International Journal on Electrical Engineering and Informatics - Volume 3, Number 1, 2011

Differential Evolution based Multi-objective Optimization of a Deregulated Power Network under Contingent State

Sawan Sen[1], Sandip Chanda[2], S. Sengupta[3], and A. Chakrabarti[4]

[1, 2] Electrical engineering Department, Techno India, Kolkata, India
[3]Department of Applied Physics, University of Calcutta, Kolkata, India
[4]EE Department, Bengal Engineering and Science University, Shibpur, Howrah, India
[1]sen_sawan@rediffmail.com, [2]sandipee1978@gmail.com
[3]samarsgp@rediffmail.com, [4]a_chakraborti55@yahoo.com

Abstract: This paper proposes a methodology to limit the variations in generation cost in a power system under normal and contingent state using Differential Evolution (DE) optimization technique keeping consumer welfare in view. The aim of this proposed methodology is to minimize the deviations of generation cost, during contingency, from a preferred value by rescheduling of the generation with a controlled load curtailment technique and hence relieving the lines from overloading for congestion management. A comparative study between rescheduling with and without load curtailment has also been presented in this paper. Numerical results on test system, namely IEEE 30 Bus System, are presented for illustration purpose and the same has been verified by a well esteemed optimization technique, Particle Swarm Optimization (PSO). The comprehensive simulation results establish that the developed method not only reduces the economic variations of the market but also ensures the voltage stability of the system during contingency.

Index Terms: congestion management, deregulated environment, Differential Evolution, generator re-scheduling, load curtailment, Particle Swarm Optimization.

1. Introduction

The restructuring of the electric power industry has involved paradigm shifts in the real time control activities of the power grids. Managing dispatch and determination of price of electricity are among important control activities in a power system [1]. One of the major role of an independent system operator (ISO) in a competitive market environment is to facilitate the complete dispatch of the power that gets contracted among the market players. These contracts are subjected to change with market conditions. Thus due to continuous change in transactions between participants, the spot price of electricity becomes volatile [2]. A contingent condition may also change the generation cost and hence spot price of electricity. The increase in spot price is quite detrimental in terms of consumer welfare, and markets having high spot price can not promote cheap generation and dispatch of power. Moreover in contingent condition the congestion management cost also gives a hike to spot price of electricity. In this scenario, a need of a multi-objective optimization technique can be felt which not only limits the variations of generation cost but also reduce the congestion cost to limit the spot price at a chosen level. With conventional OPF algorithms a generation schedule can be prepared by optimizing power loss and cost of generation. In contingent condition the conventional OPF can prepare a new schedule of power generation, suitable for the current operating conditions but it gives a rise to generation cost and hence spot price [3]. Therefore, the conventional OPF fails to manage congestion and generation cost variations simultaneously. The Security Constraints Optimal Power Flow (SCOPF), however, is capable of managing congestion during contingency but it fails to limit the variations of generation cost

Received: November 16th, 2010. Accepted: April 1st, 2011

in varying conditions of markets [4]. Congestion management based on optimum generation rescheduling and load shedding schemes are reported in [5], [6]. But the consumer welfare in terms of cost minimization has not been considered. Multi objective PSO for congestion management is presented in [7]. The authors of [8] proposed Zonal based congestion management approach. Cluster based congestion management using PSO is reported in [9]. Power transaction using ac power transfer distribution method is discussed in [10]. All these methods could not maintain the generation cost at a favorable limit. To minimize the variations of spot price, a novel formulation of complex OPF is extremely necessary, which not only takes congestion and voltage security issues as constraints but also creates a boundary for generation cost and spot price.

Conventional optimization techniques such as gradient-based algorithm, linear programming and interior point methods often have problems of convergence and difficulties in locating the global optima. Since the proposed problem is a complex optimization, use of heuristic algorithm is a vital one. Computational intelligence-based techniques, such as genetic algorithm (GA), PSO have been successfully used to solve optimization problems in power systems. However, the premature convergence of GA degrades its performance and reduces its search capability that leads to a higher probability towards obtaining a local optimum. PSO is an exciting new methodology in evolutionary computation developed by Eberhart and Kennedy. PSO is not largely affected by the size and nonlinearity of the problem, and can converge to the optimal solution in many problems where most analytical methods fail to converge [11], [12].

Differential Evolution is a relatively new member in the family of evolutionary algorithm. It was first proposed by Storn and Price over 1994-1996 [13]. Unlike the conventional evolutionary algorithms, which depend on predefined probability distribution function for mutation process, DE uses the differences of randomly sampled pairs of objective vectors. DE has drawn an increasing attention for a wide variety of engineering applications including power engineering applications such as transient stability, economic dispatch etc [14-18].

