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Power Flow Tracing Based Congestion Management Using Firefly Algorithm In Deregulated Electricity Market

A. Ahamed Jeelani Basha [1], M. Anitha [2]
[1] *Assistant Professor, Department of Electrical Engineering, Annamalai University, Annamalai Nagar, TamilNadu, India, pin-608002.*
[2] *Associate Professor, Department of Electrical Engineering, Annamalai University, Annamalai Nagar, TamilNadu, India, pin-608002,.*

Abstract:- Congestion Management (CM) is one of the critical and major tasks performed by the system operator. It is considered to be more important as it may initiate the cascading outages which forces the system to collapse. Since few generators contribute the line overloading in the CM problem, it is enough to reschedule their outputs only. To identify the most contributing generator, power flow tracing approach is used in this paper. FireFly (FF) algorithm is employed to reschedule the outputs of selected generators. The proposed method is tested on a standard IEEE 30 bus system and a practical Indian utility 62 bus system. Various case studies are carried out on the test systems to demonstrate the effectiveness of the FF algorithm and the obtained results prove that FF algorithm is indeed capable of getting high quality solution for the CM problem.

Keywords:- *Deregulation, congestion management, firefly algorithm, sensitivity factor, generator contribution factor, power flow tracing.*

List of Symbols

CC	Total congestion cost to relieve congestion
C_g	Incremental and decremental price bids submitted by generators at which the generators are willing to adjust their real power outputs to relieve congestion.
S_{ij}	MVA power flow in the line i -j
S_{ij}^{max}	Maximum MVA limit of the line *i-j*
P_{GK}^{0}	Active power generated by the Kth generator as determined by the system operator
P_{dm}^{0}	Active power consumed by the mth load as determined by the system operator
ΔP_{GK}^{min}, ΔP_{GK}^{max}	Minimum and maximum limits of the change in real power adjustment of the kth generator.
N_g	Total number of generators
N_c	Total number of participating generators in the process of rescheduling
k	Participating generator.
l	Non participating generator.
N_s	Number of transmission line in the system.
N_d	Total number of loads in the system.
m	Individual load at each bus.
P_L	Total transmission losses
P_{GK}^{f}	Active power generated by the *kth* generator after the process of rescheduling.
$P_{Gk}^{min}, P_{Gk}^{max}$	Minimum and maximum limits of the *kth* generator.
V_i, δ_i	Voltage and angle at bus *i* .
α_i^u	Set of nodes supplying the power directly to the node *i*.
P_{i-j}	Power flowing from node *i* to node j,
A_u	(nxn) upstream distribution matrix.
P	Vector of nodal through flows
P_G	Vector of nodal generations.
r	Distance between any two fireflies
β_0	Initial attractiveness at r = 0
γ	Light absorption coefficient, which controls the light intensity.

I. INTRODUCTION

In a deregulated electricity market, freedom is provided to participants to buy and sell electricity. When the producers and consumers of electric energy desire to transact power in bulk amount, unexpected congestion occurs due to violation of physical limits in transmission system. The undesirable effects of the congestion include prevention of new contracts, increase of the electricity cost in some regions of the electricity market which endanger to the system security and reliability. Congestion in a transmission system cannot be allowed beyond a short duration as it may initiate cascaded outages which forces the system to collapse. Hence an effective control action strategy is necessary to reduce the line overloads to the security limit in minimum time.

A detailed survey report of several techniques for congestion management has been reported in literature [1]. Many Optimal Power Flow (OPF) based congestion management schemes for pool and multiple transaction systems are proposed in literature [2-4]. In [5], an OPF-based approach that minimizes cost of congestion and service cost is proposed. Ashwani kumar *et al.*, solved the zonal CM problem using AC Transmission Congestion Distribution Factors (TCDF) [6] and real reactive power rescheduling method [7]. However, it is necessary to compute the sensitivity values for all the buses in the system which in turn results in a large amount of computational effort. Many researchers have solved congestion management problem using FACTS controllers in deregulated environment [8-11]. In [12], Relative Electrical Distance (RED) concept is employed to mitigate the transmission overload by real power generation rescheduling. This method minimizes the system losses and maintains good voltage profile. However, the bids of individual generating unit and the rescheduling cost are not considered in this method.

Many stochastic methods have also been used in the literature to alleviate transmission line congestion. Sudipta Dutta and Singh [13] proposed a congestion management technique using optimal rescheduling of generators based on generator sensitivities and Particle Swarm Optimization (PSO) is used to minimize the deviations of rescheduled generator power outputs. Bialek [14] have proposed power flow tracing approach to determine the contribution of each generator and this method is used for transmission pricing in the deregulated market. Rajathy and Harish kumar employed power flow tracing approach to find the most contributing generators and used Differential Evolution (DE) algorithm to reschedule their outputs so that congestion may be alleviated [15].

