A Nature Inspired Optimization Algorithm for Reactive Power Control in a Power System

S. Sakthivel, M. Gayathri, V. Manimozhi

Abstract— In power system operation, minimizing the real power loss in transmission lines and the voltage deviation at the load buses by controlling the reactive power flow is an important task. This ensures for secured operation of power systems with regard to voltage stability and economics of operation owing to loss minimization. In this paper, the nature inspired Big Bang – Big Crunch (BB-BC) algorithm is implemented to solve the multi constrained optimal reactive power flow problem in a power system. The algorithm is free from large number of operators and can be easily coded in any programming language. Generator bus voltages, transformer tap positions and settings of switched shunt var compensators are used as decision variables to control the reactive power flow. BB-BC algorithm is tested on the standard IEEE-30 bus test system and the results are compared with other methods to prove the effectiveness of the new algorithm. The results are quite encouraging and the algorithm is found to be efficient.

Index Terms—Big Bang–Big Crunch Algorithm, Optimal Reactive Power Flow, Loss Minimization, Optimal Reactive Power Flow Control.

I. INTRODUCTION

The increased demand for electric power and the insufficient power generation and transmission facility forces the power system networks being operated under stressed conditions. The security of a power system is under threat when it is operated at stressed conditions and may result in voltage instability. Nowadays voltage instability has become a new challenge to power system planning and operation. Insufficient reactive power availability or non-optimized reactive power flow may lead a power system to insecure operation under heavily loaded conditions [1]-[2]. By reallocating reactive power generations in the system the problem can be solved to a far extent.

Apart from the aforementioned method, the system losses can also be minimized via optimal reactive power flow in the system for improving the stability. Large amount of reactive power flow in a system is indicated by increased real power loss in the system. Therefore minimizing the real power loss ensures optimized reactive power flow (ORPF) through the lines. Reactive power optimization by real power loss minimization increases the power system economics to some extent. Reactive power optimization by minimization of real power loss has long been attempted for voltage stability improvement [3]-[4]. ORPF is an important tool in terms of secure and economic operation of power systems. It is a powerful concept for power system operation and planning [5]-[6]. In ORPF, the network active power loss is reduced and voltage profile is improved while satisfying a given set of operating and physical constraints [7]-[8]. Reactive power flow is optimized by properly setting the values of control parameters. A number of conventional optimization methods have been exploited for this objective. Techniques such as non linear programming technique [9] and gradient based optimization algorithm [10] are used to solve the ORPF problem. But they have several disadvantages like large numerical iteration and insufficient convergence properties which leads to large computation and more execution time.

The recently developed meta-heuristics based algorithms are proving better performance than the conventional methods. They find global best or nearly global best solutions for engineering problems. These algorithms are better utilised for power system optimization. Some of them are Tabu Search (TS) [11], Simulated Annealing (SA) [12], Genetic Algorithm (GA) [13], Evolutionary Programming (EP) [14], Hybrid Evolutionary Programming (HEP) [15], Particle Swarm Optimization PSO [16], Chaotic Ant Swarm Optimization (CASO) [17] and Differential Evolution (DE) [18] are developed which provides fast and optimal solution for reactive power optimization.

Conventional methods are sensitive to initial guess of the search point where functions have multiple local minima and not efficient in handling problems of discrete variables [19]. In addition to this a lot of algorithms have been presented to solve optimal reactive power dispatch. Chien-Feng Yang proposed a system for limiting voltage variations by means of switchable shunt reactive compensation and transformer tap setting [20].

BB-BC algorithm is a recent development and it is very simple and easy for implementation [21]-[22]. This algorithm has less number of parameters and has good convergence characteristics. In this paper, the BB-BC method is used for ORPF problem. The performance of this method is compared with other algorithms to prove its efficiency.

II. PROBLEM FORMULATION

The main objective of this work is to optimize the reactive power dispatch in a power system by minimizing the total real power loss in the system.

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A. Objective Function

This work finds the optimal settings for generator voltage magnitude, transformer tap settings and settings of SVC that minimizes the total real power loss in the system. The objective function can mathematically be written as:

$$minf_Q = \sum_{k \in N_L} P_{kloss} = \sum_{k \in N_L} g_k \left(V_i^2 + V_j^2 - 2V_i\ V_j\ cos\theta_{ij}\right) \quad (1)$$

Subject to the following constraints:

B. Equality Constraints

The power flow equations

$$P_{Gi} - P_{Di} = V_i \sum_{j \in N_B} V_j \left(G_{ij} cos\theta_{ij} + B_{ij} sin\theta_{ij}\right)\ i \in N_B \quad (2)$$

$$Q_{Gi} - Q_{Di} = V_i \sum_{j \in N_B} V_j \left(G_{ij} sin\theta_{ij} + B_{ij} cos\theta_{ij}\right)\ i\ \in N_B \quad (3)$$

