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# Application of Big Bang Big Crunch Algorithm for Optimal Power Flow Problems

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## Abstract

*Optimal power flow (OPF) is the major task in power system economics and operation. Real power outputs from the generators of a power system are so adjusted that the total production cost is minimum. Real power output from generators, generator bus voltages and transformer tap settings are controlled for optimizing the total fuel cost in this OPF problem. This work considers the Big Bang-Big Crunch (BB-BC) algorithm for optimally selecting the values for control variables. The proposed algorithm is simple, with less number of parameters and easy to implement. The performance this algorithm in OPF is tested on IEEE-30 bus test system. Numerical results show that the proposed algorithm outperforms the other recently developed algorithms. The results obtained are quite encouraging and the algorithm is found to be suitable for power system operation optimizations.*

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## I. INTRODUCTION

OPF is a special case of power flow problem with an objective for optimizing the power system operation and planning. The goal of OPF may be minimization of fuel cost, real power loss or voltage deviation at load buses. Recently, the problem of OPF has received much attention by many researchers. The OPF is the fundamental tool that enables electric utilities to specify economic operating and secure states in power systems. Main objective of the OPF problem is to optimize a chosen objective function commonly the fuel cost through optimal selection of the power system control variables while at the same time satisfying various system operating constraints such as power flow equations and inequality constraints [1]-[2]. OPF problem is a large-scale, highly constrained nonlinear nonconvex optimization problem. The concept of OPF was first proposed by Dommel and Tinney [3]. Later it gained popularity by many researchers and has become an important tool in the locational marginal pricing (LMP) based restructured power markets. Conventional optimization techniques such as interior point method, linear programming, nonlinear programming and quadratic programming have been implemented to solve the OPF problem [4]–[9]. However, the disadvantage of these techniques is that they are not reliable and have tendency to trap into local minima.

It is necessary to find new optimization methods that are capable of overcoming these drawbacks [10]. Recently, many population-based optimization techniques have been used to solve complex constrained optimization problems. These techniques have been increasingly applied for solving power system optimization problems such as economic load dispatch, optimal reactive power flow and OPF in decades. Some of the population-based methods have been used for solving the OPF problem successfully, such as genetic algorithm [11], tabu search [12], particle swarm optimization [13], differential evolution algorithm [14], simulated annealing [15], evolutionary programming [16] and recently the harmony search algorithm [17]. A nature inspired BB-BC algorithm is proposed in this study, which is based on the big bang theory on evolution of the universe. BB-BC has verified high quality performance in solving different optimization problems in the literature [18]–[20]. In this paper, a newly developed heuristic optimization called BB-BC method is proposed to solve the OPF problem which is formulated as a nonlinear optimization problem with equality and inequality constraints in a power system.

The objective function is minimization of fuel cost using the quadratic cost function. The performance of the proposed approach is tested on the standard IEEE-30 bus test system to prove its efficiency. Results obtained demonstrate that the proposed method provides very remarkable results for solving the OPF problem. The results have been compared to those reported in the recent literature.

### 1.1 Problem formulation

**Objective function**

The objective of this work is to minimize the fuel cost by adjusting the real power outputs from generators, transformer tap settings and generator bus voltages. The objective function can be written as follows:

$$f = min \sum_{i=1}^{NB} C_i(P_{Gi}) = \sum_{i=1}^{NB} (a_i + b_i P_{Gi} + c_i P_{Gi}^2) \qquad (1)$$

Subject to the following constraints

**Equality constraints**

$$P_{gi} - P_{di} - \sum_{j=1}^{NB} |V_i||V_j||Y_{ji}| \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \qquad (2)$$

$$Q_{gi} - Q_{di} - \sum_{j=1}^{NB} |V_i||V_j||Y_{ji}| \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \qquad (3)$$

$$\sum P_G - P_D - P_L = 0 \qquad (4)$$

**Inequality constraints**

Line MVA flow limit

$$|S_i| \le S_i^{max} \qquad i = 1, \dots . n_l \qquad (5)$$

Reactive power generation limit

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \qquad i = 1, \dots . NG \qquad (6)$$

Real power generation limit

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \qquad i = 1, \dots . NG \qquad (7)$$

Transformer tap setting limit

$$t_i^{min} \le t_i \le t_i^{max} \qquad i = 1, \dots . NT \qquad (8)$$

### 1.2 BB – BC ALGORITHM

**Overview**

A new nature inspired optimization technique which has low computational time and high convergence speed called BB-BC is introduced recently [18]-[19]. It has two phases, viz. 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.

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

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.

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

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.