In this paper, a multi-objective methodology of DE based optimization has been proposed which along with the congestion and voltage security constraints, takes boundary conditions of generation cost into consideration. A controlled load curtailment technique has been adopted to implement the proposed optimization technique in deregulated power system. As load curtailment can reduce reliability of power supply, the proposed optimization technique assures least variation of system security by keeping curtailment to a minimum possible limit predicted by the proposed algorithms. The same algorithm has also been tested with PSO for comparison and reliability estimation of the DE based results. ISO and participants can avoid generation cost variation by the proposed technique with a minimum possible disturbance to system reliability. Computer simulations are done on IEEE 30 Bus System to validate the potential of the proposed algorithm.

2. Theory

A. Congestion of a power network

Contingency is a state of power system where some of its components e.g. generator or transmission lines are not operational. This state may arise in the system due to the violation of engineering constraints or maintenance schedule. The effect of this inevitable state may be quite severe as it can cause power flow congestion in the line. Transmission lines have thermal limit of carrying power and if the power flow exceeds that limit, which is quite expected during contingency, the line is said to be congested. Due to line congestion the Locational marginal price (LMP) [19] may rise and along with the congestion cost the buyer has to pay for the cost of extra energy transfer. Hence line congestion introduces unexpected rise in spot price of electrical power, which may infringe the ongoing transaction between the participants. The aim of this paper is generation cost minimization such that, least variations of spot price is encountered with respect to its pre-contingent value and releasing the overload on the congested line.

There are two possible solutions of line congestion viz a) generator rescheduling without load curtailment, resulting in increased generation cost and hence spot price which will directly affect the consumer welfare. b) Generator rescheduling with minimum possible load curtailment which results in improved congestion management with same generation cost but less reliability of power supply. Generation rescheduling with load curtailment may have the above disadvantages but the spot price may be maintained at or below its pre-contingent value by limiting the deviation of generation cost. This necessitates a complex formulation of optimization problem, which can be solved by efficient optimization techniques like DE and PSO.

This paper is divided into three parts. The theory part continues to give an overview of DE and PSO, the second part formulates the problem and third part depicts the simulation results. The simulation part of this paper is divided into two sections. The first section depicts the shortcomings of generation rescheduling without load curtailment during contingency. Without disturbing the generation cost, the results of generation rescheduling with load curtailment during contingency have been presented in second section of simulation.

B. Differential Evolution (DE)

Differential Evolution is a stochastic direct search optimization method, which can be used to minimize nonlinear and non-differentiable continuous space functions with real-valued parameters. DE uses floating-point numbers to encode the parameter variables in contrast with conventional Genetic Algorithm (GA) that uses binary coding. It has been extended to handle mixed integer discrete continuous optimization problem [20]. Like the other evolutionary algorithm (EA) family, DE also relies on initial random population generation, which is then improved using selection, mutation, and crossover repeated through generations until the convergence criterion is met. These features are briefly reviewed below for completeness.

B.1 Population initialization

The first step in DE optimization process is to create an initial population ($x_{i,j}^{0}$) of candidate solutions by assigning random values to each decision parameter of each individual of population. Those values must lie inside the upper and lower bounds of the decision variable as shown below:

$$
\begin{aligned}
& x_{i,j}^{0} = x_{j}^{\min} + \eta_{j}\left(x_{j}^{\max} - x_{j}^{\min}\right) \\
& i = 1, 2, \ldots\ldots N_{p}, \qquad j = 1, 2, \ldots\ldots D
\end{aligned}
\tag{1}
$$

where $x_{j}^{\min}$ and $x_{j}^{\max}$ are the lower and upper bounds of the j^th^ decision parameter. N_p is the number of population, D is the number of parameter of the objective function and η_j is a random number within [0,1].

B.2 Mutation

Mutation is primarily responsible for keeping a population robust and for searching new territory. New parameters are generated by adding the weighted difference to another vector. DE can generate the new vectors according to the following equation

$$
v = x_{r1,g} + F * (x_{r2,g} - x_{r3,g}) \tag{2}
$$

with random vectors of $r_1, r_2, r_3 \in \left\{1, 2, \ldots. N_p\right\}$. F is the scaling factor for mutation and its value is within the range [0, 1.2]. It can control the speed and robustness of the search.

B. 3 Crossover

Crossover is the complementary process to increase the diversity of the parameter vectors by choosing a subgroup of parameters for mutation. Mathematically, it can be illustrated as:

$$u = (u_1, u_2 .....u_D)^T \tag{3}$$

$$u_{j,g} = \begin{cases} v_{j,g} & j = \langle n \rangle_D, \langle n+1 \rangle_D, ...\langle n+L+1 \rangle_D \\ \left(x_{i,g}\right)_j & otherwise \end{cases} \tag{4}$$

where the acute brackets $\langle \ \rangle_D$ denote the modulo function with modulus D. The index n is a randomly chosen integer from the interval [0, D-1]. The integer L is drawn from the interval [0, D-1] with a probability $\Pr(L = v) = (CR)^v$, where CR is the crossover probability. The random for both n and L are made anew for each trial vector.