C. Inequality Constraints

Bus voltage magnitude limit

$$V_i^{min} \le V_i \le V_i^{max} \qquad i \in N_B \quad (4)$$

Transformer tap –position limit

$$T_k^{min} \le T_k \le T_k^{max} \qquad k \in N_T \quad (5)$$

Reactive power generation limit

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \qquad i \in N_G \quad (6)$$

Static var compensator limit

$$Q_{Ci}^{min} \le Q_{Ci} \le Q_{Ci}^{max} \qquad i \in N_C \quad (7)$$

Line power flow limit

$$S_l \le S_l^{max} \qquad l \in N_l \quad (8)$$

III. BB-BC ALGORITHM

A. Overview

A new nature inspired optimization technique which has low computational time and high convergence speed called BB-BC is introduced recently [21]-[22]. It has two phases,

1. Big bang phase and 2. Big crunch phase.

In Big Bang phase, candidate solutions are randomly distributed over the search space and in the Big Crunch phase, randomly distributed particles are drawn into an orderly fashion.

The Big Bang-Big Crunch optimization method generates random points in the Big Bang phase and shrinks these points to a single point in the Big Crunch phase after a number sequential Big Bangs and Big Crunches.

The Big Crunch phase has a convergence operator that has many inputs but only one output, which is named as the ‘‘centre of mass”, since the only output has been derived by calculating the centre of mass. The point representing the centre of mass is denoted by X_c and is calculated according to the following equation.

$$X_C = \frac{\sum_{i=1}^{NP} \frac{1}{f(X_i)} X_i}{\sum_{i=1}^{NP} \frac{1}{f(X_i)}} \quad (9)$$

Where X_i is the i^{th} candidate in an *D*-dimensional search space, $f(X_i)$ is a fitness function value of this point, *NP* is the population size in Big Bang phase.

After the Big Crunch phase, the algorithm creates new candidates to be used as the Big Bang phase of the next iteration step. This can be done in various ways, the simplest one being identifying the best candidate in the population. In this work, the new candidates are generated around the centre of mass and knowledge of centre of mass of previous iteration is used for better convergence. The parameters to be supplied to normal random point generator are the centre of mass of the previous step and the standard deviation. The deviation term can be fixed, but decreasing its value along with the elapsed iterations produces better results.

$$X^{new} = X_c + \frac{r\alpha(X^{max} - X^{min})}{t} \quad (10)$$

Where *r* is a normal random number, α is a parameter limiting the size of the search space, X^{max} and X^{min} are the upper and lower limits, and *t* is the iteration step. Since normally distributed numbers can be exceeding ±1, it is necessary to limit the population to the prescribed search space boundaries. This narrowing down restricts the candidate solutions into the search space boundaries.

B. BB-BC Applied to Loss Minimization

BB-BC algorithm involves the steps shown below in reactive power flow control.

Step 1: Form an initial generation of *NP* candidates in a random manner respecting the limits of search space. Each candidate is a vector of all control variables, i.e. [V_g, T_k, Q_{SVC}]. There are 6 V_g's, 4 T_k's and 3 Q_{SVC}'s in the IEEE-30 system and hence a candidate is a vector of size 1x13.

Step 2: Calculate the fitness function values of all candidate solution by running the NR load flow. The control variable values taken by different candidates are incorporated in the system data and load flow is run. The total line loss corresponding to different candidates are calculated.

Step 3: Determine the centre of mass which has global best fitness using equation (9). The candidates are arranged in the ascending order of their fitness (loss) and the first candidate will be the candidate with best fitness (minimum loss).

Step 4: Generate new candidates around the centre of mass by adding/subtracting a normal random number according to equation (10). It should be ensured that the control variables are within their limits otherwise adjust the values of ‘*r*’ and ‘*α*’.

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Step 5: Repeat steps 2-4 until stopping criteria has not been achieved.

