EAI Endorsed Transactions
on Energy Web

Research Article **EAI.EU**

Transmission Congestion Management in Deregulated Electricity Market using Multi-Objective Grasshopper Optimization Algorithm

Benjamin Chatuanramtharnghaka[1] and Subhasish Deb[1,*]

[1]Electrical Engineering Department, Mizoram University, Aizawl, Mizoram, India

Abstract

In this paper, a study of multi-objective based congestion management is carried out by generator rescheduling with considering generator fuels cost. Due to the rapid growth of electrical load, the pressure in the transmission sector increases to provide transmission of power in a safe manner. But owing to the load growth, the transmission line power flow reaches beyond thermal limit which results in transmission congestion. The congestion management in the present work has been done in a multi-objective framework considering generator rescheduling method as one of the objectives. A Multi-objective Grasshopper Optimization Algorithm (MOGOA) is implemented to perform the optimization for elimination of congested line and minimizing the operational cost of the system. The efficacy of the proposed method has been compared and analyzed with different multi-objective algorithms in IEEE 30 bus test system.

Keywords: Congestion management, generator rescheduling, optimization, multi-objective grasshopper optimization algorithm (MOGOA).

Received on 08 October 2020, accepted on 18 November 2020, published on 27 November 2020

doi: 10.4108/eai.27-11-2020.167288

*Corresponding author. Email: subhasishdeb30@yahoo.co.in

1. Introduction

In the present day, bids are being offered by the participant in the electricity market. The operator's in the market is to manage the conflict between suppliers and the consumers. The capacity of transferring power has been limited due to the increase of load demand. There is a frequent circumstance of contingency cases due to fault in transmission line, security breakdown and equipment collapse. Thus, normal operation of the power system is achieved only when the power flow in the network is well maintained at an acceptable limit and voltage magnitude are within the acceptable range. This normal condition for the power system is to achieve in order to have a reliable, productive, better security system in the growing electricity market. Many authors have proposed different methods in the field of congestion management.

A congestion management by a method of regulating output of generators and shedding of load is proposed in [1]. Sen Transformer device are used in [2] to control the flow of power over a wide range. In [3], problem of congestion management is carried out using FACTS. In power market, problem of congestion management is quite complex compared to that of a bundled system. A zonal/cluster based is proposed in [4] in which a zone is formed for both real power and reactive power depending on their sensitivity to the line, the generators from the most sensitive zones having a substantial sensitivity index for distribution are chosen for readjusting their output power generation for congestion management. Contingencies that occur in the real time scenario caused by the interference in the security system can leads to financial breakdown to the customers and service providers. For the purpose of handling this real time scenario, a RTCM (Real Time Congestion Management) is presented in [6] and [7].In [6], the author proposed a method of adaptive RTCM where adaptive capability thermal ratings of transmission are utilized to eliminate the congestion. Also, a modeling of the demand response program comes into a single objective and a hybrid optimization algorithm for real time scenario is developed to obtain an ideal solution of congestion management problem during a short period of time. In [7], calculation of different thermal rating of the transmission line is specified for observing the performance of the conductors under different weather condition. The problem of congestion management is being design in a pattern of two or more objective function and a Pareto Frontier set for the multi-objective is obtained using a Normalized Normal Constraint (NNC) [8]. A Bacteria Foraging Optimization (BFO) has been utilized in [9] which are proposed based on a bidding strategy. A Bacterial Foraging (BF) algorithm combining with a Nelder-Mead (NM) method is utilized in [10]. FACTS are installed at an ideal location using this algorithm to eliminate overload line. Also, in [11], congestion management based on bidding strategy is shown. In [12], the author proposed a distributed algorithm to increase the predominant social welfare with balancing of power is maintained in a DC system. A FABF method is presented in [13] to determine sensitivity of each generator bus to the congested line by changing output of generator real power. An old and mostly used well known optimization algorithm, the Particle Swarm Optimization short form for PSO, an optimization method which is popular due to the clarity and less complicated is shown in [14] - [17]. In [14], the author sets two objectives i.e., elimination of power line overload and reduction of cost of operation. In [15] presents a PSO including an aging leader and challenges algorithm which is used to solved the problem that arises for optimality power flow of the system. The heuristic based optimization algorithm is utilized for proper placing and sizing of such FACTS device like UPFC in power system market [16]. A PSO algorithm for multi-objective is employed to find optimal place and size for installation of DGs (Distributed Generators) and SCB (Shunt Capacitor Banks) [17]. The article in [18] shows how an optimal location for placing a FACTS device like TCSC (Thyristor Controlled Series Compensators) in power system to improve loading capacity of the lines and minimizing power loss in lines. In addition, four types of FACTS controller are used where a genetic algorithm is performed for finding their optimal location in a power system [19]. A fuzzy-based genetic algorithm is use in [20]. The article in [21] shows the potential of Non-Sorting Genetic Algorithm-II for computing the congestion management problem which is to minimize the management cost and improving the voltage and transient stability margins in a pool-based electricity market. Handling such a multiple objective simultaneously for optimization is a very different process from a single objective problem. For solving our problem, we will use one of the latest multi-objective optimization algorithms known as Grasshopper Optimization Algorithm (GOA) which has been proposed in [24]. The work of this paper is to manage congestion in the system transmission line using an optimization algorithm and adjusting the parameter such that the operation of the system is at its minimum cost. In[28]-[31], generators for rescheduling are selected based on sensitivity factor for congestion management. In [32], the authors try to improve the reliability of the system using renewable resources by installing an Energy Storage System (ESS). The problem formulation in the article is considered as generation cost and cost of demand interruption in contingency cases for relieving transmission congestion. A congestion management in power market is attempted in [33] by Virtual Power Plant (VPP) and implementing a renewable resource. The author describes how a VPP is effective to integrate a multiple form of energy and also helps in penetration proportion of the renewable energy sources. A hybrid NSGA-II is used for optimizing the congestion problem. An optimal allocation for placing FACTS device is shown in [34] based on sensitivity factors to the congested line. A Disparity Line Utilization Factor is used as sensitivity for location of the FACTS device (TCSC). A Grey Wolf Optimization is used to optimise the parameter for TCSC. Implementation of Distributed Energy Resources (DER) is done in [35] for economic operation and system reliability. The distribution network is upgraded to Active Distribution Network, a two-stage hierarchical congestion management mechanism is used for the Active Distribution Network which are connected to a microgrid system and a multi-type DER. Also, in [36], congestion management for Active Distribution system are done with Plug in Electric Vehicles and controlling air pollution with considering the demand response program. Various renewable resources are applied to eliminate congestion and air pollution in the environment. A multi-objective congestion management is done in [37] with transmission switching by considering the overall operational cost and optimizing the number oftransmissions switching. In [38], a new method based on graphoanalytical has been introduced for determining parameters balancing devices of three-phase system. A survey on numbers of research article related to congestion management on some approaches is shown in [39]. It shows different techniques and methods on how to face congestion in the power market. Also, some of the major challenges and issues are pointed out in the article. A multi-objective congestion management based on particle swarm optimization is presented in [40].

