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Congestion Management in Deregulated Power Systems Using Generator Rescheduling with Particle Swarm Optimization

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The sizable progress of power demand has directed to viable electricity arcade in which the vertically integrated utilities are unbundled as Genco, Transco, and Disco. The structure of deregulated market is not same in all countries. But in most of the countries, the power production and retail sales are competitive, while transmission is still regulated. The most responsible entity in an exposed access power market is Self-governing System Operator (SO) whose liabilities include structure security, control delivery, transaction pricing, service quality and elevation of financial proficiency and equity. One of the most important disputes associated with modernized power market is congestion of Power transmission lines. The usage of these lines through the power producers and the consumers closer or outside the assigned limits makes the line congested. Usually higher load demands lead to congestion of transmission network. To alleviate congestion an Ideal Power Flow method with generator rescheduling is embraced in this paper. Also, Particle Swarm Optimization (PSO) algorithm is adopted to resolve the ideal power flow and the outcomes are compared with Linear Programming Optimal Power Flow (LPOPF). Congestion is replicated using Power World Simulator and the suggested method is tried on IEEE 30 bus system.

Keywords: Congestion, Ideal Power Flow, Exposed Access, SO, Generator Rescheduling, PSO Algorithm, LP OPF.

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1. INTRODUCTION

Relaxed power market has been introduced in electric power system to bear out the severe evolution of power demand. The emphasis of the modernized power market is to lift the system performance, expand the buyer focus and shrink the price of consuming electricity, leading to competition between electricity market members. The orthodox combined system is alienated into power creation, transaction/communication, and distribution/sharing sectors. There are diverse outlines for processing and guideline access to transmission systems. Deregulation catches the attention of various power patrons and supports efficient electricity production. This helps in effective utilization of power through competition among the investors which leads to new electricity pricing mechanism. The task of accomplishing fair electricity pricing mechanism is governed by Self-governing System Operator (SO) in such a way that the power generation reaches the consumer in a competitive way. Each promoter in the deregulated market tries to fully utilize the available resources for maximum gain. The MVA limits are recurrently exceeded based on the augmented electricity transaction under the relaxed electricity market. When the transmission capacity is not adequate and if all entreaties of transmission service inside an area are not fulfilled simultaneously, transmission congestion occurs. This may build further blockages and in some sections, substantial electricity prices. The occurrences of sudden upshots result in overload in one (or) further transaction lines and may lead the system to critical operating state. In such situations, congestion should be relieved by carefully accounting the security and stability constraints. Multiple methods are available in the market to dismiss congestion. The rudimentary practices used to moderate the influence of transaction line disturbances are: Generator reorganization, Load detaching and Line swapping. Administrating congestion is slightly complicated in relaxed electricity markets and requires critical planning. The policy and guidelines to tackle congestion in utility is unique in current competitive market.

Literature shows ample of congestion tackling arrangements. Generator reorganizing procedure is employed

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to relieve congestion with the focus of curtailing the reorganizing cost. Various approaches like demand side contribution, trajectory sensitivity, cluster based management, sensitivity indexes approach and a decentralized risk focused mode are dealt along with ensured voltage stability.[1–6] The results guarantee the economic considerations for a set of contingencies. Optimal generator rescheduling technique for minimizing congestion ensuring voltage stability and load sharing using MiPower and MATLAB has been presented by Prasad et al.[7] The impact of congestion on whole sale market pricing and locational market price is dealt by Modi and Parekh.[8] The concept of implementing a request response congestion management program with aeration and refrigeration loads is presented by Lu and Nguyen.[9] Generator rescheduling under wheeling transactions is dealt with transmission congestion model by Kamaraj et al.[10] Dealing with different operating regimes for congestion problem is discussed using risk management.[11]

Various development practices have been embraced and discussed to overcome normal congestion and multi-congestion problems.[12–14] The problems like high deviation of voltage has also been dealt.[15] System security preservation and the economical means in terms of cost are presented by optimizing the current flow in the system.[16]

The existing multi neutral methods for disabling congestion are slightly revised.[17]

An ideal structural alignment of electrical power contract system has been provided as a tool for administrating congestion.[18] The coefficients that speed with time have significant contribution in developing algorithm of lightening congestion.[19] The challenge of loadability limits allied with congestion has been discussed.[20] The usage of diverse FACTS devices, their limitations and scope of their application have been exposed in detail.[21–24] A comparison is made between generator reorganizing and load restriction with prime position of Series Controller for relieving congestion.[25]

This paper offers a congestion controlling scheme by means of Linear Programming Optimal Power Flow (LP OPF) and Particle Swarm Optimization (PSO) procedure. Outcomes disclose that PSO delivers superior output.