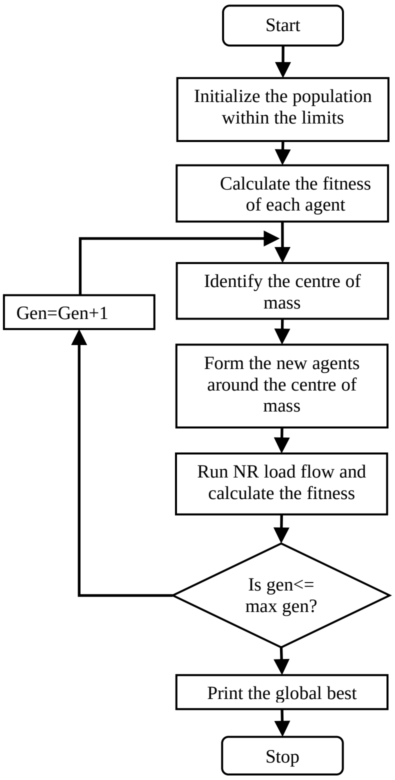

Figure 1. Flow chart for BB-BC algorithm

IV. NUMERICAL RESULTS AND DISCUSSIONS

The performance of the proposed BB-BC algorithm based reactive power optimization method is tested in the standard IEEE-30 bus test system [23]. The algorithm is coded in MATLAB 7.6 environment and a Core 2 Duo, 2.8 MHz, 2GB RAM based PC is for the simulation purpose.

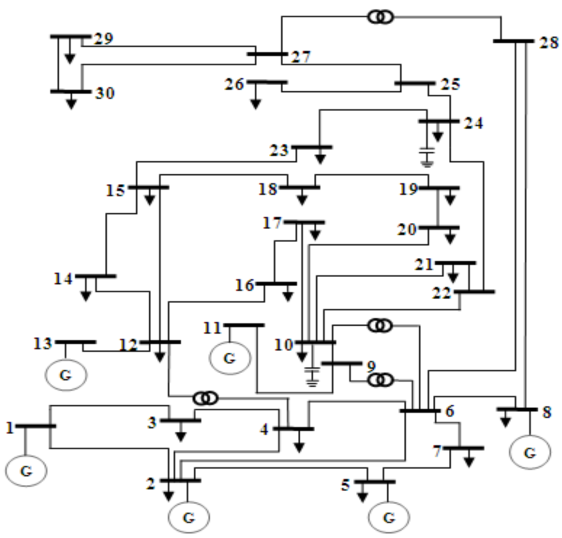

Figure 2. Single line diagram of IEEE-30 bus system.

The test system taken has six generating units connected to buses 1, 2, 5, 8, 11 and 13. There are 4 tap changing transformers connected between bus numbers 6-9, 6-10, 4-12 and 27-28. Two shunt compensators are connected in bus numbers 3, 10 and 24. The system is interconnected by 41 transmission lines. The control variables are generator's voltages, tap settings of the regulating transformers and var injection of shunt capacitors. The upper and lower bounds of the different control variables are given in table 1.

Table 1. Control variable limits

Sl. No	Control Variable	Bounds
1	Generator Voltage (V_G)	(0.9-1.1) p.u.
2	Tap Setting (T_P)	(0.9-1.1) p.u.
3	MVAR by SVCs (Q_{SVC})	(0-10)

Real power loss is minimized for reactive power optimization. The algorithm varies the control parameters within the allowable range. After several trial runs the algorithm gave the minimum value of loss and the corresponding control variable values. The optimal values for the control variables are obtained in real power loss minimization are tabulated in table 2.

Table 2. Optimal values of control variables

Sl No	Parameter	Initial Value	Optimal Value [BB-BC]
1	V_{G1}	1.05	1.1000
2	V_{G2}	1.04	1.0939
3	V_{G5}	1.01	1.0681
4	V_{G8}	1.01	1.0753
5	V_{G11}	1.05	1.0984
6	V_{G13}	1.05	1.0857
7	T_{6-9}	1.078	0.9867
8	T_{6-10}	1.069	1.0431
9	T_{4-12}	1.032	1.0338
10	T_{27-28}	1.068	0.9771
11	Q_3	0.0	0.5770
12	Q_{10}	0.0	6.0406
13	Q_{24}	0.0	9.6587

The optimization offers other advantage like reduction in total real power generation and this increases the power system economics. The strength of BB-BC algorithm is proved by power loss value after optimization. Loss reduction is from 5.744 MW to 4.69 MW and it is 18.35% this shows the strength of the proposed algorithm. The reduction achieved by the proposed algorithm is compared with that reported by other recently reported algorithms in table 3. It is clear from the comparison that BB-BC performs better than the other algorithms in the literature.

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Table 3. Comparison of real power loss minimization

Method	LP [24]	EP [24]	CGA [24]	AGA [24]	PSO [24]	CLPSO [24]	HSA [25]	BB-BC
P_{Loss} (MW)	5.988	4.963	4.980	4.926	4.8136	4.7208	4.7624	4.690

Table 4 compares the performance of BB-BC algorithm with that of other algorithms in loss minimization. BB-BC algorithm proves its ability in finding global best solution by achieving much reduction in loss value. Also the algorithm converges to loss values that are very closer.

