I J C T A, 9(15), 2016, pp. 7081-7093

MOGA Based Congestion Management in Deregulated Power Systems

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ABSTRACT

Congestion management is one of the important functions performed by system operator in deregulated electricity market to ensure secure operation of transmission system. The congestion in the transmission systems can be minimized by taking control actions like generator rescheduling, load shedding, placement of DGs and installation of FACTS devices. The main objective of this paperis to minimize transmission line loss along with congestion relief in deregulated power system. Contingency analysis based on severity index is performed based on load flow analysis. The control actions like generator rescheduling and load shedding are considered for effective congestion management. The proposed approach is studied under two cases in which multiobjective problem is solved as single objective optimization problem by genetic algorithm and it is solved by MOGA to get a set of pareto optimal solutions. This method proposes a robust and reliable algorithm for line overload alleviation due to critical line outages in deregulated power systems. The proposed algorithm is tested on IEEE 14 and IEEE 30 bus systems and promising results are obtained

Keywords: Congestion management, Generator Rescheduling, Severity Index, Genetic Algorithm, Load Shedding.

1. INTRODUCTION

The restructuring of electric power system has led to intensive usage of transmission lines. In deregulated electricity market, power system operates near its rated capacity as each player in the market is trying to gain as much as possible by full utilization of existing resources. Congestion occur in one or more transmission lines due to unexpected contingencies such as generation and line outages, sudden increase of load demand, or failure of equipments. Hence congestion management is one of the key functions of any system operator (SO) in the restructured power industry. Many methods have been reported for congestion management. In the recent years Sensitivity-based optimum generation rescheduling and/or load shedding schemes to alleviate overloading of transmission lines are reported in [1,2]. Optimal power flow (OPF) is arguably the most significant technique for congestion management in a power system with existing transmission and operational constraints [3]. Congestion management methods proposed in [3]–[6] are based on market model. In recent years, particle swarm optimization (PSO) method proposed by Kennedy and Eberhart [7] has been one of the popular method used for solving complex nonlinear optimization problems such as optimal power flow [8], [9],congestion management [10], etc.

2. PROBLEM FORMULATION

2.1. Severity Index (SI)

The severity of a contingency to line overload may be expressed as Severity Index(*SI*)

$$SI = \sum_{ij=1}^{NL} \left(\frac{P_{ij}}{p_{ij}^{\max}} \right)^2 \tag{1}$$

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This contingency analysis is conducted for base case generations and loadings and the *SI* value was computed for each contingency. The line outage which yields highest *SI* value is identified as harmful contingency. The congestion management is carried out for certain simulated case which leads to severe congestion in the system.

2.2. Generator Rescheduling and/or Load Shedding

The generator rescheduling and load shedding is done to minimize the congestion cost and congestion index simultaneously by considering these two objectives as a single objective optimization subjected to the operational and security constraints.

Objective function 1

$$\text{Congestion Cost} = \sum_{\mathrm{jN_g}} \left(\mathrm{C^u_{Gj}} \cdot \times \mathrm{P^u_{Gj}} + \mathrm{C^d_{Gj}} \cdot \times \mathrm{P^d_{Gj}} \right) + \sum_{\mathrm{iN_d}} \left(\mathrm{C^d_{Di}} \cdot \times \mathrm{P^d_{Di}} \right) \mathrm{Rs/hr} \tag{2}$$

Objective function 2

$$Congestion\ Index\ (CI) = \sum_{ij=1}^{NL} \begin{cases} 0 & P_{ij} \le P_{ij}^{\max} \\ \left(P_{ij} - p_{ij}^{\max} \right)^2 & P_{ij} > p_{ij}^{\max} \end{cases} \tag{3}$$

By combining these two objectives the multi-objective optimization problem is converted into single objective problem (TC) as follows.

$$\mathrm{TC} = \sum_{\mathrm{jN_g}} \left(\mathrm{C^u_{Gj}} \cdot \times \mathrm{P^u_{Gj}} + \mathrm{C^d_{Gj}} \cdot \times \mathrm{P^d_{Gj}} \right) + \sum_{\mathrm{iN_d}} \left(\mathrm{C^d_{Di}} \cdot \times \mathrm{P^d_{Di}} \right) \mathrm{Rs/hr} + \alpha \sum_{\mathrm{ij=1}}^{\mathrm{NL}} \left(\mathrm{P_{ij}} - \mathrm{P^{max}_{ij}} \right)^2 \tag{4}$$

is the penalty factor

Multiobjective Optimization for minimization of congestion cost and real power loss

The optimal shift in active power generation and/ or demand to minimize the total congestion cost and line loss as a multi-objective optimization problem is given as follows

Objective function 1

$$\mathrm{TC} = \sum_{\mathrm{jN_g}} \left(\mathrm{C^u_{Gj}} \cdot \times \mathrm{P^u_{Gj}} + \mathrm{C^d_{Gj}} \cdot \times \mathrm{P^d_{Gj}} \right) + \sum_{\mathrm{iN_d}} \left(\mathrm{C^d_{Di}} \cdot \times \mathrm{P^d_{Di}} \right) + {}^*\mathrm{CI}\ \ \mathrm{Rs/hr} \tag{5}$$

Objective function 2

$$P = P_{ij} + P_{ji} \tag{6}$$

Where P_{ij} and P_{ji} are the complex powers P_{ij} from bus *i* to *j* and P_{ji} from bus *j* to *i*.