2. Problem Formulation

As we mentioned earlier, the problem of congestion in a power system occurs when the generators are unable to supply sufficient amount of power required by the load or consumers due to the limited power flow allowance by the transmission lines. In order to overcome this incompetent situation, generator output by the generator bus is often adjusted for proper distribution of power to maintain the flow of power in the lines under its rated limits.

2.1. Generation Rescheduling

The objective function (Generator rescheduling) is formulated as [22]:

$$\min \sum_{g}^{N_g} C_g(\Delta \mathrm{P}_g)\Delta \mathrm{P}_g \tag{1}$$

C_g = is represented as the price or cost for adjusting power output from the generating companies.
ΔP_g= is represented as the difference in changing power at bus-g from the initial value.
N_g = is represented as the total number of generator bus.

2.2. Generation Cost Minimization

Efficiency has become an important task especially for thermal plant for sustaining and conserving the limited resources. The generation cost minimization is the other objective in the proposed work and can be formulated as, [23]

$$\min \sum_{i=1}^{N_G} a_i + b_i P_{G_i} + c_i P_{G_i}^2 \tag{2}$$

Where,
a_i, b_i and c_i=is represented as the coefficient for calculating generation cost.
P_{Gi}= is represented as the generation of active power at i^{th} unit.
N_G = is represented as the total number of generator bus.

2.3. Constraints

Equality Constraints

For the case study, the system has to satisfy an equality constraint. In order to achieve optimality for the system operation, balancing power to system load including loss has been brought up as an equality constraint. This condition is formulated in the following equation (3) and (4) [1]:

$$P_{G_y} - P_{D_y} - V_y \sum_{a=1}^{N_B} V_a \left(G_{ya}\cos\theta_{ya} + B_{ya}\sin\theta_{ya} \right) = 0; \quad \mathrm{y}=1,\ldots,\mathrm{N}_B \tag{3}$$

$$\mathrm{Q}_{G_y} - Q_{D_y} - V_y \sum_{a=1}^{N_B} V_a \left(G_{ya}\sin\theta_{ya} - B_{ya}\cos\theta_{ya} \right) = 0; \quad \mathrm{y}=1,\ldots,\mathrm{N}_B \tag{4}$$

Where index P_{G_y} indicates the real power generation at y^{th} bus, P_{D_y} is the real power demand power demand at y^{th} bus,$\mathrm{V_y}$ and $\mathrm{V_a}$ are the voltage magnitude at y^{th} and a^{th} bus, $\mathrm{G_{ya}}$ and $\mathrm{B_{ya}}$ are the conductance and susceptance of y^{th} and a^{th} bus.

Inequality Constraints

1. Generator constraints: The amount of voltage, active and reactive power generation to the system is limited by the following bounds: [1]

$$\mathrm{V}_{G_p}^{\min} \le V_{G_p} \le V_{G_p}^{\max}; \quad \mathrm{p}=1,\ldots,\mathrm{N}_G \tag{5}$$

$$\mathrm{P}_{G_p}^{\min} \le P_{G_p} \le P_{G_p}^{\max}; \quad \mathrm{p}=1,\ldots,\mathrm{N}_G \tag{6}$$

Where, the index $\mathrm{V_{Gp}}$ and $\mathrm{P_{Gp}}$ indicates the voltage magnitude and real power generation. $\mathrm{N_G}$ is the number of generating unit.

2. Security Constraint: The security constraints can be described as the constraints related to the voltage of load bus and the power flow limit of the line. It can be formulated as follows, [1].

$$V_{L_r}^{\min} \le V_{L_r} \le V_{L_r}^{\max}; \quad \mathrm{r}=1,\ldots,\mathrm{N}_L \tag{7}$$

$$\mathrm{S}_{l_n} \le \mathrm{S}_{l_n}^{\max}; \quad \mathrm{n}=1,\ldots,\mathrm{N}_{BR} \tag{8}$$

Where $\mathrm{V_{Lr}}$ is the voltage magnitude of load bus r and $\mathrm{S_{ln}}$ is the power at branch $\mathrm{N_{BR}}$.