Table 4. Performance of BB-BC in loss minimization

Compared item	SGA [25]	PSO [25]	HAS [25]	BB-BC
Best P_{loss}(MW)	4.9408	4.9239	4.9059	4.69000
Worst P_{loss}(MW)	5.1651	5.0576	4.9653	4.94170
Average P_{loss} (MW)	5.0378	4.9720	4.9240	4.80258

The efficiency of an algorithm lies in the number of iterations taken to get the global best results. BB-BC algorithm takes only less number of iterations and the results are converged to the best loss value. The algorithm converges in a better manner for the objective considered and it proves the reliability of the algorithm.

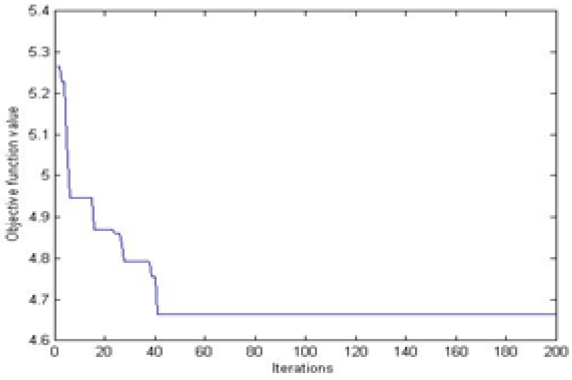

Figure 3. Convergence characteristics of BB-BC (Case 'c')

Optimal reactive power dispatch is also resulted in acceptable voltage magnitude at all load buses. It is clear from figure 4 that the magnitudes of load bus voltages are maintained at about the nominal value of 1.0 p.u. Maintenance of the load bus voltage within the allowable limit is an indication that reactive powers at those buses are optimized.

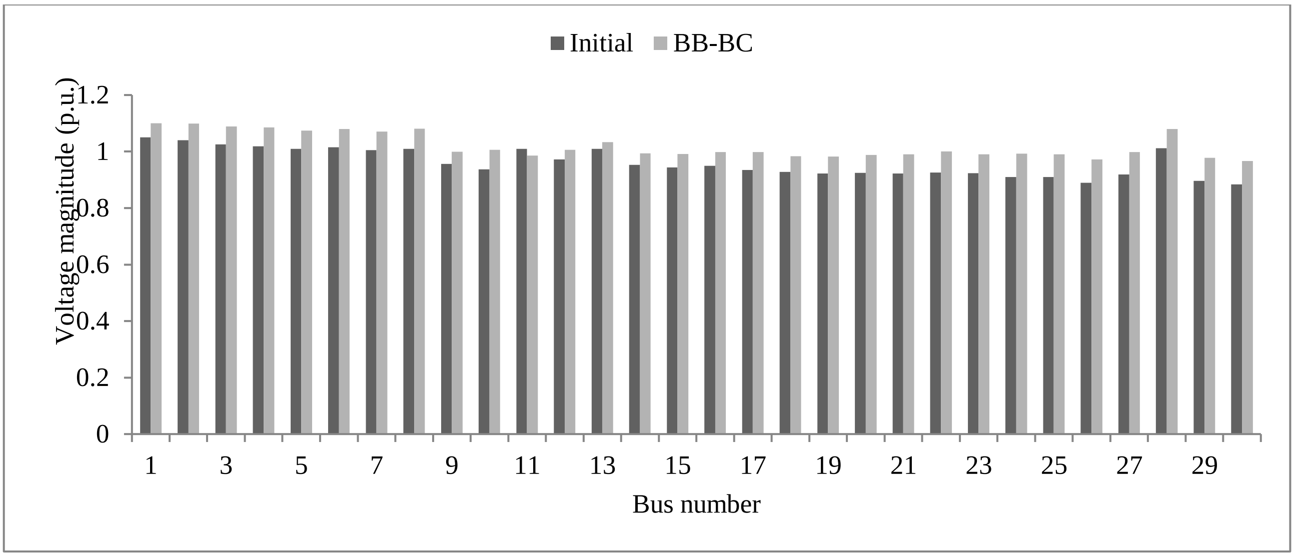

Figure 4. Voltage Profile Improvement

V. CONCLUSIONS

In this paper, a novel BB-BC based optimization algorithm is proposed to solve multi-objective reactive power optimization problem. The performance of the proposed algorithm for solving this multi-objective optimization is demonstrated using IEEE-30 bus system. The results are compared to those of other algorithms like PSO and BBO.

The test results clearly show that BB-BC outperforms other reported methods in terms of solution quality. The superiority of the proposed BB-BC method is more pronounced in optimization of power system operation. From the simulation results it may finally be concluded that among all the algorithms, BB-BC based optimization method is capable of achieving global optimal solution. This paper proves that the proposed BB-BC optimization technique is good in dealing with power system optimization problems.

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