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Single Machine Connected Infinite Bus System Tuning Coordination Control using Biogeography-Based Optimization Algorithm

In this paper, the design of hybrid coordinated damping controller (power system stabilizer (PSS) and proportional integral derivative (PID) controller) is articulated as an optimization problem. The objective function J is framed using Integral square error (ISE) and the optimal parameters can be obtained by minimizing the objective function using the proposed Biogeography Based Optimization (BBO) algorithm. The BBO algorithm is demonstrated to tune the control parameter values of coordinated damping controller. Simulations of proposed design have been performed on Single Machine Infinite Bus (SMIB) power system subjected to a nonlinear load condition with ground fault & 3 ϕ faults to examine its robustness. The simulation results obtained will confirm the effectiveness of proposed algorithm and the impact of stability studies of power system operation under disturbances. The proposed design provides robust dynamic performance and significant improvement in power system stability compared to other methods such as Particle Swarm Optimization (PSO), Adaptation law (AL) and Conventional PSS.

Keywords: *Single Machine Infinite Bus; Coordinated controller; Biogeography Based Optimization algorithm; Non-linear load*

1. INTRODUCTION

Due to cost-effective and environmental limitations, building new power lines and strengthening the present one is very difficult. This continuous demand leads to the operation of the power system at its limit. Power system engineers should take the responsibility to provide quality and stable power to the consumers by increased loading in the existing power lines. An outcome of this leads to low frequency power oscillations (LFO) between generators in a dynamical system. These LFO will damp automatically with the help of some torque produced by AVR and generator field coil. If these oscillations are not properly damped, it will damage the system. In order to avoid this problem, Power system stabilizer (PSS) damping controller is an effective solution to improve power system dynamic performance and to reduce the power oscillations. PSS is connected in the exciter loop of the generator, to speed up the reactive power delivery to damp out low frequency electromechanical oscillations and to enhance power system stability in power system. The parameters of PSS are designed for linear model of the plant using particular operating point [1]. And moreover, the practical power system is nonlinear and the operating changes with respect to the operating condition. Therefore the performance of conventional PSS fail to provide better damping to other operating conditions. Many adaptive control techniques were proposed to eliminate this issue, but are complex as well as costlier in nature [2].

In literature, several optimization algorithms were devoted to optimize the parameter values of PSS to improve power system stability. Artificial intelligent techniques such as fuzzy logic and neural network have also been proposed for SMIB system and later extended it to multi-machine power system [3, 4]. To relieve the drawbacks in intelligent methods, various tuning techniques have been proposed. Many heuristic optimization algorithms such as evolutionary algorithm (EA) [5], the differential evolution (DE) algorithm [6], genetic algorithm (GA) [7], simulated annealing (SA)[8], particle swarm optimization (PSO)[9] were introduced and have been successfully applied for optimization. However, the damping out of low frequency power oscillations using conventional PSS is still an open problem. To solve this issue other possible solutions are needed to be exposed.

The researchers are always showing interest to introduce different controller structures. The evolution of PID controller provides a possible solution to control the power flow and improve power oscillations damping. And also, the PID controller plays major role for various industrial applications due to their implementation cost and this controller is the appropriate one in the absence of their prior knowledge of the process. Therefore, PID based PSS coordinated controller is proposed to enhance the stability of electric power systems. Many optimization algorithms such as genetic algorithm

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(GA)[10], bacteria foraging algorithm (BFA)[11], artificial bee colony (ABC)[12], harmony search algorithm (HSA)[13], PSO[14] and bat algorithm (BA)[15] is effectively applied in the literature to optimize the parameters of PID based PSS.

The common method used is via trial and error, but this may result in non-optimized performance and consume a lot of time. Hence, a more systematic approach in finding the weighting matrices is needed. To improve the drawbacks of existing optimization methods, a new heuristic biogeography based optimization (BBO) algorithm is proposed to design hybrid coordinated (PID based PSS) damping controller. The objective function is formulated and the same was minimized using BBO algorithm to obtain optimal control parameter values. In view of the merits of this algorithm, it is proposed in the present work to analyze the efficiency of proposed controller subjected to nonlinear load with different fault conditions.

This work will contribute some new knowledge to the development, the model and techniques that aim to propose comprehensive methods to design a coordinated controller of a synchronous machine to enhance the stability of the power system. The contributions are: A simulink model of coordinated controller for a synchronous machine is proposed in MATLAB environment and BBO Algorithm is designed to optimize the parameters of coordinated controller by minimizing the performance index (PI) such as Integral square error (ISE) for a different operating conditions.

In this paper, the PID based power system stabilizer is modeled using Simulink block set. To optimize the parameter values of PID and PSS damping controller, a new biogeography based optimization (BBO) algorithm is designed and the performance analysis of proposed coordinated controller is demonstrated on SMIB power system subjected to non-linear load with ground and 3 ϕ fault conditions. The characteristic behavior of Conventional PSS is compared with BBO PID PSS, PSO PID PSS and AL PID PSS when subjected to different studies on the above system.

