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Dwindling of Real Power Loss by Enriched Big Bang-Big Crunch Algorithm

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ABSTRACT

In this paper, Enriched Big Bang-Big Crunch (EBC) algorithm is proposed to solve the reactive power problem. The problem of converging to local optimum solutions occurred for the Bang-Big Crunch (BB-BC) approach due to greedily looking around the best ever found solutions. The proposed algorithm takes advantages of typical Big Bang-Big Crunch (BB-BC) algorithm and enhances it with the proper balance between exploration and exploitation factors. Proposed EBC algorithm has been tested in standard IEEE 118 & practical 191 bus test systems and simulation results show clearly the improved performance of the proposed algorithm in reducing the real power loss.

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1. INTRODUCTION

Optimal reactive power dispatch (ORPD) problem is to minimize the real power loss and bus voltage deviation. Various numerical methods like the gradient method [1-2], Newton method [3] and linear programming [4-7] have been adopted to solve the optimal reactive power dispatch problem. Both the gradient and Newton methods have the complexity in managing inequality constraints. If linear programming is applied then the input-output function has to be uttered as a set of linear functions which mostly lead to loss of accuracy. The problem of voltage stability and collapse play a major role in power system planning and operation [8]. Evolutionary algorithms such as genetic algorithm have been already proposed to solve the reactive power flow problem [9-11]. Evolutionary algorithm is a heuristic approach used for minimization problems by utilizing nonlinear and non-differentiable continuous space functions. In [12], Hybrid differential evolution algorithm is proposed to improve the voltage stability index. In [13] Biogeography Based algorithm is projected to solve the reactive power dispatch problem. In [14], a fuzzy based method is used to solve the optimal reactive power scheduling method. In [15], an improved evolutionary programming is used to solve the optimal reactive power dispatch problem. In [16], the optimal reactive power flow problem is solved by integrating a genetic algorithm with a nonlinear interior point method. In [17], a pattern algorithm is used to solve ac-dc optimal reactive power flow model with the generator capability limits. In [18], F. Capitanescu proposes a two-step approach to evaluate Reactive power reserves with respect to operating constraints and voltage stability. In [19], a programming based approach is used to solve the optimal reactive power dispatch problem. In [20], A. Kargarian et al present a probabilistic algorithm for optimal reactive power provision in hybrid electricity markets with uncertain loads. This paper proposes Enriched Big Bang-Big Crunch (EBC) algorithm is proposed to solve the reactive power problem. One of the well-known models in theoretical physics is the Big Bang theory for illustration of the universe existence and its evolution from the past known historical spans over its large-scale evolution. A novel optimization algorithm named Big Bang-Big Crunch algorithm (BB-BC) based on these theories is first initiated in [21] which have been applied in many works including economic power systems [22, 23] and signal processing [24]. On the one hand, the BB-BC algorithm has been started from theoretical concepts of cosmological physics. On the other hand, the BB-BC algorithm outperforms a wide category of evolutionary algorithms which are very sensitive to initial solutions. Due to its modification of the initial solution in the process of the algorithm, BB-BC is aimed at achieving the optimal solution. Thus, BB-BC could be selected as a proper choice for a variety of different optimization and intractable problems. While the BB-BC is used in several works, it suffers from disadvantages such as slow convergence speed and trapping in local optimum solutions available in most of the optimization problems [25]. The problem of converging to local optimum solutions occurred for the BB-BC approach due to greedily looking around the best ever found solutions. Due to its explorative nature, BB-BC lacks a splendid exploitation factor. Such optimization strategies should have a mechanism to make a trade-off between exploration and exploitation. The proposed EBC algorithm takes advantages of typical BB-BC algorithm and enhances it with the proper balance between exploration and exploitation factors.Proposed EBC algorithm has been evaluated in standard IEEE 118 & practical 191 bus test systems. Simulation results show that our proposed approach outperforms all the entitled reported algorithms in minimization of real power loss.

