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A Power System Stabilizer for Multi Machine-Based on Hybrid BF0A-PSO

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ABSTRACT

Bacterial Swarm Optimization (BSO) is used to design power system stabilizers in a multi machine power system. In BSO, the search directions of tumble behavior for each bacterium are oriented by the individual's best location and the global best location of PSO. The hybrid BFOA-PSO algorithm has been applied to IEEE 14 bus test system under normal, light and heavy load conditions. Simulations results have revealed the strength of the BSO in tuning Power System Stabilizers under normal, light and heavy load conditions. The results present the effectiveness of the controller to improve the power system stability over a different range of loading conditions.

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1. INTRODUCTION

Stability of power systems is one of the most important aspects in electric system operation. This arises from the fact that the power system must maintain frequency and voltage in the desired level, under any disturbance, the development of interconnection of large electric power systems; there have been natural system oscillations at very low frequencies in the order of 0.2 to 3.0Hz. Moreover, low frequency oscillations are observed when large power systems are interconnected by weak tie lines. These oscillations may sustain and grow, causing system separation if no adequate damping is available.Low frequency oscillations present limitations on the power transfer capability. Power system stabilizers (PSSs) are now routinely used in the industry to damp out oscillations. An appropriate selection of PSS parameters results in suitable performance during system conflict. The problem of PSS parameter tuning is a complex exercise. A number of conventional techniques have been reported in the literature pertaining to design problems of conventional PSSs namely: the Eigen value assignment, mathematical programming, gradient procedure for optimization and also the modern control theory. The conventional techniques are time consuming as they are iterative and require heavy computation burden and slow convergence. In addition, the search process is susceptible to be trapped in local minima and the solution obtained may not be optimal. A novel evolutionary algorithm based approach to optimal design of multi machine PSSs is developed. This approach employs a particle swarm optimization (PSO) technique to search for optimal settings of PSS parameters. The design problem of the controller is transformed into an optimization problem. PSO based optimal tuning algorithm is used to optimally tune the parameters of the PSS. GA has attracted the attention in the field of controller parameter optimization. This is very suitable in finding global or near global optimal result of the problem; it needs a very long run time that may be several minutes or even several hours depending on the size of the system under study. However, PSO suffers from the partial optimism, which causes the less demand at the regulation of its speed and the direction.

In addition, the algorithm suffers from slow convergence in refined search stage, weak local search ability and algorithm may lead to possible entrapment in local minimum solutions. A relatively newer evolutionary computation algorithm, called Bacteria Foraging (BF) scheme has been proposed. The BF algorithm depends on random search directions which may lead to delay in reaching the global solution. Combined BFOA and PSO aims to make use of PSO ability to exchange social information and BF ability in finding a new solution by elimination and dispersal. An innovative optimization algorithm known as BSO is introduced for optimal designing of the PSSs controller in a multi-machine power system. The design problem of the proposed controller is formulated as an optimization problem and BSO is employed to search for optimal controller parameters. An Eigen value based objective function reflecting the combination of damping factor and damping ratio is optimized for different operating conditions. Simulations results assure the effectiveness of control in providing good damping characteristics to system oscillations.

2. PROBLEM STATEMENT

2.1. Power System Model

A power system can be modeled by a set of nonlinear differential equations are:

$$\dot{X} = f\ (X, U) \tag{1}$$

Where X is the vector of the state variables and U is the vector of input variables. In this study U is the PSS output signal and X=$[\delta, \omega, E'_q, E_{fd}, V_f]^T$. Here, δ and ω are the rotor angle and speed, respectively. Also, E'_q, E_{fd} and V_f are the internal, the field, and excitation voltages respectively.

In the design of PSS, the linearized incremental models around an equilibrium point are usually used. Therefore, the state equation of a power system with *m* machines and *n* PSSs can be written as:

$$\dot{X} = AX + Bu \tag{2}$$

Where A is a $5m \times 5m$ matrix and equals $\partial f / \partial X$ while B is a $5m \times n$ *matrix* and equals $\partial f / \partial U$. Both A and B are evaluated at a certain operating point. X is a $5m \times 1$ state vector and U is a $n \times 1$ input vector.

