Wind Energy Power System Stabilizer Design using H∞ Robust Technique based on Enhance ABC Optimal Power System

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ABSTRACT
Power system stabilizers (PSS) are now regularly used in the industry to damp out power system oscillations. High performance excitation system have become very important as limited generation capacity and consumer desires for power continue to increase. In this work, enhanced Artificial Bee Colony (ABC) technique is applied to design a robust power system stabilizer (PSS) in order to improve transient and dynamic stabilities of a turbo-alternator connected to an infinite bus system. The design problem of the proposed controller is formulated as an optimization problem and enhanced ABC is employed to search for optimal controller parameters. The robust power system stabilizer (RPSS) is designed using enhanced ABC for designing the controllers for dynamical systems in electrical engineering. Comparisons are also made between the Conventional power system stabilizer with a strong action (CPSS) and PSS with H∞ optimization. The simulation results show the effectiveness of proposed method for a stabilizer by enhancing the performance and robustness.

General Terms
Power system, technique

Keywords
Stability of Synchronous Machines, Robust Control, Power System Stabilizer (PSS), Stability and Robustness, Artificial Bee Colony (ABC)

1. INTRODUCTION
In the previous decades, with the emergence of large interconnected power systems all over the world, stability have become a main consideration. Power systems frequently undergo faults, load changes and many other disturbances, which in turn introduce low frequency oscillations (LFO) affecting the maximum power transfer capability limits and in the face of a extensive variation and difficulty of the power flow under the deregulation process, it is of growing concern that there may be the degradation of stability due to increased inter-area as well as local power oscillations. In order to survive with stabilization problem, the power system stabilizer (PSS) has been a cost-efficient measure to increase stability in power systems. However the general PSS design is based on the classical control theory, which usually uses the phase lead-lag type of compensator. Since the wide area power system is large and highly nonlinear and its network operating conditions experience often changes, the conventional PSS cannot stably compensate for changing multiple modes of power oscillations.

The disturbances taking place in power system because of changes in load include electro mechanical oscillations of electrical generators. These oscillations are also called as power swings and these must be effectively damped to maintain the system stability. Electromechanical oscillations can be classified in two major categories which are Local Plant Mode Oscillations: One type is associated with units at a generating station swinging with respect to the rest of the power system. Such oscillations are called as ‘local plant mode oscillations’. The frequencies of these oscillations are usually in the range 0.8Hz to 2.0 Hz, Inter-area Oscillations: The second type of oscillation is related with the swinging of several machines in one part of the system over machines in some other parts. These are also called as ‘inter area mode’ oscillations and have frequencies in the range from 0.1 to 0.7 Hz. The stability criterion with respect to synchronous machine equilibrium has been presented. The mathematical model presented for small scale stability state is a group of linear time invariant differential equations [1].

Wind power penetration is incessantly increasing in many power systems around the world in an effort to increase the penetration of renewable energy in the energy mix with cost-effective solutions. In new wind power installations typically variable-speed wind turbines with frequency converters are used, instead of the older constant-speed, squirrel-cage induction generators. The doubly fed asynchronous generator is today the most admired scheme for variable-speed wind turbines, followed by the full converter concept.

Heavy number of wind power penetration causes reasonable concerns as to potential stability threats that might be encountered, when a large percentage of system loads is supplied by new technology wind generators. One particular feature of system stability is the electromechanical oscillations damping. A mechanical analog of synchronous generators operating in synchronism is masses interconnected with springs. In steady-state all generators rotate at exactly the same speed, producing the required power to cover the system load.

In the conventional PSS, the normal controller circuit is used. It balances the load coming from the wind turbine. Here the value of K_p, K_i and K_d value are fixed and the output will be the normal output. While using H∞ technique, value of K_p, K_i and K_d value are fixed and the output as like as normal PSS output but compared to normal PSS, H∞ technique output will be better.

In this work, a novel enhanced ABC-based approach to PSS design is proposed. The problem of PSS design is formulated as an optimization problem with mild constraints and two different eigenvalue based objective functions. Then, an enhanced ABC algorithm is employed to solve this optimization problem. To examine the potential of the proposed approach, two different examples of multimachine power systems have been compared. Eigenvalue analysis and nonlinear simulation results have been carried out to estimate the effectiveness of the proposed PSSs under different disturbances, loading conditions, and system configurations.

2. LITERATURE OF REVIEW

Power System experience low-frequency oscillations due to disturbances. The oscillations may maintain and grow to cause system separation if sufficient damping is not available. To increase system damping, the generators are equipped with power system stabilizers (PSSs) that provide supplementary feedback stabilizing signals in the excitation systems [4]–[6].

DeMello and Concordia [6] offered the concepts of synchronous machine stability as affected by excitation control. They established a considerate of the stabilizing requirements for static excitation systems. In recent years, numerous approaches based on modern control theory have been applied to PSS design problem. These contain optimal control, adaptive control, variable structure control, and intelligent control [7]–[11].

Designed a Power System Stabilizer for damping of oscillations using optimization based linear control design technique. Different types of optimization algorithms are used to find out the optimum parameters of stabilizer for damping of oscillations [12].

Developed a robust control technique based on H∞ loop-shaping optimization method, applied to a Power System Stabilizer (PSS) to enhance transient and dynamic stabilities of a turbo-alternator connected to an infinite bus system[13].It can be applicable to multi machine power system but want to take care of the intra-area oscillations under perturbed conditions.

Presented a Wind PSS that can powerfully damp out unstable or marginally stable interarea oscillations as was confirmed by testing on two test systems using two types of wind generators, namely DFAG and FCWG. The resulting oscillations introduced in the rotor speed and the mechanical power of the wind turbine were shown to be very small [26].

