage regulator reference input. The idea is to produce an electrical torque at the generator proportional to speed. Power system stabilizers use a simple lead network compensator to adjust the input signal to give it the correct phase. **Objective:** This paper provides a detailed account of analytical work carried out to determine the parameters of power system stabilizers. Many different methods and approaches have been investigated to design PSS. The present work proposes a methodology to obtain setting parameters of a power system stabilizer (PSS), through the implementation of search technique based on Bat Algorithm (BAT). **Results:** To adjust the PSS using Bat Algorithm (BAT), the programming and dynamic analysis using Matlab/Simulink is performed, which includes the synchronous machine, excitation system and PSS, where the response of the machine to a disturbance is observed, to search for the stabilization of the system by an optimal setting of PSS parameters obtained using Bat Algorithm (BAT). **Conclusion:** The proposed model was achieved satisfactory results, because with the parameters of the Bat Algorithm the PSS adds a suitable and fast damping to the oscillation from the case of study, by deleting quickly and maintaining a not so great at the start the magnitude of the oscillation that is compensated

KEYWORDS: Power System Stabilizer; Dynamic Stability; Multiband PSS; Bat algorithm; PID Controller

INTRODUCTION

Realization of the system performance benefits available by applying power system stabilizers requires attention to such practical considerations as the influence of the stabilizer on turbine-generator shaft torsional modes of vibration, the effects of power system noise and, for power input stabilizers, mechanical power variations. A power system stabilizer can be most effectively applied if it is tuned with an understanding of the associated power system characteristics and the function to be performed by the stabilizer. The area of stability in Electric Power Systems (SEP) has increased in importance in recent years because of the steady increase in the capacity of the electricity demand which has led to increased short circuit capacity. So, when disturbances or changes occur in the operation of the generator system, these have a greater impact on the network. So these changes have occurred after a disturbance, change in load or increase in speed of the generators, the system does not recover so easily, and oscillations can appear for lack of damping, and that tend to increase, causing stability problems [1]. These problems of oscillatory instability, have been solved by controlling the excitation of the generator by adding damping with additional controls such as power system stabilizer PSS, compensating the deviation or error existing in the rotor speed generator, also through the excitation system of the machine to added damping and remove these electromechanical oscillations [2].

Dmitry Rimorov et al.,[9] proposed a quasi-steady-state modeling approach for an approximation of long-term frequency dynamics in power systems. A specific phenomenon of concern is an onset of frequency swings

during load/generation imbalance scenarios. The effects of system voltage characteristics, system inertia, and, more importantly, damping controllers are explained and quantified using the described quasi-steady-state models. Application of the methodology to a 14-generator benchmark system demonstrates that described models are suitable for simulation of different disturbance scenarios that can trigger frequency instability. Moreover, linearization of the proposed models can provide convenient means for impact assessment and coordinated design of damping controllers. Tuning of multiband power system stabilizers to improve frequency dynamics has been performed and validated.

Reyad et al. [10] introduced a new discrete-time fractional-order power system stabilizer that can be used to stabilize synchronous machines connected to infinite bus subject to both local and inter-area mode of oscillations. The dynamics of the proposed stabilizers are of second-order IIR-type controllers that depend only on the fractional order $0 <; \alpha \leq 1$. The discrete-time fractional-order power system stabilizer will be used in both single and multi-machine infinite bus systems triggered by severe disturbances. Mariam Jebali et al. [11] presented a novel and efficient approach for the optimal tuning of power system stabilizer parameters (PSS) using a genetic algorithm (GA) with the eigenvalue-based objective function. The objective of their study is to check the static stability of the high voltage power to small perturbations of the electrical network. In this context, after linearizing the system, power system stabilizer (PSS) has so far been extensively utilized to mitigate these problems. A method for designing coordinated power system stabilizer (PSS) was presented by Abdolazim et al. [12]. The proposed method is based on the reference model controller design. To this end, a model that is called single-machine non-infinite bus is presented for studying low-frequency oscillations. Then a reference model is proposed for designing PSS based on the single-machine non-infinite bus model. A modified fruit fly optimization algorithm (MFOA) combined with a probabilistic approach are suggested by Bian et al (2016) to coordinate and optimize the parameters of power system stabilizers (PSSs) and static VAR compensator (SVC) damping controller for improving the probabilistic small-signal stability of power systems with large-scale wind generation, taking into consideration the stochastic uncertainty of system operating conditions. It is accepted that there is a threat to the stability of power system with penetration of wind farm. Also, the stochastic fluctuations of wind generation make PSSs tuning more difficult. Yang Liu et al. (2016) have proposed a coordinated SPSS to enhance the stability of multi-machine power systems. The design of the BPSS does not rely on an accurate system model, and only the knowledge of the relative degree of the system is required. The presented switching strategy of the SPSS has twofold merits. It utilizes the time-optimum characteristic of the BPSS and, at the same time, makes full use of the damping ability of the CPSS.

