Optimal Active Power Rescheduling of Generators for Congestion Management Based On Big Bang-Big Crunch Optimization Using New Definition of Sensitivity

FarzadVazinram, MajidGandomkar, Javad Nikoukar

Abstract*— Restructuring of power systems and appearance and development of many electricity markets in all levels of power systems, introduce the congestion challenge of power transmission lines as a critical threat for power systems. Many studies have been attempted to present techniques for congestion management (CM). One of them is active power rescheduling of generators which has two steps. First step is optimum selection of generators on the basis of sensitivities of generator to power flow on congested line/lines. In this paper, the new definition of sensitivity is introduced based on the old definition of sensitivity that consists of cost factor. Next step of CM process is optimum rescheduling of generators power. In this paper, the optimization of rescheduling of generators power is performed based on Big Bang-Big Crunch (BB-BC) algorithm which is improved by Particle Swarm Optimization (PSO) method as Hybrid BB-BC (HBB-BC) optimization for the first time. Effectiveness of the results of proposed method has been tested on the 39-bus New England system and IEEE 30-bus and IEEE 118-bus systems.

Index Terms*—Big bang-big crunch algorithm, constraint, generator sensitivity, heuristic optimization, optimal rescheduling, transmission congestion management.

I. INTRODUCTION

With growth of electric-based technologies, demand for electric power has increased in recent years. Hence, electric utilities have to increase their generation. Although the electric power can transmit between every two locations of grid, many factors like: thermal limitation, voltage limitation, stability limitation, etc., can limit the transmission power in a specific value. When the demand and generation change in manner that transmission system have to transmit more than whose permissible limitation and the values exceed owing to one or more mentioned limitation, it is called that system is congested [1]. When a line in the transmission system is congested, the congestion must not exceed from a specific value inasmuch as this event beget losing some groups of loads and if this condition continues, it will conduce to deployment of congestion all over the grid and finally, a Blackout will occur. This issue can have critical economic and political consequences; Moreover, with presence and development of micro-grids with many new abilities like trading electric energy between homemade users or even homemade users and the main grid, requirement of permanent and reliable transmission lines seems to be essential [2].

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Therefore, in congestion occurring and unbalance situations, The Independent System Operator (ISO) attempt increasing the efficiency of market to keep the stability and reliability of system. As a consequence, ISO must legislate some crystal and solid rules to prevent misuse of entities from the congestion occurred between two locations of grid [3]. In retrospect, various methods are represented for CM which is explained in [4]. Deregulated electric power is deferent among the different countries and even in different locations of a country. The difference of various methods of trade, interaction between properties and different limitation of transmission system are mentioned in [5].

In this paper, the new method is presented to relieve the system congestion. In this method, specific generators are just selected. With changing the power generation of selected generators, the system will have minimum CM cost. The solution is that the power of generators with the minimum cost is increased and the power of generators with maximum cost is decreased till the congestion problem of the whole system is alleviated with the minimum cost. To achieve this goal, the new definition of sensitivity based on cost and active power has been described for the first time. Moreover, to relieve the congestion lines, an optimal active power rescheduling of generators on the ground of Big Bang-Big Crunch (BB-BC) is selected for the first time. This method has been improved by Particle Swarm Optimization (PSO) method as Hybrid BB-BC (HBB-BC) optimization. Subsequently, the results of new definition of sensitivity and the BB-BC algorithm are compared with the other methods and algorithms to determine the best way of CM.

In this paper, static CM using optimal active power rescheduling of generators based on the new definition of sensitivity is analyzed for the first time and whose results are compared with the results of FABF, SBF and PSO algorithms. This paper illustrates the effectiveness of proposed method on the 39-bus New England system and IEEE 30-bus and IEEE 118-bus systems.

This paper is organized as follows. In Section II literature survey on recent studies about CM is detailed. Section III introduces the Big Bang-Big Crunch algorithm which is improved as HBB-BC algorithm. Section IV details the problem formulation of CM using rescheduling of active power of generators based on new definition of sensitivity. The CM solution by HBB-BC is presented in Section V. Numerical examples which reveal the effectiveness of proposed method are tested on the 39-bus New England system and IEEE 30-bus and IEEE 118-bus systems in Section VI. Finally, the conclusion is described in Section VII.

II. LITERATURE SURVEY

The wide researches are attempted about CM until now. CM and control systems are utilized to avoid exceeding of system parameters from their defined limitations [1]. To relieve the system congestion, the FACTS devices (using the performance of transformers taps to manage the congestion) [6], rescheduling of power generation [7], and curtailment of pool loads or bilateral contracts can be used. Influence of coordination based transaction curtailment in power market is studied in [8] in which the open transmission dispatch is similar to pool and bilateral/multilateral dispatch coexists.

The transaction curtailment based congestion removal on the IEEE 14 node based with DC load flow is reported in [9]. In the deregulated environment, DISCOs and GENCOs are scheduling their transactions before their due date. At this moment, some transmission lines could be congested while transactions are implementing. This issue can endanger the reliability of power network, so ISO must remove the congestion problem to keep the reliability of network. Basically, ISO uses two methods for CM [3]:

1. *Cost free means*:
    a) Out-aging of congested lines.
    b) Operation of transformer taps/phase shifters.
    c) Operation of FACTS devices particularly series devices.
2. *Non-cost free means*:
    a) Re-dispatch of generation in a manner different from the natural setting point of the market.
    b) Curtailment of loads and the exercise of (non-cost-free) load interruption options.

