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Research Article

Multiobjective Optimization Methods for Congestion Management in Deregulated Power Systems

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Congestion management is one of the important functions performed by system operator in deregulated electricity market to ensure secure operation of transmission system. This paper proposes two effective methods for transmission congestion alleviation in deregulated power system. Congestion or overload in transmission networks is alleviated by rescheduling of generators and/or load shedding. The two objectives conflicting in nature (1) transmission line over load and (2) congestion cost are optimized in this paper. The multiobjective fuzzy evolutionary programming (FEP) and nondominated sorting genetic algorithm II methods are used to solve this problem. FEP uses the combined advantages of fuzzy and evolutionary programming (EP) techniques and gives better unique solution satisfying both objectives, whereas nondominated sorting genetic algorithm (NSGA) II gives a set of Pareto-optimal solutions. The methods propose an efficient and reliable algorithm for line overload alleviation due to critical line outages in a deregulated power markets. The quality and usefulness of the algorithm is tested on IEEE 30 bus system.

1. Introduction

In recent years, the power industry has undergone drastic changes due to privatization and worldwide deregulation process that has significantly affected energy markets. The restructuring of power system has led to the intensive usage of transmission grids. In deregulated electricity market, power system is operated near its rated capacity as each player in the market is trying to gain as much as possible by utilization of existing resources. Congestion in the transmission lines is one of the technical problems that appear in the deregulated environment. Congestion may occur due to lack of coordination between generation and transmission utilities or as a result of unexpected contingencies such as generation outages, sudden increase of load demand, or failure of equipments.

A large number of literatures have been reported in congestion management. Sensitivity-based methods to relieve congestion are reported in the work [1–3]. Auction-based methods are carried out in the literatures [4, 5]. Pricing-based methods are done in the papers [6–10]. A number of literature have been reported in evolutionary-based methods [11–18]. Multiobjective optimization method using various evolutionary methods [19, 20] are discussed. Very few papers [21] address the congestion management problem with security constraints of power systems with single objective only, because solving a multiobjective congestion problem with evolutionary methods is a very difficult task. For solving such complex, combinatorial optimization problem, classical techniques are unsuitable and the use of global search technique is needed. Further more if more than one objective is chosen in optimization, a suitable method must be developed to check the optimality of the solution. To overcome these difficulties, fuzzy models are developed and incorporated in EP algorithm.

This paper presents an efficient method for solving congestion management problem with two conflicting objectives in a pool-based electricity market. The two objectives are congestion cost minimization and transmission line overload alleviation. Generation rescheduling is done to relieve congestion; if it was not sufficient to alleviate overload, then load shedding is done. Here in this proposed method line, over load is alleviated with generation rescheduling alone and load shedding is not required.

Congestion management methods available consider only one objective and provide only one solution which does not provide any choice to the operator. This proposed paper provides a set of alternate solutions for congestion management problem using two approaches (1) fuzzy EP approach and (2) NSGA II approach. The first method provides a best solution satisfying both objectives, and the later method provides a set of Pareto-optimal solutions to the transmission system operators for managing congestion in transmission network.

2. Problem Formulation

In this paper, day-ahead electric energy market based on a pool is considered. Several utilities join together to form a pool, with a central broker, to coordinate the operations on an hour-to-hour basis. Within this pool, GENCOs and DISCOs submit the purchase and sell decisions in the form of sell or buy bids to the market operator, who clears the market using an appropriate market-clearing procedure. Finally it results in 24 hourly energy prices to be paid by consumers and to be charged by producers. Transmission congestion may prevent the existence of new contracts and may lead to additional outages.

2.1. Congestion Relieving Procedure. In this paper, control measures to be taken to relieve the congestion in transmission lines due to critical line outages, generator outages, or sudden load disturbances are proposed. The objective function is to find the minimal shifts in generations and demands from initial market clearing values so as to alleviate line overloads completely and also to maintain load bus voltages within the permissible limits for secure operation of the system. The line limits and voltage limits can be considered as classical optimization problem with penalty function, but if violated it forces the solution to lie near its limits; to overcome this difficulty, these constraints are taken as the objective functions. It is considered that any change from the market-clearing conditions implies a payment to the agent involved. The total cost incurred is a sum of increment in revenues for the participating producers for adjusting the power productions and sum of revenues for the participating consumers for adjusting the power consumptions for congestion management purpose. This total cost is a measure of the decrement in social welfare due to congestion management.