2. PROBLEM FORMULATION

The optimal power flow problem is treated as a general minimization problem with constraints, and can be mathematically written in the following form:

$$\text{Minimize } f(x, u) \quad (1)$$

$$\text{subject to } g(x,u)=0 \quad (2)$$

and

$$h(x, u) \leq 0 \quad (3)$$

where f(x,u) is the objective function. g(x.u) and h(x,u) are respectively the set of equality and inequality constraints. x is the vector of state variables, and u is the vector of control variables.
The state variables are the load buses (PQ buses) voltages, angles, the generator reactive powers and the slack active generator power:

$$x = \left(P_{g1}, \theta_2, .., \theta_N, V_{L1}, ., V_{LNL}, Q_{g1}, .., Q_{gng}\right)^T \quad (4)$$

The control variables are the generator bus voltages, the shunt capacitors/reactors and the transformers tap-settings:

$$u = \left(V_g, T, Q_c\right)^T \quad (5)$$

or

$$u = \left(V_{g1}, \dots, V_{gng}, T_1, .., T_{Nt}, Q_{c1}, .., Q_{cNc}\right)^T \quad (6)$$

Where ng, nt and nc are the number of generators, number of tap transformers and the number of shunt compensators respectively.

3. OBJECTIVE FUNCTION

3.1. Active power loss

The objective of the reactive power dispatch is to minimize the active power loss in the transmission network, which can be described as follows:

$$F = PL = \sum_{k \in Nbr} g_k \left(V_i^2 + V_j^2 - 2V_iV_j cos\theta_{ij}\right) \quad (7)$$

Or

$$F = PL = \sum_{i \in Ng} P_{gi} - P_d = P_{gslack} + \sum_{i \neq slack}^{Ng} P_{gi} - P_d \quad (8)$$

where g_k: is the conductance of branch between nodes i and j, Nbr: is the total number of transmission lines in power systems. P_d: is the total active power demand, P_{gi}: is the generator active power of unit i, and P_{gsalck}: is the generator active power of slack bus.

3.2. Voltage profile improvement

For minimizing the voltage deviation in PQ buses, the objective function becomes:

$$F = PL + \omega_v \times VD \quad (9)$$

where ω_v: is a weighting factor of voltage deviation.
VD is the voltage deviation given by:

$$VD = \sum_{i=1}^{Npq} |V_i - 1| \quad (10)$$

3.3. Equality Constraint

The equality constraint g(x,u) of the ORPD problem is represented by the power balance equation, where the total power generation must cover the total power demand and the power losses:

$$P_G = P_D + P_L \quad (11)$$

This equation is solved by running Newton Raphson load flow method, by calculating the active power of slack bus to determine active power loss.

3.4. Inequality Constraints

The inequality constraints h(x,u) reflect the limits on components in the power system as well as the limits created to ensure system security. Upper and lower bounds on the active power of slack bus, and reactive power of generators:

$$P_{gslack}^{min} \leq P_{gslack} \leq P_{gslack}^{max} \quad (12)$$

$$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max}, i \in N_g \quad (13)$$

Upper and lower bounds on the bus voltage magnitudes:

$$V_i^{min} \leq V_i \leq V_i^{max}, i \in N \quad (14)$$

Upper and lower bounds on the transformers tap ratios:

$$T_i^{min} \leq T_i \leq T_i^{max}, i \in N_T \quad (15)$$

Upper and lower bounds on the compensators reactive powers:

$$Q_c^{min} \leq Q_c \leq Q_C^{max}, i \in N_C \quad (16)$$

Where N is the total number of buses, N_T is the total number of Transformers; N_c is the total number of shunt reactive compensators.

4. BIG BANG-BIG CRUNCH OPTIMIZATION ALGORITHM

Two prominent theories subsist numerous theories regarding how the universe developed, in this regard are specifically Big bang and Big crunch, hypothesis. Erol et al., [21] employ of these hypothesis and launched the BB-BC optimization algorithm. According to this hypothesis, owing to debauchery, Big Bang phase produces arbitrariness along with muddle, even as in the Big Crunch phase the arbitrarily produced particles will be haggard into an order. Big Bang-Big Crunch algorithm (BB-BC) commence with the big bang segment through the production of arbitrary points in the region of a primarily elected point and it aims to shrivel the formed points into a single optimized one by the center of mass in the big crunch segment.

Ultimately, after replicate the two segments for a restricted number of times, the algorithm converges to a superlative solution. Alike to erstwhile evolutionary algorithms [26], this technique has a candidate solution where some new-fangled particles are arbitrarily distributed around it based on a consistent way all over the exploration space. The arbitrary nature of the Big Bang is related with the energy dissipation or transmission from a well-organized state to a chaotic state i.e. transmission from a candidate solution to a set of new-fangled particles. The Big Bang phase is track by the Big Crunch segment. In this segment the fresh arbitrary dispersed particles are haggard into an order via the center of mass. Subsequent to successive duplication of Big Bang and Big Crunch steps, the distribution of arbitrariness during Big Bang segment becomes further and further smaller and ultimately the algorithm converges to a solution.