B.4 Selection

Selection specifies under what conditions the new vectors can enter into the population. The selection criterion of DE can be expressed by as follows,

$$x_{i,(g+1)} = \begin{cases} u_{i,(g+1)} & f\left(u_{i,(g+1)}\right) \le f(x_{i,g}) \\ \left(x_{i,g}\right) & otherwise \end{cases} \tag{5}$$

The parent vector $x_{i,g}$ will be replaced by the child vector $u_{i,(g+1)}$ only if it improves the objective.

3. Problem Formulation

When the system is insecure and there are violations in the system, the objective of the pool central dispatcher is to eliminate the system overload and come up with the corrective rescheduling to eliminate the violations as fast as possible. Minimum operating cost, minimum shift from the optimum operation and congestion cost minimization has been used as the objective functions (OBF) for the proposed multi-objective function. Considering these criteria the problem can be formulated as:

$$\text{Minimize } OBF = \sum_{k \in N_g} C_k(P_{Gk}) + \sum_{i \in N_g} \Delta C_i \quad \text{US\$/hr} \tag{6}$$

$$\text{where, } \Delta C_i = C_{0i} - C_i \tag{7}$$

$$\text{and, } C_k(P_{Gk}) = (a_i P_{Gi}^2 + b_i P_{Gi} + c_i) \tag{8}$$

subject to the constraints

$$P_{Gi} - P_{Di} = V_i \sum_{j \in N_i} V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}\right) \tag{9}$$

$$Q_{Gi} - Q_{Di} = V_i \sum_{j \in N_i} V_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}\right) \tag{10}$$

where, i = 1,2,……..NB

$$P_{Gk} = P_{Gk}^{C} \qquad k = 1,2,\ldots\ldots.N_g \tag{11}$$

$$P_{Dj} = P_{Dj}^{C} \qquad j = 1,2,\ldots\ldots.N_d \tag{12}$$

$$P_{Gk}^{\min} \le P_{Gk} \le P_{Gk}^{\max} \tag{13}$$

Security constraint:

$$V_i^{\min} \le V_i \le V_i^{\max} \text{ and } P_{ij} \le P_{ij\max} \tag{14}$$

where C_{0i} and C_i are the generation cost of each generator for the base transaction and contingent state transaction respectively. Constraint (9) and (10) represent real and reactive power balances in each node. Constraints (13) and (14) provide upper and lower limits for real power of generators, load bus voltages and line flow. In this study, load voltage and real power flow in lines are taken as state variables.

The different symbols used in (6) to (14) are as follows: N_g - number of generators, N_d - number of loads, NB - number of buses, P_{GK}^{C} -active power produced by generator k, P_{Dj}^{C} - active power consumed by demand j, P_{GK} - final real power generation of generator k, P_{Dj} - final real power consumption of demand j, $P_{Gk}^{\min}$ and $P_{Gk}^{\max}$ - minimum and maximum limits for kth generator real power output, V_j and V_k - Voltage magnitude of bus j and k, δ_j and δ_k - Voltage angle of bus j and k and θ_{kj} - admittance angle of line k –j

A. *Conventional algorithm for generation rescheduling without load curtailment*

Step 1: Pool, bilateral and multilateral structures submit their desired transactions to the ISO.

Step 2: If all equality and inequality constraints are satisfied go to step 4. Otherwise go to the next step.

Step 3: Use the optimal dispatch to change generation schedule for the requested power transfer. The process continues until all equality and inequality constraints are satisfied in normal or contingent state of the system.

Step 4: Update the generation cost and spot price with usual/changed generation.

Step 5: Create new dispatch schedules with higher spot price and inform the participants.

Step 5: When all constraints are satisfied and participants agree with the new transaction, the generation at slack bus (loss compensation) must be spread among all participants.

Step 5: Stop.

B. *Proposed algorithm for generation rescheduling with load curtailment*

Step 1: Pool, bilateral and multilateral structures submit their desired transactions to the ISO.

Step 2: If all equality and inequality constraints are satisfied go to step 4. Otherwise go to the next step.

Step 3: Use the optimal dispatch model to curtail the requested power transfer and also change generation schedule. The process continues until all equality, inequality and boundary constraints are satisfied in normal or contingent state of the system.

Step 4: Update the generation cost and spot price with usual/changed generation.

Step 5: Check whether the generation cost is less than the preferred value. If not go to step3 otherwise step 6.

Step 6: Create new generation schedule with same spot price and inform only GENCOs.

Step 7: When all constraints are satisfied and with the new transaction, the generation at slack bus (loss compensation) must be spread among all participants.

Step 5: Stop.

4. Simulation

The suitability of the proposed method has been tested for IEEE-30 bus system. The IEEE-30 bus system description has been given in Table I and Table II along with Figure 1. In DE solution for OPF, the control variables are: active power outputs of six units, all bus voltage magnitudes and total generating cost.