2.2. Severity Index. The objective of power system control is to maintain a secure system state, that is, to prevent the power system from contingencies. This contingencies lead to overloading of the transmission lines. The severity of a contingency to line overload may be expressed as Severity Index (SI)

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

m is the integer exponent whose value is fixed as 1 in this paper. In this study, contingency analysis is conducted for base case generations and loadings (obtained by initial market clearing values) and the SI was computed for each contingency. The line outage which yields highest value of Severity Index is identified as worst contingency. Here line overloads are simulated by means of outage of critical lines and sudden increase in load demands.

2.3. Mathematical Problem Formulation. The objective function of the proposed method is to find an optimum value of shift in active power generation along with network constraints so as to minimize the total congestion cost and relieve transmission congestion simultaneously in the network. The problem of proposed algorithm may be stated as follows.

Objective 1. Minimize total congestion cost

$$\mathrm{CC} = \sum_{j=1}^{\mathrm{NG}} C_{Gj}^{u} \cdot \Delta P_{Gj}^{u} + C_{Gj}^{d} \cdot \Delta P_{Gj}^{d}. \tag{2}$$

Objective 2. Minimize the transmission congestion

$$\mathrm{TC} = \begin{cases} 0, & \text{if } P_{ij}^{\max} \leq P_{ij}^{\max}, \\ \alpha \cdot (P_{ij} - P_{ij}^{\max})^2, & \text{if } P_{ij} \geq P_{ij}^{\max}. \end{cases} \tag{3}$$

Objective 3. Minimize the voltage deviation index

$$\mathrm{VD} = \begin{cases} 0, & \text{if } V_n^{\min} \leq V_n \leq V_n^{\max}, \\ \beta \cdot (V_n^{\min} - V_n)^2, & \text{if } V_n \leq V_n^{\min}, \\ \beta \cdot (V_n - V_n^{\max})^2, & \text{if } V_n \geq V_n^{\max}. \end{cases} \tag{4}$$

α and β are the penalty factors for line flow violation and bus voltage limit violation. Precise setting of penalty factors are not needed, provided that it could be introduced to penalize the solutions with significant constraint violations. The values of α and β are taken as 10000.

Subjected to various constraints

$$P_{Gi} - P_{Di} = \sum_{j=1}^{\mathrm{NB}} |V_i| \left| V_j \right| \left| Y_{ij} \right| \cos\left(\delta_i - \delta_j - \theta_{ij}\right), \tag{5}$$

$$Q_{Gi} - Q_{Di} = \sum_{j=1}^{\mathrm{NB}} |V_i| \left| V_j \right| \left| Y_{ij} \right| \sin\left(\delta_i - \delta_j - \theta_{ij}\right), \tag{6}$$

where

$$P_{Gj} = P_{Gj}^{c} + \Delta P_{Gj}^{u} + \Delta P_{Gj}^{d}, \quad j = 1, 2 \ldots, \mathrm{NG}, \tag{7}$$

$$P_{Dj} = P_{Dj}^{c} + \Delta P_{Dj}^{d}, \quad j = 1, 2 \ldots, \mathrm{ND}, \tag{8}$$

$$Q_{Dj} = P_{Dj} \cdot \tan\left(\phi_{Dj}\right), \quad j = 1, 2 \ldots, \mathrm{ND}, \tag{9}$$

$$P_{Gj}^{\min} \leq P_{Gj} \leq P_{Gj}^{\max}, \quad j = 1, 2 \ldots, \mathrm{NG}, \tag{10}$$

$$Q_{Gj}^{\min} \leq Q_{Gj} \leq Q_{Gj}^{\max}, \quad j = 1, 2 \ldots, \mathrm{NG}, \tag{11}$$

$$V_n^{\min} \leq V_n \leq V_n^{\max}, \quad j = 1, 2 \ldots, \mathrm{ND}, \tag{12}$$

$$P_{ij} \leq P_{ij}^{\max}. \tag{13}$$

Also

$$\Delta P_{Gj}^{u} \geq 0, \quad \Delta P_{Gj}^{d} \geq 0, \quad \Delta P_{Dj}^{d} \geq 0. \tag{14}$$

