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Active Power Rescheduling for Congestion Management based on generator sensitivity factor using Ant Lion Optimization Algorithm

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ABSTRACT

In the deregulated environment, the transmission grids are used optimally. This utilization of the transmission system makes some lines congested due to the capacity constraints of the line. Congestion becomes a barrier of power trading and it affects the security of the power system. Congestion Management (CM) is one of the main issues that threaten the system security and it is one of the most challenging tasks for the system operators. This paper presents a new method of Ant Lion Optimization (ALO) algorithm-based congestion management by rescheduling the real power output of the participating generators. In this paper, the generators are selected based on their sensitivity factor. The aim of optimally rescheduling real power of the selected generator is to alleviate congestion in the transmission grid by use of ALO. To test the proposed method, IEEE 30 bus system with two different case studies has been used. The obtained results showed the performance of the ALO in terms of time and convergence. The performance is evaluated by the time taking and the number iterations for convergence. The proposed method is very much suitable for the market when congestion occurs due to line outage or due to sudden disturbance in the load

Keywords: Ant Lion Optimization, Congestion management, Deregulated power System, Generator Sensitivity Factor

I. INTRODUCTION

The deregulated power sector started some decade ago in many countries in the world. Power systems which were vertically integrated are unbundling now. This aspect of the power system changes the view about them. The network is faced with many challenges and the main challenge is the issue of congestion. Congestion is a situation where some constraints of the system are violated. These violations make the power system insecure, unreliable and reduce the power trading. The congestion management becomes the main subject of interest in deregulated environment.

According to reference [1], congestion in transmission systems is a situation where the demand for transmission capacity exceeds the transmission grid capabilities. This condition normally results in a violation of network security limits such as thermal, voltage stability and angular stability. In reference [2], a multi-objective function for congestion management by locating and sizing Series FACTS was proposed using a newly developed grey wolf optimizer. Optimal location of TCSC was proposed in [3] using PSO. Authors in [4] performed the best location of FACTS device like TCSC and UPFC by using sensitivity based Eigen value analysis and the performance analysis. active power spot price index (APSPI) was used to reduce the solution space effectively and to determine the best location of TCSC in the system in reference[5]. Reference [6] proposed also a review of congestion management by deciding optimal location of FACTS device. Authors in [7] proposed new indices to voltage drop compensation and congestion rent contribution method using sensitivity approach and pricing method.

A Genetic Algorithm based rescheduling of generators is developed to alleviate the congestion in [8]. In [9],the authors proposed an efficient method for transmission line over load alleviation in deregulated power system using cuckoo search algorithm (CSA). The authors in [10] presented a Genetic Algorithm (GA) based new reconfiguration algorithm of the network which will able to identify the most congested area of power network and fabricate the least loss condition after alleviating overload and overvoltage. According to reference [11], the authors used adaptive real coded biogeography based optimization to minimize rescheduling power and hence minimize the congestion cost. An intelligent method is proposed for congestion management in power system in [12]. According to reference [13], congestion management in hybrid electricity market for hydro-thermal was proposed. In references [14]-[15] , PSO algorithm was used to minimize the scheduled of the generator output with different objectives functions. A real coded GA was used to find the optimal generation rescheduling for relieving congestion [16]. According to reference [17], the authors proposed a new model for power system congestion management by considering power system uncertainties based on chance-constrained. In reference [18], congestion relief procedure has been discussed and compared with the objective of rescheduling cost minimization and proposed objective of real power loss minimization. Modified grey wolf optimizer used for congestion management in a deregulated power systems was proposed in [19]. The authors in [20] proposed an approach considering the risk of cascading failures for congestion management. The major contribution is its utilization on both active and reactive power cost functions in the objective function. [21] proposes a novel PSO strategy for transmission congestion management. In [22] , the authors proposed a probabilistic model to reduce the probability of line congestions and voltage violations in a smart grid located in a radial distribution network. Reference [23] proposed a flower pollination algorithm (FPA) for congestion management (CM) problem of deregulated electricity market. The aim of employing FPA is to effectively relieve congestion in the transmission line by rescheduling of real power output of the generators. A new method to manage congestion based on low power tracing was proposed in reference [24].

An obvious technique of congestion management is rescheduling the power outputs of generators in the system. Generation sensitivity factor has been used to identify the generators which affect the congested line more. However, all generators in the system need not to take part in congestion management [25].