Offers a small signal stability analysis for power systems with wind farm interaction. Power systems have damping oscillation modes that can be agitated by disturbance or fault in the grid. The power converters of the wind farms can be used to minimize these oscillations and make the system more stable [27].

Presents wind farm based power system stabilizers to assist the power system manage with potential angular instability and cascading outages. A methodology is developed to validate the use of wind based power system stabilizer, identify ideal feedback signals and tune the stabilizer controller [28].

3. H∞ ROBUST DESIGN TECHNIQUE BASED ON ENHANCE ABC OPTIMAL POWER SYSTEM STABILIZER

3.1 H∞

In Control theory, H-infinity is a mainly used design methodology. It is a combination of traditional classical control techniques like Bodes sensitivity integral and optimization techniques of H-infinity to obtain stabilized controllers. These controllers hold the performance properties in spite of bounded differences between the practical real plant and assumed nominal plant. By reviewing the plant transfer function in the frequency domain, the control system designer describes the expected responsiveness and characteristics of noise-suppression, resulting 'loop-shape' is then 'robustified' via optimization. Robustification generally has good effect on response around unity-gain crossover which is adjusted to maximize the system's stability margins.

Drawbacks of H_∞ techniques include the level of mathematical understanding needed to apply them successfully and the need for a reasonably fine model of the system to be controlled. It is significant to keep in mind that the resulting controller is only ideal with respect to the prescribed cost function and does not essentially represent the best controller in terms of the common performance measures used to validate controllers such as settling time, energy expended, etc.

3.2 Artificial Bee Colony

Artificial Bee Colony algorithm (ABC) is an optimization algorithm based on the intellectual foraging behavior of honey bee swarm, proposed by Karaboga in 2005. He showed that the ABC algorithm can be used for solving unimodal and multi-modal numerical optimization problems [14]. A customized version of the ABC algorithm for constrained optimization problems has been introduced and its performance has been compared with that of the state-of-art algorithms. It has been concluded that the ABC algorithm can be competently used for solving constrained optimization problems [15]. Artificial Bee Colony (ABC) Algorithm which has excellent exploration and exploitation abilities in searching optimal weight set is used in training neural networks [16]. ABC is utilized for optimizing a large set of numerical test functions and the results formed by ABC algorithm are compared with the results obtained by particle swarm optimization algorithm, genetic algorithm, and differential evolution algorithm and evolution strategies [17]. Applied the Artificial Bee Colony (ABC) Optimization Algorithm on training feed-forward neural networks to categorize different data sets which are widely used in the machine learning community [18]. A new method based on ABC algorithm for designing digital IIR filters is described and its concert is compared with that of a conventional optimization algorithm (LSQ-nonlin) and particle swarm optimization (PSO) algorithm.

A new design method based on artificial bee colony algorithm for digital IIR filters [19].ABC as an optimization tool, offers a population-based search procedure in which individuals called foods positions are altered by the artificial bees with time and the bee’s aim is to find out the places of food sources with high nectar amount and finally the one with the highest nectar. In ABC system, artificial bees fly around in a multidimensional search space and some (employed and onlooker bees) choose food sources depending on the experience of themselves and their nest mates, and regulate their positions. Some fly and prefer the food sources indiscriminately without using experience. If the nectar amount of a new source is higher than that of the preceding one in their memory, they memorize the new position and disregard the previous one. Thus, ABC system combines local search methods, taken by employed and onlooker bees, with global search methods, handled by onlookers and scouts, attempting to balance exploration and exploitation process.

The main steps involved in ABC algorithm can be described as follows:

Step 1: Employed bee stage

Step 2: Calculate the probabilities

Step 3: Onlooker bee stage

Step 4: Scout bee stage

Step 5: To find the iterate value of K_p, K_i and K_d value.

3.3 Enhanced Artificial Bee Colony Optimization for Robust Power System Stabilizer

The objective is to design a controller for the augmented plant. Here implement an Enhanced ABC algorithm, it gives the values of K_p,K_i,K_d i.e. gain value and the wind farm has given the input stator voltage, rotor speed, rotor speed deviation and rotor angle deviation .These values are applied to the controller and the output will be active power, terminal voltage stator angle voltage and speed deviation. Power system stabilizer is designed to stabilize the voltage from the wind turbine.

Advanced control techniques have been proposed for alleviating the voltage and frequency of power generation systems. These contain output and state feedback control, variable structure and neural network control, fuzzy logic control.

The ABC algorithm is developed by analyzing the behaviors of the real bees on finding food source, which is called the nectar, and sharing the details of food sources to the bees in the nest. In the ABC, the artificial agents are defined and classified into three types which are the employed bee, the onlooker bee, and the scout. Each of them plays diverse role in the process: the employed bee stays on a food source and offers the neighborhood of the source in its memory, the onlooker gets the details of food sources from the employed bees in the hive and select one of the food source to collect the nectar; and the scout is in charge for finding new food, the new nectar, sources. The process of the ABC algorithm is as follows:

Initialization: Spray ne percentage of the populations into the solution space arbitrarily, and then calculate their fitness values, which are called the nectar amounts, where ne represents the ratio of employed bees to the total population. Once these populations are placed into the solution space, they are called the employed bees.

Progress of the Onlookers: Calculate the probability of selecting a food source by the equation (1), select a food source to move to by roulette wheel selection for every onlooker bees and then find out the nectar amounts of them. The movement of the onlookers follows the equation (2).