The only placement of PSS in the excitation system of generators, not solve the problem of oscillations, it is necessary to have the appropriate settings to perform its function. There are various techniques of adjusting PSS, however, this work focuses on the application of Bat Algorithm (BAT) is an optimization technique and search has gained increased use in recent years in various areas due to their effectiveness, simplicity, and suitability to solving different problems.

Proposed Power System Topology With Multiband Pss:

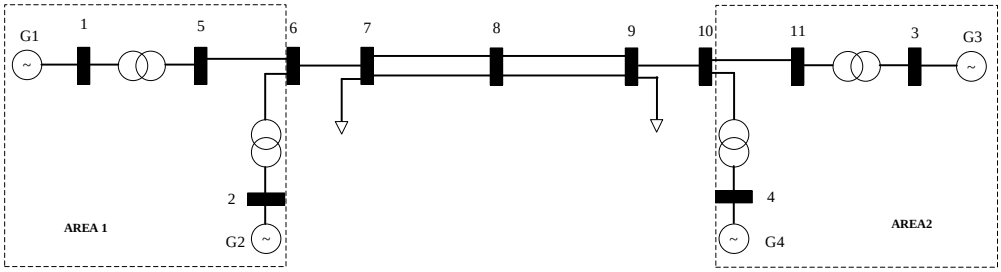
A two-area four-machine interconnected power system shown in Fig.1 is used to design PSS. Each generator is represented by a 5th-state transient model [4]. The system consists of two similar areas connected by a weak tie. Each area consists of two coupled units, each having rating of 900 MVA and 20 kV. The generator parameters in per unit on the rated MVA and kV base are as follows [8].

$$X_d = 1.8 \quad X_q = 1.7 \quad X_l = 0.2 \quad X'_d = 0.3 \quad X'_q = 0.55 \tag{1}$$

$$X''_d = 0.25 \quad X''_q = 0.25 \quad R_a = 0.0025 \quad T'_{d0} = 8.0s \quad T'_{q0} = 0.4s \tag{2}$$

$$T''_{d0} = 0.3s \quad T''_q = 0.05s \quad A_{Sat} = 0.015 \quad B_{Sat} = 9.6 \quad \psi_{T1} = 0.9 \tag{3}$$

$$H = 6.5 \text{ for M1 and M2} \quad H = 6.175 \text{ for M3 and M4} \quad K_D = 0 \tag{4}$$



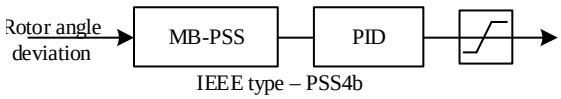


Fig. 1: Two area four machines power system

Each step –up transformer has an impedance of 0+j0.15 per unit on 900 MVA and 20/230kV base and has an off-nominal ratio of 1.0. The transmission system nominal voltage is 230kV. The line lengths are identified in Fig.1. The parameters of the line in per unit on 100 MVA, 230 kV base are,

$$R = 0.0001 pu/km \qquad X_l = 0.0001 pu/km \qquad b_c = 0.00175 pu/km \tag{5}$$

The system is operating with area 1 exporting 400 MVA to area 2, and the generating units are loaded as,

M1: P = 700 MW, Q = 185 MVAr, $E_t = 1.03\angle 20.2°$
M2: P = 700 MW, Q = 235 MVAr, $E_t = 1.01\angle 10.5°$
M3: P = 719 MW, Q=176MVAr, $E_t = 1.03\angle -6.8°$
M4: P = 700 MW, Q=202MVAr, $E_t = 1.03\angle -17.0°$ (6)