The content of the paper is organized as follows. Section 1 describes the necessity of PSS and detailed literature survey about its performance. Problem formulation, power system models, PID controller and the objective function used in optimization are explained in section 2. In Section 3, BBO algorithm and parameter optimizations are defined. The SMIB power system and nonlinear load Simulink models are described in Section 4. The simulation results of different case studies using proposed BBO-PIDPSS of SMIB system are also carried out in Section 4. Finally, the conclusions are presented in Section 5.

2. PROBLEM FORMULATION

The objective of this work is to optimize the parameter values of coordinated controller in the power system using BBO algorithm. The electric power system elements such as generators, excitation system, and PSS were modeled in Simulink environment. To complete the optimization process, it is necessary to define an objective function to produce satisfactory results. In this view, the system model and an objective function used in coordinated controller design for a SMIB system with nonlinear load are elaborated.

2.1 System Configuration

The system considered in this work is single machine infinite bus (SMIB) power system. The non-linear differential equations of power system are explained in the following equation:

$$\dot{x} = g(x, r, z, \lambda) \quad (1)$$

$$y = g(x, r, z, \lambda) \quad (2)$$

where x is the vector of system input variables, z is the vector of algebraic variables representing the transmission network, y is the current vector of system output from the device and λ is the vector of the load levels. In general, the power system [16] can be expressed in state equations as follows:

$$\dot{x}(t) = Ax(t) + Br(t) \quad (3)$$

$$y(t) = Cx(t) + Dr(t) \quad (4)$$

In the above equations, $x(t)$ represents deviation from the steady state value with respect to eqn. (1) and (2). Due to the fact that there is no direct link between system input $r(t)$ and controlled output $y(t)$ in the current model, the term $Dr(t)$ appeared in Eq.(4) can be eliminated.

2.2 SMIB Power System

Figure 1 shows the line diagram of proposed SMIB power system with non-linear load conditions. The construction details of proposed model such as transmission line to automatic AVR & excitation system, proposed coordinated controller is also shown. Hybrid coordinated controller is connected in feedback to the excitation system through AVR to produce supplementary feedback stabilizing signals to minimize electromechanical oscillations [17]. The outline of sensing signals and the optimization scheme are also shown in this figure. To adapt it for wide range of operating conditions, the power system can be modeled by a set of nonlinear differential equations as shown in eqn. (1).

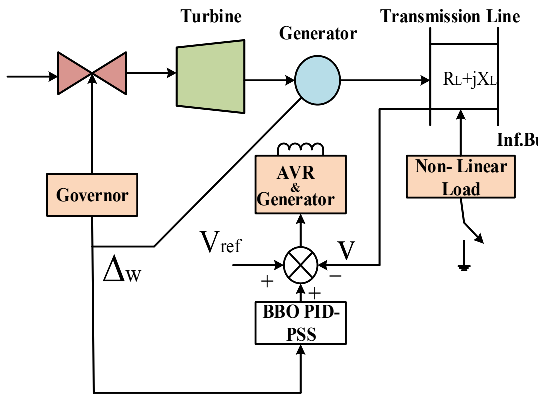

Figure 1. Line Diagram of SMIB power system

2.3 Proportional Integral Derivative PSS

The PID controller is popularly known and widely used as a feedback controller in industrial control application due to its robust control performance and easy implementation. Since, the PID controller has three modes of operation, it has tendency to improve system stability when operated at different conditions. The proportional controller can decrease the rise time but fails to minimize the offset error of the response. The value of proportional gain leads a system to become unstable. The integral controller eliminates the offset error but may degrade the transient response of a system. The derivative controller enhances the stability by minimizing overshoot and improving transient response. Therefore, a special care should be taken while designing the PID controller. The structure of coordinated damping controller for a closed-loop system is shown in Figure 2 and mathematically represented by eqn (5). Power system stabilizer is designed based on stabilizer gain (K_{PSS}), washout time (T_W) and lead - lag compensator (T_1 & T_2). The input given to the PSS damping controller is the speed deviation signal ($\Delta\omega$) and output is the stabilizing signal (ΔV_{PSS}). The parameters to be optimized in PSS are K_{PSS}, T_1 and T_2. The mathematical representation of PSS is shown in eqn (6).

