

Optimal Rescheduling of Real and Reactive Power for Congestion Management under Competitive Environment

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Abstract— In the competitive power market, congestion in the transmission line has grown as a serious problem which threatens the power system security and reliability. Congested condition leads to the increased congestion cost and it is not wise to allow the situation to persist. In this work, real and reactive power rescheduling based congestion management is proposed to relieve the transmission congestion. For optimal rescheduling of the real and reactive power, the recently introduced nature black hole algorithm (BHA) is implemented. The objective of the present work is to minimize the total transmission congestion cost while adjusting the generation pattern to relieve congestion. The work uses the generator sensitivity indices for identifying the more influencing generators. The validation of the suggested method has been studied on modified IEEE 57 bus test system with two congestion cases of bilateral and multilateral transactions and the obtained numerical results are compared with other metaheuristic algorithms like particle swarm optimization (PSO) and big bang big crunch (BB-BC) algorithm.

Keywords—black hole algorithm, deregulated power system, generator power rescheduling, real and reactive power sensitivity, Bilateral / Multilateral transactions.

I. INTRODUCTION

In the vertically integrated utility system, the classical optimization methods are usually applied to solve the optimal power flow problems with the objective functions of minimization of generation cost, transmission loss and voltage stability enhancement etc. The operating conditions of equality and inequality conditions are also satisfied with secure operations. After the emerging of the deregulation in power system, many independent system operators are involved with open access in power transactions. The market players are encouraged to have transactions within the competitive power market. Therefore bilateral and multilateral transactions are taken in open access transmission leads to congestion in transmission line by overloading beyond their thermal rating [1, 2]. In recent times the researchers consider the

congestion as objective function hence it is a crucial factor with more complexity and also to make the market profits maximization on demand sides [3, 4]. In the competitive market there is a challenge for independent system operator that to manage the congestion with economic dispatch therefore providing the good solution by optimal scheduling in power generation [5]. In the literature [6, 7] the researchers are tried to incorporate the operational and the technical constraints in additional with optimal dispatch solutions, in the competitive power market they incorporated the social welfare terms as benefits of markets with objectives. Impact of direction based transaction limitation in power market is reported in [8] such that similar to bilateral and multilateral transactions in the open transmission dispatch.

In the prior decades the operators are permitted to utilize Flexible AC transmissions systems (FACTS) devices in the existing grid infrastructure for the effective utilizations and better controls [9-11]. The influences of thyristor controlled series compensator (TCSC) and static var compensator (SVC) on transmission pricing at the competitive markets are reported in [12]. To manage the congestions in the congested critical state, re-dispatching the optimal power to alleviate the congestions from the transmissions line is presented at [13-15]. In the literatures [16-18] generator sensitivity based approaches are applied to re-dispatch the optimal active power to eliminate the congestion in the transmission line. The motive of this article is to select the optimum rescheduling generator with real and reactive power for congestion management with minimum congestion cost, at the crucial congestion state real and reactive power based sensitivity is calculated for the congested line [19-21]. In this work, both real and reactive power based sensitivity based power scheduling is proposed. Since the rescheduling is done for both real and reactive power, the resulting reduction in congestion cost is considerably high. The optimization method proposed is simple and easy to be coded in Matlab software.

II. BLACK HOLE PHENOMENON

John Michel and Pierre Laplace were projected the concept of Black Holes by integrating the Newton's law in 18th century. According to this theory, a star becomes and the absence of this star is known as a Black Hole. An American physicist, John Wheeler in 20th century who first termed a Black Hole means phenomenon of mass collapsing or absence of stars. In the space, there is a strong gravitational field in the black hole. Even light cannot escape from the gravitational field of black hole once the light enters it. The Schwarzschild radius is the radius of the black hole is also known as Event horizon. The radius of black hole can be formulated by mathematically as the equation

$$R = \frac{2GM}{C^2} \quad (1)$$

Where,

G is the gravitational constant; M is the mass of the Black Hole; C is the speed of light

The existence of black hole is distinguished by the effects experienced by objects surrounding it. When any object moves nearer to event of horizon or crosses its radius that object will be swallowed by black hole and vanish permanently. The schematic view of black hole in the space shown in figure (1).