3. Multi-objective Grasshopper Optimization Algorithm (MOGOA)

A new optimization algorithm known as Multi-Objective Grasshopper Optimization Algorithm (MOGOA) was proposed by Seyedeh Zahra Mirjalili, Seyedali Mirjalili, Shahrzad Saremi, Hossem Faris and Ibrahim Aljarah in the year 2017 [24]. As from the name itself, the Grasshopper Optimization Algorithm mimics the swarming manners of grasshopper from their natural behavior. The inspiration was taken from how the grasshopper searches for food as a swarm in nature for surviving. The algorithm procedure is somewhat similar to other nature inspired algorithm like Particle Swarm Optimization Algorithm. The searching process also includes exploring and exploiting a random search area to find a number of possible solutions in the search space which is also taken as the position of the grasshopper. In this paper, a Multi-objective approach Grasshopper Optimization is utilized to handle two objective simultaneously. The three components of the optimization include the social interaction, gravitational force and wind advection amongst the grasshopper swarm. Grasshopper position is mathematically modeled as [24]:

$$X_p = S_p + G_p + A_p \tag{9}$$

Where X_p represents the p^{th} grasshopper position, S_p represents the p^{th} grasshopper social interaction, G_p is the gravitational force and A_p is the wind advection. The social interaction which is also the main component of the algorithm can be extracted by the following equation,

$$S_p = \sum_{\substack{q=1 \\ q\ne 1}}^{M} s\left(\left| x_q - x_p \right| \right) \frac{\left(x_q - x_p \right)}{D_{pq}} \tag{10}$$

$$s\left(y \right) = f e^{-y/kk} - e^{-y} \tag{11}$$

The ‘*s*’ function in Eq. (11) is the social force between the grasshopper, ‘*f*’ is the intensity of attraction, ‘*y*’ is the distance between the grasshopper and ‘*kk*’ is the length of attraction. The position of the grasshopper can be updated by implementing the following equation,

$$x_p^z = G\left(\sum_{\substack{q=1\\ q\neq 1}}^{M} G\frac{\left(x_{\max}^z - x_{\min}^z\right)}{2} s\left(\left|x_q^z - x_p^z\right|\right)\frac{\left(x_q^z - x_p^z\right)}{D_{pq}^z}\right) + x_{gbest}^z \quad (12)$$

$$G = G_{\max} - iter\frac{G_{\max} - G_{\min}}{iter_{\max}} \quad (13)$$

Where x_p^z is the z^th^ variable p^th^ position in the population, D_{pq}^z is the distance between p^th^ and q^th^ position of z^th^ variable and x_{gbest}^z is the global best of z^th^ variable, '*G*' is the parameter of the optimization algorithm and is set to a range of 0.00002 as minimum and 1 as the maximum for this case.

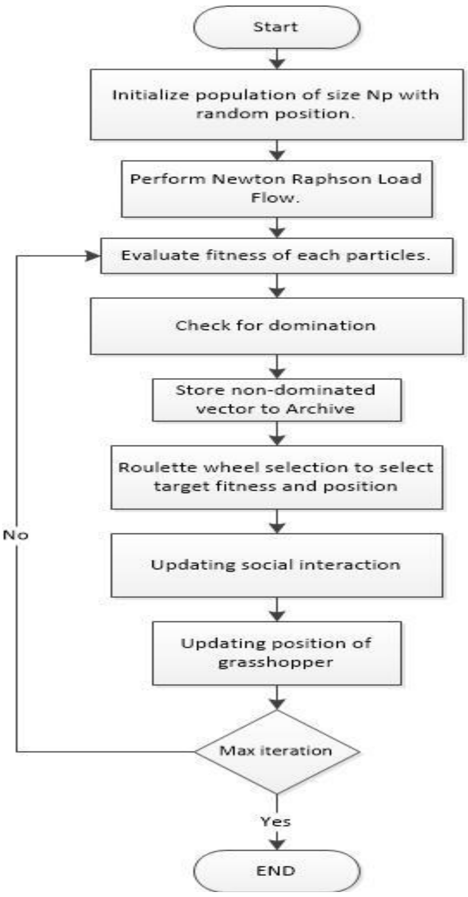

Figure 1. Flow chart of MOGOA

The Multi-objective Grasshopper Optimization algorithm is as follows [24]:

1. Initialize the input parameters for the optimization algorithm and the control variables for the objective function.
2. Create a population of size *Np* based on the input parameters.
3. Initialize an Archive memory to store the position and fitness of the grasshopper.
4. Evaluate each of the members in the population for finding the objective function.
5. Check for domination among the fitness of each position.
6. Update and store the result and position of the member into the Archive memory based on the domination.
7. Roulette-wheel selection is performed to select the target fitness and position.
8. Updating the '*G*' value, which is responsible for the exploration and exploitation of the search space.
9. Updating the social interaction among the grasshopper.
10. Update the position of the grasshopper.
11. Increment new generation.
12. Maximum generation reached. END the loop.

4. Results and Discussion

In this paper, we will be testing the effectiveness of the Multi-objective Grasshopper Optimization for the elimination of overload in the system transmission line in the IEEE 30 bus test system as well as minimizing the rescheduling cost for congestion management and operation cost of the system. The IEEE 30 bus system has 6 generator bus, 21 load bus and 41 lines. Since the test system is a small system, all the generators are participated for the congestion management. The bus data and line details are obtained from [23]. Assuming that the system is a dynamic system and sudden increase in load may occur at an instant, different case study has been made where congestion occurs due to the increasing load of the system.

Table 1. Price bid from the generator for IEEE 30 bus

No. of Gen.	1	2	3	4	5	6
Bid amount ($\$/MW^2$-Day)	11	17	19	20	15	10

Table 2.Generation cost coefficient

a ($/hr)	***b ($/MW-hr)***	***c ($\$/MW\text{-}hr^2$)***
0	2.0	0.00375
0	1.75	0.0175
0	1.0	0.0625
0	3.25	0.00834
0	3.0	0.025
0	3.0	0.025

Case 1: In the first case, congestion has been contrived by incrementing load of the system to 35% to overall load, therefore the total system load becomes 382.59 MW where the base case load is a total of 283.4 MW. For the initial case, before load has been increased the power flow in the branch connecting the bus-(1-2) is loaded to a total of 58.3 MW. After implementing the condition for 35% increase of load, power flow at branch (1-2) is loaded to 134.27 MW which violates the line operating limit by 4.27 MW. A Newton Raphson based load flow analysis is used for detecting overload lines. The power flow details in the

congested line are shown in Table 3 along with the line limit and power loss at that line. The optimization algorithm works in a way to selecting an optimal input for the system controlling parameter such that power flow in each line are not more than the line operating limit. After conducting management on the congested line, power flow in the previous congested line is reduced to an amount of 129.97 MW. Also, the total power loss for the whole system is reduced to 13.47 MW.