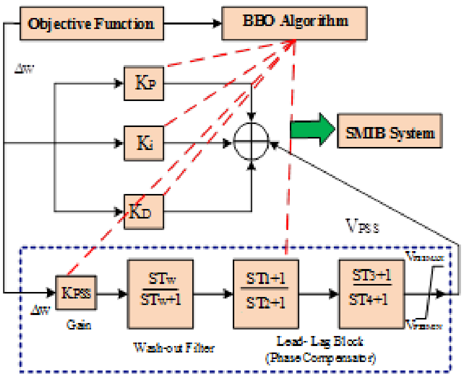

Figure 2. Structure of coordinated controller

The mathematical expression of PID controller and PSS are,

$$U_{PID} = K_P + \frac{K_I}{S} + K_D S \tag{5}$$

$$V_{PSS} = K_{PSS} \frac{sT_W}{1+sT_W} \frac{sT_1+1}{sT_2+1} \tag{6}$$

2.4 Objective Function

The objective function is a mathematical expression used to find optimal parameters results in a maximum or minimum of a function. The main aim is to improve power system stability and to maintain voltage profile effectively. To find optimal parameter values of coordinated controller installed in SMIB system, Integral Square Error (ISE) is considered as objective function [16]. In power system stability, the overshoot reduction and settling time are considered as a very important factor, since the oscillations should die out soon. This objective can be attained by minimizing the objective function (i.e ISE of speed deviation$\Delta\omega$).In this work, the SMIB power system objective function is considered as:

$$ISE : J = \int_0^{\infty} \Delta\omega^2(t)\,dt, \quad \infty = t_{sim} \tag{7}$$

where, t_{sim} is the simulation time and $\Delta\omega$ is the speed deviation of synchronous machine.

During the initialization of problem space, the set of K_P, K_I, K_D, K_{PSS}, T_1 and T_2 values are randomly generated and fed into PID controller and PSS. In order to maintain stability and to provide efficient damping, it is necessary to evaluate the performance index, *J*.

For PID based PSS the above equation is subjected to constraints that are given by,

$$K_P^{\min} \le K_P \le K_P^{\max}$$
$$K_I^{\min} \le K_I \le K_I^{\max}$$
$$K_D^{\min} \le K_D \le K_D^{\max}$$
$$K_{PSS}^{\min} \le K_{PSS} \le K_{PSS}^{\max}$$
$$T_1^{\min} \le T_1 \le T_1^{\max}$$
$$T_2^{\min} \le T_2 \le T_2^{\max}$$

The ranges of the optimized parameters are mentioned in upcoming section. Considering the objectives from the detailed state of art, the proposed work engages BBO algorithm to solve this optimization problem and to obtain optimal set of parameters.

3. REVIEW OF BIOGEOGRAPHY BASED OPTIMIZATION (BBO) ALGORITHM

This algorithm is population based technique based on the species migration between islands from less habitable places to good ones for sharing information with others by probability based migration. In biogeography, the movement of species from one island to other depend on suitability index variables (SVIs) which includes water resource, vegetation, temperature, land area, etc. represented as vector of real numbers. In BBO, the quality of each solution set is represented by the Habitat Suitability Index (HSI), as the quality or performance of particular solution set in optimization problem increases the HSI increases [18].

- The algorithm explains the migration of species between islands, forming new species and makes some species to become extinct.
- The term Habitat Suitability Index (HSI) indicates the right place for the species to reside, which features diversity of vegetation, rainfall, temperature, and land area.
- An island or habitat with high HSI are measured as a best performance on optimization problem and low HSI means poor performance. Total number of features in each habitat or an island called suitability index variable (SIV).
- The number of SIV in each of the habitat corresponds to the problem dimension. SIVs are the independent variable and HSI considered as dependent variable.

Here, S is the total number of species; S_{max} is the maximum number of species, λ - immigration rate and μ - emigration rate. Parameters such as emigration rate and immigration rate can be evaluated using Figure 2:

$$\lambda = I \cdot \left(1 - \frac{S}{S_{\max}}\right) \quad (8)$$

$$\mu = \frac{E \cdot S}{S_{\max}} \quad (9)$$

The general procedure of BBO involves:

Step1: Parameters such as mutation probability, island modification probability and elitism parameter has to be designed.

Step2: The number of population (island) was initialized.

Step3: Compute the immigration rate and emigration rate.

Step4: Choose the emigration and immigration island respectively based on the migration rate.

Step5: Migrate the randomly chosen SIVs based on the selected islands.

Step6: Mutation probability was used to perform mutation.

Step7: Estimate the objective function of each island.

Step8: Check the optimization solution. Otherwise go to step 3.

The flow chart of BBO algorithm explain detailed in [18].

The BBO algorithm has two important sub-algorithms: migration and mutation. Models of migration and mutation algorithm are developed to optimize the parameter values of PID and PSS damping controller.

Figure 2 is a simple model of biota of an island used to provide general relationships of immigration and emigration. In order to model the concepts of BBO in detail, the case of habitat containing only S species is considered. Here, changes from time t to as below:

$$\begin{aligned} P_S(t+\Delta t) = P_S(t)\big(1 - \lambda_S \Delta t - \mu_S \Delta t + \\ + P_{S-1}\lambda_{S-1}\Delta t + P_{S+1}\mu_{S+1}\Delta t\big) \end{aligned} \quad (10)$$

where, λ_S and μ_S are the immigration and emigration rates when S species reside in the habitat.