Generally, there are four methods for CM: (a) sensitivity factors based method, (b) auction based CM, (c) pricing based method and (d) re-dispatching and willingness to pay method [10]. Re-dispatching based congestion removal method with contingency constrained limits is mentioned in [11]. Influence of CM on reliability of power transaction based is discussed in [12], and the improving of voltage stability using of CM is mentioned in [13]. The auction based power transaction bidding and some extra subjects about CM is considered in [14]. The concentric relaxation based method is explained in [15]. Various techniques of CM on power market are described in [16]. Also, the role of ISO, to improve the system reliability and prevent line congestion caused by limitations, is presented in [4]. The confirmation of optimal power flow in deregulated environment using evolutionary programming based approach and Genetic algorithm is proposed in [17] and the generation rescheduling based on this algorithm is attempted in [18]. A fuzzy interactive multiobjective optimization for optimization of social welfare is reviewed in [19]. The optimal topological configuration of power system as the other method for CM is discussed in [20]. A combinatory framework to identify the services and to minimize the cost of CM an OPF-based approach is reported in [21]. The method of zonal CM to relieve congestion on ac load flow using rescheduling of active and reactive power to change the ac congestion factors is explained in [22] and [23], and also the effect of this optimal rescheduling on generators and capacitors for CM is illustrated in them. The real power generation rescheduling based (RED) to stabilize the voltage and to relieve the overload on relative electric distance is described in [24]. A coordinating mechanism between power generators and system operator to remove the congestion based on Benders Cuts is defined in [25]. To eliminate the congestion caused by thermal overload and instability of voltage in a deregulated environment, two methods is studied for unified CM in [26]. The Particle Swarm Optimization (PSO) algorithm is defined in [27] and it is developed into five groups in [28]. The PSO method is expanded in [29] and its applications is discussed in power systems too. Optimal Power Flow (OPF) based on PSO algorithm is utilized to remove congestion on IEEE 30-bus system test in [30] which proved that CM by this way is more useful in comparison with Interior Point Method (IPM) and Genetic Algorithm (GA) Approach. Cost efficient generation rescheduling and load shedding approach methods to eliminate the congestion based on Multiobjective Particle Swarm Optimization (MOPSO) is presented in [31]. Simple Bacterial Foraging (SBF) optimization algorithm in control and optimization of distribution is proposed in [32] which is improved as Fuzzy Adaptive Bacterial Foraging (FABF) for CM in [3]. CM based on Bee Colony Optimization (BCO) technique is proposed in [33] and it is conducted on IEEE 30-bus reliability test system.

III. BIG BANG-BIG CRUNCH OPTIMIZATION

Heuristics algorithms are some kind of algorithms which using a simple way to generate desired answer for optimization the problems and recently, they have been more powerful and famous. The advantages of these algorithms can be summarized as [34]:

- They do not need the complicated mathematical models and also request less initial mathematical variables.
- They do not need initial configurations of values for decision variables; therefore, they may exit from the local optimization space.
- They do not require solution space type, the number of decision variables and the number of constraints.
- The power of computation of them is desired and they do not need the extra time computation.
- Unlike the classic algorithms, they do not require alteration on the interested problems, so they adapt themselves to solve variety of problems.

A. Introduction to BB-BC Optimization

Big Bang-Big Crunch (BB-BC) optimization algorithm is one of the recent heuristic optimization algorithms which has two phases and relies on one of the theories of universe evolution [35]. In Big Bang phase, energy dissipation generates disorders and randomness as candidates' solution, whereas in Big Crunch phase randomly distributed particles and will go toward an order as convergence operator. In BB-BC optimization algorithm which is inspired from evolution of universe, random points are generated in BB phase and will be shrunk to a single point as "center of mass" through BC phase [35] like the other evolutionary algorithms. The point that is described as center of mass is denoted by $A_i^{c(k)}$ is calculated according to:

$$A_i^{c(k)} = \frac{\sum_{j=1}^{N} \frac{1}{Merj} \cdot A_i^{(kj)}}{\sum_{j=1}^{N} \frac{1}{Merj}} \ , \quad i = 1,2, \dots , ng \qquad (1)$$

where $A_i^{(kj)}$ is the ith candidate of jth solution generated in the kth iteration, N is the population size in Big Bang phase and Mer^j is merit function for the jth candidate. After The Big Crunch phase, algorithm utilizes the former information as center of mass to attempt generation of new solutions in next iteration for Big Bang phase. This purpose gets executed according to:

$$A_i^{(k+1,j)} = A_i^{c(k)} + \frac{r_j \alpha_1 (A_{max} - A_{min})}{k+1}, \quad i = 1,2,\dots,ng \quad (2)$$

where r_j is a random number which changes for each candidate, and α_1 is a parameter to limit the size of search space. These steps will repeat till the stopping criterion has been met and also the number of iterations could be selected as stopping criterion.

BB-BC algorithm does not require the crystal relation between objective function and constraints but objective function can be penalized for some of the design variables till all of the design constraints are applied. Method of utilization of penalty functions is the manner that if constraints be in the permissible limitation, penalty will be zero. Otherwise, penalty factor has to be applied.