In this paper, three methods are used to solve the congestion management problem using firefly algorithm with the objective of minimum rescheduling cost. The first method (method - 1) considers all generators in the particular area for rescheduling. In the second method (method - 2) generators are selected based on Generator Sensitivity Factors (GSF) and their outputs are rescheduled optimally using FF algorithm to relive overload in transmission lines. The third method (method - 3) employs power flow tracing approach to identify the most contributed generators to the congested line and only these generator outputs are rescheduled using FF algorithm to alleviate congestion. In this paper, congestion due to different line outages, generator outages and wheeling transactions are considered. The proposed method is tested on two test systems and the algorithm is validated by comparing the results with DE method.

II. Problem formulation

The optimal congestion management of rescheduling based on minimizing redispatch cost can be expressed as

minimize

$$CC = \sum_{k}^{n_c} C_g \times \Delta P_{Gk} \qquad \text{. . . (1)}$$

Subject to,

$$\sum_{k}^{N_c}\left(P_{GK}^{O} + \Delta P_{GK}\right) + \sum_{l,l\neq k}^{N_g} P_{GK}^{O} = \sum_{k}^{N_d} P_{dm}^{O} + P_L \qquad \text{. . . (2)}$$

$$\sum_{k}^{N_c} P_{GK}^{f} + \sum_{l,l\neq k}^{N_g} P_{GK}^{O} = \sum_{m}^{N_d} P_{dm}^{O} + P_L \qquad \text{. . . (3)}$$

$$P_{GK}^{0} - P_{GK}^{min} = \Delta P_{GK}^{min} \leqslant \Delta P_{GK} \leqslant \Delta P_{GK}^{max} = P_{GK}^{max} - P_{GK}^{0} \qquad \text{. . . (4)}$$

$$S_{i,j} \leqslant S_{i,j}^{max} \qquad \text{. . . (5)}$$

$$V_i^{min} \leqslant V_i \leqslant V_i^{max} \qquad \text{. . . (6)}$$

$$\delta_i^{min} \leqslant \delta_i \leqslant \delta_i^{max} \qquad \text{. . . (7)}$$

The power flow tracing algorithm for tracing the contribution of each generator in transmission system and allocate a charges as using the transmission line for each user. It is based on Kirchhoff's current law and proportional sharing principle. There exist two methods for tracing the power flow namely upstream and downstream algorithms [14]. In this work, the upstream tracing algorithm is proposed to find the contribution factors of each generator to the flow of power in the transmission line.

The total inflow P_i through node *i* can be expressed as

$$P_i = \sum_{j\in\alpha_i^{(u)}} \left|P_{i-j}\right| + P_{Gi} = \sum_{j\in\alpha_i^{(u)}} C_{ji} P_j + P_{Gi}\ ,\quad i = 1,2,3,\ldots.n \qquad \text{. . . (8)}$$

$$C_{ji} = \frac{\left|P_{j-i}\right|}{P_j} \qquad \text{. . . (9)}$$

Equation (9) can be rewritten as

$$P_i - \sum_{j\in\alpha^{(u)}} C_{ji} P_j = P_{Gi} \qquad \text{. . . (10)}$$

Or

$$A_u P = P_G$$

The $(i,j)^{th}$ element of A_u is given by

$$[A_u]_{ij} = \begin{cases} 1 & for\, i = j \\ -C_{ji} = -\left|P_{i-j}\right| / P_j & for\ j \in \alpha_i^{(u)} \\ 0 & otherwise \end{cases} \qquad \text{. . . (11)}$$

If A_u^{-1} exists then P = A_u^{-1} P_G and its i^{th} element is equal to

$$P_i = \sum_{k=1}^{n} \left[A_u^{-1}\right]_{ik} P_{GK} \quad i = 1,2,3,..n \qquad \text{. . . (12)}$$

which shows the contribution of the K^{th} generator to i^{th} nodal power.

A line outflow in the line *i – j* from nodel *i* can be calculated using the proportional sharing principle, as

$$\left[P_{i-j}\right] = \frac{\left|P_{i-j}\right|}{P_i} P_i = \frac{\left|P_{i-j}\right|}{P_i} \sum_{k=1}^{n} \left[A_u^{-1}\right]_{ik} P_{GK} \qquad \text{. . . (13)}$$

$$= \sum_{k=1}^{n} D_{i-j,k}^{G} P_{GK} \quad for\, all \quad j \in \alpha_i^{(d)} \qquad \text{. . . (14)}$$

and $D_{i-j,k}^{G} = \frac{|P_{i-j}||[A_u^{-1}]}{P_i}$ is the generation contribution factor, which is the flow in the line *i-j due to the* K^{th} generation and $\alpha_i^{(d)}$ is the set of nodes supplied directly from node *i*. Based on the generation contribution factor, the generators are selected for the process of rescheduling.