3.1 Migration

The parameters such as K_P, K_I, K_D, K_{PSS}, T_1 and T_2 are considered as the features of SIV. In order to check the solution quality, Habitat Suitability Index (HSI) is computed. To optimize the PID and PSS parameter values, HSI is considered as the objective function which may be defined as ITAE, IAE, ITSE or ISE. In this work, the Integral Square Error (ISE) of the speed deviation ($\Delta\omega$) is considered as the objective function to minimize the error. ISE have a tendency to produce smaller overshoots and oscillations than IAE (Integral of the Absolute Error) or ITAE (Integral Time Absolute Error).

The fitness function is defined as:

$$ISE : J = \int_0^{\infty} \Delta\omega^2(t)\,dt, \quad \infty = t_{sim} \quad (11)$$

where, t_{sim} is the simulation time.

The speed deviation ($\Delta\omega$) is selected to assess the efficiency of the design system. Initially the random values of K_P, K_I, K_D K_{PSS}, T_1 and T_2 are generated and fed into the PID and PSS damping controller. Then, the speed deviation is determined by computing the performance index, J. Finally, those K_P, K_I, K_D K_{PSS}, T_1 and T_2 values that give the minimum J value are treated as the optimal parameter values of PID and PSS.

Thus, the main problem in tuning PID and PSS parameters is to choose the best habitat (solution) so as to minimize the performance index, J. As mentioned, habitat with high HSI has more species and vice-versa. In other words, HSI indicates the immigration rate and the emigration rate of each habitat.

3.2 Mutation

Mutation in BBO is known as SIV mutation. The species count probability is used to calculate the mutation rate. Mutation is likely to occur if a habitat has medium HIS. Elitism is used to save the features of the habitat that has the optimal K_P, K_I, K_D K_{PSS}, T_1 and T_2 values in the BBO process. Therefore, even if the mutation ruins the HSI, process reversal is possible based on the saved features.

$$m = m_{\max}\left(1 - \frac{P_S}{P_{\max}}\right) \quad (12)$$

where, P_S is the probability of each island containing the S species, P_{max} is the maximum value of P_S, m_{max} is the user-defined maximum mutation rate and m is the mutation rate.

The pseudo code for the BH algorithm is shown in Algorithm.

Algorithm

1: Initialize the BBO parameters [Refer Table I]
2: Generate a random set of habitats (Ii and i ∈ [1, N])
3: Calculate the fitness (HSI) of each habitat
4: Calculate and map μ and λ
5: $I_{Best} \leftarrow$ optimal solution
6: **while** not (termination criterion) do
7: Migration process
8: Mutation process
9: Fitness, μ and λ Calculation and mapping
10: $I_{Best} \leftarrow$ optimal solution
11: **end while**
12: **return**

The typical ranges of the optimized parameters obtained using BBO algorithm are: [0.5 – 80] for K_P, [0.2 – 30] for K_I, [0.1-15] for K_D, [1- 60] for K_{PSS}, [0.2 – 2] for T_1 & T_2.

The parameters of BBO algorithm to optimize the coordinated controller parameter values are given in Table 1.

Table 1. Tuning parameters of PID based PSS using BBO Algorithm

Parameters	Size
Habitat modification probability	1
Population Number	50
Mutation rate	0.05
Iteration Count	50
Number of Elite habitat	6
Max. emigration & immigration rate	1

4. RESULT AND DISCUSSION

In this section, the Simulink model of SMIB system is presented in detail. The proposed model is tested on SMIB system connected with nonlinear load. Therefore, the model of three phase thyristor based nonlinear load in Simulink environment is also explained. Then the effectiveness of proposed coordinated damping controllers has been tested and compared with conventional techniques through Simulink under different case studies.

4.1 Simulink model of SMIB system

The simulink model of SMIB system is developed with the proposed BBO algorithm. A block diagram in simulink including all the blocks is generated in MATLAB software. Figure 3 shows the simulink model SMIB system. The input given to the proposed coordinated controller is speed deviation ($\Delta\omega$) from the generator and damping torque is provided by the coordinated controller output. The damping torque is given to AVR and excitation system to reduce the phase difference between the generator and the load.

4.2 Simulink model of non-linear load

The proposed damping controller is tested with nonlinear load. For this case a Simulink model of three phase thyristor based load is developed in MATLAB Simulink environment. The six-pulse converter with SCRs is developed as a Simulink model shown in Figure 4. The three-phase currents i_1, i_2 and i_3 are given as input to the six SCRs. The triggering currents I_{t1}, I_{t2}, I_{t3}, I_{t4}, I_{t5} and I_{t6} were used to trigger the SCRs. The distortion of voltage in the power generation was done using the non-sinusoidal current contains harmonics [19].

4.3 PID based PSS design

In order to assess the effectiveness of proposed BBO algorithm, the optimization problem is formulated in MATLAB environment. Implementation of BBO algorithm to fine optimized parameters of PID and PSS is detailed in section 3. The values of optimized PID and PSS parameters using BBO algorithm are included in Table II. The several conventional techniques such as adaptation law and PSO algorithm to design the PID and PSS parameters are enlisted in Table 2.

