Simultaneous Coordinated Design of Power System Stabilizer 3 Band (PSS3B) and SVC by using Hybrid Big Bang Big Crunch Algorithm in Multi-Machine Power System

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Abstract

Power System Stabilizers (PSS) are appropriate for nominal conditions of networks and can induce the required damping; but, with changes in the working condition, systems will encounter some difficulties. Power System Stabilizers 3 Band (PSS3B) as another type of stabilizers shows better results with changes in the working conditions of systems. On the other hand, after determining the remarkable result of Flexible AC Transmission System (FACTS) equipment in oscillation damping, nowadays, this equipment is increasingly used in power systems. Regarding the nonlinearity of power systems, it is not appropriate to use linear methods for calculating their parameters. In this paper, Hybrid Big Bang-Big Crunch (HBB-BC) algorithm was applied for consistently designing PSS3B parameters in four generators of a two-area 11 and control parameters of static VAR compensator considered in this network. Then, to investigate the effect of changing system conditions on stability, working conditions of generators were changed in two steps and a comparison was made between PSS and PSS3b and the calculated parameters in the initial mode.

Keywords: Hybrid Big Bang Big Crunch Algorithm, Low Frequency Oscillations (LFO), Multi Machine Power System, Power System Stabilizer (PSS), Power System Stabilizer 3 Band (PSS3B), Static VAR Compensator (SVC)

1. Introduction

If a multi-machine power system is disturbed, frequency, load angel, and voltage of all units will undergo oscillations. In order to study such oscillations, first, we should know whether these oscillations are damped or not. If the system is stable, these oscillations will usually disappear in a few seconds and the system will lay down in a new situation. These oscillations are known as Low Frequency Oscillations (LFO) in power systems and cause disturbance in the synchronism between generators of a continue system. Frequency of such oscillations usually ranges between a few tenths of Hertz to several Hertz. The worst type of LFO occurs when the power system has a three-phase short-circuit to the ground. In such a state, it is possible for the network to be completely instable and for protective systems to get activated. The issue of stability in power systems is important from two aspects. On the one side, in the case of disturbance, the more stable the system, the less the oscillations made in frequency, load angel, and voltage would be. So, it is less likely for protective systems to be activated and generation unit to be lost. On the other side, to reduce the exiting possibility of generation unit in the case of disturbance, the generation amount of units is considered less than their power. Therefore, with increasing the damping of the system, a higher degree of generator power will be utilized.

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PSS can be used to increase the stability of power systems. Its input includes signals of power or angle speed changes. Although these types of stabilizers are appropriate for nominal conditions and can induce enough damping, they face problems with any changes in the working conditions of the system. In other words, performance of classic stabilizers is reduced by changing the working conditions. PSS3B stabilizer is a kind of PSS stabilizer, the input of which is signals of power and angle speed changes. On the other hand, FACTS equipment can create better stability by applying several control signals at all points of transmission system along with power system stabilizers. In order for better performance of this equipment in power systems, three issues of type, settings of working point, and their installation place should be simultaneously considered. Solving this problem which is a multi-variation and nonlinear optimization one is complex.

In recent years, PSS designing by intelligent methods such as fuzzy, neural network, and methods inspired by biological phenomena has been extensively considered. Further, many studies have been conducted to make a consistency between PSS and FACTS equipment to increase the system stability. Consistent design of PSS and FACTS was performed by nonlinear programming technique and PSO algorithm. In addition, PSS and SSSC were combined to be used in the power system. In this algorithm, similar to genetic algorithm, trend of particles movement is based on the best solutions. In HBB-BC like PSO algorithm, local and global explosion and destruction of the existence. BB-BC algorithm is composed of two steps and, from the aspect of primitive population generation; it is similar to other evolutionary algorithms.