2. PROBLEM FORMULATION

The components like power production, transaction and delivery are under a solitary expert in a conservative power system. Hence, it is well governed, rather in a relaxed ambience, conveying of power is most complicated and non-linear. Re-dispatching of power transactions plays an energetic part in managing congestion in a liberalized environment.

2.1. Optimal Power Flow Problem

The AC Optimal Power Flow (ACOPF) is the prime function of ISO power markets, and is solved in some format regular interval for system planning. Identification of some or all control variables of a power system is indispensable, in fact, it is the first stage in an OPF to optimize (maximize or minimize) a predefined objective. The eminence of the solution depends on the accuracy of the model designed, thus, the problem must be clearly defined with required objectives at inception. Hence, objectives must be modelled clearly with practical contingencies. Optimal Power Flow (OPF) problem is a nonlinear problem with nonlinear constraints. The objective function varies with reference to the market structure and applications. OPF model comprises a set of power system limits such as active and reactive power limits of generators, voltage magnitude limit at each bus and limits on transmission line power flow. These are referred as operating constraints and they assure effective process of a power system. OPF is used to find the optimal settings for control variables with acceptable equality and in-equality constraints. Congestion management is considered as OPF problem and the analysis demands proper modelling of transmission lines. A π- model transmission line is considered for investigation. Rescheduling of generators for congestion management is suggested as an Optimal Power Flow (OPF) problem in this paper. It is used to lessen the fuel cost of the generating units with security limitations like optimal dispatch of generated power, load demand and line limits.

2.2. Objective Function

Objective function in a power system takes various forms such as fuel cost, reactive source allocation, transmission losses and so on. Usually the objective function of interest is the minimization of total production cost of scheduled generating units in a deregulated environment as it is critical as operational requirements in power systems. The objective function is designed to minimize the total cost of re-dispatched generation in restructured power market. The objective function corresponding to the generation cost can be approximated as a quadratic function of the active power outputs from the generating units. It is represented as

$$\text{Minimize } F_{\text{t}}^{\text{Cost}} = \sum_{i=1}^{N_{\text{g}}} f_i(P_i) \tag{1}$$

where

$$f_i(P_i) = a_i P_i^2 + b_i P_i + c_i, \quad i = 1, 2, 3, \ldots, N_{\text{g}} \tag{2}$$

The above expression shows the cost function of ith generating unit. The constants a_i, b_i and c_i represent the cost coefficients and they are the bid prices of a particular generator in deregulated market. The units of cost coefficients are \$/MW^2-hr, \$/MW-hr and \$/hr respectively. Hence the fuel cost is calculated in terms of \$/hr. P_i represents the real power output (MW) of *i*th generator. N_g is the number of active generating units. The assumptions and practical impacts enforce some constraints to the OPF problem. Some of the constraints are power balance, real and reactive power generation, voltage limits and line flow limit. The limits are substantiated for each and every load bus after load flow simulation.

2.3. Generation Constraints

The upper and lower limits on the active and reactive generations are

$$P_{\mathrm{Gi}}^{\min} \le P_{\mathrm{Gi}} \le P_{\mathrm{Gi}}^{\max} \quad (3)$$

$$Q_{\mathrm{Gi}}^{\min} \le Q_{\mathrm{Gi}} \le Q_{\mathrm{Gi}}^{\max} \quad (4)$$

2.4. Power Balance Constraints

This constraint represents the balancing of the real and reactive power among generation and demand. Usually power balance constraint is a nonlinear equation and based on symmetry between generating units and total loads of the system. The power balance constraints are characterized as

$$P_{\mathrm{Gi}} - P_{\mathrm{Di}} - \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) = 0 \quad (5)$$

$$Q_{\mathrm{Gi}} - Q_{\mathrm{Di}} - \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) = 0 \quad (6)$$

2.5. Voltage Constraints

The upper and lower bounds on the voltage magnitude can be mathematically represented as

$$V_i^{\min} \le V_i \le V_i^{\max} \quad (7)$$

This is substantiated for each and every load bus after load flow simulation.