III. Firefly algorithm

The firefly algorithm was developed by Xin-She Yang at Cambridge University in 2008 [16]. It is a meta-heuristic optimization algorithm, inspired by the flashing behavior of fireflies. The primary purpose for a firefly's flash is to act as a signal to attract other fireflies. There exist three idealized rules based on the major flashing characteristics of fireflies [17]. These are the following: (1) All fireflies are unisex, and they will move towards more attractive and brighter ones regardless of their sex. (2) The degree of attractiveness of a firefly is proportional to its brightness which decreases as the distance from other firefly increases due to the fact that the air absorbs light. If there is no brighter or more attractive firefly than a particular one, it will then move randomly. (3) The brightness or light intensity of a firefly is determined by the value of the objective function of a given problem.

A. Attractiveness

In the firefly algorithm, the attractiveness function β(*r*) of a firefly is described as a monotonically decreasing function as given by the following function:

$$\beta(r) = \beta_0 \exp(-\gamma r^m)\ \text{,with } m \geq 1 \qquad \text{. . . (15)}$$

By controlling this parameter γ, FF algorithm has ability to control its modality and adapt itself to the problem landscape [18].

B. Distance

The distance between any two fireflies *i* and *j* at x_i and x_j, respectively, is the Cartesian distance

$$r_{ij} = \left\| x_i - x_j \right\| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \qquad \ldots (16)$$

where $x_{i,k}$ is the k^{th} component of the spatial coordinate x_i of the i^{th} firefly.

In 2-D case, we have $r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$ . . . (17)

C. Movement

The movement of a firefly *i* is attracted to another more attractive (brighter) firefly *j* is determined by the following equation:

$$x_{i+1} = x_i + \beta_0 \exp(-\gamma r_{ij}^2)(x_j - x_i) + \alpha(rand - 0.5) \qquad \ldots (18)$$

Where the first term is the current position of a firefly, the second term is used for considering a firefly’s attractiveness to light intensity seen by adjacent fireflies and the third term is the random movement of a firefly in case there is no other brighter ones.

FF algorithm subdivides the population into subgroups due to the fact that local attraction is stronger than long distance attraction. As a result, FF algorithm can deal with highly non linear, multi-model optimization problem efficiently.

In the literature, FF algorithm is considered as generalization to DE algorithm [18]. From equation (18), it is seen that when γ is zero and β_0 is set to 1, then FF algorithm becomes a simplified version of DE without mutation and crossover rate is controlled by β_0. Hence standard FF algorithm includes DE as its special case. As a result, FF algorithm has all the advantages of DE algorithm and hence its performance is very efficient than DE algorithm. The implementation of FF algorithm for congestion management problem is depicted in the flowchart shown in Fig. 1.