Table 3.Congested line details before and after CM (Case 1)

	Line Congestion	**Line Flow (MW)**	**Line Limit (MW)**	**Total Loss (MW)**
Before CM	1-2	134.27	130	14.3675
After CM	1-2	129.97	130	13.47

Table 4.Power flow in some critical lines before and after rescheduling (Case 1)

	Line	**Line Flow (MW)**	**Line Limit (MW)**
Before	2-6	60.48	65
After	2-6	56.09	65

There has been some existence of uncertain power flow in the system other that the congested line. Flow in some lines might also force the line to operate at its maximum limit leaving the security system at risk. For providing a better security for the system, this has also been taken into consideration in the proposed work. The power at the branch (2-6) has been observed to operate at its critical level with a power flow of 60.48 MW. After performing congestion management, the power flow at that line is also reduced as shown in Table 4.

Table 5.Generation output value after CM (Case 1)

Gp_1 (MW)	**Gp_2 (MW)**	**Gp_3 (MW)**	**Gp_4 (MW)**	**Gp_5 (MW)**	**Gp_6 (MW)**	**Total (MW)**
197.987	79.11	40.41	27.23	26.70	24.60	396.061

The congestion management is done by generator rescheduling which means changing the generator output to adjust the power flow in the line. The generator output and the generator bus voltage are the controlling variables of the system for congestion management. The optimization algorithm will adjust the power output of the generator so as to eliminate the line overload. The generation amount is generated with respect to the operating limit of the generators. In Table 5, each generator output after the optimization is shown.

Table 6.Cost of rescheduling and generation cost (Case 1)

Rescheduling Cost ($/day)	**Generation Cost ($/hr)**
4579.87	1215.04

The cost function of the proposed work is to minimize the cost of power rescheduled and the generation cost while performing the congestion management. The generator rescheduling cost is calculated with respect to the generator bids submitted by the generators given from Table1 and the generation cost is calculated with respect to the generation cost coefficient from Table 2. The cost for rescheduling and generation after executing the optimization algorithm is shown in Table 6. The cost for rescheduling the generators is obtained to an amount of 4579.87 ($/day) and the total generation cost is evaluated at a price of 1215.04 ($/hr) after performing the optimization.

Table 7.Amount of power rescheduled (Case 1)

Gp_1 MW	**Gp_2 MW**	**Gp_3 MW**	**Gp_4 MW**	**Gp_5 MW**	**Gp_6 MW**	**Total power rescheduled (MW)**
-8.97	-0.88	-9.58	+7.23	+6.70	+4.60	37.99

The change in the amount of power generation from the base case and after congestion management due to the 35% increase in load is shown in Table 7. A total amount of 37.99 MW has been rescheduled to eliminate line limit violation. From these observation table, power at each generator bus are either increased or decreased by the optimization algorithm so as to maintain the line power flow within its limit as well as satisfying the load demand with considering power loss along the transmission process. The optimization is done by initializing the input parameters such as the population size of 200, maximum iteration of 200, the maximum and minimum value *c* is set between 1-0.00002. After executing the optimization, a number of optimal solutions are obtained which are graphically represented in Fig 2. These are also called pareto optimal solution. These solutions are the non-dominated solution. The curve in the graph is obtained from the rescheduling cost and the generation cost. The compromised solution which is taken as the most ideal solution is indicated by an arrow inside the graph. The voltage magnitude of congestion management before and after is shown in Fig. 3.

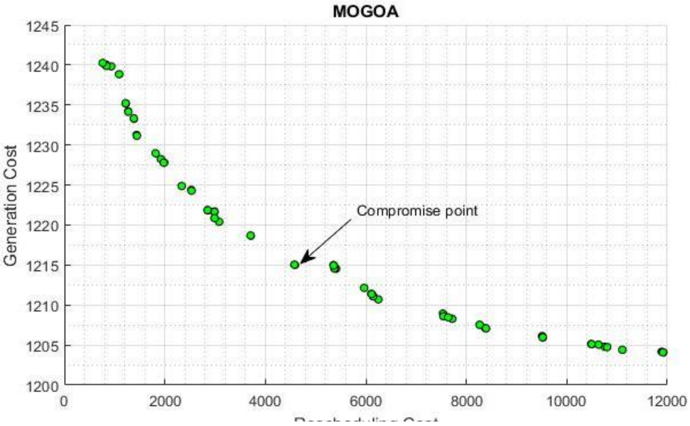

Figure 2. Generation and Rescheduling Cost Convergence curve by MOGOA (Case 1)

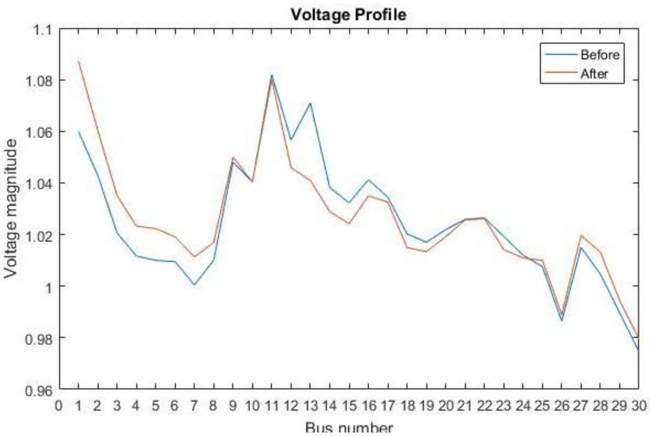

Figure 3. Voltage magnitude at each bus before and after CM (Case 1)

Case 2: For case 2, we make another condition where there is an increase of 40% load to its total load, therefore the total system load becomes 396.76 MW where the base case load is a total of 283.4 MW. For the initial case, before load has been increased the power flow in the branch connecting bus (1-2) has 58.3 MW flow in it. After that, the condition made for 40% increase of load is being applied and it is observed that the power flow in the branch (1-2) has 145.51 MW, which violates the branch flow limit by 15.51 MW. A Newton Raphson based power flow analysis has been used for detecting overload lines. The power flow details in the congested line are shown in Table 8 along with the line limit and power loss at that line. After implementation of the optimization method, the power flow at the congested line has been optimized to 129.94 MW with line loss at 14.42 MW.