### 1.3 BB-BC algorithm applied to OPF minimization:

Big Bang Big Crunch 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. [$P_g$, $V_g$, $T_k$]. There are 5 $P_g$'s, 6 $V_g$'s, and 4 $T_k$'s in the IEEE-30 system and hence a candidate is a vector of size 1x15.

**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 their fitness (fitness) 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'.

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

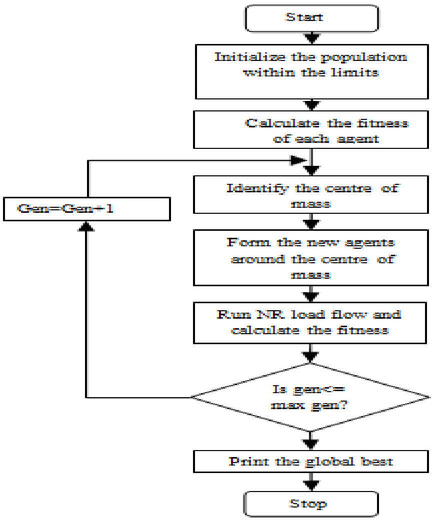

Figure 1. Flow chart for BB-BC algorithm

## II. NUMERICAL RESULTS AND DISCUSSIONS

The performance of the proposed BB-BC algorithm based fuel cost optimization method is tested in the standard IEEE-30 bus test system [21]. 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.

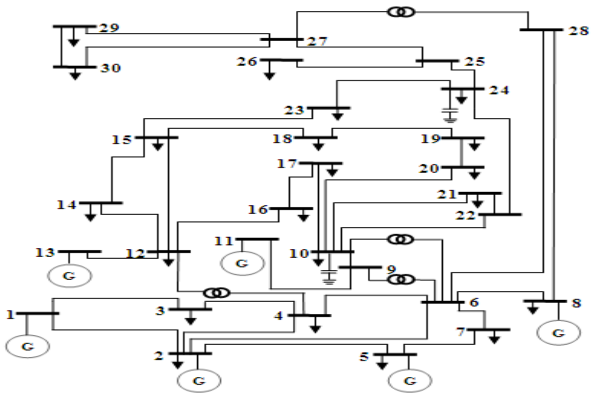

Figure 2. Single line diagram of IEEE-30 bus system.

The IEEE-30 bus system is described in table 1. There are 6 generator buses, bus 1 is taken as swing bus and the base MVA is 100.

Table 1. Parameters of the IEEE-30 bus system

| Sl.No. | Parameter | 30-bus system |
|---|---|---|
| 1 | Buses | 30 |
| 2 | Branches | 41 |
| 3 | Generator Buses | 6 |
| 4 | Shunt capacitors | 2 |
| 5 | Tap-Changing transformers | 4 |

Quadratic cost function is used for calculating the total fuel cost. The real power generation limits and three cost coefficients are given in table 2.

Table 2. Real power limits and cost coefficients of generators

| Bus No | Real power output limit(MW) | | Cost Coefficients | | |
|---|---|---|---|---|---|
| | Min | Max | a | b | c |
| 1 | 50 | 200 | 0 | 2.00 | 0.00375 |
| 2 | 20 | 80 | 0 | 1.75 | 0.01750 |
| 5 | 15 | 50 | 0 | 1.00 | 0.06250 |
| 8 | 10 | 35 | 0 | 3.25 | 0.00834 |
| 11 | 10 | 30 | 0 | 3.00 | 0.02500 |
| 13 | 12 | 40 | 0 | 3.00 | 0.02500 |

The control parameters are adjusted within their limits and the total fuel cost is minimized. The optimal values of the control variables taken by the proposed algorithm in OPF are given in table 3.

Table 3. Obtimal values by BB-BC algorithm

| SI.No | Parameters | Initial value (MW) | Final value (MW) |
|---|---|---|---|
| 1 | $P_{g1}$ | 176.4070 | 181.5091 |
| 2 | $P_{g2}$ | 48.8400 | 48.2247 |
| 3 | $P_{g5}$ | 21.5100 | 21.9221 |
| 4 | $P_{g8}$ | 22.1500 | 19.1117 |
| 5 | $P_{g11}$ | 12.1400 | 10.9305 |
| 6 | $P_{g13}$ | 12.0000 | 11.0322 |
| 7 | $V_{g1}$ | 1.05000 | 1.1000 |
| 8 | $V_{g2}$ | 1.04000 | 1.0833 |
| 9 | $V_{g5}$ | 1.01000 | 1.0585 |

| | | | |
|---|---|---|---|
| 10 | $V_{g8}$ | 1.01000 | 1.0653 |
| 11 | $V_{g11}$ | 1.05000 | 1.0609 |
| 12 | $V_{g13}$ | 1.05000 | 1.0611 |
| 13 | $T_{6-9}$ | 1.07800 | 1.0616 |
| 14 | $T_{6-10}$ | 1.06900 | 1.0612 |
| 15 | $T_{4-12}$ | 1.03200 | 1.0529 |
| 16 | $T_{28-27}$ | 1.06800 | 1.0497 |

The optimization offers two benefits viz. total fuel cost minimization and real power loss minimization. The reduction in real power loss is because of the change in the line flows and cost minimization is mainly because of optimal settings of real power output from the generators. The cost and loss reduction achieved by BB-BC algorithm is given in table 4.