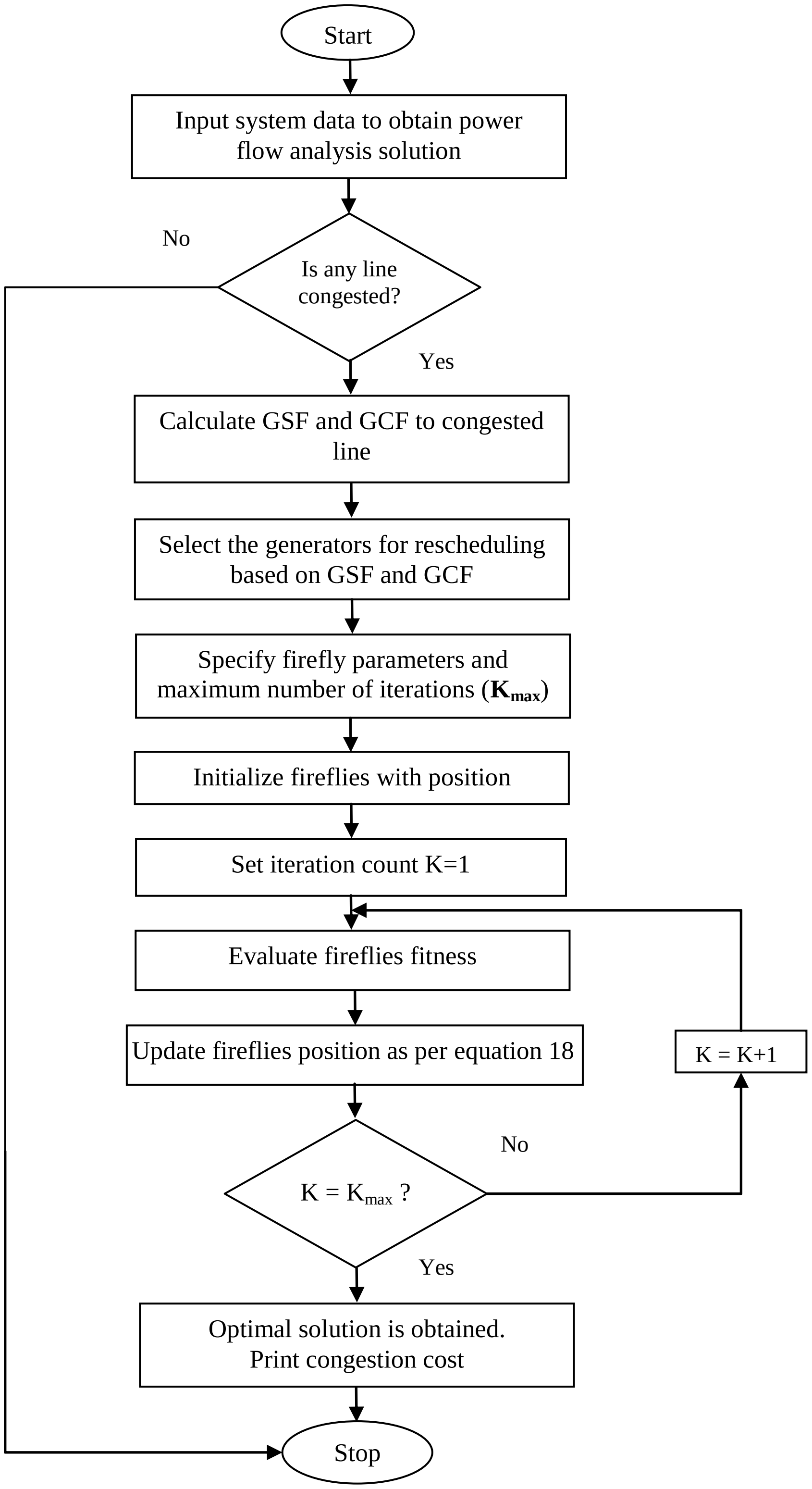

Fig. 1: Flow chart for FF algorithm based congestion management problem

IV. Results and Discussion

The proposed FF algorithm is employed to solve congestion management problem using power flow tracing approach. Standard IEEE 30-bus and a practical 62 bus Indian utility systems are used to illustrate the effectiveness of proposed algorithm. Optimal rescheduling of (method-1, method-2 and method-3) active power of generators to relieve congestion in the overloaded lines is done by FF algorithm.

FF algorithm parameters are as follows: $\gamma = 1.0$, $\alpha = 0.5$, $\beta_0 = 0.2$, number of fireflies are taken as 6 and 100 total generations are considered. Simulation studies are carried out on Intel core 2 Duo (1.8 GHz) processor in MATLAB environment.

4.1 IEEE 30 bus system

The standard IEEE 30 bus test system consists of 6 generator buses, 24 load buses and 41 transmission lines with a base load demand of 283.4 MW. The system is divided into 3 areas with two generators in each area. Incremental and decremental costs submitted by Generation Companies (GENCOs) are assumed to be same and it is taken slightly more than the marginal cost [19]. Price bids submitted by GENCOs for congestion management are given in Table-1.

Table 1: Generator price bids

Generator number	**Incremental / decremental Price bids ($/MWh)**
G_1	35
G_2	40
G_3	42
G_4	44
G_5	48
G_6	36

A. Line outage

In this case, the outage of transmission line connected between buses 14 and 15 in area 2 (line no. 24) is considered. Due to this, the transmission line connected between buses 1 and 2 in area 1 gets congested. FF algorithm is used to relieve congestion by rescheduling in all the three methods. In method 1, all the generators (G_1, G_2, G_3, G_4, G_5, G_6) are rescheduled. In method 2, sensitive generators are identified using GSF and only most sensitive generators are rescheduled to relieve congestion. In method 3, Generator Contribution Factors (GCF) are calculated using power flow tracing method and only the generators which contribute more to the congestion are rescheduled. Table-2 shows the GSF and GCF for all the generators corresponding to the outaged line.

Table 2: GSF, GCF for outage of line no. 24.

Congested Line 1-2	G_1	G_2	G_3	G_4	G_5	G_6
GSF	0.1298	0.0000	0.0000	0.0000	0.1285	0.1307
GCF	0.1869	0.0000	0.0000	0.0000	0.0000	0.2817

From the table, it is noted that in method 2, most sensitive generators (G_1, G_5 & G_6) need to be rescheduled to alleviate congestion. In method 3, most contributing generators (G_1 and G_6) are required to be rescheduled. The congestion cost is calculated using the price bids submitted by the generators and are given in Table-3. To validate the proposed method, the obtained results are compared with that of DE method. It is evident from the comparison that the FF algorithm gives minimum congestion cost in all the methods than DE method. The change in real power output of the generators in all the three methods is shown in Fig. 2.