$$P_{ij} = V_i \; I_{ij}^*$$

$$P_{ji} = V_j \; I_{ji}^*$$

The set of equality and inequality constraints considered in these studies are as follows:

$$\mathrm{P_{Gi}} - \mathrm{P_{Di}} = \sum_{\mathrm{j=1}}^{\mathrm{NB}} \left| \mathrm{V_i} \right| \left| \mathrm{V_j} \right| \left| \mathrm{Y_{ij}} \right| \cos\left({}_{\mathrm{i}} - {}_{\mathrm{j}} - {}_{\mathrm{ij}} \right) \tag{7}$$

$$\mathrm{Q_{Gi}} - \mathrm{Q_{Di}} = \sum_{\mathrm{j=1}}^{\mathrm{NB}} |\mathrm{V_i}||\mathrm{V_j}||\mathrm{Y_{ij}}| \sin\left({}_{\mathrm{i}} - {}_{\mathrm{j}} - {}_{\mathrm{ij}}\right) \tag{8}$$

Where

$$P_{Gj} = P_{Gj}^{c} + P_{Gj}^{u} + P_{Gj}^{d};\ j = 1, 2 \ldots N_g \tag{9}$$

$$P_{Di} = P_{Di}^{c} + P_{Di}^{d};\ i = 1, 2 \ldots N_d \tag{10}$$

$$\mathrm{Q_{Di}} = \mathrm{P_{Di}} * \tan\left({}_{\mathrm{Di}}\right);\ i = 1, 2 \ldots N_d \tag{11}$$

$$P_{GJ}^{\min} \le P_{Gj} \le P_{GJ}^{\max};\ j = 1, 2 \ldots N_g \tag{12}$$

$$Q_{GJ}^{\min} \le Q_{Gj} \le Q_{GJ}^{\max};\ j = 1, 2 \ldots N_g \tag{13}$$

$$V_n^{\min} \le V_n \le V_n^{\max};\ n = 1, 2 \ldots N_d \tag{14}$$

$$P_{Gj}^{u} \ge 0;\ P_{Gj}^{d} \ge 0;\ P_{Di}^{d} \ge 0 \tag{15}$$

Constraints (7) and (8) correspond to active and reactive power balances at all buses. Final powers are expressed in terms of market clearing values and are given in (9) and (10). Active and reactive power demands are related through constraint (11) considering constant power factor. Constraints (12) and (13) provide upper and lower bounds for real and reactive power of generators. Constraint (14) establishes threshold limits for load bus voltages. Constraint (15) ensures that the increment and decrement in powers are positive.The main aim of this work is to alleviate overloads in transmission lines and also to regulate load bus voltages by means of generation rescheduling. If congestion cannot be overcome by generation adjustment alone then load shedding has been made finally.

2.3. Notations and Terminologies

P_{Gj}^{u} – Active power increment in generation *j* (MW) due to congestion management.

P_{Gj}^{d} – Active power decrement in generation *j* (MW) due to congestion management.

P_{Di}^{d} – Active power decrement in demand *i* (MW) due to congestion management.

C_{Gj}^{u} – Price offered by generator *j* ($/MWhr) to increase its pool power schedule for Congestion management purposes.

C_{Gj}^{d} – Price offered by generator *j* ($/MWhr) to decrease its pool power schedule for Congestion management purposes.

C_{Di}^{d} – Price offered by demand *i* ($/MWhr) to decrease its pool power schedule for Congestion management purposes.

P_{Gj} – Final active power produced by generator *j* (MW).

P_{Di} – Final active power consumed by demand *i* (MW).

Q_{Di} – Final reactive power consumption of demand *i* (MVAR).

P_{Gj}^{c} – Active power produced by generator j and consumed by demand i in MW.

P_{Di}^{c} – Active power consumed by demand i in MW as determined by the market clearing procedure.

V_i – Bus voltage magnitude of bus i.

V_j – Bus voltage magnitude of bus j.

i^{-} – Bus voltage angle of bus i.

j^{-} – Bus voltage angle of bus j.

Y_{ii} – Self admittance of node i.

Y_{ij} – Mutual admittance between node i and j.

ij^{-} – Impedance angle of line between bus i and j.

$P_{GJ}^{\min}$ – Minimum real power output of generator j.

$P_{GJ}^{\max}$ – Maximum real power output of generator j.

P_{ij} – Actual power flow in line i-j (MW).

$P_{ij}^{\max}$ – Loading limit of line i-j (MW).

NB – Number of buses.

Ng – Number of participating generators.

N_d – Number of participating demands.

NL – Number of transmission lines.

CI – Congestion Index.

3. CONGESTION MANAGEMENT USING GENETIC ALGORITHM

3.1. Introduction to Genetic Algorithm

Genetic algorithms use the principle of natural evolution and population genetics to search and arrive at a high quality near global solution. The required design variables are encoded into a binary string as a set of genes corresponding to chromosomes in biological systems. Unlike the traditional optimization techniques that require one starting point, they use a set of points as the initial conditions. Each point is called a chromosome. A group of chromosomes are called a population. Each chromosome is a string of binary codes (genes) and may contain substrings. The merit of a string is judged by the fitness function, which is derived from the objective function and is used in successive genetic operations. During each iterative procedure (referred to as generation), a new set of strings with improved performance is generated using three GA operators (namely reproduction, crossover and mutation).

Genetic- Operators are the stochastic transition rules applied to each chromosome during each generation procedure to generate a new improved population from an old one. A genetic algorithm usually consists of reproduction, crossover and mutation operators.

Reproduction is a probabilistic process for selecting two parent strings from the population of strings on the basis of “roulette-wheel” mechanism, using their fitness values. This ensures that the expected number of times a string is selected is proportional to its fitness relative to the rest of the population. Therefore, strings with higher fitness values have a higher probability of contributing offspring.

Crossover- is the process of selecting a random position in the string and swapping the characters either left or right of this point with another similarly partitioned string. This random position is called the crossover point. In this project the characters to the right of a crossover point are swapped.

Mutation-is the process of random modification of a string position by changing “0” to “1” or vice versa, with a small probability. It prevents complete loss of genetic material through reproduction and crossover by ensuring that the probability of searching any region in the problem space is never zero

Algorithm for Generator Rescheduling and/or Load Shedding

Step 1: Initialize the parameters of GA and set generation $k = 1$.