The procedure of calculating the center of mass is done by the following equation,

$$x_j^c = \frac{\sum_{j=1}^{N} \frac{x_j^i}{f^i}}{\sum_{j=1}^{N} \frac{1}{f^i}}, for\ i = 1,2,..,N \tag{17}$$

Where x_j^c is the j-th component of the center of mass, x_j^i is the j-th component of i-th candidate, f^i is fitness value of the i-th candidate, and finally N is the number of all candidates.

Algorithm then produces fresh population of particles by the following equation,

$$x_j^{i,new} = x_j^c + r \times \frac{\left(x_j^{max} - x_j^{min}\right)}{1+k} \tag{18}$$

Where $x_j^{i,new}$ is the new value of j-th component of the i-th particle x, r is a arbitrary number with a standard normal distribution, and k is the iteration index. Also x_j^{max} and x_j^{min} are maximum and minimum acceptable values for x_j.

Big Bang Big Crunch Algorithm
Input: fitness function, number of stars
Output: output of reactive power problem

a. *Initialisation*:
b. Preliminary_ point=produce an arbitrary preliminary point with respect to variety constraints.
c. num_ of _stars=number of stars
d. dim=dimension of solution
e. replicate
f. *Big Bang Phase*: ⊲ fabricate mass in the region of preliminary point
g. for i=1 to num of stars do
h. for j=1 to dim do
i. mass [i, j]=fabricate a star based on (18)
j. end for
k. end for
l. *Big Crunch Phase*:
m. c.o.m=compute center of mass based on (17)
n. preliminary _point=c.o.m ⊲ update
o. until maximum number of iterations or convergence

5. ENRICHED BIG BANG-BIG CRUNCH (EBC) ALGORITHM

Two significant mechanisms of evolutionary algorithms are Exploration and exploitation. In order to proceed productively, every search algorithm needs to provide a excellent trade-off between these two factors. Exploration is the procedure of penetrating fresh solution regions of the exploration space, exploitation on the other hand is to search in the neighbourhood of formerly found solutions. As an example of exploration in the BB-BC algorithm equation (18) seeks to explore in the new-fangled solution regions by arbitrarily dispatch points in solution space. It can be observed from the cycles of the BB-BC algorithm, that it greedily drops the current center of mass in favour of a better one at the end of each big bang and big crunch cycle. Even though the BB-BC algorithm discovers the solution space to a great extent, it endures from lack of appropriate and effectual exploitation. Since the entire exploration of the search space to compute the center of masses in each iteration & the efficiency of the algorithm is sensitive to these points in each step. Furthermore, it is more likely to have some local solutions in the formerly computed center of masses through the procedure of the algorithm. To make exploit of previous found centers of masses and enhancing the exploitation of the algorithm, a memory with restricted size is added to the procedure of the algorithm in an elegant vein to suggest a novel approach. At the end of each big bang and big crunch cycles, the computed center of mass will be stored in the memory.

At first it is believed that all of the saved centers of masses in the memory are superior points for engendering the particles forming the fresh center of masses. Moreover, if the memory gets full during the algorithm, the nastiest solution will be replaced by the fresh center of mass based on the fitness of the currently saved solutions. We augment the particle generation based on a probabilistic arbitrary walk manner in such a way that the adaptable parameter α is considered as the selection probability of the solutions in the memory. Therefore, the superior aspects of the dimensions of the points in the memory are used in the projected method. Furthermore, the weight probabilities are linearly augmented as algorithm goes by to consider more significance on the memory points. This exploitation modification idea is alike to the declining values of pitch adjustment rate in harmony search algorithm [27] and inertia weight in PSO algorithm [28]. Such tactic results in improved performance of the meta-heuristic algorithms, due to the fact of additional exploration at commencement and more exploitative at the end in the exploration space of the algorithm [26].