Fig. 1: Black hole in the space

2.1 Black Hole Algorithm (BHA)

The BHA is a meta-heuristics algorithm, moreover it is a population based algorithm like others such as particle swarm optimization and genetic algorithm. A population of agent is randomly created and distributed as candidate solutions in the search space. Typically, any population-based algorithm, use different approaches to change the individuals to the global best solution by an assured technique. For instance, crossover and mutation are the approaches used in GA. In PSO the pbest and gbest solutions are alter to the initial solution to the gbest solutions.

In Black Hole Algorithm, the progress of the population is attained by shifting all the candidates to the best candidate in every iteration viz., In search space the newly generated candidates of stars and replacing those candidates will enters within the black hole range. In the BHA, black hole is selected as a best candidate among the other candidates in every iteration. Then, all the

candidates are shifted to the black hole depends on the current location and their random number. For BHA the searching mechanism is as below.

For the initialization process, an arbitrarily created population of solutions is taken. Depends on the fitness values of populations the best black hole is evaluated from the other black hole. In the search after initializing of stars and the black hole, thereafter the black hole will start to absorb the stars towards it and all the stars will start to move around the black hole. The black hole absorption is determined by mathematically as follows.

$$x_i(t) = x_i(t-1) + \text{rand}(0,1)(x_{BH} - x_i(t-1)) \quad (2)$$

Where,

$x_i(t)$ locations of the i^{th} star at iterations t

$x_i(t-1)$ locations of the i^{th} star at iterations $t-1$.

x_{BH} locations of the black hole

rand random number in the varies (0, 1)

The star moves towards the black hole in the search space, a star may reach a location with objective value lower than the black hole. In such a case, the black hole moves to the location of that star and vice versa. Then the BHA will continue with the black hole in the new location and then stars start moving towards this new location. In addition, there is a probability of crossing the event horizon during moving stars towards the black hole. Every candidate solution that crosses the event horizon of the black hole will be sucked by the black hole. Every time a candidate star dies and another candidate solution is born and distributed randomly in the search space and starts for a new search. This is done to keep the number of population size constant. The next iteration takes place after all the stars have been moved. The radius of the event horizon in the black hole algorithm is calculated using the following equation.

$$R = \frac{f_{BH}}{\sum_{i=1}^N f_i} \quad (3)$$

Where, f_{BH} is the fitness value of the black hole and f_i is the fitness value of the i^{th} star. N is the number of candidate solutions. When the distance between a candidate solution and the black hole is less than R, that candidate is collapsed and a new candidate is created and distributed randomly in the search space. Based on the above description the flow chart for BHA is shown in figure (1).