Step 2: Randomly generate the control variables X (k) that is (P_{Gj}^{u}, P_{Gj}^{d} and P_{Dj}^{d}) within the limit.

Step 3: Run NR- power flow for the parent population generated and compute bus voltages and line flows. Evaluate the fitness values for the parent population using (4)

Step 4: Select parents for recombination Roulette wheel selection.

Step 5: Create new particles using uniform crossover and polynomial mutation operation.

Step 6: Evaluate the fitness values for the new solution vectors. Combine parent (Np) and child solutions (N_p). Among $2N_p$ individuals, best N_p individuals are selected based on their fitness values.

Step 7: Check for stopping criteria. If maximum generation is reached then go the next step. Else go to step 4.

Step 8: Print the solution which yield minimum fitness value.

3.2. Multiobjective Algorithm for Generator Rescheduling and/or Load Shedding

Being a population-based approach, GA is well suited to solve multi-objective optimization problems. A general multi-objective optimization problem consists of a number of objectives that should be optimized simultaneously associated with a number of equality and inequality constraints. When such a method is to be used for finding multiple solutions, it has to be applied many times, hopefully finding a different solution at each simulation run.

Congestion management methods available in the literature consider only one objective and provide only one solution which does not provide any choice to the operator. In this work, multi-objective non-dominated sorting genetic algorithm NSGA II [11] is proposed to solve this complex non linear problem. The step by step procedure is given as follows.

Step 1: Set up NSGA II parameters like population size, number of generations, distribution indices for crossover (mu), and mutation (mum). Here mu and mum are 20 and 20, respectively.

Step 2: Read line data, bus data, incremental and decrement bidding costs for each generator. When applying evolutionary computation algorithm, the first step is to decide the control variables embedded in the individuals. Hence the control variables increment and decrement in generation and decrement of load are generated randomly satisfying their practical operation constraints.

Step 3: For each chromosome of population, calculate objective function-1 and objective function-2 using equ (5) & (6)

Step 4: The equality and inequality constraints are handled by Newton-Raphson Power Flow.

Step 5: Non-domination sorting of population is carried out. And then tournament selection is applied to select the best individuals based on crowding distance.

Step 6: Crossover and Mutation operators are carried out to generate offspring (Qt) and the new vectors obtained must satisfy the limits if not set it to the appropriate extrema.

Step 7: Calculate the value of each objective function of Qt and merge the parent and offspring population to preserve elites.

Step 8: Again perform non-dominated sorting on the combined population based on crowding distance measure and obtain the best new parent population (Pt +1) of size N out of 2Npopulation, so this would be the parents for next generation and this process is carried out till a maximum number of generations are reached.

Step 9: Finally pareto front is achieved, that is, a set of solutions satisfying both objectives are obtained.

4. RESULTS AND DISCUSSIONS

The proposed technique is tested on IEEE 14 and IEEE 30 bus systems. All system data are extracted from [12].

4.1. Modified IEEE 14 bus system

The system has 4 generators, 11 loads and 20 transmission lines. The total load on the system is 259 MW and 69.5 MVAR with load factor. Contingency analysis was computed for base case generations and loadings and the severe line outage cases are identified. Outage of line 1-5 has higher severity index of 10.45 followed by other line outages such as line between 1 and 2 and so on and given in Table 1.Based on the severity index the following three congested cases are considered.

Case 1A: Outage of line 1-5.

Case 1B: Outage of line 1-2.

Case 1C: Outage of line 2-5 & 20% increase in demand.

The two objectives i.e., minimization of congestion cost and congestion index are combined to form a single objective problem and solved by generation rescheduling and/or load shedding using Genetic Algorithm. The adjustments required at the participating generators and load curtailments made at the appropriate buses to alleviate congestion for the simulated cases are shown in Table 2. The convergence characteristics and the best individual for three cases are given in Figures1-3.

Table 1
Simulated cases of the Test System

Cases	*Over loaded lines*	*Line limit (MW)*	*Actual Power Flow (MW)*	*Amount of Power Violation (MW)*	*Severity Index (SI)*
1A	1-2	50	137.127	87.127	10.45
	2-3	40	47.344	7.344	
	2-4	40	55.305	15.305	
	2-5	40	49.508	9.508	
1B	1-5	60	141.879	81.879	6.86
	4-5	80	90.146	10.146	
1C	1-2	50	115.354	65.354	11.966
	1-5	60	75.850	15.850	
	2-3	40	61.800	21.800	
	2-4	40	65.209	25.209	

Table 2
Final Power adjustments for Line overload alleviation with Payment Particulars

Cases	P_{G1}	P_{G2}	P_{G3}	P_{G6}	P_{D2}	P_{D3}	P_{D4}	P_{D5}	Total Cost (Rs/hr)
1A	-86.04	29.73	32.66	57.19	2.02	8.68	22.83	–	5185.6
1B	-73.70	48.91	21.96	33.88	–	–	37.34	–	4177.4
1C	-39.46	39.17	45.67	41.13	8.20	1.80	18.99	5.71	4061.0