Table 3: Comparison of congestion cost

Methods	**Congestion Cost($/hr)**	
	DE [15]	**FF algorithm**
Method-1 (All)	305.4972	**300.8481**
Method-2 (GSF)	-	**243.9256**
Method-3 (GCF)	225.8991	**215.3208**

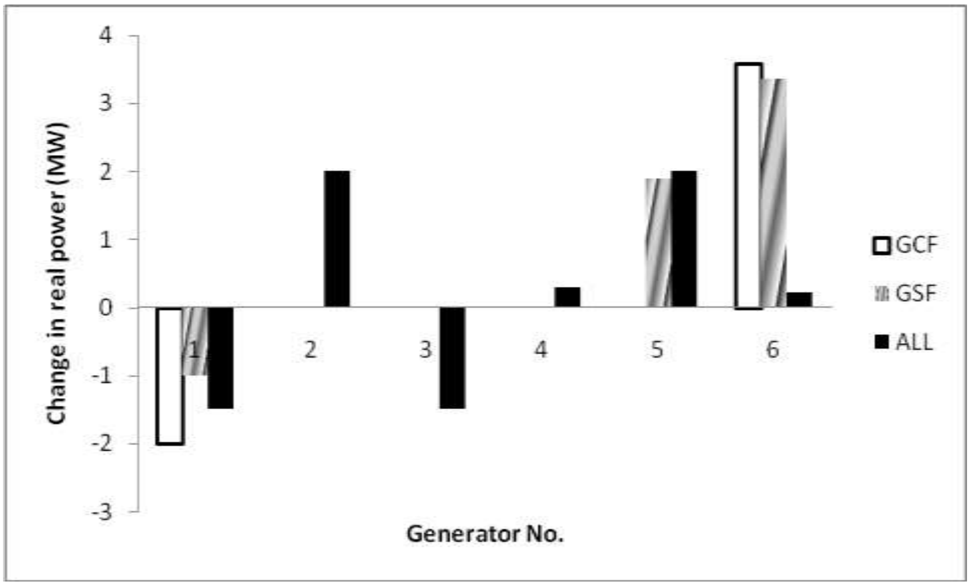

Fig. 2: Rescheduled power of participating generators.

The obtained results clearly depict the superiority of the FF algorithm over DE as the proposed algorithm has all the advantages of DE algorithm which is already mentioned in section-III. The obtained results also justify that the FF algorithm performs well than DE algorithm.

4.2 62 Bus Indian utility system

The test system consists of 19 generator buses, 89 transmission lines and 11 tap changing transformers with load demand of 2908 MW. The system is separated into three areas with six generators in area 1 and area 3 respectively, whereas area 2 has seven generators. The network topology and the data for the Indian utility 62 bus system are found in [20]. Price bids submitted by GENCOs for congestion management are given in Table-4.

Table 4: Generator price bids

Gen No.	**G_1**	**G_2**	**G_3**	**G_4**	**G_5**	**G_6**	**G_7**	**G_8**	**G_9**
Inc/ dec Price bids (Rs/MWh)	1410	1645	2115	1450	1570	1555	1622	1370	1550
G_{10}	**G_{11}**	**G_{12}**	**G_{13}**	**G_{14}**	**G_{15}**	**G_{16}**	**G_{17}**	**G_{18}**	**G_{19}**
2100	2170	2200	1850	1680	1540	1720	1600	1680	1745

A. case 1: Line outage

In this case, the line connected between the buses 61 and 62 (line no. 88) is considered to be outaged. Because of this outage, line connected between the buses 55 and 58 gets congested. In method 1, all generators in that area 1 (G_1, G_{12}, G_{13}, G_{14}, G_{15}, G_{16}, G_{17}) are rescheduled to relieve congestion. Table-5 shows the GSF and GCF of all generators corresponding to this outaged line. Based on this, the generators (G_1 ,G_{13}, G_{14}, G_{15}, G_{17}) need to be rescheduled in method 2. In method 3, the generators G_1, G_{15}, G_{17} are to be rescheduled to relieve congestion. The congestion costs obtained in three methods are given in Table-6 and it is inferred that method-3 gives a minimum congestion cost as compared to DE method. Fig 3 shows the change in real power output of the generators in all three methods.

Table 5: GSF, GCF for the outage of line no. 88

Congested Line 55-58	**G_1**	**G_2**	**G_3**	**G_4**	**G_5**	**G_6**	**G_7**	**G_8**	**G_9**
GSF	0.1123	0.0000	0.0000	0.0000	0.0001	0.0000	0.0003	0.0000	0.0000
GCF	0.1820	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
G_{10}	**G_{11}**	**G_{12}**	**G_{13}**	**G_{14}**	**G_{15}**	**G_{16}**	**G_{17}**	**G_{18}**	**G_{19}**
0.0000	0.0000	0.0000	0.3123	0.1553	0.3312	0.0000	0.2411	0.0000	0.0000
0.0000	0.0000	0.0000	0.0359	0.0359	0.1589	0.0000	0.1589	0.0000	0.0000

Table 6: Comparison of congestion cost

Methods	Congestion cost (Rs/hr)	
	DE [15]	FF algorithm
Method-1 (All)	7114.04	**7084.26**
Method-2 (GSF)	-	**6878.23**
Method-3 (GCF)	6805.11	**6790.21**