In reference [26], a contribution has been made with another technique for relieving the congested power in a transmission line using fuzzy logic with interline power flow controller. According to reference [27], the authors presented the various methods of congestion reduction in Indian power sector. The authors proposed in reference [28] a method using optimal power flow topology for congestion management in power system. In reference [29], the authors developed a method using market splitting based approach for relieving congestion. In reference [30], the authors employed an Heuristic search algorithms incorporating wireless technology method to minimize the congestion cost. In reference [31], an approach using generation rescheduling to relieve congestion is proposed. It is formulated as an optimal power flow (OPF) and solved by employing particle swarm optimization.

The authors in reference [32] tried to find the optimal rescheduling of active power generations based on real power sensitivity index of the generators so as to minimize the congestion cost. In [33], the authors proposed using of a novel Satin bowerbird optimization for real power rescheduling of generators for congestion management. In reference [34], the authors proposed the using of MATPOWER for the analysis of congestion and its using to determine the generator sensitivity factor. Changing the pattern of real power generation from generators are used for congestion management and black hole algorithm (BHA) is used for identifying the optimal generation pattern for avoiding congestion in reference [35]. In reference [36], real and reactive power rescheduling based congestion management is used to relieve the transmission congestion. In reference [37], a combined economic and emission dispatch (CEED) by employing a novel technique of optimization through artificial bee colony (ABC) algorithm have been proposed to relieve the congestion. In reference [38], generator rescheduling is proposed as the congestion management technique. The authors used the generator sensitivity factor to identify the generator participating in congestion management and Firefly algorithm is used to find the optimal rescheduling. An improved differential evolution (IDE) algorithm was presented in reference [39] to alleviate Congestion in transmission line by rescheduling of generators while considering voltage stability. In reference [40], Artificial Bee Colony algorithm was used for real power rescheduling to relieve congestion. The authors computed the generator sensitivity factor for the congested lines.

The authors proposed in reference [41] a concept of transmission congestion penalty factors and its implementation to control power overflows in transmission lines for congestion management.

Developed in 2015 by Mirijalili, Ant lion optimizer (ALO) is a novel nature inspired algorithm. ALO is based on the hunting mechanism of antlions [42]. In reference [42], ALO shows its performance compared to PSO, BA, PFA, GA. According to reference [43], the authors used ALO for optimal power flow with enhancement of voltage stability.

Congestion management problem is an optimization problem and the aim is to find the best algorithm that gives better results from the literature. ALO is selected because of its performance and simplicity. In this paper, the purpose is to use a novel algorithm called ALO for rescheduling the real output of the generators with minimum cost of congestion. The generators are selected based on their sensitivity factor

The introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

II. PROBLEM FORMULATION

In this paper, congestion management in deregulated power system based on a pool is considered. When congestion occurs after the market accord, the Independent System Operator (ISO) should determine the minimal changes in the market results that ensure a secure operation. In this work, it is considered that the pool operator provides congestion free schedule of generation of the sellers and buyers of GENCOs and DISCOs. Also, during operation of power system, congestion in transmission systems may occur due to uncertainty of load or due to contingencies. This work mainly focuses on relieving congestion when overload occurs due to single line outage and change in load. Based on the incremental/decremented price bids submitted by various GENCOs for congestion management, the ISO finds the minimal re-dispatch of generators from the preferred schedules in order to minimize the congestion management cost

✓ Objective function

The objective function is formulated in this work to minimize the total congestion management cost due to the rescheduling of real under constraint operating based on the price bids submitted by GENCOs.

Thus the objective function can be written mathematically as:

$$Fx = min\left(\sum_{g}^{ng} C_{gp}\left(\Delta P_g\right).\Delta P_g \right) \tag{1}$$

Where Fx is the total cost for congestion management which is the total cost incurred for adjusting real power generation of the participating generators by the system operator for congestion management. $C_{pg}(\Delta P_g)$ is the per MW price bid submitted by participating generator to increase and decrease their generations to manage congestion. The participating generators are interested to change their real power outputs at those prices. ΔP_g is the change in generation from scheduled value declared after market clearing procedure.