Enriched Big Bang-Big Crunch (EBC) algorithm
Input: fitness function, memory size, number of stars,
Output: optimal real power loss

a. *Initialization*:
b. solution memory=memory with size memory size
c. α=0.1 ⊲ memory selection rate
d. num of stars=number of stars
e. repeat
f. *Big Bang Phase*: ⊲ produce mass around preliminary point
g. for i=1 to num _of_ stars do
h. for j=1 to dim do
i. if rand (0, 1) <=α then
j. idx=rand ([1,..., memory_ size])
k. mass [i, j]=solution_ memory [idx, j] ⊲ select from memory
l. else
m. mass [i, j]=generate a star based on equation 18
n. end if
o. end for
p. end for
q. for each star ∈ mass do
r. mass_ fitness [star]=fitness(star)
s. end for
t. *Big Crunch Phase*:
u. c.o.m=compute center of mass (equation 17)
v. if solution_ memory is not full then
w. append c.o.m into solution _memory
x. else
y. worse=find the worst solution in solution_ memory
z. if fitness (c.o.m) > fitness (worse) then
aa. eliminate worse from the solution_ memory
bb. affix c.o.m into solution_ memory
cc. end if
dd. end if
ee. centers=c.o.m ⊲ update
ff. α=α + 0.01 × α ⊲ update
gg. until maximum number of iterations or convergence

6. SIMULATION RESULTS

At first Enriched Big Bang-Big Crunch (EBC) algorithm has been tested in standard IEEE 118-bus test system [29]. The system has 54 generator buses, 64 load buses, 186 branches and 9 of them are with the tap setting transformers. The limits of voltage on generator buses are 0.95-1.1 per-unit., and on load buses are 0.95-1.05 per-unit. The limit of transformer rate is 0.9-1.1, with the changes step of 0.025. The limitations of reactive power source are listed in Table 1, with the change in step of 0.01.

Table 1. Limitation of Reactive Power Sources

BUS	5	34	37	44	45	46	48
QCMAX	0	14	0	10	10	10	15
QCMIN	-40	0	-25	0	0	0	0
BUS	74	79	82	83	105	107	110
QCMAX	12	20	20	10	20	6	6
QCMIN	0	0	0	0	0	0	0

The statistical comparison results of 50 trial runs have been list in Table 2 and the results clearly show the better performance of proposed EBC algorithm.

Table 2. Comparison Results

Active power loss (p.u)	BBO [30]	ILSBBO/strategy1 [30]	ILSBBO/strategy1 [30]	Proposed EBC
Min	128.77	126.98	124.78	116.22
Max	132.64	137.34	132.39	118.42
Average	130.21	130.37	129.22	117.32

Then the Enriched Big Bang-Big Crunch (EBC) has been tested in practical 191 test system and the following results have been obtained. In Practical 191 test bus system-Number of Generators=20, Number of lines=200, Number of buses=191 Number of transmission lines=55. Table 3 shows the optimal control values of practical 191 test system obtained by EBC method. Table 4 shows the results about the value of the real power loss by obtained by Enriched Big Bang-Big Crunch (EBC) algorithm.

Table 3. Optimal Control Values of Practical 191 Utility (Indian) System by EBC Method

VG1	1.10	VG 11	0.90
VG 2	0.78	VG 12	1.00
VG 3	1.01	VG 13	1.00
VG 4	1.01	VG 14	0.90
VG 5	1.10	VG 15	1.00
VG 6	1.10	VG 16	1.00
VG 7	1.10	VG 17	0.90
VG 8	1.01	VG 18	1.00
VG 9	1.10	VG 19	1.10
VG 10	1.01	VG 20	1.10

T1	1.00	T21	0.90	T41	0.90
T2	1.00	T22	0.90	T42	0.90
T3	1.00	T23	0.90	T43	0.91
T4	1.10	T24	0.90	T44	0.91
T5	1.00	T25	0.90	T45	0.91
T6	1.00	T26	1.00	T46	0.90
T7	1.00	T27	0.90	T47	0.91
T8	1.01	T28	0.90	T48	1.00
T9	1.00	T29	1.01	T49	0.90
T10	1.00	T30	0.90	T50	0.90
T11	0.90	T31	0.90	T51	0.90
T12	1.00	T32	0.90	T52	0.90
T13	1.01	T33	1.01	T53	1.00
T14	1.01	T34	0.90	T54	0.90
T15	1.01	T35	0.90	T55	0.90

Table 4. Optimum Real Power Loss Values Obtained For Practical 191 Utility (Indian) System by EBC Method.

Real power Loss (MW)	EBC
Min	145.012
Max	147.214
Average	146.002

7. CONCLUSION

Enriched Big Bang-Big Crunch (EBC) algorithm has been successfully applied for solving reactive power problem. And it has been tested in standard IEEE 118 & practical 191 bus test systems. Performance comparisons with well-known population-based algorithms give enhanced results. Enriched Big Bang-Big Crunch (EBC) comes out to find high-quality solutions when compared to that of other reported standard algorithms. The simulation results presented in preceding section confirm the ability of EBC method to arrive at near to global optimal solution.

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