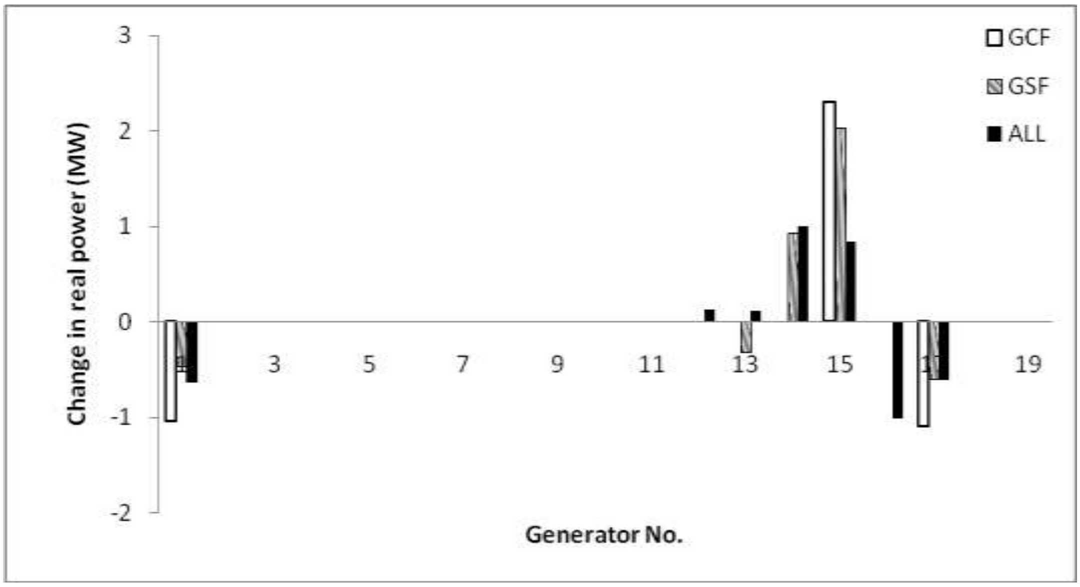

Fig. 3: Rescheduled power of participating generators

B. case 2: Wheeling transactions

In this case, multilateral transaction is carried out in the test system and their details are listed in Table-7. After carrying out these wheeling transactions, it is found that the transmission lines connected between buses 11-16 and 55-58 get congested. Tables 8 and 9 show the GSF and GCF corresponding to these congested lines.

In method 1, all generators in the area 1 (G_1, G_{12}, G_{13}, G_{14}, G_{15}, G_{16}, G_{17}) are rescheduled to relieve the congestion. Based on GSF in method -2, six most sensitive generators (G_1, G_5, G_6, G_{15}, G_{16}, G_{17}) and in method-3 most contributed generators (G_1, G_6, G_{15}, G_{17}) need to be rescheduled. The rescheduled power of different generators by all the three methods are shown in Fig. 4. The congestion cost obtained in these methods are given in Table-10 and minimum congestion cost is found to be 6568.61 Rs/hr in method-3 when compared to other methods (All & GSF).

Table 7: Details of multilateral wheeling transactions

Power injected		Load	
Bus No.	**Amount (MW)**	**Bus No.**	**Amount (MW)**
36	67	12	20
42	82	24	10
		54	51
		60	68
Total	149	Total	149

Table 8: GSF for the multilateral wheeling transactions.

Congested Line	G_1	G_2	G_3	G_4	G_5	G_6	G_7	G_8	G_9
55-58	0.1102	0.0000	0.0000	0.0000	0.0210	0.2902	0.0000	0.0081	0.0020
11-16	0.3121	0.0000	0.0000	0.0000	0.2810	0.2710	0.0042	0.0000	0.0000
G_{10}	**G_{11}**	**G_{12}**	**G_{13}**	**G_{14}**	**G_{15}**	**G_{16}**	**G_{17}**	**G_{18}**	**G_{19}**
0.0011	0.0000	0.0000	0.0000	0.0000	0.0070	0.0105	0.3118	0.0000	0.0009
0.0000	0.0000	0.0000	0.0000	0.0000	0.1123	0.1390	0.2679	0.0000	0.0000

Table 9: GCF for the multilateral wheeling transactions.

Congested Line	**G_1**	**G_2**	**G_3**	**G_4**	**G_5**	**G_6**	**G_7**	**G_8**	**G_9**
55-58	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11-16	-0.1460	-0.0773	-0.0311	-0.0496	-0.0275	-0.1683	-0.0000	-0.0000	-0.0000
G_{10}	**G_{11}**	**G_{12}**	**G_{13}**	**G_{14}**	**G_{15}**	**G_{16}**	**G_{17}**	**G_{18}**	**G_{19}**
0.0000	0.0000	0.0000	0.0359	0.0359	0.1589	0.0000	0.1589	0.0000	0.0000
-0.0000	-0.0000	-0.0000	-0.0005	-0.0005	-0.0022	-0.0000	-0.0022	-0.0136	-0.0136

Table 10: Comparison of congestion cost obtained from FFA.