2.6. Transmission Line Loading

The MVA rating of the transmission line decides the line capacity which is represented by the following constraint.

$$S_L \le S_L^{\max} \quad (8)$$

where $S_L^{\max}$ is the transfer capacity of *L*th transmission line.

In order to implement the objective function using PSO algorithm, power flow analysis during normal and overloading is required.

2.7. Power Flow Analysis

Power flow is conducted for various test systems with normal loading to receive the data pertaining to the real power, reactive power and apparent power in all the lines. The voltage at each bus is also noted from the power flow result and it is ensured that they are within the limits. Likewise, the real and reactive power limits of generators

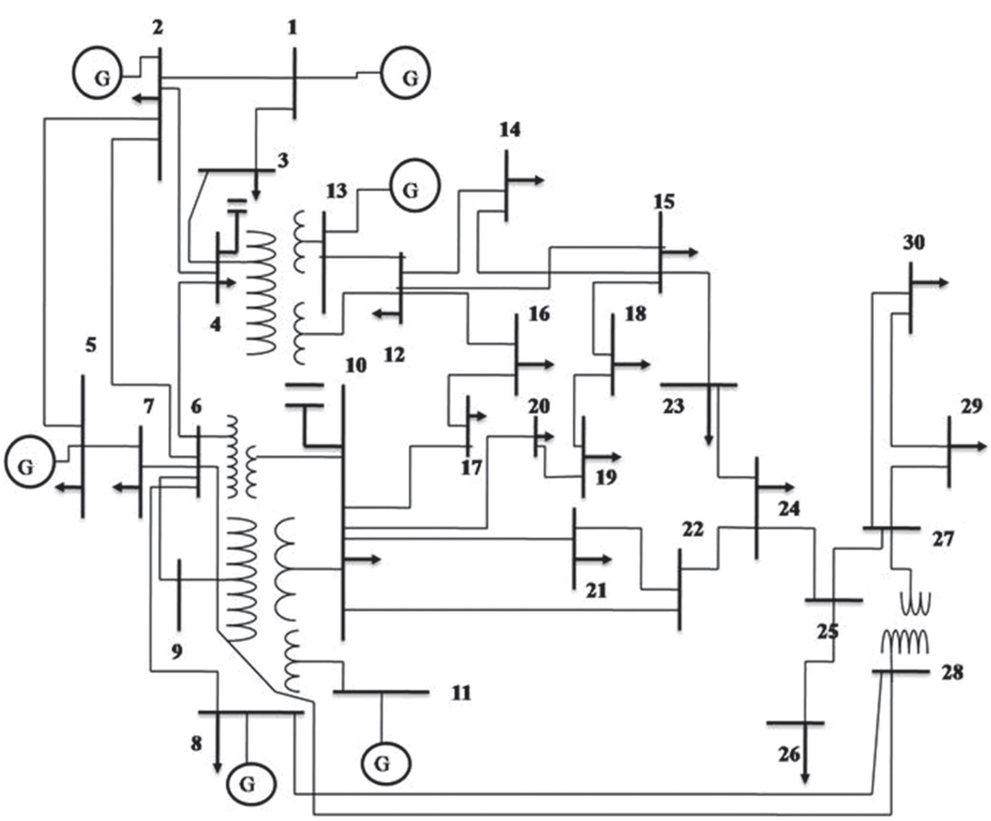

Fig. 1. IEEE 30 bus system.

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are maintained. Congestion is created in test systems by increasing the system load such that one or more lines are overloaded or by transmission line outage and the same is ensured by conducting power flow. The lines whose actual MVA capacity exceeds the maximum MVA capacity are identified as congested lines. The real power (MW) is rescheduled from the available Gencos to relieve congestion. The power flow is again conducted with rescheduled power (MW) to ascertain that the line limits are restored after rescheduling. The IEEE 30 bus system is taken as test system for validating the OPF using PSO. The power flow is conducted for IEEE 30 bus system with the above constraints.