The initial population generation step is called big bang, in which population is randomly and consistently distributed over the total searching space. Afterward, big crunch phase starts to act, which is a converging operator. This operator has a large number of inputs but only one output, which is called mass center and calculated by equation (1):

$$X_{i}^{(k)} = \frac{\sum_{j=1}^{N} X_{i}^{(k,j)} f_{j}}{\sum_{j=1}^{N} f_{j}}, \quad i = 1, 2, 3 \ldots c$$

where $X_{i}^{(k)}$ is the $i^{th}$ component of center of gravity in the $k^{th}$ repetition, $X_{i}^{(k,j)}$ is the $i^{th}$ component of the $j^{th}$ generated particle in the $k^{th}$ repetition, $f_{j}$ is the amount of target function at point $j$, $n$ is the number of points or particles, and $c$ is the number of control variables. After big bang phase, big crunch phase obtained a new situation of each of the particles by equation (2):

$$X_{i}^{(k+1,j)} = X_{i}^{(k)} + (X_{i}^{\text{max}} - X_{i}^{\text{min}}) \times \alpha_{i} \times r \times \frac{1}{K + 1}$$

In the above equation, $r$ is a random number and $X_{i}^{\text{min}}$ and $X_{i}^{\text{max}}$ are top and bottom constraints of each particle, respectively. Moreover, $\alpha_{i}$ is a parameter for restricting the search space.

## 2. HBB-BC Algorithm Technique

For the first time in 2006, BB-BC algorithm was presented by Eksin and Erol. In this algorithm, similar to genetic algorithm, trend of particles movement is based on the best situation of particle thus far. On the other hand, trend of particles movement is always progressive. Particles cannot move backward to optimize themselves. To deal with this problem using capacities of PSO algorithm, HBB-BC evolutionary algorithm was introduced. In this section, after introducing BB-BC algorithm, HBB-BC algorithm is studied.

### 2.1 BB-BC Algorithm

This algorithm is inspired by the phenomenon of the beginning and end of the universe which is called large explosion and destruction of the existence. BB-BC algorithm is composed of two steps and, from the aspect of primitive population generation; it is similar to other evolutionary algorithms.

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### 2.2 HBB-BC Algorithm

In HBB-BC like PSO algorithm, local and global optimum points are used for generating new points by equation (3).

$$X_{i}^{(k+1,j)} = a_{1}X_{i}^{(k)} + (1 + a_{2})(\alpha_{3}X_{i}^{\text{gbest}(k)} + (1 - \alpha_{3})X_{i}^{\text{pbest}(k,j)}) + r_{j}\alpha_{i}(X_{i}^{\text{max}} - X_{i}^{\text{min}}) \times \frac{1}{K + 1}$$

This equation shows the HBB-BC algorithm.
In the above equation, $A_i^{gbest(k)}$ is the best place for the $j_{th}$ particle up to the $k_{th}$ repetition and $A_i^{gbest(k)}$ is the best global place up to the $k_{th}$ repetition. $a_2$ and $a_2$ are regulated parameters which control the impact of local and global optimum points.

The following Figure 1 shows the proposed flowchart of HBB-BC algorithm.

### 3. Power System Modeling

Studies have shown that damping deficiency of electro-mechanical mode in interconnected power systems means the roots of equation (4):

\[
(Ms^2 + Ds + K_1\omega_n)\Delta \delta = 0
\]  

(4)

are the agents for LFO. When a generator is working by itself, it has enough damping and oscillations become acceptably damped. Other factors such as network dynamic can be also influential for decreasing natural damping of a generator. FACTS equipment can make suitable damping by applying different control signals at all points of transmission system along with PSS. SVC is one of the powerful, but old, FACTS equipment, which has a weaker response than new equipment like TCSC, STATCON, and SSSC. But, its' lower price than other FACTS equipment makes its application justifiable.

#### 3.1 PSS

Figure 2 shows an IEEE model of PSS stabilizer, which is the so-called CPSS.

This stabilizer consists of a wash-out block which is a derivative. Transform function of this block is equal to equation (5):

\[
\frac{T_w}{1 + ST_w}
\]  

(5)

In the case of very large disturbances, Limiter decreases over load of the power system. The number of lead-lag block depends on the system nature, PPS regulation manner, and degree of required lead-lag. Stabilizer gain is also

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**Figure 1.** The flowchart of HBB-BC algorithm.
determined by $K_p$. This stabilizer is very sensitive to noise and always contains torsional oscillations.