Methods	**Congestion Cost (Rs /hr) FF algorithm**
Method-1 (All)	**7060.76**
Method-2 (GSF)	**6755.56**
Method-3 (GCF)	**6568.61**

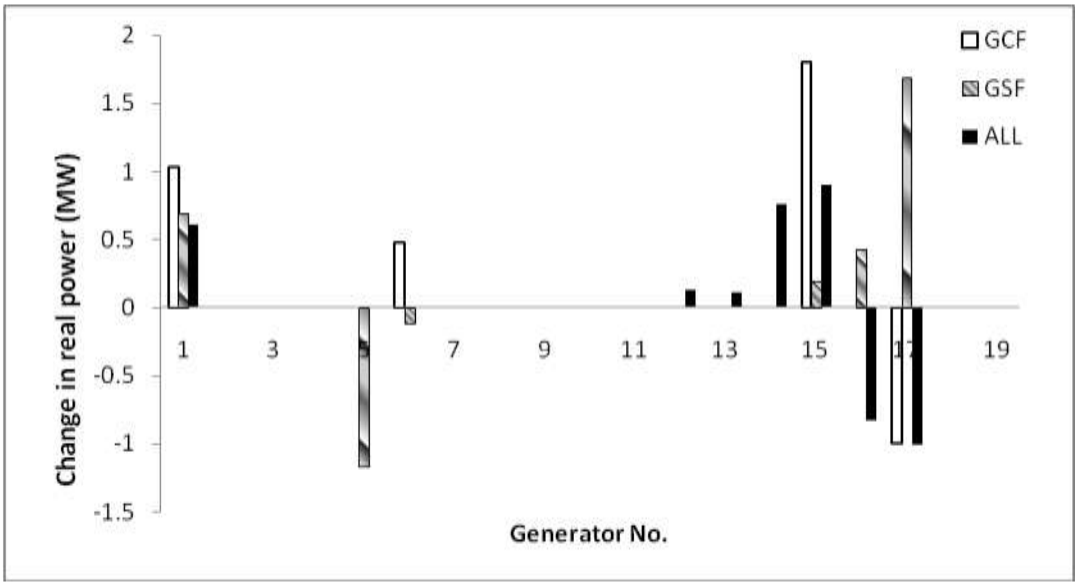

Fig.4: Rescheduled power of participating generators

C. case 3: Generator outage

In this case, outage of generator 12 at bus 37 causes congestion of lines connected between buses 35-32 and 55-58. In method 1, all generators in that area 1 (G_1, G_{13}, G_{14}, G_{15}, G_{16}, G_{17}) are rescheduled to relieve congestion. GSF and GCF corresponding to these congested lines are given in Tables 11 and 12 respectively. Based on GSF, generators G_1, G_6, G_{15}, G_{16} and G_{17} need to be rescheduled. In method-3, most contributing generators (G_1, G_{15}, G_{17}) are rescheduled. Fig. 5 shows the change in real power output of the generators in all the three methods. The congestion cost obtained in all the three methods are given in Table 13. From this table, it is inferred that method-3 gives least congestion cost (6554.60 Rs/hr) than other two methods. The convergence characteristics of firefly algorithm is shown in Fig. 6. From this figure, it is revealed that GCF based FF algorithm reaches the optimal solution in early iteration.

Table 11: GSF for the outage of generator 12.

Congested Line	**G_1**	**G_2**	**G_3**	**G_4**	**G_5**	**G_6**	**G_7**	**G_8**	**G_9**
55-58	0.2100	0.0000	0.0000	0.0000	0.0000	0.3801	0.0000	0.0081	0.0000
35-32	0.1270	0.0000	0.0000	0.0000	0.0000	0.1200	0.0042	0.0000	0.0000
G_{10}	**G_{11}**	**G_{12}**	**G_{13}**	**G_{14}**	**G_{15}**	**G_{16}**	**G_{17}**	**G_{18}**	**G_{19}**
0.0061	0.0000	0.0000	0.0000	0.0000	0.0000	0.2100	0.1198	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.1423	0.1390	0.1672	0.0000	0.0000

Table 12: GCF for the outage of generator 12.