Figure 1 shows the one line diagram of IEEE 30 bus system. Power World Simulator (PWS) software is used to simulate the various congestion cases such as Single Line (SL) Congestion, Two Line (2L) Congestion, and Three Line (3L) Congestion. The relevant data have been obtained with the respective congested case after relieving congestion with proper rescheduling of generators. Then, LP OPF and PSO algorithm techniques are applied to find the cost of rescheduling. It is inferred from the results that the PSO technique provides minimum rescheduling cost.

3. PARTICLE SWARM OPTIMIZATION

The Particle Swarm Optimization (PSO) is a biologically stimulated algorithm. It is a population based stochastic optimization and starts with a group of arbitrarily spawned population. PSO is a population-based evolutionary technique with many advantages over other optimization techniques. PSO is the best optimizer among Genetic Algorithm (GA), Neural Network (NN) and Evolutionary Programming (EP). This algorithm is well suited for complex problems such as discontinuities and high order non-linearities. Also, it has superior convergence and high solution quality. PSO algorithm combines local search methods with global search methods, trying to balance investigation and manipulation. In PSO, each single solution is a bird in the search space and referred as particle. All particles have fitness values that are assessed by the fitness function to be optimized. In addition, particles have velocities which direct the flying of particles. Each particle in PSO can be represented by its current speed/velocity, the most optimist position of each individual and the most optimist position of the neighbour. There are two terminologies such as local best and global (or) neighborhood best with respect to PSO. Local best is the best solution of the individual particle and global best is the best value, obtained so far by any particle in the population. Every particle of the population has a feasible solution. Optimal complex search spaces are found through the interaction between individual particles. The algorithm begins with N particles and every particle represents a solution to the problem. Each particle in the search space has a current position (x_i) and a current velocity (v_i). Each particle's value is determined by fitness function ($F(x_i)$). Each particle moves with a velocity about cost surface. The personal best location in the search space ($localbest_i$) relates to the position where particle i represents the best fitness function. The global best position in the search space

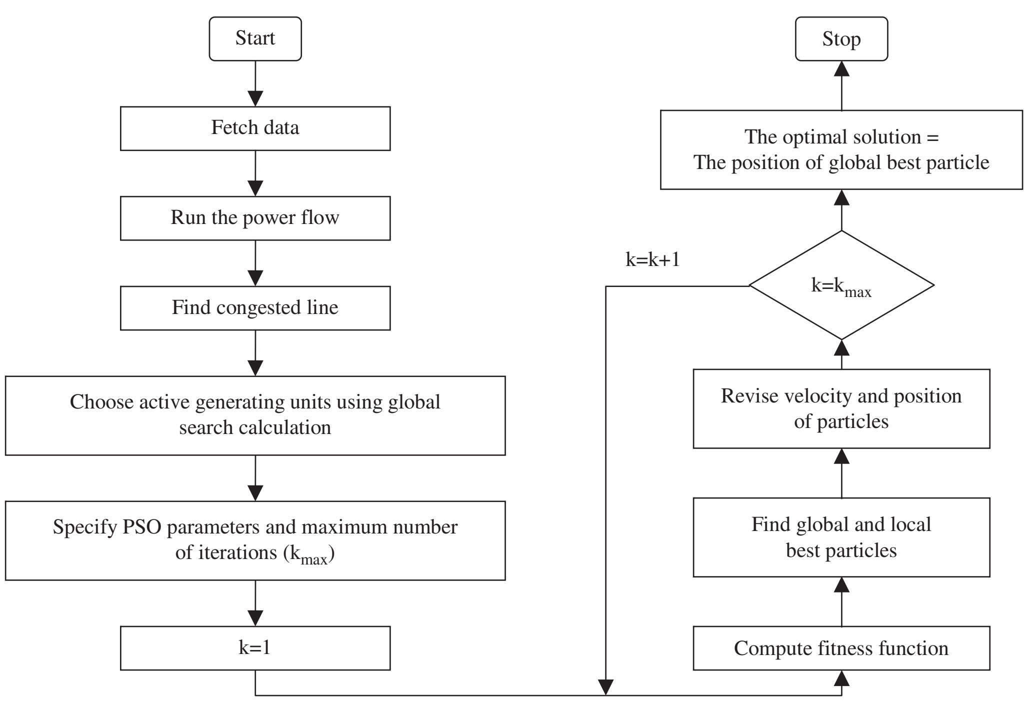

Fig. 2. Flowchart-generator rescheduling.