Table 8.Congested line details (Case 2)

	Line Congestion	**Power Flow (MW)**	**Line Limit (MW)**	**Total Loss (MW)**
Before CM	1-2	145.51	130	16.15
After CM	1-2	129.94	130	14.42

Table 9.Power flow in some critical lines before and after rescheduling (Case 2)

	Line	**Line Flow (MW)**	**Line Limit (MW)**
Before	2-6	63.58	65
After	2-6	54.86	65

Similar to Case 1 flow at some lines carry a huge amount of power nearly forcing the line to operate to its maximum limit. For providing a better security for the system, this has also been taken into consideration in the proposed work. The branch between buses (2-6) has an amount of 65 MW of power flowing through it. After running the MOGOA power at that line is also reduced as shown in Table 9.

Table 10.Generation output value after CM (Case 2)

Gp$_1$ (MW)	**Gp$_2$ (MW)**	**Gp$_3$ (MW)**	**Gp$_4$ (MW)**	**Gp$_5$ (MW)**	**Gp$_6$ (MW)**	**Total (MW)**
198.34	80	41.24	34.98	27.74	28.86	411.187

The amount of power generated from each generator bus is shown in Table 10 for the case of 40% increase in load. The optimization algorithm is still able to manage the power generation of the generator within the limits even when load is increased to 40%. The power generations are greater in amount than in Case 1 due to additional 5% increase of load. Hence, load demand is satisfied with considering the line power losses.

Table 11.Cost of rescheduling and generation cost (Case 2)

Rescheduling Cost ($/day)	**Generation Cost ($/hr)**
14272.2	1277.62

The generator rescheduling cost is calculated with respect to the bids of generators submitted to the system operator given from Table 1 and the generation cost is calculated with respect to the generation cost coefficient from Table 2. The cost for rescheduling and generation after executing the optimization algorithm by MOGOA is shown in Table 11.

Table 12.Amount of power rescheduled (Case 2)

Gp$_1$ MW	**Gp$_2$ MW**	**Gp$_3$ MW**	**Gp$_4$ MW**	**Gp$_5$ MW**	**Gp$_6$ MW**	**Total power rescheduled (MW)**
-24.57	0	-8.75	+14.98	+7.74	+8.86	64.91

The variation in power generation from the base case after the adjustment had been done from 40% increase in load is shown in` Table 12. A total power of 64 MW is being rectified for the congestion elimination. From the table observed, power at each generator bus are either increased or decreased by the optimization algorithm so as to maintain the line power flow within its limit as well as satisfying the load demand with considering power loss along the transmission process.

The optimization is done similar to the condition of Case 1, by initializing the input parameters such as the population size of 200, maximum iteration of 200, the maximum and minimum value *c* is set between 1-0.00002. After executing the optimization, a number of optimal solutions are obtained which are graphically represented in Fig 4. These are also called pareto optimal solution. These solutions are the non-dominated solution. The curve in the graph is obtained from the rescheduling cost and the generation cost. The compromised solution which is taken as the most ideal solution is indicated by an arrow inside the graph. Also, the difference in voltage magnitude before and after congestion management is shown in Fig. 5.

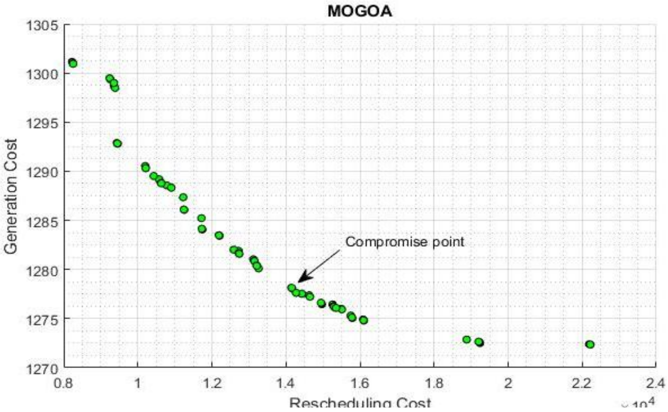

Figure 4. Convergence curve of Generation and Rescheduling Cost (Case 2)

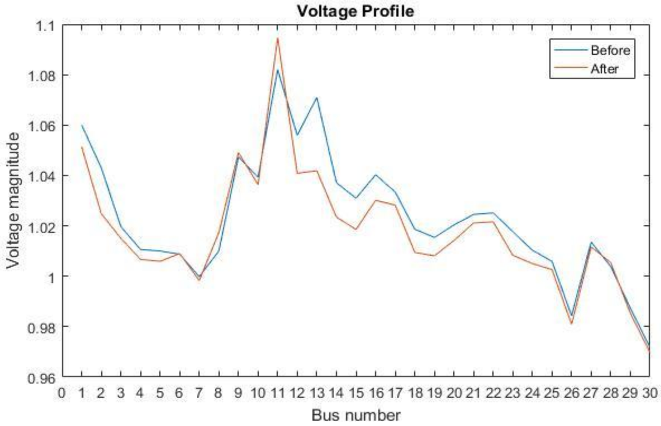

Figure 5. Voltage magnitude at each bus before and after CM (Case 2)