### 3.2 PSS3B

PSS3B stabilizer uses two inputs of electric power and rotor angular speed changes. PSS3B can be noted as the modified version of PSS2B, in which internal torsional filter has been removed. IEEE model of a stabilizer with two inputs is shown in Figure 3.

In this stabilizer, $T_1$ and $T_3$ are time constants of converter and $T_2$ and $T_4$ indicate wash-out time constants in two channels. Optimum stabilizer gain is obtained by regulating the amounts of $K_2$ and $K_3$, $T_{1n}$, $T_{1d}$, $T_{2n}$, and $T_{2d}$ are coefficients of compensators in stabilizer phase. Excitation voltage limiter was also used in the stabilizer output.

### 3.3 SVC

Static VAR compensator is connected in parallel and its output is regulated for exchanging inductive or capacitive current so that the determined parameters of the power system are maintained or controlled. The main task of SVC is rapid voltage control at the network’s weak points by appropriately controlling its influential reactance. SVC operation is based on thyristors without gate interruption and includes separate equipment for phase primacy or recency of the reactive power.

Thyristor Switched Capacitor (TSC) and Thyristor Controlled Reactor (TCR) are applied to the SVC structure. TCR is a controllable inductor with a thyristor which is in parallel to the network and its effective reactance is continuously changing by controlling the partial conductance of thyristor gate. TSC is a switching capacitor with a thyristor which is in parallel and its influential reactance changes stepwise with the performance of thyristor gate in zero or complete conductance.

Single-linear diagram of an SVC with a simplified diagram block of a synchronous generator control system is shown below in the Figure 4.

Current of SVC’s reactor is controlled in a way that a range between capacitive and inductive states could be controlled. When SVC performs the voltage regulating operation, speed of response to system voltage changes depends on voltage regulator gains by equation (6).

$$B = \left( K_p + \frac{K_i}{s} \right) (V_{svc} - V_{svc.ref})$$

$$B_{min} \leq B \leq B_{max}$$

Four-generator two-area system along with SVC is shown in the following Figure 5 and the supplementary information of this network is given in \(^1\).

### 4. Proposed Objective Function

Simultaneous determination of PSS3B parameters for each of the four network generators along with SVC parameters in a way that damping could be induced in different working conditions is a complicated problem. In this paper, HBB-BC proposed algorithm was applied to design these parameters. Design process can be defined as an optimizing problem with the following limitations:

**Figure 2.** IEEE model of a PSS stabilizer.

**Figure 3.** IEEE model of a stabilizer with two inputs.
Simultaneous Coordinated Design of Power System Stabilizer 3 Band (PSS3B) and SVC by using Hybrid Big Bang Big Crunch Algorithm in Multi-Machine Power System

For HBB-BC algorithm

\[
\text{Iteration} = 30 \\
\text{Population} = 50 \\
\alpha_1 = 2 \\
\alpha_2 = 0.7 \\
\alpha_3 = 0.2
\]

For optimization, a cost function is needed which can be minimized to obtain the desired response in the output. In this paper, ISTSE criterion was used as the cost function by equation (7).

\[
F = \int_0^{t_{\text{sim}}} (t\Delta w_{12})^2 + (t\Delta w_{13})^2 + (t\Delta w_{14})^2 + (t\Delta w_{34})^2 \quad (7)
\]

In this relation, \(\Delta w_{12}, \Delta w_{13}, \Delta w_{14},\) and \(\Delta w_{34}\) are quantities of speed difference of rotor angles related to generators 1 and 2, generators 1 and 3, generators 1 and 4, and generators 3 and 4. Also, \(t_{\text{sim}}\) states simulating period. The goal of optimum regulation of stabilizer parameters is to increase damping of low frequency oscillations with decreasing settling time and maximum overshoot.