Movement of the Scouts: If the fitness values of the employed bees do not be improved by a continuous predetermined number of iterations, which is called ”$Limit$”, those food sources are discarded, and these employed bees become the scouts. The scouts are moved by the equation (3).

Update the Best Food Source Found So Far: Memorize the best fitness value and the position, which are originate by the bees.

Termination Checking: Check if the amount of the iterations satisfies the termination condition. If the termination condition is satisfied, terminate the program and output the results; otherwise go back to the Step 2.

$$Pi = (\theta i) / \sum S\ k{=}1\ (\theta k) \qquad (1)$$

Where θi denotes the position of the i^{th} employed bee, S represents the number of employed bees, and Pi is the probability of selecting the $i\ th$ employed bee

$$xij\ (t + 1) = \theta ij + (\theta ij\ (t) - \theta kj\ (t)) \qquad (2)$$

where xi denotes the position of the i^{th} onlooker bee, t denotes the iteration number, θk is the randomly chosen employed bee, j represents the dimension of the solution and (·) produces a series of random variable in the range [−1, 1].

$$\theta ij = \theta ijmin + r \cdot (\theta ijmax -\ ) \qquad (3)$$

Where r is a random number and $r \in [0, 1]$.

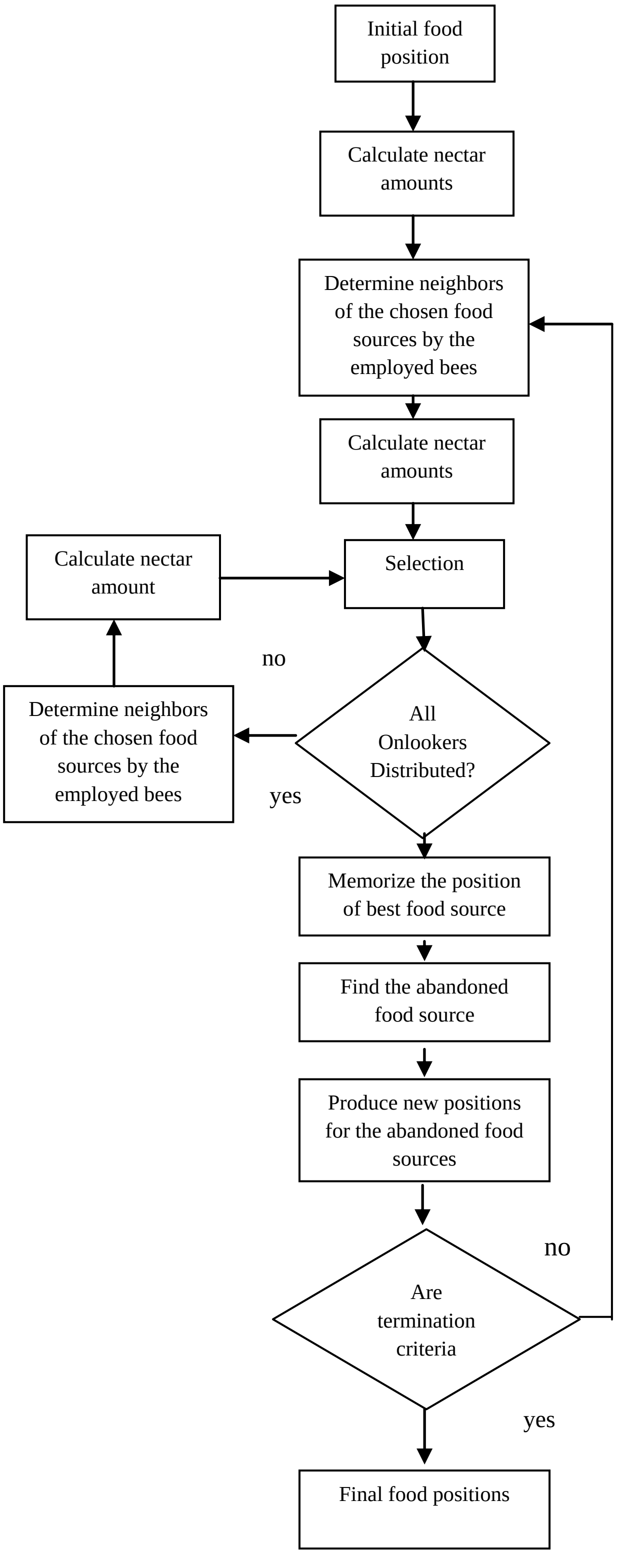


Fig.1 Flow Chart of Enhanced Artificial Bee Colony

In Fig.1 a cycle, after all employed bees and onlooker bees complete their searches, the algorithm verifies if there is any exhausted source to be abandoned. In order to determine if a source is to be discarded, the counters which have been updated during search are used. If the value of the counter is greater than the control parameter of the ABC algorithm, also called as the ‘‘limit”, then the source related with this counter is assumed to be exhausted and is abandoned. The food source discarded by its bee is replaced with a new food source discovered by the scout, which represents the negative feedback mechanism and fluctuation property in the self-organization of ABC. This is simulated by producing a site position arbitrarily and replacing it with the discarded one.

4. MODELLING OF POWER SYSTEM WITH PSS

The power system taken in this study is modeled as a single synchronous generator connected through a parallel transmission line to a very large network approximated by an infinite bus (SMIB).