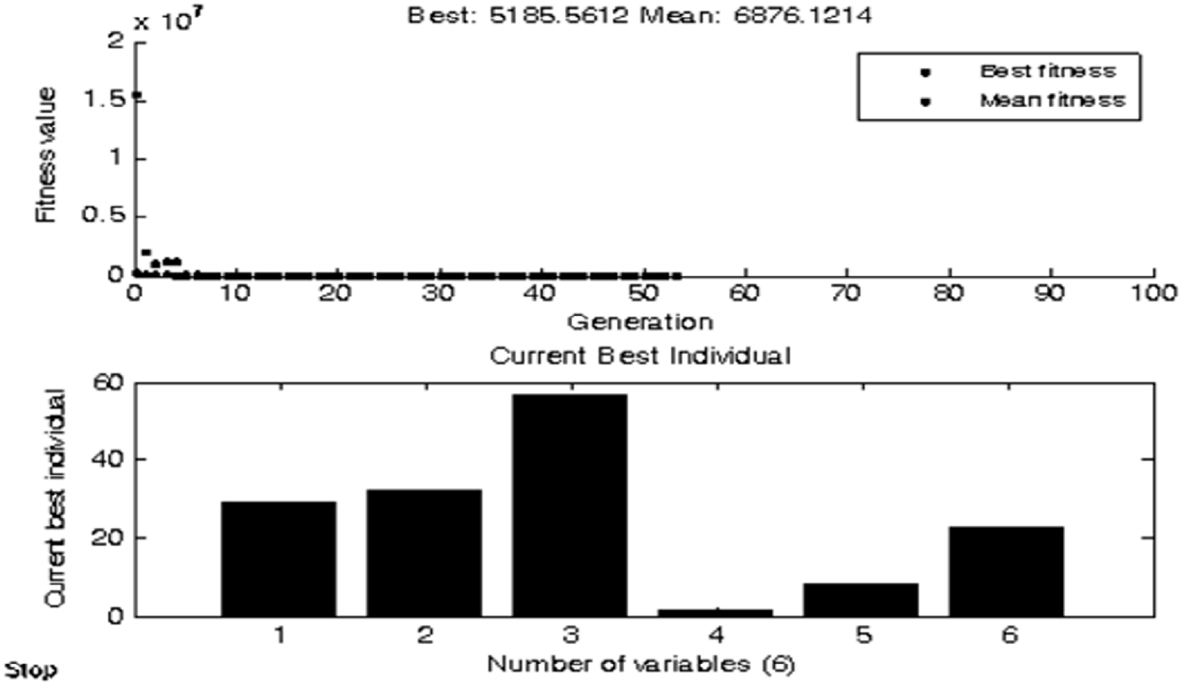

Figure 1: Convergence characteristics and the best individual for Case 1A by generator rescheduling and load shedding.

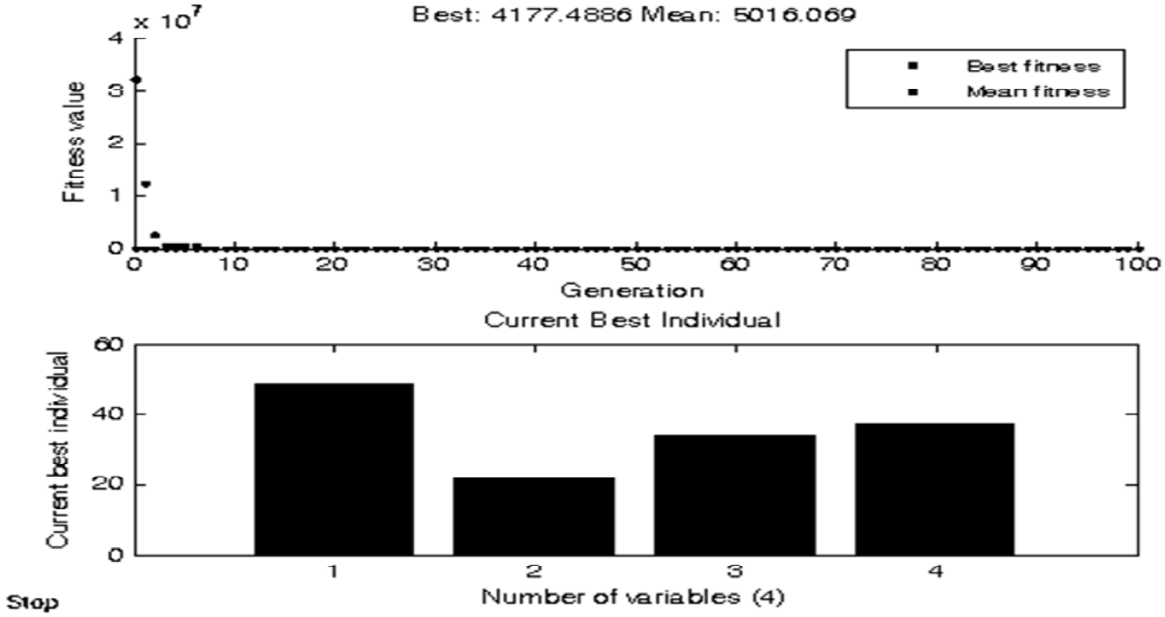

Figure 2: Convergence characteristics and the best individual for Case 1B by generator rescheduling and load shedding.

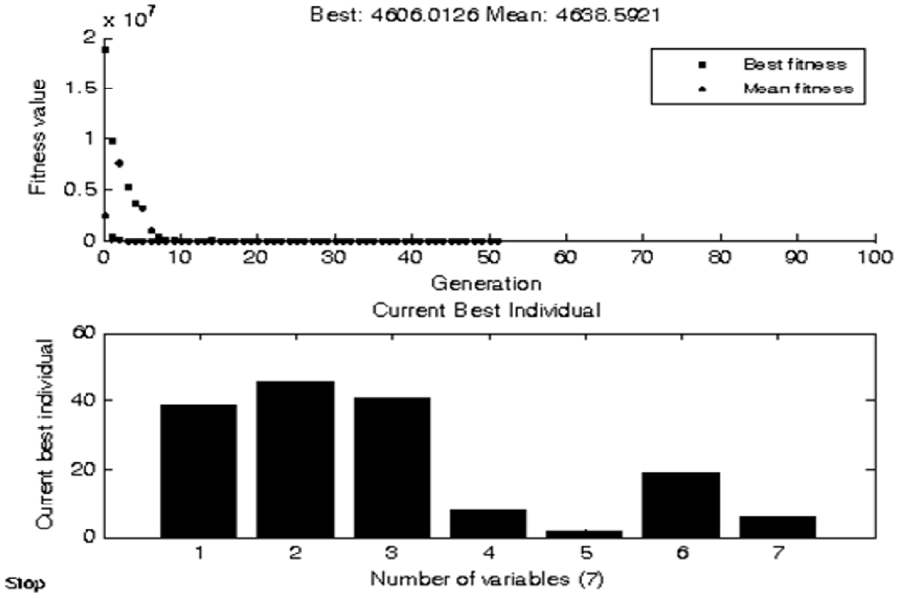

Figure 3: CConvergence characteristics and the best individual for Case 1C by generator rescheduling and load shedding.