($globalbest_i$) represents the position providing the best fitness function amongst all the ($localbest_i$).

The position and velocity of the particles are updated using the Eqs. (9) and (10).

$$x_i^{n+1} = x_i^n + v_i^{n+1} \tag{9}$$

$$v_i^{n+1} = v_i^n + \rho_1 \cdot r_1 \cdot (x_i^{localbest} - x_i^n) + \rho_1 \cdot r_1 \cdot (x_i^{globalbest} - x_i^n) \tag{10}$$

where, $n+1$ denotes the $n+1$th generation, n denotes the nth generation, ρ_1, ρ_2 are the learning factors, r_1, r_2 are independent uniform random numbers, $x_i^{localbest}$ is the best local solution for the particle, and $x_i^{globalbest}$ is the best global solution.

There are five following basic steps in PSO:

1. Initialize population in space.
2. Assess fitness of individual particle.
3. Alter velocities based on Local best and Global best.
4. Terminate on some condition.
5. Go to step 2.

The improved particle swarm optimization algorithm is discussed by Bai.[6] The detailed flow chart related to generator rescheduling using PSO is shown in Figure 2. This PSO algorithm is used after removing line loading in an open access power market to obtain the cost of generator rescheduling.

The parameters used for PSO are as follows:
Initial population: 30
Number of iterations $= 1,000$
$\rho_1 = \rho_2 = 0.5$;
Termination criteria = Number of iterations-1,000 (or) objective function ≤ 0.01.

4. RESULTS AND DISCUSSIONS

The proposed OPF problem is demonstrated using 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 is 1.0) as shown in Figure 1. The system is overloaded from 10% to 40% to generate congestion. Consequently, the three test cases viz., Single Line (SL) Congestion, Double Line (2L) Congestion and Triple Line (3L) Congestion are analyzed. The lines are said to be congested when the MVA transfer capability exceeds the maximum capacity. The power flow analysis is carried for various overloading conditions and the congested lines are identified. The congestion in overloaded lines is relieved by generator rescheduling and the same is ensured by conducting power flow after rescheduling. The 3 cases of overloading conditions for creating congestion are simulated and are discussed in the following section.

4.1. Case 1—Single Line (SL) Congestion

Single line congestion is created by increasing the load by 10% i.e., the load at bus 2 is increased to 45 MW. After running power flow, the line 1–2 is identified as overloaded line. The overload is relieved after properly rescheduling the Gencos 2 and 3. This is depicted in Figure 3, showing line 1–2 with 10% overload (SL) and the same after congestion relief.

4.2. Case 2—Two Line (2L) Congestion

A 15% overall increase in the load makes congestion in two lines. The congestion is created by increasing the load at bus 5 to 124.2 MW and at bus 8 to 39 MW. Figure 4 shows that the lines 1–2 and 6–8 are overloaded. The overload is relieved after properly rescheduling all the Gencos except 5th Genco. Figure 4 also shows that the overloaded lines are relieved from congestion after rescheduling.

4.3. Case 3—Three Line (3L) Congestion

A three line congestion is created by increasing the load at bus 5 to 188 MW and bus 8 to 45 MW i.e., a 40% overload in total leads to 3L congestion. The overloaded lines are identified by the MVA limit as 1–2, 4–6 and 6–8 respectively. The overload is relieved after properly rescheduling all the Gencos.

The overload data for IEEE 30 bus system during congestion and after congestion relief for 10%, 15% and 40% is tabulated in Table I. It is observed that the line limits are within the permissible limits in the previously congested lines after rescheduling. The real power of each Genco is adjusted or rescheduled till the congestion is cleared in all lines. The Genco data along with rescheduled power, ΔPg_i, representing MW change of ith generator for IEEE 30 bus system is tabulated in Table II.