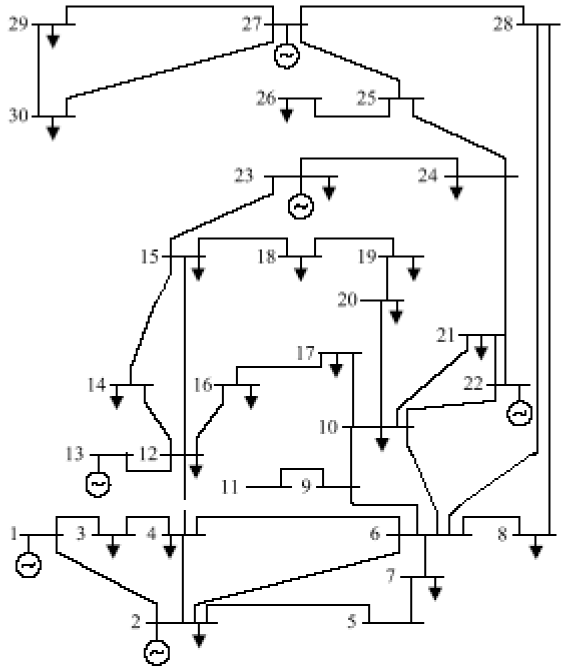

Figure 1. Single line diagram of IEEE 30 bus test system

Table 1. System Description For Case Studies

Sl. No	Variables	30 bus system
1	Buses	30
2	Branches	41
3	Generators	6

Table 2. Generator Cost Co-Efficient Of Ieee30 Bus System

Bus no	Real Power output limit of Generator (MW)		Cost Co-efficient		
	Min	Max	a	b	c
1	50	200	0.00375	2.00	0
2	20	80	0.01750	1.75	0
5	15	50	0.06250	1.00	0
8	10	35	0.00834	3.25	0
11	10	30	0.02500	3.00	0
13	12	40	0.02500	3.00	0

The objective of the proposed method is to maintain the generation cost within a favorable limit in deregulated environment. The base case (i.e. without contingency) transaction has been assumed to be the most feasible transaction in the market both from buyer and seller point of view and hence a controlled load curtailment technique has been adopted to maintain the system generation cost to a constant level during contingency. It is expected that the ISO, following the proposed method, will be able to control power market variations and rise in LMPs [19] and spot price by least interrupting the continuing transaction till the system is restored from its contingent state. The IEEE 30 bus system has been chosen as it is a benchmark system, has more control variables and provides results for comparison of the proposed method. The approach can be generalized and easily extended to large-scale practical systems.

Section I: Generation re-scheduling during normal and contingency without load curtailment

A. Generator scheduling at base case (without contingency)

In this case the system is optimized using the DE based optimal power dispatch method for 100% load level. The real power settings of the generators are taken from Table 2. To obtain the optimal values of the control variables the DE-based algorithm has been followed and the same algorithm has been applied to PSO for verification and comparison. The optimal values of the generations and power loss obtained are presented in Table 3. The optimized cost obtained from DE and PSO based OPF under pre-contingent condition have been considered as reference. It has also been assumed that these load dispatch schedule prepared by ISO has been agreed upon by both GENCOs and TRANSCOs since the same is not violating the load, generation and engineering constraints and, more over the voltages are also within safe operating limit.

Table 3. Dispatch Schedule of Generators for Base Case (Without Contingency)

	Gen Bus No	**Voltage (p.u)**	**Scheduled dispatch (MW)**	**Operating Loss (MW)**	**Optimized Cost (US$/hr)**
DE based OPF	1	1.060	176.7301	9.3760	801.8436
	2	1.043	48.8300		
	5	1.010	21.4738		
	8	1.010	21.6481		
	11	1.082	12.0940		
	13	1.071	12.0000		
PSO based OPF	1	1.060	176.9341	9.3884	801.8441
	2	1.043	48.7255		
	5	1.010	21.4395		
	8	1.010	21.5965		
	11	1.082	12.0929		
	13	1.071	12.0000		

A.1 Generator re- scheduling at different contingency states

To calculate the generator re-scheduling, the proposed algorithm has been applied for worst possible contingencies. The harmful contingencies can be found by proper weak bus and line selection. For this purpose, a sensitivity index [21] has been chosen and ranking of weak bus has been shown in Table 4.