2.2. Structure of PSS

The operating function of a PSS is to produce a proper torque on the rotor of the machine occupied in such a way that the phase lag between the exciter input and the machine electrical torque is compensated. The supplementary stabilizing signal considered is one proportional to speed. The transfer function of the *jth* PSS:

$$\Delta U_j = K_j \frac{ST_W}{(1 + ST_W)} \left[\frac{(1 + ST_{1j})\ (1 + ST_{3j})}{(1 + ST_{2j})\ (1 + ST_{4j})} \right] \Delta\omega_j \tag{3}$$

Where $\Delta\omega_j$ is the deviation in speed from the synchronous speed. This type of stabilizer consists of a washout filter, a dynamic compensator. The output signal is fed as a supplementary input signal, U_j to the regulator of the excitation system. The washout filter, which basically is a high pass filter, is used to reset the steady state offset in the output of the PSS. The value of the time constant T_W is usually not critical and it can range from (0.5-20) s. The dynamic compensator is made up to two lead lag circuits, limiters and an additional gain. The adjustable PSS parameters are the gain of the PSS, K_j and the time constants, T1j –T4j. The lead lag block present in the system provides phase lead compensation for the phase lag that is introduced in the circuit between the exciter input and the electrical torque.

A standard IEEE14 bus system is shown in figure1.

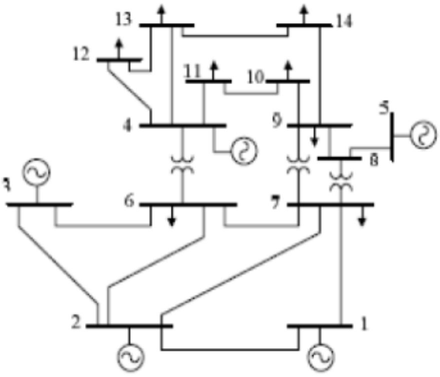

Figure 1. IEEE 14 System Bus

2.3. Objective Function

To maintain stability and provide greater damping, the parameters of the PSSs may be selected to minimize the following objective function:

$$J_t = \sum_{i=1}^{Np} \sum_{\sigma_{ij} \geq \sigma_0} (\sigma_0 - \sigma_{ij})^2 + \sum_{j=1}^{Np} \sum_{\varepsilon_{ji} \geq \varepsilon_0} (\varepsilon_0 - \varepsilon_{ij})^2 \tag{4}$$

It will place the system closed loop eigenvalues in the D-shape sector characterized by $\sigma_{jij\leq}\sigma_0$ and $\varepsilon_{ij} > \varepsilon_0$ as shown in Figure 2.

Where, Np is the number of operating points considered in the design process, σ and ε are the real part and the damping ratio of the eigenvalue of the operating point. In this study, σ_0 and σ_0 chosen to be -0.5 and 0.1 respectively. And to reduce the computational burden in this study, the value of the wash out time constant T_W is fixed to 10 second, the values of T_{2i} and T_{4i} are kept constant at a reasonable value of 0.05 second and tuning of T_{1i} and T_{3i} are chosen to achieve the net phase lead required by the system. Typical ranges of the optimized parameters are [1- 100] for K and [0.06- 1.0] for T_{1i} and T_{3i}. Based on the objective function J_t optimization problem can be stated as: Minimize J_t subjected to:

$$\begin{aligned} &K_i^{min} \leq K_i \leq K_i^{max} \\ &T_{1i}^{min} \leq T_{1i} \leq T_{1i}^{max} \\ &T_{3i}^{min} \leq T_{3i} \leq T_{3i}^{max} \end{aligned} \tag{5}$$

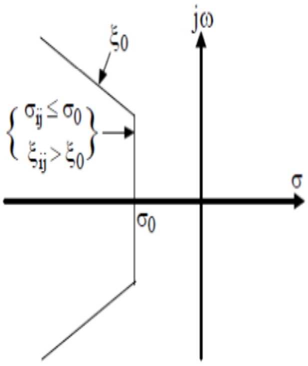

Figure 2. D-shape sector in the s-plane

2.4. The Bacterial Swarm Optimization Algorithm

BSO combines both algorithms BFOA and PSO thus using advantages of both techniques. The aim is to make use of PSO ability to exchange social information and BFOA ability in finding a new solution by elimination and dispersal. In BFOA, a unit length direction of tumble behavior is randomly generated which may lead to delay in reaching the global solution. In the BSO, technique the unit length random direction of tumble behavior can be obtained by the global best position and the best position of each bacterium by PSO algorithm.