The pseudo-code of BB-BC algorithm can be summarized as follows in five steps [35]:

1) Initial candidates are generated randomly as respects of permissible limitation (Big Bang phase).
2) The merit function values of all the candidates are calculated.
3) The center of mass is computed (1) (Big Crunch phase)
4) The new candidates are calculated around the center of mass in step 3 (2).
5) Return to step 2 until the stopping criterion has been met.

B. BB-BC Optimization Improvement using PSO Optimization method (HBB-BC)

However the BB-BC optimization method has the mentioned advantages like the fine search around a local optimum but it has some problems in global investigation of search place [34]. If all candidates of initial BB phase are collected in small area of search space, it is possible that BB-BC cannot find the optimum solution and may be trapped in that subdomain [34]. One solution is increasing the number of candidates to overbear the problem but it causes the increasing the merit evaluation and computational costs. To improve the performance of BB-BC algorithm in optimum manner, it is used the Particle Swarm Optimization (PSO) algorithm which improves the exploration ability of it.

By this way, the Hybrid BB-BC (HBB-BC) not only utilizes the center of mass but also uses the best position of each candidate ($A_i^{lbest(k,j)}$) and the best global position ($A_i^{gbest(k)}$) to generate a new candidate [27], as:

$$A_i^{(k+1,j)} = \alpha_2 A_i^{c(k)} + (1-\alpha_2)\left(\alpha_3 A_i^{gbest(k)} + (1 - \alpha3Ailbestk,j + rj\alpha1(Amax-Amin)k+1, \qquad i=1,2,\dots, ngj=1,2,\dots, N \quad (3)$$

where $A_i^{lbest(k,j)}$ is the best position of the jth particle up to the k and $A_i^{gbest(k)}$ is the best position among all candidates up to the kth iteration. α_2 And α_3 are adjustable parameters which control the influence of the global and local best on the new position of candidates, respectively.

To generate the new solutions, it will be utilized the (3) rather than (2).

IV. PROBLEM FORMULATION

In the power system, economic operation of generation equipment is preferred. In deregulated market environment, the first part of power dispatch is detecting the desired scheduling using OPF and second part is rescheduling of generation to remove the congestion [3]. The goal of OPF is minimizing the fuel cost of generating units that is considering of load demand, generator operation constraints and line flow limits. The merit function of OPF problem is illustrated in [10]. The generators in the power systems have different sensitivity to power flow on the congested lines. A changing in real power flow in a line between bus i and bus j (line k) due to change in power generation by generator g can be presented as generator sensitivity (GS) to congested line. GS could be expressed as:

$$GS_g = \frac{\Delta P_{ij}}{\Delta P_g} \qquad (4)$$

where P_{ij} is the real power flow on the congested line k and P_g is the real power generated by generator g. It is noteworthy that GSs is computed as regards the slack bus as reference, so the GS of slack bus in every congested line is considered zero.

To calculate the GSs, the power flow equation on congested line can be represented as

$$P_{ij} = -V_i^2 Y_{ij} cos\theta_{ij} + V_i V_j Y_{ij} cos(\theta_{ij} + \delta_{ji})$$
$$= -V_i^2 Y_{ij} cos\theta_{ij} cos\delta_{ji} - V_i V_j Y_{ij} sin\theta_{ij} sin\delta_{ji}$$
$$= -V_i^2 G_{ij} + V_i V_j G_{ij} cos(\delta_i - \delta_j) + V_i V_j B_{ij} sin(\delta_i - \delta_j) \quad (5)$$

where V_i and δ_i are the voltage magnitude and phase angle at ith Bus, and Y_{ij} and θ_{ij} are magnitude and phase angle of ij th element of Y_{Bus} matrix respectively. G_{ij} and B_{ij} express, respectively, the conductance and susceptance of line between bus i and j. Neglecting P-V coupling and using Taylor series approximation, (5) can be written as

$$\Delta P_{ij} = \frac{\partial P_{ij}}{\partial \delta_i} \Delta\delta_i + \frac{\partial P_{ij}}{\partial \delta_j} \Delta\delta_j \quad (6)$$

The first terms of two products in (6) can be calculated by (5) as

$$\frac{\partial P_{ij}}{\partial \delta_i} = -V_i V_j G_{ij} sin\delta_{ij} + V_i V_j B_{ij} cos\delta_{ij} \quad (7)$$
$$\frac{\partial P_{ij}}{\partial \delta_j} = +V_i V_j G_{ij} sin\delta_{ij} - V_i V_j B_{ij} cos\delta_{ij} \quad (8)$$
$$\frac{\partial P_{ij}}{\partial \delta_i} = -\frac{\partial P_{ij}}{\partial \delta_j}. \qquad (9)$$

Neglecting P-V coupling, the relation between active power and phase angle of voltages can be written as

$$\Delta P = [J_{11}][\Delta\delta] \qquad (10)$$

From (10), it can be written

$$\Delta\delta = [J_{11}]^{-1}[\Delta P] = [M][\Delta P] \quad (11)$$

The second terms of the two products in (6) are obtained by rewriting (11) in a new form

$$\Delta\delta_i = \sum_{k=1}^{n} m_{ik}\,\Delta P_k, \quad i = 1,2,3,\dots n, i \neq s \qquad (12)$$
$$\Delta\delta_j = \sum_{k=1}^{n} m_{jk}\,\Delta P_k, \quad j = 1,2,3,\dots n, j \neq s \qquad (13)$$

where n is the number of buses and s is the slack bus in the system.