Table 4. Ranking of Weakness of Load Buses of IEEE 30 Bus Test System

Ranking	**Load bus number**	**Sensitivity parameter**
1	26	1.7819
2	30	2.9037
3	29	3.5253
4	14	5.7121
5	23	7.2606
6	25	7.9527
7	16	9.0340
8	27	9.4692
9	24	9.5473
10	18	10.3940
11	17	15.6612
12	20	16.6348
13	15	16.8424
14	7	18.6705
15	19	18.8634
16	28	23.1528
17	12	26.1363
18	3	29.8400
19	9	30.0212
20	22	46.2081
21	21	47.8387
22	10	54.3835
23	4	57.1654
24	6	85.6604

From Table 4, the bus number 26 has been found to be the weakest bus. However the bus 26 has only one interconnecting line with rest of the system and a contingency on this line will cause complete isolation of bus number 26. On the other hand, bus 30 (2nd weakest bus) has got connections to both bus 27 and 29. Hence, the weaker line 29-30 has been tripped. The tripping procedure continued for several other cases according to the contingency ranking table (Table 4). As expected, with DE optimization, in this contingent condition the generation schedule changes and also the generation cost increases (Table 5). The PSO based optimization also confirms the above fact. This increase in generation cost violates the previous agreement between market participants, and ISO has to place new proposals to the participants which may be unacceptable for any one of them. Again with contingency not only the GENCOs face higher operating cost but TRANSCOs and DISCOs also suffer with high LMPs and hence spot price and congestion management cost.

Table 5. Generator Re-Scheduled Dispatch For Different Contingent States

	Line trip	**Re-scheduled dispatch (MW)**						Optimized generation Cost (US$/hr)
		Generator Bus No						
		1	**2**	**5**	**8**	**11**	**13**	
DE based OPF	29-30	176.78	48.84	21.47	21.68	12.10	12.00	802.2851
	27-30	176.95	48.88	21.49	21.79	12.13	12.00	803.5179
	29-27	176.90	48.87	21.48	21.75	12.12	12.00	803.1148
	12-14	176.79	48.84	21.48	21.72	12.15	12.00	802.6358
	14-15	176.72	48.82	21.47	21.65	12.09	12.00	801.8630
	12-16	176.59	48.81	21.47	21.74	12.26	12.00	802.2926
	16-17	176.64	48.81	21.47	21.68	12.17	12.00	801.9346
PSO based OPF	29-30	176.81	48.79	21.48	21.71	12.10	12.00	802.2852
	27-30	177.03	48.84	21.52	21.82	12.03	12.00	803.5183
	29-27	176.64	48.93	21.49	21.89	12.15	12.00	803.1153
	12-14	176.78	48.86	21.53	21.65	12.08	12.00	802.6362
	14-15	176.70	48.90	21.44	21.64	12.09	12.00	801.8632
	12-16	176.84	48.74	21.50	21.60	12.20	12.00	802.2932
	16-17	176.66	48.86	21.47	21.59	12.21	12.00	801.9348

Section II: Generation rescheduling with load curtailment during contingency to limit the deviation of generation cost

To limit the generating cost using the proposed algorithm, the proposed algorithm based OPF searches for an optimum schedule until the operating cost goes below the base value. For each of these simulations, load has been curtailed according to ‘willing to pay’ ranking and the technique adopted is just like pool curtailment where the main plan is to minimize the deviation of the transactions from the desired values. The results have been shown in Table 6.

The generation cost more or less remains same with DE and PSO algorithms. In some cases PSO based results offer more reliability with less curtailment of load but with higher generation cost. The comparisons are shown in the graphs (Figure 2 and 3).

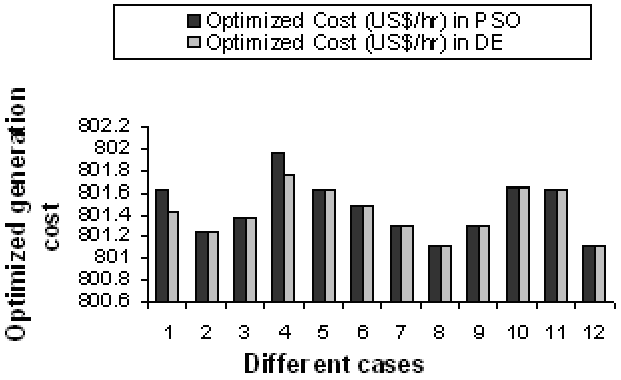

Figure 2. Comparison of generation cost with DE and PSO

The ISO can choose the solutions depending upon the market conditions and reliability issues. But with DE or PSO based results, as the generating cost remains same, there can be least variation of spot price and most of the transactions can be sustained with the changed schedule. As the minimum possible load curtailment is promoted, the proposed method tries to maintain maximum reliability of the power system in deregulated environment. However, ISO also can offer a schedule without load curtailment but with higher price during contingency

(Table 5). In that case, all the participants have to agree upon this new transaction and compromise about the price hike.