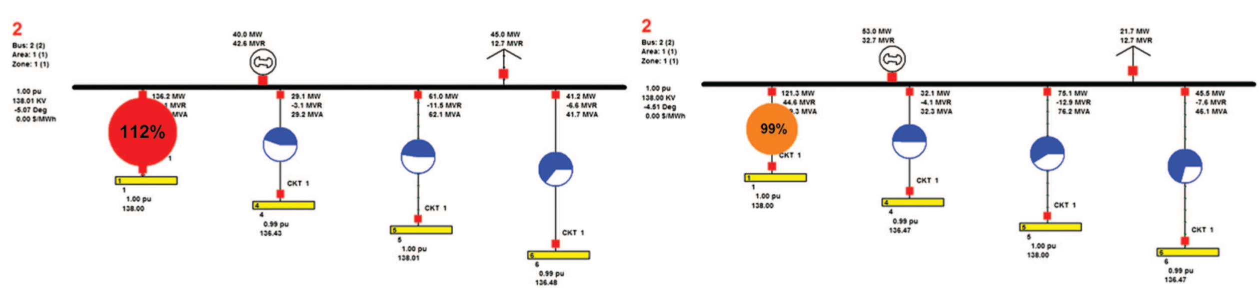

Fig. 3. Case 1: Line 1–2 with 10% overload (SL) and after congestion relief.

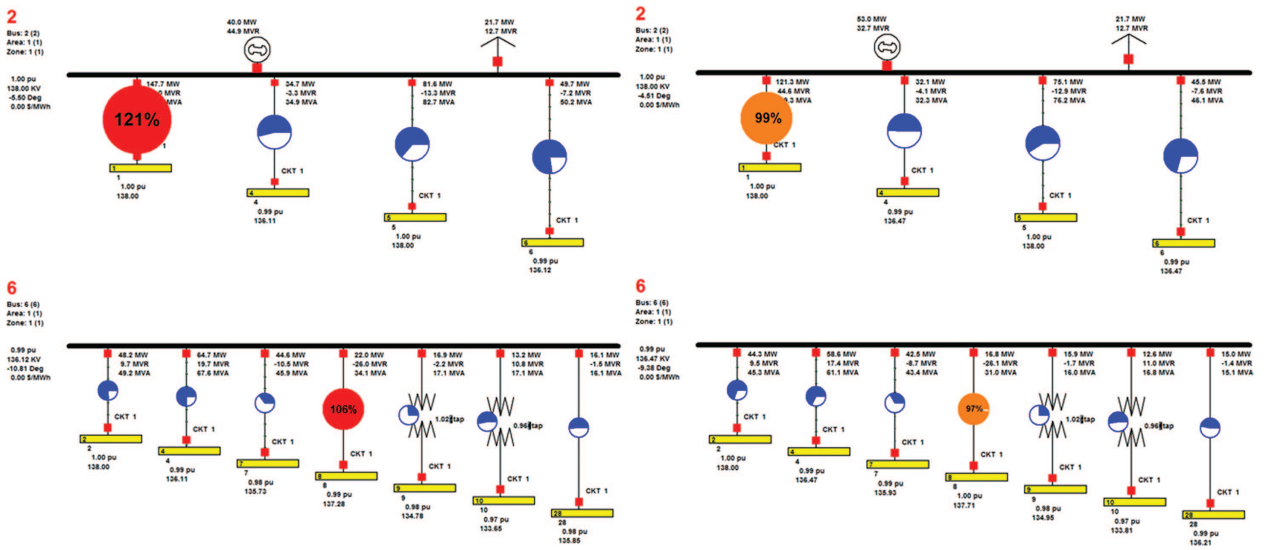

Fig. 4. Case 2: Lines 1–2 and 6–8 with 15% overload (2L) and after congestion relief.

4.4. Cost Analysis

One of the operational requirements in deregulated power system is to minimize the generator rescheduling cost of active power since cost incurred for adjusting and re-dispatching power is directly proportional to MW of power adjusted. The cost of re-dispatch is computed using the data obtained from power flow analysis of test systems after rescheduling and the bid prices from the generating

Table I. Over-load data-IEEE 30 bus system during congestion and after congestion relief.