PSO is a stochastic optimization technique that draws inspiration from the behavior of a flock of birds or the collective intelligence of a group of social insects with limited individual capabilities. In PSO a population of particles is initialized with random positions $\vec{x_i}$ and velocities $\vec{v_i}$, and a fitness function using the particle's positional coordinates as input values. Positions and velocities are adjusted, and the function is evaluated with the new coordinates at each time step. The velocity and position update equations for the d-th dimension of the i-th particle in the swarm may be given as follows:

$$V_{id}(t+1) = \omega V_{id}(t) + C_1\varphi_1(V_{lid} - X_{id}(t)) + C_2\phi_2(P_{gd-}X_{id}(t)) \tag{6}$$

$$X_{id}(t+1) = X_{id}(t) + V_{id}(t+1) \tag{7}$$

In addition, the BF is based upon search and optimal foraging decision making capabilities of the Escherichia coli bacteria. The coordinates of a bacterium here represent an individual solution of the optimization problem. Such a set of trial solutions converges towards the optimal solution following the foraging group dynamics of the bacteria population. Chemo tactic movement is continuous until a bacterium goes in the direction of positive nutrient gradient. After a certain number of complete swims the best half of the population undergoes reproduction, eliminating the rest of the population. In order to escape local optima, an elimination dispersion event is carried out where, some bacteria are liquidated at random with a very small probability and the new replacements are initialized at random locations of the search space. The proposed BSO algorithm to search optimal values of parameters is described as follows:

Step 1: Initialize parameters i, S, N_C, N_{Re}, N_{Ed}, P_{Ed}
C(l)(l=1,2,………,N), $\emptyset^1$.

Where,

i : Dimension of the search space.
S : The number of bacteria in population,
N_C : The number of chemotactic steps,
N_{Re}: The number of reproduction steps,
N_{Ed} : The number of elimination-dispersal events to be imposed over the bacteria,
P_{Ed}: The probability with which the elimination and dispersal will continue
$C(l)$: The size of the step taken in the random direction specified by the tumble,
ω: Inertia weight
C_I: The swarm confidence
$\vec{\theta}(l,m,n)$: Position vector of the l-th bacterium, in m-th chemotactic step and n-th reproduction.
$\vec{V_l}$: Velocity vector of the l-th bacterium.

Step 2: Update the following

$J(l, m, n)$: Cost or fitness value of the l-th bacterium in the m-th chemotaxis, and the n-th reproduction loop.

$\vec{\theta}_{g\_best}$: Position vector of the best position found by all bacteria.

J_{best} (l,,m,n): Fitness value of the best position found so far.

Step 3: Reproduction loop: n=n+1

Step 4: Chemotaxis loop: m=m+1

Sub step (i): For l=1, 2, …., S take a chemotaxis step for bacterium l as follows.

Sub step (ii): Compute fitness function, $J(l,m,n)$.

Sub step (iii): Let $J_{last} = J(l,m,n)$ to save this value since one may find a better cost via a run.

Sub step (iv): Tumble: generate a random vector $\Delta(l) \in R^k$ with each element $\Delta_k(l), k = 1,2,....,p.a$ random number on [-1,1].

Sub step (v): Move:

Let $\theta(l,m+1,n)=\theta(l,m,n)+C(l)\frac{\Delta(l)}{\sqrt{\Delta^T(l)\Delta(l)}}$

Sub step (vi): Compute J(l,m+1,n).
Sub step (vii): Swim: one considers only the l-th bacterium is swimming while the others are not moving then

a) Let k=0 (counter for swim length)
b) While k < N_S (have not climbed down too long)

- Let k=k+1
- If $J(l,m+1,n)<J_{last}$ (if doing better),

  Let $J_{last}=J(l,m+1,n)$ and let

$$\theta(l,m+1,n)=\theta(l,m,n)+C(l)\frac{\Delta(l)}{\sqrt{\Delta^T(l)\Delta(l)}}$$

And use this $\theta(l,m+1,n)$ to compute the new $\theta(l,m+1,n)$ as shown in [sub step 6].

- Else let k= N_S . This is the end of the while statement.