✓ Constraints

The objective function is a minimized subject to the following constraints:

- Equality constraints:

These constraints represent power flow equations as follows.

$$P_{gi} - P_{di} - \sum_{j=1}^{N} |V_i||Y_{ji}|\cos\left(\delta_i - \delta_j - \theta_{ij}\right) = 0 \tag{2}$$

$$Q_{gi} - Q_{di} - \sum_{j=1}^{N} |V_i||Y_{ji}|\sin\left(\delta_i - \delta_j - \theta_{ij}\right) = 0 \tag{3}$$

- Inequality constraints

The inequality constraints of the OPF reflect the limits on physical devices in the power system as well as the limits created to ensure system security.

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}, i = 1, \ldots\ldots\ldots\ldots\ldots, ng \tag{4}$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max}, i = 1, \ldots\ldots\ldots\ldots\ldots, ng \tag{5}$$

Incremented or decremented real and reactive power limit:

$$\left(P_{gi} - P_{Gi}^{\min}\right) = \Delta P_{Gi}^{\min} \le \Delta P_{Gi} \le \Delta P_{Gi}^{\min} = \left(P_{Gi}^{\max} - P_{gi}\right) \tag{6}$$

$$\left(Q_{gi} - Q_{Gi}^{\min}\right) = \Delta Q_{Gi}^{\min} \le \Delta Q_{Gi} \le \Delta Q_{Gi}^{\min} = \left(Q_{Gi}^{\max} - Q_{gi}\right) \tag{7}$$

- MW flow limit of ij transmission line : system security

$$\sum_{g}^{ng} ((GS_g^{ij}).\Delta P_g) + F_{ij}^{o} \le F_{ij}^{\max} \tag{8}$$

P_{ij} and Q_{ij}: original active and reactive power flow between bus-I and bus-j;

P_{gi}, Q_{gi}: Active and reactive power generator at bus i

P_{di}, Q_{di}: Active and reactive demand at bus I;

P_{Gi}^{max}, P_{Gi}^{min}: Real power generation limits of generator g at bus i

ΔP_{Gi}^{max}, ΔP_{Gi}^{min}: Maximum and minimum limits of the change in generator active power output respectively;

Q_{Gi}^{max}, Q_{Gi}^{min}: Reactive power generation limits of generator g at bus i

ΔQ_{Gi}^{max}, ΔQ_{Gi}^{min}: Maximum and minimum limits of the change in generator reactive power output respectively;

F_{ij}^{0}: MW flow of the transmission line connected between bus-i and bus-j;

F_{ij}^{max}: MW flow limit of the transmission line connected between bus-i and bus-j

N: total number of buses;

ng: total number of participated generator buses

III. GENERATOR SENSITIVITY FACTOR

The Generator sensitivity technique indicates the change of active power flow due to change in the active power generation. The generators in the system under consideration have different sensitivities to the power flow on the congested line. A change in active power flow (ΔP_{ij}) in a transmission line k connected between bus i and bus j due to unit change in active power injection (ΔPG_{gn}) at bus-n by generator-g can be defined as an active power generator sensitivity factor (GS_{pgn}^{k}) developed in references [38],[40] and [44]. Mathematically, it can be written for line k as:

$$GS_g^{ij} = \frac{\Delta P_{ij}}{\Delta PG_{gn}} \tag{9}$$

IV. ANT LION OPTIMIZATION ALGORITHM

Ant-Lion Optimizer (ALO) is a novel nature-inspired algorithm proposed by Seyedali Mirjalili in 2015. The ALO algorithm copies the hunting mechanism of ant lions in nature in reference [42]. The ALO algorithm mimics interaction between ant lions and ants in the trap. To model such interactions, ants are required to move over the search space, and ant lions are allowed to hunt them and become fitter using traps. Since ants move stochastically in nature when searching for food, a random walk is chosen for modeling ants' movement as follows:

$$X(t) = [0, cumsum(2r(t_1)-1), cumsum(2r(t_2)-1), \ldots\ldots, cumsum(2r(t_n)-1)] \tag{10}$$

Where *cumsum* calculates the cumulative *sum*, n is the maximum number of iteration, *t* shows the step of random walk and $r(t)$ is a stochastic function defined as follows:

$$r(t) = \begin{cases} 1 \text{ if } & \text{rand} > 0.5 \\ 1 \text{ if } & \text{rand} \leq 0.5 \end{cases} \quad (11)$$

However, equation (10) cannot be used directly for updating the position of ants. In order to keep the random walks inside the search space, they are normalized using the following equation (min-max normalization):

$$X_i^t = \frac{(X_i^t - a_i)(d_i - c_i^t)}{(d_i - a_i^t)} + c_i \quad (12)$$

Where a_i is the minimum of random walk of i^{th} variable, b_i is the maximum of random walk in i^{th} variable, c_i^t is the minimum of i^{th} variable at t^{th} iteration, and d_i^t indicates the maximum of i^{th} variable at t^{th} iteration.