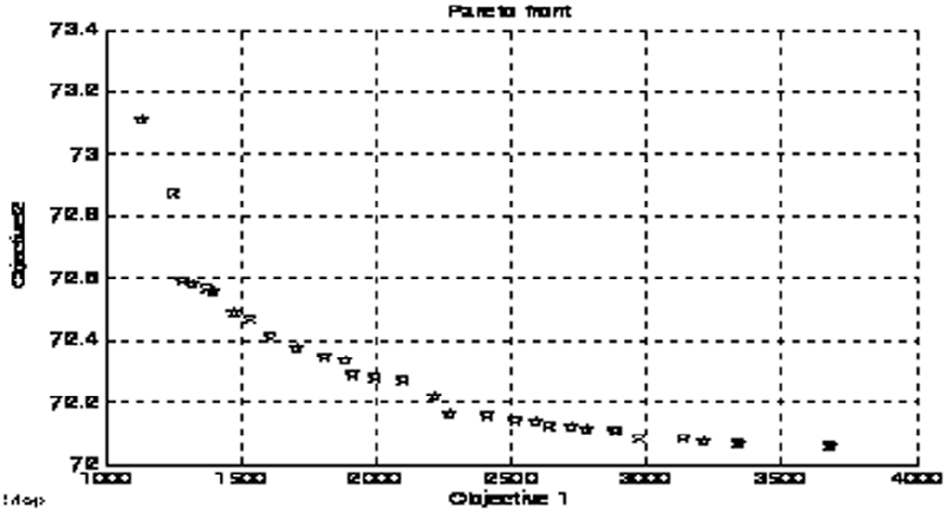

Figure 4: Pareto front for Case 1A by generator rescheduling and load shedding.

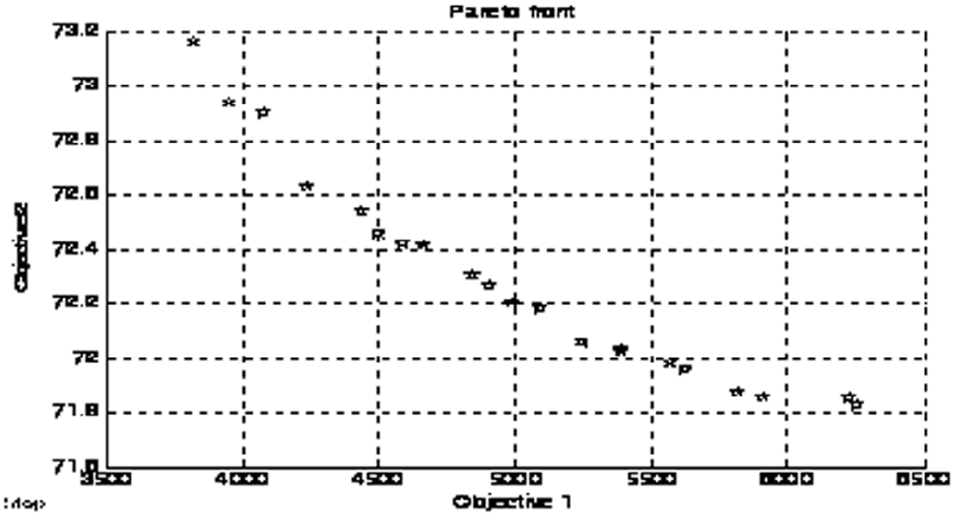

Figure 5: Pareto front for Case 1B by generator rescheduling and load shedding.

The multi objective optimization for minimization of congestion cost and real power loss by rescheduling of generators and/or load shedding using NSGA II. The set of pareto optimal solution for all the three cases considered are given in Figures 4-6. The three solutions among the pareto front are given in Table 3.

4.2. Modified IEEE 30 bus system

This system has 6 generators, 21 loads and 41 transmission lines with total load of 283.4 MW and 126.2 MVAR (Load factor LF as 1.0). For generators the up cost is taken slightly more than the corresponding marginal cost and down cost is taken slightly less than the corresponding marginal cost whereas it is reverse for demands.

Contingency analyses were conducted under base case loading condition. Outage of line 1-2 have high severity index followed by line 1-3 and they are given in Table 4.

Based on the severity index the following three congested cases are considered.

Case 2A: Outage of line 1-2 & Generator 2.