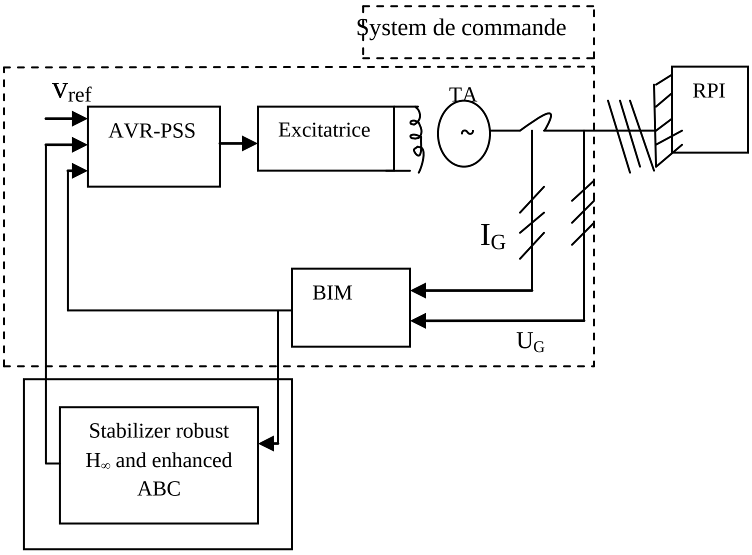


Fig.2 Block diagram of the proposed SMIB power system

The state variables considered here be speed deviation and power system acceleration.

$$\chi_1 = \Delta\omega$$

$$\chi_2 = \Delta P = P_m - P_c$$

$$\chi_1 = \alpha\, \chi_2$$

$$\alpha\, \chi_2 = f(\chi_1, \chi_2) + g((\chi_1, \chi_2)u$$

$$y = \chi_1$$

Let P_m and P_c represents the mechanical and electrical power respectively.

The developed simulink model of the power system is shown in the following figure

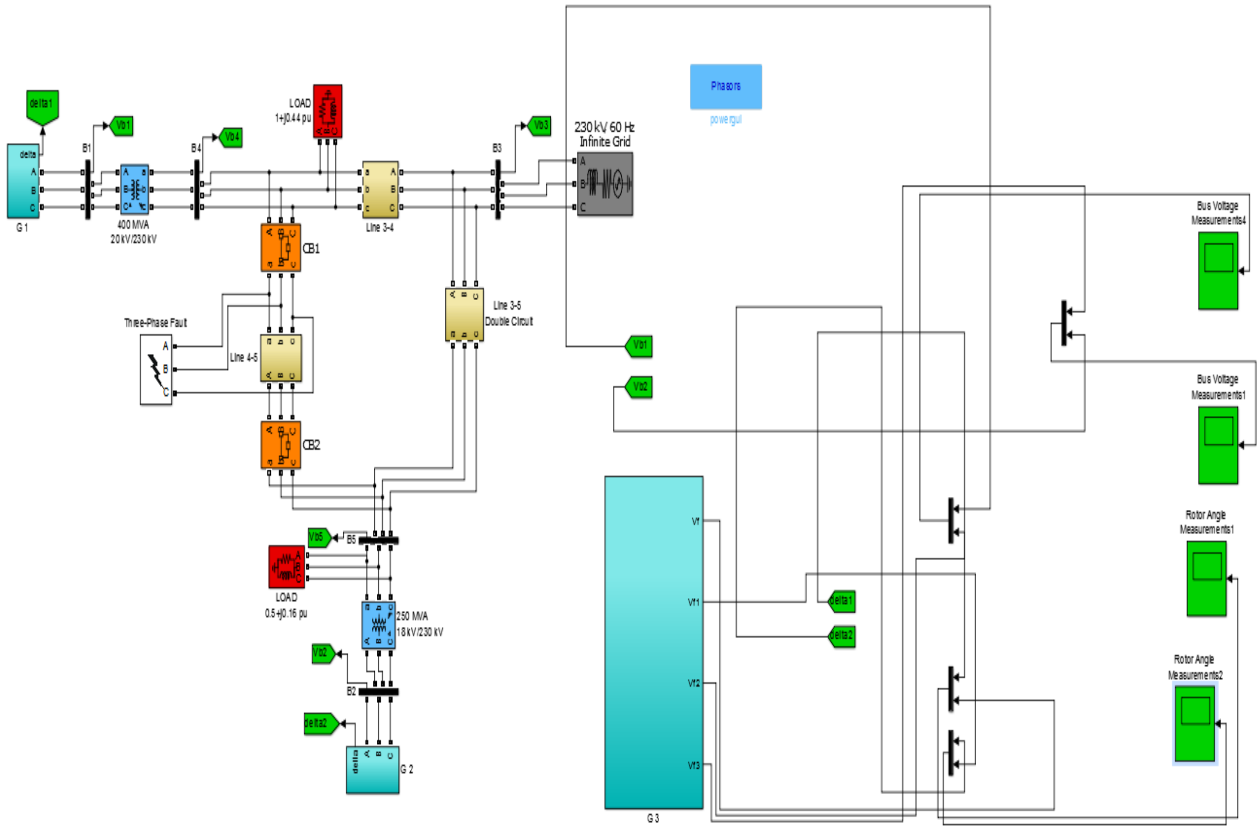


Fig.3 Simulink model of with (RPSS) and (CPSS) control for the PSS

General PSS model consists of three phase transformer, synchronous machine, three-phase parallel RLC load, lines, three phase breaker, three phase source, three phase fault, double circuit. In this a three-phase transformer of 250 MVA 18kv/230kv by using three single-phase transformers is implemented. Set the winding connection when to access the neutral point of the Wye. A 3-phase synchronous machine modeled in the dq rotor reference frame. Stator windings are attached in wye to an internal neutral point. A three-phase parallel RLC load is implemented. Connect this block in series with the three-phase element for switching. It can define the breaker timing directly from the dialog box or apply an external logical signal. Three-phase voltage source in series with RL branch is implemented. A fault circuit is used to program a fault (short-circuit) between any phase and the ground. It can define the fault timing directly from the dialog box or apply an external logical signal.