Table 13.Comparison of MOGOA, MOPSO and MOALO for Case 1

Parameters	**MOGOA**	**MOPSO**	**MOALO**
Rescheduling Cost($/day)	4579.87	4942.48	5007.27
Generation Cost($/hr)	1215.04	1215.12	1215.31
Congested line (Line 1-2)(MW)	129.97	129.84	129.75
Power Loss(MW)	13.47	13.35	13.34
ΔP_g1(MW)	-8.97	-9.81	-9.5
ΔP_g2(MW)	-0.88	-0.75	-3.08
ΔP_g3(MW)	-9.58	-9.95	-8.61
ΔP_g4(MW)	+7.23	+6.38	+8.89
ΔP_g5(MW)	+6.70	+7.62	+6.37
ΔP_g6(MW)	+4.60	+5.50	+4.93
Total Rescheduling (MW)	37.99	40.03	41.43
Total Power Generation (MW)	396.06	395.94	395.93

For this case, a Multi-objective Particle Swarm Optimization (MOPSO) and a Multi-objective Ant Lion Optimization (MOALO) are used since they are a competitive optimization algorithm in the optimization platform. Table 13 and Table 14 shows the comparison of the MOGOA, MOPSO and MOALO algorithm. From the table we observe that these optimization algorithms are capable of solving the congestion management problem.

Table 14.Comparison of MOGOA, MOPSO and MOALO for Case 2

Parameters	**MOGOA**	**MOPSO**	**MOALO**
Rescheduling Cost ($/day)	14272.2	14444.5	14285.6
Generation Cost ($/hr)	1277.62	1277.78	1278.01
Congested line (Line 1-2)(MW)	129.97	129.78	129.65
Power Loss (MW)	14.42	13.45	13.58
ΔP_g1(MW)	-24.57	-25.66	-25.87
ΔP_g2(MW)	0	0	-1.15
ΔP_g3(MW)	-8.75	-7.05	-8.49
ΔP_g4(MW)	+14.98	+15	+11.43
ΔP_g5(MW)	+7.74	+10	+7.33
ΔP_g6(MW)	+8.86	+5.02	+14.19
Total Rescheduling (MW)	64.91	62.74	68.48
Total Power Generation (MW)	411.187	410.212	410.34

The convergence curves or the cost curves for both MOPSO and MOALO for Case 1 and Case 2 have been shown in Fig 6-9. The compromise points are also highlighted in the convergence curves.

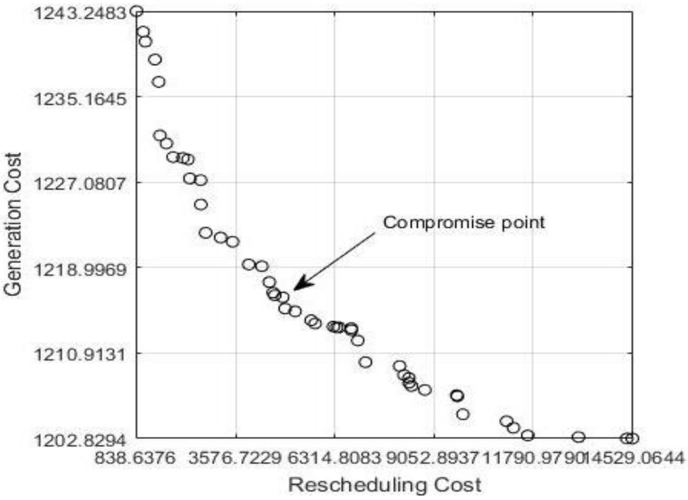

Figure 6. Convergence curve of Generation and Rescheduling Cost by MOPSO (Case 1)

The data obtained from each of the optimization algorithm shows how well the proposed algorithm is able to perform in minimizing the objective function (which is our

Generation cost and Rescheduling Cost) as compared to the other optimization algorithm.

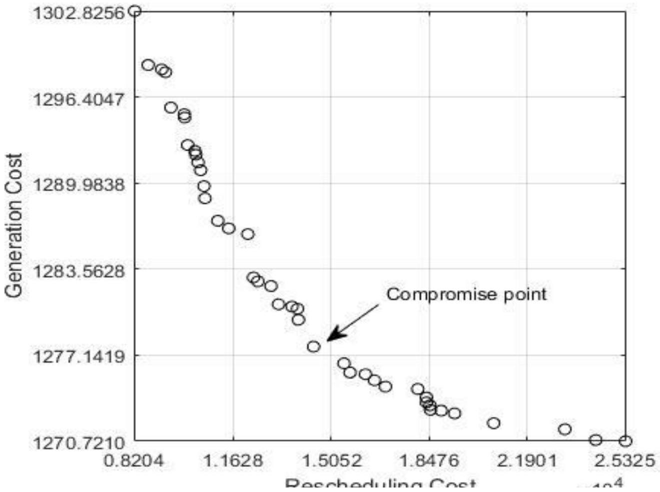

Figure 7. Convergence curve of Generation and Rescheduling Cost by MOPSO (Case 2)

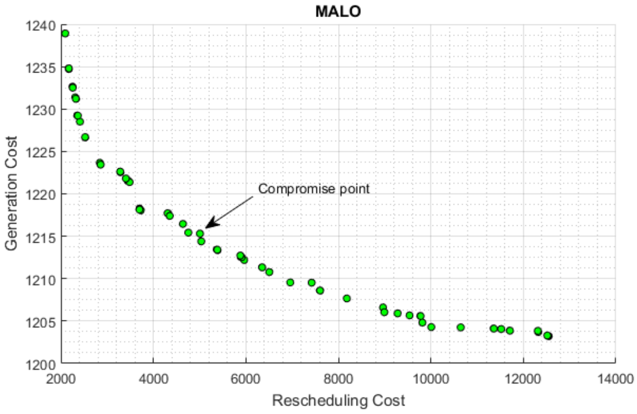

Figure 8. Generation and Rescheduling Cost Convergence curve by MOALO (Case 1)