The test system consists of two fully symmetrical areas linked together by two 230 kV lines of 220 km length. It was specifically designed in [7,4] to study low frequency electromechanical oscillations to high interconnected power systems. Despite its small size, it mimics the behavior of typical systems in actual operation very carefully. Each area is equipped with two identical round rotor generators rated 20 kV/900 MVA. The synchronous machines have identical parameters (W. Watson and G. Manchur, 1973, F. P. deMello et al. 1978), except for inertias which are H = 6.5s in area 1 and H = 6.175s in area 2 [4]. Thermal plants having identical speed regulators are further assumed at all locations, in addition to fast static exciters with a 200 gain [7,4]. The load is represented as constant impedances and split between the areas in such a way that area 1 is Exporting 413MW to area 2. Since the surge impedance loading of a single line is about 140 MW [4], the system is somewhat stressed, even in steady-state. The reference load-flow with M2 considered the slack machine is such that all generators are producing about 700 MW each. The results can be seen by opening the Powergui and selecting Machine and Load-Flow Initialization. They are slightly different from [4] because the load voltage profile was improved (made closer to unity) by installing 187 MVAr more capacitors in each area. Also, transmission and generation losses may vary depending on the detail level in line and generator representation.

Design Of Pid-Pss:

PID controllers have been used for several decades in industries for process control applications. The reason for their broad popularity lies in the simplicity of design and good performance including low percentage overshoot and small settling time for slow process plants. The most appreciated feature of the PID controllers is their relative easiness of use because the three associated parameters have a clear physical meaning (). This makes their tuning possible for the operators also by trial and error and in any case, a large number of tuning rules have been developed.

Although all the existing techniques for the PID controller parameter tuning perform well, a continuous and an intensive research work is still underway towards system control quality enhancement and performance improvements. A PID controller is essentially a generic closed loop feedback mechanism. In working principle is that it monitors the error between a measured process variable and the desired setpoint; from this error, a corrective signal is computed and is eventually feedback to the input side to adjust the process accordingly. The differential equation for the PID controller is as follows,

$$u(t) = K_p e(t) + T_i \int_o^t e_p(t)dt + T_d \frac{d}{dt} e(t) \tag{7}$$

Thus, the PID controller algorithm is described by a weighted sum of the three times functions were the three distinct weights are: K_P (Proportional gain) determines the influence of the present error value on the control mechanism, I (integral gain) decides the reaction based on the area under the error time curve up to the present point and T_d (derivative gain) account for the extent of the response to the rate of change of the error with time.

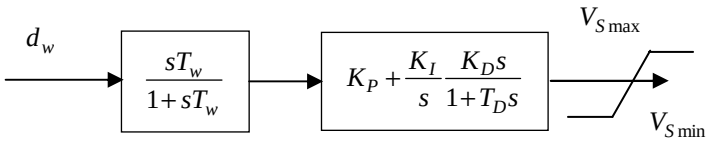


Fig. 2: Structure of PID-PSS

For simplicity, a PID type PSS is modeled by some identical stages, PID, which is represented by a gain K_P, K_I, and K_D, washout function, the value of T_W is not critical and may be in the range of 1 to 20 seconds and the output limits V_{smax} and V_{smin}. The structure of the PID type power system stabilizer, to modulate the excitation voltage is shown in Fig. 2.

Bat Algorithm:

The Bat Algorithm is an optimization algorithm based on the echolocation behavior of bats. The capability of echolocation of bats is fascinating as these bats can find their prey and discriminate different types of insects even in complete darkness. The advanced capability of echolocation of bats has been used to solve various optimization problems. Echolocation of bats works as a type of sonar in bats, emits a loud and short pulse of sound, waits as it hits an object and, after a fraction of the time, the echo o returns to their ears. Thus, bats can compute how far they are from an object.

Also, this amazing orientation mechanism makes bats being able to distinguish the difference between an obstacle and prey, allowing them to hunt even in complete darkness. Based on the behavior of the bats, Yang has developed a new and exciting metaheuristic optimization technique called Bat Algorithm. Such technique has been developed to behave like a band of bats tracking prey/foods using their capability of echolocation.