Table 2. Comparison of PID based PSS parameters

Tuning – Method		PID gains			PSS Parameters		
		K_P	K_I	K_D	K_{PSS}	T_1	T_2
BBO Algorithm		52	20	9	31.7	0.8	0.4
PSO Algorithm		5	0.9	2	74.6	1.8	0.1
Adaptation law	Non-linear load with ground fault	-0.3	-1.9	1.5	125	5000	2000
	Non-linear load with 3-ϕ fault	-0.2	-1.5	1.2			
CPSS		50	5	2	125	5000	2000

The parameters values used to determine PID based PSS damping controller using PSO algorithm are: Iteration K_{max} = 50; Generation N = 20; w_{min} = 0.4; w_{max} = 0.9 and C_1 = C_2 = 2. The range of PID and PSS parameters considered in the PSO algorithm are: $0 \leq K_P \leq 9$, $0 \leq K_I \leq 1.2$ and $0 \leq K_D \leq 1.9$, $0 \leq K_{PSS} \leq 110$, $0 \leq T_1 \leq 3$ and $0 \leq T_2 \leq 0.2$.

Table 3. Parameters obtained using RLS algorithm

Load	a_1	a_2	b_1	b_2
Non-linear load with ground fault	-0.0599	-0.2905	-0.0072	0.0074
Non-linear load with 3-ϕ fault	-0.241	-0.612	-0.022	0.023

Figure 5 shows the comparison of fitness function between PSO based PID PSS and BBO based PIDPSS. From Fig 5 it is found that the proposed BBO is a better algorithm that exhibits good convergence compared to the PSO algorithm.

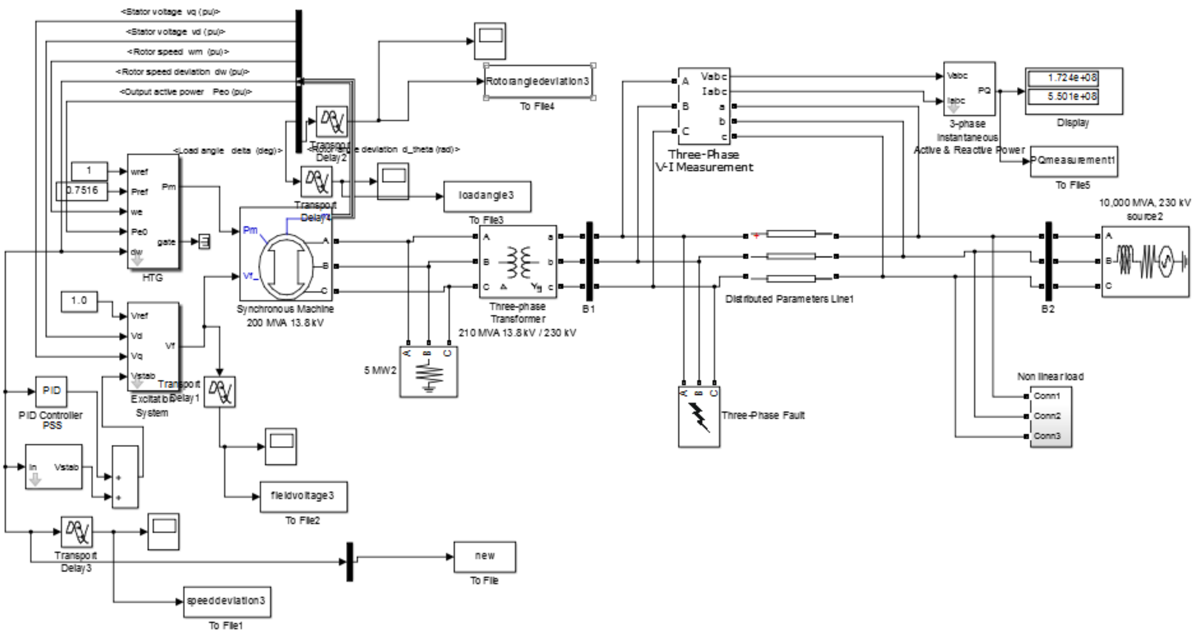

Fig. 3. Simulink model of SMIB system

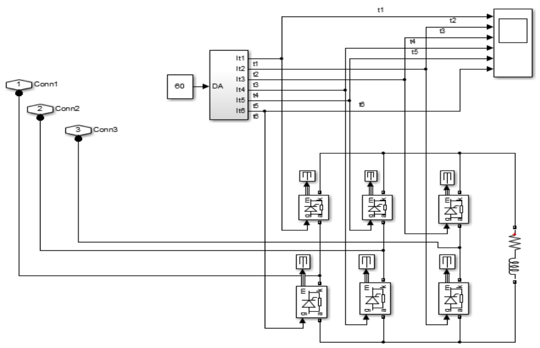

Figure 4. Simulink model of three phase thyristor based load

The statistical indices mean (M) and standard deviation (σ) equations are expressed as:

$$M = \frac{\sum_{i=1}^{n} f(K_i)}{n} \tag{13}$$

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(f(K_i) - M\right)^2} \tag{14}$$

where, $f(K_i)$ is the fitness value of individual K_i and n is the population size.