Constraints (5) and (6) correspond to active and reactive power balance at all buses. Final powers are expressed in terms of market clearing values and are given in (7) and (8). Active and reactive power demands are related through constraint (9) with constant power factor; even varying power factor can also be considered. Constraints (10) and (11) provide upper and lower bounds for real and reactive power of generators. Constraint (12) establishes threshold limits for load bus voltages. Constraint (13) ensures secure loading of transmission lines. Finally constraint (14) ensures that the increment and decrement in powers are positive in magnitude.

Since the proposed problem is complex, combinatorial optimization problem, application of conventional optimization technique such as gradient-based methods is not suitable because it depends on the existence of the first and second derivatives. So the use of heuristic technique is needed. Furthermore if more than one objective is chosen in optimization problem, a suitable method must be developed to check the optimality of the solution. Deciding the weightage for different objective function is difficult in multiobjective EP or any artificial intelligence (AI) techniques. These draw backs can be overcome using fuzzy models; so fuzzy models are developed and incorporated in EP algorithm.

3. Fuzzy EP Approach

In this section, the Fuzzy EP algorithm is developed for this problem. It includes the development of fuzzy models of the objective functions. These fuzzy models are incorporated into the EP algorithm forming the fuzzy EP algorithm. The objective of the solution technique is to determine the redispatch of generators such that the transmission congestion is relieved with voltage at all buses within limits.

Let the vector $X = [X_1 X_2 \cdots X_{\text{NG}}]$ be the vector comprising of the combination of real power generation. Hence the control variable ΔP_{Gj}^{u} and ΔP_{Gj}^{d} are randomly generated increment or decrement of the generation dispatch satisfying their practical constraints

$$\begin{aligned} &\left(P_{Gj} - P_{Gj}^{\min}\right) \\ &\quad = \Delta P_{Gj}^{\min} \leq \Delta P_{Gj} \leq \Delta P_{Gj}^{\max} = \left(P_{Gj}^{\max} - P_{Gj}\right). \end{aligned} \tag{15}$$

The EP initially chooses NC combinations of starting guesses. The objective functions 2–4 are evaluated considering the NC combination of solution vectors $X_1 X_2 X_3 \cdots X_{\text{NC}}$. The fuzzy models are developed as follows.

3.1. Fuzzy Model for Total Congestion Cost. Let the total congestion cost be $\text{CC}^i = f_{\text{CC}}(X^i)$. The function $f_{\text{CC}}(X^i)$ is defined in (2). A fuzzy satisfaction parameter μ_{CC}^i is then

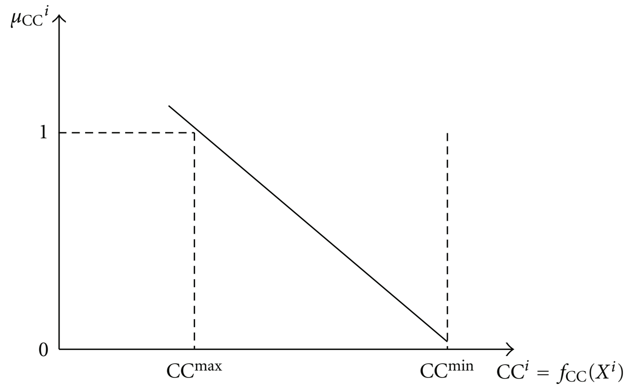

Figure 1: Fuzzy model of congestion cost.

defined associating the satisfaction level with the solution vector X^i as below

$$\mu_{\text{CC}}^i = \frac{\text{CC}^{\max} - \text{CC}^i}{\text{CC}^{\max} - \text{CC}^{\min}} = \frac{\text{CC}^{\max} - f_{\text{CC}}(X^i)}{\text{CC}^{\max} - \text{CC}^{\min}}. \tag{16}$$

$\text{CC}^{\max}$ and $\text{CC}^{\min}$ refer to the maximum and minimum congestion cost that would occur when the solutions X_1 to X_{NC} are considered for implementation. The diagram for the satisfaction of parameters is shown in Figure 1.