A. Bat algorithm idealized rules:

- All bats use echolocation to sense distance, and they also know the difference between food/prey and background barriers in some magical way.
- Bats fly randomly with velocity v_i at position x_i with a fixed frequency f_{min}, varying wavelength λ and loudness A_0 to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission $r \in [0, 1]$ depending on the proximity of their target.
- Although the loudness can vary in many ways, it is assumed that the loudness ranges from a significant (positive) A_0 to a constant minimum value Amin

B. Pseudo code of the bat algorithm (X. S. Yang, 2010):

Objective function f(x), x = (x1,….,xd) T.
Step 1: Initialize the bat population x_i = (i=1, 2,…, n).
Step 2: Define pulse frequency f_i at x_i
Step 3: Initialize pulse rates r_i and the loudness A_i
Step 4: Check whether (t < Max - number of iterations), if yes go to step 5, else go to step 11
Step 5: Generate new solutions by adjusting frequency, and updating velocities and solutions.
Step 6: Check whether (r and > r_i), if yes go to step 7, else go to step 8.
Step 7: Select a solution among the best solutions and generate a local solution around the selected best solution. Generate a new solution by flying randomly.
Step 8: Check whether (rand < A_i & f (x_i) < f(x*)). If yes, go to step 9, else step 10.
Step 9: Accept the new solutions. Increase ri and reduce A_i
Step 10: Rank the bats and find the current best x * and go to step 4.
Step 11: Print the Results.

The positions x_i and velocities v_i in a dimensional search space are updated using the following equations. The new solutions X_i^t and velocities V_i^t at time step t are given by:

$$f_i = f_{\min} + (f_{\max} - f_{\min}) \tag{8}$$

$$V_i^t = V_{i-1}^t + (X_i^t - X^*) f_i \tag{9}$$

$$X_i^t = X_{i-1}^t + V_i^t \tag{10}$$

Where, $\beta \in [0, 1]$ is a random vector drawn from a uniform distribution. Here x* is the current global best location (solution) which is located after comparing all the solutions among all the n bats. As the product $\lambda_i f_i$ is the velocity increment, we can use either f_i (or λ_i) to adjust the velocity change while fixing the other factor λ_i

(or f_i), depending on the type of the problem of interest. Initially, each bat is randomly assigned a frequency which is drawn uniformly from [f_{min} , f_{max}].For the local search part, once a solution is selected among the current best solutions, a new solution for each bat is generated locally using random walk:

$$X_{new} = X_{old} + \varepsilon A^t \tag{11}$$

Where, $\varepsilon \in [-1, 1]$ is a random number, while $A^t = < A_i^t >$ is the average loudness of all the bats at this time step [7].

Simulation Results:

PSS typically utilizes phase compensation and adjusting phase compensation is the main task in PSS tuning. Phase compensation is accomplished by adjusting the PSS to compensate for phase lags through the generator, excitation system, and power system such that PSS provides torque changes in phase with speed changes. Tuning should be performed when system configurations and operating conditions result in the least damping. Verification should demonstrate that instability is not introduced through normal operating ranges as well as expected faults. For the simulation, the model of machine with excitation system and PSS is used Matlab/Simulink toolbox is obtained the rotor speed deviation Δω, which is sent to a Bat algorithm in Matlab to check the minimization of the increase in the speed. In the Bat algorithm, Matlab is performed and sends the response speed for each population evaluated to Bat algorithm to guide the search towards the global o desired number of generations. The tuning of PSS differs based on the type of input. However, in the general tuning of PSS consists of a). Verifying the functionality of all aspects of the PSS equipment. This includes the compensating features, limits, and protections. All potentiometers, if so equipped, should have smooth and continuous control throughout their range. B) PSS Output Limiter. It includes the set output limits so that PSS cannot move generator terminal voltage beyond a predetermined value. The typical range of settings is from ±5% to ±10% of rated generator terminal voltage. Asymmetrical limits may be employed. c) A gain as high as practicable is required for best contribution to system damping. Since the maximum gain that is safely usable depends on upon many factors, it is best determined by test. The gain test shall be performed under operating conditions that result in maximum overall system gain so that the actual gain margin is identified.