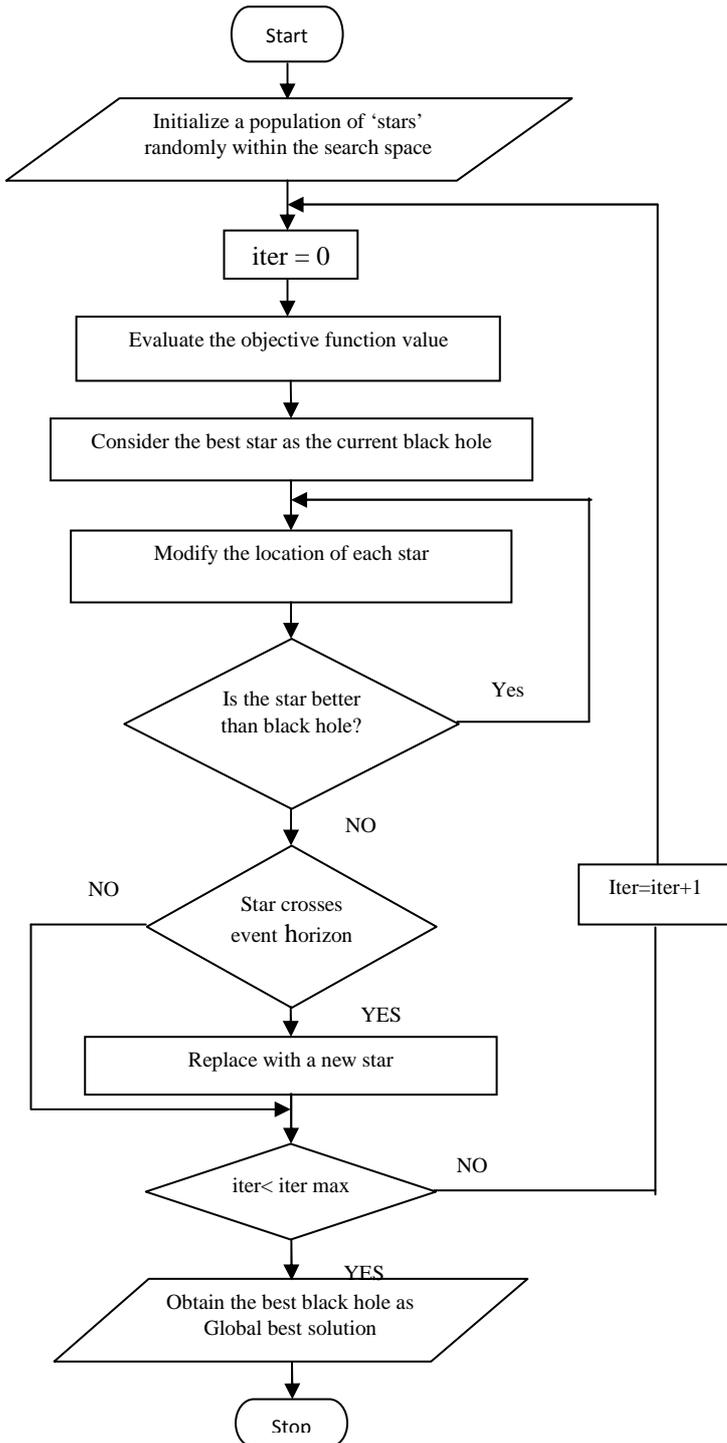


Fig. 2: Flow chart for Black Hole Algorithm

III. PROBLEM FORMULATION

3.1 Formulation of Generator Sensitivity Factors

Different generators have different sensitivity to the power flow through a congested line. A change in active power flow ΔP_{ij} in a transmission line connected between bus i and bus j due to unit change in active power injection. ΔP_{Gg} at bus n by generator 'g' can be

defined as the active power generator sensitivity factor GS_{Pg}

Mathematically, it can be written for line as:

$$GS_{Pg} = \frac{\Delta P_{ij}}{\Delta P_{Gg}} \quad (4)$$

The detailed explanation on the derivation for the Eq. (4) is given in [16].

Reactive power generator sensitivity index, in the same way [19] for line can be written as:

$$GS_{Qg} = \frac{\Delta Q_{ij}}{\Delta Q_{Gg}} \quad (5)$$

Neglecting $P-V$ coupling, Eq. (4) can be written as

$$GS_{Pg} = \frac{\partial P_{ij}}{\partial V_i} \cdot \frac{\partial V_i}{\partial P_g} + \frac{\partial P_{ij}}{\partial V_j} \cdot \frac{\partial V_j}{\partial P_g}$$

Neglecting $Q-\delta$ coupling, Eq. (5) can be written as

$$GS_{Qg} = \frac{\partial Q_{ij}}{\partial V_i} \cdot \frac{\partial V_i}{\partial Q_{Gg}} + \frac{\partial Q_{ij}}{\partial V_j} \cdot \frac{\partial V_j}{\partial Q_{Gg}}$$

3.2 Objective Function

The objective of this present work is to minimize the total congestion cost due to rescheduling of real and reactive power generation. The objective function can be mathematically written as:

$$\text{Minimize} \sum_g^{ng} C_{Pg} (\Delta P_g) \Delta P_g + \sum_g^{ng} C_{Qg} (\Delta Q_g) \Delta Q_g \quad (6)$$

Subject to the following equality and inequality constraints.