3.2. Fuzzy Model for Transmission Congestion. Let the transmission congestion index $\text{TC}^i = f_{\text{TC}}(X^i)$; the solution X^i is considered. The function $f_{\text{TC}}(X^i)$ is defined in (3). The $f_{\text{TC}}(X^i)$ is the transmission congestion calculated for X^i real power redispatch by running NR power flow. A fuzzy parameter μ_{TC}^i is the defined considering the satisfaction level with the solution X^i as below

$$\mu_{\text{TC}}^i = \frac{\text{TC}^{\max} - \text{TC}^i}{\text{TC}^{\max} - \text{TC}^{\min}} = \frac{\text{TC}^{\max} - f_{\text{TC}}(X^i)}{\text{TC}^{\max} - \text{TC}^{\min}}. \tag{17}$$

$\text{TC}^{\max}$ and $\text{TC}^{\min}$ refer to the maximum and minimum transmission overload that would occur when the solutions X_1 to X_{NC} are considered for implementation. The diagram for the satisfaction of parameters is shown in Figure 2.

3.3. Fuzzy Model for Voltage Deviation. Let $\text{VD}^i = f_{\text{VD}}(X^i)$ be the the voltage deviation index for X^i real power generation redispatch considered. The function $f_{\text{VD}}(X^i)$ is defined in (4). The $f_{\text{VD}}(X^i)$ is evaluated after running NR power flow for a solution vector X^i considered. A fuzzy parameter μ_{VD}^i is defined, considering the satisfaction level with the solution X^i as below

$$\mu_{\text{VD}}^i = \frac{\text{VD}^{\max} - \text{VD}^i}{\text{VD}^{\max} - \text{VD}^{\min}} = \frac{\text{VD}^{\max} - f_{\text{VD}}(X^i)}{\text{VD}^{\max} - \text{VD}^{\min}}. \tag{18}$$

$\text{VD}^{\max}$ and $\text{VD}^{\min}$ refer to the maximum and minimum transmission voltage deviation index that would occur when the solutions X_1 to X_{NC} are considered for implementation. The diagram for the satisfaction of parameters is shown in Figure 3.

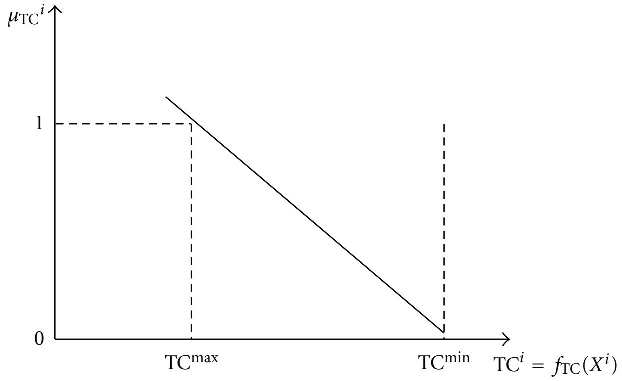

Figure 2: Fuzzy model of transmission congestion.

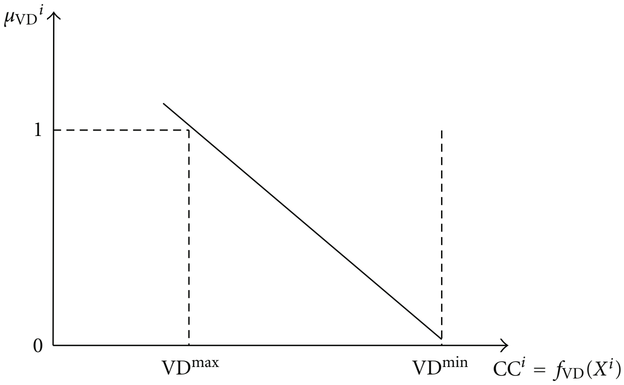

Figure 3: Fuzzy model of voltage deviation.