Table 6. Generator Re-Scheduled Dispatch For Different Contingent States With Load Curtailment To Limit Generation Cost

		Line trip	Load Curtailed at bus (n)	% load Curtailed at bus (n)	Re-scheduled dispatch (MW)						Optimized Generation Cost (US$/hr)
					Generator bus number						
					1	2	5	8	11	13	
DE based proposed algorithm	1	29-30	29	9.7500	176.67	48.81	21.46	21.61	12.08	12.0	801.4273
	2		30	2.5000	176.23	48.81	21.46	21.59	12.07	12.0	801.2529
	3	27-30	30	4.9375	176.66	48.81	21.46	21.60	12.08	12.0	801.3765
	4	29-27	29	14.3900	176.70	48.83	21.47	21.65	12.09	12.0	801.7662
	5	12-14	12	2.5000	176.65	48.81	21.47	21.65	12.12	12.0	801.6405
	6		14	4.9375	176.63	48.80	21.46	21.63	12.12	12.0	801.4873
	7	14-15	14	2.5000	176.64	48.81	21.46	21.60	12.08	12.0	801.3042
	8		15	2.5000	176.62	48.80	21.46	21.59	12.07	12.0	801.1175
	9	12-16	12	2.5000	176.45	48.77	21.46	21.66	12.24	12.0	801.3007
	10		16	4.9375	176.50	48.78	21.47	21.69	12.24	12.0	801.6593
	11	16-17	16	2.5000	176.59	48.80	21.47	21.66	12.16	12.0	801.6222
	12		17	2.5000	176.53	48.78	21.46	21.62	12.14	12.0	801.1180
PSO based proposed algorithm	1	29-30	29	7.3141	176.67	48.83	21.44	21.69	12.09	12.0	801.6416
	2		30	2.5000	176.65	48.85	21.46	21.53	12.11	12.0	801.2530
	3	27-30	30	4.9375	176.64	48.86	21.44	21.58	12.12	12.0	801.3766
	4	29-27	29	11.8904	176.67	48.88	21.46	21.66	12.12	12.0	801.9663
	5	12-14	12	2.5000	176.59	48.88	21.48	21.54	12.23	12.0	801.6409
	6		14	4.9375	176.71	48.82	21.48	21.61	12.05	12.0	801.4874
	7	14-15	14	2.5000	176.74	48.78	21.52	21.50	12.08	12.0	801.3045
	8		15	2.5000	176.48	48.82	21.49	21.56	12.17	12.0	801.1179
	9	12-16	12	2.5000	176.57	48.70	21.45	21.56	12.24	12.0	801.3008
	10		16	4.9375	176.46	48.85	21.50	21.59	12.30	12.0	801.6596
	11	16-17	16	2.5000	176.48	48.77	21.47	21.85	12.11	12.0	801.6226
	12		17	2.5000	176.58	48.77	21.48	21.52	12.20	12.0	801.1182

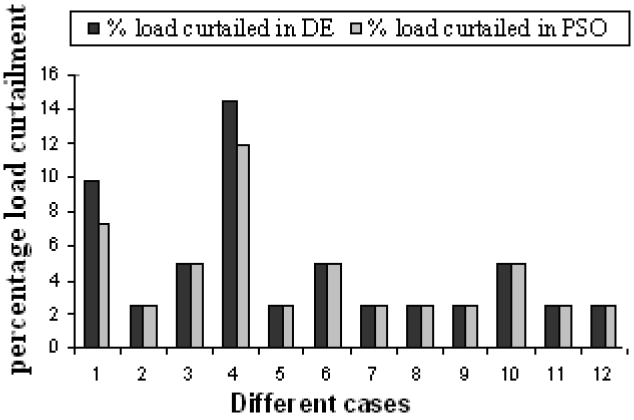

Figure 3 Comparison of load curtailment with DE and PSO

The results, shown in Table VI, are quite satisfactory as it not only limits the generation cost but also relieves the lines from overloading and hence manages congestion. The overload relief of these lines is depicted in Table VII.

The bus voltage profile for the base case, contingent case and contingent case with controlled load curtailment are shown in Fig 4. It can be inferred that as the proposed algorithm not only limits the spot price but also tests the feasibility of generation rescheduling by running load flow for each of the cases.

The above methodology, being adopted by ISO, can create a fair competition between the market participants which will encourage them for minimum load curtailment enhancing the system security and hence reducing revenue loss.

Table 7. Overload Relief Of Congested Lines With Generator Re-Schedule Dispatch

LINE TRIP	**Two most congested line**	**Real power flow (MW)**			**Percentage Over load factor (For Case I)**	**Percentage Over load factor (For Case II)**
		w/o line trip	**Line trip but same generation Case I**	**Line trip but with new generation and load curtailment Case II**		
29-30	27-30	7.1063	11.4982	9.8075	61.8029	38.01
	28-27	14.2988	14.7609	14.0079	3.2317	-2.03
27-30	29-30	3.7071	10.9500	5.9520	195.3791	60.55
	28-27	14.2988	14.8632	14.0002	3.9472	-2.08
29-27	28-27	14.2988	14.8632	14.2307	3.9472	-0.47
	27-30	7.1063	13.7018	11.6543	92.812	63.99
12-14	12-15	17.3815	23.6686	19.9887	36.1712	14.99
	12-16	5.8184	7.5406	5.5002	29.5992	-5.46
14-15	14-12	5.6612	6.2456	5.8654	10.3229	3.60
	12-15	17.3817	18.5233	18.0038	6.5678	3.57
12-16	12-14	7.6612	8.8765	7.5520	15.8631	-1.42
	12-15	17.3817	19.7696	18.0032	13.738	3.57
16-17	12-16	5.8184	7.6543	5.8022	31.5533	0.065
	10-17	6.7431	9.0331	8.0331	33.9606	19.13