- **Trapping in ant lion's pits**: random walks of ants are affected by antlions' traps. In order to mathematically model this assumption, the following equations are proposed:

$$C_i^t = \text{antlion}_j^t + C^t \quad (13)$$

$$d_i^t = \text{antlion}_j^t + d^t \quad (14)$$

- **Building trap**: In order to model the ant-lion's hunting capability, a roulette wheel is employed. The ALO algorithm is required to utilize a roulette wheel operator for selecting ant lions based on their fitness during optimization. This mechanism gives high chances to the fitter antlions for catching ants.
- **Sliding ants towards ant lion**: With the mechanisms proposed so far, antlions are able to build trapsproportional to their fitness and ants are required to move randomly. However, antlions shoot sands outwards the center of the pit once they realize that an ant is in the trap.

$$c^t = \frac{c^t}{I} \quad (15)$$

$$d^t = \frac{d^t}{I} \quad (16)$$

Where I is a ratio, c^t and d^t are the minimum of all variables at t^{th} iteration

- **Catching prey and re-building the pit**: The final stage of hunt is when an ant reaches the bottom of the pit and is caught in the antlion's jaw. After this stage, the antlion pulls the ant inside the sand and consumes its body. For mimicking this process, it is assumed that catching prey occur when ants become fitter (goes inside sand) than its corresponding antlion. An antlion is then required to update its position on the latest position of the hunted ant to enhance its chance of catching new prey.

$$Antlion_j^t = Ant_i^t \quad if\ f(Ant_i^t) > f(Antlion_j^t) \tag{17}$$

- **Elitism:** Elitism is an important characteristic of evolutionary algorithms that allow them to maintain the best solution(s) obtained at any stage of the optimization process. Since the elite is the fittest antlion, it should be able to affect the movements of all the ants during iterations.

V. APPLICATION OF ALO IN CONGESTION MANAGEMENT

The implementation of ALO for congestion management is shown in the following steps:

Step 1: Line and bus data are used to perform the load flow;

Step 2: Creation of line outage and check whether there is any congested line;

Step 3: If yes, Compute the GSF of each overloaded line to all the generators;

Step 4: Selection of the participating generator based on the GSF;

Step 5: ALO parameters such as: Search Agent, dimension, lower bound and upper bound, maximum iteration are specified: initialization;

Step 6: The fitness function is evaluated for each ants and antlions and the best antlion which is the elite is identified.

Step 7: The elite antlions are selected using Roulette Wheel: Building traps;

Step 8: Sliding ants towards antlion: Update the value of c and d using eq (15) and (16);

Step 9: Update the positions of each ant with random walk using (12): Random walk;

Step 10: Calculate the fitness of updated ants using (17): Ants fitness;

Step 11: Catching preys and rebuilding traps.

Step 12: If the maximum number of iteration is reached then it is stopped if not it goes to 6.

VI. SIMULATION RESULTS AND DISCUSSIONS

In this paper, the ALO for congestion management was implemented using Matlab R2014a software on a computer system based on an intel core i5 Processor, with 2.40 GHz and 8GB of RAM. The validity of the proposed approach has been tested in two different scenarios using IEEE 30 bus system. The data is taken in reference[45]. It consists of 6 generators, 24 load buses and 41 transmission lines. The bus number 1 is the slack bus and the other generators are assigned to number 2,5 8, 11 and 13. The total load is 283.4 MW and 126.2 MVAR. The first scenario is outage of the line 1-2 and increased all load bus by 20% and the second scenario is outage of the line 3-4 and increased the load by 250% at bus 2. In ALO, for the simulation, the search agent which is the population is taken as 35 and the maximum iteration was taken as 100.