In this paper, a new definition for generator sensitivity has been proposed. As mentioned, the common definition of GS is computed by (4). Participating generators are determined using their GSs by operator. The goal of rescheduling of generators is minimizing the cost, whereas in this definition of sensitivity, cost has not been considered and GS is just based on power flow of each generator on congested line. As to cost issue, this is completely manifest that minimizing the cost using optimization algorithm based on this definition of sensitivity of generators will not give the best answer. Accordingly, a new definition of generator sensitivity, which considers the cost, is expressed as:

$$GS'_g = \begin{cases} GS_g . C_g & , GS_g > 0 \\ \frac{GS_g}{C_g} & , GS_g < 0 \end{cases} \qquad (14)$$

where GS_g is the old definition of generator sensitivity, GS'_g is new definition of generator sensitivity considering the cost and C_g is the cost of increasing the power of transmission line k (ΔP_{ij}) by increasing the power of generator g (ΔP_g). As it is obvious in (14), GS'_g is divided into two groups based on positive and negative GS_g s. positive GS_g means that increasing the power of generator g causes increasing the power of congested line k and the negative GS_g means that increasing the generator g causes decreasing the power of congested line k. To remove the congestion, the generators with negative GS_g must increase their generation and the generators with positive GS_g must decrease their generation until the power flow of congested line reaches to its permissible limits. To have minimum cost, increasing power generation must be done by the generators with minimum cost generation and decreasing power generation must be done by generators with maximum cost of generation. The new definition of sensitivity (GS'_g) with cost valuable divides the generators into two groups with positive or negative GS'_g. The maximum values of GS'_g in each group, without considering the signal of GS'_g, are desired to select by operator. This proposed method causes that the generators which have low GS but have low cost generation to increase their generation (or have high cost to decrease their generation) and were not used by operator, participate in CM process.

Generally, the power system operators select the generators which have large magnitude of sensitivity line and non-uniform values based on GS. These generators participate in CM with rescheduling of the output power of them. The proposed method of generators sensitivity should be considered by operators to achieve the CM with the minimum cost. Actually, selection of generators is based on both definitions of sensitivity, generators with large magnitude of GS' s (without considering the signal of GS') and non-uniform values of GSs.

Based on the bids received from the participant generators, the amount of rescheduling required is calculated by solving the following optimization problem as merit function [7]:

$$C_c = \text{minimize} \sum_{g}^{N_g} C_g(\Delta P_g)\,\Delta P_g \quad (15)$$

Subject to

$$\sum_{g=1}^{N_g} \left((GS_s)\Delta P_g\right) + PF_k^0 \leq PF_k^{max}, \quad k = 1,2,3,\dots,Nl \ (16)$$
$$\Delta P_g^{min} \leq \Delta P_g \leq \Delta P_g^{max} \qquad (17)$$
$$\Delta P_g^{min} = P_g - P_g^{min} \qquad (18)$$
$$\Delta P_g^{max} = P_g^{max} - p_g, \quad where \quad g = 1,2,3,\dots,N_g \quad (19)$$
$$\sum_{g=1}^{N_g} \Delta P_g = 0 \quad (20)$$

where ΔP_g is the real power adjustment at bus-g and $C_g(\Delta P_g)$ are the incremental and decremented price bids submitted by generators and these generators are willing to adjust their real power outputs.

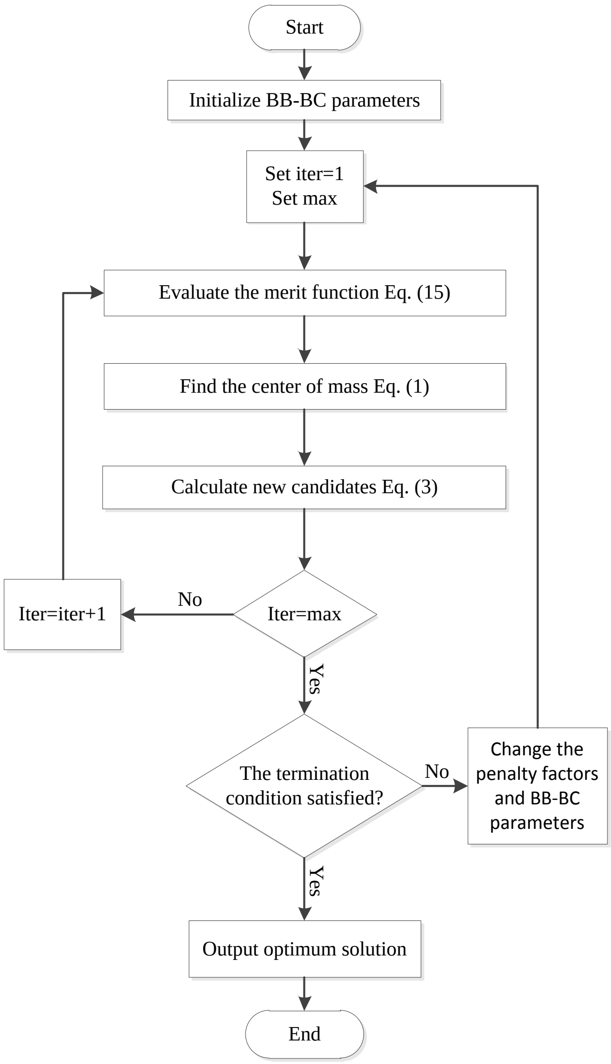

Fig. 1.Flow chart of BB-BC congestion management using active power rescheduling.