5. SIMULATION RESULTS

Simulations are performed using the Simulink model shown in the figure 3 for a period of 14 seconds with the designed CPSS and RPSS .The following results show that comparison of conventional PSS and PSS with enhanced ABC optimization technique.

In this PSS design, an important subject is to assess the designed PSS under power system condition changing. The robustness of PSS should be evaluated in different loading conditions and system operating conditions. The variation of operating conditions corresponds to the variation of transmission line parameters and the active and reactive powers. Certain attention was dedicated to the problem of the reactive power consumption, which is very essential for all electric power systems and generating stations.

The quantitative results of the comparison of the static and dynamic performances with CPSS and RPSS of the different parameters are shown respectively in table I and II .Comparing the results of the system wants to directly identify very large improvements of static and dynamic performances of the system with the RPSS in comparison with the application of the CPSS.

Response of active power, terminal voltage, stator angle voltage, speed deviation was observed. Simulation results demonstrate the good damping performance of the robust designed PSS with enhanced ABC. Comparison of the robust optimization technique enhanced ABC with the conventional PSS and PSS with H∞ technique show that optimization technique can achieve excellent robustness, while the design procedure used in much simpler. The proposed Table clearly shows the effectiveness of the proposed method in comparison with CPSS.

5.1 Comparison of Conventional PSS and PSS with enhanced ABC optimization technique

5.1.1 Active Power

Active (Real or True) Power is measured in watts (W) and is the power drawn by the electrical resistance of a system doing useful work.

5.1.2 Terminal Voltage

Terminal voltage is the voltage output of a device is measured across its terminals. Terminal voltage is calculated by V = emf - Ir.

5.1.3 Stator Angle Voltage

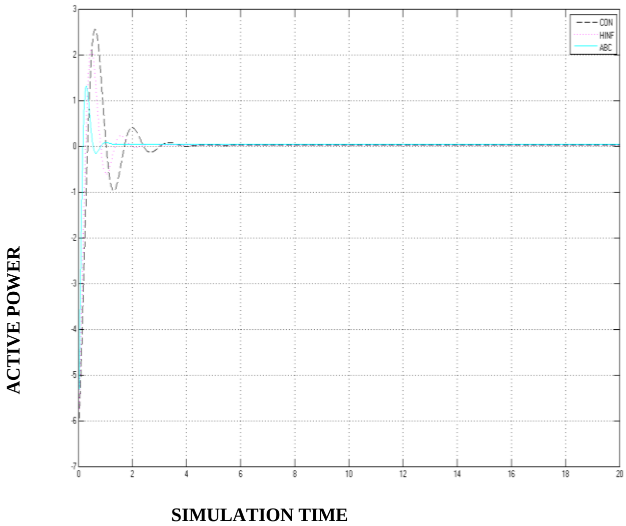
Voltage measured at the stator side.

5.1.4 Speed Deviation

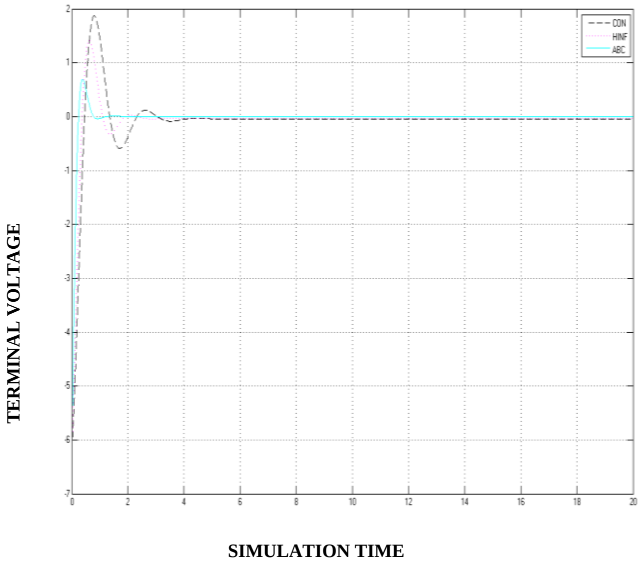
The difference between the value of a set speed and the rotation speed of a motor