The incremental and decremental price bids are in reference [15]

Scenario 1: Outage of the line 1-2 and increased the load by 20% in all buses

The results of the load flow of the scenario 1 are presented in Table 1. It has showed that three lines are overloaded. The power flow in line 1-3 and line 3-4 are respectively 163.3MW and 148.3 MW and the line flow limit is130 MW. The line 4-6 has as power flow 90.9 MW and the limit is 90 MW. The total violated amount of power is 52.5 MW.

Table 1: Congested line after Outage of the line 1-2 and increased all load bus by 20%:

Lines	Line limit (MW)	Current line flow (MW)	Line violation (MW)
1-3	130	163.3	33.3
3-4	130	148.3	18.3
4.6	90	90.9	0.9

For each overloaded line and in order to find out the generators which participated in the congestion management the generator sensitivity factor has been computed using Equation (9). The results of GSF are shown in Table 2. From this table, the sensitivity factor of all the generators except the slack bus depends on the effect of the generators on the congested line, the highest values of the GSFs for all the three overloaded lines are found at Generator 2, 5 , 8 and 11. This means that those generators with highest values have been selected to contribute for congestion management. After the selection of the generators, ALO has been used to reschedule optimally the real updated value of the generators and the minimum cost of congestion has been found and it is 2114.9443$/hr.

Table 2. Generator sensitivity factor

Congested Lines	G1	G2	G5	G8	G11	G13
1-3	**0**	**-1.306016**	**-1.376851**	**-1.302924**	-1.301487	-1.256327
3-4	**0**	**-1.111668**	**-1.171927**	**-1.108778**	-1.107547	-1.069071
4-6	**0**	-0.51304	-0.71298	-0.84783	-0.71491	-0.30942

In the Table 3 the updated values are shown for each generator. It permitted to see that the generator 2 has the high updated value. It contributed for congestion management for a large amount of real power. The contributed value {+36.765, +4.35971, +11.6111, +1.789} and the slack bus has contributed with an amount of -32.4208MW. The total amount of rescheduling power is 86.94 MW.

After alleviation of the congestion in the lines, the power flowing in those lines has been tabulated in Table 4. The line flows after the congestion management within the line limit. This is shown in the Table 4.

Table 3: Real power optimally rescheduling

Participated generators	Updated value (MW)
ΔP_1	-32.4208
ΔP_2	36.765
ΔP_3	4.35971
ΔP_4	11.6111
ΔP_5	1.789
ΔP_6	Not participating
Total rescheduling power	86.94 MW
Congestion cost	2114.9443$/hr

Table 4: Power flow in the branch before and after congestion management

Lines	Line limit (MW)	Before CM (MW)	After CM (MW)
1-3	130	163.3	128.8
3-4	130	148.3	118.8
4.6	90	90.9	76.3

The fig 1 presented the line flow of each line before and after congestion management.

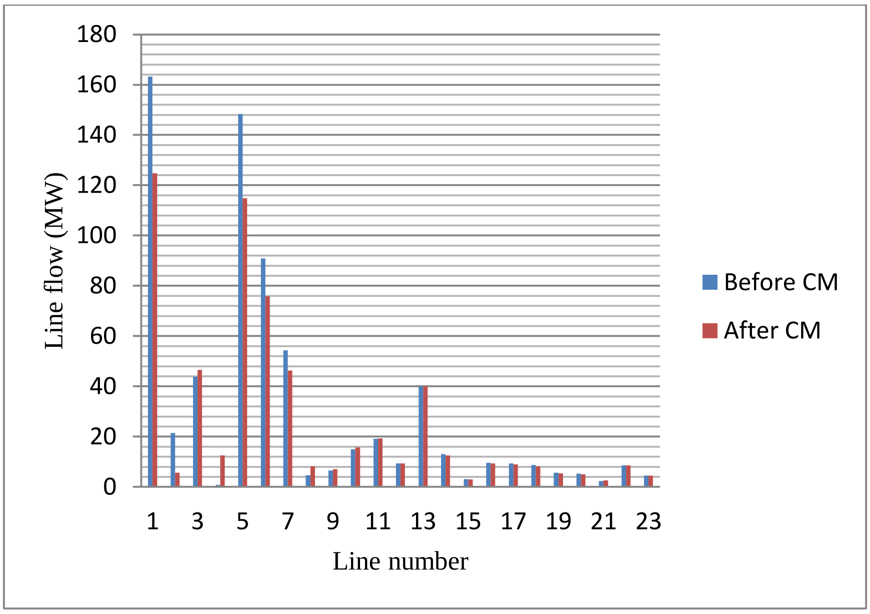

Figure 1: Line flow before and after congestion management

The Fig 2 shows the convergence curve of Ant Lion Optimization the minimization of the congestion cost for IEEE 30 bus system used in this scenario. The graph indicates that the rescheduling cost decreases piecemeal with a number of iteration and converges to the optimal value. From first to 38th iteration the cost was decreasing and from 38th to 100th the cost of rescheduling was constant.