PF_k^0 is the power flow caused by all contracts requesting the transmission service. PF_k^{max} is the line flow limit for the line connecting bus-I and bus-j. N_g is the number of participating generators, N_l is the number of transmission lines in the system, P_g^{min} and P_g^{max} denote the minimum and maximum limits of generator outputs, respectively. It can be seen that the power flow solutions are not utilized during the process of optimization.

V. SOLUTION BY BIG BANG-BIG CRUNCH

For CM of power systems, influence of every generator on congested transmission line is computed by (14). By this way, the generators with high sensitivity can be selected by operator to relieve the congested transmission line/lines. The merit function is selected as (15) and constraints (16)–(20) are applied to (15) as penalty factors. With optimization of merit function, the amount of generation of each generator is determined with respect of generation limits, power balance, power generating and demanding balance, and limitation of other transmission lines.

To detect the congested line/lines, an OPF is carried out. By this way, the power flow of each line is compared with the limitations of each line to detect the congested line/lines. After it, the center of mass must be calculated using (1) (the mentioned merit function is applied to (1)). New candidates are computed by (3). These steps will be repeated to the extent that iteration number which is defined by operator. After all iterations, the results are compared with mentioned constraints and if they do not terminate the constraints, the answers will be accepted and program will go to next iteration, otherwise parameters of penalty factors and HBB-BC algorithm must be modified and be applied again. After it, all recent steps will be repeated again. The performance of this method is completely presented in Fig. 1.

VI. NUMERICAL EXAMPLES

HBB-BC algorithm for CM is performed by MATLAB software. Performance of this algorithm is tested on the 39-bus New England system and IEEE 30-bus [36] and IEEE 118-bus systems [37]. The results of proposed method on the 39-bus New England system are compared with [7] and [24] and the results of IEEE 30-bus system based on proposed method are compared with the results of [3], [7], [32] and [38] and performance of which on IEEE 118-bus system is compared with [7] and [38].

A. 39-Bus New England System

The 39-bus New England system comprises ten generator buses and 29 load buses. The congested line in this system connects the bus-14 to bus-34. The generators price bids for this system is represented in Table I. According to Table I, the GS' s, based on the GS amounts which are adapted from [7], are calculated and are represented in Table II. For comparing the results of proposed method with [7] and [24], an outage has been created on the line which connects bus-14 to -34. This issue results in congestion of the line joining buses 15 and 16. Based on the Table II, all GS' s have negative amounts which must increase their generations, so the generators with highest GS' , without considering the signal of GS' , should be selected. Accordingly, the participating generators include generator number 1, 2, 5, 8, 9, and 10. The generator number 1 is selected as increasing generator which must increases its generation. The number of participating generators in comparison with [24] is decreased but it is equal to number of participating generators of [7]. The comparative results are represented in Table III. From these results, it is completely obvious that the system losses are lower and congestion is managed better as illustrated, by the proposed method. So, the effectiveness of selecting generators by new methodology and using new optimization algorithm is proved.

B. Modified IEEE 30-Bus System

The IEEE 30-bus system includes six generator buses and 24 load buses. For better presenting the effectiveness of proposed method, two cases are considered. In the case A, line-26 which connects bus-10to bus-17 is congested. The power flow of this line before rescheduling of generators is 7.01 MW, whereas power flow limit of this line is 6.99 MW.

TABLE I
GENERATOR PRICE BIDS FOR 39-BUS NEW ENGLAND SYSTEM

Gen. No.	1	2	3	4	5
Bids	5.2	4.2	5.4	7.25	4.9
Gen. No.	6	7	8	9	10
Bids	5.05	7.4	5	8.2	4.1

TABLE II
GS' FOR 39-BUS NEW ENGLAND SYSTEM (CONGESTED LINE 15-16)

Gen. No.	1	2	3	4	5
Bids	0.00	-0.11	-0.01	-0.05	-0.07
Gen. No.	6	7	8	9	10
Bids	-0.07	-0.05	-0.1	-0.05	-0.12

TABLE III
SYSTEM PARAMETERS BEFORE AND AFTER RESCHEDULING FOR 39-BUS NEW ENGLAND SYSTEM

System Parameters	Pre-rescheduling	Post-rescheduling		
		Method reported in [24]	Method reported in [7]	Proposed Method
P loss (MW)	59.35	58.00	57.31	56.98
Total rescheduling (MW)		518.45	554.2	556.61

TABLE IV
GS AND GS' FOR IEEE 30-BUS SYSTEM (CASE A-CONGESTED LINE 10-17)

Gen. No.	1	2	3	4	5	6
GS	0	0.65	0.74	0.87	0.48	0.43
GS'	0	11.05	14.06	17.4	7.2	4.3

Hence, the congestion of this line must be removed by optimal rescheduling active power of generators. So, the sensitivity of generators is calculated by (4) and (14) and is given in Table IV (To calculate the GS' s, C_g is adapted from [7]). The generators which are participating in CM must be selected based on their cost and sensitivity to the power flow of congested line. In virtue of the small size of this system against real systems, strong connection of transmission lines and the number of congested lines (in this case is one), all of the generators participate in CM and all of GS' s signals are positive.