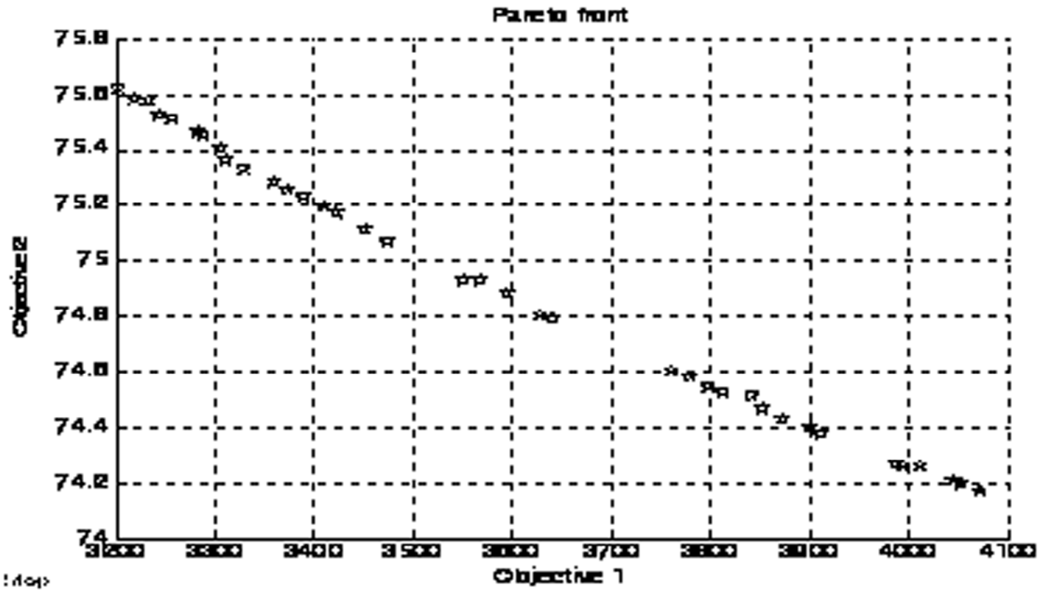

Figure 6: Pareto front for Case 1C by generator rescheduling and load shedding.

Table 3
Three solutions among the pareto front for generator rescheduling and load shedding for 14 bus

Cases	*Congestion Cost (Rs/hr)*	*Real Power Loss (kW)*
1A	1141	73.11
	2550	72.19
	3688	72.05
1B	3953	72.93
	4988	72.20
	6251	71.82
1C	3202	75.61
	3594	74.88
	4071	74.17

Case 2B: Outage of line 1-2 & 40% increase in demand.

Case 2C: Outage of line 1-3 & 50% increase in demand.

The adjustments required at the participating generators and load curtailments made at the appropriate buses to alleviate congestion for the simulated cases are shown in Table 5. The convergence characteristics and the best individual for three cases are given in Figures 7-9.

Table 4
Simulated cases of the Test System

Cases	*Over loaded lines*	*Line limit (MW)*	*Actual Power Flow (MW)*	*Amount of Power Violation (MW)*	*Severity Index (SI)*
2A	1-3	130	222.25	92.25	6.7955
	3-4	130	199.75	69.77	
	4-6	90	110.64	20.64	
2B	1-3	130	311.25	181.25	12.882
	3-4	130	267.86	137.86	
	4-6	90	153.38	63.38	
2C	1-2	130	310.48	180.48	10.471
	2-4	65	97.126	32.126	
	2-6	65	103.465	38.465	

Table 5
Final Power adjustments for Line overload alleviation with Payment Particulars

Cases	P_{G1}	P_{G2}	P_{G5}	P_{G8}	P_{G11}	P_{G13}	P_{D2}	P_{D5}	P_{D8}	Total Cost (Rs/hr)
2A	-7.37	0	22.57	12.51	15.99	19.83	-	-	-	4040.7
2B	0	31.56	54.29	34.84	17.73	21.55	1.74	42.62	2.25	4172.8
2C	0	42.31	27.09	24.60	28.18	43.01	2.69	18.27	2.54	5136.8

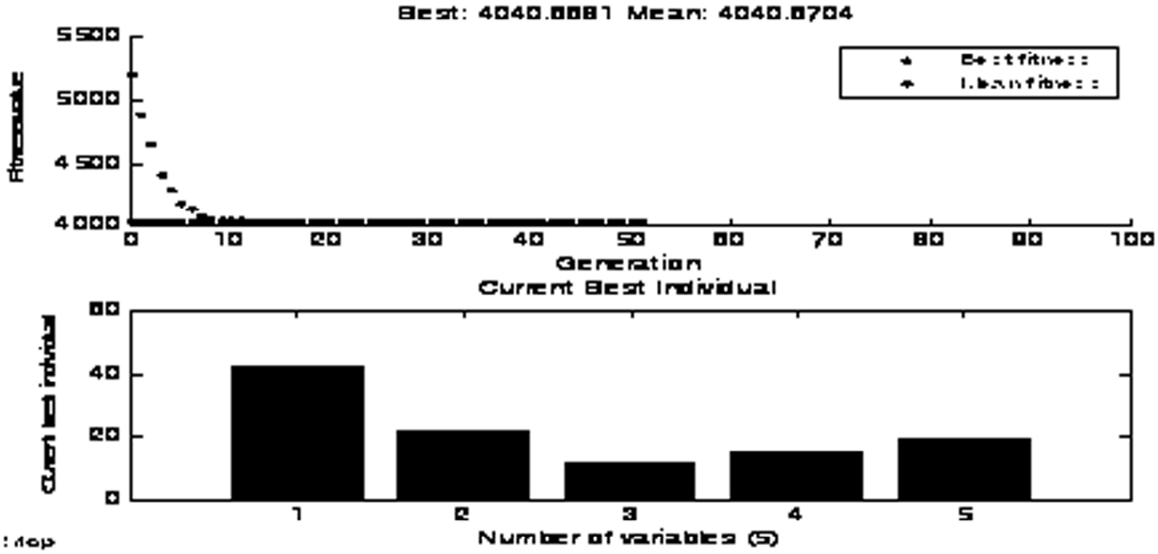

Figure 7: Convergence characteristics and the best individual for Case 2Aby generator rescheduling and load shedding.