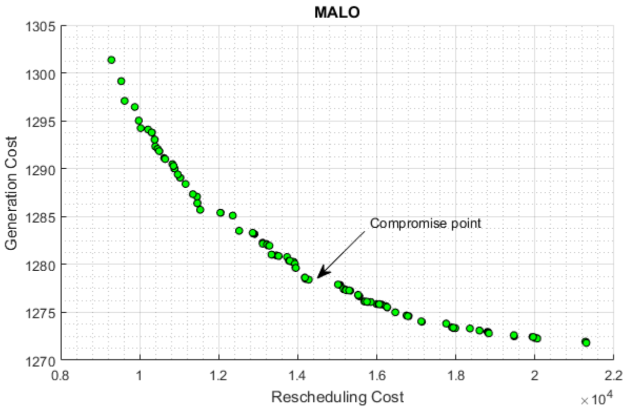

Figure 9. Generation and Rescheduling Cost Convergence curve by MOALO (Case 2)

4. Conclusion

The work of this paper is to deal with congestion problem in power system with considering the minimization of cost and expenditure for efficient functionality of the system. Mathematical formulation for the objectives is shown in section 2 with their constraints. From section 4, we have demonstrated how congestion can occur by a rapid increase of load in which we make two cases for the changing load. Rescheduling of generator, a technique involving change of generator output to adjust power flow in the transmission line is being utilized. The power flow in the system is studied by Newton Raphson load flow method, power flow at each line are calculated w.r.t generation of power and are inspect for line limit violation. The MOGOA optimizer is implemented to optimize the controlling variables such that line overload are eliminated as well as minimizing the objective function which are the rescheduling cost and generation cost. The results obtained clarify that the MOGOA is suitable for congestion management with the cost-effectiveness of the system operation. This result is also being compared with results obtained from MOPSO and MOALO, thus MOGOA provides more convincing solution in contrast to MOPSO and MOALO. The proposed method is carried out using MATLAB 2016 software.

References

[1] S. S. Reddy, "Multi-Objective based congestion management using generation rescheduling and load shedding," IEEE Transaction on Power Systems, vol. 32, no. 2, pp. 852-863.

[2] A. Kumar and C. Shekhar, "Comparison of Sen Transformer and UPFC for congestion management in hybrid electricity markets," Electrical Power and Energy Systems, 2015, vol. 47, pp. 1369–1387.

[3] A. Kumar and R. K. Mittapalli, "Congestion management with generic load model in hybrid electricity markets with FACTS devices," Electrical Power and Energy Systems, 2014,vol. 57, pp. 49–63.

[4] A. Kumar, S.C. Srivastava, and S.N. Singh, "A zonal congestion management approach using real and reactive power rescheduling," IEEE Transactions on Power Systems, 2004, vol. 19, no. 1, pp. 554-562.

[5] A. Kumar, S.C. Srivastava and S.N. Singh, "A zonal congestion management approach using ac transmission congestion distribution factors," Electric Power System Research, 2004, vol. 72 pp. 85-93.

[6] M. M. Esfahani, A. S. and O. Mohammed, "Adaptive real-time congestion management in smart power system using a real-time hybrid optimization algorithm," Electric Power System Research, 2017, vol. 150, pp. 118-128.

[7] M. M. Esfahani and G. R. Yousefi, "Real Time Congestion Management in Power Systems Considering Quasi-Dynamic Thermal Rating and Congestion Clearing Time," IEEE Transaction on Industrial Informatics, 2016, vol. 12, no. 2, pp. 745-754.

[8] S. A. Hosseini, N. Amjady, M. Shafie-Khah and J. P.S. Catalao, "A new multi-objective solution approach to solve transmission congestion management problem of energy market," Applied Energy, 2016, vol. 165, pp. 462-471.

[9] A. K. Jain, S. C. Srivastava, S. N. Singh and L. Srivastava, “Bacteria Foraging Optimization Based Bidding Strategy Under Transmission Congestion,” IEEE Systems Journal, 2015, vol.9, no.1, pp. 141-151.

[10] Rahmat-Allah Hooshmand, Mohammad Javad Morshed and MoeinParastegari, “Congestion management by determining optimal location of series FACTS devices using hybrid bacterial foraging and Nelder-Mead algorithm,” Applied Soft Computing, 2015, vol. 28, pp. 57-68.

[11] T. Peng and K. Tomsovic, “Congestion Influence on Bidding Strategies in an Electricity Market,” IEEE Transactions on Power Systems, 2003, vol.18, no.3, pp. 1054-1061.

[12] Y. Xu, H. Sun, H. Liu and Q. Fu, “Distributed solution to DC optimal power flow with congestion management,” Electrical Power and Energy Systems, 2018, vol. 95, pp. 73-82.

[13] Ch. Venkaiah and D.M. Vinod Kumar, “Fuzzy adaptive bacterial foraging congestion management using sensitivity based optimal active power re-scheduling of generators,” Applied Soft Computing, 2011, vol. 11, pp. 4921-4930.

[14] J. Hazra and A. K. Sinha, “Congestion Management Using Multiobjective Particle Swarm Optimization,” IEEE Transactions on Power Systems, 2007, vol.22, no.4, pp. 1726-1734.

[15] R. P. Singh, V. Mukherjee and S.P. Ghoshal, “Particle Swarm Optimization with an aging leader and challengersalgorithm for the solution of optimal power flow problem,” Applied Soft Computing, 2016, vol. 40, pp. 161-177.

[16] S. Hajforoosh, S.M.H Nabavi and M.A.S. Masoum, “Coordinated aggregated based particle swarm optimization algorithm for congestion management in restructured power market by placement and sizing of unified power flow controller,” IET Sci. Meas. Technol, 2012, vol.6, Iss.4, pp. 267-278.

[17] A. Zeinalzadeh, Y. Mohammadi and M. H.Moradi, “Optimal muti objective placement and sizing of multiple DGs and shunt capacitor banks simultaneous considering load uncertainty via MOPSO approach,” Electrical Power and Energy Systems, 2015, vol. 67, pp. 336-349.