3.4. Development of Fuzzy Evaluation Method of Solution Vector. With the three fuzzy models for total congestion cost minimization, transmission congestion index minimization, and voltage deviation index minimization defined in the previous subsections, the overall evaluation of a solution vector $\mathbf{X^i}$ may be done by selecting any of the fuzzy operators. In this paper, one of the simplest fuzzy operator intersection is chosen. Thus the resultant satisfaction parameter associated with a solution $\mathbf{X^i}$ is determined as

$$\mu_X{}^{i} = \mu_{CC}{}^{i} * \mu_{TC}{}^{i} * \mu_{VD}{}^{i}. \qquad (19)$$

In order to determine the best solution vector amongst the NC solution vectors from $\mathbf{X_1}$ to $\mathbf{X_{NC}}$, the associated satisfaction parameter values from $\mu_X{}^{1}$ to $\mu_X{}^{NC}$ have to be evaluated. Then the solution vector $\mathbf{X^*}$ having the highest satisfaction parameter value is chosen as the best solution vector.

3.5. Fuzzy EP Algorithm for Transmission Congestion Alleviation. The steps of the fuzzy EP technique for transmission congestion alleviation are given below.

(1) Randomly generate NC combination of solution

$$X_1\ X_2\ X_3 \cdots X_{NC}. \qquad (20)$$

(2) Set iteration count $k = 1$.

(3) Evaluate fuzzy objective function μ_X^i using 19 for each of X^i, $i = 1, 2, \ldots, \mathrm{NC}$.

(4) Generate NC more solution vectors $X_{NC+1}X_{NC+2} \cdots X_{2NC}$ through crossover

$$X^{NC+i} = \beta \frac{2(r) - r_m}{r_m}(X_{max} - X_{min}) \frac{\mu_X{}^{max}}{\mu_X{}^{i}} + X^i, \qquad (21)$$

where $\beta = 0.75$, r = random number between 0 to r_m, $r_m = 2$ to 3, and $X^{max}X^{min}$ are maximum and minimum values of X.

(5) Evaluate the newly generated solution vector $X_{NC+1}X_{NC+2} \cdots X_{2NC}$.

Choose the best NC solution vector having the highest satisfaction value of μ_X^i among 2NC solution vectors $X_1X_2X_3 \cdots X_{2NC}$ and designate the chosen set as $X_1X_2X_3 \cdots X_{2NC}$.

(6) Increment iteration count $k = k + 1$.

(7) Check maximum iteration count, if $k <$ max iteration, stop. Else go to step 4.

Choose the best among the NC solution set X_1X_2 $X_3 \cdots X_{NC}$ having highest value of μX^i.

4. NSGA II Approach

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, multiobjective nondominated sorting genetic algorithm NSGA II [22] is proposed to solve this complex nonlinear problem. Classical optimization methods (including the multicriterion decision-making methods) suggest converting the multiobjective optimization problem to a single-objective optimization problem by emphasizing one particular Pareto-optimal solution at a time. 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. Over the past decade, a number of multi objective evolutionary algorithms (MOEAs) have been suggested to find multiple Pareto-optimal solutions in one single simulation run. The nondominated sorting genetic algorithm [23–25] is one of the Pareto-based approaches. These algorithms demonstrated the necessary additional operators for converting a simple EA to an MOEA. Two common features of MOEA are (i) assigning fitness to population members based on nondominated sorting and (ii) preserving diversity among solutions of the same nondominated front. Over the years, the main criticisms of the NSGA approach have been as follows:

(1) high computational complexity of nondominated sorting,

(2) lack of elitism,

(3) need for specifying the sharing parameter.

Table 1: Severity index of IEEE 30 bus system.

Outage of line	Severity index
1-2	3.1464
1–3	2.1743
3-4	1.1189
2–5	1.0781
2–4	0.0654
6-7	0.0564
5–7	0.0454
4–12	0.0456

So all the above issues have been solved using improved version of NSGA called NSGA II, that can find diverse set of solutions and converge near the true Pareto-optimal set. So this efficient NSGA II algorithm has been proposed to solve the congestion management problem with 2 objectives considered simultaneously that can provide set of alternative solutions to the operator instead of single solution.