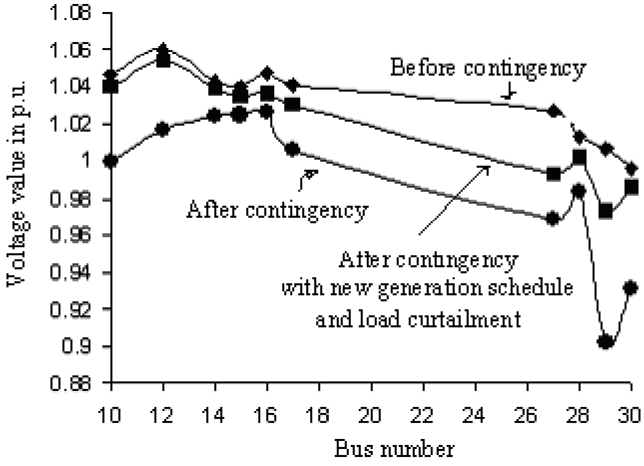

Figure 4. Bus voltage profile for normal, contingent and curtailed load conditions

5. Conclusion

Power market variations and spot price has become a matter of great concern after the introduction of deregulation in power sector. For consumer welfare and to encourage cheap generation of power, the variations of generation cost should be limited to a preferred level. But due to continuous change in transactions between participants the spot price becomes volatile. A contingent condition may also change the generation cost and hence spot price of electricity. In this statement, the role for the transmission system operator is to create a set of rules that ensure sufficient control over producers and consumers. An optimal power flow, with two simultaneous objectives: cost minimization and minimization of deviation of cost, can be developed to minimize the variation of generation cost and hence spot price along with congestion cost in contingent condition. The OPF algorithm proposed in this paper, however, is capable of fixing the generation cost by least affecting system reliability with a controlled load curtailment technique. The control variables in the proposed algorithm have been changed in such a way that the generation cost does not exceed a favored value. The DE based simulation results (being verified by PSO) show that the proposed algorithm not only reduces generation cost but also manages congestion by relieving the lines from overloading. Hence the system operator can use this multi-objective optimization technique to limit the deviation of generation cost for consumer welfare and also to promote cheap generation of power in deregulated power system networks.

References

[1] S. Balaraman, N. Kamaraj, “Application of Differential Evolution for congestion management in power system,” *Modern Applied Science*, vol. 4, no. 8, pp. 33-42, 2010.

[2] Cuello-Reyna A.A. and Cedefio-Maldonado J. R., “OPF Framework for congestion management in Deregulated Environments Using Differential Evolution,” *Power Symposium*, 23-25 Oct.2005, pp. 127-133.

[3] K. Vaisakh, L. R. Srinivas, “Differential Evolution approach for optimal power flow solution,” *Journal of theoretical and applied Information Technology*, vol. 4, no. 4, pp. 261-268, 2008

[4] F. Capitanes, M.Glavic, D. Ernst, L. Wehenkel, “Contingency Filtering techniques for preventive security constrained optimal power flow,” *IEEE Transaction on Power System*, Vol. 22, no. 4, pp. 1690-1697, 2007.

[5] K. Talukdar, A. K. Sinha, S. Mukhopadhyay, and A. Bose, “A computationally simple method for cost efficient generation rescheduling and load shedding for Congestion Management,” *Electrical Power and Energy Systems*, vol. 27, pp. 379-388, 2005.

[6] S. Dutta, & S. P Singh, “Optimal Rescheduling of Generators for Congestion Management based on Particle Swarm Optimization,” *IEEE Transaction on Power System*, Vol. 23, no. 4, pp.1560– 1569, 2008.

[7] J. Hazra, & A. K. Sinha, “Congestion Management using multi objective Particle Swarm Optimization,” *IEEE Transaction on Power System*, Vol. 22, no. 4, pp. 1726–1734, 2007.

A. Kumar, S. C. Srivastava, & S. N Singh, “A zonal Congestion Management Approach using real and Reactive Power Rescheduling,” *IEEE Transaction on Power System*, Vol. 19, no. 1, pp. 554-562, 2004.

[8] Meena,T., & Selvi, K, “Cluster Based Congestion Management in Deregulated Electricity Market Using PSO,”. *IEEE Indicon Conference, Chennai*, India, 2005, pp. 627-630.

[9] Kumar, A., & Srivastava, S.C. “AC Power Transfer Distribution Factors for Allocating Power Transactions in a Deregulated Market,” *IEEE Power Engineering Review*, pp. 42-43, 2002.