5. Simulation Result

Matlab software was used for the stimulation. First, the multi-machine network model in Figure 5 was designed in the Simulink environment. Then, PSS3B parameters applied in four generators of the network were consistently regulated along with SVC control parameters by HBB-BC algorithm. Effectiveness and capability of performance of this system in transient conditions were tested by applying three-phase error within 200 ms in the connection line between 8 and 9 buses. The proposed system should have the appropriate performance ability in different working conditions and can create the required damping in the case of disturbance. For evaluating the performance of the proposed stabilizer, its response was compared with the PSS response designed by PSO algorithm which was better than other optimization methods. For a more precise investigation of each of the designed stabilizers, after calculating the parameters in the first case and studying the network synchronism, the system was tested in other two working conditions to consider the effect of changing working conditions on two stabilizers. Per unit quantities of active and reactive power of each unit are shown in the following Table 1.
The first condition was considered as the basic condition and optimization process was performed in this condition, second condition was related to the increasing mode of the active and reactive generated power in two areas, and third condition was related to decrease active and reactive generated power in two areas.

Optimum amounts of PSS stabilizers designed by PSO algorithm are shown in the Table 2 below.

Optimum amounts of PSS3B and SVC stabilizer parameters which were consistently designed by HBB-BC algorithm are demonstrated in the following Table 3.

In PSSS3B stabilizer, $10 = T_2 = T_{1d}$, $0.02 = T_{1n}$, $0.01 = T_{1d}$, $0.03 = T_{2n}$ and $0.01 = T_{2d}$ were considered.

5.1 Case 1
Optimization process was performed in this mode. Thus, 200 ms three-phase error was applied to the system. Figure 6 shows speed changes of angles in each generator relative to the first generator.

For the first condition, quantities of ITAE and ISTSE criteria and maximum overshoot and undershoot are given in the Table 4.

In Figure 7, a comparison is made between change in target function during optimization using two PSO and HBB-BC algorithms, which displays more speed of HBB-BC algorithm.

5.2 Case 2
At this stage, by increasing active and reactive power of each generator, putting these quantities based on Table 1, and applying three-phase error to the ground with 200 ms durability, speed changes of angles of each generator were investigated relative to the first generator in Figure 8.

For the second condition, quantities of ISTSE and ITAE criteria and maximum overshoot and undershoot are given in the Table 5.

5.3 Case 3
In this step, active and reactive power of generators was reduced so that the system was working with its maximum capacity. In this case, if stabilizers are not properly designed, the smallest disturbance would lead to instability. Active and reactive power of each generator was considered according to Table 1 and three-phase error

| Table 1. Operating condition of two area power system (pu) |
|-----------------------------------------------------------|
| Operating condition | P1 | Q1 | P2 | Q2 | P3 | Q3 | P4 | Q4 |
|---------------------|----|----|----|----|----|----|----|----|
| Case 1              | 0.7778 | 0.1021 | 0.7777 | 0.1308 | 0.7989 | 0.0914 | 0.7778 | 0.0918 |
| Case 2              | 0.8889 | 0.1240 | 0.6022 | 0.0943 | 0.8333 | 0.0989 | 0.8333 | 0.0955 |
| Case 3              | 0.6667 | 0.0992 | 0.9624 | 0.2083 | 0.7778 | 0.0960 | 0.6667 | 0.1036 |

| Table 2. Parameters of PSS by PSO algorithm for two-area power system |
|---------------------------------------------------------------------|
| Parameters | PSO |
|------------|-----|
| PSS1       | PSO |
| K_p        | 17.0513 |
| T_{1n}     | 0.3304 |
| T_{1d}     | 0.3366 |
| T_{2n}     | 0.7840 |
| T_{2d}     | 0.4735 |

| Table 3. Parameters of SVC controllers and PSS3B by HBB-BC algorithm for two-area power system |
|-----------------------------------------------------------------------------------------------|
| Parameters | HBB-BC |
|------------|--------|
| K_p        | 8.2032 |
| K_{p3}     | 20.8156 |
| T_1        | 0.6262 |
| T_2        | 0.0184 |
Simultaneous Coordinated Design of Power System Stabilizer 3 Band (PSS3B) and SVC by using Hybrid Big Bang Big Crunch Algorithm in Multi-Machine Power System

Figure 6. Local and Inter-area mode of oscillation for case 1

(a) Local mode \((w_1 - w_2)\) of oscillations for case 1

(b) inter-area \((w_1 - w_3)\) of oscillations for case 1

(c) Inter-area \((w_1 - w_4)\) of oscillations for case 1

(d) local mode \((w_3 - w_4)\) of oscillations for case 1

Figure 7. Variations of objective function for PSO and HBB-BC algorithms.