4.1. NSGA II Algorithm for Congestion Management.

(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.

(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. In this work, control variable is generator real power redispatch. Hence the control variables are generated randomly satisfying their practical operation constraints

$$\left(P_{Gj} - {P_{Gj}}^{\min}\right) = \Delta {P_{Gj}}^{\min} \leq \Delta P_{Gj} \leq \Delta {P_{Gj}}^{\max} = \left({P_{Gj}}^{\max} - P_{Gj}\right). \tag{22}$$

(3) For each chromosome of population, calculate objective function-1 using (2) and run Newton Raphson power flow to calculate the objective function-2 and 3 using (3) and (4).

(4) The equality and inequality constraints are handled by Newton Raphson Power Flow.

(5) Nondomination sorting of population is carried out. And then tournament selection is applied to select the best individuals based on crowding distance.

(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.

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

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

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

5. Results and Discussions

The proposed technique is tested on IEEE 30 bus system. All system data are extracted from [26]. Demand data given in [26] are taken as initial market clearing values, that is, (P_{Di}^{C}). For generators, the initial market clearing values (P_{Gj}^{c}) with their bus numbers are given in Appendix A. Price bids are submitted by GENCOs ($/MWhr) and DISCOS ($/MWhr) to alter their scheduled productions and consumptions, and the generator/load up and down costs are given in Appendix A.

For IEEE 30 bus, Three cases are considered. Case A is outage of lines 1-2 and total load raised by 40%, Case B is outage of lines 1-2 and outage of generator 2, Case C is outage of lines 1–3 and load at all buses raised by 50%. The total load increases by 40% or 50% even though not realistic in deregulated system, but it is considered to have a severe congestion in the system and to show that the proposed algorithm gives better solution without any load curtailment.

5.1. Severity Index of IEEE 30 Bus System. This system has 6 generation companies (GENCOs), 21 demand supply companies (DISCOs), and 41 transmission lines with total load of 283.4 MW and 126.2 MVAR (Load factor LF as 1.0). Contingency analysis was conducted under base case loading condition. For this system, line outages 1-2, 1–3, 3-4, and 2–5 have resulted in overloading of other lines. These lines outages are considered to be critical line outages. Outage of lines 1-2 has high severity index followed by lines 1–3, and they are given in Table 1.

5.2. Simulated Case for IEEE 30 Bus System. Table 2 shows the overloaded lines for different cases and the amount of power violated in each cases. Then the total power violation is shown with the severity index value. Case A has the highest severity index.

5.3. Final Power Adjustments for Line Overload Alleviation with Payment Particulars. Table 3 shows the new incremented or decremented power of each generator for different cases. Total congestion cost in ($/hr) found by FEP method is compared with particle swarm optimization (PSO) [17]. Even though the PSO method is found to be better than the other existing methods, the proposed method gives even better results than PSO, that is, congestion cost by the proposed method is low when compared to PSO. Moreover, congestion is relieved by generation rescheduling alone, that is, without any load curtailment.

Table 2: Simulated case for IEEE 30 bus system.

Cases	Lines overloaded	Line limit	Actual power flow	Power violation	Total power violation	Severity index
	1–3	130	315.26	185.26		
A	3-4	130	268.29	138.29	386.7	12.96
	4–6	90	153.16	63.160		
	1–3	130	222.14	92.14		
B	3-4	130	199.71	69.71	181.6	6.77
	4–6	90	109.89	19.89		
	1-2	130	289.93	159.93		
C	2–4	65	104.54	39.54	244.2	10.41
	2–6	65	109.80	44.80		

Table 3: Generation rescheduled power and congestion cost.