The convergence was attained at 38th iteration. This was permitted to say that ALO performed very well in little iteration.

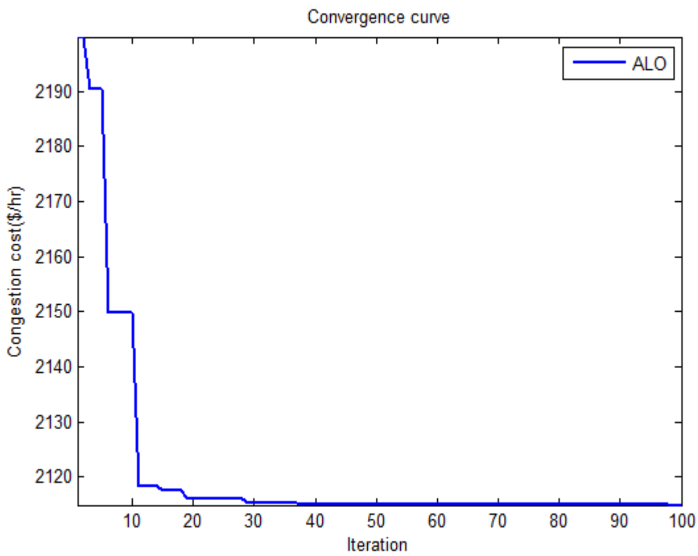

Figure 2: Total cost congestion progressing with iteration

Scenario 2: Outage of the line 3-4 and increased the load at bus 2 by 250 %

In this scenario, the load flow has been performed and the line flows are analyzed for each branch. It showed that the branch one (01), the line between the buses 1 and 2 had its power flow (138.3 MW) more than the line power flow limit (130 MW). This is shown in the Table 5. Since this line is overloaded it meant there is congestion

Table 5: Line flow analysis

Congested line	Line Limit	Current flow	Violated Value
1-2	130 MW	138.3 MW	8.3

The generator sensitivity of the congested line to the generators was computed and taken as slack bus- the generator bus 1. The GSFs are shown in Table 6. From this table, the generators G5, G8 and G11 show uniform sensitivity factor value. Uniform GSF means that all those generators have uniform impact on the congested line. So these generators did not take part in the congestion management. The generators G2, G13 are the remaining generators. If their sensitivity values are not uniform, then they will participate in the congestion management. The reference bus, G1 the slack will reschedule to reduce the system real power losses. In summary, the generators G1, G2, and G13 have been used for congestion management. The system operator has used the three generators to alleviate the congestion in the transmission system by updating their real output with minimum cost.

Table 6: Generator sensitivity factor

Congested line	G1	G2	G5	G8	G11	G13
1-2	0	-1.06016	-1.115094	-1.102266	-1.104506	-1.085792

The updated real power of each generator is shown in Table 7. The total rescheduling real power is 32.353 MW and the total cost of congestion is evaluated at 642.1$/hr. Before and after congestion management, the line flow in the branch 1-2 has been analyzed. It is shown in Fig 3, the line flow after congestion management. It alleviates the congestion by reducing the line flow to 118.7 MW. ALO has been used to optimally reschedule the updated value of the selected generator and the load flow performing has been used to update the value of the slack bus.

Table 7: Updated real power of the participating generators

Participated generators	Updated value (MW)
ΔP_1	-13.334
ΔP_2	18.868
ΔP_3	Not participating
ΔP_4	Not participating
ΔP_5	Not participating
ΔP_6	-0.151339
Total rescheduling power	32.353
Congestion cost	642.1$/hr