Table 4. Minimization of cost and loss by BB-BC algorithm

| SI.No | Parameters | Initial value | Final value |
|---|---|---|---|
| 1 | Fuel cost (USD/hr) | 802.9367 | 800.6908 |
| 2 | Power loss (MW) | 9.6470 | 9.3303 |

The efficiency of the algorithm is proved by comparing its performance with that of other recently reported algorithms like TS, EP and DE. It is obvious from table 5 that the reduction in the total fuel cost is quite encouraging. The cost obtained by other methods is about 802 USD/hr whereas BB-BC has achieved only 800.6908 USD/hr and this is a great advantage.

Table 5. Total fuel cost obtained by different methods

| IEEE-30 bus system | TS [22] | TS/SA [22] | ITS[22] | EP [22] | IEP [22] | DE [22] | BB-BC |
|---|---|---|---|---|---|---|---|
| Cost (USD/hr) | 802.502 | 802.788 | 804.556 | 802.907 | 802.465 | 802.230 | 800.6908 |

Voltage magnitudes at all load buses are improved after optimization. Figure 3 depicts the voltage magnitude at all the buses in the system. Magnitudes of load bus voltages are adjusted to about 1.0 p.u. Maintaining the load bus voltages within the allowable limit is an indication that real power loss is optimized.

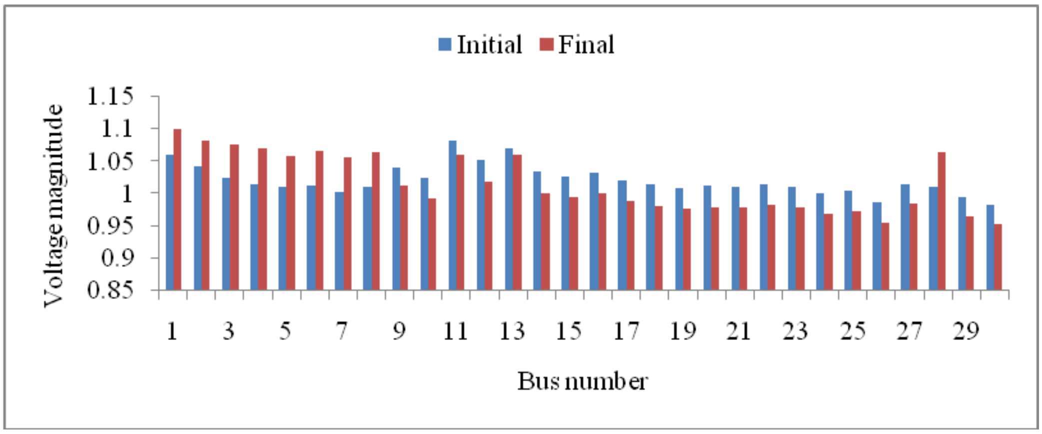

Figure 3. Voltage profile improvement

The strength of an optimization technique is characterised by its convergence speed or the number of iterations taken to get the optimized results. In this work, the minimum fuel cost is obtained within 45 iterations. This proves the effectiveness of the algorithm. Fig 4 graphically depicts the excellent convergence quality of BB-BC algorithm.

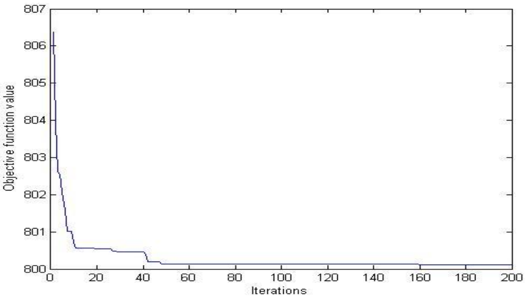

Figure 4. Convergence characteristics of BB-BC

## III. CONCLUSIONS

In this work, the nature inspired BB-BC based optimization algorithm is proposed to solve multi-constrained optimal power flow problem. The performance of the proposed algorithm in solving this OPF is demonstrated using IEEE-30 bus system. The results are compared to those of other algorithms like TS and DE. The test results clearly show that BB-BC outperforms other recently 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 all 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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