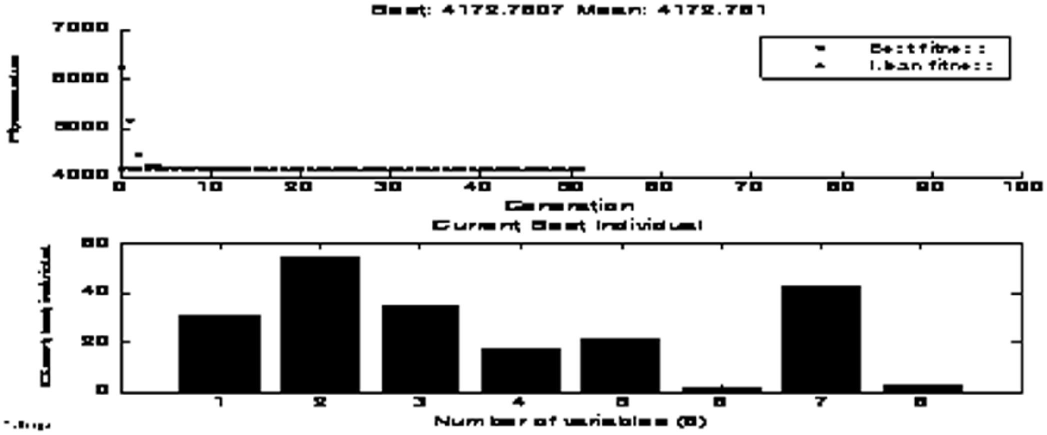

Figure 8: Convergence characteristics and the best individual for Case 2Bby generator rescheduling and load shedding.

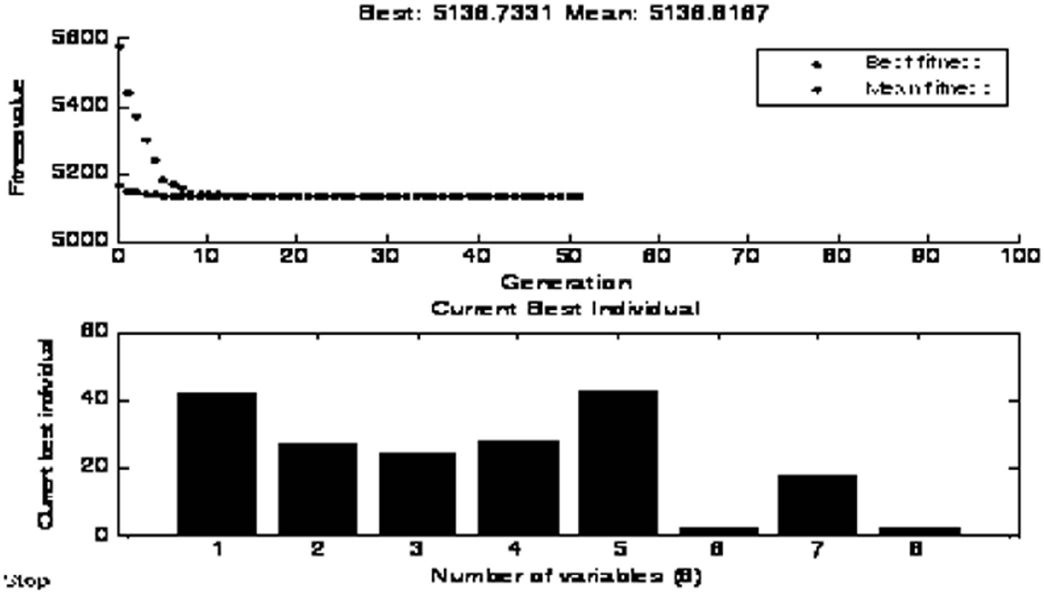

Figure 9: Convergence characteristics and the best individual for Case 2Cby generator rescheduling and load shedding.

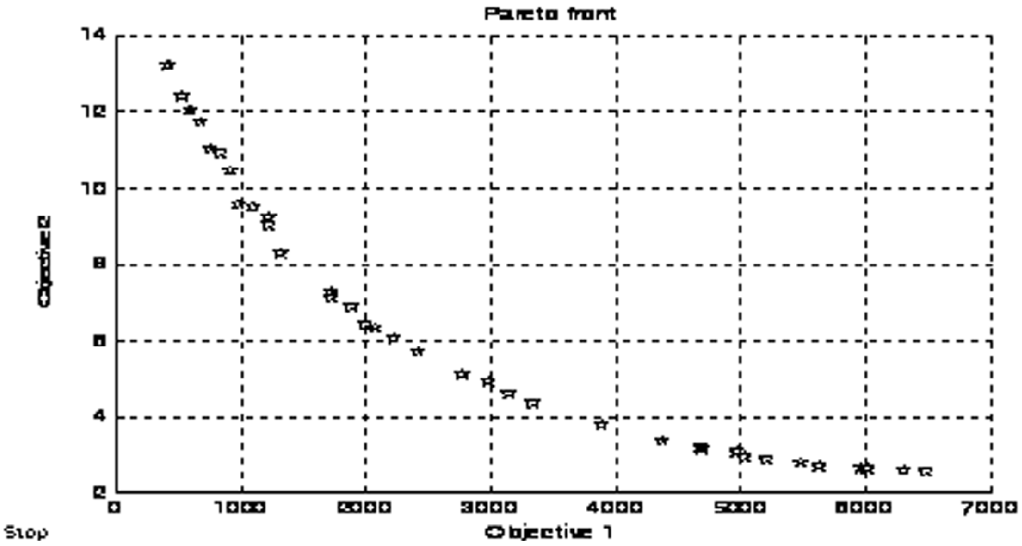

Figure 10: Pareto front for Case 2A by generator rescheduling and load shedding.

The set of pareto optimal solution for all the three cases considered for 30 bus system are given in Figures 10-12. The three solutions among the pareto front are given in Table 6.