The traditional method of tuning does not guarantee optimal parameters and in most cases, the tuned parameters need improvement through trial and error. The optimal tuning for determining the PSS and PID Controller parameters was carried out. To evaluate the effectiveness of the proposed Bat Algorithm (BAT) on PID and PSS to improve the stability of the power system, the dynamic performance of the proposed BAT was examined under different loading conditions. For comparison, however, the PID controller parameters were also obtained using the conventional tuning technique. The conventional rules were used to form the intervals for the design parameters in tuning the controller by minimizing an objective function.

Through the simulation results, it is clearly shown that the proposed BAT-PSS can perform an efficient search to obtain optimal PSS gain parameters that can achieve better performance criterion. It is recognized that the highest magnitude of power system disturbance is caused by the three phase fault. The PSS can track the system operating conditions, and thus, as seen from the results in figures below, can adjust and provide a uniformly excellent performance over a wide range of operating conditions and disturbances. The following observations are made on the stability of the system.

Fig. 3: Voltage response of Bus1 and Bus2 and active power transfer between them at the period of 1 – 1.2 sec. From the figure 3, it is clear that the response of PID +BAT PSS is superior to other controllers by generating the voltage with fewer oscillations. Fig. 4: Rotor angle deviation on generator 4 at the period of 1 – 1.2 sec. From figure 4, it is observed that the optimum rotor angle is obtained using BAT PSS + PID controller only. Fig. 5: Rotor speed response of generator 1, 2, 3 & 4 at the period of 1 – 1.2 sec. From figure 5, it is clear that the speed is reached its steady state value in PID+BAT PSS controller compared with other controllers. Power loss at generator 1, 2, 3 & 4 at the period of 1 – 1.2 sec is shown in Fig.6, it is evident the minimum power loss is generated from all generators with the implementation of PID+BAT PSS controller.

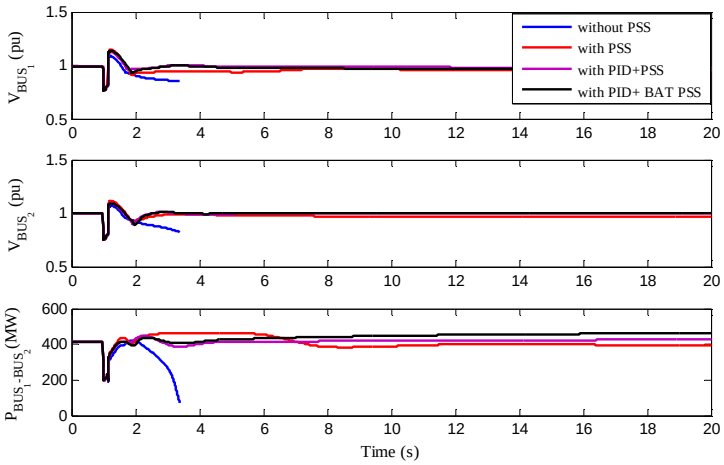


Fig. 3: Voltage response of Bus1 and Bus2 and active power transfer between them at the period of 1 – 1.2 sec.

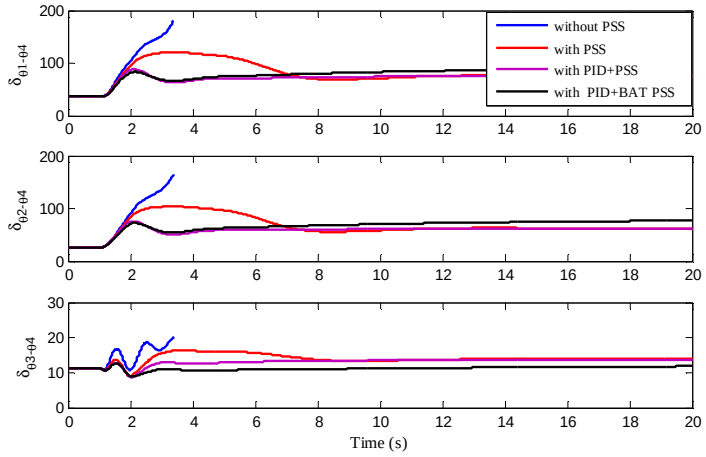


Fig. 4: Rotor angle deviation on generator 4 at the period of 1 – 1.2 sec.