TABLE V
ACTIVE POWER GENERATION AFTER CONGESTION MANAGEMENT FOR IEEE 30-BUS SYSTEM (CASE A)

Bus. No.	After CM active power generation (MW)			
	BB-BC	FABF [3]	SBF [32]	PSO [7]
1	196.01	194	194.22	184.24

2	43.26	44.83	43.84	46.63
5	17.93	18.10	18.00	20.56
8	9.87	10.67	10.73	10
11	10.51	10.70	10.78	10
13	11.96	12.50	12.97	12

Table V consists of active power generation of six participant generators after CM. In this Table, the results of proposed method are compared with the other methods. The relationship of generators sensitivity and changing of output power after CM is presented in Fig. 2. The total power generation in proposed method is lower than [3] and [32] but it is higher than [7], although the cost analysis will clarify the best method. The got results by proposed algorithm for cost of CM are expressed as best, worst and mean values in Table VI and are compared with the other algorithms. This point could be strongly said that in spite of the higher amount of total power generation of proposed method against [7], the CM cost of it is significantly lower than [7] and it is obvious that minimizing the CM cost is the main goal.

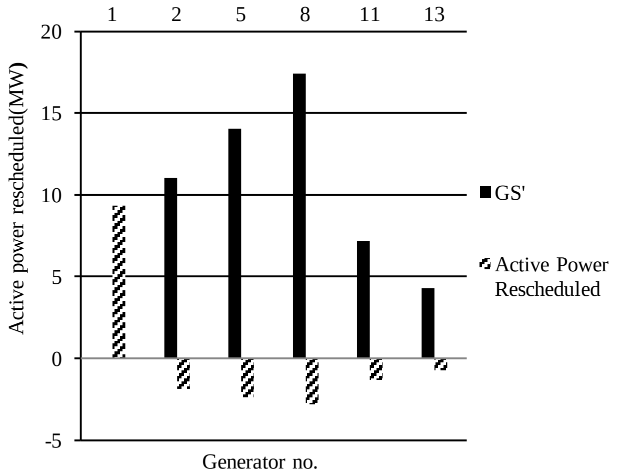

Fig. 2. Plot of active power rescheduled and GS' for generators of 30-bus system (case A).

TABLE VI
COMPARISONS OF CONGESTION MANAGEMENT COST FOR IEEE 30-BUS SYSTEM (CASE A)

Cost of CM ($/MWh)	BB-BC	FABF [3]	SBF [32]	PSO [7]
Best	2.890	2.903	3.429	3.102
Mean	2.905	2.911	3.433	3.126
Worst	2.919	2.912	3.434	3.128

TABLE VII
ACTIVE POWER FLOW IN THE CONGESTED LINE BEFORE AND AFTER CONGESTION MANAGEMENT FOR IEEE 30-BUS SYSTEM (CASE A)

Congested Line	Power Flow(MW) before CM	Power Flow(MW) after CM			
		BB-BC	FABF [3]	SBF [32]	PSO [7]
10-17	7.01	6.88	6.78	6.98	6.9

TABLE VIII
CONGESTED LINES DETAILS OF IEEE 30-BUS SYSTEM (CASE B)

Congested Line	Power Flow(MW)	Line Limit(MW)
2-1	170	130
9-2	66	65

TABLE IX
GS' FOR IEEE 30-BUS SYSTEM (CASE B-CONGESTED LINE 2-1)

Gen. No.	1	2	3	4	5	6
GS'	0.00	-0.05	-0.04	-0.03	-0.04	-0.06

Active power flow of line-26 which connects bus-10 and bus-17 in IEEE 30-bus system, before and after CM, is presented in Table VII and is compared with result of other methods.

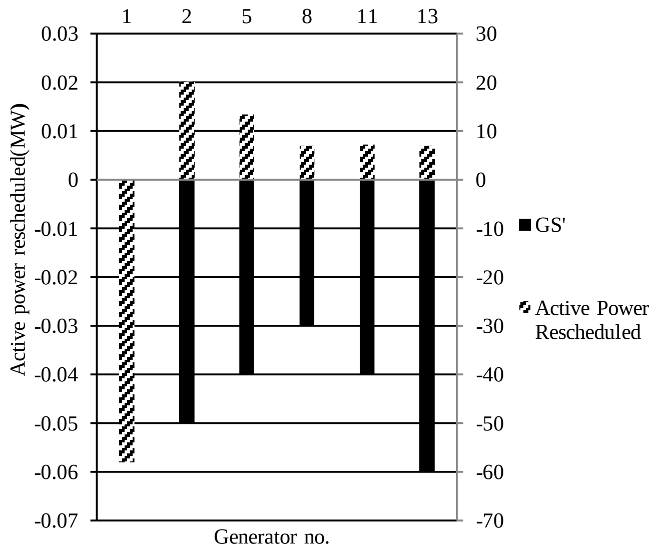

Fig. 3. Plot of active power rescheduled and GS' for generators of 30-bus system (case B).