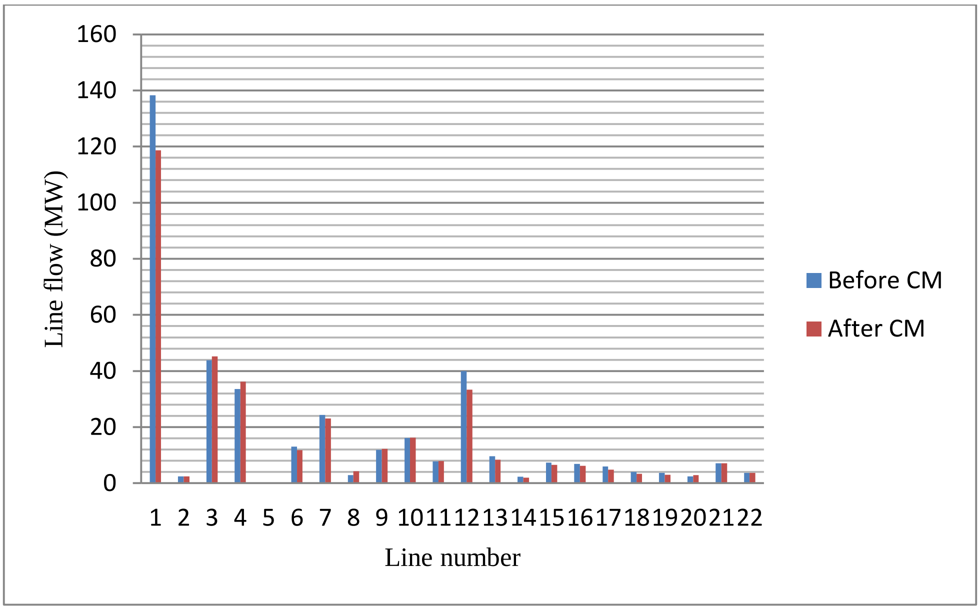

Figure 3: Line flow analysis before and after congestion management

The Fig 4 shows the convergence curve of Ant Lion Optimization the minimization of the congestion cost for IEEE 30 bus system used in the case study. The graph indicates that the rescheduling cost decreases piecemeal with a number of iteration and converges to the optimal value.

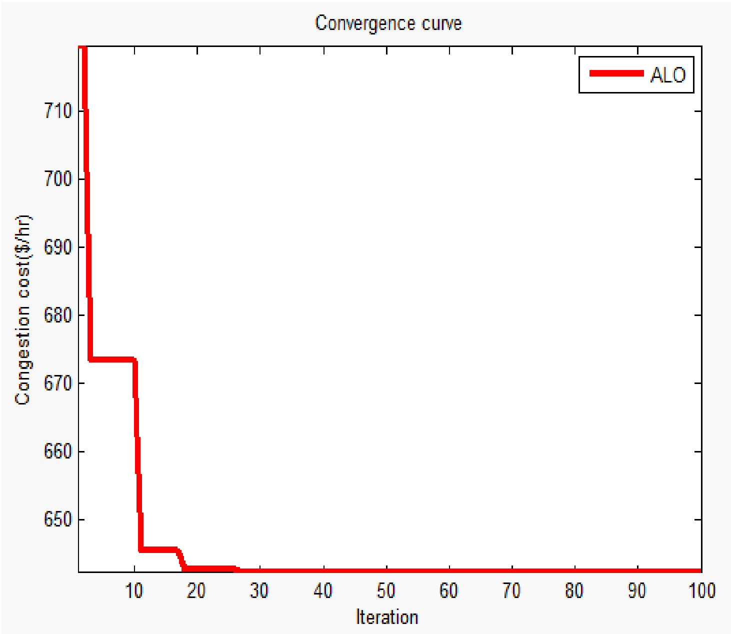

Figure 4: Total cost congestion progressing with iteration

The convergence was attained after 28 iterations. ALO Algorithm deals with the congestion from the violated lines within 100 iterations which prove the fact that ALO is a fast method.

VII. CONCLUSION

Line outage and increased load create congestion in the transmission system. The alleviation of this congestion is done using GSF for selecting the participated generator. The optimally rescheduling of real updated power of the selected generators has been performed well with ALO. From the results above, the congestion cost went high with the number of congested lines. The higher the number of congested lines the higher is the cost of congestion. Then the congestion cost depends on the amount of violation power. For the minimization of the congestion cost, ALO proved its performance in the two scenarios by giving very good convergence characteristics and achieved its convergence in less than 45 iterations. The proposed technique is successfully implemented on IEEE 30 bus system to manage the two different congestions scenarios. Moreover results found to be effective.

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