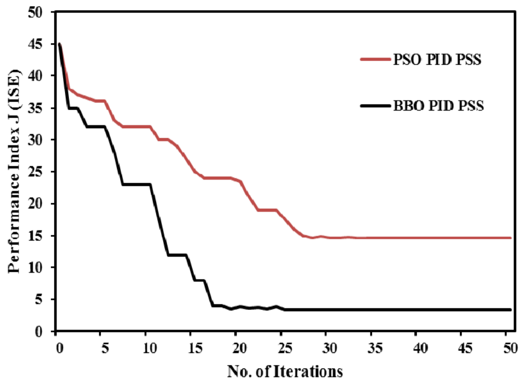

Figure 5. Comparison of fitness function for PSO PID PSS and BBO PID

The statistical analysis on BBO algorithm and PSO algorithm is shown in Table IV.

Table 4. Computation Efficiency Comparison

Tuning Methods	Max.	Min.	Range	Mean (M)	Standard Deviation (σ)
PSO	45	14.6	30.4	21.90	8.6291
BBO	45	3.4	41.6	10.376	11.356

The performance of BBO PID-PSS, PSO PID-PSS, AL PID-PSS and CPSS was studied in the Simulink environment for different operating conditions and the following case studies was considered for simulations.

4.4 Ground fault condition

The analysis is made based on the stability of the system (Figures 6–9). The system parameters like speed deviation, rotor angle deviation, load angle and field voltage were analyzed when the system subjected to non- linear load with ground fault condition.

From Figure 6 it may be observed that the BBO algorithm improves settling time to 2secs compared to other methods. And also the overshoot is reduced to 0.01 from 0.03 this implies the system to reach the stable state quickly. Due to this, the field voltage (Figure 9) will be stable and ensures the system stability. According to Figure 7, BBO algorithm improves the rotor angle deviation to the settling time before 2 secs. However the rotor angle in the negative side, the BBO based PID with PSS improves the performance compared to other controllers. From the Figure 8, the load angle reaches the stable state around 30 degree. Here also it is inferred that after the inclusion BBO based PID PSS the power damping oscillation was reduced and also it boosts up the load angle. Figure 10 shows the comparison results among the algorithms with respect to settling time.

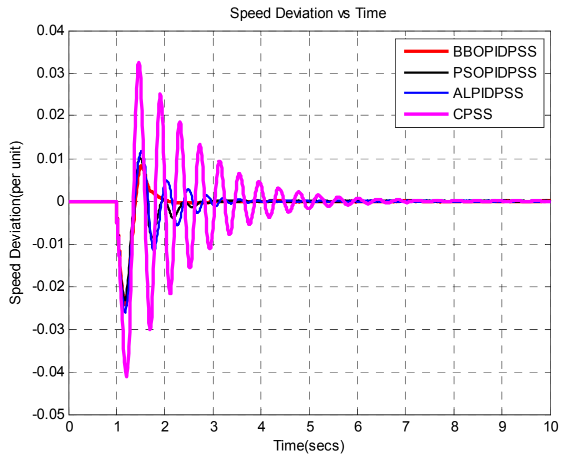

Figure 6. Ground fault condition speed response for BBO PID PSS, PSO PID PSS, AL PID PSS, CPSS

This case study illustrates the stability of the system when subjected to 3-ϕ fault condition. A 3-ϕ fault was assumed to occur at the transmission line. The fault continued in the system for 0.01 seconds, and it was cleared after 0.02 seconds. The performance of the synchronous machine in this case study is illustrated in Figures 11 –14. It may be observed that when the BBO algorithm based coordinated controller connected to the system, the overshoot and settling time of the system are minimized and improves the system stability. Figure 15 explains the comparison result between algorithms with respect to settling time.

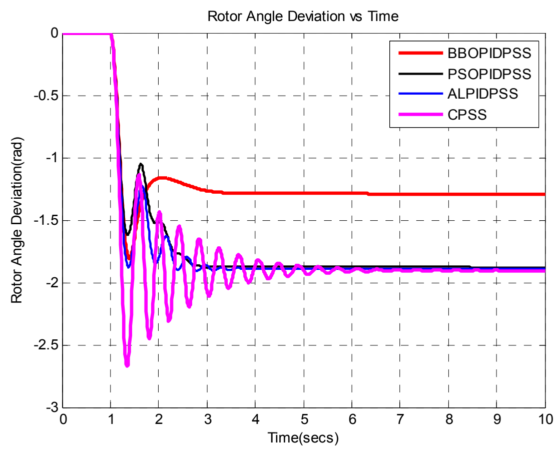

Figure 7. Ground fault condition rotor angle deviation for BBO PID PSS, PSO PID PSS, AL PID PSS, CPSS