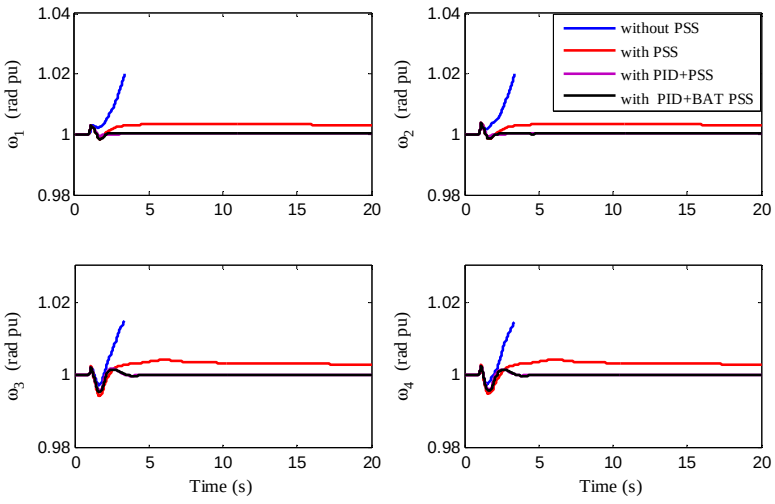


Fig. 5: Rotor speed response of generator 1, 2, 3 & 4 at the period of 1 – 1.2 sec.

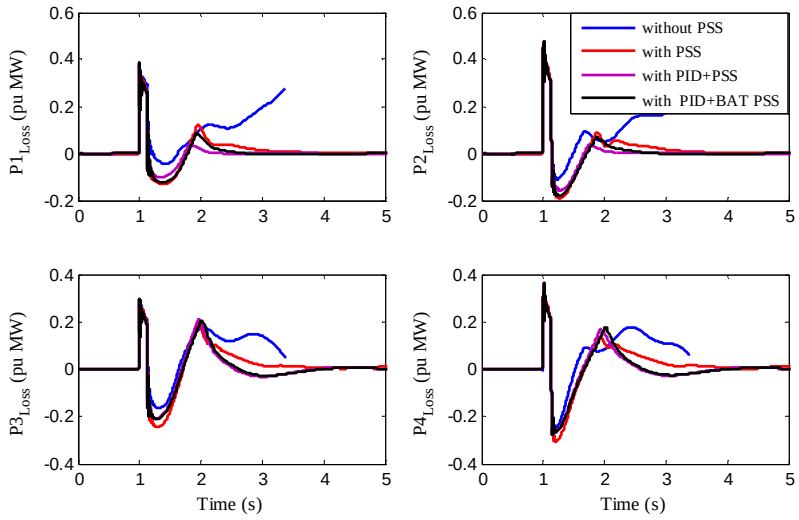


Fig. 6: Power loss at generator 1, 2, 3 & 4 at the period of 1 – 1.2 sec.

Conclusion:

The presence of disturbances and changes in operating the systems can contribute to the instability of the power systems, with the appearance of oscillations for deficiency damping in the system. To achieve its objective, the PSS must have the appropriate settings for proper operation. The setting of PSS has been done through various techniques, some of which needs to be performed complex calculations and procedures. However, in this article we use the technique of search and optimization Bat Algorithm to obtain the proper adjustment of PSS for damping adequately to the oscillation present in the case of study. With the objective of achieving the setting of PSS, the problem was adapted to Bat Algorithm, optimizing the time constants of the compensator lead-lag and the value of the gain, of the PSS model that was used, because this variable gives us the amount of damping to eliminate the frequency of oscillation of the machine. The adaptation of the Bat Algorithm to the problem of adjustment, required evaluations in Simulink toolbox, to observe the dynamics response of the system to each solution proposed in the development of genetic algorithm programmed in Matlab. These simulations showed if the proposed adjustments in each evaluation mitigated the increase in speed of the rotor of the machine, paying attention to the times of the signal stabilization, percentage error of the signal stabilization and the magnitude of the peaks in the compensation at the start the oscillation, all for each adjust evaluated in the simulations, until reaching to optimal adjustment to comply with the above observations especially with lower time of stabilization. When testing this setting in the Simulink model were achieved satisfactory results, because with the parameters of the Bat Algorithm the PSS adds a suitable and fast damping to the oscillation from the case of study, by deleting quickly and maintaining a not so great at the start the magnitude of the oscillation that is compensated.

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