Congested Line	**G_1**	**G_2**	**G_3**	**G_4**	**G_5**	**G_6**	**G_7**	**G_8**	**G_9**
55-58	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35-32	-0.1110	-0.0273	-0.0411	-0.0116	-0.0175	-0.0201	-0.0000	-0.0000	-0.0000
G_{10}	**G_{11}**	**G_{12}**	**G_{13}**	**G_{14}**	**G_{15}**	**G_{16}**	**G_{17}**	**G_{18}**	**G_{19}**
0.0000	0.0000	0.0000	0.0359	0.0359	0.1589	0.0000	0.1589	0.0000	0.0000
-0.0000	-0.0000	-0.0000	-0.0000	-0.0001	-0.1027	-0.0000	-0.0008	-0.0006	-0.0210

Table 13: Comparison of congestion cost obtained from FFA

Methods	**Congestion Cost (Rs /hr) FF algorithm**
Method-1 (All)	7030.57
Method-2 (GSF)	6892.99
Method-3 (GCF)	**6554.60**

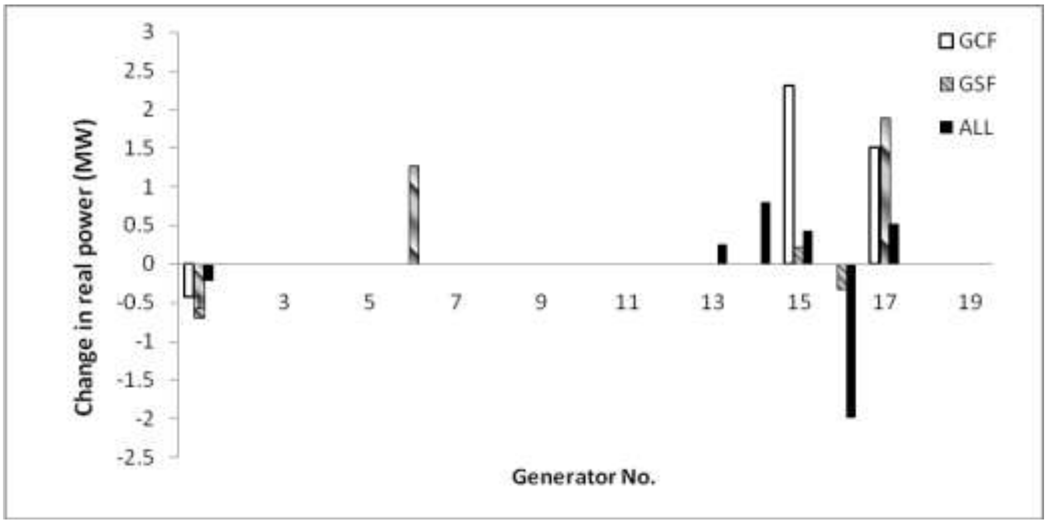

Fig. 5: Rescheduled power of participating generators.

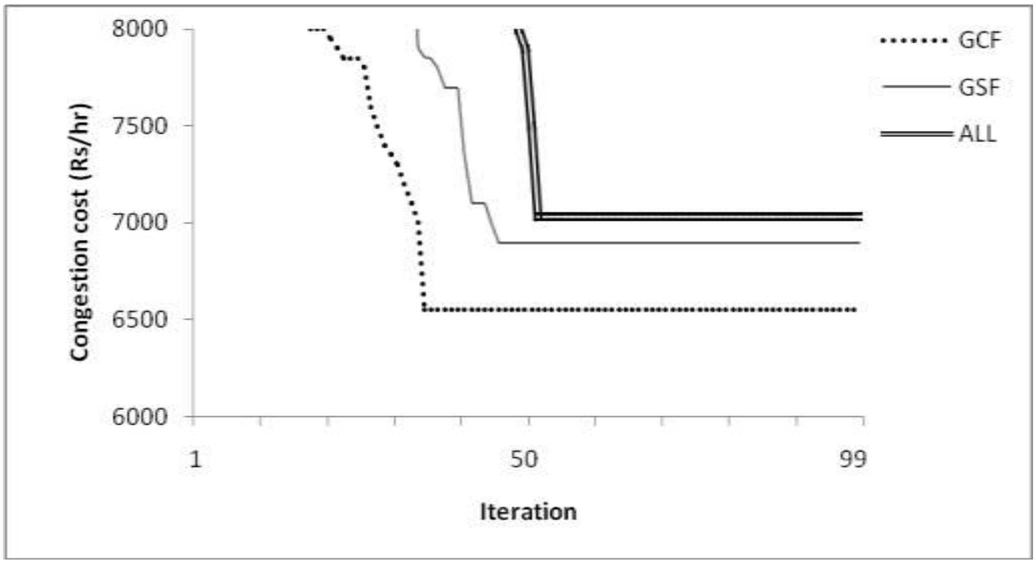

Fig. 6 Convergence characteristics of firefly algorithm

V. Conclusion

This paper presents the formulation of congestion management problem to minimize congestion cost and is solved using FF algorithm. The generators responsible for congestion are identified using power flow tracing algorithm. Participating generators are found using generator shift factor also. IEEE 30 bus and 62 bus Indian utility systems are considered for the purpose of illustration. In this paper congestion is simulated by considering critical line outage, generator outage and performing wheeling transactions. In all the cases, firefly algorithm is capable of giving optimal solution with least congestion cost. To validate the result, it is compared with that of DE method. Comparison ensures that the proposed method is effective for CM problem with good convergence characteristics.

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