Table 4. Comparison of the ISTSE, ITAE, %OV and %US performance index for case 1

| Type of methods          | Case 1 |
|--------------------------|--------|
|                         | ISTSE  | ITAE  | %OV  | %US  |
| PSS design by PSO in case 1 | 0.0066 | 3.5   | 0.18 | -0.17 |
| PSS3B design by HBB-BC in case 1 | 0.0022 | 1.4   | 0.13 | -0.14 |
| PSS3B & SVC design in case 1 | 0.0019 | 1.2   | 0.12 | -0.12 |

was applied to the ground with 200 ms durability. Figure 9 shows speed changes of angles in the case of decreasing output power of generators.
Table 5. Comparison of the ISTSE, ITAE, %OV and %US performance index for case 2

| Type of methods                  | Case 2  | ISTSE | ITAE | %OV  | %US  |
|----------------------------------|---------|-------|------|------|------|
| PSS design by PSO in case 1      | 0.0052  | 1.5   | 0.15 | -0.13|
| PSS3B design by HBB-BC in case 1 | 0.0037  | 1.2   | 0.096| -0.11|
| PSS3B & SVC design in case 1     | 0.0018  | 0.8   | 0.087| -0.11|

For the third condition, quantities of ITAE and ISTSE criteria and maximum overshoot and undershoot are demonstrated in the Table 6.

The following diagrams show a comparison between ISTE and ITAE criteria in three different cases for three designed stabilizers.

Table 6. Comparison of the ISTSE, ITAE, %OV and %US performance index for case 3

| Type of methods                  | Case 3  | ISTSE | ITAE | %OV  | %US  |
|----------------------------------|---------|-------|------|------|------|
| PSS design by PSO in case 1      | 0.0101  | 6.1   | 0.26 | -0.27|
| PSS3B design by HBB-BC in case 1 | 0.0063  | 3.8   | 0.18 | -0.24|
| PSS3B & SVC design in case 1     | 0.0048  | 3.0   | 0.17 | -0.21|

6. Conclusion

In this paper, a consistent design was done between SVC and PSS3B stabilizer parameters in a four-machine power system by HBB-BC algorithm. PSS could induce appropriate damping in nominal conditions; however,
Simultaneous Coordinated Design of Power System Stabilizer 3 Band (PSS3B) and SVC by using Hybrid Big Bang Big Crunch Algorithm in Multi-Machine Power System

Figure 9. Local and Inter-area mode of oscillation for case 3

(a) Local mode ($w_1 - w_2$) of oscillations for case 3
(b) Inter-area ($w_1 - w_4$) of oscillations for case 3
(c) Inter-area ($w_3 - w_4$) of oscillations for case 3
(d) Local mode ($w_3 - w_4$) of oscillations for case 3

Figure 10. Values of performance index ISTSE for different operating point.

Figure 11. Values of performance index ITAE for different operating point.
any change in the system condition leads to decreased efficiency of this stabilizer. To deal with this problem, PSS3b stabilizer was applied. Using FACTS equipment along with stabilizers not only increased the system's stability in nominal conditions, but also guaranteed stability in the system damping if conditions were changed. Meanwhile, SVC was superior owing to its low cost. Comparison of the obtained results showed that PSS3B had better damping in nominal conditions than PSS. Also, in the case of using maximum generation capacity, quality of the induced damping would be equal to the nominal mode of PSS stabilizer. Consequently, higher power can be received from generators. Further, to optimize the target function, HBB-BC algorithm reached a more optimum response than PSO algorithm during a shorter period.

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