[10] Mo. N., Zou, Z.Y., Chan, K.W., & Pong, T.Y.G. “Transient stability constrained optimal Power flow using Particle Swarm Optimization”, *IET Generation., Transmission, Distribution*, vol. 1, no. 3,pp. 476-483, 2007.

[11] Saravanan, M., Slochanal, S.M.R., Venkatesh, P., & Abraham, J. P.S. “Application of particle Swarm Optimization technique for optimal location of FACTS devices considering cost of installation and system load-ability,” *Electrical Power System Research*., vol. 77, pp. 276- 283, 2007.

[12] Storn,R., & Price,K., “Differential Evolution- A Simple and efficient adaptive scheme for Global optimization over continuous spaces,” *Berkeley, CA,tech.Rep*.TR-95-012, 1995.

[13] Wong, K. P., & Dong, Z.Y. “Differential Evolution, an Alternative Approach to Evolutionary Algorithm,” *ISAP, PP*. 73-83, 2005.

[14] Rahnamayan, S., Tizhoosh, H.R., & Salama, M.M.A. (2008). Opposition- Based Differential Evolution.,” *IEEE Transactions on Evolutionary computation*, vol. 12, no. 1, pp. 64-79, 2008.

[15] Cai H.R., Chung C.Y., & Wong K.P. “Application of Differential Evolution Algorithm for Transient Stability Constrained Optimal Power Flow,” *IEEE Transactions on power system*, vol. 23, no. 2, pp. 719-728, 2008.

[16] Coelho.L.D.S., Mariani.V.C. “Combining of Chaotic Differential Evolution and Quadratic Programming for Economic Dispatch Optimization with Valve-Point Effect,” *IEEE Transactions on Power Systems*, vol. 21, no. 2, pp. 989- 996, 2006.

[17] Cheng, S.L., Hwang, C. “Optimal Approximation of Linear Systems by a Differential Evolution Algorithm,” *IEEE Transactions on Systems, man, and cybernetics—part a: systems and humans*, vol. 31, no. 6, pp. 698-707, 2001.

[18] S.parnandi, K Schoder, A. Feliachi. “Power market analysis tool for congestion management,” *Journal of Electrical System*, vol.4, issue.3, September 2008.

[19] Gamperie, R. &, Muller,S. “A parameter study for Differential Evolution,” *Advances in Intelligent systems, Fuzzy systems, Evolutionary computation, WSEAS Press.*, pp. 293 – 298, 2002.

[20] Chanda C. K, Dey S, Chakrabarti A, Mukhopadhyay A. K, “Determination of bus security governed by sensitivity indicator in a reactive power constraint longitudinal power supply (LPS) system,” *Indian Journal of Engineering and Materials Sciences*, vol. 9, no. 4, pp. 260-264, 2002.

Sawan Sen received the B.Sc. (Hons.) degree in Physics and the B.Tech. in Electrical Engineering from University of Calcutta in 2001 and 2004 respectively. In 2006 she obtained her M.Tech. Degree in Electrical Engineering from the University of Calcutta, India, where she is currently working toward the Ph.D. degree. She is currently Asst. Prof. of Techno India (Electrical Engineering department), Salt Lake, Kolkata. Her main research interests include Power System Stability, Power System Protection and different soft computing tools for solving power system problems under regulated and deregulated environment.

Sandip Chanda received the B.E. degree in Electrical Engineering form Jadavpur University in 2007. In 2010 he obtained his M.Tech. degree in Electrical Engineering (Electrical Power) from the University of Calcutta, India. He has been working as Asst. Prof. of Techno India (Electrical Engineering department), Salt Lake. He is currently working toward the Ph.D. degree in Bengal Engineering and Science University, Shibpur. His main research interests include Power System Security and reliability.

Samarjit Sengupta received the B.Sc. (Hons.) degree in physics and the B.Tech, M.Tech, and Ph.D. degrees in electrical engineering from the University of Calcutta, Kolkata, West Bengal, India. He is currently a Professor of electrical engineering with the Department of Applied Physics, University of Calcutta. His main research interests include power quality instrumentation, power system stability, and power system protection.

Abhijit Chakrabarti is professor in the Department of Electrical Engineering in Bengal Engineering and Science University, Shibpur, West Bengal, India. He received B.E. degree from National Institute of Technology, Durgapur in 1978 and M. Tech (Power Apparatus and Systems) degree from IIT, Delhi in 1987. He did his Ph.D. (tech) from Calcutta University in 1991. Dr. Chakrabarti is the author of several books on Power System and Circuit Theory. Dr. Abhijit Chakrabarti is a recipient of several Awards like “Pandit Madan Mohan”, “Best Research Paper Award” and “Merit Paper Award”. Dr. Chakrabarti has active interest on Power System, Electric Circuits and Power Electronics.