% Loading (No. of lines overloaded)	Over loaded lines	Line limit in MVA	Actual line MVA		Real power loss in MW		Reactive power loss in MVAR	
			During congestion	After congestion relief	During congestion	After congestion relief	During congestion	After congestion relief
10 (1)	1–2	130	145.50	126.70	4.09	3.10	9.61	6.65
15 (2)	1–2	130	157.90	129.70	4.82	3.25	11.79	7.11
	6–8	32	34.10	31.20	0.14	0.12	0.05	−0.03
40 (3)	1–2	130	222.20	127.40	9.52	3.14	25.88	6.77
	4–6	90	90.70	66.60	1.02	0.54	3.12	1.42
	6–8	32	37.50	27.80	0.18	0.09	0.18	−0.12

Table II. Genco data and rescheduled power of IEEE 30 bus system.

% Loading	No. of lines overloaded	Generator bus	Rescheduled power (ΔPg_i) in MW	Real power (MW)		Reactive power (MVAR)	
				During congestion	After rescheduling	During congestion	After rescheduling
10	1	1	−22	201	179	0	0
		2	+13	40	53	43	35
		5	+8	25	33	53	49
		8	0	17	17	60	60
		11	0	15	15	11	11
		13	0	20	20	18	18
15	2	1	−37	221	184	0	0
		2	+13	40	53	45	33
		5	+8	25	33	66	62
		8	+6	17	23	60	60
		11	0	15	15	11	11
		13	+7	20	27	19	18
40	3	1	−124	305	181	0	0
		2	+40	40	80	87	30
		5	+25	25	50	80	80
		8	+18	17	35	60	59
		11	+12	15	27	14	11
		13	+16	20	36	21	17

Table III. Bid prices of Gencos-IEEE 30 bus system.

Generator bus	*a* [$/MW^2-hr]	*b* [$/MW-hr]	*c* [$/hr]
1	0.00375	2.00	0
2	0.01750	1.75	0
5	0.06250	1.00	0
8	0.00834	3.25	0
11	0.02500	3.00	0
13	0.02500	3.00	0

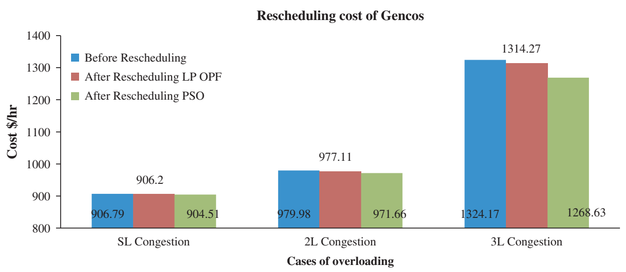

Fig. 5. Graphical results of rescheduling cost of Gencos.

companies. The bid prices for IEEE 30 bus system is tabulated Table III.

PSO algorithm has been used to meet the objective of minimizing the rescheduling cost with the data obtained using Power World Simulator. The fuel cost is computed using PSO and compared with LPOPF. The computation using the PSO is effective and yields less cost. The same is compared with LP OPF and the graphical result of rescheduling cost of Gencos is shown in Figure 5.

It is observed from Figure 5 that the rescheduling cost is compared for SL congestion, 2L congestion and 3L congestion. The percentage of cost saving after rescheduling with PSO is 0.19% for SL congestion, 0.56% for 2L congestion and 3.47% for 3L congestion while comparing the results with LPOF. Also the cost of power flow through transmission line is high for all cases of overloading before rescheduling. The graph also reveals that maximum cost saving is obtained with high degree of overloading (3L congestion). In practical restructured system the demand from the consumers will be high leading to high degree of overloading. Hence the analysis becomes more prominent and PSO can be implemented for relieving the congestion of overloaded lines using generator rescheduling.

5. CONCLUSION

In this paper, generator rescheduling method of congestion management using particle swarm optimization is presented. The cost of minimizing the re-dispatch is designed as an Optimal Power Flow (OPF) problem. The congested cases are simulated by overloading some of the lines using Power World Simulator. The rescheduling cost is computed using PSO and the same is compared with LP OPF technique. The test results on IEEE 30 bus system reveal that the cost of rescheduling using PSO is less in all cases compared to LP OPF technique. Also it is evident that the maximum cost saving is obtained in three line congested case. It is concluded that the rescheduling of generators provides an efficient solution for congestion management in overloaded transmission line and the cost of rescheduling is less with PSO technique.

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