Case	ΔP_{g1}	ΔP_{g2}	ΔP_{g5}	ΔP_{g8}	ΔP_{g11}	ΔP_{g13}	Total cost	
							FEP	PSO
A	−9.7	82.4	2.2	9.7	20.9	17.6	3810	3916
B	−5.9	0.0	20.3	0.43	28.2	20.6	3041	3099
C	−85	0.5	3.3	21.2	40.0	16.8	5001	5355

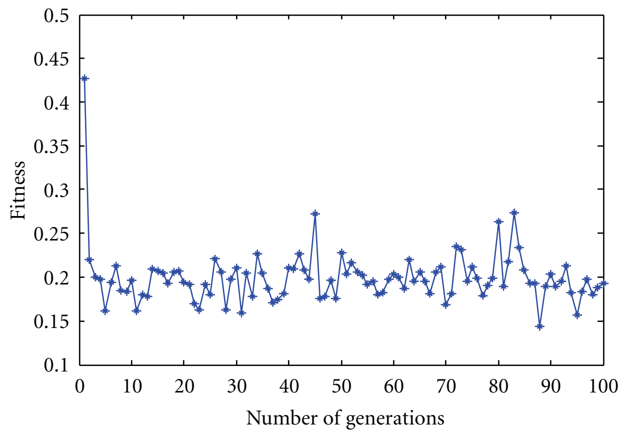

Figure 4: Convergence characteristics for Case A.

Figure 4 shows the convergence characteristic for Case A. Similarly for other cases also the fitness function becomes constant after some iteration.

The multiobjective optimization using NSGA II algorithm is developed and tested for the above-mentioned three cases. The parameters used for NSGA II are

population size: 50,

no. of generation: 100,

tournament selection,

simulated binary crossover with rate 0.9,

polynomial mutation with rate 0.1,

The Pareto-optimal solutions, for all the three cases are given in the Figures 5, 6 and 7.

Among the Pareto-optimal solutions, the three nondominated solutions from the truncated archive are presented in Table 4 for all three cases. If the operator wants to alleviate congestion totally, then the generation cost increases by 4285 (\$/hr) for Case A, 3699 (\$/hr) for Case B, and 5197 (\$/hr) for Case C. If the operator wants to minimize cost rather than congestion, solution 1 is to be selected, whereas solution 2 can be selected if some congestion is allowed with some increase in cost. The congestion can be relieved only by sacrificing the generation cost.

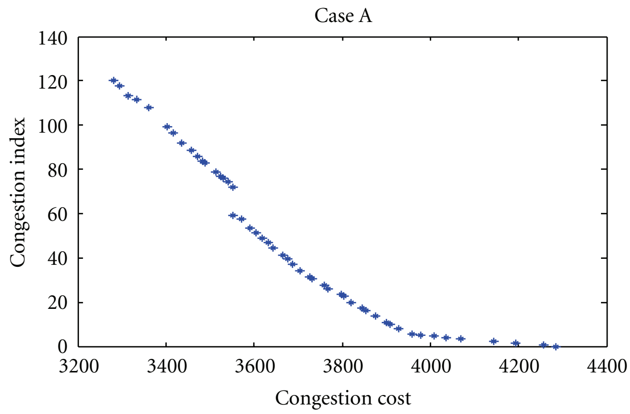

Figure 5: Pareto optimal front for Case-A.

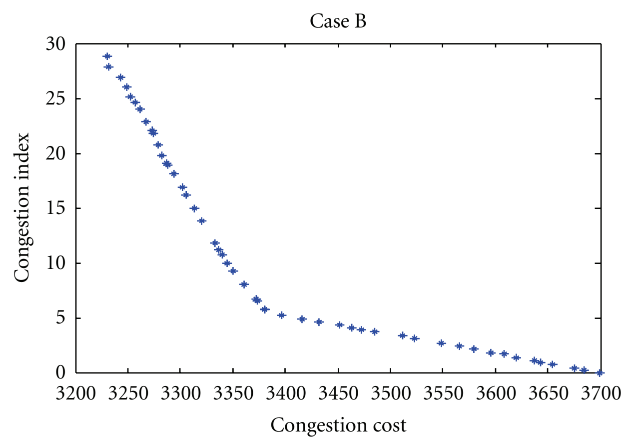

Figure 6: Pareto optimal front for Case-B.

Table 4: Pareto optimal solution for all three cases.