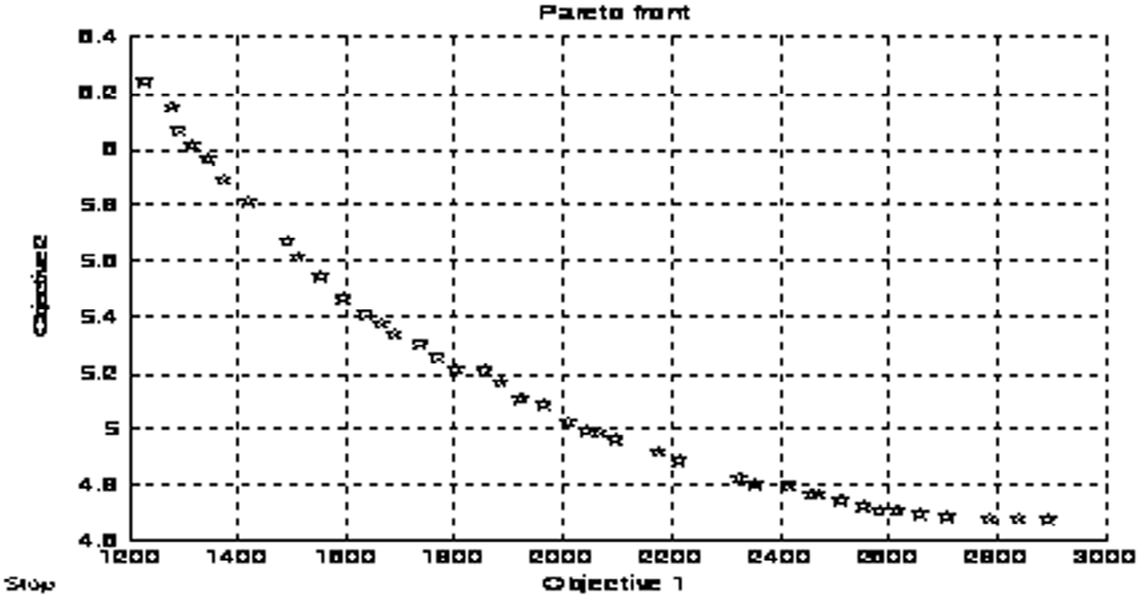

Figure 11: Pareto front for Case 2B by generator rescheduling and load shedding.

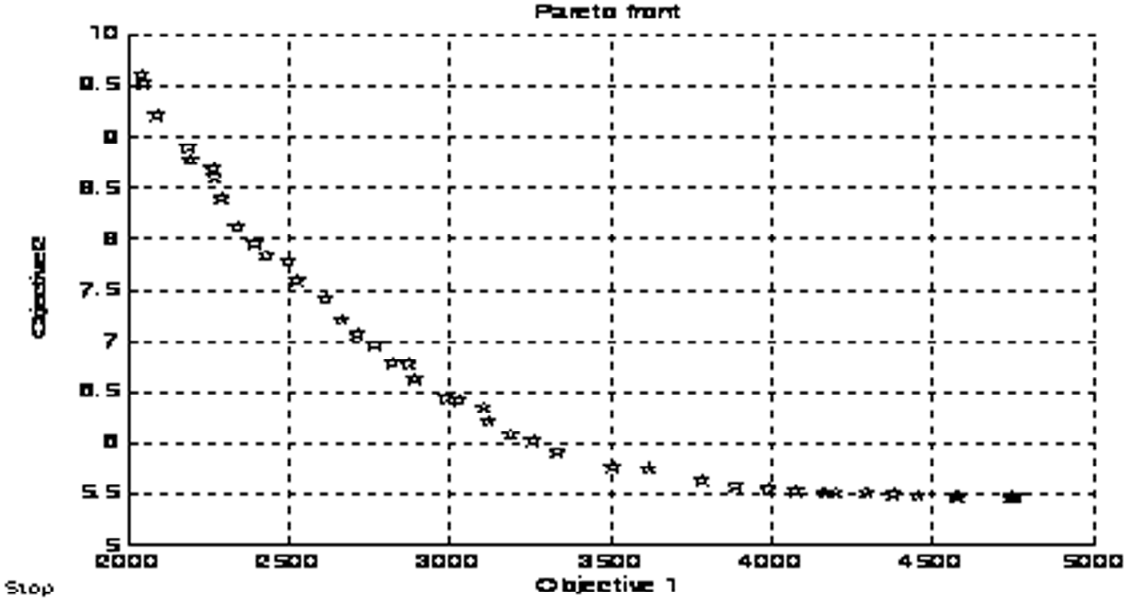

Figure 12: Pareto front for Case 2C by generator rescheduling and load shedding.

Table 6
Three solutions among the pareto front for generator rescheduling and load shedding for 30 bus system

Cases	*Congestion Cost (Rs/hr)*	*Real Power Loss (kW)*
2A	597	12.0
	2090	6.31
	6490	2.54
2B	1230	6.2
	1866	5.3
	2897	4.6
2C	2051	9.5
	3420	6.3
	4759	5.4

5. CONCLUSION

In this paper two efficient approaches are proposed for solving congestion management problem in a day ahead electricity market based on pool using Genetic Algorithm. In the first approach the objectives considered are the minimization of the congestion cost and Congestion Index. These two objectives are considered to form a single objective and the problem is solved using Genetic Algorithm by rescheduling of generators. If not sufficient to relieve congestion, then load shedding is considered. For the three severe cases considered, it is not possible to relieve congestion by generation rescheduling alone and so load shedding is also considered. By this method it gives only one compromised solution considering both the objectives, which does not provide any choice to the operators. When this method is used to get multiple solutions, it has to be run hopefully many times. So it is time consuming and cannot be used for real time problems. So in the second approach, both the objectives are considered separately and solved using multiobjective, NSGA II method. This method gives a set of pareto optimal solution, so operator has a flexibility in choosing the solution based on the need.

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