TABLE X
COMPARISON OF CONGESTION MANAGEMENT COST AND TOTAL POWER, AND POWER FLOW FOR IEEE 30-BUS SYSTEM (CASE B)

	Proposed Method	Method reported in [7]	Method reported in [38]
Approx. Cost of CM($/day)	50 281	50 466	50 700
Power Flow on 2-1(MW)	129	129	130
Power Flow on 9-2(MW)	59	60	60
Total CM(MW)	112.6	111.4	110.2

TABLE XI
CONGESTED LINE DETAILS OF IEEE 118-BUS SYSTEM

Congested Line	Power Flow(MW)	Line Limit(MW)
13-16	262	200

In the case B, it is considered that two lines are congested, the lines which connect bus-2 and -1 and bus-9 and -2. Congested line flow of this system is reported in Table VIII. In this case study, because of the huge difference between line limit and power flow of line 2-1 and the number of the congested lines which are more than one, the results are more similar to reality. GS' s for congested line 2-1 are presented in Table IX. On account of the large amount of difference between line limit and power flow of congested line 2-1 in comparison with line 9-2, GS' s are just calculated based on congested line 2-1 and line limit of congested line 9-2 will be applied to (15) as penalty factor.

For comparison the proposed method with other methodologies, it is compared with [7] and [38]. In the [38], the MF value for comparison has been considered as 0.6 because these results against other MF values are more desired.

The relationship of GS' s with the change in power outputs of generators has been illustrated in Fig. 3 and cost of CM, power flow of congested lines, and total power rescheduling are represented in Table X.

C. Modified IEEE 118-Bus System

In the recent case study, because of the small size of the system in comparison with realistic systems, all the generators had high value of sensitivity and they were participating in CM process. To study practically the proposed method, it is performed on the IEEE 118-bus system as large power network and is compared with results of the other algorithms.

In this case, the congested line is the connector of bus-13 and bus-16.

TABLE XII

GS' FOR IEEE 118-BUS SYSTEM (CONGESTED LINE 13-16)

Gen. No.	GS′	Gen. No.	GS′	Gen. No.	GS′
1	0.00	19	0.14	37	-0.00022
2	0.025	20	0.3	38	-0.00018
3	-0.000053	21	0.4	39	-0.000125
4	-0.0025	22	0.189	40	-0.00013
5	-0.002	23	0.052	41	-0.00002
6	-0.0033	24	0.054	42	-0.00006
7	-0.0031	25	0.08	43	-0.00003
8	-0.0029	26	-0.000067	44	-0.00002
9	-0.0024	27	-0.00024	45	-0.00001
10	-0.0021	28	-0.00011	46	0.015
11	-0.00071	29	-0.00024	47	-0.00071
12	-0.002	30	-0.00022	48	-0.001
13	-0.0088	31	-0.0006	49	-0.0005
14	4.18	32	-0.001	50	-0.00048
15	9	33	-0.00082	51	-0.00045
16	9.45	34	-0.0016	52	-0.00043
17	3.8	35	-0.001	53	-0.00053
18	7.74	36	-0.00025	54	-0.0004

Congested line flow of this system has been presented in Table XI. The amounts of generator sensitivities (GS') for the mentioned congested line, are presented in Table XII (To calculate the GS' s, C_g and GS are adapted from [7]). For better view, GS' versus generators number are illustrated in Fig. 4 too. As it is cleared in Tables, generators number 14-18 in positive groups and generators number 6, 7 and 13 in negative groups, have non uniform amount of sensitivities, and magnitudes of the sensitivities of them are larger than the other generators, so these groups of generators are selected to participate in CM. In this case, bus-1 is considered as slack bus. Accordingly, there are just 8 generators from 54 generators that participate in CM process and a salient decreasing in the number of participant generators is achieved. The number of generators in comparison with [3] is larger, eight versus six, but the total cost of generators rescheduling is improved significantly. Hence, to evaluate the cost issues, cost of CM, power flow of congested line after CM and total rescheduling power are presented in Table XIII. For evaluation got results of proposed method against other methods, results are compared with [7] and [38]. In the [38], the MF value for comparison has been considered as 0.6 because these results against other MF values are more desired.