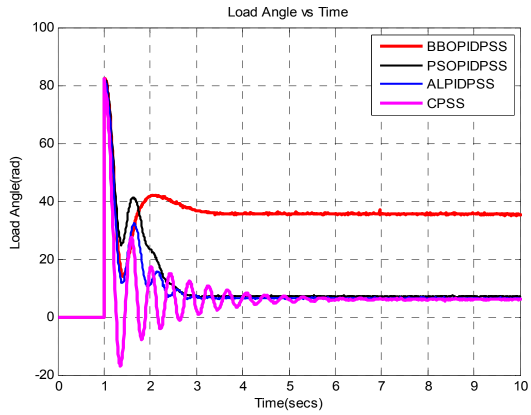

Figure 8. Ground fault condition load angle for BBO PID PSS, PSO PID PSS, AL PID PSS, CPSS

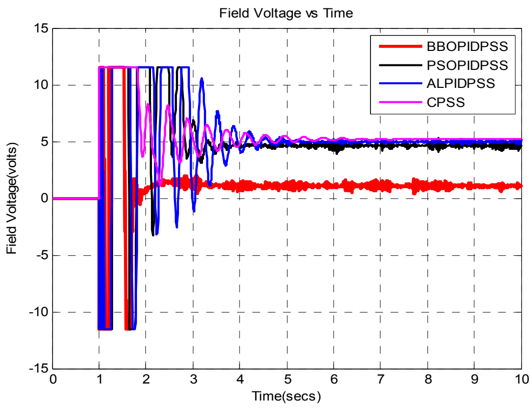

Figure 9. Ground fault condition field voltage for BBO PID PSS, PSO PID PSS, AL PID PSS, CPSS

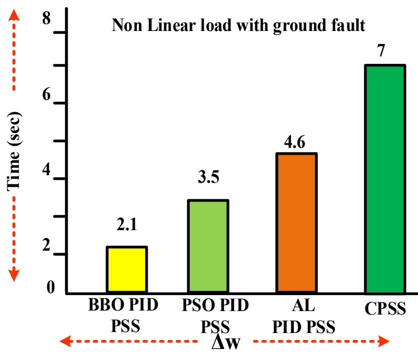

Figure 10. Settling time comparison of Speed Deviation

4.5 Three phase fault condition

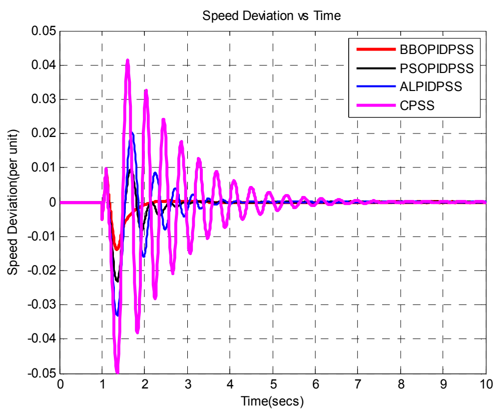

Figure 11. Three phase fault condition speed response for BBO PID PSS, PSO PID PSS, AL PID PSS, CPSS

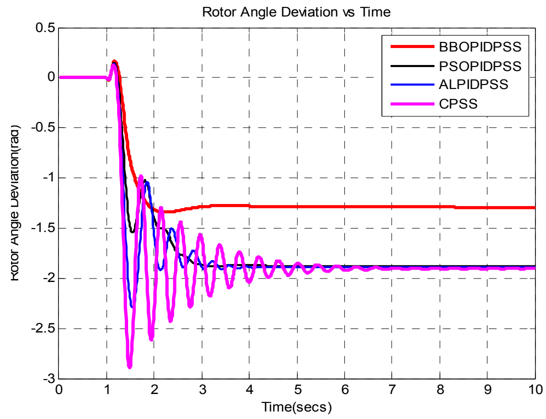

Figure 12. Three phase fault condition rotor angle deviation response for BBO PID PSS, PSO PID PSS, AL PID PSS, CPSS

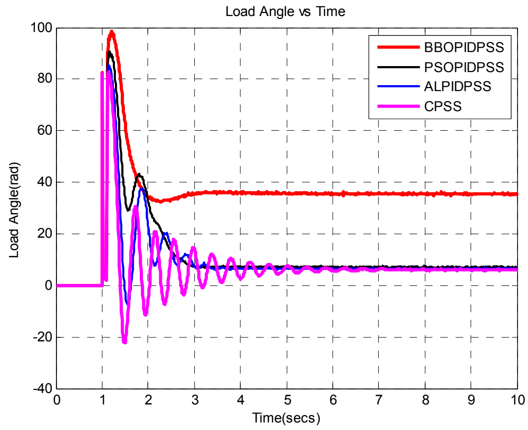

Figure 13. Three phase fault condition load angle response for BBO PID PSS, PSO PID PSS, AL PID PSS, CPSS