1. **Under-exited mode x=0.5 , y=0.85 , z=0.1802**

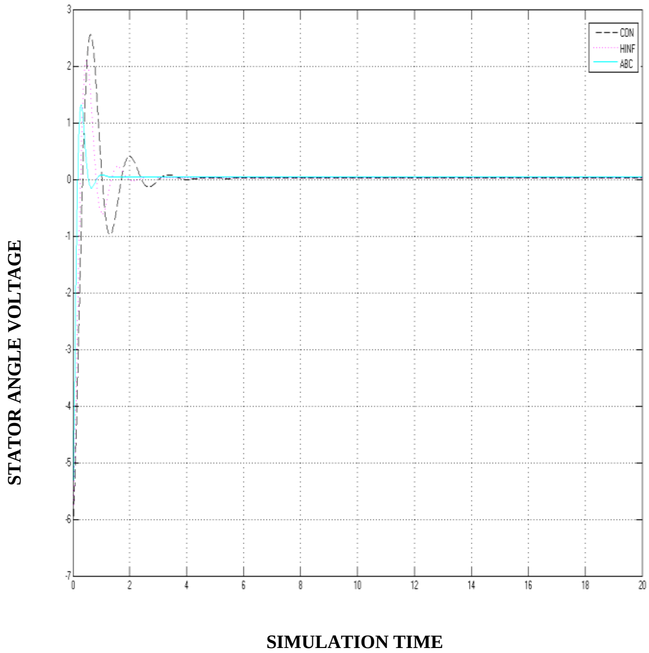
a) Active Power



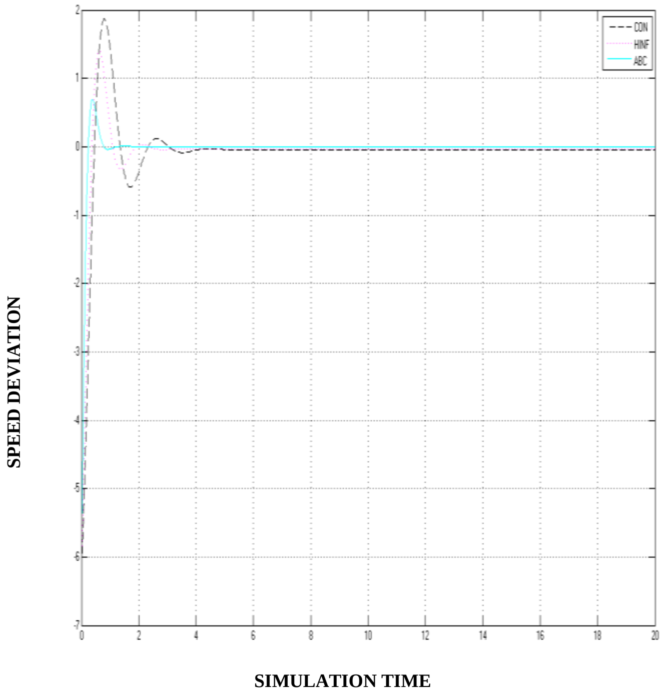
b) Terminal Voltage



c) Stator Angle Voltage

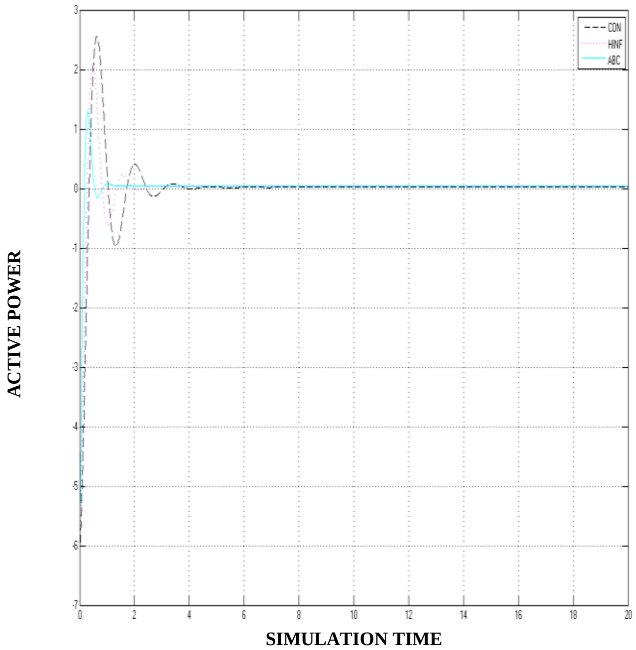


d)Speed Deviation

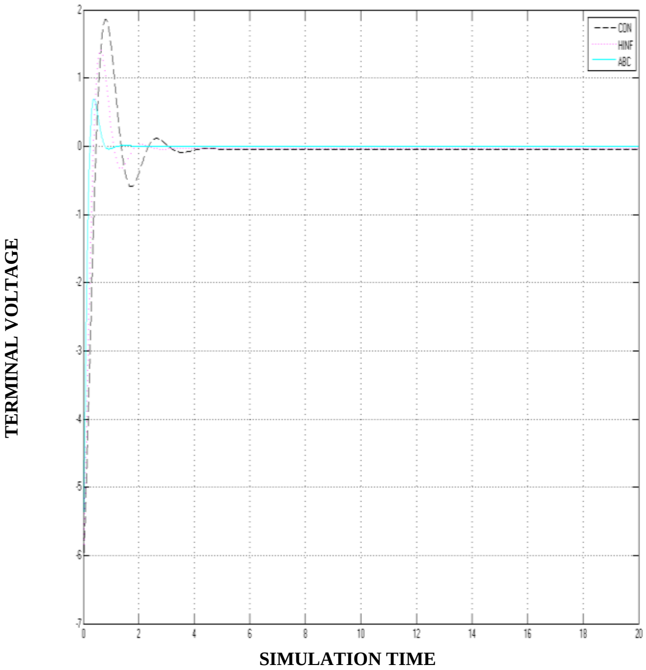


2. Nominale mode x=0.3, y=0.85, z=0.1102

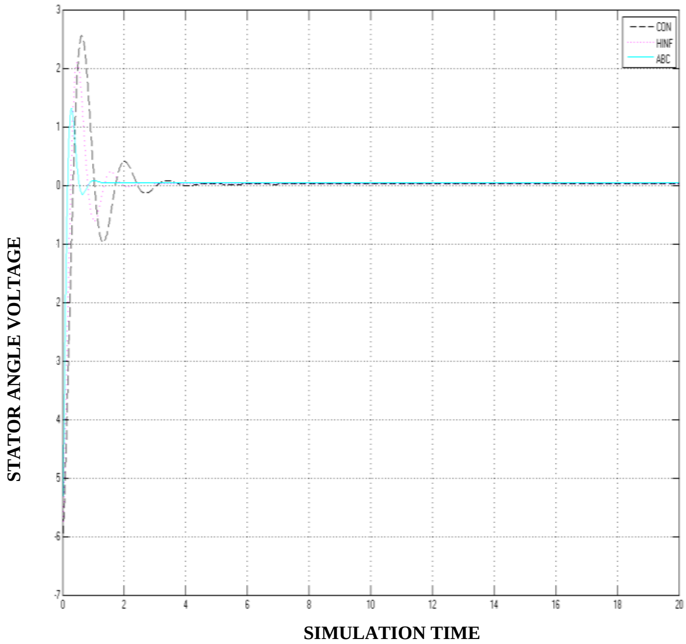
a) Active Power



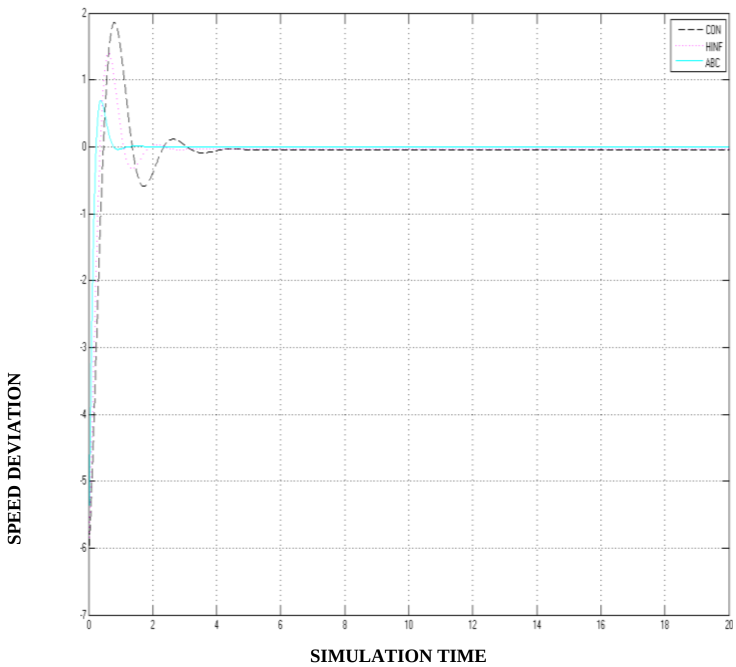
b) Terminal Voltage



c) Stator Angle Voltage

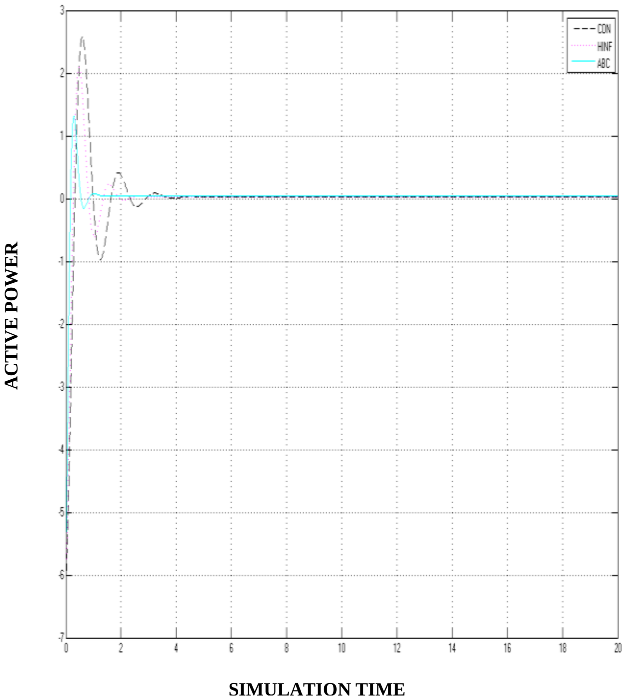


d) Speed Deviation

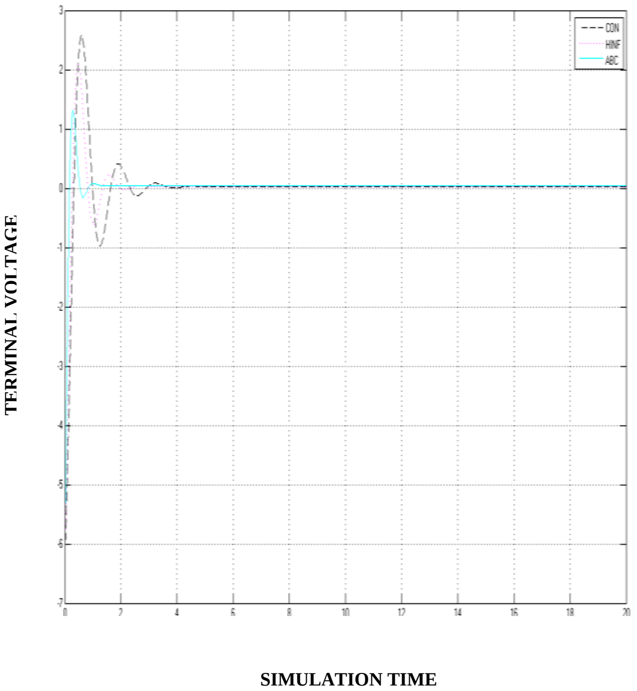


3. Over-excited mode x=0.2, y=0.85, z=0.6760

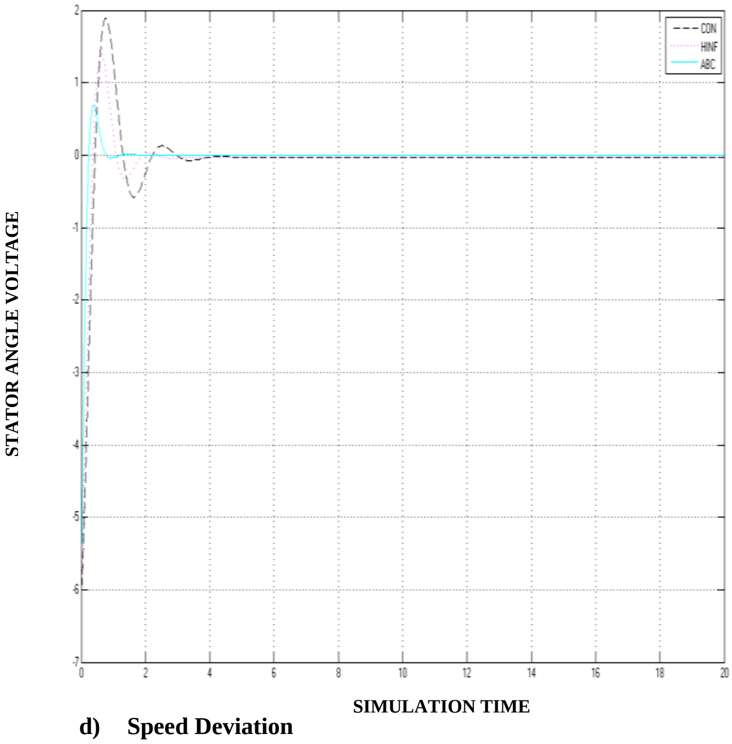
a) Active Power



b) Terminal Voltage



c) Stator Angle Voltage



d) Speed Deviation

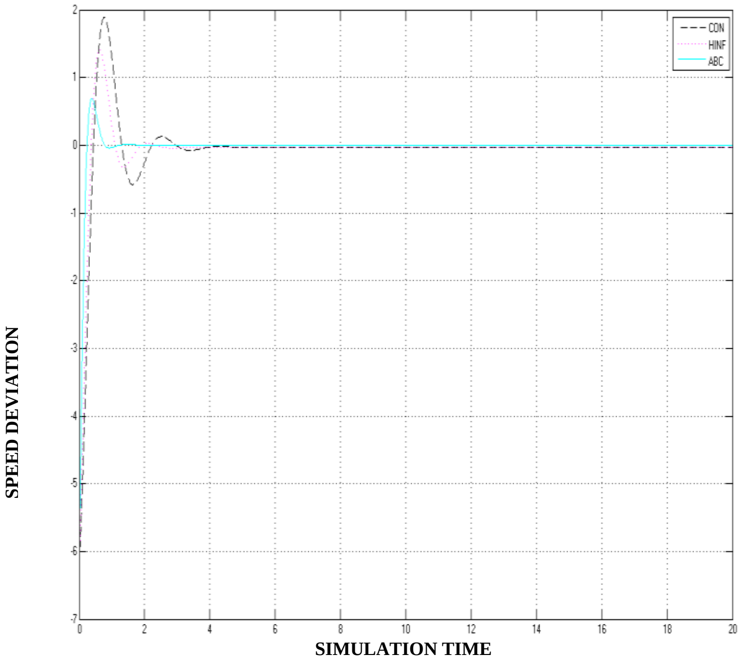