Step 5: Mutation with PSO operator
For i=1, 2…S

- Update the $\vec{\theta}_{g\_best}$ and $J_{best}(i,j,k)$
- Update the position and velocity of the d-th coordinate of the i-th bacterium according to the following rule:

$$V_{id}^{new}=\omega V_{id}^{new}+C_1.\varphi_{1.}(\theta_{g\_best_d}-\theta_d^{old}(l,m+1,n))$$

$$\theta_d^{new}(l,m+1,n)=\theta_d^{old}(l,m+1,n)+V_{id}^{new}$$

Step 6: Let S_r =S/2. The S_r bacteria with highest cost function(J) values die and other half bacteria population with the best values split (and the copies are made placed at the same location as their parent).

Step 7: If m< N_{Re}, go to (step 1). One has not reached the number of specified reproduction steps, so one starts the next generation in the chemotaxis loop.

3. SIMULATION RESULT

This deals with testing of hybrid BFOA-PSO algorithm for IEEE 14 Bus test systems. The standard IEEE 14 systems are considered to investigate the effectiveness of the proposed methodology. The test is carried with a 2.20-GHz Intel Core 2 Duo CPU T6600 PC. The IEEE 14-bus system has 5 generators and 16 transmission lines.

3.1. Response for Heavy Load Condition

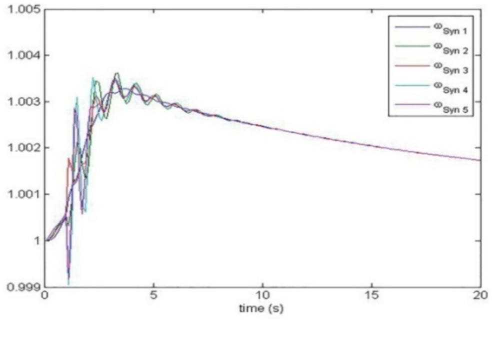

Figure 3. Rotor angles of generators under heavy load condition

The response of the rotor angle of generators under heavy load condition is shown in figure 3. Under heavy load condition, the average peak overshoot of all the generators reach upto 1.0035 P.U and the mean settling time of the oscillations is about 90 to 110 seconds.

3.2. Response for Normal Load Condition

The response of the rotor angle of generators under heavy normal condition is shown in figure 4. Under normal load condition, the average peak overshoot of all the generators reach upto 1.001 P.U and the mean settling time of the oscillations is about 60 to 80 seconds. As compared to under heavy load condition, both the peak overshoot and mean settling time of the oscillations are reduced.

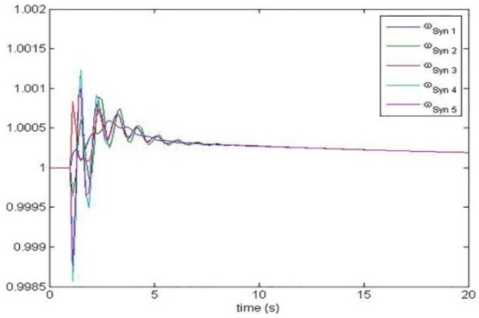

Figure 4. Rotor angle of generators under normal load condition

3.3. Response for Light Load Condition

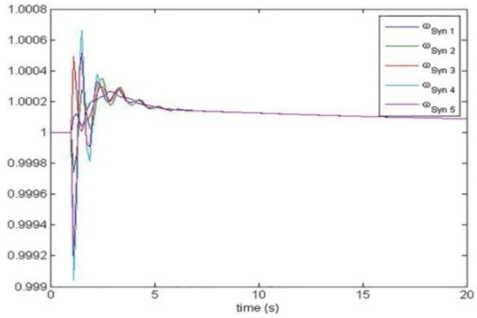

Figure 5. Rotor angle of generators under light load condition

Under light load condition, the average peak overshoot of all the generators reach upto 1.0005 P.U and the mean settling time of the oscillations is about 30 to 40 seconds. As compared to both the cases heavy load condition and normal load condition, both the peak overshoot and mean settling time of the oscillations are reduced under the light load condition.

4. CONCLUSION

This paper intends a new optimization algorithm known as BSO, which synergistically couples the BFOA with the PSO for optimal designing of PSSs controller. The design problem of the proposed controller is formulated as an optimization problem and BSO is employed to search for optimal controller parameters. The potential of the proposed design approach has been demonstrated by applying it to IEEE 14 bus 5 generator systems with different loading conditions. Simulations results assure the effectiveness of the controller in providing good damping characteristic to system oscillations over a wide range of loading conditions. Our future work includes the comparison of the proposed algorithm with the latest optimization techniques as cukoo search, NSGA-II.

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