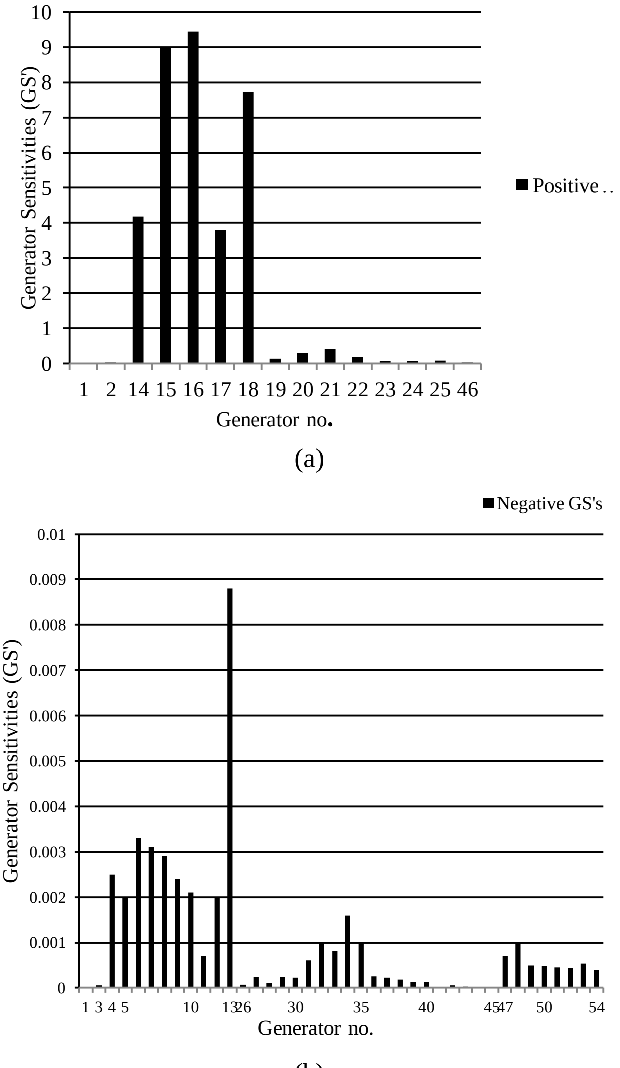

Fig. 4.Plot of generator sensitivities for IEEE 118-bus system.(a) Positive GS' s. (b) Negative GS' s.

It is noteworthy that the generator-7 has the negative amount of GS' but the power of which is decreased to relieve the congestion. Comparison of this generator with other generators with negative GS' s shows that it has the minimum amounts of GS' among the others, so to satisfy the mentioned constraints, its power generation should be decreased.

TABLE XIII

COMPARISON OF CONGESTION MANAGEMENT COST AND TOTAL POWER, AND POWER FLOW OF 13-16 FOR IEEE 118-BUS SYSTEM

	Proposed Method	Method reported in [7]	Method reported in [38]
Approx. Cost of CM($/day)	1 69 281	1 77 154	1 78 568
Power Flow on 13-16(MW)	199.4	199	200
Total CM(MW)	192.1	199.4	190.5

The total rescheduling power in proposed method is lower than [7] but is higher than [38]. This issue can be connived due to low cost of rescheduling of proposed method in comparison with the other one and the main goal is to minimize the cost of CM, so the desired performance of proposed method is clearly explicit. These results are notable in Table XIII.

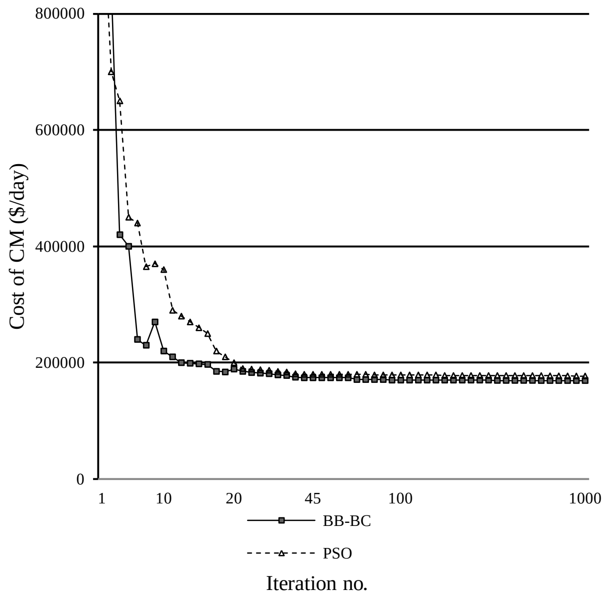

Fig. 5.Plot of convergence of merit function (cost of CM) using BB-BC and PSO algorithms on IEEE 118-bus system.

The evaluation of convergence of merit function (cost of CM) using BB-BC and PSO algorithms on IEEE 118-bus system is illustrated in Fig. 5. The speed and accuracy of BB-BC convergence diagram is clearly viewable against PSO algorithm. On account of the desired convergence of PSO against the other algorithms which is presented in references, the comparison is performed just between PSO and HBB-BC. Execution time of HBB-BC algorithm is approximately 7 s against 10 s for PSO algorithm. The simulation is carried out on Pentium IV, 3.2-GH personal computer.

VII. CONCLUSION

In this paper, a method for congestion management (CM) of transmission lines has been presented. Based on this method, generators are selected using a new definition of sensitivity based on cost and sensitivity of generators to power flow of congested line/lines. As the next step, rescheduling of generators to relieve the congestion is formed as a problem and is optimized by Big Bang-Big Crunch (BB-BC) optimization algorithm which is improved by Particle Swarm Optimization (PSO) method as Hybrid BB-BC (HBB-BC) optimization for the first time. Main goal of this optimization is minimizing the costs and satisfying all of the constraints. This methodology is analyzed on the 39-bus New England system and IEEE 30-bus and IEEE 118-bus systems and whose results are compared with the other proposed methods. The results of HBB-BC algorithm in comparison with the other algorithms reveal the ability of proposed method for CM with minimum cost of CM and minimum number of participating generators. In study case of IEEE 118-system, the number of selected generators for rescheduling by using of new definition of sensitivity is increased against the old definition of sensitivity. This issue is because of using the cost factor in sensitivity definition, and the result of it reveals that a significant decreasing of CM cost, which is the main goal, is achieved in comparison with the other methods. All results are noted as figures and tables to prove obviously the effectiveness of proposed methodology against the others.

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