Equality constraints:

The real power flow equality constraint is

$$P_{Gi} - P_{Di} - \sum_{n=1}^{nb} |V_i| |V_j| |Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (7)$$

The reactive power flow equality constraint is

$$Q_{Gi} - Q_{Di} - \sum_{n=1}^{nb} |V_i| |V_j| |Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (8)$$

Inequality constraints:

The real power generation limits are

$$P_g - P_g^{\min} = \Delta P_g^{\min} \leq \Delta P_g \leq \Delta P_g^{\max} = P_g^{\max} - P_g \quad \forall g$$

The reactive power generation limits are

$$Q_g - Q_g^{\min} = \Delta Q_g^{\min} \leq \Delta Q_g \leq \Delta Q_g^{\max} = Q_g^{\max} - Q_g \quad \forall g$$

IV. SIMULATION RESULTS AND DISCUSSIONS

Two experimental test cases are carried out for congestion condition in the modified IEEE 57 bus by using proposed algorithm and to prove its efficiency. The bilateral transactions and multilateral transactions are the testing cases. In the IEEE 57 bus has 80 transmission lines, 7 generators and 50 load buses with load of 1250.8MW real power and 336.4 MVAR reactive power. This line data and bus data are taken from [24], a slight modification is done in IEEE 57 bus like the generator bus are numbered first and then the load buses follow them.

4.1 CASE A: Bilateral transactions

In the competitive power market, the contract is made between two buses for power transactions that is injecting power at one bus and consuming the power at another end is known as Bilateral transactions. In this experiment two cases of bilateral transactions are done for congestion state, for the first case 20 MW of is injected in bus number 9 then same amount power is consumed at bus number 13 and for the second case 10 MW is injected in bus number 3 and the same amount of power is consumed at bus number 40. Therefore 30 MW of net power is being transacted in the network is leading to congestion in two lines.

The real and reactive power sensitivity is calculated for the congested line to reschedule the optimal real power generations. the rescheduling time is saved in sensitivity based rescheduling by giving the priority for the influencing generator instead of rescheduling of all the generators. The calculated real and reactive sensitivity factor is tabulated in the table no: 1

Table: 1 Generator Sensitivity Factors of Congested Lines (Bilateral Transactions)

Congested lines	Line No:8 (bus 5-6)		Line No:10 (bus 6-12)	
	P	Q	P	Q
G ₁	0	-0.0089	0	-0.1837
G ₂	0.0213	-0.0028	0.0021	-0.0589
G ₃	0.0931	-0.0320	0.0090	-0.0395
G ₄	0.4016	-0.1407	0.1062	-0.1215
G ₅	0.6311	-3.1808	0.1723	-0.4856
G ₆	-0.2132	-1.2799	0.2237	-0.8746
G ₇	-0.0777	-0.9673	-0.0116	-0.7044

The real power and reactive power in congested state of network is rescheduled to eliminate the congestions in the transmission lines. The calculated sensitivity factors are highly useful to obtain the optimal real and reactive powers and the obtained values from the aforementioned approaches are tabulated in table no: 2 those values are within the permissible limits of the system constraints by satisfying the equality and inequality of the system constraints.

Table.2: Optimal Rescheduling Power

Rescheduled power	BBC Technique		PSO Technique		BHA Technique	
	Real power	Reactive power	Real power	Reactive power	Real power	Reactive power
G ₁	161.3530	-52.9147	165.2406	58.0347	142.1220	83.6887
G ₂	100.0000	26.9221	95.5969	86.3138	100.0000	56.8852
G ₃	45.4366	60.0000	41.6806	57.7512	43.9639	85.0061
G ₄	88.2702	25.0000	89.3368	44.7625	89.9595	88.2489
G ₅	426.0728	200.0000	445.9567	64.4896	449.3212	2.3893
G ₆	100.0000	9.0000	83.0642	87.6830	81.4709	100.0000
G ₇	51.1589	155.0000	352.1721	44.8255	365.9776	24.7799

(Bilateral Transaction)

The objective function is to minimize the congestion cost, which is obtained by the optimization algorithms and tabulated in table no: 3 as worst value, average value and best value. Among the three approaches, BHA has given the best cost value 2793.8000 \$/day as the congestion cost, but remaining two algorithms, the BB-BC approach gives 3254.7000 \$/day as best cost value and PSO approaches gives 3008.9000 \$/day as the best cost value. From this obtained value, it is easy to conclude that BHA approach has explored the best solution for this experiment.