Cases	Pareto-optimal solution					
	Solution 1		Solution 2		Solution 3	
	Congestion	Cost ($/hr)	Congestion	Cost ($/hr)	Congestion	Cost ($/hr)
A	120	3282	31.2	3727	0.0	4285
B	28.25	3230	5.233	3396	0.0	3699
C	170.3	3555	70.69	4285	0.0	5197

Table 5

Bus no.	Initial generation P^c_{Gj} (MW) as determined by market clearing procedure.	Price bid submitted by GENCOs ($/MWhr)	
		C^u_{Gj}	C^d_{Gj}
1	138.59	22	18
2	57.56	21	19
5	24.56	42	38
8	35.00	43	37
11	17.93	43	35
13	16.91	41	39

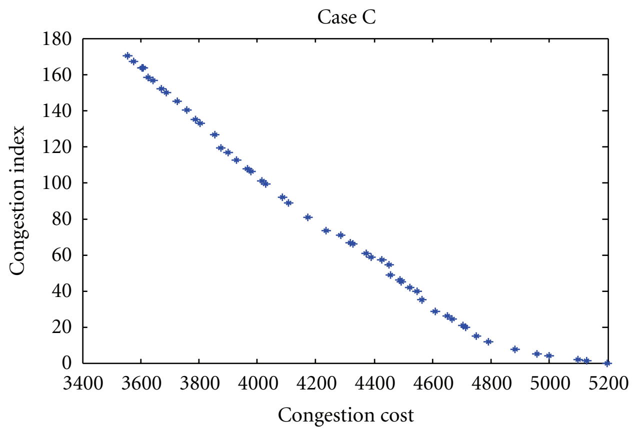

Figure 7: Pareto optimal front for Case-C.

The FEP method gives only one best solution considering both the objectives which does not provide any choice for the operator, whereas NSGA II method gives a set of non dominated solutions, the operator can use his discretion to choose the solution.

6. Conclusions

In this paper, two efficient methods are proposed for solving congestion management problem in a day ahead electricity market by generator rescheduling. The fuzzy EP approach and NSGA II approach are used. FEP gives unique solution satisfying both objectives. It has been found that the results obtained using FEP are better than PSO. That is, the congestion cost is less in FEP than PSO, also congestion is alleviated with load shedding even for the very severe congested scenario. The FEP method gives only one best solution considering both the objectives simultaneously, which may not provide any choice for the operator some times. So NSGA II algorithm is used to find a set of non dominated Pareto-optimal solutions. The system operator can use his discretion for selecting the proper solution for either for congestion alleviation or congestion cost minimization. The feasibility of the proposed method is demonstrated on IEEE 30 system for severe line outages.

Appendix

A. IEEE 30 Bus System Data

The data are taken from MATPOWER toolbox (see Table 5).

Nomenclature

ΔP^u_{Gj}: Active power increment in generator j (MW) due to congestion management

ΔP^d_{Gj}: Active power decrement in generator j (MW) due to congestion management

ΔC^u_{Gj}: Price offered by generator j to increase its pool schedule due to congestion management

ΔC^d_{Gj}: Price offered by generator j to decrease its pool schedule due to congestion management

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 consumed by demand i (MVAR)

P^c_{Gj}: Active power produced by generator j as determined by market clearing procedure

P^c_{Dj}: Active power consumed by demand i (MW) as determined by market clearing procedure

V_i & V_j: Bus voltage magnitude at i and j, respectively

δ_i & δ_j: Bus voltage angle at i and j, respectively
Y_{ij}: Mutual admittance between node i and j
Y_{ii}: Self admittance of node i
$P_{Gj}^{\min}$: Minimum real power output of generator j
$P_{Gj}^{\max}$: Maximum real power output of generator j
$Q_{Gj}^{\min}$: Minimum reactive power output of generator j
$Q_{Gj}^{\max}$: Maximum reactive 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)
$V_n^{\max}$ & $V_n^{\min}$: Maximum and Minimum limit of voltage at bus—n
NB: Number of buses
NL: Number of lines
N_d: No. of participating demand
L_O: Set of overloaded lines.

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