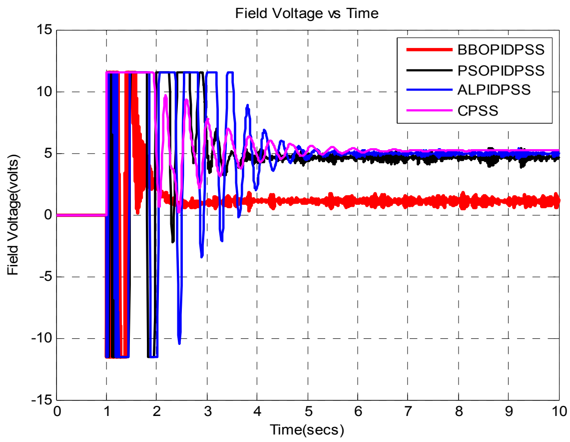

Figure 14. Three phase fault condition field voltage for BBO PID PSS, PSO PID PSS, AL PID PSS, CPSS

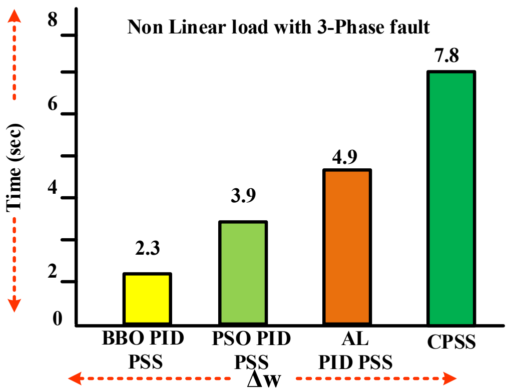

Figure 15. Settling time comparison of Speed Deviation

5. CONCLUSION

In this work, the main aim is to damp low frequency electromechanical oscillations and to enhance the stability of power system under severe disturbances. To increase the dynamic performance of the system, the coordinated design of PID based PSS damping controller is much desired. The tuning of coordinated controller parameters is formulated as an optimization problem. The objective function is framed and is minimized using the proposed Biogeography Based Optimization (BBO) algorithm. The performance of proposed coordinated controller is analyzed for a simple SMIB system connected with a nonlinear load. Simulation results show that the proposed coordinated controller provided effective damping than that of other conventional methods. Therefore, the coordination of PID and PSS damping controller provides solution to improve the behavior of networks by damping out low frequency oscillation of the synchronous machine for the SMIB case.

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APPENDIX

Generator parameters (per unit)
Nominal power, $P_n = 200 \times 10^6$ VA
Frequency, $f_n = 50$ Hz
$X_d = 1.305$; $X_q = 0.474$
Time constants, $T_d = 1.01$ s; $T_d = 0.053$ s; $T_{q0} = 0.1$ s
Stator resistance, $R_s = 2.8544 \times 10^{-3}$ohm
Inertia coefficient, H = 3.2 s

Exciter parameters (per unit)
Low-pass filter time constant, $T_r = 20 \times 10^{-3}$s
Regulator gain and time constants, $K_A = 300$; $T_A = 0.001$ sec
Exciter, $K_E = 1$; $T_E = 0$ s
Damping filter gain and time constant,
$K_F = 0.001$; $T_F = 0.1$ s
Regulator output limits and gain,
$E_{fmin} = -11.5$; $E_{fmax} = 11.5$; $K_p = 0$
Initial values of terminal voltage and field voltage,
$V_{t0} = 1.0$ volt; $V_{f0} = 1.0$ volt

Distributed line parameters
Number of phases, N = 3
Frequency used for RLC specification = 50 Hz
Resistance per unit length: 6.365×10^{-3} to 0.1932 ohms/km
Inductance per unit length: 13×10^{-4} to 3×10^{-3} H/km
Capacitance per unit length: 10×10^{-9} to 4×10^{-9} F/km
Line length = 100 km

ПОДЕШАВАЊЕ КОНТРОЛЕ КООРДИНАЦИЈЕ ЕНЕРГЕТСКОГ СИСТЕМА SMIB ПРИМЕНОМ АЛГОРИТМА ОПТИМИЗАЦИЈЕ ЗАСНОВАНОГ НА БИОГЕОГРАФИЈИ

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Дизајн хибридног координисаног контролера пригушења (PSS) и пропорционално-интегрално-дериватног (PID) контролера формулисан је као проблем оптимизације. Објективна функција Ј је добијена помоћу интеграла квадрата грешке а оптимални параметри се могу добити минимизирањем објективне функције применом BBO алгоритма. Показано је да се алгоритам усаглашава са вредностима контролних параметара координисаног контролера пригушења. Симулације предложеног дизајна су извршене на енергетском систему SMIB изложеном нелинеарном оптерећењу са грешком на уземљењу и грешком од 3 ρ у циљу испитивања робустности. Резултати симулације потврђују ефикасност предложеног алгоритма и утицај стабилности функционисања система у условима поремећаја. Предложени дизајн обезбеђује робусне динамичке перформансе и значајно побољшање стабилности енергетског система у поређењу са другим методама као што су PSO, AL и конвенционални PSS.