Table: 3 Congestion Cost (Bilateral Transaction).

Rescheduling cost \$/Day	WORST COST	AVERAGE COST	BEST COST
BB-BC	3268.1631	3259.1645	3254.7000
PSO	3021.1754	3014.3516	3008.9000
BHA	2808.7853	2799.6168	2793.8000

Change in powers from the optimal scheduling for congestion is shown in figure no: 2 the ups and downs of the change in real and reactive powers are shown in the figure is achieved by rescheduling the generators based on real and reactive sensitivity values.

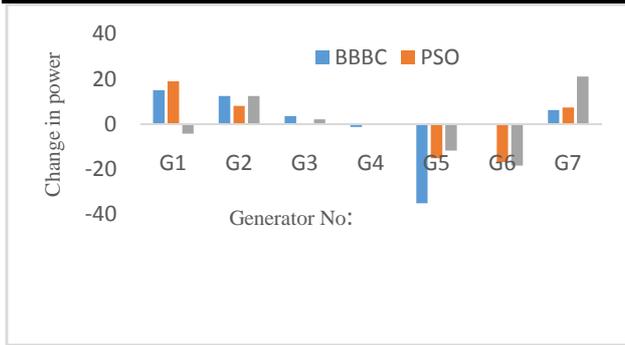


Fig.3: Change in Real Power (Bilateral Transaction)

Power flow patterns in the line before and after the congestion is given in simple manner to understand the congestion concept. For the bilateral transactions, two lines line number 8 and line number 10 are in congestion. The rated value for the line number 8 is 200 MW and the rated value for the line number 10 is 50 MW respectively, but under the congested duration the power flows is 204.9707 MW in line number 8 and 56.4711 MW in line number 10. The net violations of power is 11.4418 MW of powers, for the normal operation by eliminating the congestions, above mentioned approaches are used to obtain the optimal values.

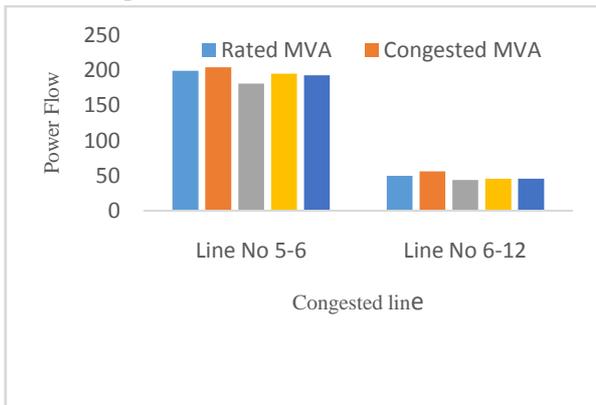


Fig. 5: Change in Line Flow (Bilateral Transaction)

Convergence of the algorithm in congestion management is shown in figure. The algorithm takes about 20 iterations to get converged showing that the algorithm is efficient in achieving good results.

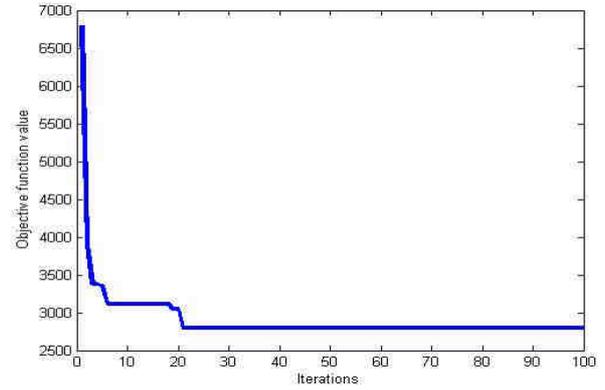


Fig. 4: Convergence Characteristics of BHA (Bilateral Transaction)