Table 1. Damping Coefficients 'α' and static error 'ξ' in the closed loop system with RPSS and CPSS in different operating conditions of the power system

Reactive Power	α_{PSS}	ξ_{PSS}	$\alpha_{PSSH\infty}$	$\xi_{PSSH\infty}$	$\alpha_{PSSEABC}$	$\xi_{PSSEABC}$
-0.2033	0.6574	0.00119	0.6846	0	0.7121	0
-0.2449	0.6564	0.0012	0.6853	0	0.7211	0
-0.1238	0.6695	0.00112	0.6960	0	0.7321	0
-0.3402	0.6671	0.00089	0.7038	0	0.7382	0
-0.6840	0.6574	0.00071	0.6877	0	0.7401	0

Table 2. Settling time 'T_s' and peak time 'T_p' in the closed loop system with RPSS and CPSS in different operating conditions of the power system

Reactive Power	$T_{S\ PSS}$	$T_{P\ PSS}$	$T_{S\ PSSH\infty}$	$T_{P\ PSSH\infty}$	$T_{S\ PSSEABC}$	$T_{P\ PSSEABC}$
-0.2033	0.93	0.51	0.6	0.464	0.38	0.34
-0.2449	0.92	0.51	0.594	0.461	0.372	0.334
-0.1238	0.65	0.5	0.59	0.46	0.367	0.3217
-0.3402	0.81	0.46	0.549	0.435	0.3211	0.312
-0.6840	0.84	0.47	0.56	0.44	0.303	0.304

6. CONCLUSION

This work highlights a systematic approach for automated designing a power system stabilizer using enhanced Ant Colony Optimization technique applied on the AVR-PSS system of a turbo alternator to improve transient stability and its robustness for a single machine infinite bus system. Three cases were considered, control with Conventional PSS, PSS with H∞ technique and using a robust PSS based on enhanced ABC optimization.

The method presented in this work illustrate that the efficiency, performance, reliability and robustness of the power system have increased. The above procedure can be applied to multi-machine power system to design the robust controller to take care of the intra-area oscillations under disturbed conditions.

7. ACKNOWLEDGMENTS

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