[18] A.Y. Abdelaziz, M.A. El-Sharkawyamd M.A. Attia, “Optimal location of Thyristor-Controlled Series Compensators in Power Systems for Increasing Loadability by Genetic Algorithm,” Electric Power Components and Systems,2011,vol. 39, pp. 1373-1387.

[19] S. Gerbex, R. Cherkaoui and A. J. Germond, “Optimal Location of Multi-Type FACTS Devices in a Power System by Means of Genetic Algorithms,” IEEE Transactions on Power Systems, 2001, vol.16, no.3, pp. 537-544.

[20] S. M.H. Nabavi, M. A.S. Masoum and A. Kazemi, “A fuzzy-based Genetic Algorithm for Social Welfare maximization by placement and sizing of Static Synchronous Series Compensator,” Electric Power Components and Systems, 2011, vol. 39, pp. 1329-1352.

[21] T. Bhattacharjee and A. K. Chakraborty, “NSGA-II based Congestion Management in a Pool-based Electricity Market Incorporating Voltage and Transient Stability”, Electric Power Components and Systems, vol. 41, pp. 990-1001, 2013.

[22] S. Dutta and S.P Singh, “Optimal Rescheduling of Generators for Congestion Management Based on Particle Swarm Optimization,” IEEE Transaction on Power Systems, 2008vol. 23, no. 4, pp. 1560-1569.

[23] O. Alsac and B. Stott, “Optimal load flow with steady-state security,” IEEE Trans. Power App. Syst, 1974, vol. PAS-93, pp. 745–751.

[24] S. Z. Mirjalili, S. Mirjalili, S. Saremi, H. Faris and I. Aljarah, “Grasshopper optimization algorithm for multi-objective optimization problems,” Applied Intelligence,2017,vol. 48, pp. 805-820.

[25] T. Kulworawanichpong, “Simplified Newton-Raphson power flow solution method,” International Journal of Electrical Power and Energy Systems, 2010, vol. 32, Iss. 6, pp. 551-558.

[26] Carlos A. Coello Coello, Gregorio Toscano Pulido, and Maximino Salazar Lechuga, “Handling Multiple Objectives With Particle Swarm Optimization,” IEEE Transactions on Evolutionary Computation,2004,vol. 8, no. 3, pp. 256-279.

[27] S. Mirjalili, P. Jangir, and S. Saremi, “Multi-objective ant lion optimizer: a multi-objectiveoptimization algorithm for solving engineering problems,” Applied Intelligence, 2016, vol. 46, pp. 79-95.

[28] S. Deb, and A. K. Goswami, “Congestion Management by Generator Rescheduling using Artificial Bee Colony Optimization Technique,” Annual IEEE India Conference (INDICON), 2012, pp. 909 – 914.

[29] S. Deb, and A. K. Goswami, “Mitigation of Congestion by Generator Rescheduling using Particle Swarm Optimization,” International Conference on Power and Energy in NERIST (ICPEN),2012, pp. 1-6.

[30] S. Deb and A. K. Goswami, “Congestion Management by Generator Real Power Rescheduling using Flower Pollination Algorithm,” Int. Conf. on Control, Instrumentation, Energy & Communication (CIEC), 2016, pp. 437-441.

[31] S. Deb and A. K. Goswami, “Rescheduling of Real Power for Congestion Management using Cuckoo Search Algorithm,”Annual IEEE India Conference (INDICON), 2014, pp. 1-6.

[32] V. K. Prajapati and V. Mahajan, “Reliability Assessment and Congestion Management of Power System with Energy Storage System and Uncertain Renewable Resources,” Energy, 2020, pp. 1-39.

[33] N. Lou, Y. Zhang, Y. Wang, Q. Liu, H. Li, Y. Sun and Z. Guo, “Two-Stage Congestion Management Considering Virtual Power Plant With Cascade Hydro-Photovoltaic-Pumped Storage Hybrid Generation,” IEEE Access, 2020, vol. 8, pp. 186335-186347.

[34] A. Gautam, P. Sahrma and Y. Kumar, “Congestion Management by Sensitivity based approach for optimal allocation & parameter setting of TCSC using Grey Wolf Optimization,” First International Conference on Power, Control and Computing Technologies (ICPC2T),2020, pp. 50-55.

[35] E. Luo, P. Cong, H. Lu and Y. Li, “Two-Stage Congestion Management Method for Active Distribution Networks With Multi-Type Distributed Energy Resources,”IEEE Access,2020, vol. 8, pp. 120309-120320.

[36] J. Salehi and A. Abddolahi, “Optimal scheduling of active distribution networks with penetration of PHEV considering congestion and air pollution using DR program,” Sustainable Cities and Society, 2019, vol. 51, pp. 1-15.

[37] M. Sheikh, J. Aghaei, M. Rajabdorri, M. Shafie-khah, M. Lotfi, M. S. Javadi and J. P.S Catalao, “Multiobjective Congestion Management and Transmission Switching Ensuring System Reliability,” IEEE International Conference on Environment and Electrical Engineering and IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), 2019, pp. 1-5.

[38] D. Shymuk, A. Hnatov, S. Arhun, S. Ponikarovska, V. Mygal, and N. Kunicina, “Solving the Problem of Balancing and Complete Compensation of Reactive Power for a Three-

Phase Power Supply System," EAI Endorsed Transactions on Energy Web, 2020, vol. 7 (28), pp. 1-11.

[39] A. Narain, S.K. Srivastava and S.N. Singh, "Congestion management approach in restructured power system: Key issues and challenges," The Electricity Journal, 2020, vol. 33, pp. 1-8.

[40] B. Chatuanramtharnghaka, and S. Deb, "Multi-Objective Particle Swarm Optimization based Congestion Management considering Generation Rescheduling and Cost Minimization," International Conference on Advances in Computing, Communication and Materials (ICACCM), pp. 362-367,2020.