4.2 Case B Multilateral transactions

The agreement is made with more than two buses is known as multilateral transactions, when the desired power is injected at any one of the bus and the same amount of power is consumed at more than two agreed buses . For this second experiment, the first multilateral transactions is injecting 50MW of power at bus number 4 and same amount of power is consumed in bus number 15 and bus number 19 as 20MW of power and 30MW of power respectively. In the second multilateral transaction, 25MW of power is injected in bus number 10 and the same amount of power is consumed in different buses as 10 MW at bus number 47 and 15 MW at bus number 56. The impact of this transactions leads congestions in three lines, sensitivity values are calculated for congested line based on real and reactive powers are tabulated in Table No 4.

Table: 4 Generator Sensitivity Factors of Congested Lines (Multilateral Transactions)

Congested lines	Line No:8 (bus 8-4)		Line No:10 (bus 5-6)		Line No:10 (bus 6-12)	
	P	Q	P	Q	P	Q
G ₁	0	-	0	-	0	-
G ₂	0.0133	0.0027	0.0214	0.0078	0.0020	0.1530
G ₃	0.0584	0.0009	0.0939	0.0025	0.0090	0.0487
G ₄	-	0.0106	0.3990	0.0312	0.1052	0.0363
G ₅	0.3088	-	0.5355	0.1398	-	0.1169
G ₆	-	0.6310	-	3.1882	0.1715	0.4802
G ₇	0.1761	0.1186	-	-	0.2238	-
	0.1148	0.2107	0.2139	1.2849	-	0.8701
	-	-	-	-	-	-
	0.0458	0.3292	0.0783	0.9754	0.0116	0.6992

The optimal values of real and reactive powers obtained based on sensitivity factors through three approaches are tabulated in table no 5 after eliminating the congestion in the transmission lines. The obtained values are within the range of system constraints and guaranteed with system security and reliability. Which is very helpful for multilateral transactions with maximum profit for the market participants.

Table: 5 Optimal Rescheduling Power (Multilateral Transaction)

Reschedule Generator	BBC Technique		PSO Technique		BHA Technique	
	Real power	Reactive power	Real power	Reactive power	Real power	Reactive power
G ₁	103.2778	-31.4303	194.2509	284.061	109.3897	141.8282
G ₂	100.0000	50.0000	88.2500	24.0560	100.0000	65.7306
G ₃	60.7422	60.0000	49.0254	55.3895	57.4829	76.0310
G ₄	86.6934	25.0000	90.0445	17.9582	90.3981	80.5521
G ₅	434.0842	200.0000	441.6396	49.0229	446.7535	48.2638
G ₆	85.3772	9.0000	75.1639	15.6120	73.5471	-1.7742
G ₇	410.0000	155.0000	344.4734	44.2857	403.4210	74.9448

The rescheduling cost reported by three approaches are tabulated in table no: 6 in the form as worst cost, average cost and best cost. The BHA approach suggests a best minimum congestion cost as 5984.8000 \$/day where as in the other approaches like BB-BC suggests 6242.0000 \$/day and PSO suggests 6424.6000 \$/day as a result that BHA approaches is dominant in giving the best solutions.

Table: 6 Congestion Cost (Multilateral Transaction)

Rescheduling cost \$/Day	WORST COST	AVERAGE COST	BEST COST
BB-BC	6252.7214	6247.0834	6242.0000
PSO	6435.1654	6429.9784	6424.6000
BHA	5996.2655	5989.2546	5984.8000

The up and downs found in the figure No: 5 shows change in the real powers based on sensitivity of the congested lines, influencing generators which has more sensitivity to the congestion is rescheduled to alter the

power flow pattern without violating the system constraints.

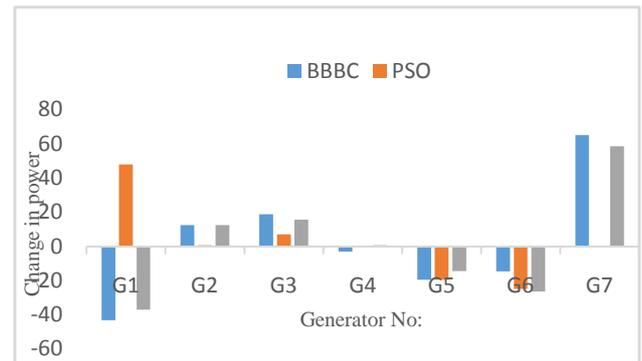


Fig. 6: Change in Real Power (Multilateral Transaction)

Multilateral transactions as a second experiment is conducted in modified IEEE 57 bus with conditions above mentioned leads a result with congestion found in three lines they are line numbers 5, 8 and 10. The rated value for line number 5 is 50 MW but the congested power flow is 53.1822 MW, for the line 8 the congested power flow is 224.6511MW but the rated value is 200MW and for the line number 10 the congested power flow is 63.6805 MW but the rated value is 50 MW. The net power violations in the multilateral transactions case is 41.5138 MW, to eliminate the congested power flow the optimization algorithms are implemented for the effective utilization of the transmission lines are shown in the figure No:6

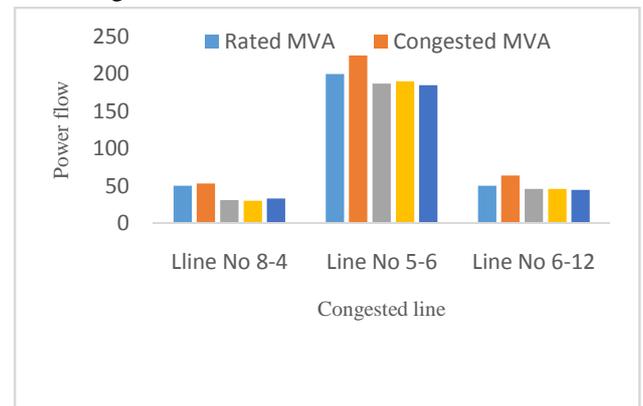


Fig. 7: Change in Line Flow (Multilateral Transaction)

Convergence quality of the algorithm in base B is shown in figure (8). The algorithm retains the best results from iteration number 40 to 100. The reliability of the algorithm is proved from this information.

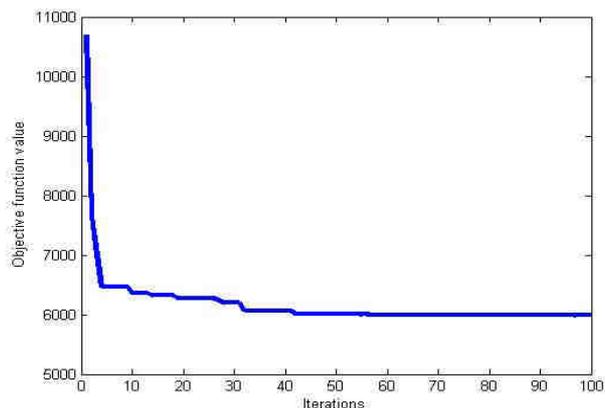


Fig. 8: Convergence Characteristics of BHA (Multilateral Transaction)

V. CONCLUSION

In this proposed work, a BHA approach is implemented to minimise the congestion cost by sensitivity based rescheduling and relieving the transmission congestion. The participating generators, which involves in rescheduling are selected by generator sensitivity of real power and reactive power. Two different cases of bilateral transactions and multilateral transactions are experimented in the modified IEEE 57 bus test system. The proposed work contributes to manage the congestion by selecting the influencing generators which has more sensitivity than the other generators instead of encouraging all the generators to reschedule randomly. The generator reactive powers of corresponding generators are taken into account for calculating the sensitivity index. The results obtained numerically are capable of efficient and quality solutions, the suggested encouraging results are compared with other optimization methods like particle swarm optimization (PSO) and big bang big crunch (BB-BC) algorithms. The proposed BHA algorithm can be implemented to other dynamic congestion management problems and also power system optimization problems.

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